Aquatic Settlement Agreement. 2008.

AQUATIC SETTLEMENT AGREEMENT

A Settlement Agreement in Support of the Measures identified within the:

White Sturgeon Management Plan
Bull Trout Management Plan
Pacific Lamprey Management Plan
Resident Fish Management Plan
Aquatic Nuisance Species Management Plan
and
Water Quality Management Plan

Wells Hydroelectric Project
FERC Project No. 2149

October 2008

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AQUATIC SETTLEMENT AGREEMENT
Wells Hydroelectric Project
FERC License No. 2149

1.0 PARTIES

This Aquatic Settlement Agreement (Agreement) is entered into by and between the Public Utility District No. 1 of Douglas County, Washington (Douglas), a Washington municipal corporation, the United States Fish and Wildlife Service (USFWS), the Washington State Department of Fish and Wildlife (WDFW), the Washington State Department of Ecology (Ecology), the Confederated Tribes of the Colville Reservation (Colville), the Confederated Tribes and Bands of the Yakama Nation (Yakama), the Bureau of Indian Affairs (BIA), and the Bureau of Land Management (BLM). The above entities who have executed this Agreement, herein collectively referred to as the "Parties" and individually as "Party," have actively participated in the development of this Agreement and associated Aquatic Resource Management Plans.

This Agreement shall be binding on, and inure to the benefit of, the above-listed Parties and their successors and assigns, unless otherwise specified in this Agreement.

The National Marine Fisheries Service (NMFS) was invited to participate in the development of this Agreement, but declined to be a signatory Party because its interests are currently satisfied by the measures within the Wells Anadromous Fish Agreement and Habitat Conservation Plan (HCP). Additional entities may become Parties to this Agreement following unanimous consent of all the existing Parties to the Agreement and after executing a signature page and submitting it to Douglas and the Federal Energy Regulatory Commission (FERC).

2.0 RECITALS

2.1 The Wells Hydroelectric Project (Wells Project) is located at river mile 515.6 on the Columbia River in the State of Washington. Wells Dam is located approximately 30 river miles downstream from the Chief Joseph Hydroelectric Project, owned and operated by the United States Army Corps of Engineers, and 42 miles upstream from the Rocky Reach Hydroelectric Project, owned and operated by Chelan County Public Utility District. The nearest town is Pateros, Washington, which is located approximately 8 miles upstream from Wells Dam.

2.2 The Wells Project is the chief generating resource for Douglas. It includes ten generating units with a nameplate rating of 774,300 kilowatts (kW) and a peaking capacity of approximately 840,000 kW. The design of the Wells Project is unique in that the generating units, spillways, switchyard, and fish passage facilities were combined into a single structure referred to as the hydrocombine. Adult fish

passage facilities reside on both sides of the hydrocombine, which is 1,130 feet long, 168 feet wide, with a crest elevation of 795 feet in height. Juvenile fish passage facilities are located across the powerhouse of the dam. The system was developed by Douglas and uses a barrier system to modify the intake velocities on spillways 2, 4, 6, 8, and 10. The Wells Project fish bypass system is the most efficient juvenile fish bypass system on the mainstem Columbia River. The bypass system on average collects and safely passes 92.0 percent of the spring migrating salmonids (yearling Chinook, steelhead, and sockeye) that arrive at Wells Dam and 96.2 percent of the summer migrating subyearling Chinook that arrive at the dam (Skalski et al., 1996).

2.3 The Wells Reservoir is approximately 30 miles long. The Methow and Okanogan rivers are tributaries of the Columbia River within the Wells Reservoir. The Wells Project boundary extends approximately 1.5 miles up the Methow River and approximately 15.5 miles up the Okanogan River. The normal maximum surface area of the reservoir is 9,740 acres with a gross storage capacity of 331,200 acre-feet (ac-ft) and usable storage of 97,985 ac-ft at elevation of 781 feet above mean sea level (MSL).

2.4 Douglas has various reservoir and surface water rights associated with the operation of the Wells Project including the following certificates (S3-00362, R3-00363, R4-26075, and S4-26074). These certificates provide reservoir impoundment rights for 331,200 ac-ft of water and power generation rights for 220,000 cubic feet per second (cfs) of water.

2.5 In March 1979, in response to petitions from tribes and other entities, FERC initiated a consolidated proceeding on juvenile fish protection for the Mid-Columbia hydroelectric projects, including the Wells Project.

2.6 In 1990, following the installation of 10 new high-efficiency turbine runners and the installation and preliminary testing of a new and highly effective juvenile fish bypass system, Douglas entered into a long-term fisheries settlement agreement with NMFS, USFWS, WDFW, Colville, Yakama, and Confederated Tribes of the Umatilla Indian Reservation (CTUIR).

2.7 On June 21, 2004, FERC approved the HCP. The HCP superseded the 1990 long-term fisheries settlement agreement. The HCP represents the culmination of over 10 years of negotiations between Douglas, NMFS, USFWS, WDFW, Colville, Yakama, CTUIR, and American Rivers. The HCP is the first hydropower HCP for anadromous salmon and steelhead. The HCP is a 50-year agreement included as an amendment to the Original Operating License. The HCP addresses Project related impacts to spring Chinook, summer/fall Chinook, steelhead, sockeye and coho, collectively referred to as Plan Species. With respect to Plan Species, the HCP parties have agreed to be supportive of Douglas's long-term relicensing efforts. The HCP also provides Endangered Species Act (ESA) coverage for all of the permit species (spring Chinook, summer/fall Chinook, sockeye and steelhead). The HCP also is intended to constitute the HCP participants' terms,

conditions and recommendations for Plan Species under Sections 10(a), 10(j), and 18 of the Federal Power Act (FPA), the Fish and Wildlife Conservation Act, the Essential Fish Habitat provisions of the Magnuson-Stevens Fishery Conservation and Management Act, the Pacific Northwest Electric Power Planning and Conservation Act, and Title 77 of the Revised Code of Washington (RCW) of the State of Washington. On October 16, 2007, FERC officially recognized the HCP as a qualifying Comprehensive Plan pursuant to section 10(a)(2)(A) of the FPA.

2.8 On November 1, 2004, Douglas and Colville executed a settlement agreement to resolve all claims regarding any section 10(e) payments to Colville for the term of the original license and any new FERC license arising from the use of lands within the Wells Project Boundary. Pursuant to the settlement agreement, Douglas and Colville also executed a power sales contract and a power sales service agreement. On February 11, 2005 the FERC issued an order approving the settlement agreement and granting approval of the power sales contract under section 22 of the FPA.

2.9 The Original Operating License for the Wells Project will expire on May 31, 2012. Douglas is using the Integrated Licensing Process (ILP) as required by FERC regulations issued July 23, 2003 (18 CFR Part 5). Pursuant to the ILP regulations Douglas submitted to FERC, on December 1, 2006, a Notice of Intent to file an application for a New License and a Pre-Application Document.

2.10 In March of 2006, following two years of collaborative discussions related to relicensing studies, Douglas approached stakeholders regarding its desire to develop an Aquatic Settlement Agreement for those resources not already protected by the Original Operating License, the HCP, or other related agreements. Stakeholders active in the development of this Agreement included the USFWS, NMFS, WDFW, Ecology, Colville, and Yakama.

2.11 Douglas plans to file a Draft License Application (DLA) with FERC on or before December 31, 2009, and plans to file a Final License Application (FLA) for a New License with FERC on or before May 31, 2010. Douglas plans to include this Agreement in the DLA and FLA. It is the Parties' expectation that the Agreement will be signed prior to filing the DLA.

3.0 DEFINITIONS

3.1 "Adaptive Management" means an iterative and rigorous process used by the Aquatic Settlement Work Group (Aquatic SWG) to achieve biological goals and objectives. In the context of the relicensing of the Wells Project, this process is intended to improve the management of Aquatic Resources affected by Project operations, in order to achieve the desired goals and objectives of the Aquatic Resource Management Plans as effectively and efficiently as possible, in accordance with the provisions of this Agreement. The process used by the Aquatic SWG has many steps including the following:

a. Develop initial hypotheses regarding any potential Project impacts and potential protection or mitigation measures;

b. Complete studies to determine whether the hypothesized impacts are valid, and if valid, quantify the impact resulting from the Project;

c. If the hypothesized impact is validated and quantified, then the Aquatic SWG shall identify appropriate goals and objectives and implementing measures;

d. Implement reasonable and appropriate measures to avoid, minimize or mitigate the identified Project impact;

e. Develop monitoring and evaluation methodologies for determining whether the goals and objectives have been achieved;

f. Should the measures be successful at mitigating or minimizing Project impact(s), then periodic monitoring shall take place to confirm that such goals and objectives continue to be achieved;

g. Should the implemented measures fail to achieve the goals and objectives over a reasonable time frame, then the Aquatic SWG shall evaluate additional or revised measures, including those previously considered in the six Aquatic Resource Management Plans, and implement any additional or revised appropriate and reasonable measures, or explain why such goals and objectives cannot be achieved;

h. If such goals and objectives have not been achieved over a reasonable time frame, then the Aquatic SWG may reevaluate and revise such goals and objectives.

3.2 "Aquatic Settlement Agreement" means this document as well as Attachment A (Proposed License Articles) and Attachments B through G (Aquatic Resource Management Plans).

3.3 "Aquatic Resource Management Plans" refers to the six aquatic management plans developed in close collaboration with the Aquatic SWG. These six plans

are independently known as the White Sturgeon Management Plan (WSMP), Bull Trout Management Plan (BTMP), Pacific Lamprey Management Plan (PLMP), Resident Fish Management Plan (RFMP), Aquatic Nuisance Species Management Plan (ANSMP) and Water Quality Management Plan (WQMP).

3.4 "Aquatic Resources" refers to the resources addressed by the six Aquatic Resource Management Plans contained within Attachments B through G.

3.5 "Aquatic SWG" refers to the Aquatic Settlement Work Group. The Aquatic SWG is comprised of one voting representative from each of the Parties to this Agreement. The Aquatic SWG is the group charged with the responsibility of implementing this Agreement.

3.6 "Chair" refers to a neutral third party, selected unanimously by the Parties and funded by Douglas to coordinate the Aquatic SWG meetings.

3.7 "HCP" refers to the Wells Anadromous Fish Agreement and Habitat Conservation Plan.

3.8 "Licensee" means the Public Utility District No. 1 of Douglas County or Douglas.

3.9 "New Operating License" means the first long-term operating license for Project No. 2149 to be issued by the FERC to Douglas that takes effect after the expiration of the Original Operating License and any subsequent annual licenses that take effect after expiration of the New Operating License.

3.10 "Original Operating License" means the original 50-year operating license, as amended, for Project No. 2149 issued by the FERC with an expiration date of May 31, 2012 and any subsequent annual licenses that take effect after expiration of the Original Operating License, but before the effective date of the New Operating License.

3.11 A "Party" means an entity who has executed a signature page for this Agreement, and who is identified in Section 1 (Parties) or meets the criteria in Section 1 (Parties).

3.12 "Plan Species" refers to the five anadromous fish species covered by the HCP. The five species of fish covered by the HCP are spring Chinook, summer/fall Chinook, steelhead, sockeye and coho.

3.13 "Project" means the Wells Hydroelectric Project, licensed to Douglas by the FERC as Project No. 2149.

3.14 "Proposed License Articles" means license articles proposed by the Parties to the FERC in this Agreement, and contained in Attachment A hereto.

3.15 "Unanimous" and "unanimously" mean that all of the Parties who vote or abstain at an appropriately noticed meeting pursuant to this Agreement agree or abstain

on an action. An abstention does not affect or prevent a vote from being unanimous. See Section 11.5 (Voting).

4.0 THE PURPOSE OF THE AGREEMENT

The Parties agree that the purpose of this Agreement is to resolve all remaining Aquatic Resource issues related to compliance with all federal and state law applicable to the issuance of a New Operating License for the Project. Subject to the reservations of authority in Section 13 (Reservations of Authority) of this Agreement, this Agreement establishes Douglas's obligations for the protection, mitigation, and enhancement of Aquatic Resources affected by Project operations under the New Operating License and its obligations to comply with all related federal and state laws applicable to the issuance of the New Operating License for the Project. It also specifies procedures to be used by the Parties to ensure that the New Operating License is implemented consistent with this Agreement and other laws. The Parties agree that this Agreement is fair, reasonable, and in the public interest within the meaning of FERC Rule 602, 18 C.F.R. § 385.602(g)(3).

The six Aquatic Resource Management Plans contained in Attachments B through G, together with the HCP will function as the Water Quality Attainment Plan (WQAP) in support of the Clean Water Act Section 401 Water Quality Certification for the Wells Project. As of the effective date of the Agreement, pursuant to Section 5 (Term of License and This Agreement), the Parties agree that the measures set forth in the Aquatic Resource Management Plans are adequate to identify and address Project impacts to Aquatic Resources and are expected to achieve the goals and objectives set forth in each of the six Aquatic Resource Management Plans. However, during the course of the New Operating License, there may be instances where the measures found in individual management plans may need to be adapted. In these instances, "Adaptive Management" will be used to achieve the biological goals and objectives.

5.0 TERM OF LICENSE AND THIS AGREEMENT

Douglas will seek a term of 50 years for the New Operating License. The Parties agree to support a 50-year term for the New Operating License. Subject to Section 7 (Effective Dates and Implementation of Attachments), this Agreement shall become effective when signed by Douglas and at least one other Party and shall remain in effect throughout the term of the New Operating License unless this Agreement is terminated sooner pursuant to Section 8 (Termination of Agreement).

6.0 TRANSFER OF LICENSE AND AGREEMENT

In the event the New Operating License is transferred in whole from Douglas to another entity and Douglas is not a co-licensee of the Project, the Parties agree that Douglas shall have no further obligations under the New Operating License or this Agreement following such transfer.

7.0 EFFECTIVE DATES AND IMPLEMENTATION OF ATTACHMENTS

The proposed measures contained within Attachment A (Proposed License Articles) and Attachments B through G (Aquatic Resource Management Plans) shall become effective upon issuance of a FERC order granting a New Operating License to Douglas, except to the extent the implementation of any such measures is prohibited, prevented, or rendered impracticable by the FERC order.

8.0 TERMINATION OF AGREEMENT

8.1 Automatic Termination Events

This Agreement shall terminate automatically: (1) at the end of the term of the Agreement as set forth in Section 5 (Term of License and This Agreement); (2) in the event the FERC does not issue a New Operating License to Douglas for the Project; (3) in the event Douglas withdraws from this Agreement based on Section 8.2 (Withdrawal Events); or (4) in the event the New Operating License is revoked.

8.2 Withdrawal Events

8.2.1 Non-Compliance

A Party may elect at any time to withdraw from the Agreement pursuant to Section 8.2.4 (Conditions Precedent to Withdrawal) based on non-compliance of another Party with the provisions of the Agreement, subject to the following procedures: (1) a Party asserts that another Party is not complying with the terms of the Agreement; (2) the Party documents and presents evidence supporting assertion of non-compliance in writing; and (3) the issue of non-compliance is taken to Dispute Resolution, Section 12 (Dispute Resolution).

8.2.2 Governmental Action

Should a government agency take an action that is materially inconsistent with the terms of this Agreement, including a material inconsistency with or modification of Attachment A (Proposed License Articles) or Attachments B through G (Aquatic Resource Management Plans), then the Parties (not including the government agency, if a Party) shall meet and consider the available actions to address the material inconsistency. Such actions may include a joint or separate request(s) for rehearing with the FERC, a joint or separate appeal(s) to the Washington State Pollution Control Hearing Board (PCHB), judicial review to remove or modify the material inconsistency, or any other action that would address the inconsistency. One or more Parties may proceed to pursue such actions even if all Parties do not wish to participate.

If the material inconsistency is sustained upon the completion of such actions, a Party may: (1) elect to withdraw from this Agreement pursuant to Section 8.2.4 (Conditions Precedent to Withdrawal); (2) agree to implement this Agreement subject to such

governmental action; or (3) enter into additional discussions to determine whether an alternative agreement can be reached.

8.2.3 Impossibility

A Party may elect to withdraw from the Agreement pursuant to Section 8.2.4 (Conditions Precedent to Withdrawal) in the event the Parties agree in writing that the obligations imposed by this Agreement are impossible to achieve.

8.2.4 Conditions Precedent to Withdrawal

Two conditions must be satisfied before a Party can withdraw from the Agreement pursuant to Section 8.2.1 (Non-Compliance), Section 8.2.2 (Governmental Action), or Section 8.2.3 (Impossibility). First, the Party proposing to withdraw from the Agreement shall provide written notice to all other Parties of the substantive basis for its intent to withdraw. The notice shall include a complete statement of reasons and be served in accordance with the requirements of Section 17.2 (Special Notifications). Second, the substantive basis for the proposed withdrawal must be taken to Dispute Resolution (Section 12).

Following Dispute Resolution, a Party choosing to withdraw shall provide all other Parties with notice of withdrawal. The notice shall be in writing and served in accordance with the requirements of Section 17.2 (Special Notifications). A notice of withdrawal shall become effective sixty (60) days from the date the notice was provided to all other Parties. The right to withdraw shall be waived if not exercised within sixty (60) days of completion of Dispute Resolution.

8.2.5 Effect of Withdrawal

Except as set forth in Section 8.2.6 (Effect of Termination), in the event a Party withdraws from this Agreement, this Agreement places no constraints on the withdrawing Party, shall not thereafter be binding on the withdrawing Party, and the withdrawing Party may exercise all rights and remedies that the Party would otherwise have outside this Agreement.

8.2.6 Effect of Termination

Upon expiration of this Agreement, or in the event this Agreement is terminated, voided or determined for any reason to be unenforceable before the end of its term, then: (1) Douglas shall continue to implement the last agreed-upon measures until the FERC orders otherwise and (2) the Parties are not restrained in any manner from advocating to the FERC appropriate measures to replace this Agreement.

9.0 OBLIGATIONS OF THE PARTIES

9.1 Licensee Obligations

Douglas shall file this Agreement with the FERC as an offer of settlement pursuant to Rule 602 consisting of a fully executed copy of this Agreement and an explanatory statement. The offer of settlement related to this Agreement shall be included within both the Draft and Final License Applications, and Attachments B through G shall be identified therein as Douglas's proposed environmental measures for Aquatic Resources pursuant to 18 C.F.R. § 5.18(a)(5)(C). Douglas shall request that the FERC incorporate, without modification, the Attachments to this Agreement as conditions of the New Operating License. Douglas shall use reasonable efforts to obtain a FERC order issuing the New Operating License in a timely manner. Douglas shall also: (1) submit a statement in support of this Agreement to NMFS and USFWS, as part of any comments in the ESA Section 7 consultation process; (2) ensure that any supplemental information, comments, or responses to comments filed by Douglas with the FERC in the context of the relicensing process are consistent with this Agreement; (3) in the event of an appeal of the Project's 401 certification, submit a statement in support of this Agreement to the PCHB and any court reviewing a decision of the PCHB; and (4) actively support incorporation of the Proposed License Articles into the New Operating License in all other relevant regulatory proceedings.

9.2 Obligations of All Parties (Including Licensee)

Except as provided below and in Section 13 (Reservations of Authority), each Party shall support this Agreement by ensuring that all documents filed with the FERC or any other agency or forum, are consistent with this Agreement. Documents covered by this Section include: (1) any recommendations, conditions and/or prescriptions, or any terms and conditions related to Aquatic Resources; (2) as to Parties other than the USFWS, any ESA Section 7 consultation documents or comments on such documents; (3) as to USFWS, any ESA Section 7 consultation documents, or comments on such documents, or any biological opinions, subject to Section 13 (Reservations of Authority); and (4) any supplemental information, comments or responses to comments.

In the event that a Party receives or develops new information, data, or analyses that it intends to file with the FERC or any other agency or administrative body, such Party shall consult with the Aquatic SWG pursuant to Section 11 (Aquatic Settlement Work Group) of this Agreement, to the extent practicable, and shall notify all Parties as soon as practicable.

Except as provided in Section 13 (Reservation of Authority), if a Party proposes to submit to FERC a condition and/or prescription based upon new information, data, or analyses, the Party must comply with the procedures of Section 12 (Dispute Resolution) if the Aquatic SWG does not unanimously approve such condition or prescription.

10.0 MODIFICATION OF AGREEMENT

This Agreement may be amended or modified only in writing and with written unanimous consent of all Parties.

11.0 AQUATIC SETTLEMENT WORK GROUP

11.1 Committee Representation

There shall be an Aquatic SWG composed of one technical representative and a separate policy representative for each Party. The policy representative shall be an individual of a higher management level within each organization relative to the technical representative. Each Party shall provide all other Parties with written notice of its designated representatives and designated alternate(s) to the Aquatic SWG. Each Party with representation on the SWG shall have one vote.

Upon request by any Party, Douglas shall provide a forum for a meeting or meetings of the policy representatives. The Parties anticipate that the policy representatives will meet at least once annually during the term of the New Operating License to review progress and implementation of this Agreement.

11.2 Meetings

The Aquatic SWG shall meet as specified in the respective Aquatic Resource Management Plans or when requested by any member following notice. However, such notice may be waived by a member if done so expressly in writing to the Chair. NMFS may attend all meetings of the Aquatic SWG for coordination purposes with HCP activities and shall be provided copies of notices and agendas for Aquatic SWG meetings. Individuals representing entities that are not a Party to this Agreement may attend meetings following unanimous approval from all of the Parties. Nothing in this Agreement shall preclude any Party from having multiple non-designated representatives from their organization participate in any properly noticed Aquatic SWG meeting.

11.3 Chair of the Aquatic SWG

The Parties shall unanimously select and Douglas shall fund a neutral, non-voting Chair for the Aquatic SWG. The Chair will prepare an annual list of statements of agreement based upon the results of studies, prepare progress reports, prepare meeting minutes, facilitate and mediate the meetings, and assist the members of the Aquatic SWG in making decisions. The Aquatic SWG shall evaluate the performance of the Chair at least every three (3) years or upon request of two or more members of the Aquatic SWG.

11.4 Meeting Notice

The Chair shall provide all committee members with a minimum of ten (10) business days advanced written notice of all meetings unless a member waives notice in writing or

such waiver is reflected in the approved meeting minutes. The notice shall contain an agenda of all matters to be addressed and voted on during the meeting. Means of notice will be determined by the Parties. Unless urgent action is required, to determine the date for a meeting, the Chair will poll the Parties in an effort to identify a meeting date on which all interested Parties are able to attend. If a date is not available for all Parties to meet within a reasonable time, the Chair will select the date that best accommodates the most Parties.

11.5 Voting

The Aquatic SWG shall act by unanimous vote of those present in person or by telephone. However, the Aquatic SWG may develop its own rules and procedures for voting, which may include expanding the methods of voting (e.g., proxy, writing, or other methods). The Chair shall ensure that all members are sent notices with agenda items that may be brought to a vote during the proposed Aquatic SWG meeting.

If a Party's designated representative(s) cannot be present for an agenda item scheduled for a vote, that Party may request the Chair in advance of his/her expected absence to delay a vote or determination of unanimous approval for up to five (5) business days on the subject agenda item. Alternatively, if the Parties cannot convene for a vote within five (5) business days once a vote has been delayed, the Chair shall consult with the absent Party to solicit and record that Party's vote or abstention. The Chair and Parties shall make a reasonable effort to ensure that a vote on any specified agenda item is delayed only once.

If the Aquatic SWG cannot reach unanimous consent, then upon request by any Party, that agenda item shall be referred to the dispute resolution process set forth in Section 12 (Dispute Resolution). The Parties shall negotiate in good faith and attempt to resolve issues at a technical level prior to elevating issues to Dispute Resolution.

Any entity who is not a Party to this Agreement does not have voting rights on the Aquatic SWG or any other committee established under this Agreement.

11.6 Authority and Purpose of Aquatic SWG

The Aquatic SWG will be used as the primary forum for consultation and coordination among the Parties in connection with conducting studies and implementing the measures set forth in this Agreement and as set forth in Section 12 (Dispute Resolution). Any entity not executing this Agreement shall not be a Party to this Agreement and shall not be entitled to vote on any committee established by this Agreement.

In connection with implementation of the Aquatic Resource Management Plans, the Parties agree to use Adaptive Management as defined herein. Adaptive Management involves many steps that may include forming a hypothesis regarding any potential Project related impacts, initial hypothesis development and testing, identifying potential Project related impacts, protection or mitigation measures, and the collection of data or

information necessary to test the hypothesis and developing studies to determine whether the hypothesis is valid. If the hypothesized impact is validated, certain process and study steps are necessary to quantify the impact(s) resulting from the Project.

When hypothesized impacts are validated and quantified through a systematic process, the Aquatic SWG may refine management goals and objectives set forth in the affected Aquatic Resource Management Plans, or add new goals and objectives as appropriate. The next step will be to implement appropriate and reasonable measures to avoid, minimize, or mitigate the identified Project impacts. Following the implementation of appropriate and reasonable measures to avoid, minimize, or mitigate the identified Project impacts, the Aquatic SWG will develop and Douglas will implement monitoring and evaluation methods for determining whether the goals and objectives of the plan are being achieved. If those refinements are successful, then periodic monitoring shall be implemented to confirm that such goals and objectives continue to be achieved. If the implemented measures fail to achieve the refined or new goals and objectives over a reasonable time frame, then the Aquatic SWG shall: (1) evaluate additional or modified measures, including those previously considered in the six Aquatic Resource Management Plans, and implement any additional or revised appropriate and reasonable measures; or (2) explain why such goals and objectives cannot be achieved.

If after a reasonable period of time such goals and objectives have not been achieved, the Aquatic SWG will, as needed, reevaluate and further refine such goals and objectives. The Aquatic SWG may establish its own procedural guidelines for Adaptive Management decisions and related decision process steps, as necessary, to monitor and evaluate established Aquatic Resource Management Plan goals and objectives and to develop new goals and objectives, studies and mitigation measures.

The Aquatic SWG will consult on, coordinate, and oversee all aspects of implementation of the Aquatic Resource Management Plans. If the Aquatic SWG cannot reach agreement, then these decisions shall be referred to the dispute resolution process in Section 12 (Dispute Resolution).

11.7 Studies, Reports, and Meeting Minutes

The Chair will make available all study plans and reports prepared under this Agreement to all members of the Aquatic SWG as soon as reasonably possible. Draft study plans and reports will be distributed to all of the Aquatic SWG representatives for review and comment. Comments will be provided in writing to the Chair within thirty (30) days of receipt of the plan or report unless the Aquatic SWG decides otherwise. Comments will either be addressed in order within the document or made an appendix to the approved study plan or final report.

The Chair will provide draft meeting minutes, including any proposed or final statement(s) of agreements, within ten (10) days after each meeting. Statements of agreement shall be based on a unanimous vote. Minutes shall reflect all significant group discussions and decisions. All Party representatives who were present and participated in

the meeting will be allowed ten (10) days to provide corrections and comments in writing to the Chair. Final meeting minutes will be provided to the members of the Aquatic SWG as soon as reasonably possible after comments have been received. If disagreements exist, as to the proposed meeting minutes, then the Chair will include all perspectives in the final minutes.

The Chair will work with Douglas to compile all relevant materials into one annual calendar-year report. The annual report shall include all final study plans, reports, meeting minutes and statements of agreements, and a list of future proposed actions as agreed to by the Aquatic SWG. The Chair will provide the annual report to Aquatic SWG members for review and approval prior to being filed with FERC. Comments on the annual report shall be provided in writing to the Chair within thirty (30) days of receipt unless the Aquatic SWG decides otherwise. Douglas PUD shall work with the Aquatic SWG to establish a central electronic database that is accessible to all of the Parties. This electronic database will contain all of the documents related to implementation of this Agreement.

12.0 DISPUTE RESOLUTION

12.1 Dispute Resolution Process

If a dispute arises out of or relates to this Agreement, the disputing Parties agree to first use their best efforts to cooperatively resolve such dispute. The disputing Parties shall use their best efforts to resolve disputes arising in the normal course of business at the technical level between each disputing Party's staff with appropriate authority to resolve such disputes.

When a dispute arises between two or more Parties and cannot be resolved in the normal course of business at the technical level, one or more of the disputing Parties shall provide written notice specifying the disputed issues to the Chair, with copies to all Parties. The notice shall describe the specific nature and background of the dispute. All notices shall be served in accordance with the requirements of Section 17.2 (Special Notifications).

Within three (3) days of receiving the notice, or as the Parties otherwise agree, the Chair shall schedule a meeting of the technical representatives of the Aquatic SWG to consider and attempt to resolve the dispute. The technical representatives of the Aquatic SWG shall meet within thirty (30) days or as the Parties otherwise agree, after receiving the notice of dispute.

If after ten (10) business days, or as otherwise agreed, the Chair determines that the Parties' technical representatives are unable to resolve the dispute then the Chair shall immediately submit the matter in writing to the policy representatives of each of the respective Parties. The policy representatives shall meet within thirty (30) days or as the Parties otherwise agree, after receiving notice from the Chair.

If after ten (10) business days, or as otherwise agreed, the Chair determines that the Parties' policy representatives are unable to resolve the dispute then the Chair shall immediately submit the matter in writing to the executive representatives of each of the respective Parties. The executive representatives shall meet within thirty (30) days or as otherwise agreed, after receiving notice from the Chair. If the executive representatives are unable to resolve the dispute within fifteen (15) business days or as otherwise agreed, then the disputing Parties may agree to submit the dispute to voluntary mediation or binding arbitration but are not obligated to do either. If the disputing Parties are unable to resolve the dispute through the above processes any Party may pursue other appropriate remedies, including withdrawal from this Agreement pursuant to Section 8.2.4 (Conditions Precedent to Withdrawal).

12.2 Arbitration and Mediation

In the event the disputing Parties agree pursuant to Section 12.1 (Dispute Resolution Process) to submit a dispute to binding arbitration or voluntary mediation, the following procedures shall apply. The dispute shall then be referred to a mutually acceptable arbitrator or mediator, or if one cannot be agreed upon, to the nearest office of Washington Arbitration & Mediation Service ("WAMS") for resolution within ninety (90) days of the agreement of the Parties to submit the dispute to arbitration or mediation. If the disputing Parties cannot agree on a mutually acceptable arbitrator or mediator within ten (10) business days of such agreement to arbitrate/mediate, the dispute will be referred to WAMS for preparation of a Strike List for arbitrator/mediator selection. Mediation may occur at any time if agreed upon by the Parties. All arbitration proceedings shall be conducted in accordance with the Rules of Arbitration of WAMS or any other mutually agreed upon arbitrator and shall include reasonable discovery provisions as may be stipulated or ordered. The arbitrator's decision shall be final and binding and judgment may be entered thereon, with all remedies otherwise available in court also available in arbitration.

The disputing Parties shall equally share in the cost of arbitration and mediation associated with this Agreement. Parties that do not have an interest in the outcome of the arbitration or mediation proceeding may elect to abstain from further participation in either arbitration or mediation. The Parties agree that the existence of a dispute notwithstanding, they will continue without delay to carry out all their respective responsibilities under this Agreement that are not affected by the dispute.

Any legal action to enforce a decision of the arbitrator shall be brought either in the United States District Court for the Eastern District of Washington or the FERC, if jurisdiction exists, otherwise such action may be brought in any court of competent jurisdiction. The Colville and Yakama hereby provide a waiver of sovereign immunity that is expressly limited to a legal action filed under this section to enforce a decision of the arbitrator.

13.0 RESERVATIONS OF AUTHORITY

The reservation of authority under Section 13.1 (Federal Power Act) of this Agreement is not intended to limit the right of any Party to seek redress with FERC with respect to an issue related to the implementation or enforcement of this Agreement.

13.1 Federal Power Act

Each Party reserves any authority it may have pursuant to the FPA in the event that: (1) this Agreement is not filed with the FERC; (2) the Party withdraws from this Agreement pursuant to the procedures set forth in Section 8.2 (Withdrawal Events); or (3) this Agreement is terminated pursuant to Section 8.1 (Automatic Termination Events).

The USFWS reserves the Secretary of the Interior's authorities pursuant to the FPA. The USFWS may exercise any reserved authority under Section 18 of the FPA regarding those species covered by this Agreement including but not limited to bull trout, white sturgeon, Pacific lamprey, and resident fish. In the event that the USFWS includes a reservation of authority in the preliminary, modified or final conditions that it submits to FERC, the inclusion of such reservation shall not be considered to be materially inconsistent with this Agreement.

The USFWS shall provide notice to the Aquatic SWG before exercising its Federal Power Act authority. Following notice, the Aquatic SWG may make recommendations to the USFWS regarding how the exercise of such authority can be accomplished in a manner that is consistent with this Agreement. In the event that the Aquatic SWG does not reach a unanimous decision regarding such recommendations, then Section 12 (Dispute Resolution) shall apply.

13.2 Clean Water Act

Ecology reserves its authority to issue a 401 certification under the Clean Water Act (CWA) for the Wells Project under such terms and conditions as it determines are necessary to comply with state and federal laws. The Parties intend that this Agreement, together with the HCP, will satisfy Ecology's requirements for the 401 certification with respect to Aquatic Resources and Plan Species affected by the Wells Project; however, this Agreement does not predetermine the outcome of the 401 certification proceeding or prevent Ecology from responding to new information or analysis or from addressing additional resources that may be affected. Section 12 (Dispute Resolution) shall not apply to the issuance of the 401 certification or a re-issuance of the 401 certification prior to the effective date of the New Operating License.

Ecology reserves all authority it may have to amend the 401 certification or to invoke a reopener clause in the 401 certification to amend the 401 certification for the New Operating License, including, but not limited to, modifying schedules and deadlines, under such terms and conditions as it determines are necessary to comply with state and federal law. Section 12 (Dispute Resolution) shall apply to the exercise of Ecology's

reserved authority to amend, modify or reopen the 401 certification during the term of the New Operating License.

Ecology reserves any authority it may have to enforce the 401 certification, state water quality standards, or other appropriate requirements of state law.

13.3 Endangered Species Act

This Agreement does not affect the terms of the HCP. USFWS anticipates that the measures in this Agreement together with the measures contained within the HCP will be adequate to satisfy ESA responsibilities for aquatic species under the jurisdiction of USFWS. In addition, USFWS shall use reasonable efforts to exercise its authority under the ESA in a manner that allows this Agreement to be fulfilled. By signing this Agreement, however, the USFWS does not formally bind itself to make any specific recommendations or take any particular action with respect to ESA compliance. The USFWS expressly reserves the right, consistent with federal law, to take such future actions as it may deem necessary to meet its obligations under the ESA.

If the FERC requests draft biological opinion(s), the USFWS shall provide such documents to the FERC. If, in its consultation with the FERC pursuant to Section 7 of the ESA, the USFWS requests any measures that are materially inconsistent with the terms of this Agreement, any Party may invoke Section 12 (Dispute Resolution). The USFWS shall participate in Dispute Resolution to the extent practicable and consistent with its ESA responsibilities.

13.4 Douglas Reservation of Authority

Douglas reserves any rights it may have to contest the existence and/or exercise of any reserved authority claimed under this Agreement. In the event that a Party exercises its reserved authority and declines to participate in Dispute Resolution, then Douglas shall have the right to withdraw from the Agreement pursuant to Section 8.2.4 (Conditions Precedent to Withdrawal).

13.5 Exercise of Reserved Authority

To the extent practicable, a Party shall provide notice to the Aquatic SWG at least sixty (60) days before exercising any authority reserved under this Agreement that may be materially inconsistent with this Agreement. Following notice, the Aquatic SWG will meet to discuss and make recommendations regarding the exercise of such authority. If the Aquatic SWG does not reach a unanimous decision regarding such recommendations, then any Party may initiate Dispute Resolution (Section 12). However, if in its sole discretion a Party determines expeditious action is required to perform its statutory duties or responsibilities, such Party shall not be required to wait in exercising reserved authority until Dispute Resolution is initiated or concluded. This provision does not apply to the issuance of a 401 certification prior to the effective date of the New Operating License.

14.0 CHOICE OF LAWS

This Agreement shall be governed by, and construed, interpreted and enforced in accordance with, the substantive law of the State of Washington (without reference to any principles of conflicts of laws) and applicable federal law.

15.0 LIMITATIONS OF REOPENINGS

Except as provided in Section 13 (Reservations of Authority), the Parties shall not invoke or rely upon any reopener clause set forth in the New Operating License for the Wells Project for the purposes of obtaining additional license articles, conditions or measures or to promote changes in Project structures or operations related to the protection, mitigation and enhancement of Aquatic Resources.

16.0 FORCE MAJEURE

16.1 No Liability for Force Majeure

No Party shall be liable to any other Party for breach of this Agreement as a result of a failure to perform or for delay in performance of any provision of this Agreement if, based on evidence provided by the non-performing Party to the other Parties, such performance is delayed or prevented by Force Majeure. In the event of an enforcement action, the non-performing Party bears the burden of proving by a preponderance of the evidence the existence of Force Majeure, including the absence of negligence. The term "Force Majeure" means any cause reasonably beyond the performing Party's control, which could not be avoided with the exercise of due care, and which occurs without the fault or negligence of the Party whose performance is affected by the Force Majeure. Force Majeure events may be unforeseen, foreseen, foreseeable, or unforeseeable, including without limitation natural events; labor or civil disruption; terrorism; breakdown or failure of Project works not caused by failure to properly design, construct, operate, or maintain; new regulations or laws that are applicable to the Project; orders of any court or agency having jurisdiction over the Party's actions; delay in a FERC order becoming final; or delay in issuance of any required permit.

16.2 Notice

The Party whose performance is affected by Force Majeure shall notify the other Parties in writing within seven (7) days, or as soon thereafter as practicable, after becoming aware of any event that such Party contends constitutes Force Majeure. Such notice shall identify the event causing the delay or anticipated delay, estimate the anticipated length of delay, state the measures taken or to be taken to minimize the delay, and estimate the timetable for implementation of the measures. The affected Party shall make all reasonable efforts to promptly resume performance of this Agreement and, when able, resume performance of its obligations and give the other Parties written notice to that effect.

17.0 NOTICES

17.1 Routine Notifications

Unless this Agreement specifically requires otherwise, any routine notice, demand or request provided for in this Agreement, or served, given or made in connection with it, shall be in writing and shall be deemed properly served, given or made if delivered in person or sent by delivery, including email, or sent by mail, postage prepaid to the designated technical and policy representatives of each Party.

17.2 Special Notifications

Unless this Agreement specifically requires otherwise, special notice shall be defined as any notice related to either a withdrawal or dispute resolution notification. All special notices prepared, served, given or made in connection with either withdrawal or dispute resolution, shall be in writing and shall be deemed properly served, given or made if delivered in person or sent by acknowledged delivery, including return receipt email, or sent by registered mail return receipt requested, postage prepaid to the technical, policy and executive representatives officially designated by each Party.

18.0 MISCELLANEOUS

18.1 Further Assurances

The Parties shall use best efforts to assist each other in performing their obligations under this Agreement including providing documents and information as may reasonably be requested.

18.2 No Consequential, Incidental or Punitive Damages

There shall be no liability under this Agreement for any consequential, punitive, exemplary, incidental or indirect losses or damages.

18.3 Severability

If any provision of this Agreement is held to be illegal, invalid, or unenforceable under any present or future law, and if the rights or obligations of any Party under this Agreement will not be materially and adversely affected thereby: (1) such provision will be fully severable; (2) this Agreement shall be construed and enforced as if such illegal, invalid, or unenforceable provision had never comprised a part thereof; (3) the remaining provisions of this Agreement shall remain in full force and effect and will not be affected by the illegal, invalid or unenforceable provision or by its severance here from; and (4) in lieu of such illegal, invalid or unenforceable provision, the Parties shall, in good faith, negotiate a mutually acceptable, legal, valid and enforceable provision as similar in terms to such illegal, invalid or unenforceable provision as may be possible, and shall promptly

take all actions necessary to amend the Agreement to include the mutually acceptable, legal, valid and enforceable provision.

18.4 Waivers

Except as otherwise provided herein, no provision of this Agreement may be waived except in writing. No failure by any Party to exercise, and no delay in exercising, short of the statutory period, any right, power, or remedy under this Agreement shall operate as a waiver thereof. Any waiver at any time by a Party of its right with respect to a default under this Agreement, or with respect to any other matter arising in connection therewith, shall not be deemed a waiver with respect to any subsequent default or matter.

18.5 No Third-Party Beneficiaries

None of the promises, rights, or obligations contained in this Agreement shall inure to the benefit of any person or entity not a Party to this Agreement; and no action may be commenced or prosecuted against any Party by any third party claiming to be a third-party beneficiary of this Agreement or the transactions contemplated hereby.

18.6 No Reliance

Each Party acknowledges that in entering into this Agreement, it has not relied on any statement, representation, or promise of the other Party or any other person or entity, except as expressly stated in this Agreement.

18.7 Assumption of Risk

In entering into this Agreement, each of the Parties assumes the risk of any mistake of fact or law, and if either or both of the Parties should subsequently discover that any understanding of the facts or the law was incorrect, none of the Parties shall be entitled to, nor shall attempt to, set aside this Agreement or any portion thereof. This provision does not affect the right of any Party to withdraw from this Agreement in accordance with Section 8.2 (Withdrawal Events).

18.8 Waiver of Defenses

The Parties release each other from any and all claims relating to the formation and negotiation of this Agreement, including reformation, rescission, mistake of fact, or mistake of law. The Parties further agree that they waive and will not raise in any court, administrative body or other tribunal any claim in avoidance of or defense to the enforcement of this Agreement other than the express conditions set forth in this Agreement.

18.9 Independent Counsel

The Parties acknowledge that they have been represented by independent counsel in connection with this Agreement, they fully understand the terms of this Agreement, and they voluntarily agree to those terms for the purposes of making a full compromise and settlement of the subject matter of this Agreement.

18.10 Headings

The headings used for the sections herein are for convenience and reference purposes only and shall in no way affect the meaning or interpretation of the provisions of this Agreement.

18.11 Interpretations

In this Agreement, unless a clear contrary intention appears: (1) the singular number includes the plural number and vice versa; (2) reference to any person includes such person's successors and assigns but, if applicable, only if such successors and assigns are permitted by this Agreement, and reference to a person in a particular capacity excludes such person in any other capacity; (3) reference to any gender includes each other gender; (4) reference to any agreement (including this Agreement), document or instrument means such agreement, document or instrument as amended or modified and in effect from time to time in accordance with the terms thereof and, if applicable, the terms hereof; (5) reference to any Section, Schedule, Attachment, or Exhibit means such Section, Schedule, Attachment, or Exhibit to this Agreement, and references in any Section, Schedule, Attachment, Exhibit, or definition to any clause means such clause of such Section, Schedule, Attachment, Exhibit, or definition; (6) "hereunder", "hereof", "hereto", "herein," and words of similar import are references to this Agreement as a whole and not to any particular section or other provision hereof unless specifically stated; (7) relative to the determination of any period of time, "from" means "from and including", "to" means "to but excluding" and "through" means "through and including"; (8) "including" (and with correlative meaning "include") means including without limiting the generality of any description preceding such term; and (9) reference to any law (including statutes and ordinances) means such law as amended, modified, codified or reenacted, in whole or in part, and in effect from time to time, including rules and regulations promulgated thereunder.

18.12 Venue

To the extent permitted by law, the venue for any action to enforce or interpret this Agreement involving any Federal or Tribal Parties shall be the United States District Court for the Eastern District of Washington or the FERC, and the venue for all other Parties shall be a Washington State court of competent jurisdiction or the FERC.

18.13 Legal Authority

Each Party represents and warrants to the other Parties that it has full authority and power to enter into this Agreement, that the Party's representatives who sign below are duly authorized by it to enter into this Agreement, and that nothing herein violates any law, regulation, judicial or regulatory order, or agreement applicable to such warranting Party.

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Agreement Execution

IN WITNESS WHEREOF, the Parties have caused this Agreement to be executed by their proper officers respectively being thereunto duly authorized, and their respective corporate seals to be hereto affixed, the 19 day of January, 2009

PUBLIC UTILITY DISTRICT NO. 1 of DOUGLAS COUNTY, WASHINGTON

By: _____
T. James Davis, President

By: _____
Lynn M. Heminger, Vice President

By: _____
Ronald E. Skagen, Secretary

Address of Notice:

Public Utility District No. 1 of Douglas County
1151 Valley Mall Parkway
East Wenatchee, Washington 98802-4497

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UNITED STATES FISH AND WILDLIFE SERVICE

Dated: 7/31/2009

By: Ken S. Berg

Title: Project Leader

Address of Notice:

United States Fish and Wildlife Service
11103 East Montgomery Drive
Spokane, Washington 99206

United States Fish and Wildlife Service
215 Melody Lane, Suite 119
Wenatchee, WA 98801-5933

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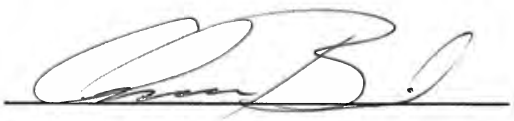
STATE OF WASHINGTON, DEPARTMENT OF FISH & WILDLIFE

Dated: 11/20/08

By: 

Title: RD Region 2

Address of Notice:

Washington State Department of Fish and Wildlife
600 Capital Way North
Olympia, Washington 98501-1091

Washington State Department of Fish and Wildlife
1540 Alder Street N.W.
Ephrata, Washington 98823-7669

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STATE OF WASHINGTON, DEPARTMENT OF ECOLOGY

Dated: 11/19/08

By: _____

Title: SECTION MANAGER
WATER QUALITY PROGRAM

Address of Notice:

Washington State Department of Ecology
15 West Yakima Avenue, Suite 200
Yakima, Washington 98902-3452

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CONFEDERATED TRIBES OF THE COLVILLE RESERVATION

Dated: 11-10-08

By: Michael Finley

Title: Vice Chairman

Address of Notice:

Confederated Tribes of the Colville Reservation
Natural Resource Committee
P.O. Box 150
Nespelem, Washington 99155

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CONFEDERATED TRIBES AND BANDS OF THE YAKAMA NATION

Dated: February 24, 2009

By: Ralph Sampson Jr.

Title: Yakama Nation Tribal Council, Chairman

Address of Notice:

Confederated Tribes and Bands of the Yakama Nation
PO Box 151
Toppenish, Washington 98948

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UNITED STATES, BUREAU OF LAND MANAGEMENT

Dated: Nov 13, 2009

By: _____

Title: Field Manager

Address of Notice:

Bureau of Land Management
915 North Walla Walla
Wenatchee, Washington 98801-1521

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UNITED STATES, BUREAU OF INDIAN AFFAIRS

Dated: _____

By: _____

Title: _____

Address of Notice:

Bureau of Indian Affairs
911 NE 11th Avenue
Portland, OR 97232

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ATTACHMENT A: PROPOSED LICENSE ARTICLES

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ATTACHMENT A: PROPOSED LICENSE ARTICLES

Article 1. The licensee shall implement the measures set forth in section 4 of the White Sturgeon Management Plan, dated August 2008, which is incorporated herein by reference, in consultation with the Aquatic Settlement Working Group. The licensee shall obtain prior Commission approval for any substantial modification or addition to Project works or operations necessary to implement such measures. The licensee shall also submit any proposed amendment to the White Sturgeon Management Plan to add to, or modify any of, the measures or objectives set forth therein to the Commission for approval. The licensee shall file an annual report with the Commission by May 31st of each year to document all studies, measures and other activities completed in the previous year.

Article 2. The licensee shall implement the measures set forth in section 4 of the Bull Trout Management Plan, dated August 2008, which is incorporated herein by reference, in consultation with the Aquatic Settlement Working Group. The licensee shall obtain prior Commission approval for any substantial modification or addition to Project works or operations necessary to implement such measures. The licensee shall also submit any proposed amendment to the Bull Trout Management Plan to add to, or modify any of, the measures or objectives set forth therein to the Commission for approval. The licensee shall file an annual report with the Commission by May 31st of each year to document all studies, measures and other activities completed in the previous year.

Article 3. The licensee shall implement the measures set forth in section 4 of the Pacific Lamprey Management Plan, dated August 2008, which is incorporated herein by reference, in consultation with the Aquatic Settlement Working Group. The licensee shall obtain prior Commission approval for any substantial modification or addition to Project works or operations necessary to implement such measures. The licensee shall also submit any proposed amendment to the Pacific Lamprey Management Plan to add to, or modify any of, the measures or objectives set forth therein to the Commission for approval. The licensee shall file an annual report with the Commission by May 31st of each year to document all studies, measures and other activities completed in the previous year.

Article 4. The licensee shall implement the measures set forth in section 4 of the Resident Fish Management Plan, dated August 2008, which is incorporated herein by reference, in consultation with the Aquatic Settlement Working Group. The licensee shall obtain prior Commission approval for any substantial modification or addition to Project works or operations necessary to implement such measures. The licensee shall also submit any proposed amendment to the Resident Fish Management Plan to add to, or modify any of, the measures or objectives set forth therein to the Commission for approval. The licensee shall file an annual report with the Commission by May 31st of each year to document all studies, measures and other activities completed in the previous year.

Article 5. The licensee shall implement the measures set forth in section 4 of the Aquatic Nuisance Species Management Plan, dated August 2008, which is incorporated herein by reference, in consultation with the Aquatic Settlement Working Group. The licensee shall obtain prior Commission approval for any substantial modification or addition to Project works or operations necessary to implement such measures. The licensee shall also submit any proposed amendment to the Aquatic Nuisance Species Management Plan to add to, or modify any of, the measures or objectives set forth therein to the Commission for approval. The licensee shall file an annual report with the Commission by May 31st of each year to document all studies, measures and other activities completed in the previous year.

Article 6. The licensee shall implement the measures set forth in section 4 of the Water Quality Management Plan, dated October 2008, which is incorporated herein by reference, in consultation with the Aquatic Settlement Working Group. The licensee shall obtain prior Commission approval for any substantial modification or addition to Project works or operations necessary to implement such measures. The licensee shall also submit any proposed amendment to the Water Quality Management Plan to add to, or modify any of, the measures or objectives set forth therein to the Commission for approval. The licensee shall file an annual report with the Commission by May 31st of each year to document all studies, measures and other activities completed in the previous year.

ATTACHMENTS B - G: AQUATIC RESOURCE MANAGEMENT PLANS

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ATTACHMENT B: WHITE STURGEON MANAGEMENT PLAN

ATTACHMENT C: BULL TROUT MANAGEMENT PLAN

ATTACHMENT D: PACIFIC LAMPREY MANAGEMENT PLAN

ATTACHMENT E: RESIDENT FISH MANAGEMENT PLAN

ATTACHMENT F: AQUATIC NUISANCE SPECIES MANAGEMENT PLAN

ATTACHMENT G: WATER QUALITY MANAGEMENT PLAN

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ATTACHMENT B: WHITE STURGEON MANAGEMENT PLAN

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WHITE STURGEON MANAGEMENT PLAN

WELLS HYDROELECTRIC PROJECT

FERC PROJECT NO. 2149

August 2008

Prepared by:
Public Utility District No. 1 of Douglas County
East Wenatchee, Washington

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EXECUTIVE SUMMARY

The White Sturgeon Management Plan (WSMP) is one of six Aquatic Resource Management Plans contained within the Aquatic Settlement Agreement (Agreement). Collectively, these six Aquatic Resource Management Plans are critical to direct implementation of Protection, Mitigation, and Enhancement measures (PMEs) during the term of the new license and, together with the Wells Anadromous Fish Agreement and Habitat Conservation Plan (HCP) will function as the Water Quality Attainment Plan (WQAP) in support of the Clean Water Act Section 401 Water Quality Certification for the Wells Hydroelectric Project (Project).

To ensure active stakeholder participation and support, the Public Utility District No. 1 of Douglas County (Douglas) developed all of the resource management plans in close coordination with agency and tribal natural resource managers (Aquatic Settlement Work Group or Aquatic SWG). During the development of this plan, the Aquatic SWG focused on developing management priorities for resources potentially impacted by Project operations. Members of the Aquatic SWG include the U.S. Fish and Wildlife Service (USFWS), Washington Department of Ecology (Ecology), Washington State Department of Fish and Wildlife (WDFW), the Confederated Tribes of the Colville Reservation (Colville), the Confederated Tribes and Bands of the Yakama Indian Nation (Yakama), and Douglas.

The National Marine Fisheries Service (NMFS) was invited to participate in the development of Aquatic Resource Management Plans, but declined because its interests are currently satisfied by the measures within the HCP.

The goal of the WSMP is to increase the white sturgeon (*Acipenser transmontanus*) population in the Wells Reservoir to a level that can be supported by the available habitat and characterized by a diverse age structure consisting of multiple cohorts (juvenile and adult). In addition, the WSMP is intended to support spawning, rearing and migration as identified by the aquatic life designated use under WAC 173-201A in the Washington state water quality standards. Based upon the information available as of December 2006, the Aquatic SWG determined that an assessment of Project effects on white sturgeon was not practical given sturgeon life history characteristics and the limited number of fish estimated to exist in the Project. Therefore, the Aquatic SWG concluded that resource measures related to white sturgeon should focus on population protection and enhancement by means of supplementation as an initial step in order to increase the number of fish within the Wells Reservoir. In addition to the initial supplementation activities, implementation of a monitoring and evaluation program shall be conducted to accurately assess natural recruitment, juvenile habitat use, emigration rates, carrying capacity, and the potential for natural reproduction so as to inform the scope of a future, longer-term supplementation strategy. All objectives were developed in order to meet the WSMP goal. The PMEs presented within the WSMP are designed to meet the following objectives:

Objective 1: Supplement the white sturgeon population in order to address Project effects, including impediments to migration and associated bottlenecks in spawning and recruitment;

Objective 2: Determine the effectiveness of the supplementation activities through a monitoring and evaluation program;

Objective 3: Determine the potential for natural reproduction in the Wells Reservoir in order to appropriately inform the scope of future supplementation activities;

Objective 4: Adaptively manage the supplementation program as warranted by the monitoring results;

Objective 5: Evaluate whether there is biological merit to providing safe and efficient adult upstream passage;

Objective 6: Identify white sturgeon educational opportunities that coincide with WSMP activities.

This WSMP is intended to be compatible with other white sturgeon management plans in the Columbia River mainstem. Furthermore, this management plan is intended to be not inconsistent with other management strategies and recovery goals of federal, state and tribal natural resource management agencies. The WSMP is not intended to be a harvest management plan and does not create or supersede jurisdiction over fisheries management decisions made by the responsible fishery agencies and tribes. However, the WSMP activities are expected to ultimately support appropriate and reasonable harvest opportunities consistent with the goals of the responsible fishery agencies and tribes and designated use for harvest under WAC 173-201A identified in the Washington state water quality standards. Should the responsible fishery agencies and tribes determine that there is an ongoing harvestable surplus of sturgeon in the Wells Reservoir, then this indicates significant progress toward achievement of the goals and objectives of this plan.

1.0 INTRODUCTION

The White Sturgeon Management Plan (WSMP) is one of six Aquatic Resource Management Plans contained within the Aquatic Settlement Agreement (Agreement). Collectively, these six Aquatic Resource Management Plans are critical to direct implementation of Protection, Mitigation, and Enhancement measures (PMEs) during the term of the new license and, together with the Wells Anadromous Fish Agreement and Habitat Conservation Plan (HCP) will function as the Water Quality Attainment Plan (WQAP) in support of the Clean Water Act Section 401 Water Quality Certification for the Wells Hydroelectric Project (Project).

To ensure active stakeholder participation and support, the Public Utility District No. 1 of Douglas County (Douglas) developed all of the resource management plans in close coordination with agency and tribal natural resource managers (Aquatic Settlement Work Group or Aquatic SWG). During the development of this plan, the Aquatic SWG focused on developing management priorities for resources potentially impacted by Project operations. Entities invited to participate in the Aquatic SWG include the U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), Bureau of Land Management (BLM), Bureau of Indian Affairs (BIA), Washington Department of Ecology (Ecology), Washington State Department of Fish and Wildlife (WDFW), the Confederated Tribes of the Colville Reservation (Colville), the Confederated Tribes and Bands of the Yakama Indian Nation (Yakama), and Douglas.

The WSMP will direct implementation of measures to protect against and mitigate for potential Project impacts on white sturgeon (*Acipenser transmontanus*). To ensure active stakeholder involvement and support, Douglas developed this plan, along with the other aquatic management plans, in close coordination with the members of the Aquatic SWG.

The Aquatic SWG agrees on the need to develop a plan for the long-term management of white sturgeon in the Project. This management plan summarizes the relevant resource issues and background (Section 2), identifies the goal and objectives of the plan (Section 3), and describes the relevant PMEs (Section 4) for white sturgeon during the term of the new license.

2.0 BACKGROUND

2.1 White Sturgeon Biology

White sturgeon are the largest of all North American freshwater fish. They are found in marine waters and freshwaters of rivers along the Pacific coast from Monterey, California to Cook Inlet in northwestern Alaska (Wydoski and Whitney 2003). Significant populations of the Pacific Coast appear to be restricted to three locations: the Sacramento, Fraser, and Columbia rivers (Lane 1991). White sturgeon are distributed throughout the U.S. portion of the Columbia River and in many of its larger tributaries. Historically, white sturgeon migrated throughout the mainstem Columbia River from the estuary to the headwaters, although passage was probably limited at times by large rapids and falls (Brannon and Setter 1992).

White sturgeon are long-lived fish, with fin ray analysis documenting fish over 100 years in age (Beamesderfer et al. 1995). This anadromous species has been reported to reach a length of 20 feet and a weight of 1,800 pounds (Wydoski and Whitney 2003). In the Columbia River, white sturgeon spawn in the spring between April and July. Only a small percentage of adult white sturgeon in the Columbia River spawn in a given year. Intervals between spawning have been estimated to be between 3 and 11 years. White sturgeon deposit eggs through broadcast spawning at water temperatures between 10 and 18°C. Mature white sturgeon commonly produce between 100,000 and 300,000 eggs, but larger fish may produce up to 3 million eggs (Wydoski and Whitney 2003). Spawning and egg incubation in the Columbia River occur in the swiftest water available (2.6-9.2 feet per second) at depths between 13.1 and 65.6 feet over cobble, boulder, and bedrock substrates (Wydoski and Whitney 2003). In mainstem Columbia River reservoirs, spawning occurred within 5 miles downstream of the mainstem dams. Eggs hatch in approximately 7 days at 15°C.

Columbia River white sturgeon are reported to have declined in numbers because of numerous factors, including obstruction of migration by mainstem hydroelectric dams, altered stream flows, altered hydrologic regimes, altered temperature regimes, reduced spawning habitat, and over harvest (van der Leeuw et al. 2006; Wydoski and Whitney 2003). Variations in population characteristics also have been attributed to differences in exploitation rates and recruitment success, access to marine food resources, and suitability of hydrologic conditions and available habitats (Devore et al. 1995). During the 1800s, prior to construction of mainstem hydroelectric dams on the Columbia River, white sturgeon were in great demand for their caviar and smoked flesh. In 1892, during the peak of commercial harvest activities, approximately 2.5 million kilograms of white sturgeon were harvested (Wydoski and Whitney 2003). Regulations of the white sturgeon fishery began with a 4-foot minimum size limit established in 1899. Several regulations were established from 1899 to 2000 to manage the fishery in the lower Columbia River, although, effective recovery efforts did not begin until spawners were protected in the 1950s (Wydoski and Whitney 2003).

Beginning in the 1930s, with the construction of Rock Island, Grand Coulee, and Bonneville dams, migration was disrupted because white sturgeon generally do not pass upstream through fishways that were built for salmon, although they do pass downstream through dams (Lepla et al. 2001). Construction of hydroelectric projects in the mid-Columbia River Basin, such as Priest Rapids, Wanapum, Rock Island, Rocky Reach, and Wells has also affected the upstream movement of white sturgeon. Current populations in the Columbia River basin can be divided into three groups: fish below the Bonneville Dam, with access to the ocean; fish isolated functionally, but not genetically, between dams; and fish in several large tributaries. However, the population dynamics and factors regulating production of white sturgeon within isolated populations in the mid-Columbia River reservoirs such as the Rocky Reach and Wells reservoirs are not well understood.

2.2 White Sturgeon Management and Recovery Efforts

Management programs to protect and restore white sturgeon in the Kootenai River and the upper Columbia River are on-going and have provided a relevant framework for the development of a white sturgeon management plan in the Wells Reservoir. The Kootenai and upper Columbia sturgeon recovery efforts have also provided a good technical framework for implementing a sturgeon management plan. The strategies and activities outlined in these aforementioned management programs have provided important information, which has been used to develop an effective WSMP.

2.2.1 Kootenai River White Sturgeon Recovery

In the early 1990s following concerns that white sturgeon populations were decreasing due to near total recruitment failure, a detailed monitoring program was instituted by the Idaho Department of Fish and Game (IDFG) to provide more information on white sturgeon species status in the Kootenai River system. In 1994, the USFWS listed the Kootenai stock of white sturgeon as an endangered species, which introduced a higher level of management and control by various authorities in the drainage and region. A Recovery Team was established to provide technical direction regarding hatchery supplementation efforts. A final Kootenai White Sturgeon Recovery Plan was signed by the USFWS in 1999.

Kootenai white sturgeon recovery efforts consist of a multi-faceted approach aimed at improving survival at various life history stages. Coordinated flow releases during spring are a major habitat restoration focus designed to increase natural recruitment, although currently it is difficult to assess the relationship between flows and recruitment success (USFWS 1999). Directed stocking programs, which address genetic concerns, stocking rates, and fish size at release, have also been implemented to boost juvenile sturgeon in the Kootenai system. The Kootenai Tribe of Idaho in collaboration with the Kootenay Trout Hatchery (KTH) in Canada are primarily responsible for producing high-quality juvenile white sturgeon for the directed stocking program. Information collected from annual monitoring activities, which assess survival, growth rates, and natural spawning success, allow for an adaptive management approach with regards to the stocking program.

2.2.2 Upper Columbia River White Sturgeon Recovery

In 2002, a bi-national Recovery Team, termed the Upper Columbia White Sturgeon Recovery Initiative (UCWSRI) finalized the Upper Columbia White Sturgeon Recovery Plan in response to concerns that the transboundary white sturgeon population residing between Hugh L. Keenleyside Dam and Grand Coulee Dam consists of an aging and declining population with extremely limited recruitment. The Recovery Team, consisting of technical representatives from Federal, Provincial, and State resource management agencies and from Canadian and U.S. tribes, directs the recovery program.

Due to near total recruitment failure over the past two decades, a decision was made early in the recovery planning process to move immediately to development of a hatchery program to produce juvenile sturgeon for stocking (UCWSRI 2002). The breeding plan (Kincaid 1993) developed for the Kootenai sturgeon program was used as a model for the upper Columbia

sturgeon. Rearing of all fish for the stocking program occurs at the KTH. Similar to the Kootenai recovery strategy, a juvenile index monitoring program to assess growth, survival, health, distribution, and relative abundance of released juveniles shall provide information essential to monitoring the upper Columbia sturgeon population and the success of the hatchery stocking program.

2.2.3 Rocky Reach White Sturgeon Management Plan

The relicensing process for the Rocky Reach Hydroelectric Project brought fisheries agencies, tribes, and interested parties together in a Natural Resources Working Group (NRWG) that provided an opportunity for comprehensive review of current and future management priorities for fish resources potentially impacted by ongoing Project operations (Chelan PUD 2005). In 2004 and 2005, NRWG members collaborated on the development of goals and objectives to manage the white sturgeon population within the Rocky Reach Project boundary under the new license. Based upon the information collected from white sturgeon field studies implemented by Chelan PUD in 2001 and 2002, a white sturgeon management plan was developed to promote population growth of sturgeon to a level commensurate with the available habitat. The Rocky Reach management plan measures include the implementation of a white sturgeon supplementation program, a monitoring program to determine population characteristics, and tracking surveys to determine movements and to assess potential spawning locations.

2.2.4 Priest Rapids Project White Sturgeon Management Plan

As part of the Priest Rapids Project relicensing, white sturgeon populations were investigated in the Priest Rapids and Wanapum reservoirs from 1999 to 2003. Results of the study have assisted in identifying a framework for the future development and implementation of a Priest Rapids Project White Sturgeon Management Plan. Biological objectives associated with this management plan consist of increasing white sturgeon populations to a level commensurate with available habitat through a supplementation program and the implementation of a monitoring program to determine population characteristics such as natural recruitment, spawning, rearing, growth, survival, and rates of emigration.

2.3 Project White Sturgeon Study

Since little information existed on the status of white sturgeon populations in the mid-Columbia, Chelan, Grant, and Douglas PUDs each initiated studies of white sturgeon to support their current or upcoming relicensing processes. The information gathered from these studies was intended to provide basic white sturgeon life history information, distribution, and current population sizes in the mid-Columbia River Basin. Additionally, study results provided the foundation for the development of appropriate management goals and objectives.

From 2001-2003, Douglas implemented a study to examine the white sturgeon population within the Project. Prior to the implementation of this study, little information on white sturgeon was available for the Wells Reservoir. WDFW catch record card returns for 1993 and 1994 indicate that legal size white sturgeon were present in the Wells Reservoir (Brad James, WDFW, pers. comm.). Additionally, information from previous studies in reservoirs upstream and downstream supported the existence of a population. The primary objectives of the study were to provide

basic information on the population abundance, age structure, size, and growth of Project white sturgeon; analyze movements of white sturgeon within the Reservoir; and compare the data collected during this study with data collected during assessments at other projects (Jerald 2007).

During the summers of 2001 and 2002, setlines were deployed in the Wells Reservoir. Sturgeon captured on setlines were measured, marked with passive integrated transponder (PIT) tags and with scute markings. Additionally, a select number of captured fish were fitted with radio-transmitters to track movements and had pectoral fin rays removed for age analysis using standard methodologies (Beamesderfer et al. 1989).

Setline sampling took place over a two-year timeframe with a total of 129 setlines deployed and retrieved from throughout the reservoir. In total, 13 white sturgeon were captured during the 2-year study with the majority of the fish being captured in the Columbia River within five miles of the mouth of the Okanogan River. Twelve of the captured fish were PIT tagged. Subsequently, five recapture events were recorded for a total of 18 capture events during the mark-recapture period (one fish was recaptured twice). Population abundance was estimated to be 31.35±17.51. The 95% confidence interval for sturgeon abundance was calculated to be CI ($13<N<218$). The results of the mark-recapture portion of the study indicated that the sturgeon population in the Wells Reservoir is small with a point estimate of 31 fish over 50 cm in length (Skalski and Townsend 2005).

The length of the 13 fish captured during the study ranged from 60-202 cm. Two of the fish were classified as juveniles (<90 cm fork length) while 11 were classified as sub-adults or adults. It is important to note that the capture methodology was not designed to provide accurate sampling of fish under 50 cm. Captured sturgeon ranged in age from 6 to 30 years old (based on 11 fish) demonstrating that all of these fish recruited to the Wells Reservoir after Wells Dam was completed in 1967 with strong year class recruitment between the years 1972 and 1978 and again between 1988 and 1996. The presence of fish within these age classes suggests that successful recruitment within or to the Wells Reservoir is occurring either through (1) spawning within the Wells Reservoir and/or (2) immigration into the Wells Reservoir from populations upstream. Two white sturgeon were captured in 2001 and subsequently recaptured in 2002 to provide limited growth rate information. One juvenile fish was measured at 65 cm (fork length) on July 11, 2001. The fish was again captured on September 26, 2002 and measured 87 cm. This represented a growth rate of 22 cm in 14 months, or 18.9 cm/year. One adult fish was captured on August 9, 2001 measuring 197 cm (fork length). The fish was subsequently captured on September 6, 2002 and measured 199 cm representing a 2 cm growth rate over approximately 13 months, or 1.85 cm/year (Jerald 2007). In October 2006, this fish was found dead along the shoreline of the Columbia River adjacent to the mouth of the Okanogan River. At that time, biologists measured the fish at 228.5 cm representing a 29.5 cm increase in length over a four year period or an average of 7.4 cm of growth per year.

A total of six white sturgeon were fitted with radio-tags and monitored throughout the study period using mobile and fixed telemetry. Telemetry data along with setline capture data verify that white sturgeon congregate in the Columbia River near the Okanogan River confluence during the summer, fall, and winter months with none of the six fish being detected downstream from Brewster (RM 530) or upstream of Park Island (RM 538). Very little movement of tagged

sturgeon was observed during winter months. In the spring of 2002, one of the five mature fish radio-tagged made an upstream migration into the Okanogan River and two different radio-tagged mature sized sturgeon made movements into the Okanogan River during 2003.

In general, the results of the white sturgeon study in the Wells Reservoir were similar to the results of a study conducted in the neighboring Rocky Reach Reservoir in 2001-2002 (Chelan PUD 2005). Results indicate that the Wells Reservoir adult sturgeon population is estimated from 13-217 fish. These results are similar to the Rocky Reach assessment which estimated numbers of sturgeon from 50-115 fish. Both studies captured similar numbers of sturgeon using similar amounts of effort and similar capture techniques (Rocky Reach=18 sturgeon, Wells=13 sturgeon). Radio-telemetry data from both studies suggest that very little activity occurs during the overwintering period. Wells Reservoir sturgeon ranged in age from 6 to 30 years old while Rocky Reach sturgeon ranged in age from 7 to 50 years old. Both studies suggest that some recruitment into each population is occurring given the presence of juvenile fish in their respective reservoirs (Chelan PUD 2005; Jerald 2007).

3.0 GOAL AND OBJECTIVES

The goal of the WSMP is to increase the white sturgeon population in the Wells Reservoir to a level that can be supported by the available habitat and characterized by a diverse age structure consisting of multiple cohorts (juvenile and adult). In addition, the WSMP is intended to support spawning, rearing and migration as identified by the aquatic life designated use under WAC 173-201A in the Washington state water quality standards. Based upon the available information, the Aquatic SWG agreed that a rigorous and reliable assessment of ongoing Project effects on white sturgeon was not practical given sturgeon life history characteristics and the limited number of fish estimated to exist in the Wells Reservoir. Therefore, the Aquatic SWG concluded that efforts should focus, initially, on supplementation efforts to increase the population within the Wells Reservoir in order to address Project effects. Once the population numbers have been increased to a level that can be studied, as determined by the Aquatic SWG, Douglas shall implement a monitoring and evaluation program to accurately assess natural recruitment, juvenile habitat use, emigration rates, carrying capacity, and the potential for natural reproduction so as to inform the scope of a future, long-term supplementation strategy. The PMEs of the WSMP are designed to meet the following objectives:

Objective 1: Supplement the white sturgeon population in order to address Project effects, including impediments to migration and associated bottlenecks in spawning and recruitment;

Objective 2: Determine the effectiveness of the supplementation activities through a monitoring and evaluation program;

Objective 3: Determine the potential for natural reproduction in the Wells Reservoir in order to appropriately inform the scope of future supplementation activities;

Objective 4: Adaptively manage the supplementation program as warranted by the monitoring results and in consultation with the Aquatic SWG;

Objective 5: Evaluate whether there is biological merit to providing safe and efficient adult upstream passage;

Objective 6: Identify white sturgeon educational opportunities that coincide with WSMP activities.

This WSMP is intended to be compatible with other white sturgeon management plans in the Columbia River mainstem. Furthermore, this management plan is intended to be not inconsistent with other management strategies and recovery goals of federal, state and tribal natural resource management agencies. The WSMP is not intended to be a harvest management plan and does not create or supersede jurisdiction over fisheries management decisions made by the responsible fishery agencies and tribes. However, the WSMP activities are expected to ultimately support appropriate and reasonable harvest opportunities consistent with the goals of the responsible fishery agencies and tribes and designated use for harvest under WAC 173-201A identified in the Washington state water quality standards. Should the responsible fishery agencies and tribes determine that there is an ongoing harvestable surplus of sturgeon in the Wells Reservoir, then this indicates significant progress toward achievement of the goals and objectives of this plan.

Douglas in consultation with the Aquatic SWG, developed the goal, objectives, and PMEs described in this section. The extent to which implementation of the proposed PMEs successfully achieve the WSMP goal and objectives identified shall be determined through the monitoring and evaluation program. Once the results of the monitoring and evaluation program have been considered, Douglas shall determine, in consultation with the Aquatic SWG, whether changes to the sturgeon stocking program are needed to meet the goals and objectives of the management plan.

The schedule for implementation of specific measures within the WSMP is based on the best information available at the time the Plan was developed. As new information becomes available, implementation of each activity may be adjusted through consultation with the Aquatic SWG.

4.0 PROTECTION, MITIGATION AND ENHANCEMENT MEASURES

In order to fulfill the goal and objectives described in Section 3.0, Douglas, in consultation with the ASWG, shall develop and implement a white sturgeon management program that includes PMEs. The Program shall be designed for implementation in two phases. Phase I of the PMEs shall be implemented during the first ten years of the new license and consist of supplementation, monitoring and evaluation activities. Results of Phase I PMEs will be used to inform the scope of continued PMEs during Phase II, which shall be implemented for the remainder of the new license.

Douglas, in consultation with the ASWG, shall initiate implementation of the following PMEs during the 50-year license term:

Phase I (Years 1-10)

- Development of a Brood Stock Collection and Breeding Plan (Year 1 and updated as determined by the Aquatic SWG, See Section 4.1.1);
- Brood Stock Collection (Years 1-4 and other years TBD by the Aquatic SWG, see Section 4.1.1);
- Juvenile Stocking (Years 2-5 and other years TBD by the Aquatic SWG, see Section 4.1.2);
- Index Monitoring Program (Years 3-5 and 2 more years prior to Year 10 TBD by the Aquatic SWG, see Section 4.2.1);
- Marked Fish Tracking (Years 3-5 and 2 more years prior to Year 10 TBD by the Aquatic SWG, see Section 4.2.2);
- Natural Reproduction Assessments (5 annual assessments over the license term, see Section 4.2.3)[*];

[*] Natural reproduction assessments can be implemented over the term of the license (Phase I and Phase II) as determined by the Aquatic SWG.

Phase II (Years 11-50)

- Long-term juvenile stocking (stocking rate and frequency TBD by Aquatic SWG in Years 11-50, see Section 4.4.1);
- Supplementation Program Review (Years 11-50 TBD by the Aquatic SWG, see Section 4.4.2);
- Long-term Index Monitoring Program (Year 12 and once every 3-5 years thereafter TBD by the Aquatic SWG, see Section 4.4.3);
- Adult Passage Evaluation (Year 11 and once every 10 years thereafter, see Section 4.4)

As determined by the Aquatic SWG, appropriate educational opportunities coinciding with implementation of WSMP activities (Section 4.5) will be made available during the entire 50 year license term.

The following sections describe, in detail, the components, timing of implementation, and decision-making process of the PMEs to be conducted during Phase I and II of the white sturgeon management program.

4.1 Phase I Supplementation Program (Objective 1)

4.1.1 Brood Stock Collection and Breeding Plan

Due to the low numbers of sturgeon indicated by the 2001-2003 white sturgeon study and the need to increase genetic variation, there is a low probability that brood stock from only the Wells Reservoir can be utilized as the basis for supplementation activities. Consequently, other sources of fish must be considered in addition to capturing fish from Wells Reservoir to increase the white sturgeon population. Within one year of issuance of the new license Douglas shall prepare and implement a Brood Stock Collection and Breeding Plan, in consultation with the Aquatic SWG, which considers such factors as genetics and questions of imprinting, and are consistent with the goal and objectives of the WSMP and includes the level of detail provided in other existing white sturgeon breeding plans.

Following is a prioritized list of juvenile fish source options that shall be incorporated into a Brood Stock Collection and Breeding Plan:

- Brood stock collected from the Wells Reservoir;
- Brood stock collected from nearby reservoirs (Priest Rapids, Wanapum, Rocky Reach, Rock Island);
- Brood stock collected from McNary Reservoir;
- Juvenile production from the Lake Roosevelt white sturgeon recovery effort;
- Brood stock collected from below Bonneville Dam in the lower Columbia River;
- Juveniles purchased from a commercial facility.

A white sturgeon supplementation program may include, but may not be limited to, the following implementation options (Not listed in a priority order):

- Build new or retrofit existing Douglas funded hatchery facilities to accommodate white sturgeon brood stock, egg incubation, and juvenile rearing;
- Development of a mid-Columbia hatchery facility funded by the three PUDs (Douglas, Chelan, and Grant) to accommodate various phases of white sturgeon supplementation; brood stock, egg incubation, and juvenile rearing;
- Direct release into the Wells Reservoir of juveniles produced via appropriate Breeding Plan criteria and reared at a commercial facility;
- Direct release into the Wells Reservoir juveniles or adults trapped and hauled from the lower Columbia River.

The initial source of brood stock shall be determined within the first year of issuance of the new license. Collection of brood stock shall occur consistent with the brood stock collection plan in years 1-4 of the new license. Any additional years during the Phase I program (first ten years of the new license) in which brood stock collection shall occur in order to facilitate additional juvenile stocking into the Wells Reservoir (Section 4.1.2) will be determined by the Aquatic SWG. The intent of brood stock collection is to use their progeny, if feasible, for future white sturgeon stocking activities in the Wells Reservoir. The brood stock collection plan shall be updated annually, or as otherwise recommended by Douglas in consultation with the ASWG, to incorporate new and appropriate information.

4.1.2 Juvenile White Sturgeon Stocking

Within two years following issuance of the new license, Douglas shall release up to 5,000 yearling white sturgeon into the Wells Reservoir annually for four consecutive years (20,000 fish total). Additional years and numbers of juvenile sturgeon to be stocked during Phase I will be determined by the Aquatic SWG and will not exceed 15,000 juvenile sturgeon (total of 35,000 juvenile sturgeon during Phase I). In consultation with the Aquatic SWG, yearling fish for release shall be acquired through one or more of the sources listed in priority order in Section 4.1.1 above, or through other measures identified by the Aquatic SWG. If juvenile sturgeon stocking deadlines cannot be achieved, the Aquatic SWG will determine alternative implementation measures that will be undertaken by Douglas (see Table 4.7-1, footnote 2).

Douglas shall ensure that all hatchery-reared juvenile white sturgeon released into the Wells Reservoir are marked with Passive Integrated Transponder (PIT) tags and year-specific scute marks for monitoring purposes described in Section 4.2 of this plan. In order to allow for tracking of juvenile white sturgeon emigration described under Section 4.2.2, Douglas shall ensure that up to one percent (or a maximum of 50) of the juvenile white sturgeon released into the Wells Reservoir are large enough to allow implantation of an active tag prior to release. In addition, following the third year of supplementation (unless the Aquatic SWG determines more analysis is required), the Aquatic SWG may elect to release juveniles at an earlier or later life stage for the fourth year in order to compare success of fish released at varying life stages. For example, the Aquatic SWG may elect to have a proportion of the hatchery-reared juveniles released at differing size intervals (with the minimum size being that which permits PIT tagging), in order to monitor potential differences in survival and growth during future indexing periods.

4.2 Phase I Monitoring and Evaluation Program (Objective 2)

Douglas shall conduct a monitoring and evaluation program within the Wells Reservoir for the purpose of assessing the effectiveness of the supplementation activities described in Section 4.1 and outlined in Table 4.7-1. Monitoring shall include both an Index Monitoring Program (Section 4.2.1) and a Marked Fish Tracking Program (Section 4.2.2). Both of these studies will be used to collect life history and population dynamics information including rates of fish movements into and out of the Wells Reservoir and habitat use. Douglas shall also obtain updated information, when available, on other white sturgeon recovery programs (e.g., Upper Columbia River, Kootenai River, mid-Columbia PUDs), in order to improve the monitoring and evaluation program and refine its implementation. The results of this information will also inform supplementation, monitoring and evaluation activities during implementation of Phase II of the WSMP.

4.2.1 Index Monitoring Program

Within three years following issuance of the New License, Douglas shall initiate a three-year index monitoring program (Years 3-5) for juvenile and adult sturgeon in the Wells Reservoir to determine age-class structure, survival rates, abundance, density, condition factor, growth rates, and to identify distribution and habitat selection of juvenile sturgeon. The indexing methods shall include using gillnets, set lines or other appropriate recapture methods for juveniles and adults.

As a component of the Phase I indexing program, Douglas shall capture and implant active tags in a portion of the juvenile and sexually mature adult sturgeon population found in the Wells Reservoir. This tagging effort shall be used to augment broodstock collection (Section 4.1.1), population level information and juvenile habitat use (Section 4.2.2) and natural reproduction potential (Section 4.2.3).

After the initial three-year indexing period (Years 3-5), Douglas shall conduct an additional two years of index monitoring in Phase I as determined by the Aquatic SWG. After year 9, an additional year of index monitoring would take place in year 12 and then every three to five years over the term of the new license (Phase II) to assess age-class structure, survival rates, abundance, condition factor, growth rates; identify distribution and habitat selection of juvenile sturgeon; and to inform the supplementation program strategy (see Table 4.7-1).

Frequency (every 3, 4 or 5 years) of implementation of a long-term index monitoring activities (after year 12) will be determined by the Aquatic SWG. Phase II index monitoring activities will not consist of implantation of active tags in captured individuals.

4.2.2 Marked Fish Tracking Program

Beginning in year three of the new license and continuing for three years (Years 3-5), Douglas shall conduct tracking surveys of the juvenile white sturgeon that were released with active tags as part of supplementation activities. This will require one percent of each of the annual classes of juvenile sturgeon (up to a maximum of 50 fish each year) released in years 2, 3, 4, and 5 to be reared large enough to implant an active tag for tracking purposes (See Table 4.7-1). The purpose of tracking active-tagged fish is to determine juvenile white sturgeon emigration rates out of the Wells Reservoir and habitat use within the Wells Reservoir.

Douglas shall repeat the tracking survey for two additional years during Phase I (see Table 4.7-1). The additional two years of surveys shall track: 1) active tags implanted in a percentage of juvenile fish from previous years of supplementation activities (dependent upon tag life) and 2) any juvenile and adult fish implanted with active tags during the last indexing period preceding the survey. Subsequent Phase I surveys are likely to coincide with the additional Phase I index monitoring and juvenile stocking activities.

4.2.3 Determining Natural Reproduction Potential (Objective 3)

In years where environmental conditions are appropriate, Douglas shall track sexually mature adult sturgeon that were captured and implanted with active tags under Section 4.2.1 for the purpose of identifying potential spawning locations and determining natural reproduction potential. Appropriate environmental conditions may be determined by examining the following factors: water quality and quantity (i.e., flow, temperature, and turbidity), the presence of reproductively viable adults during index monitoring activities, and the status of maturity for supplemented fish. In years in which sexually mature adult sturgeon are tagged under Section 4.2.1, Douglas may also utilize egg collection mats in combination with tracking in areas of the Wells Reservoir for the purpose of identifying potential spawning locations and activity. Five surveys of natural reproduction using adult tracking and/or egg mat placement shall occur over the term of the new license. Several of these surveys are intended to be implemented during the latter part of the license in order to examine the natural reproductive potential of supplemented fish recruiting to sexually maturity. These activities will support the aquatic life designated use for spawning under WAC 173-201A in the Washington state water quality standards.

4.3 Phase II Supplementation and Monitoring Program (Objective 2 and 4)

The information collected through activities described in Section 4.1-4.3 will provide insight into the population dynamics, habitat availability, and limiting factors that affect the natural population structure of white sturgeon within the Wells Reservoir. This information will inform supplementation, monitoring and evaluation activities during implementation of Phase II supplementation and monitoring activities in the WSMP for the duration of the new license term after year 10.

4.3.1 Long-Term Juvenile White Sturgeon Stocking

The number and frequency of yearlings released in Phase II of the white sturgeon supplementation program will range from 0 to 5,000 fish. Stocking rates shall be based on the results of the Phase I Monitoring and Evaluation Program (Section 4.2) and determination of carrying capacity (Section 4.3) and shall be consistent with the goal and objectives of the WSMP. The Phase II stocking rates can also be adjusted as determined by the Aquatic SWG (also see Table 4.7-1, footnotes 2 and 3).

4.3.2 Supplementation Program Review

Douglas shall compile information on other white sturgeon supplementation programs in the Columbia River Basin in order to assess whether the white sturgeon supplementation program being implemented at the Project is: (i) consistent and comparable with the technology and methods being implemented by other supplementation programs in the region; (ii) reasonable in cost and effective to implement at the Project; and (iii) consistent with the supplementation program goals and objectives. The supplementation program review will be conducted annually in coordination with the development of the annual report (Section 4.6).

4.3.3 Long-term Index Monitoring Program

Beginning in Year Twelve of the new license and every 3 to 5 years thereafter for the duration of the new license, Douglas shall continue to conduct a Phase II Index Monitoring Study for juvenile and adult sturgeon in the Wells Reservoir. This program will be used to monitor age-class structure, survival rates, abundance, condition factor, growth rates, identify distribution and habitat selection of juvenile sturgeon, and may continue to support broodstock collection activities. The indexing methods will include using gillnets or other appropriate recapture methods for juveniles and set lines for adults and will not consist of actively tracking fish. Frequency (every 3, 4, or 5 years) of implementation of long-term index monitoring activities (after year 12) will be determined by the Aquatic SWG.

4.4 Evaluation and Implementation of Adult Passage Measures (Objective 5)

In Year Eleven of the new license and every 10 years thereafter for the duration of the new license unless otherwise determined by the Aquatic SWG, the Aquatic SWG shall evaluate the biological merit to providing upstream passage for adult white sturgeon. The assessment of biological merit shall be determined by: (i) evaluating information gathered from monitoring and evaluation activities and determining whether there is significant biological benefit and need for upstream passage; (ii) the availability of reasonable and appropriate means to provide upstream passage; and (iii) consensus from all other operators of the mid-Columbia projects to implement adult upstream passage measures[1]. If all three criteria above are met, Douglas, in consultation with the Aquatic SWG shall develop adult passage measures that are consistent with measures being implemented by other mid-Columbia project operators.

4.5 Educational Opportunities Coinciding with WSMP Activities (Objective 6)

Douglas, in consultation with the Aquatic SWG, shall identify appropriate WSMP activities as opportunities for education to local public entities such as schools, cities, fishing and recreation groups, and other interested local groups. WSMP activities that may be appropriate for public participation are hatchery tours, release of hatchery juveniles, and tagging of juveniles prior to release.

4.6 Reporting

Douglas will provide a draft annual report to the Aquatic SWG summarizing the previous year's activities undertaken in accordance with the WSMP. The report will document all white sturgeon activities conducted within the Project. Furthermore, any decisions, statements of agreement, evaluations, or changes made pursuant to this WSMP will be included in the annual report. If significant activity was not conducted in a given year, Douglas will prepare a memorandum providing an explanation of the circumstances in lieu of the annual report.

[1] The intent is to provide connectivity to the Hanford Reach white sturgeon population.

4.7 Implementation Schedule

Table 4.7-1 outlines an estimated long-term schedule of the activities described in Sections 4.1-4.4.

Table 4.7-1 Project White Sturgeon Implementation Schedule

New License Year	Brood Stock Plan and Collection[1]	Release Fish into Wells Reservoir[2]	Index Monitoring[3]	Tracking Marked Fish[4]	Natural Production Assessment[5]	Adult Passage Evaluation
PHASE I						
1	X				TBD	
2	X	X				
3	X	X	X	X	TBD	
4	X	X	X	X		
5	TBD	X	X	X		
6	TBD	TBD			TBD	
7	TBD	TBD	TBD	TBD		
8	TBD	TBD				
9	TBD	TBD	TBD	TBD		
10	TBD	TBD			TBD	
PHASE II[6]						
11	Level and frequency TBD	Level and frequency TBD				X[7]
12			X			
13-50			TBD		TBD	Every ten years after Year 11

[1]Douglas brood stock plan shall be completed within one year following this issuance of the new license. Brood stock collection activities will occur at a minimum in years 1-4 during the new license term. Additional years, during Phase I, will be determined by the Aquatic SWG. In Year 11 (Phase II), level and frequency of activity will be determined by the Aquatic SWG and will be based upon the level of long-term supplementation identified from monitoring results.

[2]No more than a total of 35,000 fish will be stocked in Phase I (Years 1-10). The Phase II supplementation program will be determined by the Aquatic SWG and consistent with the goal of the WSMP.

[3] Results of the index monitoring activities will be used to determine the scope of future supplementation activities. Index monitoring activities from year 12 through the remainder of the new license term will occur at a frequency of 3-5 years as determined by the Aquatic SWG.

[4] Active-tagged juvenile and adult sturgeon will be tracked to assess emigration, habitat use, and potential spawning locations. This activity will occur in years 3, 4, and 5. Two additional years will be determined by the Aquatic SWG but will likely be consistent with years in which index monitoring activities are implemented.

[5] Tracking of reproductively viable adult sturgeon in combination with deployment of egg collection mats to identify natural production in the Wells Reservoir during 5 separate years over the term of the new license based on flow conditions or other data as determined by the Aquatic SWG.

[6] Phase II activities will consist only of brood stock plan and collection, stocking activities, index monitoring, and potentially natural reproduction assessments for the remainder of the new license.

[7] Adult Passage Evaluations will occur in Year 11 and every 10 years thereafter for the term of the new license.

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ATTACHMENT C: BULL TROUT MANAGEMENT PLAN

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BULL TROUT MANAGEMENT PLAN

WELLS HYDROELECTRIC PROJECT

FERC PROJECT NO. 2149

August 2008

Prepared by:
Public Utility District No. 1 of Douglas County
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EXECUTIVE SUMMARY

The Bull Trout Management Plan (BTMP) is one of six Aquatic Resource Management Plans contained within the Aquatic Settlement Agreement (Agreement). Collectively, these six Aquatic Resource Management Plans are critical to direct implementation of Protection, Mitigation, and Enhancement measures (PMEs) during the term of the new license and, together with the Wells Anadromous Fish Agreement and Habitat Conservation Plan (HCP), will function as the Water Quality Attainment Plan (WQAP) in support of the Clean Water Act Section 401 Water Quality Certification for the Wells Hydroelectric Project (Project).

To ensure active stakeholder participation and support, the Public Utility District No. 1 of Douglas County (Douglas) developed all of the resource management plans in close coordination with agency and tribal natural resource managers (Aquatic Settlement Work Group or Aquatic SWG). During the development of this plan, the Aquatic SWG focused on developing management priorities for resources potentially impacted by Project operations. Members of the Aquatic SWG include the U.S. Fish and Wildlife Service (USFWS), Washington Department of Ecology (Ecology), Washington State Department of Fish and Wildlife (WDFW), the Confederated Tribes of the Colville Reservation (Colville), the Confederated Tribes and Bands of the Yakama Indian Nation (Yakama), and Douglas.

The National Marine Fisheries Service (NMFS) was invited to participate in the development of Aquatic Resource Management Plans, but declined because its interests are currently satisfied by the measures within the HCP.

The goal of the BTMP is to identify, monitor, and address impacts, if any, on bull trout (*Salvelinus confluentus*) resulting from the Project in a manner consistent with the USFWS Bull Trout Recovery Plan and the terms of the Section 7 Incidental Take Statement (ITS). This BTMP is intended to continue the implementation of management activities to protect bull trout during the new license term in a manner consistent with the original Wells Bull Trout Monitoring and Management Plan (WBTMMP) (Douglas 2004). The 2004 WBTMMP was developed in coordination with the USFWS, as required by the USFWS Bull Trout Section 7 Biological Opinion (BO) in association with the Federal Energy Regulatory Commission's (FERC) approval of the HCP. The PMEs presented within the BTMP are designed to meet the following objectives:

Objective 1: Operate the upstream fishways and downstream bypass systems in a manner consistent with the HCP;

Objective 2: Identify any adverse Project-related impacts on adult and sub-adult bull trout passage;

Objective 3: Implement reasonable and appropriate options to modify upstream fishway, downstream bypass, or operations if adverse impacts on bull trout are identified and evaluate the effectiveness of these measures;

Objective 4: Periodically monitor for bull trout entrapment or stranding during low Wells Reservoir elevations;

Objective 5: Participate in the development and implementation of the USFWS Bull Trout Recovery Plan including information exchange and genetic analysis. Should bull trout be delisted, the Aquatic SWG will re-evaluate the needs and objectives of the BTMP;

Objective 6: Identify any adverse impacts of Project-related hatchery operations on adult and sub-adult bull trout.

This BTMP is intended to be compatible with other bull trout management plans and the Upper Columbia Salmon Recovery Plan (UCSRP) in the Columbia River mainstem. Furthermore, this management plan is intended to be not inconsistent with other management strategies of federal, state and tribal natural resource management agencies and supportive of designated uses for aquatic life under WAC 173-201A, the Washington state water quality standards.

1.0 INTRODUCTION

The Bull Trout Management Plan (BTMP) is one of six Aquatic Resource Management Plans contained within the Aquatic Settlement Agreement (Agreement). Collectively, these six Aquatic Resource Management Plans are critical to direct implementation of Protection, Mitigation, and Enhancement measures (PMEs) during the term of the new license and, together with the Wells Anadromous Fish Agreement and Habitat Conservation Plan (HCP) will function as the Water Quality Attainment Plan (WQAP) in support of the Clean Water Act Section 401 Water Quality Certification for the Wells Hydroelectric Project (Project).

To ensure active stakeholder participation and support, the Public Utility District No. 1 of Douglas County (Douglas) developed all of the resource management plans in close coordination with agency and tribal natural resource managers (Aquatic Settlement Work Group or Aquatic SWG). During the development of this plan, the Aquatic SWG focused on developing management priorities for resources potentially impacted by Project operations. Entities invited to participate in the Aquatic SWG include the U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), Bureau of Land Management (BLM), Bureau of Indian Affairs (BIA), Washington Department of Ecology (Ecology), Washington State Department of Fish and Wildlife (WDFW), the Confederated Tribes of the Colville Reservation (Colville), the Confederated Tribes and Bands of the Yakama Indian Nation (Yakama), and Douglas.

The BTMP will direct implementation of measures to mitigate project impacts, if any, on bull trout (*Salvelinus confluentus*). To ensure active stakeholder participation and support, Douglas developed this plan, along with the other aquatic management plans, in close coordination with the members of the Aquatic SWG.

The Aquatic SWG agrees on the need to develop a plan to direct the long-term management of bull trout in the Project. This management plan summarizes the relevant resource issues and background (Section 2), identifies goals and objectives of the plan (Section 3), and defines the relevant PMEs (Section 4) for bull trout during the term of the new license.

Additionally, this management plan is intended to continue implementation activities aimed at protecting bull trout in a manner consistent with measures specified in the original Wells Bull Trout Monitoring and Management Plan (WBTMMP) (Douglas 2004). The 2004 WBTMMP was developed in consultation with the USFWS, as required by the USFWS Bull Trout Biological Opinion (BO) in association with the implementation of the HCP.

2.0 BACKGROUND

2.1 Bull Trout Biology

Bull trout are native to northwestern North America, historically occupying a large geographic range extending from California north into the Yukon and Northwest Territories of Canada, and east to western Montana and Alberta (Cavender 1978). They are generally found in interior drainages, but also occur on the Pacific Coast in Puget Sound and in the large drainages of British Columbia.

Bull trout currently occur in lakes, rivers and tributaries in Washington, Montana, Idaho, Oregon (including the Klamath River basin), Nevada, two Canadian Provinces (British Columbia and Alberta), and several cross-boundary drainages in extreme southeast Alaska. East of the Continental Divide, bull trout are found in the headwaters of the Saskatchewan River in Alberta, and the McKenzie River system in Alberta and British Columbia (Cavender 1978; McPhail and Baxter 1996; Brewin and Brewin 1997). The remaining distribution of bull trout is highly fragmented.

Bull trout are a member of the char group within the family Salmonidae. Bull trout closely resemble Dolly Varden (*Salvelinus malma*), a related species. Genetic analyses indicate, however, that bull trout are more closely related to an Asian char (*Salvelinus leucomaenis*) than to Dolly Varden (Pleyte et al. 1992). Bull trout are sympatric with Dolly Varden over part of their range, most notably in British Columbia and the Coastal-Puget Sound region of Washington State.

Bull trout are believed to have more specific habitat requirements than other salmonids (Rieman and McIntyre 1993). Growth, survival, and long-term persistence are dependent upon habitat characteristics such as clean, cold, connected, and complex instream habitat, a stable substrate with a low percentage of fine sediments, high channel stability, and stream/population connectivity (USFWS et al. 2000). Stream temperature and substrate type, in particular, are critical factors for the sustained long-term persistence of bull trout. Spawning is often associated with the coldest, cleanest, and most complex stream reaches within basins. However, bull trout may exhibit a patchy distribution, even in pristine habitats, and should not be expected to occupy all available habitats at the same time (Rieman and McIntyre 1995; Rieman et al. 1997).

Bull trout exhibit four distinct life history types: resident, fluvial, adfluvial, and anadromous. The fluvial, adfluvial, and resident forms exist throughout the range of the bull trout (Rieman and McIntyre 1993). These forms spend their entire life in freshwater. The anadromous life history form is currently known only to occur in the Coastal-Puget Sound region within the coterminous United States (Volk 2000; Kraemer 1994; Mongillo 1993). Multiple life history types may be expressed in the same population, and this diversity of life history types is considered important to the stability and viability of bull trout populations (Rieman and McIntyre 1993).

The majority of growth and maturation for anadromous bull trout occurs in estuarine and marine waters, adfluvial bull trout in lakes or reservoirs, and fluvial bull trout in large river systems.

Resident bull trout populations are generally found in small headwater streams where fish remain their entire lives.

For migratory life history types, juveniles tend to rear in tributary streams for 1 to 4 years before migrating downstream into a larger river, lake, or estuary and/or nearshore marine area to mature (Rieman and McIntyre 1993). In some lake systems, age 0+ fish (less than 1 year old) may migrate directly to lakes (Riehle et al. 1997). Juvenile and adult bull trout in streams frequently inhabit side channels, stream margins and pools with suitable cover and areas with cold hyporheic zones or groundwater upwellings (Sexauer and James 1993; Baxter and Hauer 2000).

2.2 Species Status

On June 10, 1998, the USFWS listed bull trout within the Columbia River basin as threatened under the Endangered Species Act (ESA) (FR 63(111)). Later (November 1, 1999), the USFWS listed bull trout within the coterminous United States as threatened under the ESA (FR 64(210)). The USFWS identified habitat degradation, fragmentation, and alterations associated with dewatering, road construction and maintenance, mining, and grazing; blockage of migratory corridors by dams or other diversion structures; poor water quality; incidental angler harvest; entrainment into diversion channels; and introduced non-native species as major factors affecting the distribution and abundance of bull trout. They noted that dams (and natural barriers) have isolated population segments resulting in a loss of genetic exchange among these segments (FR 63(111)). The USFWS believes many populations are now isolated and disjunct. In October 2002, the USFWS completed the first draft of a bull trout recovery plan intended to provide information and guidance that will lead to recovery of the species, including its habitat (USFWS 2002). Threatened bull trout population segments are widely distributed over a large area and because population segments were subject to listing at different times, the USFWS adopted a two-tiered approach to develop the draft recovery plan for bull trout (USFWS 2002). In November 2002, the USFWS published in the federal register a proposed rule for the designation of critical habitat for the Klamath River and Columbia River distinct population segments of bull trout (67 FR 71235). In October 2004 the USFWS published a final rule in the Federal Register designating critical habitat for the Klamath River and Columbia River populations of bull trout (69 FR 59995).

In April 2008, the USFWS completed the 5-year status review for Columbia River bull trout with two recommendations: maintain “threatened” status for the species, and determine if multiple distinct population segments exist within the Columbia River and merit protection under the ESA. The recommendations intend to facilitate analysis of project effects over more specific and biologically appropriate areas, ultimately allowing a greater focus of regulatory protection and recovery resources (USFWS 2008a). The review also identified specific issues that limit the overall ability to accurately and quantitatively evaluate the current status of bull trout. Seven recommendations were made to improve future evaluation and management decisions, all of which are largely based on improvement and standardization of monitoring and evaluation techniques, better delineation and agreement of core areas and Recovery Units, and multi-agency cooperation and management (USFWS 2008b).

The Wells Project is situated within the Upper Columbia River Recovery Unit and the USFWS has identified the Wenatchee, Entiat, and Methow Rivers as its core areas. A core area represents the closest approximation of a biologically functioning unit for bull trout. A core area functions as a metapopulation for bull trout. Not all core areas are equal and each has specific functions that are unique. For example, the Entiat Core Area depends heavily on the mainstem Columbia River to provide overwinter, migration, and forage habitats. The Wenatchee Core Area has populations using lake and riverine (both the Wenatchee and Columbia Rivers) habitat for overwintering, migration, and foraging. Within a core area, many local populations may exist. A local population is assumed to be the smallest group of fish that is known to represent an interacting reproductive unit. Nineteen local populations have been identified in the Wenatchee (7), Entiat (2) and Methow (10) core areas (USFWS 2002).

2.3 Project Bull Trout Studies

2.3.1 2001-2003 Project Bull Trout Study

Listed Columbia River bull trout have been observed and counted at Wells Dam since 1998. In 2000, due to the potential for operations at mid-Columbia dams to affect the movement and survival of bull trout, the USFWS requested that the three mid-Columbia PUDs (Douglas, Chelan, and Grant PUDs) evaluate the movement and status of bull trout in their respective project areas. At that time, little was known about the life-history characteristics (e.g., movements, distribution, habitat use, etc.) of bull trout in the mid-Columbia River. Therefore, in order to assess the operational effects of hydroelectric projects on bull trout within the mid-Columbia, a three PUD coordinated radio-telemetry study was implemented beginning in 2001. The goal of the study was to monitor the movements and migration patterns of adult bull trout in the mid-Columbia River using radio-telemetry (Figure 2.3-1). The number of trout to be collected and tagged at each dam (Rock Island, Rocky Reach, and Wells) was based on the proportion of fish that migrated past those dams in 2000.

From 2001-2003, bull trout were collected from the Wells, Rocky Reach, and Rock Island dams and radio-tagged. Multiple-telemetry techniques were used to assess the movement of tagged bull trout within the study area. At Wells Dam, a combination of aerial and underwater antennas was deployed. The primary purpose for this system was to document the presence of bull trout at the Project, identify passage times and determine their direction of travel (upstream/downstream). In addition to these systems, a number of telemetry systems were deployed to address specific questions posed by the USFWS and Douglas. At Wells Dam, several additional systems were installed to identify tagged bull trout that could enter, ascend, and exit specific gates and fish ladders. All possible access points to the adult fish ladders and the exits were monitored individually in 2001, 2002, and 2003, allowing the route of passage to be determined as well as the ability to establish the exact time of entrance and exit from the ladder system. English et al. (1998; 2001) provides a detailed description of the telemetry systems at each of the dams and within the tributaries.

To assess bull trout movements into and out of the Wells Reservoir, fixed-telemetry monitoring sites were established at the mouth of the Methow and Okanogan rivers and periodic aerial surveys were conducted on the reservoir and throughout both watersheds (English et al. 1998, 2001). Key findings of the multi-year study are as follows:

- Total upstream fishway counts (May 1st to November 15th) at Wells Dam from 2000 to 2003 were 90, 107, 76, and 53 bull trout, respectively.
- Adult bull trout migrate upstream through Wells Dam from May through November. Peak movement occurs in May and June with 94, 95, 92, and 89 percent of adult bull trout being detected during these months at Wells Dam for years 2000-2003, respectively.
- Tagged migratory adult bull trout successfully move both upstream and downstream past the Project (radio-telemetry). From the 79 bull trout radio-tagged in 2001 and 2002 at Rock Island, Rocky Reach, and Wells, five bull trout passed downstream through Wells Dam with no documented mortality. Twelve downstream passage events occurred at Rocky Reach (4) and Rock Island (8) through turbines from 2001 to 2003. None of the 17 (5 Wells, 4 Rocky Reach and 8 Rock Island) observed downstream passage events resulted in observed mortality of bull trout.
- Between 2001 and 2003, a total of 10 (2 tagged at Rock Island, 4 Rocky Reach, 4 Wells), 11 (4 Wells, 5 Rocky Reach, 2 from 2001), and 1 (1 Wells) tagged bull trout were detected moving upstream of the Project, respectively.
- Median tailrace times (tailrace detection to ladder entrance detection) during the telemetry study at Wells in 2001-2003 were 1.53, 7.84, and 1.00 days, respectively. Median travel times (tailrace detection to ladder exit detection) during the telemetry study at Wells in 2001-2003 were 8.87, 7.60, and 1.16 days, respectively. Median ladder passage times (entrance detection to ladder exit detection) during the telemetry study at Wells in 2001-2003 were 5.70, 0.23, and 0.16 days, respectively.
- Adult bull trout migrating upstream of Wells Dam appear to be destined for the Methow River. Between 2001 and 2003, no bull trout selected the Okanogan system (one trout moved into the Okanogan, but left shortly thereafter and moved into the Methow system).
- Median travel time from Wells Dam (detection at ladder exit) to first detection in the Methow River in 2001-2003 was 0.40, 2.78, and 1.09 days, respectively.
- All tributary entrance events (fixed station detections) into the Methow River by bull trout (28 total events, 2001-2003) occurred before June 27. An additional two bull trout, not detected by the tributary fixed station systems, were detected in the Methow River via 2002 aerial surveys. Bull trout in the Methow system selected two primary areas, the mainstem Methow River and the Twisp River.
- To date, 30% (9/30) of bull trout that entered the Methow River have been detected leaving the system. Tributary exit dates were recorded for 78% (7/9) of these emigrating bull trout and 86% (6/7) of bull trout with a recorded exit date left the Methow River system between October and December.
- Bull trout migrating upstream through Wells Dam in 2001 were 5 year old (n=2, mean fork length=55.6cm) and 6 year old (n=6, mean fork length= 54.6cm) fish as determined by scales.

- 92% (11/12) and 53% (8/15) of tagged bull trout detected in the vicinity of Wells Dam entered the Wells Hatchery Outfall in 2001 and 2002, respectively. It is possible that the bull trout frequented the outfall in search of prey. Typical operation at the hatchery is to volitionally release yearling chinook smolts between April 15 and 30, and subyearling chinook smolts in early June. Given that bull trout feed opportunistically (Goetz 1989), it is likely that the tagged bull trout were taking advantage of the large concentration of juvenile salmonids within the hatchery outfall system.

2.3.2 2005-2008 Project Bull Trout Study

On December 10, 2003, the USFWS received a request from the Federal Energy Regulatory Commission (FERC) for formal consultation to determine whether the proposed incorporation of the HCP into the FERC license for operation of the Project was likely to jeopardize the continued existence of the Columbia River distinct population segment (DPS) of ESA-listed bull trout, or destroy or adversely modify proposed bull trout critical habitat. In response to the FERC request and based upon the results of the 2001-2003 study, which suggested that continued operations are not likely to jeopardize bull trout, the USFWS filed the BO and Incidental Take Statement (ITS) with FERC. On June 21, 2004, FERC issued an order incorporating the HCP and the terms and conditions of the ITS into the FERC license for the Project.

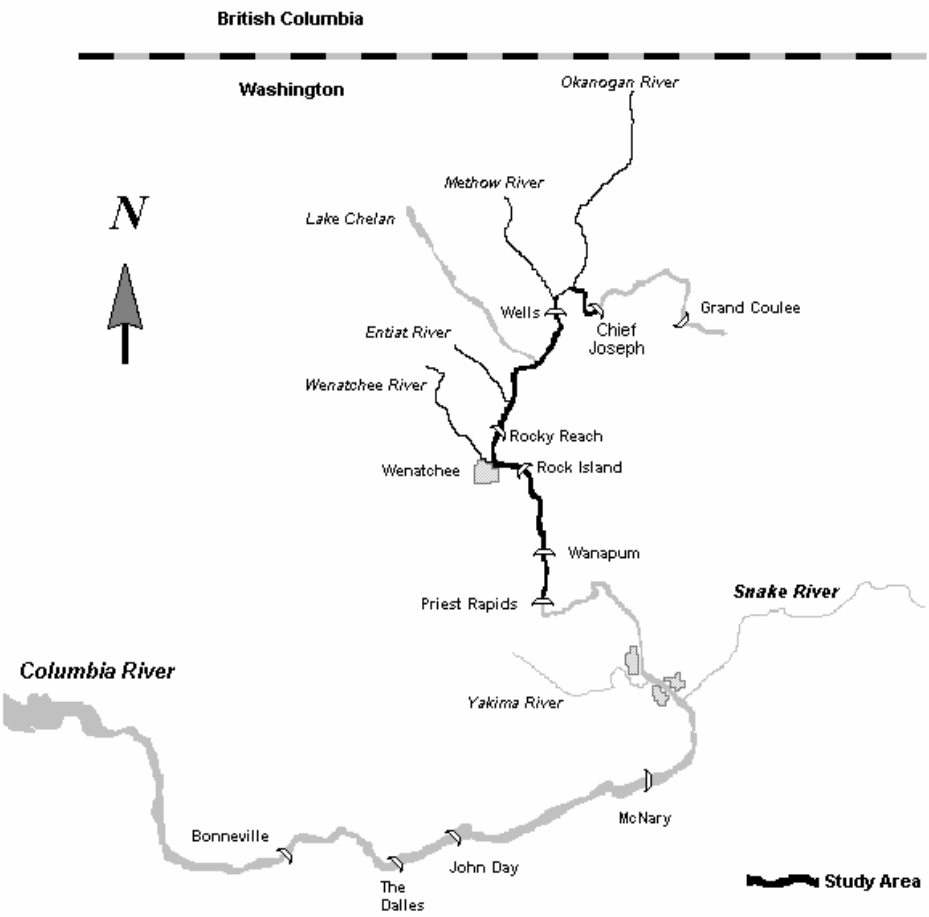

Figure 2.3-1 Study area for assessing migration patterns of bull trout in the mid-Columbia River (2001-2003). Fixed radio-telemetry sites monitored the movement of bull trout near Priest Rapids, Wanapum, Rock Island, Rocky Reach and Wells dams. Fixed sites placed in the Wenatchee, Entiat, Methow and Okanogan rivers monitored time of entry and exodus of bull trout in large tributaries of the mid-Columbia River.

In 2004, Douglas in consultation with the USFWS and as required under the HCP BO, developed the WBTMMP. The goal of the WBTMMP is to continue monitoring and evaluating bull trout in the Project to quantify and address, to the extent feasible, potential Project impacts on bull trout. Implementation of WBTMMP measures specifically include: (1) address ongoing Project impacts through the life of the existing operating license; (2) provide consistency with recovery actions as outlined in the USFWS bull trout recovery plan; and (3) monitor and minimize the extent of incidental take of bull trout, if any, consistent with Section 7 of the ESA. WBTMMP implementation started in 2005 and will continue through the spring of 2008. Objectives of the plan include identifying Project impacts, if any, on upstream and downstream passage of adult and sub-adult bull trout through Wells Dam, investigating the potential for sub-adult entrapment or stranding in off-channel or backwater areas of Wells Reservoir, and identifying the Core Areas and Local Populations, as defined in the USFWS Bull Trout Recovery Plan, of bull trout that utilize the Project.

To address Project impacts, if any, on upstream and downstream passage of adult bull trout, Douglas captured and radio-tagged 6, 10, and 10 adult bull trout at Wells Dam in 2005, 2006, and 2007, respectively (LGL and Douglas PUD, 2008). In 2005, all six fish traveled upstream into the Methow River and no downstream passage events were recorded. Travel time from release (after tagging) until entrance into the Methow River ranged from 7 hours to 12 days. In 2006, in addition to the 10 adult bull trout radio-tagged at Wells Dam, the USFWS radio-tagged 13 bull trout in the Methow River Core Area and Public Utility District No.1 of Chelan County (Chelan PUD) released 29 tagged bull trout from Rocky Reach and Rock Island dams. In total, 13 downstream passage events and 8 upstream passage events were recorded at Wells Dam in 2006. There were no observed instances of bull trout mortality resulting from these passage events. In 2007, 10 bull trout were tagged at Wells Dam, the USFWS tagged 5 bull trout in the Methow River Core Area, and Chelan PUD released 19 tagged bull trout from Rocky Reach and Rock Island dams. In total, 1 downstream passage event and 3 upstream passage events were recorded at Wells Dam in 2007. Similar to 2006, no instances of bull trout mortality were observed resulting from these passage events. From 2005 to 2008 (all radio-tagged fish combined), 25 downstream passage events and 52 upstream passage events by 40 individual bull trout were recorded at Wells Dam with no observances of bull trout injury or mortality (LGL and Douglas PUD, 2008). From 2005-2007, no adult or sub-adult bull trout were observed utilizing Wells Dam fishways during the winter monitoring period (typically November 16 to April 30). Monitoring of radio-tagged adult bull trout ended in June 2008.

To address potential project-related impacts on sub-adult bull trout, fish were opportunistically tagged with passive integrated transponder (PIT) tags when encountered during standard fish sampling operations at Wells Dam or during off-Project tributary smolt trapping activities. In 2005, 2006, 2007, and 2008 a total of 16, 20, 14, and 17 sub-adult bull trout were PIT tagged during tributary smolt sampling activities, respectively. No sub-adult bull trout were observed during Wells Dam fish sampling operations or by the adult PIT-tag detection system in the fishways. Over the 2005-2008 period, no sub-adult bull trout were observed utilizing Wells Dam fishways during the winter period.

In 2005, Douglas collected high resolution bathymetric information of Project waters to address the potential for entrapment or stranding of bull trout in off-channel or backwater areas of the Wells Reservoir. This data combined with Wells inflow patterns, reservoir elevations, and backwater curves would allow Douglas to begin identifying entrapment or stranding areas. In 2006, a field survey of potential bull trout stranding sites using bathymetric and operations information was conducted during a period of low reservoir elevation associated with the Methow River flood control program. Following a complete survey of the project, no stranded bull trout (sub-adult or adult) were found during the 2006 low water event. In 2007, reservoir conditions were not sufficiently low to warranted further field investigations.

In support of identifying the local populations and core areas of bull trout utilizing the Project area, Douglas funded the collection of genetic samples from 22, 20, and 24 bull trout in 2005, 2006 and 2007, respectively. In 2005, 6 samples were collected at Wells Dam and 16 were collected at off-Project operations (Methow and Twisp river screw traps). In 2006, 10 samples were collected at Wells Dam and 10 samples were collected at off-Project operations. In 2007,

10 samples were collected at Wells Dam and 14 samples were collected at off-Project operations. All genetic samples were provided to the USFWS.

3.0 GOALS AND OBJECTIVES

The goal of the BTMP is to identify, monitor and address impacts, if any, on bull trout resulting from the Project in a manner consistent with the USFWS Bull Trout Recovery Plan and the terms of the Section 7 ITS (See Section 4.7). This BTMP is intended to continue the implementation of management activities to protect bull trout during the new license term in a manner consistent with the original WBTMMP (Douglas 2004). The 2004 WBTMMP was developed in coordination with the USFWS, as required by the USFWS Bull Trout BO in association with the HCP. The PMEs presented within the BTMP are designed to meet the following objectives:

Objective 1: Operate the upstream fishways and downstream bypass systems in a manner consistent with the HCP;

Objective 2: Identify any adverse Project-related impacts on adult and sub-adult bull trout passage;

Objective 3: Implement reasonable and appropriate options to modify upstream fishway, downstream bypass, or operations if adverse impacts on bull trout are identified and evaluate effectiveness of these measures;

Objective 4: Periodically monitor for bull trout entrapment or stranding during low Wells Reservoir elevations (similar to WBTMMP);

Objective 5: Participate in the development and implementation of the USFWS Bull Trout Recovery Plan, including information exchange and genetic analysis. Should bull trout be delisted, the Aquatic SWG will re-evaluate the needs and objectives of the BTMP;

Objective 6: Identify any adverse impacts of Project-related hatchery operations on adult and sub-adult bull trout.

This BTMP is intended to be compatible with other bull trout management plans and the UCSRP in the Columbia River mainstem. Furthermore, this management plan is intended to be not inconsistent with other management strategies of federal, state and tribal natural resource management agencies and supportive of designated uses for aquatic life under WAC 173-201A, the Washington state water quality standards.

The schedule for implementation of specific measures within the BTMP is based on the best information available at the time the Plan was developed. As new information becomes available, implementation of each activity may be adjusted through consultation with the Aquatic SWG.

4.0 PROTECTION, MITIGATION AND ENHANCEMENT MEASURES

In order to fulfill the goals and objectives described in Section 3.0, Douglas, in consultation with the Aquatic SWG, will implement PMEs for Project bull trout consistent with the objectives identified in Section 3.0. The measures proposed in this section are intended to serve both as PMEs for bull trout throughout the new license term and to adequately monitor and minimize any incidental take of bull trout consistent with Section 7 of the ESA.

4.1 Operate the Upstream Fishways and Downstream Bypass Systems in a Manner Consistent with the HCP (Objective 1)

4.1.1 Provide Upstream and Downstream Passage for Adult and Sub-Adult Bull Trout

Douglas will continue to provide upstream passage for adult bull trout through the existing upstream fishways and downstream passage of adult and sub-adult bull trout through the existing downstream bypass system. Both upstream fishway facilities (located on the west and east shores) are operational year around with maintenance occurring on each fishway at different times during the winter to ensure that one upstream fishway is always operational. Maintenance activities on Wells fishways occur during the winter when bull trout have not been observed passing Wells Dam. Operation of the downstream passage facilities for bull trout will be consistent with bypass operations for Plan Species identified in the HCP. Currently the bypass system is operated from April 12 through August 26 of each year. This operating period is consistent with the period of high bull trout and anadromous fish presence at the Project.

4.1.2 Upstream Fishway Counts

Douglas shall continue to conduct video monitoring in the Wells Dam fishways from May 1st through November 15th to count and provide information on the population size of upstream moving bull trout.

4.1.3 Upstream Fishway Operations Criteria

Douglas shall continue to operate the upstream fishway at Wells Dam in accordance with criteria outlined in the HCP.

4.1.4 Bypass Operations Criteria

Douglas shall continue to operate the bypass system at Wells Dam in accordance with criteria outlined in the HCP.

4.2 Identify Any Adverse Project-related Impacts on Adult and Sub-adult Bull Trout Passage (Objective 2)

4.2.1 Adult Bull Trout Upstream and Downstream Passage Evaluation

Douglas shall continue to monitor upstream and downstream passage and incidental take of adult bull trout through Wells Dam and in the Wells Reservoir through the implementation of a radio-telemetry study. Specifically, in years 5 and 10 of the new license, and continuing every ten years thereafter during the new license term, Douglas will conduct a one-year monitoring program to determine whether Douglas remains in compliance with the ITS. The same study protocols used during past radio-telemetry assessments at Wells Dam (LGL and Douglas PUD 2007) will be employed for these monitoring studies.

If the adult bull trout counts at Wells Dam increases more than two times the existing 5-year average or if there is a significant change in the operation of the fish ladders or hydrocombine, then the Aquatic SWG will determine whether additional years of take monitoring are needed beyond those identified in this section of the BTMP. If the authorized incidental take level is exceeded during any one-year period, Douglas will conduct another monitoring study in the succeeding year. If the authorized incidental take level is exceeded in this second year, Douglas will develop a plan, in consultation with the Aquatic SWG, to address the identified factors contributing to exceedance of the allowable level of incidental take.

4.2.2 Adult Bull Trout Passage Evaluation at Off-Project Collection Facilities

Douglas shall assess upstream and downstream passage and incidental take of adult, migratory bull trout at off-Project (outside of the Project boundary) adult salmon and steelhead brood stock collection facilities associated with the Wells HCP. Specifically, beginning in year one of the new license, Douglas will conduct a one-year radio-telemetry study to assess passage and incidental take at off-Project adult collection facilities (i.e., Twisp weir). Douglas will capture and tag up to 10 adult, migratory bull trout (>400mm) at adult collection facilities and use fixed receiver stations upstream and downstream of collection facilities to examine upstream and downstream passage characteristics and incidental take. Study protocols that have been used during past radio-telemetry assessments at Wells Dam (LGL 2008) will be employed for this assessment.

If negative impacts to passage associated with Off-Project collection facilities are observed or the authorized incidental take level is exceeded during any one-year period, Douglas will conduct another monitoring study in the succeeding year. If negative impacts to passage continue to be observed or the authorized incidental take level is exceeded in this second year, Douglas will develop a plan, in consultation with the Aquatic SWG, to address the identified factors contributing to passage impacts or the exceedance of the allowable level of incidental take.

After year one of the new license, the implementation of this sub-objective will be integrated into the one-year telemetry monitoring program that is to be conducted every ten years (beginning in year 10 of the new license) at Wells Dam as identified in Section 4.2.1. In year 10 of the new license and every 10 years thereafter, bull trout will be captured and tagged only at Wells Dam

(Section 4.2.1) since data show that bull trout passing Wells Dam are migrating back into the Methow River watershed (LGL 2008). Through the continued deployment of fixed station monitoring at off-Project adult salmon and steelhead brood stock collection facilities, these tagged bull trout will continue to provide passage and take information in support of this sub-objective throughout the term of the new license.

4.2.3 Sub-Adult Bull Trout Monitoring

While an objective of the BTMP is to identify potential Project impacts on upstream and downstream passage of sub-adult bull trout, Aquatic SWG members (including the USFWS) agree that it is not feasible to assess sub-adult passage because sub-adult bull trout have not been observed at Wells Dam. During the previous six years of bull trout data collection at Wells Dam (BioAnalyst Inc. 2004; LGL 2008), sub-adult bull trout have not been documented passing Wells Dam (based upon fishway video counts and bull trout trapping for radio-telemetry). However, it is expected that through the increased monitoring associated with the implementation of the BTMP that there may be additional encounters with sub-adult bull trout. If at any time during the new license term, sub-adult bull trout are observed passing Wells Dam in significant numbers (>10 per calendar year), the Aquatic SWG will recommend reasonable and appropriate methods for monitoring sub-adult bull trout. Specifically, Douglas may modify counting activities, continue to provide PIT tags and equipment, and facilitate training to enable fish sampling entities to PIT tag sub-adult bull trout when these fish are collected incidentally during certain fish sampling operations. This activity will occur the following year of first observation of sub-adult bull trout (>10 per calendar year) and subsequently as recommended by the Aquatic SWG.

4.3 Implement Reasonable and Appropriate Measures to Modify the Upstream Fishway and Downstream Bypass if Adverse Impacts on Bull Trout are Identified (Objective 3)

Douglas shall continue to operate the upstream fishway and downstream bypass at Wells Dam in accordance with the HCP. However, if upstream or downstream passage problems for bull trout are identified (as agreed to by the USFWS and Douglas), Douglas will identify and implement, in consultation with the Aquatic SWG and HCP Coordinating Committee, reasonable and appropriate options to modify the upstream fishway, downstream bypass, or operations to reduce the identified impacts to bull trout passage.

4.4 Investigate Entrapment or Stranding of Bull Trout during Periods of Low Reservoir Elevation (Objective 4)

During the implementation of the WBTMMP from 2004-2008, Douglas, through the use of high resolution bathymetric information, hydraulic and elevation data, and backwater curves, identified potential bull trout entrapment and stranding areas in the Wells Reservoir. Although no stranded bull trout were observed in these areas during the implementation of the WBTMMP, Douglas will continue to investigate potential entrapment or stranding areas for bull trout through periodic monitoring when periods of low reservoir elevation expose identified sites. During the first five years of the new license, Douglas will implement up to five bull trout entrapment/stranding assessments during periods of low reservoir elevation (below 773’ MSL).

If no incidences of bull trout stranding are observed during the first five years of study, additional assessment will take place every fifth year during the remainder of the license term, unless waived by the Aquatic SWG. If bull trout entrapment and stranding result in take in exceedance of the authorized incidental take level, then reasonable and appropriate measures will be implemented by Douglas, in consultation with the Aquatic SWG, to address the impact.

4.5 Participate in the Development and Implementation of the USFWS Bull Trout Recovery Plan (Objective 5)

4.5.1 Monitoring Other Aquatic Resource Management Plan Activities and Predator Control Program for Incidental Capture and Take of Bull Trout

Douglas will monitor activities associated with the implementation of other Aquatic Resource Management Plans (white sturgeon, Pacific lamprey, resident fish, aquatic nuisance species, and water quality) and Predator Control Program that may result in the incidental capture and take of bull trout. If the incidental take of bull trout is exceeded due to the implementation of other Aquatic Resource Management Plan activities, then Douglas will develop a plan, in consultation with the Aquatic SWG, to address the identified factors contributing to the exceedance of the allowable level of incidental take. If the incidental take of bull trout is exceeded due to the implementation of the Predator Control Program, then Douglas will develop a plan, in consultation with the HCP Coordinating Committee and the Aquatic SWG, to address the identified factors contributing to the exceedance of the allowable level of incidental take.

4.5.2 Funding Collection of Tissue Samples and Genetic Analysis

Beginning in year 10 of the new license, and continuing every 10 years thereafter for the term of the new license, Douglas will, if recommended by the Aquatic SWG, collect up to 10 adult bull trout tissue samples in the Wells Dam fishway facilities over a period of one year and fund their genetic analysis. Genetic tissue collection will take place concurrent with the implementation of the bull trout radio-telemetry monitoring study. Samples will be submitted to the USFWS Central Washington Field Office in Wenatchee, Washington. Any sub-adult bull trout collected during these activities will also be incorporated into the bull trout genetic analysis.

Beginning in year one of the new license, Douglas will collect up to 10 adult bull trout tissue samples from the Twisp River brood stock collection facility over a period of one year and will fund their genetic analysis. Genetic tissue collection will take place concurrent with the implementation of the Off-Project bull trout radio-telemetry monitoring study.

4.5.3 Information Exchange and Regional Monitoring Efforts

Douglas will continue to participate in information exchanges with other entities conducting bull trout research and regional efforts to explore availability of new monitoring methods and coordination of radio-tag frequencies for bull trout monitoring studies in the Project.

Douglas will make available an informational and educational display at the Wells Dam Visitor Center to promote the conservation and recovery of bull trout in the Upper Columbia River and associated tributary streams.

4.6 Identify Any Adverse Impacts of Project-related Hatchery Operations on Adult and Sub-adult Bull Trout (Objective 6)

4.6.1 Bull Trout Monitoring During Hatchery Activities

During the term of the new license, Douglas shall monitor hatchery actions (e.g., salmon trapping, sturgeon brood stocking and capture activities) that may encounter adult and sub-adult bull trout for incidental capture and take. Actions to be monitored shall be associated with the Wells Hatchery, the Methow Hatchery, and any future facilities directly funded by Douglas.

If the incidental take of bull trout is exceeded due to Douglas's hatchery actions then Douglas will develop a plan, in consultation with the Aquatic SWG, to address the identified factors contributing to the exceedance of the allowable level of incidental take.

4.7 USFWS Section 7 Consultation

The PMEs contained within the BTMP were specifically developed, in consultation with the USFWS, to address potential Reasonable and Prudent Measures (RPMs) for the Project relicensing and associated section 7 consultation. All of the FWS's potential RPMs for the Wells Project can be found in Appendix A. Each of these RPMs has been cross referenced with the specific supporting objective and PME (Sections 4.1 - 4.6) found within the BTMP. The purpose of Appendix A is to provide consistency with Douglas PUD's Aquatic Settlement Agreement and the FWS' subsequent section 7 consultation on the relicensing of the Wells Project.

4.8 Reporting

Douglas will provide a draft annual report to the Aquatic SWG summarizing the previous year's activities undertaken in accordance with the BTMP. The report will document all bull trout activities conducted within the Project and describe activities proposed for the following year. Furthermore, any decisions, statements of agreement, evaluations, or changes made pursuant to this BTMP will be included in the annual report. If significant activity was not conducted in a given year, Douglas will prepare a memorandum providing an explanation of the circumstances in lieu of the annual report.

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APPENDIX A

CROSS REFERENCED UNITED STATES FISH AND WILDLIFE SERVICE (USFWS) REASONABLE AND PRUDENT MEASURES (RPMS) WITH WELLS BULL TROUT MANAGEMENT PLAN (BTMP) OBJECTIVES AND SUPPORTING PROTECTION, MITIGATION AND ENHANCEMENT MEASURES (PMES)

FWS RPM 1: FERC shall require Douglas PUD, in coordination with the Service, to provide adequate year-round passage conditions for all life history stages of bull trout at all Project facilities.

Associated BTMP Objectives and PMEs:

Objective 1: Operate the upstream fishways and downstream bypass systems in a manner consistent with the HCP (Section 4.1).

PME: Provide Upstream and downstream Passages for Adult and Sub-Adult Bull Trout (Section 4.1.1).

PME: Upstream Fishway Counts (Section 4.1.2).

PME: Upstream Fishway Operations Criteria (Section 4.1.3).

PME: Bypass Operations Criteria (Section 4.1.4).

Objective 2: Identify any adverse Project-related impacts on adult and sub-adult bull trout passage (Section 4.2).

PME: Adult Bull Trout Upstream and Downstream Passage Evaluation (Section 4.2.1).

PME: Adult Bull Trout Passage Evaluation at Off-Project Collection Facilities (Section 4.2.2).

PME: Sub-Adult Bull Trout Monitoring (Section 4.2.3).

Objective 3: Implement reasonable and appropriate options to modify upstream fishway, downstream bypass, or operations if adverse impacts on bull trout are identified and evaluate effectiveness of these measures.

FWS RPM 2. FERC shall require Douglas PUD, in coordination with the Service, to minimize the effect of spillway operations and hydrographic variation to all life history stages of bull trout at all Project facilities.

Associated BTMP Objectives and PMEs:

Objective 1: Operate the upstream fishways and downstream bypass systems in a manner consistent with the HCP (Section 4.1).

PME: Provide Upstream and downstream Passages for Adult and Sub-Adult Bull Trout (Section 4.1.1).

PME: Upstream Fishway Operations Criteria (Section 4.1.3).

PME: Bypass Operations Criteria (Section 4.1.4).

Objective 3: Implement reasonable and appropriate options to modify upstream fishway, downstream bypass, or operations if adverse impacts on bull trout are identified and evaluate effectiveness of these measures (Section 4.3).

Objective 4: Periodically monitor for bull trout entrapment or stranding during low Wells Reservoir elevations (Section 4.4).

FWS RPM 3. FERC shall require Douglas PUD, in coordination with the Service, to minimize the effects of the Hatchery Supplementation Program to all life stages of bull trout.

Associated BTMP Objectives and PMEs:

Objective 2: Identify any adverse Project-related impacts on adult and sub-adult bull trout passage (Section 4.2).

PME: Adult Bull Trout Passage Evaluation at Off-Project Collection Facilities (Section 4.2.2).

Objective 6: Identify any adverse impacts of Project-related hatchery operations on adult and sub-adult bull trout.

PME: Bull Trout Monitoring During Hatchery Activities (Section 4.6.1).

FWS RPM 4. FERC shall require Douglas PUD, in coordination with the Service, to minimize the effects of the other Aquatic Resource Management Plans and Predator Control Program to all life stages of bull trout.

Associated BTMP Objectives and PMEs:

Objective 5: Participate in the development and implementation of the USFWS Bull Trout Recovery Plan, including information exchange and genetic analysis (Section 4.5).

> PME: Monitor other Aquatic Resource Management Plan Activities and Predator Control Program for Incidental Capture and Take of Bull Trout (Section 4.5.1).

FWS RPM 5. FERC shall require Douglas PUD, in coordination with the Service, to design and implement a bull trout monitoring program that will adequately detect and quantify Project impacts. This information will reduce uncertainty regarding Project impacts over the life of the project and shall be used to modify Project operations to the extent practicable to further minimize the manner or extent of take.

Associated BTMP Objectives and PMEs:

Refer to Wells Bull Trout Management Plan in its entirety.

Additional PMEs Proposed in the BTMP (not listed above):

> PME: Funding Collection of Tissue Samples and Genetic Analysis (Section 4.5.2).
> PME: Information Exchange and Regional Monitoring Efforts (section 4.5.3).

ATTACHMENT D: PACIFIC LAMPREY MANAGEMENT PLAN

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PACIFIC LAMPREY MANAGEMENT PLAN

WELLS HYDROELECTRIC PROJECT

FERC PROJECT NO. 2149

September 2009

Prepared by:
Public Utility District No. 1 of Douglas County
East Wenatchee, Washington

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EXECUTIVE SUMMARY

The Pacific Lamprey Management Plan (PLMP) is one of six Aquatic Resource Management Plans contained within the Aquatic Settlement Agreement (Agreement). Collectively, these six Aquatic Resource Management Plans are critical to direct implementation of Protection, Mitigation, and Enhancement measures (PMEs) during the term of the new license and, together with the Wells Anadromous Fish Agreement and Habitat Conservation Plan (HCP) will function as the Water Quality Attainment Plan (WQAP) in support of the Clean Water Act Section 401 Water Quality Certification for the Wells Hydroelectric Project (Project).

To ensure active stakeholder participation and support, the Public Utility District No. 1 of Douglas County (Douglas) developed all of the resource management plans in close coordination with agency and tribal natural resource managers (Aquatic Settlement Work Group or Aquatic SWG). During the development of this plan, the Aquatic SWG focused on developing management priorities for resources potentially impacted by Project operations. Members of the Aquatic SWG include the U.S. Fish and Wildlife Service (USFWS), Washington Department of Ecology (Ecology), Washington State Department of Fish and Wildlife (WDFW), the Confederated Tribes of the Colville Reservation (Colville), the Confederated Tribes and Bands of the Yakama Indian Nation (Yakama), and Douglas.

The National Marine Fisheries Service (NMFS) was invited to participate in the development of Aquatic Resource Management Plans, but declined because its interests are currently satisfied by the measures within the HCP.

The goal of the PLMP is to implement measures to monitor and address impacts, if any, on Pacific lamprey (*Lampetra tridentata*) resulting from the Project during the term of the new license. Douglas, in collaboration with the Aquatic SWG, has agreed to implement several Pacific lamprey PMEs in support of the PLMP. The PMEs presented within the PLMP are designed to meet the following objectives:

Objective 1: Identify and address any adverse Project-related impacts on passage of adult Pacific lamprey;

Objective 2: Identify and address any Project-related impacts on downstream passage and survival and rearing of juvenile Pacific lamprey;

Objective 3: Participate in the development of regional Pacific lamprey conservation activities.

The PLMP is intended to be compatible with other Pacific lamprey management plans in the Columbia River mainstem. Furthermore, the PLMP is intended to be supportive of the HCP, the critical research needs identified by the Columbia River Basin Technical Working Group, the Resident Fish Management Plan, Bull Trout Management Plan, and White Sturgeon Management Plan by continuing to monitor and address ongoing impacts, if any, on Pacific lamprey resulting from Project operations. The PLMP is intended to be not inconsistent with other management strategies of federal, state and tribal natural resource management agencies and supportive of designated uses for aquatic life under Washington state water quality standards found at WAC 173-201A.

1.0 INTRODUCTION

The Pacific Lamprey Management Plan (PLMP) is one of six Aquatic Resource Management Plans contained within the Aquatic Settlement Agreement (Agreement). Collectively, these six Aquatic Resource Management Plans are critical to direct implementation of Protection, Mitigation, and Enhancement measures (PMEs) during the term of the new license and, together with the Wells Anadromous Fish Agreement and Habitat Conservation Plan (HCP), will function as the Water Quality Attainment Plan (WQAP) in support of the Clean Water Act Section 401 Water Quality Certification for the Wells Hydroelectric Project (Project).

To ensure active stakeholder participation and support, the Public Utility District No. 1 of Douglas County (Douglas) developed all of the resource management plans in close coordination with agency and tribal natural resource managers (Aquatic Settlement Work Group or Aquatic SWG). During the development of this plan, the Aquatic SWG focused on developing management priorities for resources potentially impacted by Project operations. Entities invited to participate in the Aquatic SWG include the U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), Bureau of Land Management (BLM), Bureau of Indian Affairs (BIA), Washington Department of Ecology (Ecology), Washington State Department of Fish and Wildlife (WDFW), the Confederated Tribes of the Colville Reservation (Colville), the Confederated Tribes and Bands of the Yakama Indian Nation (Yakama), and Douglas.

The PLMP will direct implementation of measures to protect against and mitigate for potential Project impacts on Pacific lamprey (*Lampetra tridentata*). To ensure active stakeholder involvement and support, Douglas developed this plan, along with the other aquatic management plans, in close coordination with the members of the Aquatic SWG.

The Aquatic SWG agrees on the need to develop a plan for the long-term management of Pacific lamprey in the Project. This management plan summarizes the relevant resource issues and background (Section 2), identifies the goal and objectives of the plan (Section 3), and describes the relevant PMEs (Section 4) for Pacific lamprey during the term of the new license.

2.0 BACKGROUND

2.1 Pacific Lamprey Biology

Pacific lamprey are present in most tributaries of the Columbia River and in the mainstem Columbia River during their migration stages. They have cultural, utilitarian and ecological significance in the basin, because Native Americans have historically harvested them for subsistence, ceremonial and medicinal purposes (Close et al. 2002). As an anadromous species, they also play an important role in the food web by contributing marine-derived nutrients to the basin and may act as a predatory buffer for juvenile salmon and steelhead. Little specific information is available on the life history or status of lamprey in the mid-Columbia River watersheds. They are known to occur in the Methow, Wenatchee and Entiat rivers (NMFS 2002) and recently have been captured during juvenile salmon and steelhead trapping operations in the Okanogan River.

In general, adults are parasitic on fish in the Pacific Ocean while ammocoetes (larvae) are filter feeders that inhabit the fine silt deposits in backwaters and quiet eddies of streams (Wydoski and Whitney 2003). Adults generally spawn in low-gradient stream reaches in the tail areas of pools and in riffles, over gravel substrates (Jackson et al. 1997). Adults die after spawning. After hatching, the ammocoetes burrow into soft substrate for an extended larval period filtering particulate matter from the water column (Meeuwig et al. 2002). The ammocoetes undergo a metamorphosis into macrophthalmia (outmigrating juvenile lamprey) between 3 and 7 years after hatching, and then migrate from their parent streams to the ocean (Close et al. 2002). Adults typically spend 1-4 years in the ocean before returning to freshwater tributaries to spawn.

Pacific lamprey populations of the Columbia River have generally declined in abundance over the last 40 years according to counts at dams on the lower Columbia and Snake rivers (Close et al. 2002). Starke and Dalen (1995) reported that adult lamprey counts at Bonneville Dam regularly exceeded 100,000 fish in the 1960s and more recently have ranged between 20,000 and 120,000 for the period 2000-2004 (DART - www.cqs.washington.edu/dart/adult.html).

In the mid-Columbia River Basin, adult lamprey count data at hydroelectric projects varies by site but is generally available for all projects since 1998 (with the exception of Wanapum Dam where data is only available for 2007). As is expected, the general trend for mid-Columbia River counts is relatively consistent with observations at Bonneville Dam from year to year (i.e., relatively high count years at Bonneville result in relatively high count years in the mid-Columbia River). It is important to note that the daily and seasonal time periods as well as the counting protocols may differ at each project. These differences may affect data reliability and need to be considered when examining and comparing these data. Table 2.1-1 provides a summary of adult lamprey passage data for mid-Columbia River hydroelectric facilities.

Table 2.1-1. Minimum, maximum, and average counts for adult Pacific lamprey at mid-Columbia River hydroelectric projects from 1998 to 2007.

	Priest Rapids	Wanapum*	Rock Island	Rocky Reach	Wells
Min	1,130	4,771	559	303	21
Max	6,593	4,771	5,074	2,583	1,417
Average	3,016	4,771	2,157	952	326

* Wanapum Dam counts are only available for 2007.

Close et al. (1995, 2002) identified several factors that may account for the decline in lamprey counts in the Columbia River Basin. This includes reduction in suitable spawning and rearing habitat from flow regulation and channelization and pollution, reductions of prey in the ocean, and juvenile and adult passage problems at dams. Mesa et al. (2003) found that adult Pacific lamprey had a mean critical swimming speed of approximately 85 cm/s which suggests that they may have difficulty negotiating fishways with high current velocities that were designed for salmon and steelhead passage.

The study of adult Pacific lamprey migration patterns past dams and through reservoirs in the lower Columbia River has provided the first data sets on lamprey passage timing, travel times, and passage success at hydroelectric projects (Vella et al. 2001; Ocker et al. 2001; Moser et al. 2002a; Moser et al. 2002b). These studies have shown that approximately 90% of the radio-

tagged lamprey released downstream of Bonneville Dam migrated back to the tailrace below Bonneville Dam; however, less than 50% of the lamprey which encountered a fishway entrance actually passed through the ladder exit at the dam (Nass et al. 2005).

Similar collection and passage efficiency results were observed at Rocky Reach, Wanapum, and Priest Rapids dams during tagging studies conducted at those projects (Nass et al. 2003; Stevenson et al. 2005).

Of the 125 radio-tagged lampreys released approximately 7 kilometers downstream of Rocky Reach Dam, 93.6% were detected at the project, and of those fish, 94.0% entered the fishway. Of the fish that entered the Rocky Reach fishway, 55.5% exited the ladder (Stevenson et al. 2005).

During studies at Wanapum and Priest Rapids dams, a total of 51 and 74 lamprey were radio-tagged and released downstream of Priest Rapid Dam in 2001 and 2002, respectively. Over the two years of study, the proportion of fish that approached the fishway that exited the ladders was 30% and 70% at Priest Rapids and 100% and 51% at Wanapum Dam in 2001 and 2002, respectively (Nass et al. 2003).

Two recent reviews of Pacific lamprey (Hillman and Miller 2000; Golder Associates Ltd. 2003) in the mid-Columbia River have indicated that little specific information is available regarding their population status (Stevenson et al. 2005).

2.2 Status of Pacific Lamprey

In January 2003, the USFWS received a petition from 11 environmental groups seeking the listing of four lamprey species (Pacific lamprey, river lamprey, western brook lamprey, and Kern brook lamprey). The petition cited population declines and said lampreys are threatened by artificial barriers to upstream and downstream migration, de-watering and habitat degradation among other threats. In response to the petition, the USFWS conducted an initial review to determine whether an emergency listing was warranted and decided in March 2003 that such a situation did not exist.

In an agreement stemming from a lawsuit filed by the petitioners in response to the initial finding, the USFWS committed to the issuance of a 90-day finding on the petition by December 20, 2004. Again, the USFWS announced that the petition seeking a listing of the four lamprey species did not contain enough information to warrant further review and the agency was not going to place the lamprey species on the Endangered Species list. For Pacific lamprey, the petitioners provided information showing a drop in range and numbers, but did not provide information describing how the regional portion of the species' petitioned range, or any smaller portion, is appropriate for listing under the Endangered Species Act (ESA). The agency did however decide it will continue to work with others on efforts to gather information related to the conservation of lamprey and their habitats.

2.3 Monitoring and Studies of Outmigrating Juvenile Lamprey (Macrophthalmia)

Little information in the mid-Columbia River basin exists with regard to the outmigration timing and abundance of juvenile Pacific lamprey. Upstream of the Project, recent juvenile salmonid trapping operations by WDFW and the Colville Tribe have provided preliminary information on the presence of juvenile lamprey outmigrants in both the Methow and Okanogan rivers. This information represents incidental captures of juvenile lamprey, and may not be reflective of actual abundance or population trends. In the Okanogan River, information is available for 2006 and 2007 where 220 and 24 juvenile lamprey were observed, respectively, during spring trapping operations. In the Methow River watershed, information is available for two sites; the Twisp and Methow rivers. At the Twisp River site, no juvenile lamprey have been observed since data has been collected (2005). At the Methow River site, for the years 2004-2007, 89, 84, 831, and 37 juvenile lamprey were observed, respectively, in trapping operations that typically last from April to November with peaks generally occurring in the spring. Data collection from these activities is likely to continue and provide information on juvenile Pacific lamprey as they begin their outmigration through the Columbia River hydrosystem towards the Pacific Ocean.

Although there is a growing body of information on adult Pacific lamprey and their interactions at hydroelectric projects, relatively little information exists describing the effects of hydroelectric plant operations on outmigrating juvenile lamprey (macrophthalmia). Recent juvenile lamprey studies at hydroelectric projects have addressed testing for lamprey macrophthalmia survival through juvenile bypass facilities (Bleich and Moursund 2006), impingement at intake diversion screens (Moursund et al. 2000 and 2003), validation of existing screening criteria (Ostrand 2005), and responses of juvenile Pacific lamprey to simulated turbine passage environments (Moursund et al. 2001; INL 2006). Results of other studies targeting predaceous birds and fish suggest that juvenile lamprey may compose a significant proportion of the diets of these predators (Poe et al. 1991; Merrell 1959).

A review of the recent body of work addressing juvenile lamprey at hydroelectric facilities concludes that there is a current lack of methods and tools to effectively quantify the level of survival for juvenile lamprey migrating through hydroelectric facilities. Furthermore, no studies exist that assign a level of survival attributed to a project's operations. This is due to the lack of miniaturized active tag technologies to overcome two study limitations. Macrophthalmia (juvenile outmigrating lamprey) are relatively small in size and unique in body shape and they tend to migrate low in the water column resulting in the rapid attenuation of active tag signal strength. In an effort to develop a tagging protocol, the Bonneville Power Administration (BPA) funded Oregon State University (OSU) to identify and develop tag technologies for lamprey macrophthalmia. Recent reports on this developmental effort have concluded that the smallest currently available radio-tag was still too large for implantation in the body cavity of a juvenile lamprey (Schreck et al. 2000). Additionally, external application was not effective as animals removed tags within the first week and fish performance was affected. This report also concluded that internal implantation of Passive Integrated Transponder (PIT) tags was the most viable option for tagging juvenile lamprey although this method included severe limitations such as the limited range of detection systems and the ability to tag only the largest outmigrating juvenile lamprey (Schreck et al. 2000).

2.4 Project Adult Pacific Lamprey Counts and Passage Timing

Returning adult Pacific lamprey have been counted at Wells Dam since 1998. Between the years of 1998 and 2007, the number of lamprey passing Wells Dam annually has averaged 326 fish and ranged from 21 fish in 2006 to 1,417 fish in 2003 (Table 2.3-1). In addition to the overriding condition that Pacific lamprey numbers are declining in the Columbia River system, the relatively small number of adult lamprey observed at Wells Dam may be attributed to fact that the Project is the last of nine passable dams on the mainstem Columbia River and the fact that the Project is over 500 miles upstream from the Pacific Ocean and the bioenergetic expenditure for a relatively poor swimming species such as Pacific lamprey is likely great.

Adult lamprey pass Wells Dam from early July until late November with peak passage times between mid-August and late October (Figures 2.4-1 and 2.4-2). In all years since counting was initiated, Pacific lamprey counts at the east fish ladder were greater than at the west fish ladder except for 2007. It is important to note that historically, counting protocols were designed to assess adult salmonids and did not necessarily conform to lamprey migration behavior (Moser and Close 2003). Traditional counting times for salmon did not coincide with lamprey passage activity which occurs primarily at night; the erratic swimming behavior of adult lamprey also makes them inherently difficult to count (Moser and Close 2003). Beamish (1980) also noted that lamprey overwinter in freshwater for one year prior to spawning. Consequently, lamprey counted in one year may actually have entered the system in the previous year (Moser and Close 2003) which confounds annual returns back into the Columbia River Basin. In addition to salmonid-specific counting protocols, adult fishway facilities have been constructed specifically for passage of salmonids. Recent research has identified areas such as picketed lead structures downstream of fish count windows that adult lamprey may access to bypass count stations and avoid being enumerated (LGL 2008). It is unknown to what degree lamprey behavior and methodological and structural concerns are reflected in Columbia River lamprey passage data. However, it is important to consider such caveats when examining historic lamprey count data at Columbia River dams including Wells Dam.

Table 2.4-1 Adult Pacific lamprey counts at Wells Dam for east and west fish ladders, 1998-2007.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
East	174	47	96	153	226	724	263	151	13	17
West	169	26	59	106	117	694	140	64	8	18
Total	343	73	155	259	343	1418	403	215	21	35

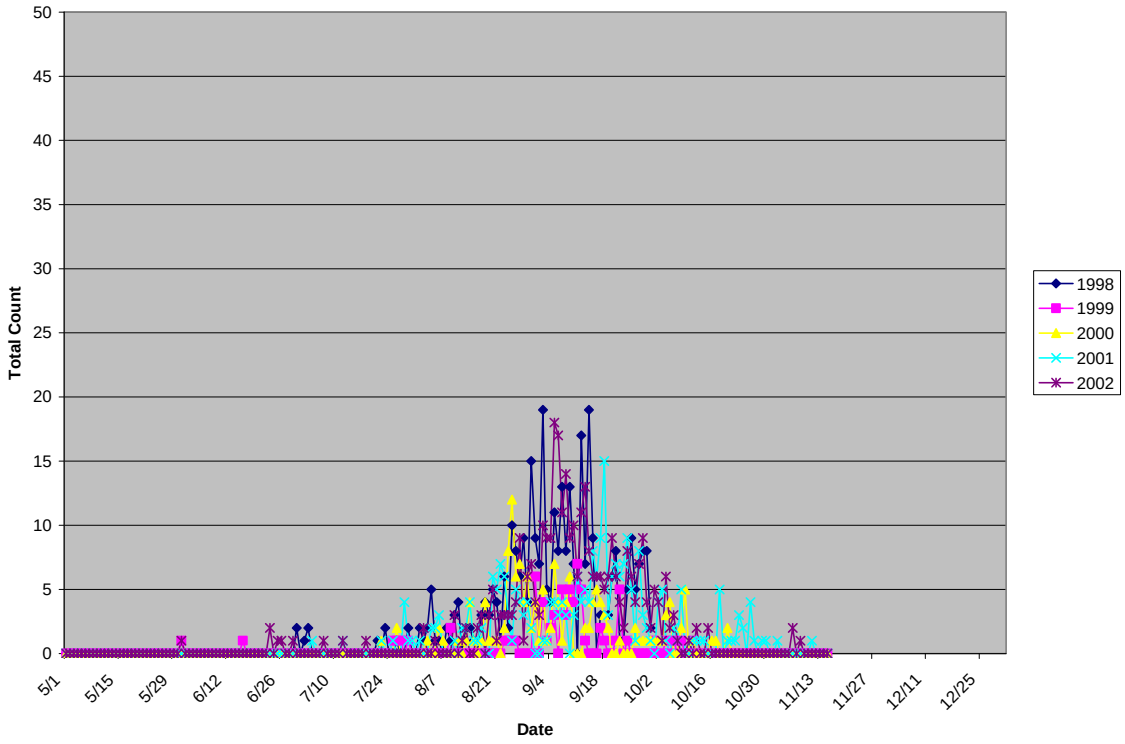

Figure 2.4-1 **Daily counts of adult Pacific lamprey at Wells Dam during the fish counting season, 1998-2002.**

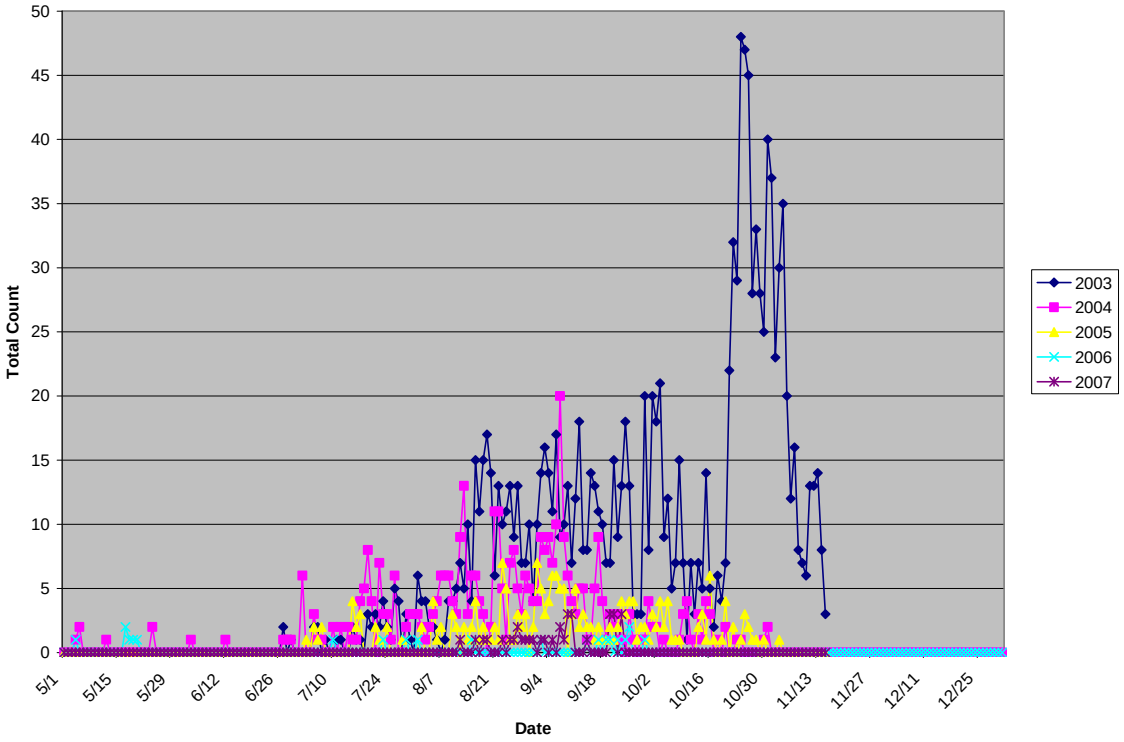

Figure 2.4-2 **Daily counts of adult Pacific lamprey at Wells Dam during the fish counting season, 2003-2007.**

2.5 Project Pacific Lamprey Studies

Until recently, relatively little information was available on Pacific lamprey in the mid-Columbia River Basin. However, with increased interest in the species coupled with a petition for listing under the ESA (Section 2.2), Douglas has initiated studies to address Pacific lamprey passage and migratory behavior in the Project consistent with currently available technology.

2.5.1 2001-2003 Project Pacific Lamprey Study

In 2004, Douglas contracted with LGL Limited to conduct a lamprey radio-telemetry study at Wells Dam in coordination with Chelan PUD, which was conducting a similar study at Rocky Reach Dam. A total of 150 lamprey were radio-tagged and released at or below Rocky Reach Dam. The radio-tags used in this study had an expected operational life of 45 days (Nass et al. 2005). It is important to note that as a result of the lamprey release site being located over 50 miles downstream of Wells Dam, the value of the study results for the Project was limited by the relatively small numbers of tagged fish detected upstream at Wells (n=18) and the fact that many of the radio-tags detected at Wells Dam were within days of exceeding their expected battery life.

The 2004 study at Wells Dam was implemented through a combination of fixed-station monitoring at the dam and fixed-stations at tributary mouths. Collectively, these monitoring sites were used to determine migration and passage characteristics of lamprey entering the Project Area. Of the 150 adult lamprey released at or below Rocky Reach in 2004, 18 (12% of 150) were detected in the Wells Dam tailrace, and ten (56% of 18) of these were observed at an entrance to the fishways at Wells Dam. A total of 3 radio-tagged lamprey passed Wells Dam prior to expiration of the tags, resulting in a Fishway Efficiency estimate of 30% (3 of 10) for the study period. A single lamprey was detected upstream of Wells Dam at the mouth of the Methow River (Nass et al. 2005).

For lamprey that passed the dam, the majority (92%) of Project Passage time was spent in the tailrace. Median time required to pass through the fishway was 0.3 d and accounted for 8% of the Project Passage time (Nass et al. 2005).

Although the 2004 study at Wells Dam provided preliminary passage and behavioral information for migrating adult lamprey, the limited observations due to the small sample size (n=18) were insufficient in addressing the objectives of the 2004 study.

2.5.2 2007-2008 Project Pacific Lamprey Study

In 2007, Douglas contracted with LGL Limited to conduct a second lamprey radio-telemetry study at Wells Dam. The study was scheduled to occur from early August through November and utilized tags that had 87 days of battery life. A total of 21 adult lamprey were tagged and released for the purpose of this study. However, due to very low adult lamprey returns to Wells Dam in 2007 (n=35) and low trapping efficiency, only 6 adult Pacific lamprey were captured at Wells Dam during trapping activities (August 14 to October 3). Therefore, 15 additional adult lamprey were collected at Rocky Reach Dam, transported to Wells Dam, tagged and released. The project was continued in 2008 to obtain additional information.

A comprehensive report was produced in February of 2009 containing the results from the two-year radio-telemetry behavior studies (Robichaud et al. 2009). Results indicated that the "greatest impediment to successful passage of adult lamprey at Wells Dam appears to be the conditions at the fishway entrance, probably related to water velocities that limit swimming and attachment capabilities." An equally significant impediment to successful passage of adult lamprey at Wells Dam in 2008 was the installation of perforated plates on the floor of the weir orifices in an effort to increase trapping efficiency. Robichaud et al. further recommended the following:

- Implement a reduction in fishway head differential to reduce entrance velocities to levels within the swimming capabilities of Pacific lamprey (0.8 to 2.1 m/s). These proposed flow reductions should be restricted to hours of peak lamprey activity (i.e., nighttime) and within their primary migratory period at Wells Dam (August-September).
- Remove perforated plates from orifice floors at the current trapping locations and discontinue trapping efforts at Wells Dam.
- Consider using monitoring tools that are less intrusive, do not require the collection of fish from the ladders at Wells Dam, and minimize the surgical implantation of tags in fish that are nearing their physiological limits.

2.5.3 2009 Pacific Lamprey Ladder Modification Study

In response to Robichaud et al. (2009), Douglas PUD, in consultation with the Aquatic SWG, prepared a plan to implement and evaluate measures to enhance passage of adult Pacific lamprey at Wells Dam (Murauskas and Johnson, 2009). These measures, originally scheduled for year two after license issuance (2013), were designed to determine whether temporary velocity reductions at the fishway entrances would enhance the attraction and relative entrance success of adult lamprey at Wells Dam. Three alternative entrance flow velocities (i.e., existing high, moderate, and low) will be assessed using Dual-frequency Identification Sonar (DIDSON) in a randomized block design during the fall of 2009. The goal is to identify optimal hydraulic conditions conducive to entry of adult lampreys into the fishways at Wells Dam.

3.0 GOALS AND OBJECTIVES

The goal of the PLMP is to implement measures to monitor and address impacts, if any, on Pacific lamprey resulting from the Project during the term of the new license. Douglas, in collaboration with the Aquatic SWG, has agreed to implement several Pacific lamprey PMEs in support of the PLMP. The PMEs presented within the PLMP are designed to meet the following objectives:

Objective 1: Identify and address any adverse Project-related impacts on passage of adult Pacific lamprey;

Objective 2: Identify and address any Project-related impacts on downstream passage and survival, and rearing of juvenile Pacific lamprey;

Objective 3: Participate in the development of regional Pacific lamprey conservation activities.

The PLMP is intended to be compatible with other Pacific lamprey management plans in the Columbia River mainstem. Furthermore, the PLMP is intended to be supportive of the HCP, the critical research needs identified by the Columbia River Basin Technical Working Group, the Resident Fish Management Plan, Bull Trout Management Plan, and White Sturgeon Management Plan by continuing to monitor and address ongoing impacts, if any, on Pacific lamprey resulting from Project operations. The PLMP is intended to be not inconsistent with other management strategies of federal, state and tribal natural resource management agencies and supportive of designated uses for aquatic life under Washington state water quality standards found at WAC 173-201A.

The schedule for implementation of specific measures within the PLMP is based on the best information available at the time the Plan was developed. As new information becomes available, implementation of each activity may be adjusted through consultation with the Aquatic SWG.

4.0 PROTECTION, MITIGATION AND ENHANCEMENT MEASURES

Douglas, in consultation with the Aquatic SWG, will implement PMEs for Pacific lamprey in the Project consistent with the goals and objectives identified in Section 3.0. The measures proposed in this section are intended to serve as PMEs for Pacific lamprey throughout the new license term.

4.1 Adult Pacific Lamprey Passage (Objective 1)

4.1.1 Upstream Fishway Operations Criteria

Douglas shall operate the upstream fishways at Wells Dam in accordance with criteria outlined in the HCP. Based upon information collected from activities conducted in Sections 4.1.3 - 4.1.7, Douglas, in consultation with the Aquatic SWG and the HCP Coordinating Committee, may evaluate various operational and structural modifications to the upstream fishways (e.g., reduction in fishway flows at night) for the benefit of Pacific lamprey passing upstream through Wells Dam during the new license term. If requested, the Aquatic SWG shall develop an Operations Study Plan (OS Plan) that specifically identifies all operational modifications to be evaluated, the proposed monitoring strategy, implementation timeline and criteria for success. The plan shall include a component to evaluate the effects of lamprey modifications on salmon. Upon completion of the evaluation, the Aquatic SWG, in consultation with the HCP Coordinating Committee, will determine whether the proposed modifications should be made permanent, removed, or modified.

4.1.2 Salvage Activities During Ladder Maintenance Dewatering

Douglas shall continue to implement the Adult Fish Passage Plan and associated Adult Ladder Dewatering Plan as required by the HCP. These plans include practices and procedures utilized during fishway dewatering operations to minimize fish presence in the fish ladders and then once dewatered directs Douglas staff to remove stranded fish and safely place them back into the

Columbia River. All fish species, including Pacific lamprey that are encountered during dewatering operations are salvaged consistent with the protocol identified in the HCP. Any adult lamprey that are captured during salvage activities will be released upstream of Wells Dam, unless otherwise determined by the Aquatic SWG. Douglas will coordinate salvage activities with the Aquatic SWG and allow for member participation. Douglas will provide a summary of salvage activities in the annual report.

4.1.3 Upstream Fishway Counts and Alternative Passage Routes

Douglas shall continue to conduct annual adult fish passage monitoring in the Wells Dam fishways using the most current technology available, to count and provide information on upstream migrating adult Pacific lamprey 24-hours per day during the adult fishway monitoring season (May 1- November 15). Based upon information collected from activities conducted in Sections 4.1.6 - 4.1.7, Douglas, in consultation with the Aquatic SWG, may choose to address the use of alternative upstream passage routes around Wells Dam fishway counting stations by adult Pacific lamprey. Potential measures to improve counting accuracy, following consultation and approval of the Aquatic SWG, may include, but may not be limited to, the development of a correction factor based upon data collected during passage evaluations (Sections 4.1.6 and 4.1.7) or utilization of an alternative passage route as a counting facility for adult Pacific lamprey.

4.1.4 Upstream Passage Improvement Literature Review

If additional passage improvement measures are deemed necessary by the Aquatic SWG, then within six months after this determination, Douglas, in consultation with the Aquatic SWG, shall complete a literature review on the effectiveness of upstream passage measures (i.e., lamprey passage systems, plating over diffuser grating, modifications to orifices, rounding sharp edges, fishway operational changes, etc.) implemented at other Columbia and Snake river hydroelectric facilities. The literature review will be conducted in support of activities identified in Section 4.1.5 to help in the selection of reasonable measures that may be implemented to improve adult lamprey passage at Wells Dam.

4.1.5 Fishway Modifications to Improve Upstream Passage

If additional passage improvement measures are deemed necessary by the Aquatic SWG, based upon the results of studies conducted at Wells Dam, then within one year or as soon as practicable following consultation with the Aquatic SWG, Douglas shall identify, design and implement any reasonable upstream passage modifications (structural and/or operational). Passage measures will be designed to improve passage performance by providing safe, effective, and volitional passage for Pacific lamprey through the Wells Dam fishways without negatively impacting the passage performance of adult anadromous salmonids. The following components shall be included in these passage measures:

- Fishway Inspection: Within one year of license issuance or as soon as practicable following consultation with the Aquatic SWG, Douglas shall conduct a fishway inspection with the Aquatic SWG and regional lamprey passage experts to identify and prioritize measures to improve adult lamprey passage and enumeration at Wells

Dam. Additional ladder inspections will be conducted at the request of the Aquatic SWG, consistent with winter ladder dewatering operations.

- Entrance Efficiency: Within one year of license issuance or as soon as practicable following consultation with the Aquatic SWG, Douglas shall develop a Lamprey Entrance Efficiency Plan (LEE Plan) for evaluating operational and physical ladder entrance modifications intended to create an environment at the fishway entrances that are conducive to adult lamprey passage without significantly impacting the passage of adult salmonids. These improvements shall be evaluated until compliance, as described below, is attained.
- Diffuser Gratings: Within five years of license issuance or as soon as practicable following consultation with the Aquatic SWG, Douglas shall identify and address, if needed, diffuser gratings within fishways at Wells Dam that adversely affect passage of adult Pacific lamprey.
- Transition Zones: Within five years of license issuance or as soon as practicable following consultation with the Aquatic SWG, Douglas shall identify and address, if needed, transition zones within fishways at Wells Dam that adversely affect passage of adult Pacific lamprey.
- Ladder Traps and Exit Pools: Within five years of license issuance or as soon as practicable following consultation with the Aquatic SWG, Douglas shall identify and address, if needed, lamprey ladder traps and exit pools within fishways at Wells Dam that adversely affect passage of adult Pacific lamprey.

Douglas shall exhibit steady progress, as agreed to by the Aquatic SWG, towards improving adult lamprey passage until performance at Wells Dam is determined to be similar to other mid-Columbia River hydroelectric dams, or until scientifically rigorous standards and evaluation techniques are established by the Lamprey Technical Workgroup, or its successor, and adopted regionally. The Aquatic SWG will then evaluate, and if applicable and appropriate, adopt these standards for use at Wells Dam. If compliance is achieved, Douglas shall only be required to implement activities pursuant to Section 4.1.7 (Periodic Monitoring) for adult Pacific lamprey passage.

4.1.6 Adult Pacific Lamprey Upstream Passage Evaluation

Should upstream passage measures be implemented under Section 4.1.5, then within one year following the implementation of such measures, Douglas, in consultation with the Aquatic SWG, shall conduct a one-year study to monitor the effectiveness of such measures on upstream passage performance of adult Pacific lamprey through Wells Dam. If monitoring results indicate that passage rates at Wells Dam are not similar to passage rates at other mid-Columbia River dams or within standards as described in Section 4.1.5, Douglas, in consultation with the Aquatic SWG, shall develop and implement additional measures to improve upstream Pacific lamprey passage. Measures described in Sections 4.1.5 and 4.1.6 may be repeated, as necessary, until adult passage through Wells Dam is similar to passage rates at other mid-Columbia River hydroelectric dams or within standards as described in Section 4.1.5.

4.1.7 Periodic Monitoring

Once adult Pacific lamprey upstream passage rates at Wells Dam are similar to rates at other mid-Columbia River dams or within standards as described in Section 4.1.5, Douglas, in consultation with the Aquatic SWG, shall periodically monitor adult Pacific lamprey passage performance through Wells Dam fishways to verify the effectiveness of passage improvement measures. Specifically, every ten years after compliance has been achieved, or as determined by the Aquatic SWG, Douglas shall implement a one-year study to verify the effectiveness of the adult fish ladders with respect to adult lamprey passage. If results of the monitoring program confirm the effectiveness of adult lamprey passage measures and the results indicate that passage rates are still in compliance, then no additional measures are needed. If the results indicate that adult upstream passage rates are out of compliance, then the upstream passage study will be replicated to confirm the results. If the results after two years of study both indicate that passage rates have not been maintained, Douglas, in consultation with the Aquatic SWG, shall develop and implement measures to improve upstream Pacific lamprey passage, if any (see Section 4.1.5).

4.2 Juvenile Pacific Lamprey Downstream Passage and Survival and Rearing (Objective 2)

4.2.1 Downstream Bypass Operations Criteria

Douglas is required to operate the downstream bypass system at Wells Dam in accordance with criteria outlined in the HCP.

4.2.2 Salvage Activities During Ladder Maintenance Dewatering

Douglas shall continue to conduct salvage activities as required by the HCP's Adult Fish Passage Plan during fishway dewatering operations. All fish species, including Pacific lamprey that are encountered during dewatering operations shall be salvaged consistent with the protocol identified in the HCP. Any juvenile Pacific lamprey that are captured during salvage activities will be released downstream of Wells Dam. Douglas will coordinate salvage activities with the Aquatic SWG and allow for member participation. Douglas will provide a summary of salvage activities in the annual report.

4.2.3 Juvenile Pacific Lamprey Passage and Survival Literature Review

Beginning in year five and every five years thereafter during the new license, Douglas, in consultation with the Aquatic SWG, shall conduct a literature review to summarize available technical information related to juvenile lamprey passage and survival through Columbia and Snake river hydroelectric facilities. This information will be used to assess the feasibility of conducting activities identified in Section 4.2.4.

4.2.4 Juvenile Pacific Lamprey Downstream Passage and Survival Evaluation

Based upon the current state of the science regarding tag technology and methodologies for Pacific lamprey macrophthalmia (Section 2.3), coupled with the challenges of obtaining

macrophthalmia in sufficient numbers within the Project to meet sample size requirements for a statistically rigorous study, a juvenile downstream passage and survival evaluation is not feasible at this time.

During the term of the new license, if tag technology and methodologies are developed and field tested and a sufficient source of macrophthalmia in or upstream of the Project are identified to ensure that a field study will yield statistically rigorous and unbiased results, Douglas, in consultation with the Aquatic SWG, shall implement a one-year juvenile Pacific lamprey downstream passage and survival study.

If statistically valid study results indicate that Project operations have a significant negative impact on the Pacific lamprey population above the Wells Dam, Douglas, in consultation with the Aquatic SWG, shall identify and implement scientifically rigorous and regionally accepted measures (e.g., translocation, artificial production or habitat enhancement), if any, or additional studies to address such impacts. If operational changes are needed to improve passage survival of juvenile lamprey migrants, then those changes need to be coordinate with the HCP Coordinating Committee.

4.2.5 Juvenile Pacific Lamprey Habitat Evaluation

Within three years of the effective date of the new license, Douglas shall implement a one-year study to examine presence and relative abundance of juvenile Pacific lamprey in habitat areas within the Project that may be affected by Project operations. As part of this measure, Douglas shall identify areas of potential juvenile Pacific lamprey habitat for future evaluation. Sampling of these areas will assess presence/absence and relative abundance. Any sampling methodologies used in support of this activity will require coordination with the HCP Coordinating Committee and regulatory approval of the federal and state agencies.

4.3 Participate in Regional Pacific Lamprey Conservation Activities (Objective 3)

4.3.1 Regional Lamprey Working Groups

Douglas shall participate in Pacific lamprey work groups in order to support regional conservation efforts (e.g., the Pacific Lamprey Technical Work Group and the USFWS Lamprey Conservation Initiative). Activities may include but are not limited to information exchanges with other entities, meeting attendance, and coordination of Douglas' Pacific lamprey activities with other entities conducting lamprey research in the mid-Columbia River. Activities may also include conducting PLMP research within the Project, and sharing that information with other entities.

4.4 Reporting

Douglas will provide an annual report to the Aquatic SWG summarizing the previous year's activities and proposed activities for the following year undertaken in accordance with the PLMP. The report will document all Pacific lamprey activities conducted within the Project and describe activities proposed for the following year. Furthermore, any decisions, statements of agreement, evaluations, or changes made pursuant to this PLMP will be included in the annual report. If significant activity was not conducted in a given year, Douglas will prepare a memorandum providing an explanation of the circumstances in lieu of the annual report.

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ATTACHMENT E: RESIDENT FISH MANAGEMENT PLAN

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RESIDENT FISH MANAGEMENT PLAN

WELLS HYDROELECTRIC PROJECT

FERC PROJECT NO. 2149

August 2008

Prepared by:
Public Utility District No. 1 of Douglas County
East Wenatchee, Washington

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EXECUTIVE SUMMARY

The Resident Fish Management Plan (RFMP) is one of six Aquatic Resource Management Plans contained within the Aquatic Settlement Agreement (Agreement). Collectively, these six Aquatic Resource Management Plans are critical to direct implementation of Protection, Mitigation, and Enhancement measures (PMEs) during the term of the new license and, together with the Wells Anadromous Fish Agreement and Habitat Conservation Plan (HCP) will function as the Water Quality Attainment Plan (WQAP) in support of the Clean Water Act Section 401 Water Quality Certification for the Wells Hydroelectric Project (Project).

To ensure active stakeholder participation and support, the Public Utility District No. 1 of Douglas County (Douglas) developed all of the resource management plans in close coordination with agency and tribal natural resource managers (Aquatic Settlement Work Group or Aquatic SWG). During the development of this plan, the Aquatic SWG focused on developing management priorities for resources potentially impacted by Project operations. Members of the Aquatic SWG include the U.S. Fish and Wildlife Service (USFWS), Washington Department of Ecology (Ecology), Washington State Department of Fish and Wildlife (WDFW), the Confederated Tribes of the Colville Reservation (Colville), the Confederated Tribes and Bands of the Yakama Indian Nation (Yakama), and Douglas.

The National Marine Fisheries Service (NMFS) was invited to participate in the development of Aquatic Resource Management Plans, but declined because its interests are currently satisfied by the measures within the HCP.

The goal of the RFMP is to protect and enhance native resident fish populations and habitat in the Project during the term of the new license. Douglas, in collaboration with the Aquatic SWG, has agreed to implement several resident fish PMEs in support of the RFMP. The PMEs presented within the RFMP are designed to meet the following objectives:

Objective 1: Continue to provide additional benefits to resident fishery resources in the Project as a result of continued implementation of the HCP, Predator Control Programs and Douglas PUD's Land Use Policy.

Objective 2: In year 2 and every 10 years thereafter during the new license term, Douglas will conduct a resident fish study to determine the relative abundance of the various resident fish species found within the Project. The study objectives will focus on (1) identifying whether there have been major shifts in the resident fish populations resulting from the implementation of the White Sturgeon, Bull Trout, Pacific Lamprey, and Aquatic Nuisance Species (ANS) Management Plans, and (2) collecting information on resident predator fish populations found within the Wells Reservoir. The results of this study may be used to inform the implementation activities of the other Wells aquatic resource management (ANS, bull trout, Pacific lamprey, and white sturgeon) plans and HCP predator control activities.

Objective 3: If any statistically significant negative changes to native resident fish populations of social, economic, and cultural importance are identified, and are not caused by and cannot be addressed through implementation of other aquatic resource management plans or activities (white sturgeon, Pacific lamprey, bull trout, ANS, HCP, predator control), reasonable and appropriate implementation measures to address negative changes, if any, will be undertaken by Douglas.

Objective 4: In response to proposed major changes in Wells Dam operations requiring FERC approval, Douglas will assess the potential effects, if any, on Project habitat functionally related to spawning, rearing, and migration of native resident fish, in order to make informed management decisions towards the success of the RFMP. Douglas will implement reasonable and appropriate measures to address any effects on social, economic, and culturally important native species.

This RFMP is intended to be compatible with other resident fish management plans in the Columbia River mainstem. Furthermore, the RFMP is intended to be supportive of the HCP, Bull Trout Management Plan, Pacific Lamprey Management Plan and White Sturgeon Management Plan by continuing to monitor changes, if necessary, in the resident fish assemblage within the Project. The RFMP is intended to be not inconsistent with other management strategies of federal, state and tribal natural resource management agencies and supportive of designated uses for aquatic life under WAC 173-201A, the Washington state water quality standards.

1.0 INTRODUCTION

The Resident Fish Management Plan (RFMP) is one of six Aquatic Resource Management Plans contained within the Aquatic Settlement Agreement (Agreement). Collectively, these six Aquatic Resource Management Plans are critical to direct implementation of Protection, Mitigation, and Enhancement measures (PMEs) during the term of the new license and, together with the Wells Anadromous Fish Agreement and Habitat Conservation Plan (HCP) will function as the Water Quality Attainment Plan (WQAP) in support of the Clean Water Act Section 401 Water Quality Certification for the Wells Hydroelectric Project (Project).

To ensure active stakeholder participation and support, the Public Utility District No. 1 of Douglas County (Douglas) developed all of the resource management plans in close coordination with agency and tribal natural resource managers (Aquatic Settlement Work Group or Aquatic SWG). During the development of this plan, the Aquatic SWG focused on developing management priorities for resources potentially impacted by Project operations. Entities invited to participate in the Aquatic SWG include the U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), Bureau of Land Management (BLM), Bureau of Indian Affairs (BIA), Washington Department of Ecology (Ecology), Washington State Department of Fish and Wildlife (WDFW), the Confederated Tribes of the Colville Reservation (Colville), the Confederated Tribes and Bands of the Yakama Indian Nation (Yakama), and Douglas.

The RFMP will direct implementation of measures to protect and enhance native resident fish populations in the Wells Reservoir. To ensure active stakeholder involvement and support, Douglas developed this plan, along with the other aquatic management plans, in close coordination with the members of the Aquatic SWG.

The Aquatic SWG agrees on the need to develop a plan for the long-term management of native resident fish populations in the Project. This management plan summarizes the relevant resource issues and background (Section 2), identifies goals and objectives of the plan (Section 3), and describes the relevant PMEs (Section 4) for native resident fish during the term of the new license.

2.0 BACKGROUND

2.1 Resident Fish Species

The resident fish assemblage present in the Wells Reservoir is composed of a diverse community of native and introduced, warm and coldwater, and recreational and non-recreational fish species. Since the construction of Wells Dam several studies have either directly (McGee 1979; Beak 1999) or indirectly (Dell et al. 1975; Burley and Poe 1994) addressed the resident fish assemblage in the Wells Reservoir.

2.1.1 Project Resident Fish Assessments

In assessing the occurrence of gas bubble disease in fish in the mid-Columbia River reservoirs, Dell et al. (1975) observed that the most abundant resident fish species in the Wells Reservoir were northern pikeminnow (*Ptychocheilus oregonensis*), stickleback (*Gasterosteus spp.*), and suckers (*Catostomus* spp.). They also determined that mountain whitefish (*Prosopium williamsoni*) and pumpkinseed (*Lepomis gibbosus*) were the most abundant resident game fish, although these two species accounted for less than two percent of the total 32,289 fish sampled. Overall, 27 species of resident and migratory fish were identified in the study area (Table 2.1-1).

In 1993, a one-year study was conducted to determine the relative predation by northern pikeminnow on outmigrating juvenile salmonids and to develop relative predation indices for each of the five mid-Columbia River reservoirs. During the study, incidental catch (species captured other than northern pikeminnow) was high with over 25 fish species recorded and catch dominated by Catostomidae (suckers) (Burley and Poe 1994).

Table 2.1-1 Native and non-native resident fish species that have been documented in the Wells Reservoir from past resident fish assessments, monitoring efforts, and miscellaneous studies (Dell et al. 1975; McGee 1979; Burley and Poe 1994; Beak 1999; NMFS 2002; BioAnalyst, Inc. 2004).

Native Species	Non-Native Species
White sturgeon *Acipenser transmontanus*[*]	Carp *Cyprinus carpio*
Chiselmouth *Acrocheilus alutaceus*	Black bullhead *Ictalurus melas*
Longnose sucker *Catostomus catostomus*	Brown bullhead *Ictalurus nebulosus*
Bridgelip sucker *Catostomus columbianus*	Pumpkinseed *Lepomis gibbosus*
Largescale sucker *Catostomus macrocheilus*	Bluegill *Lepomis macrochirus*
Lake whitefish *Coregonus clupeaformis*	Smallmouth bass *Micropterus dolomieu*
Prickly sculpin *Cottus asper*	Largemouth bass *Micropterus salmoides*
Threespine stickleback *Gasterosteus aculeatus*	Yellow Perch *Perca flavescens*
Burbot *Lota lota*	Black crappie *Pomoxis nigromaculatus*
Peamouth *Mylocheilus caurinus*	Walleye *Stizostedion vitreum*
Rainbow trout *Oncorhynchus mykiss*	Tench *Tinca tinca*
Mountain whitefish *Prosopium williamsoni*	
Northern pikeminnow *Ptychocheilus oregonensis*	
Redside shiner *Richardsonius balteatus*	
Dace Rhinichthys spp.	
Bull Trout *Salvelinus confluentus*[*]	

[*] Individual management plans for both white sturgeon and bull trout have been developed and as such, they are not addressed in this Resident Fish Management Plan.

McGee (1979) noted that chiselmouth (*Acrocheilus alutaceus*), redside shiners (*Richardsonius balteatus*), and largescale suckers (*Catostomus macrocheilus*) were the most abundant non-game fish captured during Wells Reservoir surveys while pumpkinseed were the most abundant game fish caught. Similar sampling design and methodology to the 1974 study (Dell et al. 1975) were employed in order to ensure that results of the study were comparable with past observations. In total, 2,480 fish were collected during the study using live traps, beach seines and angling.

Twenty of the 27 known species previously trapped in other mid-Columbia reservoirs (Dell et al. 1975) were captured in the Wells Reservoir during the study.

In 1998, Douglas conducted an updated Wells Reservoir resident fish assessment (Beak 1999). Again, an effort was made to implement a sampling design similar to the two previous studies (1974 and 1979) so as to be consistent and allow comparisons with past results. In total, 22 species of fish were identified with 5,657 fish captured using beach seines and 716 fish observed via diving transects. Beak (1999) reported suckers (*Catostomus* spp.) as the most abundant resident fish captured in beach seining sampling in the Wells study area. These species represented 41 percent of the beach seining catch and 46 percent of the underwater dive survey count. Other abundant species in the beach seine catch were bluegill (*Lepomis macrochirus*) (32 percent), northern pikeminnow (10 percent), peamouth (*Mylocheilus caurinus*) (6 percent), and carp (*Cyprinus carpio*) (5 percent). Fifteen other species represented the remaining 7 percent of the total catch of 3,783 fish. Table 2.1-2 ranks the relative abundance of dominant fish species captured in the 1974, 1979, and 1998 Project studies and how species abundance has shifted over time.

Table 2.1-2 Ranking of relative abundance of dominant fish species in the 1974, 1979, and 1998 Wells Reservoir resident fish assessments (Beak 1999).

Species	1974	1979	1998
Largescale sucker *Catostomus macrocheilus*	1	4	1
Redside Shiner *Richardsonius balteatus*	3	3	3
Northern Pikeminnow *Ptychocheilus oregonensis*	2	5	4
Bluegill *Lepomis macrochirus*	16	0	2
Pumpkinseed *Lepomis gibbosus*	11	2	18
Chiselmouth *Acrocheilus alutaceus*	4	1	10

2.1.2 Recreational Fish Species

Kokanee

Landlocked sockeye (*Oncorhynchus nerka*), known as kokanee are a native fish which occur in several lakes in the mid and upper Columbia basins including Lake Wenatchee, Lake Chelan, Lake Osoyoos, and Lake Roosevelt. Although previous resident fish assessments have not detected the presence of this fish species in the Project, anecdotal information exists indicating that low numbers of kokanee may be present in the Project. These fish likely originate from Lake Roosevelt, above Grand Coulee Dam, and during periods of high spring flow are displaced downstream through Grand Coulee and Chief Joseph dams and into the Wells Reservoir.

Largemouth Bass

Largemouth bass (*Micropterus salmoides*) were widely introduced in Washington in the late 1800s (Wydoski and Whitney 2003). They are listed as a priority species in Washington State because of their vulnerability to habitat loss or degradation and their recreational importance (WDFW 2002). They prefer clear water habitat with mud and sand substrates, which is best suited for aquatic vegetation production (Wydoski and Whitney 2003). Little is known about the

populations in the Wells Reservoir as they are infrequently captured (Beak 1999; Duke 2001; Burley and Poe 1994).

Mountain Whitefish

Mountain whitefish are assumed to occur in all small-order tributaries to the Methow, Okanogan, Wenatchee and Entiat rivers, and in connecting larger lake systems. They are also believed to occur in the mainstem reservoirs, although their behavior patterns are not known. They mostly inhabit riffles in summer and large pools in winter (Wydoski and Whitney 2003). Spawning typically occurs from October through December, generally in riffles, but also on gravel shoals of lake shores. Mountain whitefish feed primarily on instar forms of benthic aquatic insects, although they also occasionally eat crayfish, freshwater shrimp, leeches, fish eggs and small fish. In lakes, they feed extensively on zooplankton, particularly cladocerans. There is evidence that mountain whitefish still spawn in the lower reaches of some tributaries (NMFS 2002). Mountain whitefish appear to use the Wells Reservoir principally as a migration route between spawning areas in the Methow River and the Wells Dam tailrace (Zook 1983).

Northern Pikeminnow

Northern pikeminnow are a slow-growing, long-lived predator native to the Columbia River basin. In summer, adult northern pikeminnow prefer shallow, low velocity areas in cool lakes or rivers. During the winter, they use deeper water and pools (Scott and Crossman 1973). Spawning occurs during the summer, in shallow water areas with gravel substrate. They tend to concentrate in tailrace areas downstream of mainstem dams during the juvenile salmonid migration period, holding in relatively slow-moving water areas (less than about 3 feet per second) near passage routes (NMFS 2002). Due to their large numbers and distribution throughout the Columbia River basin, northern pikeminnow are considered to pose the greatest predation threat to migrating juvenile anadromous salmonids (NMFS 2002).

Resident Rainbow Trout

Rainbow trout (*Oncorhynchus mykiss*) are an inland (remains in freshwater) form of steelhead. However, some rainbow trout remain in freshwater for most of their life but undergo a physiological change to a smolt and migrate to the ocean late in life. In addition to the potential for rainbow trout to become anadromous, the progeny of steelhead are believed to have the potential to become resident rainbow (Peven 1990). Inland rainbow and juvenile steelhead are not distinguishable from each other until the steelhead undergo smoltification. The mid-Columbia River tributaries contain a mixture of resident rainbow and ocean-migrating steelhead. Resident rainbow trout are likely present in low numbers in the Wells Reservoir. During the 1998 resident fish assessment, rainbow trout consisted of 0.05 percent of the relative catch (Beak 1999).

Smallmouth Bass

Smallmouth bass (*Micropterus dolomieu*) are a non-native game fish that have inhabited the mid-Columbia River reach since at least the 1940s. They are listed as a priority species in Washington State because of their vulnerability to habitat loss or degradation and their

recreational importance (WDFW 2002). Preferred habitat for this species includes rocky shoals, banks, or gravel bars. Adult smallmouth bass in the mid-Columbia River are most abundant around the deltas of warmer tributary rivers. In the Wells Reservoir, smallmouth bass are typically found in the lower Okanogan River and the confluence of the Okanogan and Columbia rivers (Beak 1999). They are also abundant in areas upstream of the mid-Columbia River.

Smallmouth bass were the second most abundant predator species captured in the mid-Columbia River during predator assessment sampling conducted in 1994. They were most frequently captured from forebay sampling sites (Burley and Poe 1994). Similar relative abundance estimates of smallmouth bass were observed in recent sampling programs in other mid-Columbia River reservoirs (Beak 1999; Duke 2001). They are a significant fish predator species in the Columbia River, and prey on juvenile salmonids. In the 1994 predator assessment, fish composed 87 percent of the smallmouth bass diet, with salmonids consisting of 11 percent of the prey fish.

Walleye

Walleye (*Stizostedion vitreum*) are a cool-water, piscivorous game fish believed to have moved downstream into the mid-Columbia River reach from a population established for recreational fishing in Lake Roosevelt in the late 1950s (Zook 1983). They were the least abundant predator species captured in the mid-Columbia River in 1994 (Burley and Poe 1994). They are listed as a priority species in Washington State because of their vulnerability to habitat loss or degradation and their recreational importance (WDFW 2002).

Walleye occur throughout the mainstem reservoirs but are not typically found in the tributaries. Although suitable spawning habitat appears to be plentiful in the mid-Columbia River, peak summer temperatures in this section of river are suboptimal and appear to restrict the recruitment of subyearling walleye to the yearling age class (Zook 1983). Recruitment of walleye into the mid-Columbia River reservoirs is suspected to result from the entrainment of young fish through Grand Coulee Dam during spring run-off (Zook 1983).

2.1.3 Other Resident Species

Resident, non-recreational species make up the bulk of the standing crop of fish in the Wells Reservoir. Many of these species are native to the Wells Reservoir, including burbot (*Lota lota*), chiselmouth, peamouth chub, redside shiner, largescale sucker, bridgelip sucker (*C. columbianus*), longnose sucker (*C. catostomus*), lake whitefish (*Coregonus clupeaformis*), Prickly sculpin (*Cottus asper*), threespine stickleback (*Gasterosteus aculeatus*), and dace species (*Rhinichthys spp.)*(See Table 2.1-1). Currently, no management actions or active fisheries for these species occur.

2.2 Resident Fish Habitat

2.2.1 Spawning habitat

Objectives of past resident fish studies (McGee 1979; Zook 1983; Beak 1999) did not specifically address spawning habitat but rather focused on species diversity, relative abundance and spatial distribution. Therefore, little information exists about the location and availability of spawning habitat for resident fish species in Project waters. It is likely that some resident fish species (cyprinids, catostomids, cottids) that spend their entire lives in Project waters utilize areas of the Wells Reservoir, tailrace, and lower tributaries (Methow and Okanogan rivers) to reproduce while other resident species, although present in the Wells Reservoir, utilize areas outside of the Project Boundary. Zook (1983) in his review of resident fish in the Wells Reservoir, hypothesized that some resident species such as mountain whitefish, rainbow trout, and walleye, although present, may not be successfully reproducing. Zook's review (1983) suggests that resident rainbow trout are primarily a product of residualism of hatchery-produced steelhead and that mountain whitefish appear to use the Wells Reservoir principally as a migration route between spawning areas in the Methow River and the Wells Tailrace. The report also suggests that walleye populations in the Wells Reservoir are recruited from the Lake Roosevelt population that was introduced in the late 1950s. The report also states that although spawning habitat appears to be available, evidence of successful reproduction has not been observed (Zook 1983).

Northern pikeminnow control efforts have been implemented at the Wells Reservoir starting in 1995. Part of these efforts included the identification of known spawning locations through the use of radio-telemetry. Based upon results of this study, northern pikeminnow spawning habitat is located in the Wells Reservoir near Park Island, near river mile (RM) 1.5 on the Methow River and in the Wells tailrace immediately downstream of the east bank fish ladder (Bickford and Skillingstad 2000).

2.2.2 Rearing habitat

Past resident fish surveys (McGee 1979; Beak 1999) observed significant spatial trends in species distribution within the Wells Reservoir. Both McGee (1979) and Beak (1999) noted that in general, spiny ray species (centrarchids) were most abundant between RM 530 and RM 540 and in the lower Okanogan River portion of the Project. This unique area of the Wells Reservoir is shallow and broad with slower water velocities, finer substrate, warmer water temperatures, and higher turbidity (Beak 1999) and is conducive to rearing spiny ray fish species while excluding more streamlined fish that prefer fast flowing water. Both surveys also found that the more streamlined resident fish species, such as chiselmouth and redside shiner (cyprinids), were most abundant downstream of RM 530 where water velocities increased, turbidity decreased, and the amount of shallow littoral habitat decreased. Other resident fish such as various sucker species and white sturgeon are most likely distributed throughout the Wells Reservoir but reside and feed at depths near the river bottom. Migratory, cold water species such as bull trout and whitefish spawn outside of the Wells Reservoir and it is likely that the majority of juvenile fish of these species rear in tributary habitats. Sub-adult bull trout, however, have been observed passing over other mid-Columbia River dams and recent studies suggest that bull trout forage for resident species present in the Wells Reservoir (BioAnalysts Inc. 2004).

2.3 Management Activities Affecting Resident Fish

2.3.1 Habitat Conservation Plan's Predator Control Program

Section 4.3.3 of the Wells Anadromous Fish Agreement and Habitat Conservation Plan (HCP) includes the requirement that Douglas implement a northern pikeminnow and piscivorous bird harassment and control program to reduce the level of predation upon anadromous salmonids in the mid-Columbia Basin. The northern pikeminnow removal program includes a northern pikeminnow control program, participation in fishing derbies and tournaments and the use of long-line fishing equipment. These efforts are designed to provide an immediate and substantial reduction in the predator populations present within the waters of the Project.

Since efforts were first initiated in 1995, Douglas's northern pikeminnow removal program has captured over 134,000 northern pikeminnow (1995-2006). The continual harvest of northern pikeminnow from these waters will provide additional decreases in predator abundance. Yearly removal efforts will also keep the northern pikeminnow population in a manageable state.

The other component of the predator control program is the implementation of control measures for piscivorous birds. The focus of Douglas's piscivorous bird control program is not removal but hazing and access deterrents. Hazing includes propane cannons, pyrotechnics and the physical presence of hazing staff. Access deterrents include steel wires across the hatchery ponds and tailrace, fencing and covers for hatchery ponds, and electric fencing. When hazing and access deterrents fail, options for removal are also implemented by the US Department of Agriculture (DOA) Animal Control staff hired to conduct the hazing programs.

Although the intent of the predator control program is for the protection of anadromous salmonids, reductions in aquatic and terrestrial predator abundance within the Reservoir may benefit many native resident fish species.

2.3.2 Project Shoreline Management and Land Use Policy

Douglas owns approximately 89 miles of shoreline in fee title and addresses shoreline management issues through the implementation of a strict Land Use Policy that requires formal approval of all land use activities that take place within the Project Boundary. Applications to permit activities such as construction of boat docks, piers, and landscaping are reviewed and considered for approval by Douglas after all required regulatory permits are acquired by the applicant. Additionally, when making land use or related permit decisions on Douglas owned lands that affect habitat within the Project Boundary, Douglas is required by Section 5 of the HCP to notify and consider comments from the HCP signatory parties (Douglas 2002). Shoreline management activities directly related to Project land use benefit resident fish, juvenile anadromous fish, and aquatic invertebrates and plants by minimizing impact in littoral areas within the Project Boundary.

3.0 GOALS AND OBJECTIVES

The goal of the RFMP is to protect and enhance native resident fish populations and habitat in the Project during the term of the new license. Douglas, in collaboration with the Aquatic SWG, has agreed to implement several resident fish PMEs in support of the RFMP. The PMEs presented within the RFMP are designed to meet the following objectives:

Objective 1: Continue to provide additional benefits to resident fishery resources in the Project as a result of continued implementation of the HCP, Predator Control Programs and Doulas PUD's Land Use Policy.

Objective 2: In year 2 and every 10 years thereafter during the new license term, Douglas will conduct a resident fish study to determine the relative abundance of the various resident fish species found within the Project. The study objectives will focus on (1) identifying whether there have been major shifts in the resident fish populations resulting from the implementation of the White Sturgeon, Bull Trout, Pacific Lamprey, and Aquatic Nuisance Species (ANS) Management Plans, and (2) collecting information on resident predator fish populations found within the Wells Reservoir. The results of this study may be used to inform the implementation activities of the other Wells aquatic resource management (ANS, bull trout, Pacific lamprey, and white sturgeon) plans and HCP predator control activities.

Objective 3: If any statistically significant negative changes to native resident fish populations of social, economic, and cultural importance are identified, and are not caused by and cannot be addressed through implementation of other aquatic resource management plans or activities (white sturgeon, Pacific lamprey, bull trout, ANS, HCP, predator control), reasonable and appropriate implementation measures to address negative changes, if any, will be undertaken by Douglas.

Objective 4: In response to proposed major changes at Wells Dam requiring FERC approval, the Aquatic SWG will assess the potential effects, if any, on Project habitat functionally related to spawning, rearing, and migration of native resident fish, in order to make informed management decisions towards the success of the RFMP. Douglas will implement reasonable and appropriate measures to address any effects on social, economic, and culturally important native species.

This RFMP is intended to be compatible with other resident fish management plans in the Columbia River mainstem. Furthermore, the RFMP is intended to be supportive of the HCP, Bull Trout Management Plan, Pacific Lamprey Management Plan, and White Sturgeon Management Plan by continuing to monitor changes, if necessary, in the resident fish assemblage within the Project. This management plan is intended to be not inconsistent with other management strategies of federal, state and tribal natural resource management agencies and supportive of designated uses for aquatic life under WAC 173-201A, the Washington state water quality standards.

The schedule for implementation of specific measures within the RFMP is based on the best information available at the time the Plan was developed. As new information becomes available, implementation of each activity may be adjusted through consultation with the Aquatic SWG.

4.0 PROTECTION, MITIGATION AND ENHANCEMENT MEASURES

In order to fulfill the goal and objectives described in Section 3.0, Douglas, in consultation with the Aquatic SWG, shall develop and implement a resident fish management program that includes the following PMEs.

4.1 Implementation Of Programs that Benefit Resident Fish (Objective 1)

4.1.1 HCP Predator Control Programs

Douglas shall continue to conduct annual predator control activities for northern pikeminnow and avian predators as outlined in the HCP (Douglas 2002). Although implementation of this program is targeted at reducing predation on anadromous species covered by the HCP, it is also anticipated to have direct benefits for resident fish species.

4.1.2 Project Shoreline Management and Land Use Policy

Douglas shall continue to implement the Douglas Land Use Policy which requires approval of all land use activities that take place within the Project Boundary. All permit activities such as construction of boat docks, piers, and landscaping within Project Boundary will be subject to review and approval by Douglas only after the applicant has received all other required regulatory permits, in addition to consideration by the HCP signatory parties and permit review by state and federal action agencies. The intent of the review and approval process captured in the Land Use Policy is to protect aquatic habitats and aquatic species that may be affected by proposed land use activities within the Project.

4.2 Monitoring the Resident Fish Assemblage within the Wells Reservoir (Objective 2)

Douglas shall conduct a resident fish study to determine the relative abundance of the various resident fish species found within the Wells Reservoir. This assessment shall occur in year 2 and every 10 years thereafter during the term of the new license. The study objectives will focus on (1) identifying whether there have been major shifts in the resident fish populations resulting from the implementation of the White Sturgeon, Bull Trout, Pacific Lamprey, and Aquatic Nuisance Species Management Plans, and (2) collecting information on resident predator fish populations found within the Wells Reservoir.

In order to maintain comparative assemblage information over time to inform Project resident fish status and trends, methodology for monitoring activities shall remain consistent with the methods described in Beak (1999). Information collected from these monitoring activities may be used to inform the implementation activities of the other Wells aquatic resource management plans and the HCP predator control activities.

4.3 Actions to Address Major Shifts in Native Resident Fish Assemblage (Objective 3)

Based upon information collected during the resident fish status and trends monitoring (Section 4.2), if any statistically significant negative changes to native resident fish populations of social, economic, and cultural importance are identified, and are not caused by and cannot be addressed through the implementation of other Aquatic Resource Management Plans or activities (white sturgeon, Pacific lamprey, bull trout, ANS, HCP, predator control), reasonable and appropriate implementation measures to address negative changes, if any, will be undertaken by Douglas.

4.4 Monitoring in Response to Proposed Changes in Project Operations (Objective 4)

If at any time during the new license term, future changes in Wells Dam operations are proposed that require FERC approval and the Aquatic SWG concludes that either reservoir or tailrace habitat within Project Boundary may be affected with regards to spawning, rearing, and migration (aquatic life designated uses) of native resident fish, an assessment will be implemented to identify potential effects, if any, in order to make informed license decisions. If the results of the assessment identify adverse effects to native resident fish species of social, economic and cultural importance, attributable to such changes in Project operations, then Douglas will consult with the Aquatic SWG to select and implement reasonable and appropriate measures to address such effects.

4.5 Reporting

Douglas will provide a draft annual report to the Aquatic SWG summarizing the previous year's activities undertaken in accordance with the RFMP. The report will document all native resident fish activities conducted within the Project. Furthermore, any decisions, statements of agreement, evaluations, or changes made pursuant to this RFMP will be included in the annual report. If significant activity was not conducted in a given year, Douglas will prepare a memorandum providing an explanation of the circumstances in lieu of the annual report.

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ATTACHMENT F: AQUATIC NUISANCE SPECIES MANAGEMENT PLAN

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AQUATIC NUISANCE SPECIES MANAGEMENT PLAN

WELLS HYDROELECTRIC PROJECT

FERC PROJECT NO. 2149

August 2008

Prepared by:
Public Utility District No. 1 of Douglas County
East Wenatchee, Washington

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EXECUTIVE SUMMARY

The Aquatic Nuisance Species Management Plan (ANSMP) is one of six Aquatic Resource Management Plans contained within the Aquatic Settlement Agreement (Agreement). Collectively, these six Aquatic Resource Management Plans are critical to direct implementation of Protection, Mitigation, and Enhancement measures (PMEs) during the term of the new license and, together with the Wells Anadromous Fish Agreement and Habitat Conservation Plan (HCP) will function as the Water Quality Attainment Plan (WQAP) in support of the Clean Water Act Section 401 Water Quality Certification for the Wells Hydroelectric Project (Project).

To ensure active stakeholder participation and support, the Public Utility District No. 1 of Douglas County (Douglas) developed all of the resource management plans in close coordination with agency and tribal natural resource managers (Aquatic Settlement Work Group or Aquatic SWG). During the development of this plan, the Aquatic SWG focused on developing management priorities for resources potentially impacted by Project operations. Members of the Aquatic SWG include the U.S. Fish and Wildlife Service (USFWS), Washington Department of Ecology (Ecology), Washington State Department of Fish and Wildlife (WDFW), the Confederated Tribes of the Colville Reservation (Colville), the Confederated Tribes and Bands of the Yakama Indian Nation (Yakama), and Douglas.

The National Marine Fisheries Service (NMFS) was invited to participate in the development of Aquatic Resource Management Plans, but declined because its interests are currently satisfied by the measures within the HCP.

The goal of the ANSMP is to prevent the introduction and/or spread of aquatic nuisance species in Project waters. Douglas, in collaboration with the Aquatic SWG, has agreed to implement several PMEs in support of the ANSMP. The PMEs presented within the ANSMP are designed to meet the following objectives:

Objective 1: Implement best management practices to prevent Eurasian watermilfoil (*Myriophyllum spicatum*) proliferation during in-water (i.e., construction, maintenance, and recreation improvements) improvement activities in the Project.

Objective 2: Continue participation in regional and state efforts to prevent the introduction and spread of aquatic nuisance species. Activities include continued monitoring for the presence of ANS, monitoring bycatch data collected during other aquatic management plan activities, and conducting education outreach within the Project.

Objective 3: In response to proposed changes in the Project requiring FERC approval, the Aquatic SWG will assess the potential effects, if any, with respect to the introduction or proliferation of aquatic nuisance species in the Project to inform management decisions to support success of the ANSMP and will implement reasonable and appropriate measures to address any potential effects.

This ANSMP is intended to be compatible with other aquatic nuisance species management plans in the Columbia River mainstem. Furthermore, this management plan is intended to be

supportive of the HCP, Bull Trout Management Plan, Pacific Lamprey Management Plan, Resident Fish Management Plan, White Sturgeon Management Plan, and Water Quality Management Plan by continuing to prevent the introduction and/or spread of aquatic nuisance species in Project waters. The ANSMP is intended to be not inconsistent with other management strategies of federal, state and tribal natural resource management agencies.

1.0 INTRODUCTION

The Aquatic Nuisance Species Management Plan (ANSMP) is one of six Aquatic Resource Management Plans contained within the Aquatic Settlement Agreement (Agreement). Collectively, these six Aquatic Resource Management Plans are critical to direct implementation of Protection, Mitigation, and Enhancement measures (PMEs) during the term of the new license and, together with the Wells Anadromous Fish agreement and Habitat Conservation Plan (HCP), will function as the Water Quality Attainment Plan (WQAP) in support of the Clean Water Act Section 401 Water Quality Certification for the Wells Hydroelectric Project (Project).

To ensure active stakeholder participation and support, the Public Utility District No. 1 of Douglas County (Douglas) developed all of the resource management plans in close coordination with agency and tribal natural resource managers (Aquatic Settlement Work Group or Aquatic SWG). During the development of this plan, the Aquatic SWG focused on developing management priorities for resources potentially impacted by Project operations. Entities invited to participate in the Aquatic SWG include the U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), Bureau of Land Management (BLM), Bureau of Indian Affairs (BIA), Washington Department of Ecology (Ecology), Washington State Department of Fish and Wildlife (WDFW), the Confederated Tribes of the Colville Reservation (Colville), the Confederated Tribes and Bands of the Yakama Indian Nation (Yakama), and Douglas.

The ANSMP will direct implementation of measures to prevent the introduction and/or spread of aquatic nuisance species in Project waters. To ensure active stakeholder participation and support, Douglas developed this plan, along with the other aquatic management plans, in close coordination with the members of the Aquatic SWG.

The Aquatic SWG agrees on the need to develop a plan for the long-term management and prevention of aquatic nuisance species in the Project. This management plan summarizes the relevant resource issues and background (Section 2), identifies goals and objectives of the plan (Section 3), and describes the relevant PMEs (Section 4) for aquatic nuisance species during the term of the new license.

2.0 BACKGROUND

Nonnative aquatic species may be released or “introduced” into an aquatic environment intentionally or unintentionally. Most often, such species are unable to adapt to their new environments and do not form self-sustaining populations (ANSC 2001). However, if such a species is able to adapt, become established, and thrive, it has the potential to threaten the diversity or abundance of native species and aquatic habitats and may even affect economic resources and human health. Such species are considered aquatic nuisance species or ANS (ANSC 2001).

RCW 77.60.130 defines the term aquatic nuisance species as a “nonnative aquatic plant or animal species that threatens the diversity or abundance of native species, the ecological stability of infested waters, or commercial, agricultural, or recreational activities dependent on such

waters" (RCW 2007). Since few natural controls exist in their new habitat, ANS may spread rapidly, damaging recreational opportunities, lowering property values, clogging waterways, impacting irrigation and power generation, destroying native plant and animal habitat, and sometimes destroying or endangering native species (ANSC 2001).

2.1 Aquatic Nuisance Species of Concern

2.1.1 Eurasian Watermilfoil (*Myriophyllum spicatum*)

Eurasian watermilfoil (EWM) is an aquatic plant native to Europe, Asia, northern Africa, and Greenland. It was once commonly sold as an aquarium plant (Ecology 2007). EWM may have been introduced to the North American continent at Chesapeake Bay in the 1880's, although evidence shows that the first collection was made from a pond in the District of Columbia during the fall of 1942. By 1985, EWM had been found in 33 states, the District of Columbia, and the Canadian provinces of British Columbia, Ontario, and Quebec (Ecology 2007). The first documented occurrence of EWM in the State of Washington was in 1965. The source of introduction was most likely from sources in Canada and despite an effort to stop its spread, EWM infestations in Lake Osoyoos, British Columbia spread down through the Okanogan Lakes and into the Okanogan River and the Columbia River in 1974 (Duke 2001).

EWM is extremely adaptable with the ability to thrive in a variety of environmental conditions. It grows in still to flowing waters, can tolerate salinities of up to 15 parts per thousand, grows rooted in water depths from 1 to 10 meters, and can survive under ice (Ecology 2007). Relative to other submersed plants, EWM requires high light, has a high photosynthetic rate, and can grow over a broad temperature range (Ecology 2007). EWM exhibits an annual pattern of growth. In the spring, shoots begin to grow rapidly as water temperatures approach 15 degrees centigrade. When they near the surface, shoots branch profusely, forming a dense canopy (Ecology 2007). Typically, plants flower upon reaching the surface and die back to the root crowns, which sprout again in the spring.

Although EWM can potentially spread by both sexual and vegetative means, vegetative spread is considered the major method of reproduction. During the growing season, the plant undergoes autofragmentation. The plant fragments often develop roots at the nodes before separation from the parent plants. Fragments are also produced by wind and wave action, control harvest activity and boating activities, with each plant fragment having the potential to develop into a new plant (Ecology 2007).

EWM is classified as a class B noxious weed by the Washington State Noxious Weed Control Board (WNWCB 2007). Class B noxious weeds are nonnative plants whose distribution is limited to portions of Washington State. Additionally, EWM has been identified as a nuisance species in the Washington State Aquatic Nuisance Species Management Plan (ANSC 2001). EWM can adversely impact aquatic ecosystems by forming dense canopies that often shade out native vegetation. Monospecific stands of EWM affect aquatic habitat, water quality, can impact power generation and irrigation, and interfere with recreational activities. In Washington, private and government sources spend about $1,000,000 per year on EWM control (Ecology 2007).

2.1.2 Zebra Mussel (*Dreissena polymorpha*) and Quagga Mussel (*Dreissena rostriformis bugensis*)

Zebra and quagga mussels are freshwater, bivalve mollusks that typically have a dark and white (zebra-like) pattern on their shells. They are native to Eurasia and were both introduced into the Great Lakes as a result of ballast water discharge from transoceanic ships that were carrying veligers, juveniles, or adult mussels (USGS 2007). Zebra mussels first invaded North America in the mid-1980s and quagga mussels invaded a few years later in 1989 (USFWS 2007). These two species are closely related with subtle morphological differences. More research is needed on North American quagga mussels to assess ecological differences between the two species, but the practical implications of both species are essentially identical (USFWS 2007). The North American distribution of these species has been concentrated in the Great Lakes region of the U.S. with the zebra mussel distribution also spanning farther into the southern U.S. (Figure 2.1-1). Despite recent measures to prevent their westward expansion, quagga mussels were discovered in the Lake Mead Recreation Area. Populations have subsequently been found throughout the Boulder Basin of Lake Mead (Figure 2.1-1) and in more than a dozen reservoirs serving Southern California (Pam Meacham, pers. comm.).

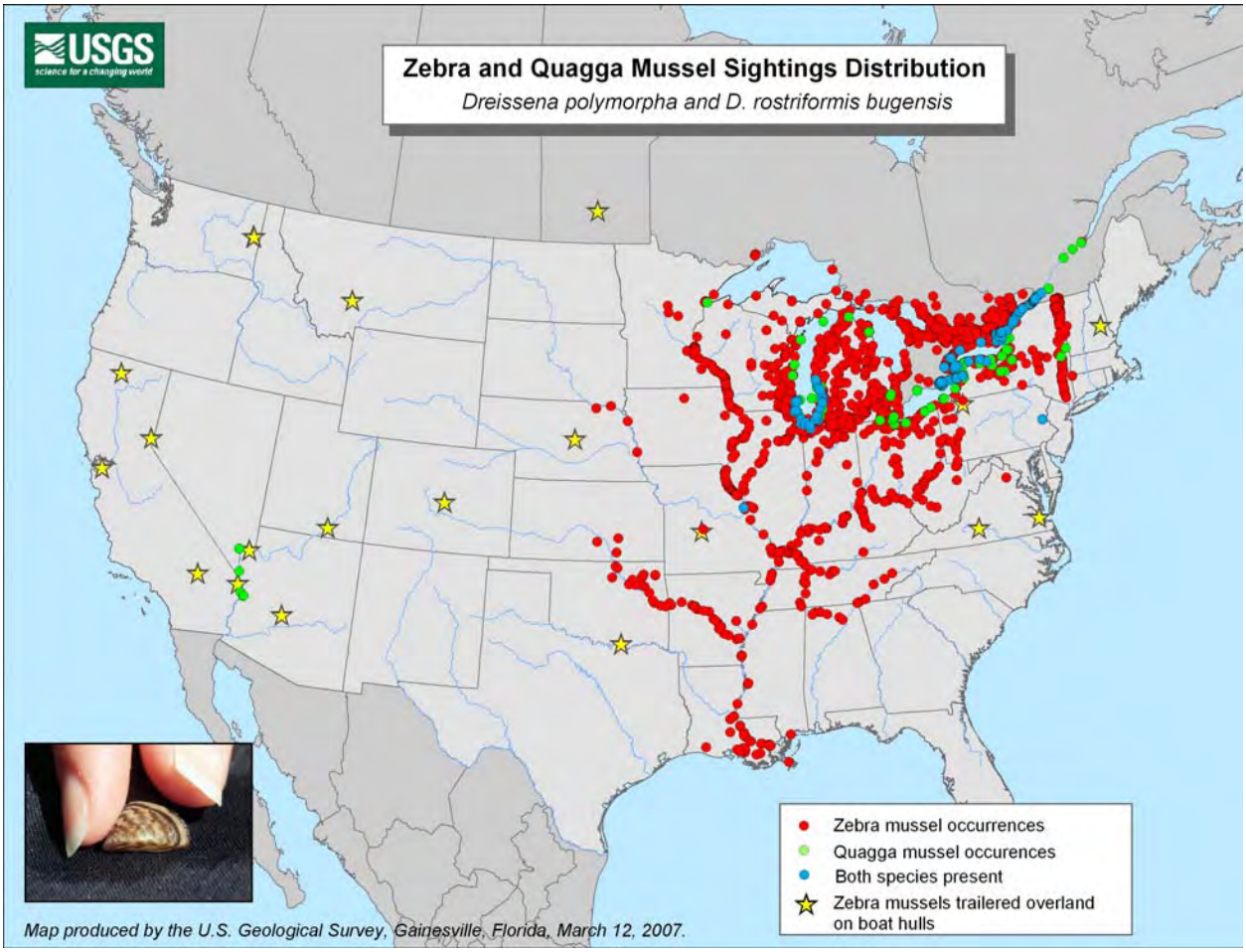

Figure 2.1-1 Zebra and Quagga Mussel Sightings Distribution Map (USGS 2007).

Zebra and quagga mussel size varies from microscopic to two inches long. Typical lifespan is up to 5 years. Both species may spawn year around if conditions are favorable. Peak spawning typically occurs in spring and fall. *Dreissena* are dioecious (either male or female) with external fertilization. Both species are prolific reproducers. Fecundity is high with a few individuals having the capability of producing millions of eggs and sperm (USFWS 2007). After fertilization, pelagic microscopic larvae, or veligers, develop within a few days and these veligers soon acquire minute bivalve shells. Free-swimming veligers drift with currents for three to four weeks until suitable substrate for settling is located. Adults attach to hard surfaces via byssal threads, but can detach and move to new habitat. Both species can tolerate a wide range of water temperatures (1-30°C), low velocities (<2 m/sec), and prefer hard surfaces for attachment although quagga mussels can live in soft sediments (USFWS 2007). Zebra mussels are typically found just below the surface to about 12 meters and quagga mussels are typically found at any depth where oxygen is available (USFWS 2007).

Zebra mussels have caused major ecological and economic problems since their arrival in North America, and quagga mussels pose many of the same threats. Both species are prolific filter feeders, removing substantial amounts of phytoplankton and suspended particulate from the water thus impacting aquatic ecosystems by potentially altering food webs (USGS 2007). *Dreissena's* ability to rapidly colonize hard surfaces causes serious economic problems. These major bio-fouling organisms can clog water intake structures such as pipes and screens, therefore reducing capabilities for power and water treatment plants. Recreation-based industries and activities have also been heavily impacted; docks, breakwalls, buoys, boats, and beaches have all been heavily colonized (USGS 2007). Zebra mussel densities have been reported to be over 700,000 individuals per square meter in some facilities in the Great Lakes area. Each year, the economic impact to the U.S. and Canada is approximately $140 million in damage and control costs (Sea Grant 2007).

2.2 Project Information

Past aquatic studies contributing information to aquatic nuisance species of concern, discussed above, consisted of an aquatic macrophyte species composition and mapping survey (Lê and Kreiter 2005) and a macroinvertebrate assessment and rare, threatened, and endangered (RTE) species survey (Bioanalysts 2006). Results of these studies and other Project aquatic studies indicate that the aquatic ecosystem within the Project is composed of a diverse community of flora and fauna consisting of varied aquatic taxa such as plankton, macroinvertebrates (insects, snails and bivalves), fish, and plants. Although nonnative species are present within Project waters, the aquatic community is characterized by a native species dominated assemblage. It is important to note the varying degree to which a nonnative species can be characterized as a "nuisance" species. The many factors that determine a nonnative species' magnitude of infestation and impact are complex and not always well understood.

2.2.1 Aquatic Macrophytes

Some information exists on aquatic macrophyte communities in the mid-Columbia River system. Vegetation mapping in and around the Rocky Reach Reservoir (River Miles (RM) 473.6 to 515.5) identified 979 acres of aquatic macrophytes (Duke 2001) out of a total surface area of 8,167 acres (Duke 2001). Nonnative EWM represented 34 percent of the biomass samples

collected from within the Rocky Reach Reservoir (Duke 2001). In the Priest Rapids and Wanapum reservoirs, the composition of EWM in the aquatic macrophyte community was higher at 42 percent of littoral plant biomass (Normandeau et al. 2000).

In August and September 2005, Douglas conducted an aquatic macrophyte study in the Wells Reservoir. Sixty-one transects totaling 369 sample points were completed during the 2005 study (Lê and Kreiter 2005). Depths of up to 30 feet were sampled and sampling points along transects were completed at intervals of 5 feet or less. A total of nine aquatic plant species were documented (Table 2.2-1). Table 2.2-1 presents the percentage of samples in which each of the identified aquatic species was categorized as the dominant species (consisting of >60 percent of the sample composition). The two most dominant species in samples collected were common waterweed (*Elodea canadensis*) and leafy pondweed (*Potamogeton foliosus*) at 24.7 percent and 16.7 percent, respectively. Both of these species are native. EWM was dominant in only 6.3 percent of samples (Table 2.2-1). Samples with no plants (absent) consisted of 41.7 percent of all samples taken. This observation supports the concept that macrophyte communities maintain a patchy distribution.

Table 2.2-1 Aquatic macrophyte species identified and the frequency at which each of the species was considered the dominant species (consisting of >60 percent of the total sample) in a given sample during the Macrophyte Identification and Distribution Study, 2005 (Lê and Kreiter 2005).

Scientific Name	Common Name	Percentage of samples in which dominant
Chara spp.	Muskgrass	.003% (1/396)
Elodea canadensis	Common waterweed	24.7% (98/396)
Myriophyllum spicatum	Eurasian watermilfoil	6.3% (25/396)
Potamogeton crispus	Curly leaf pondweed	4.3% (17/396)
Potamogeton foliosus	Leafy pondweed	16.7% (66/396)
Potamogeton nodosus	American pondweed	1.3% (5/396)
Potamogeton pectinatus	Sago pondweed	0.8% (3/396)
Potamogeton zosteriformis	Flat-stemmed or eelgrass pondweed	2.3% (9/396)
Absent		41.7% (165/396)

Although EWM is present in the Project, the 2005 study indicated that it is not a dominant component of the Project aquatic plant community. During the Project study, EWM was often sub-dominant to several native species in samples collected. These contrasting observations between the Wells Reservoir and downstream reservoirs (Rocky Reach, Priest Rapids, and

Wanapum) where EWM was found to be the most abundant species are not clearly understood. One possible explanation may be that EWM, which is a species that can proliferate from plant fragments (Ecology 2001), has increased its ability to colonize due to potentially higher levels of disturbance in the downstream reservoirs as compared to the Wells Reservoir. The Rocky Reach Reservoir serves a larger population base, maintains an EWM removal program at recreational sites, and has higher levels of recreational use and development as compared to the Wells Reservoir. It is possible that these activities directly and indirectly re-mobilize EWM plant fragments and increase the potential for colonization in the Rocky Reach Reservoir as well as in downstream reservoirs (Lê and Kreiter 2005).

2.2.2 Aquatic Macroinvertebrates

In September and October 2005, Douglas conducted an aquatic invertebrate inventory and an assessment of the presence of rare, threatened, and endangered (RTE) aquatic invertebrates within the Wells Reservoir. The overall objective of the study was to document the distribution, habitat associations and qualitative abundance of the current aquatic invertebrate (e.g., clams, snails and insects) assemblage in the Wells Reservoir.

Samples were collected within representative habitats throughout the Wells Reservoir using an air lift suction device, Ponar grabs and colonization baskets. A total of 17 sites were sampled. In addition to the varied aquatic insects and worms found during the survey, approximately 20 species of freshwater mollusks were identified during the inventory from dredge samples (Table 2.3-1). Within the Methow, Okanogan and Columbia portions of the Wells Reservoir, 13, 11, and nine species of mollusks were present, respectively. Of the 20 species, 10 gastropods (snails) and 10 bivalves (clams, mussels) were identified. The gastropods included nine native species and one nonnative species (Big-ear radix, *Radix auricularia*). Similarly, the bivalves also included nine native species and one nonnative species (Asian clam, *Corbicula fluminea*) (BioAnalysts, Inc. 2006). The 2005 macroinvertebrate assessment did not discover the presence of any zebra mussels or quagga mussels within the Project.

2.2.3 Project Aquatic Nuisance Species Monitoring

In 2006, Douglas, in coordination with the Aquatic Nuisance Species Division of WDFW, began monitoring for zebra mussels and quagga mussels in Project waters. Activities consisted of monthly plankton tows to target mussel veligers at sites downstream of boat launches within the Wells Reservoir. Sampling activities were conducted during the summer and early fall when recreational boating activity is at a peak. Sampling protocols were provided by WDFW. All samples were sent back to WDFW for analysis. To date, none of the samples collected within the Project have contained any signs of zebra or quagga mussel presence.

In 2007, Douglas, in coordination with the Center for Lakes and Reservoirs at Portland State University, installed a permanent substrate sampler in the Wells Dam forebay to monitor for zebra and quagga mussel colonization within the Project. Douglas staff checks the substrate sampler monthly throughout the year as specified by the monitoring protocol. To date, no signs of zebra or quagga mussel presence have been detected. Both of these monitoring activities are ongoing.

Table 2.3-1 Mollusks collected from sampling stations on the Methow, Okanogan, and Columbia rivers during the 2005 Project Aquatic Macroinvertebrate Inventory.

Location	Common Name	Taxon
Methow River	Western pearlshell	*Margaritinopsis falcata*
	Striate fingernail clam	*Sphaerium striatinum*
	Ridgebeak peaclam	*Pisidium compressum*
	Western lake fingernail clam	*Musculium raymondi*
	Shortface lanx	*Fisherola nuttalli*
	Ashy pebblesnail	*Fluminicola fuscus*
	Western floater	*Anodonta kennerlyi*
	Ubiquitous peaclam	*Pisidium casertanum*
	Big-ear radix*	*Radix auricularia*
	Golden fossaria	*Fossaria obrussa*
	Prairie fossaria	*Fossaria (Bakerilymnaea) bulimoides*
	Ash gyro	*Gyraulus parvus*
		Corbicula sp.
Okanogan River	Western ridgemussel	*Gonidea angulata*
	Striate fingernail clam	*Sphaerium striatinum*
	Ridgebeak peaclam	*Pisidium compressum*
	Ubiquitous peaclam	*Pisidium casertanum*
	Asian clam*	*Corbicula fluminea*
	Ashy pebblesnail	*Fluminicola fuscus*
	Fragile ancylid	*Ferrissia californica*
	Ash gyro	*Gyraulus parvus*
	Western lake fingernail clam	*Musculium raymondi*
		Physella sp.
		Anodonta sp.
Columbia River	Western floater	*Anodonta kennnerlyi*
	Asian clam*	*Corbicula fluminea*
	Ridgebeak peaclam	*Pisidium compressum*
	Three ridge valvata	*Valvata tricarinata*
	Rocky Mountain physa	*Physella propinqua propinqua*
	Ash gyro	*Gyraulus parvus*
	Golden fossaria	*Fossaria (F.) obrussa*
	Prairie fossaria	*Fossaria (Bakerilymnaea) bulimoides*
	Big-ear radix*	*Radix auricularia*

*Nonnative taxon.

3.0 GOAL AND OBJECTIVES

The goal of the ANSMP is to prevent the introduction and/or spread of aquatic nuisance species in Project waters. Douglas, in collaboration with the Aquatic SWG, has agreed to implement several PMEs in support of the ANSMP. The PMEs presented within the ANSMP are designed to meet the following objectives:

Objective 1: Implement best management practices to prevent Eurasian watermilfoil proliferation during in-water (i.e., construction, maintenance and recreation improvements) improvement activities in the Project.

Objective 2: Continue participation in regional and state efforts to prevent the introduction and spread of aquatic nuisance species. Activities include continued monitoring for the presence of ANS, monitoring bycatch data collected during other aquatic management plan activities and conducting education outreach within the Project.

Objective 3: In response to proposed changes in the Project requiring FERC approval, the Aquatic SWG will assess the potential effects, if any, with respect to the introduction or proliferation of aquatic nuisance species in the Project to inform management decisions to support success of the ANSMP and will implement reasonable and appropriate measures to address any potential effects.

The ANSMP is intended to be compatible with other aquatic nuisance species management plans in the Columbia River mainstem. Furthermore, this management plan is intended to be supportive of the HCP, Bull Trout Management Plan, Pacific Lamprey Management Plan, Resident Fish Management Plan, White Sturgeon Management Plan, and Water Quality Management Plan by continuing to prevent the introduction and/or spread of aquatic nuisance species in Project waters. The ANSMP is intended to be not inconsistent with other management strategies of federal, state, and tribal natural resource management agencies.

The schedule for implementation of specific measures within the ANSMP is based on the best information available at the time the Plan was developed. As new information becomes available, implementation of each activity may be adjusted through consultation with the Aquatic SWG.

4.0 PROTECTION, MITIGATION AND ENHANCEMENT MEASURES

In order to fulfill the goals and objectives described in Section 3.0, Douglas, in consultation with the Aquatic SWG, has agreed to implement the following PMEs.

4.1 Implement Best Management Practices During Recreational Improvement Activities (Objective 1)

If at any time during the new license term, Douglas is required to construct, improve or maintain recreation access at boat launches and swim areas and the removal or disturbance of aquatic macrophtye beds that contain Eurasian watermilfoil may potentially occur, Douglas will implement containment efforts utilizing best management practices agreed to by the Aquatic SWG during such activities.

4.2 Participation in Regional and State ANS Efforts (Objective 2)

4.2.1 Coordination with Regional and State Entities

Douglas shall continue to coordinate with regional and state entities to implement activities in Project waters to monitor for the presence of ANS, specifically zebra and quagga mussels. Activities covered by this objective will consist of monitoring for the presence of zebra and quagga mussels as is identified in Section 2.2.3. If ANS are detected during monitoring activities, Douglas will immediately notify the appropriate regional and state agencies and assist in the implementation of reasonable and appropriate measures to address the ANS presence as is consistent with ANS Management protocols.

Douglas shall participate in information exchanges and regional efforts to coordinate monitoring activities.

4.2.2 Monitor Bycatch from other Project Aquatic Resource Management Activities

Douglas shall monitor bycatch data collected from ongoing Project aquatic resource management activities for aquatic nuisance species presence to support regional and state efforts and the ANSMP. Such ongoing activities may consist of broodstock collection activities at Wells Dam and in associated Project tributaries, the northern pikeminnow removal program, water quality monitoring and any other aquatic resource activities related to implementation of Aquatic Resource Management Plans for bull trout, Pacific lamprey, white sturgeon, and resident fish.

4.2.3 ANS Information and Education

Douglas shall make information regarding the effects of ANS introductions and the importance of prevention available to the public. Such outreach activities may consist of posting signage at Project recreation areas and boat launches.

Douglas shall also provide literature produced by appropriate state entities (Ecology and WDFW) for distribution at the visitor centers of local communities of the Project (Pateros, Brewster, Bridgeport) including Wells Dam.

4.3 Monitor and Address ANS Effects to Aquatic Communities During Changes in Project Operations (Objective 3)

If at any time during the new license term, future changes in Project operations requiring FERC approval are proposed and the Aquatic SWG concludes that such proposed operations may encourage the introduction or proliferation of aquatic nuisance species within the Project, the Aquatic SWG will assess the potential effects, if any, in order to make informed management decisions.

If the assessment identifies adverse effects to Aquatic Resources due to aquatic nuisance species attributable to changes in Project operations, Douglas shall consult with the Aquatic SWG to select and implement reasonable and appropriate PMEs to address the identified adverse effect(s).

4.4 Reporting

Douglas will provide a draft annual report to the Aquatic SWG summarizing the previous year's activities undertaken in accordance with the ANSMP. The report will document all ANS activities conducted within the Project. Furthermore, any decisions, statements of agreement, evaluations, or changes made pursuant to this ANSMP will be included in the annual report. If significant activity was not conducted in a given year, Douglas will prepare a memorandum providing an explanation of the circumstances in lieu of the annual report.

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ATTACHMENT G: WATER QUALITY MANAGEMENT PLAN

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WATER QUALITY MANAGEMENT PLAN

WELLS HYDROELECTRIC PROJECT

FERC PROJECT NO. 2149

August 2009

Prepared by:
Public Utility District No. 1 of Douglas County
East Wenatchee, Washington

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EXECUTIVE SUMMARY

The Water Quality Management Plan (WQMP) is one of six Aquatic Resource Management Plans (Plans) contained within the Aquatic Settlement Agreement (Agreement). To ensure active stakeholder participation and support, the Public Utility District No. 1 of Douglas County (Douglas) developed all of the resource management plans in close coordination with agency and tribal natural resource managers (Aquatic Settlement Work Group or Aquatic SWG). The goal of the WQMP is to protect the quality of the surface waters affected by the Wells Hydroelectric Project (Project) with regard to the numeric criteria. Studies conducted during the relicensing process have found water quality within the Wells Project to be within compliance. Douglas, in collaboration with the Aquatic SWG, has agreed to implement measures in support of the WQMP. Reasonable and feasible measures will be implemented in order to maintain compliance with the numeric criteria of the Washington State Water Quality Standards (WQS), Chapter 173-201A WAC. The measures presented within the WQMP (Section 4.0) are designed to meet the following objectives:

Objective 1: Maintain compliance with state WQS for TDG. If non-compliance is observed, the Aquatic SWG will identify reasonable and feasible measures, which will be implemented by Douglas;

Objective 2: Maintain compliance with state WQS for water temperature. If information becomes available that suggests non-compliance is occurring or likely to occur, the Aquatic SWG will identify reasonable and feasible measures, which will be implemented by Douglas;

Objective 3: Maintain compliance with state WQS for other numeric criteria. If information becomes available that suggests non-compliance is occurring or likely to occur, the Aquatic SWG will identify reasonable and feasible measures, which will be implemented by Douglas;

Objective 4: Operate the Project in a manner that will avoid, or where not feasible to avoid, minimize, spill of hazardous materials and implement effective countermeasures in the event of a hazardous materials spill; and

Objective 5: Participate in regional forums tasked with improving water quality conditions and protecting designated uses in the Columbia River basin.

The WQMP is intended to be compatible with other water quality management plans in the Columbia River mainstem, including Total Maximum Daily Loads (TMDL). Furthermore, the WQMP is intended to be supportive of the Habitat Conservation Plan (HCP), Bull Trout Management Plan, Pacific Lamprey Management Plan, Resident Fish Management Plan, White Sturgeon Management Plan, and Aquatic Nuisance Species Management Plan through the protection of designated uses (WAC 173-201A-600) in Project waters. The WQMP is intended to be not inconsistent with other management strategies of federal, state and tribal natural resource management agencies.

1.0 INTRODUCTION

The Water Quality Management Plan (WQMP) is one of six Aquatic Resource Management Plans (Plans) contained within the Aquatic Settlement Agreement (Agreement). Collectively, these six Plans are critical to direct implementation of Protection, Mitigation, and Enhancement measures (PMEs) during the term of the new license. The Plans, together with the Wells Anadromous Fish Agreement and Habitat Conservation Plan (HCP), will function as the Water Quality Attainment Plan (WQAP) for aquatic life in support of the Clean Water Act (CWA) Section 401 Water Quality Certification (401 Certification) for the Wells Hydroelectric Project (Project).

During the development of this plan, the Aquatic Settlement Work Group (Aquatic SWG) focused on management priorities for resources potentially impacted by Project operations. Entities that participated in the Aquatic SWG include the U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), Bureau of Land Management (BLM), Bureau of Indian Affairs (BIA), Washington Department of Ecology (Ecology), Washington State Department of Fish and Wildlife (WDFW), the Confederated Tribes of the Colville Reservation (Colville), the Confederated Tribes and Bands of the Yakama Nation (Yakama), and Douglas.

The Washington State Water Quality Standards (WQS) found at WAC 173-201A include designated uses (recreation, agriculture, domestic and industrial use, and habitat for aquatic life) and supporting numeric criteria. The WQMP is intended to address only the numeric criteria of the WQS. Aquatic life uses of the Project identified by the WQS shall be addressed by the five other Aquatic Resource Management Plans within the Agreement and by the measures implemented in the HCP.

This management plan summarizes the relevant resource issues and background (Section 2), identifies goals and objectives of the plan (Section 3), and describes the relevant measures (Section 4) to maintain compliance with the numeric criteria of state WQS during the term of the new license.

2.0 BACKGROUND

Section 401 of the Clean Water Act (33 USC Chapter 26 § 1341 *et seq.*) requires that applicants for a hydroelectric project license from the Federal Energy Regulatory Commission (FERC) provide FERC with a 401 Certification that provides reasonable assurance that the Project will comply with applicable WQS and any other appropriate requirements of state law. In Washington State, Ecology is responsible for issuing 401 Certifications.

2.1 Water Quality Standards

Congress passed the CWA in 1972, and designated the U.S. Environmental Protection Agency (EPA) as the administering federal agency. This federal law requires that a state's water quality standards protect the surface waters of the U.S. for beneficial or designated uses, such as recreation, agriculture, domestic and industrial use, and habitat for aquatic life. Any state WQS,

or amendments to these standards, do not become effective under the CWA until they have been approved by EPA.

Ecology is responsible for the protection and restoration of Washington State's waters. Ecology establishes WQS that set limits on pollution in lakes, rivers, and marine waters in order to protect water quality and specified designated uses of such water bodies. These standards are found in WAC 173-201A.

2.1.1 Water Quality Standards for the Project

The Project includes the mainstem Columbia River above Wells Dam, one mile of the mainstem Columbia River below Wells Dam, the Methow River (up to river mile [RM] 1.5) and the Okanogan River (up to RM 15.5).

Under the 2006 WQS, the Project includes designated uses for spawning/rearing (aquatic life), primary contact recreation, and all types of water supply and miscellaneous uses. Numeric criteria to support the protection of these designated uses consist of various physical, chemical, and biological parameters including total dissolved gas (TDG), temperature, dissolved oxygen (DO), pH, turbidity, and toxins.

Unless stated otherwise in the subsections below, WQS criteria discussed in subsections 2.1.1.1 to 2.1.1.6 apply to all waters within the Project.

2.1.1.1 Total Dissolved Gas

TDG is measured as a percent saturation. Based upon criteria developed by Ecology, TDG measurements shall not exceed 110% at any point of measurement in any state water body. The WQS state that an operator of a dam is not held to the TDG standards when the river flow exceeds the seven-day, 10-year-frequency (7Q10) flood. The 7Q10 flow is the highest value of a running seven consecutive day average using the daily average flows that may be seen in a 10-year period. The 7Q10 total river flow for the Project was computed by Ecology (Pickett et al 2004) using the hydrologic record from 1974 through 1998 and a statistical analysis to develop the number from 1930 through 1998. The U.S. Geological Survey Bulletin 17B, "Guidelines for Determining Flood Flow Frequency" was followed. The resulting 7Q10 flow at Wells Dam is 246,000 cubic feet per second (cfs).

In addition to allowances for TDG standard exceedances during natural flood flows in excess of 7Q10, the TDG criteria may be adjusted to accommodate spill to facilitate fish passage over hydroelectric dams when consistent with an Ecology-approved Gas Abatement Plan (GAP). Ecology has approved on a per application basis, an interim exemption to the TDG standard (110%) to allow spill for juvenile fish passage on the Columbia and Snake rivers (WAC 173-201A-200(1)(f)(ii)). Dams in the Columbia and Snake rivers may be granted such an exemption. The GAP must be accompanied by fisheries management, physical, and biological monitoring plans (173-201A-200(1)(f)(ii)).

Columbia and Snake River TDG Exemption

On the Columbia and Snake rivers, three conditions apply to the TDG exemption. First, in the tailrace of a dam, TDG shall not exceed 125% as measured in any one-hour period during spillage for fish passage. Second, TDG shall not exceed 120% in the tailrace of a dam, as an average of the 12 highest consecutive hourly readings in any one day (24-hour period), relative to atmospheric pressure. Third, TDG shall not exceed 115% in the forebay of the next dam downstream, also based on an average of the 12 highest consecutive hourly readings in any one day (24-hour period), relative to atmospheric pressure.

The increased levels of spill resulting in elevated TDG levels are intended to allow increased fish passage without causing more harm to fish populations than caused by turbine passage. The TDG exemption provided by Ecology is based on a risk analysis study conducted by the NMFS (NMFS 2000).

2.1.1.2 Temperature

Temperature is measured by the 7-day average of the daily maximum temperatures (7-DADMax). The 7-DADMax for any individual day is calculated by averaging that day's daily maximum temperature with the daily maximum temperatures of the three days prior and the three days after that date (WAC 173-201A-020).

Under the WQS, the 7-DADMax temperature within the Columbia, Methow, and Okanogan river portions of the Project shall not exceed 17.5°C (63.5°F) (WAC 173-201A-602 and 173-201A-200(1)(c)). Additionally, the WQS contains additional supplemental temperature requirements for the Project portion of the Methow River (see Methow River Supplemental Requirements section below). When a water body's temperature is warmer than 17.5°C (or within 0.3°C (0.54°F) of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the 7-DADMax temperature of that water body to increase more than 0.3°C (0.54°F).

When the background condition of the water is cooler than 17.5°C, the allowable rate of warming up to, but not exceeding, the numeric criteria from human actions is restricted as follows:

(A) Incremental temperature increases resulting from individual point source activities must not, at any time, exceed 28/(T+7) as measured at the edge of a mixing zone boundary (where "T" represents the background temperature as measured at a point or points unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge).

(B) Incremental temperature increases resulting from the combined effect of all non-point source activities in the water body must not, at any time, exceed 2.8°C (5.04°F).

Temperatures are not to exceed the criteria at a probability frequency of more than once every ten years on average. Temperature measurements should be taken to represent the dominant aquatic habitat of the monitoring site. This typically means samples should:

(A) Be taken from well mixed portions of rivers and streams.

(B) Not be taken from shallow stagnant backwater areas, within isolated thermal refuges, at the surface, or at the water's edge.

The following guidelines on preventing acute lethality and barriers to migration of salmonids are also used in determinations of compliance with the narrative requirements for use protection established in WAC 173-201A (e.g., WAC 173-201A-310(1), 173-201A-400(4), and 173-201A-410 (1)(c)). The following site-level considerations do not, however, override the temperature criteria established for waters in WAC 173-201A-200(1)(c) or WAC 173-201A-602:

(A) Moderately acclimated (16-20°C, or 60.8-68.0°F) adult and juvenile salmonids will generally be protected from acute lethality by discrete human actions maintaining the 7-DADMax temperature at or below 22°C (71.6°F) and the 1-day maximum (1-DMax) temperature at or below 23°C (73.4°F).

(B) Lethality to developing fish embryos can be expected to occur at a 1-DMax temperature greater than 17.5°C (63.5°F).

(C) To protect aquatic organisms, discharge plume temperatures must be maintained such that fish could not be entrained (based on plume time of travel) for more than two seconds at temperatures above 33°C (91.4°F) to avoid creating areas that will cause near instantaneous lethality.

(D) Barriers to adult salmonid migration are assumed to exist any time the 1-DMax temperature is greater than 22°C (71.6°F) and the adjacent downstream water temperatures are 3°C (5.4°F) or cooler.

Methow River Supplemental Requirements

Ecology has identified water bodies, or portions thereof, which require special protection for spawning and incubation in accordance with Ecology publication 06-10-038. This publication indicates where and when the following criteria are to be applied to protect the reproduction of native char, salmon, and trout. Water temperatures are not to exceed 13°C from October 1 to June 15 in the lower Methow River including the portion within the Project boundary (up to RM 1.5).

2.1.1.3 Dissolved Oxygen

DO criteria are measured in milligrams per liter (mg/L). Under the WQS, DO measurements shall not be under the 1-day minimum of 8.0 mg/L. 1-day minimum is defined as the lowest DO reached on any given day. When a waterbody's DO is lower than the 8.0 mg/L criteria (or within 0.2 mg/L of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the DO of that water body to decrease more than 0.2 mg/L. Concentrations of DO are not to fall below 8.0 mg/L at a probability frequency of more than once every ten years on average.

DO measurements should be taken to represent the dominant aquatic habitat of the monitoring site. This typically means samples should:

(A) Be taken from well mixed portions of rivers and streams.

(B) Not be taken from shallow stagnant backwater areas, within isolated thermal refuges, at the surface, or at the water's edge.

2.1.1.4 pH

pH is defined as the negative logarithm of the hydrogen ion concentration. Under the WQS, pH measurements shall be in the range of 6.5 to 8.5, with a human-caused variation within the above range of less than 0.5 units.

2.1.1.5 Turbidity

Turbidity is measured in nephelometric turbidity units (NTUs). Turbidity shall not exceed 5 NTU over background when the background is 50 NTU or less; or a 10% increase in turbidity when the background turbidity is more than 50 NTU.

2.1.1.6 Toxins

Toxic substances shall not be introduced above natural background levels in waters of the state which have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic toxicity to the most sensitive biota dependent upon those waters, or adversely affect public health, as determined by Ecology.

Ecology shall employ or require chemical testing, acute and chronic toxicity testing, and biological assessments, as appropriate, to evaluate compliance with WAC 173-201-240 and to ensure that aquatic communities and the existing and characteristic beneficial uses of waters are being fully protected.

Within the Project Area, specifically within the Project portion of the Okanogan River, two toxic substances are of concern: Dichloro-Diphenyl-Trichloroethane (DDT) and Polychlorinated Biphenyls (PCBs). DDT is a synthetic organochlorine insecticide that was frequently used in agriculture prior to being banned in 1972. PCBs are an organic compound that were used as coolants and insulating fluids for transformers, and capacitors. PCBs are classified as persistent organic pollutants and production was banned in the 1970s due to its high level of toxicity.

Toxic substances criteria identified in the WQS for these two substances are as follow:

(A) In freshwater, DDT (and metabolites) shall not exceed 1.1 µg/L as an instantaneous concentration at any time. Exceedance of the criteria is defined as an acute condition. DDT (and metabolites) shall not exceed 0.001 µg/L as a 24-hour average. Exceedance of the criteria is defined as a chronic condition.

(B) In freshwater, PCBs shall not exceed 2.0 μg/L as a 24-hour average. Exceedance of the criteria is defined as an acute condition. PCBs shall not exceed 0.01 μg/L as a 24-hour average. Exceedance of the criteria is defined as a chronic condition.

2.1.2 305(b) Report, 303(d) List and Total Maximum Daily Loads

Every two years, the EPA, as specified in section 305(b) of the CWA, requires Ecology to compile an assessment of the state's water bodies. Data collected from the water quality assessment are used to develop a 305(b) report. The report evaluates and assigns each water body into five categories based upon the Ecology's evaluation of the water quality parameters collected from within each water body.

Category 1 states that a water body is in compliance with the State WQS for the parameter of interest.
Category 2 states a water body of concern.
Category 3 signifies that insufficient data are available to make an assessment.
Categories 4a-4c indicates an impaired water body that does not require a Total Maximum Daily Load (TMDL) for one of three reasons:

- Category 4a indicates a water body with a finalized TMDL.
- Category 4b indicates a water body with a Pollution Control Program.
- Category 4c indicates a water body impaired by a non-pollutant (e.g., low water flow, stream channelization, and dams).

Category 5 represents all water bodies within the state that are considered impaired and require a Water Quality Implementation Plan (WQIP) (formerly TMDL). The 303(d) list consists of only water bodies with Category 5 listings.

Information presented below in subsections 2.1.2.1 to 2.1.2.6 are based upon the Draft 2008 Water Quality Assessment and candidate 303(d) list that has been finalized by Ecology and submitted to the EPA for approval.

2.1.2.1 Total Dissolved Gas

The reach of the Columbia River within the Project is on the state's 1998 303(d) list for TDG impairment (Category 5 listing). In 2004, Ecology developed a TDG TMDL (which was approved by EPA) for the mid-Columbia River and as such, this reach of the Columbia River, which includes the Project, is no longer on the 303(d) list for TDG (Category 4a).

Neither the reach of the Methow River within the Project (RM 1.5) nor the reach of the Okanogan River within the Project (RM 15.5) are listed on the 2008 303(d) list for TDG.

2.1.2.2 Temperature

The reach of the Columbia River within the Project is on the state's 2004 303(d) list for temperature impairment. The EPA has developed a draft temperature TMDL for the mainstem Columbia River, including that portion of the Columbia River contained within the Project. It is anticipated that the EPA will issue the final temperature TMDL for the Columbia River at some future date. The TMDL will address the water temperature effects of dams and other human

actions, including model analyses and load allocations for mainstem hydroelectric projects including Wells Dam.

The reach of the Methow River within the Project (RM 1.5) is not on the 2008 303(d) list for temperature.

The reach of the Okanogan River within the Project (RM 15.5) is not on the 2008 303(d) list for temperature. However, reaches of the Okanogan River upstream of the Wells Project boundary are listed on the 2008 303(d) list for temperature.

2.1.2.3 DO

No part of the Project area is on the 2008 303(d) list for DO.

2.1.2.4 pH

No part of the Project area is on the 2008 303(d) list for pH.

2.1.2.5 Turbidity

No part of the Project area is on the 2008 303(d) list for turbidity.

2.1.2.6 Toxins

Neither the reach of the Columbia River within the Project nor the reach of the Methow River within the Project (RM 1.5) is on the 2008 303(d) list for toxins.

The reach of the Okanogan River within the Project (RM 15.5) is not listed on the 2008 303(d) list for toxins. In 1998, Ecology put the portion of the Okanogan River within Project boundary on the 303(d) list for 4, 4'-DDE, 4,4'-DDD, PCB-1254, and PCB 1260 concentrations above standards in edible carp tissue (Ecology 1998). In 2004, Ecology completed the Lower Okanogan River DDT and PCB TMDL (which was approved by EPA).

2.2 Project Water Quality Monitoring Results

2.2.1 Total Dissolved Gas

TDG supersaturation is a condition that occurs in water when atmospheric gasses are forced into solution at pressures that exceed the pressure of the overlying atmosphere. Water containing more than 100% TDG is in a supersaturated condition. Water may become supersaturated through natural or dam-related processes that increase the amount of air dissolved in water. Supersaturated water in the Columbia River may result from the spilling of water at Columbia River dams. The occurrence of TDG supersaturation in the Columbia River system is well documented and has been linked to mortalities and migration delays of salmon and steelhead (Beiningen and Ebel 1970; Ebel et al. 1975).

At Wells Dam, Douglas has monitored TDG for compliance with state and federal water quality regulations since 1998 and more recently in support of its GAP and TDG exemption issued by Ecology for juvenile fish passage (Le 2008). Douglas is required to monitor TDG in the Wells Dam forebay and tailrace area (on the Columbia River, near RM 515.6). Douglas uses Rocky Reach forebay TDG data collected by Chelan County PUD for downstream forebay monitoring compliance data.

A TDG study conducted in 2006 indicated that the current location of the TDG compliance monitoring stations are appropriate in providing representative TDG production information both longitudinally and laterally downstream of Wells Dam (EES Consulting et al. 2007). Detailed information regarding the study is provided in Section 2.3.1.2.

Since 2003, Douglas has operated the Project during the juvenile fish passage season (April – August) in accordance with an Ecology-approved GAP and associated TDG exemption. TDG monitoring at Wells Dam is facilitated through the deployment of Hydrolab Minisonde probes in the center of the Wells forebay and approximately 3 miles downstream of Wells Dam. TDG data are logged every fifteen minutes, averaged (4 in an hour) and transmitted on the hour. Probes are serviced and checked monthly for accuracy and calibrated if necessary. Average, minimum, and maximum TDG measurements in the Wells Dam forebay and tailrace since monitoring began are provided in Table 2.2-1. Also included in Table 2.2-1 are Rocky Reach forebay TDG data acquired from Chelan County PUD's TDG monitoring program.

Levels of TDG at Wells Dam and the Rocky Reach Dam forebay that result in exceedances of the numeric criteria are most likely to occur during April through August as a result of high flows caused by either rapid snow melt or federal flow augmentation intended to aid downstream juvenile salmonid passage. Douglas monitors for TDG at Wells Dam between April 1 and September 15 annually to coincide with this observation (Figure 2.2.1 and 2.2.2). Chelan County PUD monitors for TDG at Rocky Reach Dam between April 1 and August 31 (Figure 2.2.3). High TDG values at both Wells Dam and Rocky Reach Dam resulting in exceedances are often associated with various factors including high spring flows, unit outages, and upstream Federal Columbia River Power System operations, including federal flow augmentation, resulting in water entering the Project with relatively high TDG levels. During these time periods, river conditions in the mid-Columbia River system are conducive to exceedances of the TDG criteria.

In past years, Wells forebay monitoring data show that on average TDG values at this location range from 107-110% with maximum values sometimes exceeding the 115% standard specified by the TDG exemption. Rocky Reach forebay monitoring data indicate that on average TDG values at this location range from 108-110% with maximum values sometimes exceeding the 115% standard. In general, Wells Dam adds relatively small amounts of TDG through the use of spill intended to aid in the passage of juvenile salmonids (0-2%). However, similar to other hydroelectric facilities on the Columbia River system, probabilities for exceedances are more likely during late spring periods of high river flow and low electrical demand. Table 2.2-1 contains historic average, minimum and maximum TDG measurements associated with the Wells Project. Note that the high TDG values recorded during 2006 were a direct result of the 2006 TDG Study that required Douglas to intentionally spill water in various spillway

configurations. This study was intended to define the gas generation dynamics of the Wells Project under various operating parameters.

Table 2.2-1 **Average, minimum, and maximum TDG measurements at Wells Dam from Hydrolab MiniSonde stations placed in the Wells Forebay, Wells Tailrace and Rocky Reach Forebay. Values are in percent dissolved gas and are 12-hour high (non-consecutive) averages.**

Location	TDG	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Wells Forebay	Avg.	108.3	110.1	108.5	107.1	110.8	108.1	108.2	107.4	109.9	108.3
	Min	104.4	104.0	101.8	100.1	102.6	101.3	102.0	110.8	102.5	100.9
	Max	113.7	113.9	113.2	111.7	118.5	114.5	113.5	100.9	116.1	113.2
Wells Tailrace	Avg.	111.1	112.4	110.1	108.1	113.9	109.8	109.6	109.1	114.0	110.9
	Min	105.5	105.6	102.2	100.4	103.9	101.9	101.6	102.8	103.2	103.5
	Max	122.4	125.7	125.4	112.0	136.9	126.0	113.7	116.8	131.3	122.0
Rocky Reach Forebay	Ave	109.4	N/A	108.5	108.5	112.9	110.1	109.1	109.6	114.4	110.4
	Min	101.8	N/A	101.9	104.7	103.9	103.8	104.7	103.3	102.7	104.5
	Max	118.7	N/A	112.6	113.0	133.8	120.8	114.3	120.4	130.0	118.0

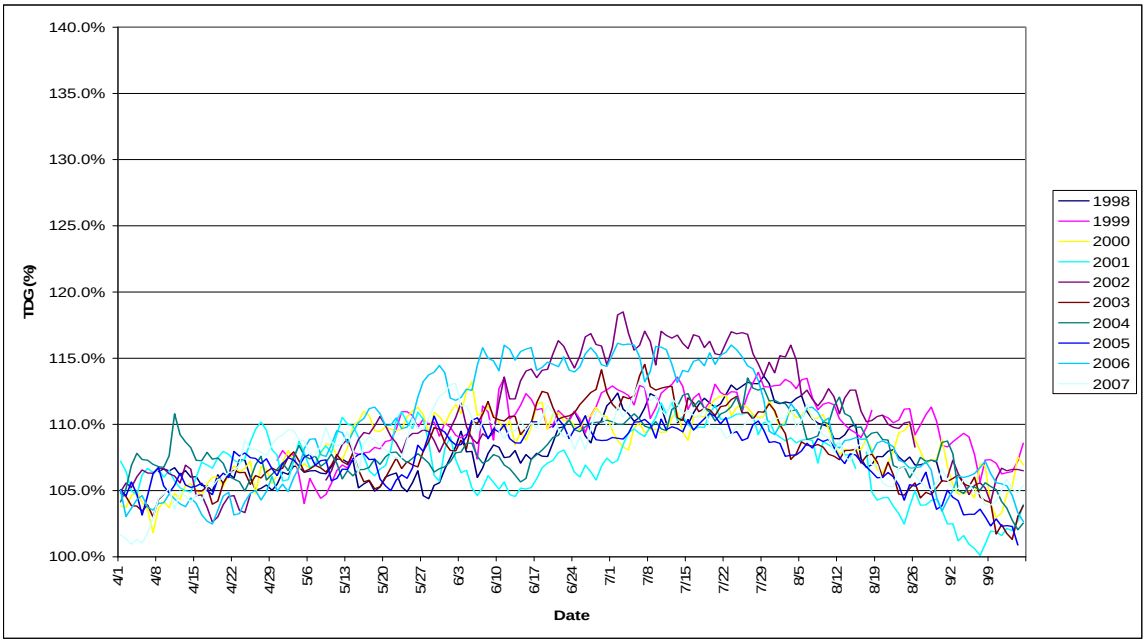

Figure 2.2-1 **Wells Dam forebay average 12-hour high TDG measurements. The average 12-hour high is defined as the average of the 12 highest hourly readings within a 24-hour period. Monitoring season is typically April 1 to September 15. Data for years 1998-2007.**

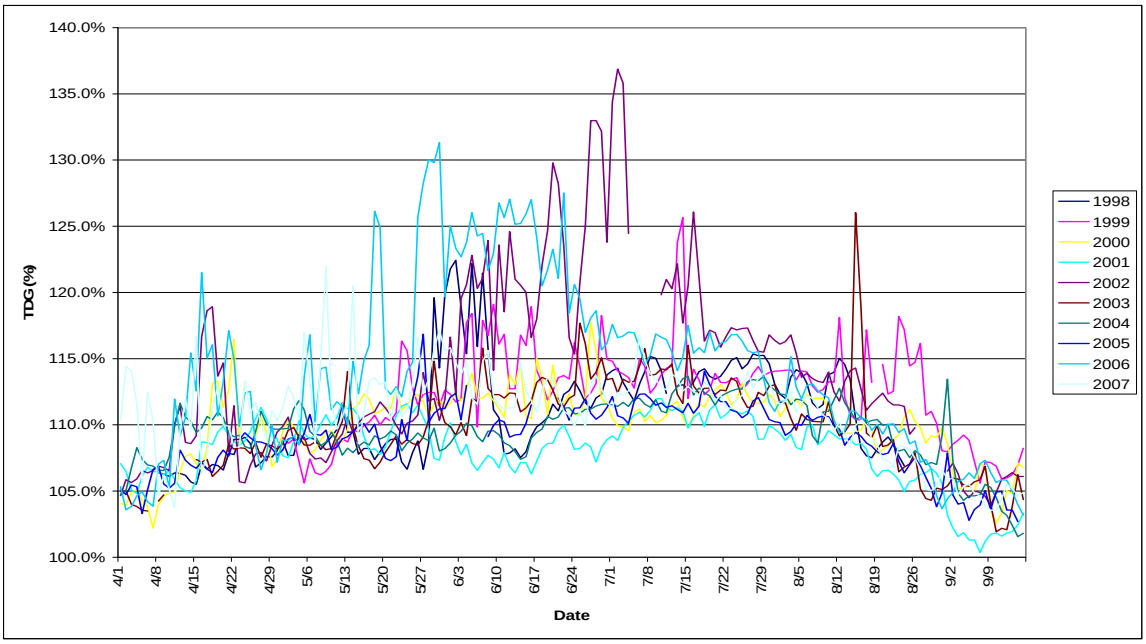

Figure 2.2-2 **Wells Dam tailrace average 12-hour high TDG measurements. The average 12-hour high is defined as the average of the 12 highest hourly readings within a 24 hour period. Monitoring season is typically April 1 to September 15. Data for years 1998-2007 (Breaks in data are the result of equipment malfunction).**

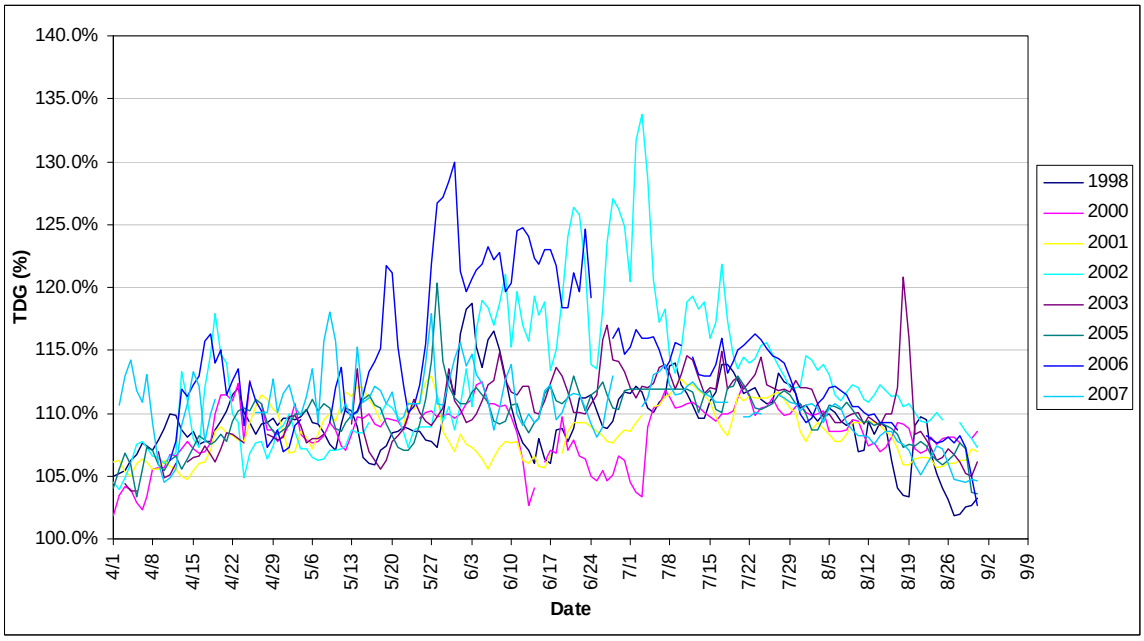

Figure 2.2-3 **Rocky Reach forebay average 12-hour high TDG measurements. The average 12-hour high is defined as the average of the 12 highest hourly readings within a 24 hour period. Monitoring season is typically April 1 to August 31. Data for years 1998-2007 (Breaks in data are the result of equipment malfunction).**

2.2.2 Temperature

Beginning in 2001, an extensive water temperature monitoring effort was initiated by Douglas in order to better understand the temperature dynamics throughout the Wells Reservoir. Temperature data was collected by Douglas at four locations in the Columbia River (RM 544.5, RM 535.3, RM 530.0, and RM 515.6) and at one site each on the Okanogan (RM 10.5) and Methow (RM 1.4) rivers. Data collected by Douglas were collected hourly using Onset tidbit temperature loggers. Monitoring start and end dates varied from year to year but generally began in the early spring and ended in late fall. Quality assurance and control measures were implemented prior to deploying and upon retrieving temperature loggers to ensure that data collected were accurate. Due to sensor loss or sensor malfunction in some years, the availability of data at some of these monitoring locations is sporadic.

In general, 7-DAD Max temperature data indicate that the portion of the Columbia River upstream of and within the Project generally warms to above 17.5°C (WQS numeric criteria) in mid-July and drops below the numeric criteria by early October (Figure 2.2-4). Water temperatures in the Methow River upstream of the Project warm to above 17.5°C in mid-July and drop below the numeric criteria by September (Figure 2.2-5), while trends in the Okanogan River (upstream of the Project) indicate warming above 17.5°C from early June with cooling by late September (Figure 2.2-6). Maximum water temperatures typically occur in late summer (August) with temperatures below Chief Joseph Dam, the Methow River (RM 1.4), and the Okanogan River (RM 10.5) reaching 20.0°C, 22.5°C, and 27.0°C, respectively. It is important to note that these data are representative of water temperatures as they flow into the Project. In 2006, Douglas expanded the Project temperature monitoring season to cover the entire year and implemented a more frequent downloading schedule. Douglas also added additional monitoring stations at the mouths of the Okanogan (RM 0.5) and Methow (RM 0.1) rivers. These have been used to model temperature and allocate the effects of Project operations on water temperatures at Wells Dam and within the Wells Reservoir as they relate to compliance with the WQS numeric criteria for temperature.

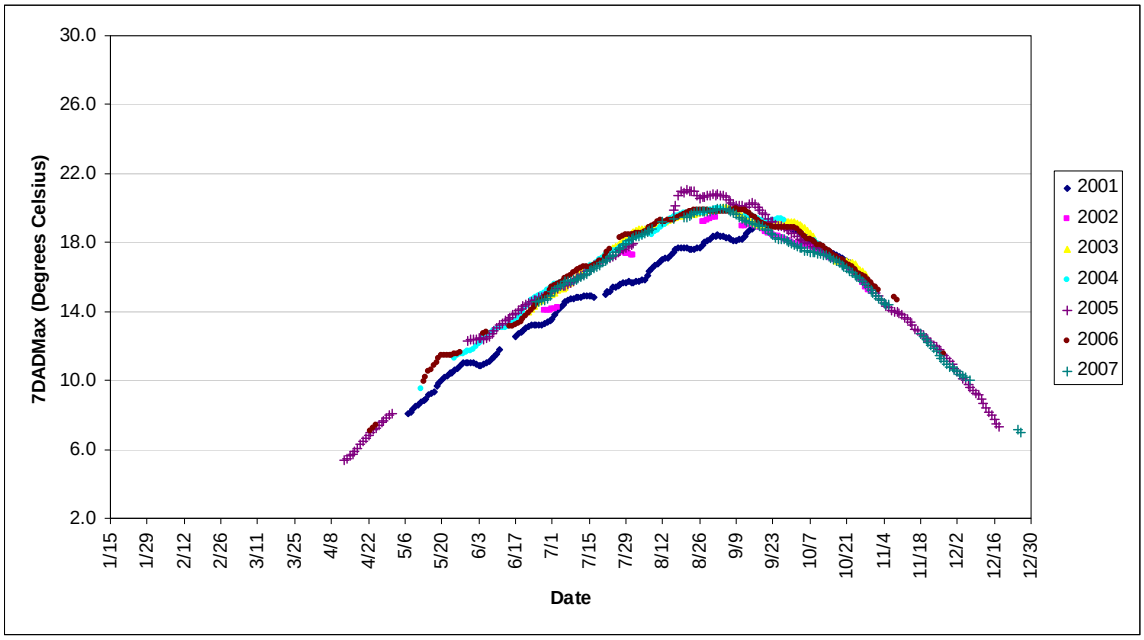

Figure 2.2-4 **7-DAD Max water temperature collected in the tailrace of Chief Joseph Dam (RM 544) using Onset temperature loggers for years 2001-2007.**

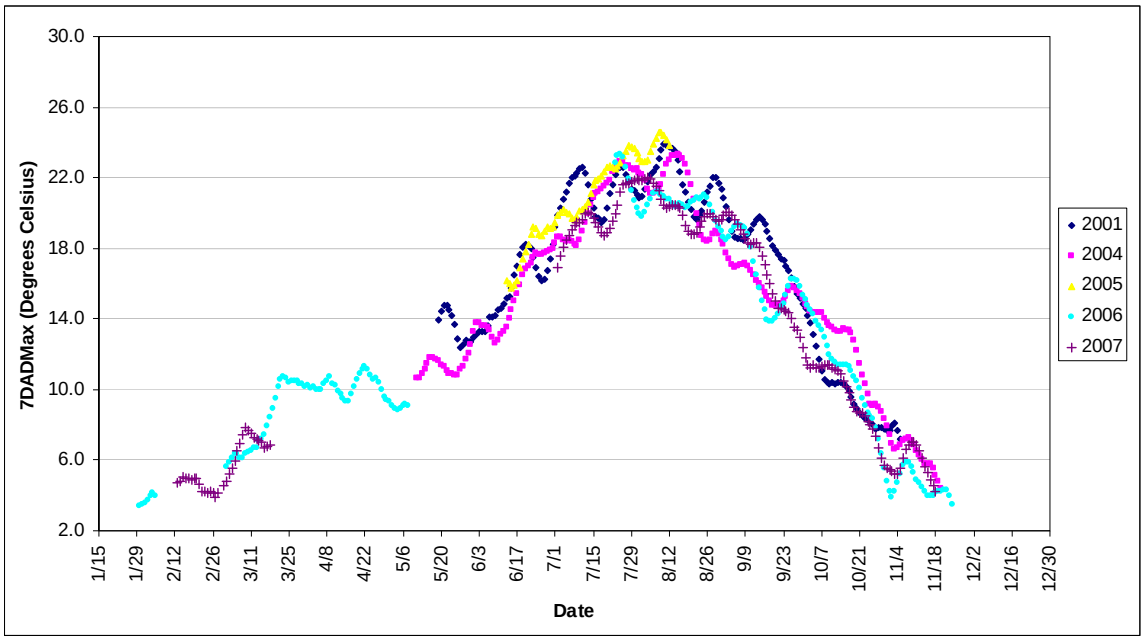

Figure 2.2-5 **7-DADMax water temperature collected in the Methow River upstream from the influence of Wells Dam (RM 1.4) using Onset temperature loggers for years 2001-2007. Data were unavailable in 2002 and 2003.**

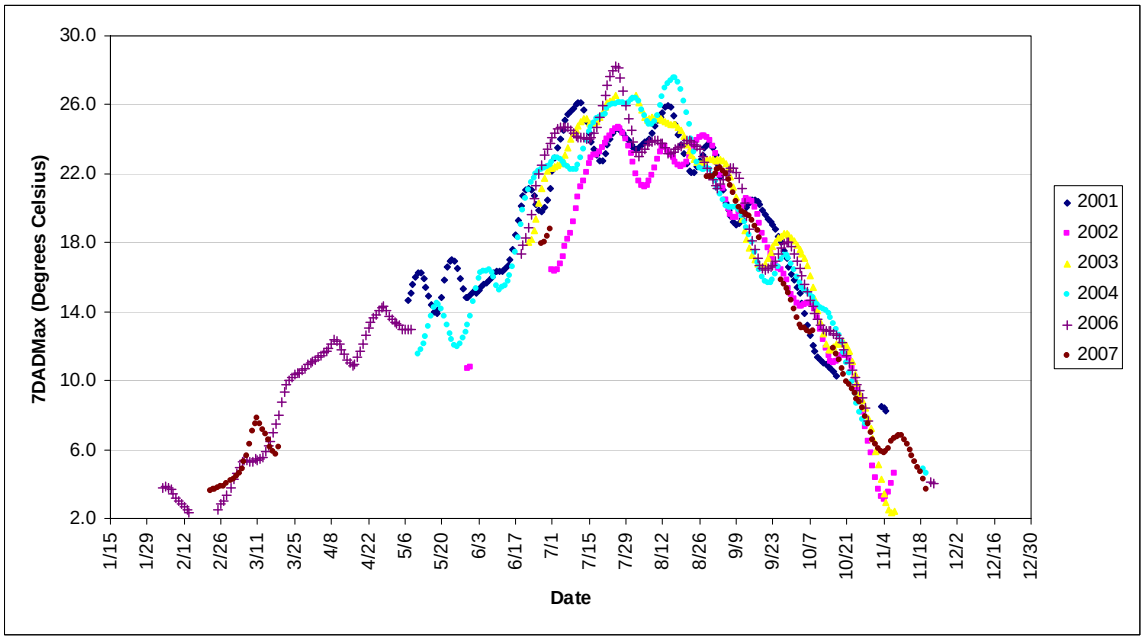

Figure 2.2-6 **7-DADMax water temperature collected in the Okanogan River (RM 10.5) using Onset temperature loggers for years 2001-2007.**

2.2.2.1 Wells Dam Fish Ladder Temperature Monitoring

Wells Dam has two fish ladders, one at each end of the dam. The two fish ladders are conventional staircase type fish ladders with 73 pools. The water source for the upper pools is the Wells Dam forebay. The flow through the upper 17 pools varies from 44 cfs at full reservoir to approximately 31 cfs at maximum reservoir drawdown. The lower 56 pools discharge a constant 48 cfs of water. To maintain the flow at 48 cfs in the lower ladder pools, supplementary water (auxiliary water supply) is introduced into Pool No. 56 through a pipeline from the reservoir. Pools are numbered in order from the bottom (near the collection gallery and entrance) to the top (exit to the Wells Dam forebay). The ladders are enclosed.

According to the HCP Biological Opinion (BO) issued by NMFS, all entities that use the fish trapping facilities at Wells Dam are required to discontinue trapping operations when fish ladder water temperatures exceed 68.0º F (20.6°C). In 2001 and 2003, Douglas added supplemental temperature recording equipment at Pool 39 near the broodstock collection facilities in the east fishway at Wells Dam to ensure compliance with requirements in the NMFS BO. In 2001, hourly data indicated that water temperatures at this location in the east fish ladder did not exceed 68.0ºF (20.6°C) at any time during the monitoring period (Figure 2.2-7), which ran from late July to early December. In 2003, data were recorded every two hours and exceedances of greater than 68.0ºF (20.6°C) were observed on three hourly occasions (Figure 2.2-8).

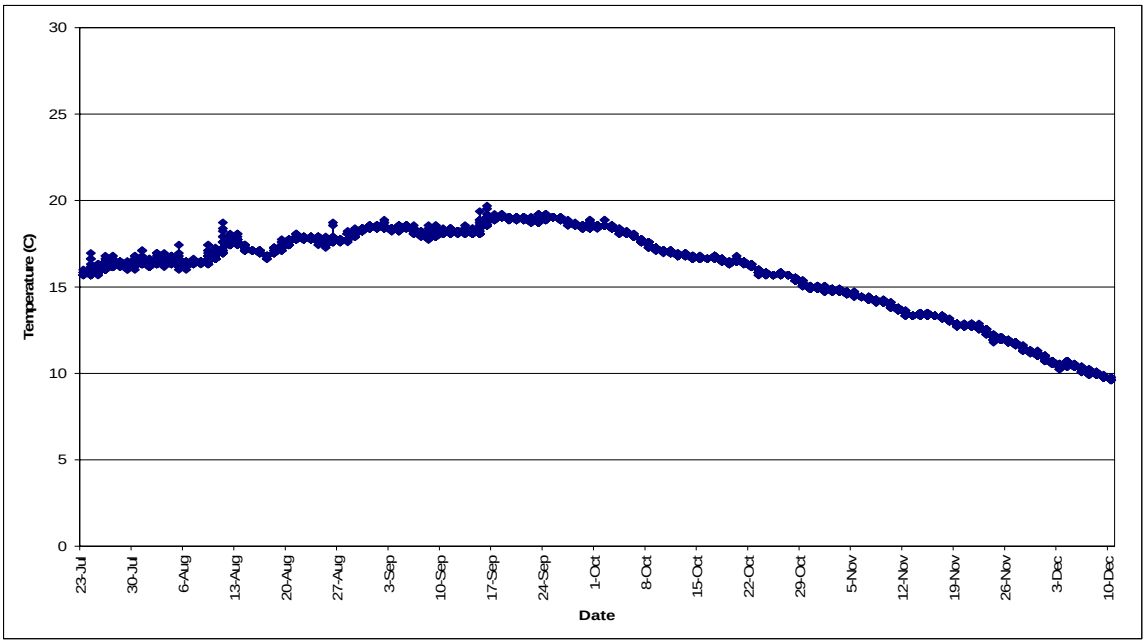

Figure 2.2-7 Hourly water temperatures collected at the Wells Dam east fish ladder trap during 2001.

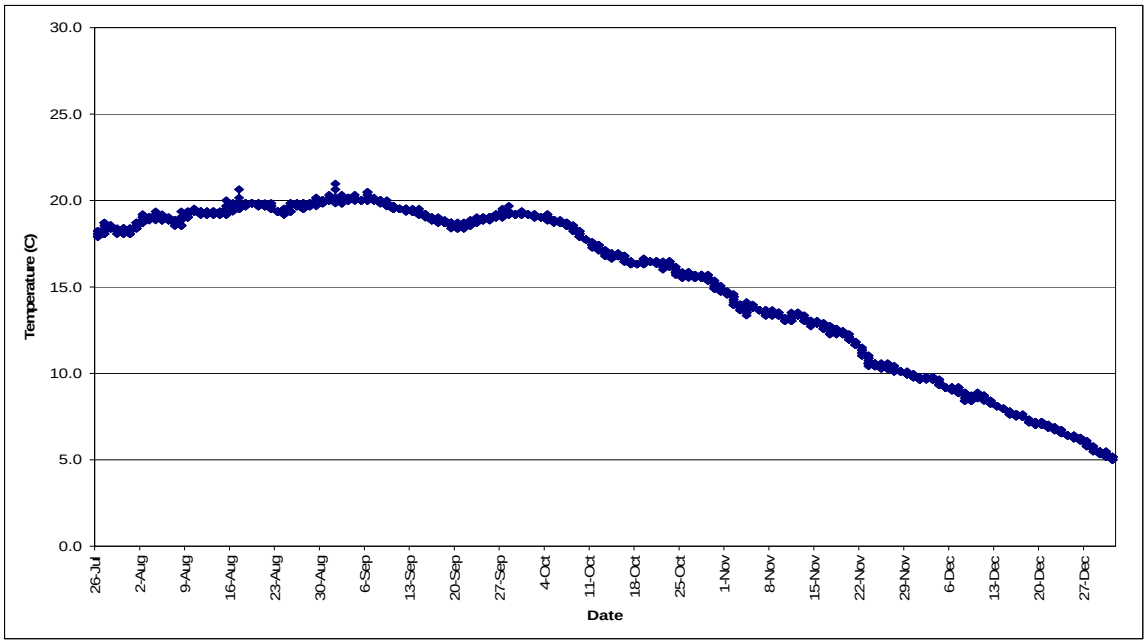

Figure 2.2-8 Water temperatures collected every two hours at the Wells Dam east fish ladder trap during 2003.

2.2.3 DO, pH, and Turbidity

2.2.3.1 DO and pH

In 2005, Douglas added sensors to its existing forebay TDG monitoring equipment (Hydrolab Minisonde) in order to collect preliminary information on pH and DO within the Project to monitor these parameters during the late summer when probabilities of exceedance are highest. In 2006, Douglas expanded the monitoring period to include the entire late summer period. In 2007, Douglas further expanded the monitoring period to begin in July and end in early December (Figure 2.2-9 and 2.2-10). The monitoring data indicate that values for these parameters are generally in compliance with the WQS numeric criteria at this site. pH values are consistently within the range of 6.5 to 8.5 as specified by the numeric criteria. During August and September periods of this study, there were periodic excursions of DO below the numeric criteria of 8.0 mg/L. Probable causes are likely due to the physiological processes of aquatic plants; however, these exceedances do not appear to be the dominant trend.

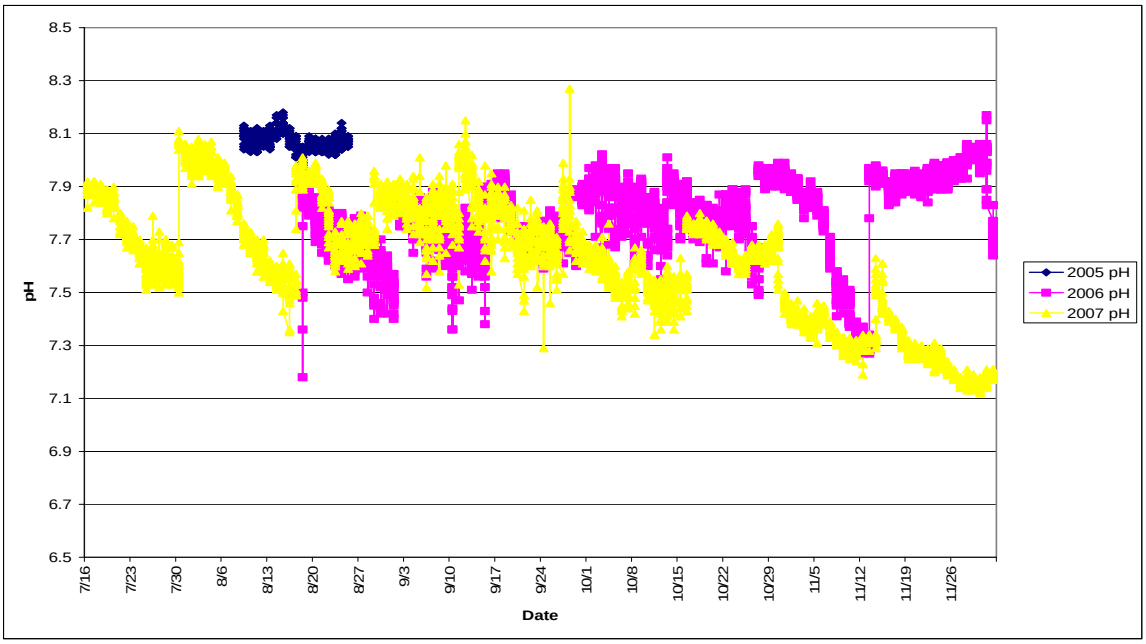

Figure 2.2-9 pH measurements collected at the Wells Forebay TDG monitoring station (Hydrolab MiniSonde), 2005-2007.

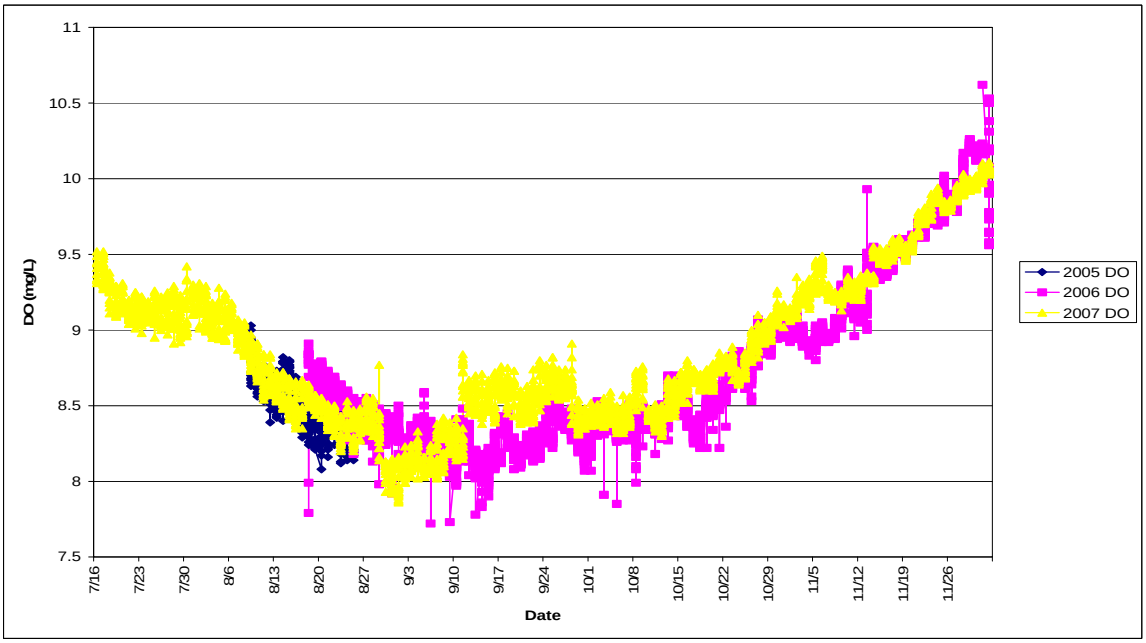

Figure 2.2-10 DO measurements collected at the Wells Forebay TDG monitoring station (Hydrolab MiniSonde), 2005-2007.

2.2.3.2 Turbidity

At Wells Dam, Secchi disk readings are taken daily during the adult fish passage assessment period of May 1 to November 15 to examine turbidity. A standard Secchi disk is lowered into the forebay on the west side of Wells Dam near the exit to the west fishway. Measurements are recorded in meters of visibility and records have been made since the early 1970s; however, continuous, reliable information adhering to a standard protocol has been collected since 1998. General trends of Secchi disk data suggest relatively lower periods of visibility (0.6 meters to 1.2 meters) during the spring and early summer. These relatively low periods of visibility are highly correlated with high flows during the spring runoff period. As the high flow period subsides, Secchi disk values increase to between 3.4 and 4.6 meters for the remainder of the monitoring period. In 2008, Douglas installed a fixed turbidity sensor near the east fishway exit in the Wells forebay and collected turbidity data in the Wells Dam forebay.

2.3 Project Water Quality Studies

2.3.1 Total Dissolved Gas

Each year from 2003-2008, Douglas implemented spill testing activities to examine the relationship between water spilled over the dam and the production of TDG. These results were subsequently used by IIHR-Hydroscience and Engineering of University of Iowa to develop and calibrate an unsteady state three-dimensional (3D), two-phase flow computational fluid dynamics (CFD) tool to predict the hydrodynamics of gas saturation and TDG distribution within the Wells tailrace. These tools were then used to reliably predict TDG production at Wells Dam and establish how preferred operating conditions and spillway configurations can be used as methods to manage TDG within WQS numeric criteria (Politano et al. 2009b).

2.3.1.1 Project TDG Assessments 2003-2005

In 2003 and 2004, Douglas hired Columbia Basin Environmental (CBE) to determine the effectiveness of the tailwater sensor relative to the tailwater cross section profile for TDG and better define the relationship between spillway releases and TDG production (CBE 2003, 2004). CBE deployed TDG sensors along two transects. Based on the results of these studies, the tailwater station provided an accurate record of daily average TDG values in the Wells Dam tailrace. The studies also showed that at times, gas levels from some turbine flows were being affected by spill.

In spring 2005, Douglas contracted with CBE to implement a TDG study at Wells Dam designed to measure TDG pressures resulting from various spill patterns at the dam (CBE 2006). An array of water quality data loggers was installed in the Wells Dam tailwater for a period of two weeks between May 23, 2005 and June 6, 2005. The Wells Dam powerhouse and spillway were operated through a predetermined range of operational scenarios that varied both total flow and shape of the spillway discharge. A total of eight configurations were tested including flat spill patterns (near equal distribution of spill across the entire spillway), crowned spill patterns (spill is concentrated towards the center of the spillway) and spill over loaded and unloaded units (Table 2.3-1).

Table 2.3-1 Test matrix for 2005 Wells Dam TDG Production Dynamics Study.

Test	Description
1A	Spill over load, east spill/east generation
1B	Spill over unloaded units, east spill/west generation
1C	Spill over unloaded units, west spill/east generation
1D	Spill over load, west spill/west generation
2A	Crowned spill, modest flow
2B	Dentated spill, modest flow
2C	Crowned spill, high flow
2D	Flat spill, high flow

Results from the study indicated that spill from the west side of the spillway resulted in consistently higher TDG saturations than similar spill from the east side. All Dentated spill patterns and flat spill patterns at high river flow yielded higher TDG saturations than crowned spill for similar total discharges. The results of this study also indicated that TDG levels of powerhouse flows may have been influenced by spill.

2.3.1.2 EES Consulting 2006 Project TDG Production Dynamics Study

In 2006, Douglas continued TDG assessments at the Project by examining the best spillway configurations and project operations to minimize the production of TDG. Douglas hired a team of hydraulic and TDG experts from the Pacific Northwest to help design a monitoring program for a study that would examine various operational scenarios and their respective TDG production dynamics.

Thirteen sensors were placed along three transects at 1,000, 2,500, and 15,000 feet below Wells Dam. There were also three sensors placed across the forebay, one being the fixed monitoring station midway across the face of the dam and two more a distance of 300 feet from the dam. The sensors were programmed to collect data in 15-minute intervals for both TDG and water temperature. Each test required the operations of the dam to maintain static flows through the powerhouse and spillway for at least a three-hour period. While there were 30 scheduled spill events, there were an additional 50 events where the power house and spillway conditions were held constant for a minimum three-hour period. These “incidental” events provided an opportunity to collect additional TDG data on a variety of Project operations that met study criteria and are included in the results of the 2006 TDG Abatement Study. Spill amounts ranged from 5.2 to 52% of project flow; the volume of spill ranged from 2.2 to 124.7 kcfs and the total discharge ranged from16.4 to 254.0 kcfs. There were six tests that were done at flows that exceeded the Wells Dam 7Q10 flows of 246 kcfs.

Results of the study indicated that two operational scenarios, spread spill and concentrated spill, produced the lowest levels of TDG. The EES Consulting team recommended continued testing of operational measures to ameliorate TDG production at Wells Dam (EES Consulting et al. 2007). The 2006 study confirmed that the current locations of the forebay and tailwater TDG compliance monitoring station are appropriate in providing representative TDG production information both longitudinally and laterally downstream of Wells Dam.

2.3.1.3 IIHR-Hydroscience and Engineering TDG Modeling

A study was initiated with the University of Iowa IIHR-Hydroscience and Engineering in 2007 to develop a numerical model capable of predicting the hydrodynamics and TDG concentrations in the tailrace of the Wells Project. The purpose of the model was to assist in the understanding of the underlying dynamics of TDG production allowing an accurate evaluation of the effectiveness of various spill configurations and plant operations in reducing TDG at Wells Dam. The modeling efforts were divided into three phases. Phase I was a developmental stage for calibration and validation. The results from Phase I were successful and the model was proven to provide a reliable predictor of tailrace TDG and therefore a useful tool to identify Project operations that can minimize TDG concentrations downstream of Wells Dam (Politano et al. 2008). Phase II was a series of model runs using varying spill configurations based on typical 7Q10 events observed over the past decade. The final model run, referred to as Scenario-9, showed that preferred operating conditions and spillway configurations are able to reduce tailrace TDG to levels within Washington State WQS (< 120%) during a 7Q10 flow (Politano et al. 2009a).

Phase III included a final series of model runs aimed at gaining further reductions in tailrace TDG by reconfiguring the spillway operations used to achieve the tailrace standard in Phase II (Scenario-9). In addition to gaining additional reductions in TDG, IIHR-Hydroscience and Engineering ran a "Standard Compliance Comparison" scenario. The Standard Compliance Comparison scenario included a forebay TDG of 115%, along with 9 of 10 units operating at full capacity (i.e., 90% of total powerhouse capacity), to provide results comparable to downstream hydroelectric project TDG evaluations. The Phase III report also demonstrated compliance with two other requirements of the state WQS: (1) the ability to meet 115% in the forebay of Rocky Reach Dam during fish spill; and (2) the ability to maintain 110% in the tailrace during non-fish spill periods (Politano et al. 2009b).

2.3.1.4 Project TDG Playbooks

Since 2007, spill playbooks have been developed annually for operators at Wells Dam. The original spill playbook in 2007 focused on a range of operations to evaluate TDG production along with potential operational constraints. The subsequent playbooks evolved to the current 2009 format that simply focuses on strategies that have been identified to effectively manage TDG production in the tailrace of Wells Dam. The resulting spill strategies are based on three basic principles:

- Spill operations concentrated through a single spillbay (as opposed to spread through several spillbays) reduce TDG production and increase degasification at the tailwater surface.
- Discharge from spillbays (denoted S hereafter) located near the middle of the dam (e.g., S7) prevent water with high TDG from attaching to the shoreline.
- Forced spill exceeding Juvenile Bypass System (JBS) flows of 2.2 kcfs must be increased to ≥ 15 kcfs to ensure that the submerged spillway lip below the ogee is engaged. The resulting force creates flows that are surface oriented, ultimately promoting degasification at the tailwater surface.

The above principles are used as a guideline for Project operators to spill at a range of outflows to ensure the future compliance with the Washington State WQS for TDG.

2.3.2 EES Consulting 2006 Project Limnology

In 2005, Douglas implemented a study to collect baseline limnological information for waters within the Project (EES Consulting 2006). The objectives of this study were to further document existing water quality conditions within the Project and to collect information to fill water quality data gaps identified by Douglas to support the water quality certification process administered by Ecology. A total of nine sampling sites, consisting of 5 mainstem sites, 2 tributaries and 2 littoral habitats, were selected to represent the spatial variability within the Project (Table 2.3-2). The year-long study began in May 2005 and investigated various water quality parameters at each of the nine sampling sites. Sampling included physical, chemical and biological water quality characteristics. A total of 22 water quality characteristics were sampled. All procedures used for the purpose of collecting, preserving and analyzing samples followed established EPA 40 CFR 136 protocol.

Table 2.3-2 Water quality sampling sites for the 2005-2006 Project Limnological Investigation.

Site	Description
1	Downstream of Chief Joseph Dam (at Hwy 17 bridge)
2	Columbia River just downstream of the Brewster Bridge
3	Bridgeport Bar littoral site
4	Columbia River downstream of Pateros where the thalweg approaches maximum depth in the lower Wells Reservoir
5	Okanogan River upstream of confluence with Columbia River
6	Methow River upstream of confluence with Columbia River
7	Lower Wells Reservoir/Starr Boat Launch littoral site
8	Wells Forebay
9	Wells Tailrace

Results from the limnological investigation showed that the Project is characterized by low to moderately low levels for nutrients, slightly basic pH (range 7.5–8.5), well-oxygenated water and low turbidity with moderately low algae growth. Average Secchi depth for the Wells Reservoir varied minimally during May through August with only a slight increase as the season progressed (study average per site range 4.1 meters to 4.5 meters). Secchi depth (transparency) increased to a seasonal peak in September of 6.25 meters before slightly decreasing in October to a mean depth of 5.3 meters. Transparency increased downstream at the Brewster Bridge and Wells Forebay relative to the head of the reservoir at the Chief Joseph Dam tailrace for all months.

Turbidity in the Columbia River showed little seasonal variation with an annual average of 0.98 NTU and a variation of 0.38 NTU in September, 2005 (Wells Forebay site) to 3.81 NTU in February, 2006 (Brewster Bridge site). Longitudinal variation in turbidity was also minimal; sampling did not occur within the mixing zone plume of the Okanogan River. Turbidity in the Okanogan River was consistently higher than the Columbia River. Turbidity in the Methow

River was higher than in the Columbia River in May (due to sediment load) and in August due to phytoplankton growth. The only turbidity reading over 5.0 NTU was in the Methow River during May where turbidity was 5.6 NTU.

Under the EES Consulting limnology study, water temperature in the Wells Reservoir is primarily governed by the temperature of inflowing water at Chief Joseph Dam with little warming occurring as water traverses the Wells Reservoir's length. Similar to the Wells hourly temperature monitoring data (Section 2.2.2), results of the study indicate that the Project waters remained unstratified throughout the entire study period and was vertically homogeneous for DO. Figure 2.3-1 shows a vertical water profile of the Project. Low respiration rates at depth, a lack of vertical stratification and short water retention times resulted in homogeneous DO levels at all depths within the Project.

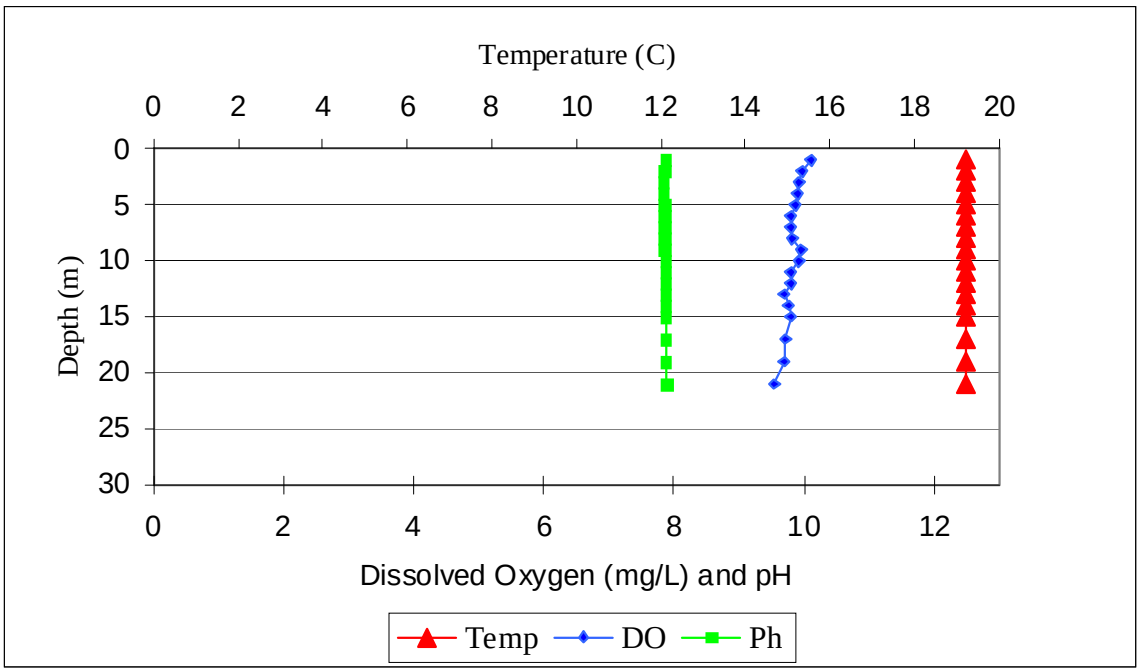

Figure 2.3-1 Vertical water quality profile of the Project forebay from sampling date August 17, 2005.

DO levels at one meter depth increased from upriver to downriver; the average difference (May through October) was 1.07 mg/L. The difference was more pronounced during May through August. The difference in September and October was 0.3 mg/L, which is at the limit of instrument reliability. Upstream to downstream differences in surface DO were negligible for the February 2006 sampling event. Littoral DO was similar or slightly higher than pelagic DO for surface waters. DO saturation levels were equal to or greater than 100% for all sites and all depths in all months except October when DO percent saturation for surface waters ranged from 110% to 91% saturation. The lower saturation levels in October may be due to reduced primary productivity while water temperatures were still relatively warm. All DO readings were above 8.0 mg/L and in compliance with the WQS numeric criteria.

Nitrogen and phosphorus are the two primary macronutrients needed for plant growth. Silica is important for diatomaceous phytoplankton. Ammonia (Nitrogen) levels were near or below detection levels for pelagic and littoral Columbia River Project waters as well as the Okanogan River for May through August and in February. Ammonia levels were only slightly higher in September and October. Ammonia peaked in the Methow River in August. Nitrates/Nitrites (Nitrogen) for Columbia River Project waters were higher in May before leveling off during the summer and fall. Nitrates/Nitrites were significantly higher at all sites for the February sample than any other month. Nitrates within littoral waters were lower than pelagic waters except in February when levels were similar. Nitrates/Nitrites in both the Okanogan and Methow rivers showed an increasing trend during the growing season. Total nitrogen levels for Columbia River pelagic and littoral waters were similar and relatively constant with the exception of significantly higher levels at most sites during February.

Orthophosphorus peaked for all stations in July. Orthophosphorus levels for pelagic and littoral waters were similar in all months except July when littoral orthophosphorus concentrations were significantly higher than observed for pelagic areas. Orthophosphorus levels in the Methow and Okanogan rivers were higher than in the Columbia River. Orthophosphorus was partially depleted in the Okanogan River but not in the Methow River at the time of the August sampling. Total phosphorus was slightly higher in littoral waters than in pelagic areas. Wave disturbance to bottom sediments may be a factor for this difference. Total phosphorus levels in pelagic surface waters ranged from below detection limits to 30.8 ug/L. Total phosphorus was higher for the Okanogan River than elsewhere, which is likely due to the higher sediment load. Total phosphorus for all stations peaked in July before gradually declining throughout the rest of the growing season.

The range in Nitrogen to Phosphorus (N:P) ratios for the Project waters was 2.5 to 30.8. The average Total Nitrogen to Total Phosphorus (TN:TP) ratio in the Project waters was 13.7 for the photic zone and averaged 14.8 for samples from all depths. These values are within the suggested literature ranges for phosphorus limitation. The N:P ratios peaked in July with pelagic and littoral waters showing similar trends. A decreasing N:P ratio through the major part of the algae growing season is typical of moderate to low nutrient waters as algae assimilate available nutrients. The N:P ratios were higher in the tributary rivers relative to the Columbia River. The N:P ratios are an indicator but not an absolute confirmation of factors limiting productivity.

Moderate to low chlorophyll *a* concentrations (range 0.5 *u*g/L to 5.8 *u*g/L) occurred throughout the sample period with peaks in July and October for the Project waters. Concentrations were lowest in August and also had the least variability among sites for the August sampling event. Pelagic and littoral waters were similar for chlorophyll *a* concentrations in most months except October when littoral waters reported twice as high *c*hlorophyll *a* levels.

Phytoplankton were dominated by diatoms for all months at all sites sampled with Chryptophyta (small unicellular flagellates) being second dominant based on biovolume. Diatoms and Chryptophyta are both considered a good food source for the rest of the aquatic food web. Diatoms comprised 75% to 84% of the total phytoplankton biomass for the Project sites. Chlorophytes (green algae) were sub-dominant in the tailrace but only a minor component elsewhere. Total phytoplankton biomass was relatively low for all Project sample sites; total

biomass was generally less than 200,000 um^3/ml. Biomass peaked in July and August for pelagic areas of the Project waters and minor peaks occurred in October for littoral sites. The timing of peaks varied among all stations. Cyanophyta (blue-green algae) were only recorded in the Project sites for the July sample at Brewster Bridge where they comprised 16% of the total biomass; however, the biomass of Cyanophytes were comprised of relatively few but very large multicellular units. Cyanophytes also were recorded in the Wells Tailrace (4.7% biomass) in July. Diatoms dominated phytoplankton in the Methow River where peak biomass occurred in August (1,455,158 um^3/ml). This peak is much higher than biomass observed anywhere else in the Project. Biomass levels in the Okanogan River were only slightly higher than in the Columbia River for most months with minor peaks occurring in May and October. Cyanophytes were a small proportion of the August biomass sample for the Okanogan River.

Diatoms also dominated periphyton. Seasonal lows occurred in July for all sites except Bridgeport shallows where the trend was decreasing periphyton biovolume as the season progressed.

Zooplankton density for pelagic waters was greatest in July (6,080/m^3) and lowest (1,289/m^3) in August. Copepods dominated the zooplankton population. Zooplankton densities in the tributary river mouths peaked in May. Although rotifers were present in all months, their density dropped to very low levels after May. Cladocera were the third most prevalent group with a minor peak occurring in July for this group.

Trophic Status Index (TSI) developed by Carlson (1977, 1996) and modified for nitrogen by Kratzer and Brezonik (1981) is an indication of the productivity of a lake based on Secchi depth, TP, TN and chlorophyll *a* concentrations for summer months (June through September). Project waters are classified as oligo-mesotrophic based on a mean TSI score of 36.5 with 40 to 50 being the range for mesotrophic classification (EES 2006).

2.3.3 Okanogan River Sediment Loading Analysis

In 2006, Douglas, at Ecology's request, conducted an analysis to assess sediment accumulation within the Project portion of the Okanogan River (lower 15.5 miles). The request was based upon concerns that Project operations might be contributing to the accumulation of DDT and PCB-laden sediment that could impact aquatic life designated use. Douglas contracted with Erlandsen and Associates to collect bathymetric information at nine transects (RM 0.8, 1.3, 2.7, 4.9, 8.2, 10.5, 14.4, 16.6, and 19.0) within and above the Project portion of the Okanogan River. Bathymetric data of these same nine transects were collected previously by the Bechtel Corporation in 1997. A comparison of the bathymetric data for all nine transects between 1997 and 2006 indicated that sediment is not accumulating in the Project portion of the Okanogan River. It was concluded that with regard to sediment loading, the Okanogan River is exhibiting natural riverine processes and is not affected by Project operations. Douglas presented the results of the information to Ecology and the issue has been resolved.

2.3.4 Temperature, Dissolved Oxygen, pH, and Turbidity

2.3.4.1 Water Temperature Modeling

To assess compliance with the State temperature standards, two 2D laterally-averaged temperature models (using CE-QUAL-W2) were developed that represent existing (or "with Project") conditions and "without Project" conditions of the Wells Project including the Columbia River from the Chief Joseph Dam tailrace to Wells Dam, the lowest 15.5 miles of the Okanogan River, and the lowest 1.5 miles of the Methow River. The results were processed to develop daily values of the seven-day average of the daily maximum temperatures (7-DADMax), and then compared for the two conditions (West Consultants, Inc. 2008).

The model analyses demonstrated that "with Project" temperatures in the Columbia, Okanogan and Methow rivers do not increase more than 0.3^{o}C compared to ambient ("without Project") conditions anywhere in the reservoir, and that the Project complies with state water quality standards for temperature. The analyses also show that backwater from the Wells Project can reduce the very high summer temperatures observed in the lower Okanogan and Methow rivers. The intrusion of Columbia River water into the lowest 1-2 miles of the Okanogan River and lowest 1.5 miles of the Methow River can significantly decrease the temperature of warm summer inflows from upstream, and can also moderate the cold winter temperatures by 1-3^{o}C, reducing the extent and length of freezing.

2.3.4.2 Dissolved Oxygen, pH, and Turbidity

A study to collect additional DO, pH, and turbidity data from within the Wells Project was proposed by the Aquatic Resource Workgroup in 2007. The goal of this study was to obtain required DO, pH, and turbidity information for the Wells Dam forebay and lower Okanogan River, both above and within the Wells Project boundary. The information gathered from these monitoring efforts demonstrated that the Project, as proposed to be operated under the new license, will meet the numeric criteria for WQS (Parametrix, Inc. 2009).

DO measurements demonstrated that the Okanogan River and the forebay of Wells Dam were in compliance with WQS. Project effects on DO concentrations in the Okanogan River were not evident as incoming water quality closely resembled that of the inundated portions of the Okanogan River. Changes in background minimum DO levels at Malott (above Project boundary) have a strong and significant linear relationship ($P < 0.0001$) with minimum values recorded within Project boundaries at both Monse and the Highway 97 Bridge. These results indicate that there is no statistically significant difference between minimum DO measurements collected above the Project and within the Project. DO concentrations in the forebay of Wells Dam remained well above the minimum numeric water quality criterion, excluding an instrument-related malfunction observed in early October (Parametrix, Inc. 2009).

Only on one occasion did pH within the Project exceed background measurements, but only by 0.06 units, well within the water quality allowance for human caused conditions. These results indicate that pH measurements within the Project boundary are well within the numeric criteria for WQS (Parametrix, Inc. 2009).

It is not clear what effect, if any, the Wells Project may have had on turbidity. Elevated turbidity values appeared to coincide with snowmelt and precipitation causing increased river flow. Turbidity levels in the Okanogan River above the Project (at Malott) were inconsistent with readings collected at both Monse (5 of 122 comparable days, or 4%) and Highway 97 (8 of 165 comparable days, or 5%), suggesting that such events are not widespread or persistent within the Wells Project (Parametrix, Inc. 2009). In 2009, Douglas contracted Columbia Basin Environmental to continue monitoring turbidity for an additional year. Results from the 2009 field season indicate that turbidity decreases from the background monitoring location (Malott, RM 17.0), to both Monse (RM 5.0) and the Highway 97 Bridge (RM 1.3). No exceedances were observed and the data showed that the Wells Project is in compliance with the Washington State water quality standards for turbidity (DCPUD and CBE 2009).

2.3.5 Summary of Compliance with WQS

Based on the Initial and Updated Study Reports the Aquatic SWG was able to determine that waters within the Wells Project currently meet state numeric criteria of WQS as defined in Chapter 173-201A WAC. The following table presents supporting studies, by standard:

Standard	Studies	Result(s)	Continued Monitoring
TDG	Politano et al. 2008, 2009a, 2009b.	Compliance met under preferred operating conditions and standard compliance scenario.	Yes
Temperature	West Consultants, Inc. 2008	Compliance met, zero exceedances. Potential future TMDL.	Yes
DO	Parametrix, Inc. 2009	Compliance met, zero exceedances	No
pH	Parametrix, Inc. 2009	Compliance met, zero exceedances	No
Turbidity	Parametrix, Inc. 2009; DCPUD and CBE 2009.	Compliance met, zero exceedances	No

3.0 GOAL AND OBJECTIVES

The goal of the WQMP is to protect the quality of the surface waters affected by the Project with regard to the numeric criteria. Studies conducted during the relicensing process have found water quality within the Wells Project to be within compliance. Douglas, in collaboration with the Aquatic SWG, has agreed to implement measures in support of the WQMP. Reasonable and feasible measures will be implemented in order to maintain compliance with the numeric criteria of the Washington State WQS, Chapter 173-201A WAC. The measures presented within the WQMP (Section 4.0) are designed to meet the following objectives:

Objective 1: Maintain compliance with state WQS for TDG. If non-compliance is observed, the Aquatic SWG will identify reasonable and feasible measures, which will be implemented by Douglas;
Objective 2: Maintain compliance with state WQS for water temperature. If information becomes available that suggests non-compliance is occurring or likely to occur, the Aquatic SWG will identify reasonable and feasible measures, which will be implemented by Douglas;

Objective 3: Maintain compliance with state WQS for other numeric criteria. If information becomes available that suggests non-compliance is occurring or likely to occur, the Aquatic SWG will identify reasonable and feasible measures, which will be implemented by Douglas;

Objective 4: Operate the Project in a manner that will avoid, or where not feasible to avoid, minimize, spill of hazardous materials and implement effective countermeasures in the event of a hazardous materials spill; and

Objective 5: Participate in regional forums tasked with improving water quality conditions and protecting designated uses in the Columbia River basin.

The WQMP is intended to be compatible with other water quality management plans in the Columbia River mainstem, including TMDLs. Furthermore, the WQMP is intended to be supportive of the HCP, Bull Trout Management Plan, Pacific Lamprey Management Plan, Resident Fish Management Plan, White Sturgeon Management Plan, and Aquatic Nuisance Species Management Plan through the protection of designated uses (WAC 173-201A-600) in Project waters. The WQMP is intended to be not inconsistent with other management strategies of federal, state and tribal natural resource management agencies.

The schedule for implementation of specific measures within the WQMP is based on the best information available at the time the Plan was developed. As new information becomes available, the measures proposed in the WQMP may be adjusted through consultation with the Aquatic SWG.

4.0 WATER QUALITY MEASURES

In order to fulfill the goals and objectives described in Section 3.0, Douglas, in consultation with the Aquatic SWG, has agreed to implement the following measures.

4.1 TDG Compliance (Objective 1)

4.1.1 Monitoring

Douglas shall continue to maintain fixed monitoring stations in the forebay and tailrace area of Wells Dam to monitor TDG and barometric pressure. TDG will be monitored hourly during the fish spill season each year. Data from the Wells forebay and tailrace stations will be transmitted on a daily basis to the applicable web-accessible database used by Ecology and regional fish management agencies. Douglas shall maintain this monitoring program consistent with activities described in the then-current Wells Gas Abatement Plan (Section 4.1.3).

Douglas shall provide an annual report of all spill (and predicted TDG levels in the tailrace) occurring outside the fish passage season (currently October 1 to March 15).

4.1.2 Spill Operations

Within one year of issuance of the new license, Douglas shall coordinate the annual HCP Project Fish Bypass/Spill Operations Plan with the Aquatic SWG and the GAP, using best available information to minimize the production of TDG during periods of spill. All operations identified within the plan shall require the approval of the Wells HCP Coordinating Committee and the Aquatic SWG in order to ensure that spill operations are aimed at protecting designated uses and complying with the WQS numeric criteria for TDG in the Columbia River at the Project. In consultation with the Wells HCP Coordinating Committee and Aquatic SWG, the spill operations plan will be reviewed and updated, as necessary.

4.1.3 Project Gas Abatement Plan and TDG Exemption

Pending Ecology's approval of each subsequent GAP (which provides for the TDG exemption), Douglas shall continue to implement the activities identified within the previously-approved plan. Douglas shall submit the GAP to Ecology by February 28th of each year, or on a less frequent basis, as documented by Ecology in writing. Douglas shall submit the GAPs through the term of the new license or until no longer required by Ecology.

The GAP will include the Spill Operations Plan (Section 4.1.2) and will be accompanied by a fisheries management plan and physical and biological monitoring plans. The GAP shall include information on any new or improved technologies to aid in the reduction in TDG.

It is anticipated that: (1) the TDG monitoring activities described in Section 4.1.1 will be adequate for the physical monitoring plan requirement; and (2) the Wells HCP and Aquatic Resource Management Plans in the Aquatic Settlement Agreement with respect to fish passage will be adequate for fish management plans, for the purposes of the GAP. Additional biological monitoring studies for purposes of Gas Bubble Trauma Monitoring may be required.

Douglas shall provide an annual TDG report as required by the Ecology-approved GAP.

4.1.4 Measures to Address Non-Compliance

Douglas shall report all occurrences of non-compliance with TDG numeric criteria immediately to Ecology for regulatory discretion and to the Aquatic SWG for consideration.

If the Project is found to be consistently out of compliance with TDG at any time during the new license term, Douglas shall, in coordination with the Aquatic SWG, take the following steps:

(A) Evaluate any new reasonable and feasible technologies that have been developed; and

(B) After the evaluation, if no new reasonable and feasible improvements have been identified, propose an alternative to achieve compliance with the standards, such as site-specific criteria, a use attainability analysis, or a water quality offset.

4.2 Water Temperature Compliance (Objective 2)

4.2.1 Monitoring

Douglas shall continue to monitor temperature at the Wells Dam forebay and tailrace in conjunction with its TDG monitoring program (currently April 1-September 15). Temperature data from the TDG monitoring program will be recorded hourly and reported daily to regional databases. Water temperatures shall also be monitored at all boundary conditions of the Project (Methow River RM 1.5, Okanogan River RM 10.5, and Columbia River RM 544.5) and in the Well Dam forebay and tailrace as required by the Aquatic SWG.

Douglas shall continue to collect hourly fish ladder temperatures 24 hours a day during the fish passage season (May 1 to November 15) at Pool No. 39 on the east ladder. Water temperatures shall also be monitored hourly in the auxiliary water supply system and near the east shore of the Wells Dam forebay (bottom, middle, and surface depths) during this same time period.

4.2.2 Temperature TMDL Development and Implementation

Douglas shall participate in EPA Region 10's water temperature TMDL development for the U.S. portion of the Columbia River, in coordination with the Parties of the Aquatic SWG. Temperature data from the monitoring program at Wells Dam (Section 4.2.1) and software and results of the CE-QUAL-W2 model will be made available to EPA and other entities to assist in the development of the Columbia River temperature TMDL.

Where the measures identified in the TMDL are more protective than other measures in this plan, provisions of the temperature TMDL and implementation plans relevant to the Project and its operations, including specified time frames for implementing improvement measures, shall be implemented at the Project.

If a TMDL is not timely approved by EPA, Ecology may establish an allocation. In this case, Ecology will work with the Aquatic SWG and other interested parties to identify reasonable and feasible measures.

This plan does not exclude the option of the Aquatic SWG to consider modifying the water quality standard through a use attainability analysis or other process.

4.2.3 Measures to Address Non-Compliance

Douglas shall report information indicative of non-compliance with water temperature immediately to Ecology for regulatory discretion and to the Aquatic SWG for consideration. Such information may include changes in Project operations likely to increase water temperature or observations inconsistent with related environmental parameters.

If the Project is found to be consistently out of compliance with water temperature at any time during the new license term, Douglas shall, in coordination with the Aquatic SWG, take the following steps:

(A) Evaluate alternative Project operations or any new reasonable and feasible technologies that have been developed; and

(B) After the evaluation, if no new reasonable and feasible improvements have been identified, propose an alternative to achieve compliance with the standards, such as site-specific criteria, a use attainability analysis, or a water quality offset.

4.3 Compliance with Other Numeric Criteria (Objective 3)

Douglas shall report information indicative of non-compliance with other numeric criteria immediately to Ecology for regulatory discretion and to the Aquatic SWG for consideration. This includes existing or developed criteria for toxic substances in water or sediments within Project Boundaries. The Aquatic SWG shall evaluate the information, and, if needed, require Douglas to develop a plan to identify and address Project-related impacts, if any.

After the evaluation, if no reasonable and feasible improvements have been identified, Douglas may propose an alternative to achieve compliance with the standards, such as site-specific criteria, a use attainability analysis, or a water quality offset.

4.4 Spill Prevention and Control (Objective 4)

4.4.1 Spill Prevention and Control Requirements

Douglas shall operate the Project in a manner that will minimize spill of hazardous materials and implement effective countermeasures in the event of a hazardous materials spill. The Project Spill Prevention Control and Countermeasures Plan (SPCC) will be updated pursuant to FERC requirements and recommendations as provided by Ecology. Douglas shall comply with the updated version(s) of the SPCC.

4.4.2 Participation in the Columbia and Snake River Spill Response Initiative

Douglas shall continue participation in the Columbia and Snake River Spill Response Initiative (CSR-SRI). The CSR-SRI is a collaborative effort made up of local, state, and federal oil spill response community as well as members of industry and was developed to address the immediate need for oil spill preparedness and response in the area along the Columbia and Snake rivers. In addition to participation in the CSR-SRI, Douglas shall continue to operate the Project in accordance with its SPCC (Jacobs 2007).

4.4.3 Inspections

For the term or the new license, Douglas shall, upon reasonable notice, allow Ecology staff or representatives access to inspect the Project, including inside the dam, for the purpose of assessing Spill Prevention and Control measures and compliance with Section 4.4.1. Following inspection, Douglas shall address oil and hazardous material prevention and control issues identified by Ecology.

4.5 Regional Forums (Objective 5)

4.5.1 Participation in Regional Water Quality Forums

Douglas shall continue its participation in both the Water Quality Team and Adaptive Management Team meetings to address regional water quality issues, including sharing the results from monitoring, measuring, and evaluating water quality in the Wells Project. However, Douglas will not advocate for any water quality measures in regional forums without consulting with the Aquatic SWG.

4.5.2 Project Operations

Douglas may, following notice and opportunity for hearing, coordinate the operation of the project, electrically and hydraulically, with other mid-Columbia hydroelectric operations to the extent practicable. Coordinated operations are intended to reduce spill, increase generating efficiencies and thereby reduce the potential for exceedances of the TDG numeric criteria. These coordinated operations should be beneficial to TDG compliance and Aquatic Resources.

4.6 Reporting

Douglas shall provide a draft annual report to the Aquatic SWG summarizing the previous year's water quality activities and activities proposed for the coming year, in accordance with the WQMP and as determined by the Aquatic SWG. The report will include any decisions, statements of agreement, evaluations, or changes made pursuant to this WQMP. If significant activity was not conducted in a given year, Douglas may prepare a memorandum providing an explanation of the circumstances in lieu of the annual report. A summary of monitoring results, any analyses and compliance with the WQS numeric criteria will be included in an appendix to the annual report.

4.6.1 Study Plans

Douglas shall prepare study plan(s) that include quality assurance project plan(s) (QAPP) for each parameter to be monitored. The QAPPs shall follow the Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies (July 2004 Ecology Publication Number 04-03-030) or its successor. The QAPPs shall contain, at a minimum, a list of parameter(s) to be monitored, a map of sampling locations, and descriptions of the purpose of the monitoring, sampling frequency, sampling procedures and equipment, analytical methods, quality control procedures, data handling and data assessment procedures and reporting protocols.

Douglas shall review and update the QAPPs annually based on a yearly review of data and data quality. Ecology may also require future revisions to the QAPP based on monitoring results, regulatory changes, changes in Project operations, and/or the requirements of TMDLs.

The initial QAPPs and any changes shall be submitted to the Aquatic SWG for review and are subject to approval by Ecology. Implementation of the monitoring program shall begin upon Ecology's written approval of the QAPP, unless otherwise provided by Ecology.

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UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

Public Utility District No. 1 of Douglas County, Washington	)	**Wells Project No. 2149-131**

APPLICATION FOR APPROVAL OF AQUATIC SETTLEMENT AGREEMENT AS AN OFFER OF SETTLEMENT AND ADOPTION OF PROPOSED LICENSE ARTICLES AND AQUATIC RESOURCE MANAGEMENT PLANS

Pursuant to section 385.602 of the regulations of the Federal Energy Regulatory Commission ("FERC" or "Commission"),[1] Public Utility District No. 1 of Douglas County, Washington ("Douglas PUD"), United States Fish and Wildlife Service ("USFWS"), Washington Department of Ecology, ("Ecology"), Washington Department of Fish and Wildlife ("WDFW"), Confederated Tribes of the Colville Reservation ("Colville"), Confederated Bands and Tribes of the Yakama Nation ("Yakama"), and the Bureau of Land Management ("BLM") (collectively, the "Parties") submit this Application for Approval of Aquatic Settlement Agreement as an Offer of Settlement and Adoption of Proposed License Articles and Aquatic Resource Management Plans ("Application") in connection with the issuance of a new license for the Wells Hydroelectric Project No. 2149 ("Project").

The Parties have entered into the Aquatic Settlement Agreement ("Agreement") for the purpose of resolving all remaining aquatic resource issues related to compliance with all federal and state laws applicable to the issuance of a new license for the Project. The Aquatic Settlement Agreement includes proposed license articles and six aquatic resource management plans for white sturgeon, bull trout, Pacific lamprey, resident fish, aquatic nuisance species and

[1] 18 C.F.R. § 385.602 (2009).

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water quality, respectively. The measures set forth in each aquatic resource management plan are intended to establish Douglas PUD's obligations for the protection, mitigation and enhancement of such resource affected by Project operations under the new license and its obligations to comply with all related federal and state laws applicable to issuance of such license.

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II. OFFER OF SETTLEMENT

In accordance with section 385.602(c)(1) of the Commission's regulations,[2] the Parties hereby submit a copy of the Aquatic Settlement Agreement, including Attachments A through G, as an offer of settlement of all remaining aquatic resource issues in the relicensing proceeding for the Project. Attachment A to the Agreement contains six Proposed License Articles, which would require Douglas PUD, in consultation with the Parties and subject to the Commission's

[2] 18 C.F.R. § 385.602(c)(1) (2009).

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regulatory oversight, to implement the measures set forth in each of the respective aquatic resource management plans. Attachment B contains the White Sturgeon Management Plan. Attachment C contains the Bull Trout Management Plan. Attachment D contains the Pacific Lamprey Management Plan. Attachment E contains the Resident Fish Management Plan. Attachment F contains the Aquatic Nuisance Species Management Plan. Attachment G contains the Water Quality Management Plan.

The Aquatic Settlement Agreement, which has been approved and executed by all Parties, was negotiated in the context of the Commission's Integrated Licensing Process ("ILP") for the Project. Although the Agreement is currently effective, and Douglas PUD is currently complying with the terms of the Agreement, Douglas PUD's obligation to implement the aquatic resource management plans is contingent upon the Commission's adoption of the proposed license articles and the aquatic resource management plans as conditions of the new license without material modification.

III. JOINT EXPLANATORY STATEMENT

A. The Wells Project ILP

The original license for the Project will expire on May 31, 2012. In accordance with FERC regulations, 18 C.F.R. Part 5 (2009), Douglas PUD initiated the ILP for the relicensing of the Project on December 1, 2006 by filing a Notice of Intent to apply for a new license and a Pre-Application Document. The FERC staff issued Scoping Document 1 on January 29, 2007. Following consultations with various entities, Douglas PUD filed its Proposed Study Plan Document and Revised Study Plan Document on May 16, 2007, and September 14, 2007, respectively. The FERC staff issued its Study Plan Determination on October 11, 2007.

Douglas PUD filed its Initial Study Report Document on October 15, 2008, and the FERC staff issued a Determination on Requests for Modification to the Project Study Plan on February 4, 2009. Douglas PUD filed an Updated Study Report Document on April 15, 2009.

The FERC designated Douglas PUD as its non-federal representative to conduct informal consultations under section 7 of the Endangered Species Act,[3] and Douglas PUD prepared a draft Biological Assessment in informal consultation with the USFWS and National Marine Fisheries Service (NMFS) during the pre-application process. Douglas PUD distributed a Draft License Application for comment on December 18, 2009. By the March 31, 2010 deadline, interested parties filed comments on the Draft License Application. On May 27, 2010, Douglas PUD filed a Final License Application for the continued operation and maintenance of the Project. Exhibit E to the Final License Application contains a Draft Environmental Assessment prepared in accordance with the Commission's Guidelines under the National Environmental Policy Act[4] ("NEPA").

In March of 2006, following two years of collaborative discussions related to the relicensing studies, Douglas PUD approached stakeholders regarding its desire to develop an Aquatic Settlement Agreement for those resources not already protected by the original license, the Wells Anadromous Fish Agreement and Habitat Conservation Plan ("Wells HCP" or "HCP") and other related agreements. Stakeholders active in the development of the Aquatic Settlement Agreement included the USFWS, NMFS, Ecology, WDFW, Colville, Yakama, and BLM. The final Agreement was distributed for execution in October 2008 and signed by Douglas PUD, USFWS, Ecology, WDFW, Colville, Yakama, and BLM.

[3] 16 U.S.C. §§ 1531 – 1599 (2006).
[4] 42 U.S.C. §§ 4321-4370h (2006).

The Aquatic Settlement Agreement contains six aquatic resource management plans intended to protect and enhance populations of white sturgeon, Pacific lamprey, bull trout and native resident fish; protect and restore surface water quality affected by the Project; and prevent the introduction and further spread of aquatic nuisance species. These resource management plans have been identified in the Final License Application as Douglas PUD's proposed environmental measures for such resources pursuant to section 5.15(a)(5)(C) of the Commission's regulations.[5] Douglas PUD requests the Commission to incorporate, without modification, the proposed license articles and aquatic resource management plans as conditions of the new license. The six aquatic resource management plans, together with the Wells HCP, form the foundation of Douglas PUD's Final License Application for the Project with respect to aquatic resources. In addition to measures to protect aquatic resources, the Final License Application includes several management plans for the protection and enhancement of terrestrial, recreation and cultural resources associated with the Wells Project.

B. The Wells Project Anadromous Fish Agreement and Habitat Conservation Plan

The Wells HCP contains Douglas PUD's proposed salmon and steelhead measures for the relicensing of the Wells Project. The HCP is the first hydropower Habitat Conservation Plan in the nation for anadromous salmon and steelhead. The Wells HCP is a 50-year agreement that became effective upon FERC approval in 2004. The Wells HCP addresses all Project-related impacts to spring Chinook, summer/fall Chinook, steelhead, sockeye and coho, collectively referred to as Plan Species. The Wells HCP commits Douglas PUD to a 50-year program to ensure that its Project has "no net impact" (NNI) on Plan Species. The NNI goal will be accomplished at the Wells Project through a combination of juvenile fish bypass system operations, hatchery programs and evaluations, and habitat restoration work conducted in mid-

[5] 18 C.F.R. § 5.15(a)(5)(C) (2009).

Columbia tributary rivers and streams. Entities that have signed the Wells HCP (HCP Signatory Parties) include the NMFS, USFWS, WDFW, Colville, Yakama, the Power Purchasers, and Douglas PUD.

With respect to Plan Species and the relicensing of the Wells Project, the HCP Signatory Parties have agreed to be supportive of Douglas PUD's long-term license application to the FERC, filed during the term of the Wells HCP. The Wells HCP also provides ESA coverage for all of the Incidental Take Permit (ITP) species (spring Chinook, summer/fall Chinook, sockeye, and steelhead) and is intended to constitute the HCP Signatory Parties' terms, conditions and recommendations for Plan Species under Sections 10(a), 10(j) and 18 of the FPA, the Fish and Wildlife Coordination Act, the Essential Fish Habitat provisions of the Magnuson-Stevens Fishery Conservation and Management Act, the Pacific Northwest Electric Power Planning and Conservation Act, and Title 77 of the Revised Code of Washington.

C. Summary of the Aquatic Settlement Agreement

The six aquatic resource management plans, together with the Wells HCP, form the foundation of Douglas PUD's Final License Application for the Project with respect to aquatic resources. The purpose of the Aquatic Settlement Agreement is to resolve all remaining aquatic resource issues related to compliance with all federal and state laws applicable to the issuance of a new operating license for the Project. The Parties recognize that during the course of the new license there may be instances where the measures found in individual management plans may need to be adapted, and in such instances the Parties will use adaptive management, as defined in Section 3.1 of the Agreement, to achieve the biological goals and objectives. The Aquatic Settlement Agreement establishes Douglas PUD's obligations for the protection, mitigation and enhancement of aquatic resources affected by Project operations under the new license, and its

obligations to comply with all federal and state laws applicable to the issuance of the new license.

The Aquatic Settlement Agreement became effective upon execution by the Parties and will remain in effect throughout the term of the new license, unless it is terminated earlier for the reasons permitted under Section 8 of the Agreement. The Agreement recognizes that Douglas PUD will seek a license term of 50 years, and the Parties agree to support a 50-year term for the new operating license. The measures contained in the aquatic resource management plans will become effective upon issuance of a FERC order granting a new license to Douglas PUD, except to the extent the implementation of any such measures is prohibited, prevented or rendered impracticable by the FERC order. If FERC or another government agency takes any action that is materially inconsistent with the terms of the Agreement, including an action that results in a material modification of Attachments A through G, a Party may elect to withdraw pursuant to Section 8 of the Agreement.

The six aquatic resource management plans contained in Attachments B through G, together with the Wells HCP, are intended to serve as the Water Quality Attainment Plan[6] in support of the Clean Water Act Section 401[7] water quality certification for relicensing of the Project. The Parties agree that the measures set forth in the six resource plans are adequate to identify and address Project impacts to such resources and are expected to achieve the objectives set forth in the respective management plans. However, the Parties recognize that during the course of the new license there may be instances where the measures found in individual management plans may need to be adapted, and in such instances the Parties will use adaptive

[6] WAC 173-201A-510 (5)
[7] 33 U.S.C. § 1341 (2006).

management, as defined in Section 3.1 of the Agreement, to achieve the biological goals and objectives.

The Agreement establishes an Aquatic Settlement Working Group ("Aquatic SWG"), which will be the primary forum for consultations and coordination among the Parties in connection with conducting studies and implementing the measures set forth in the resource management plans. The Aquatic SWG will act by unanimous vote of its members. The Parties have selected a neutral, non-voting Chair of the Aquatic SWG, whose duties include preparation of an annual list of statements of agreement based upon the results of studies, preparation of progress reports and meeting minutes, facilitation of meetings and assisting the members in making decisions. The Chair will also work with Douglas PUD to compile an annual report, which will be approved by the Aquatic SWG and filed with FERC by Douglas PUD.

The Aquatic Settlement Agreement also establishes a dispute resolution process, which involves submitting the disputed matter successively to the technical, policy and ultimately the executive representatives of the Parties for potential resolution.

Section 13 of the Agreement acknowledges that certain Parties have reserved their respective authorities under the Federal Power Act,[8] Clean Water Act[9] and Endangered Species Act[10]. To the extent practicable, a Party must provide notice to the Aquatic SWG before exercising any reserved authority that may be materially inconsistent with the Agreement. Thereafter, the Aquatic SWG is authorized to make recommendations regarding the exercise of such authority. If the Aquatic SWG does not reach a unanimous decision regarding such recommendations, any Party may initiate dispute resolution. However, if a Party determines that

[8] 16 U.S.C. §§ 791a-823c (2006).
[9] 33 U. S. C. §§ 1251-1387 (2006).
[10] 16 U. S. C. §§ 1531-1599 (2006).

expeditious action is required to perform its statutory duties, such Party is not required to wait in exercising reserved authority until dispute resolution is initiated or concluded.

Under Section 8 of the Agreement, a Party may elect to withdraw from the Agreement based on non-compliance of another Party, subject to specified procedures including notice and dispute resolution. A Party may also elect to withdraw if a government agency takes an action that is materially inconsistent with the terms of the Agreement, including Attachments A through G, and the material inconsistency is sustained upon completion of available actions to appeal or otherwise address the inconsistency.

Upon expiration of the Agreement, or in the event the Agreement is terminated before the end of its term, Douglas PUD will continue to implement the last agreed-upon measures until the FERC orders otherwise, and the Parties are not restrained in any manner from advocating to FERC appropriate measures to replace the Agreement.

D. Summary of Proposed License Articles and Aquatic Resource Management Plans

1. Proposed License Articles

Attachment A to the Agreement contains six proposed license articles, one for each aquatic resource management plan, for the new license. The language of the proposed articles is identical except for the reference to the specific resource management plan to which each article applies. For example, under proposed Article 1, Douglas PUD is obligated to implement the measures set forth in section 4 of the White Sturgeon Management Plan, dated August 2008, which is incorporated by reference, in consultation with the Aquatic SWG. Consistent with section 10(b) of the Federal Power Act[11] and Commission policy,[12] Article 1 provides that Douglas PUD shall obtain prior Commission approval for any substantial modification or

[11] 16 U.S.C. § 803(b) (2006).
[12] Policy Statement on Hydropower Licensing Settlements, Docket PL06-5-000, issued Sept. 21, 2006, at P. 37.

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addition to Project works or operations necessary to implement such measures. The licensee is also obligated to submit any proposed amendment to the management plan to the Commission for approval and to file an annual report with the Commission to document all studies, measures and other activities completed during the previous year.

2. White Sturgeon Management Plan

The goal of the White Sturgeon Management Plan ("WSMP") is to increase the white sturgeon (*Acipenser transmontanus*) population in Wells Reservoir to a level that can be supported by the available habitat and characterized by a diverse age structure consisting of multiple cohorts (juveniles and adults). In addition, the WSMP is intended to support spawning, rearing and migration as identified by the aquatic life designated use in the Washington Water Quality Standards ("WQS"). The Aquatic SWG concluded that resource measures related to white sturgeon should focus on population protection and enhancement by means of supplementation as an initial step to increase the number of fish within Wells Reservoir. In addition to the initial supplementation activities, the Aquatic SWG has proposed a monitoring and evaluation program to assess natural recruitment, juvenile habitat use, carrying capacity, and the potential for natural reproduction in order to inform the scope of a future, long-term supplementation strategy. Phase I of the WSMP will be implemented during the first ten years of a new license and includes juvenile stocking, and monitoring and evaluation activities. Phase II will include long-term juvenile stocking, adult passage evaluation and monitoring for the remainder of the new license. The scope of the Phase II activities will be determined by the Aquatic Settlement Work Group based upon the results of the Phase I measures.

3. Bull Trout Management Plan

The goal of the Bull Trout Management Plan ("BTMP") is to identify, monitor, and address impacts to bull trout resulting from the Project, in a manner that is consistent with the USFWS Bull Trout Recovery Plan and the terms of the ESA Section 7 Incidental Take Statement ("ITS") for the issuance of the new license. The BTMP is intended to continue the implementation of management activities to protect bull trout during the new license term in a manner consistent with the original Bull Trout Monitoring and Management Plan (Douglas PUD 2004), which was adopted in the ESA Section 7 consultation for the FERC approval of the Wells HCP.[13] The objectives of the BTMP include: (1) operation of the upstream fishways and downstream bypass systems in a manner consistent with the HCP; (2) identification of any adverse Project-related impacts on adult and sub-adult bull trout passage; (3) implementation of reasonable and appropriate options to modify upstream fishway, downstream bypass, or operations if adverse impacts on bull trout are identified and evaluation of the effectiveness of the measures implemented; (4) periodic monitoring for bull trout entrapment or stranding during low Wells Reservoir elevations; (5) participation in the development and implementation of the USFWS Bull Trout Recovery Plan, including information exchange and genetic analysis; and (6) identification of any adverse impacts of Project-related hatchery operations on adult and sub-adult bull trout.

4. Pacific Lamprey Management Plan

The goal of the Pacific Lamprey Management Plan ("PLMP") is to implement measures to monitor and address impacts on Pacific lamprey (*Lampetra tridentata*) resulting from the Project during the term of the new license. The PLMP is intended to be compatible with other

[13] *Public Utility District No. 1 of Chelan County, WA and Public Utility District No. 1 of Douglas County, WA*, 107 FERC ¶ 61,280 (2004), *order on rehearing*, 109 FERC ¶ 61,208 (2004); *Public Utility District No. 1 of Douglas County, WA*, 107 FERC ¶ 61,283 (2004).

Pacific lamprey management plans in the Columbia River. Furthermore, the PLMP is intended to be supportive of the Wells HCP, the critical research needs identified by the Columbia River Basin Lamprey Technical Working Group, the Resident Fish Management Plan, BTMP and WSMP.

Douglas PUD, in consultation with the Aquatic SWG, will implement measures for Pacific lamprey in the Project boundary consistent with the goals and objectives identified in the PLMP. The measures are designed to meet the following objectives: (1) identify and address any adverse Project-related impacts on passage of adult Pacific lamprey; (2) identify and address any Project-related impacts on downstream passage and survival and rearing of juvenile Pacific lamprey; and (3) participate in the development of regional Pacific lamprey conservation activities.

5. Resident Fish Management Plan

The goal of the Resident Fish Management Plan ("RFMP") is to protect and enhance native resident fish populations and habitat in the Project boundary during the term of a new license. The RFMP is intended to be compatible with other resident fish management plans in the Columbia River mainstem. Furthermore, the RFMP is intended to be supportive of the Wells HCP, BTMP, PLMP and WSMP by continuing to monitor changes, if necessary, in the resident fish assemblage within the Project boundary. Douglas PUD, in collaboration with the Aquatic SWG, has agreed to implement several measures in support of the goals and objectives of the RFMP. These measures include: (1) implementation of programs that benefit resident fish; (2) monitoring of resident fish assemblage; (3) actions to address major shifts in native resident fish assemblage; and (4) monitoring in response to proposed changes in Project operations.

6. Aquatic Nuisance Species Management Plan

The goal of the Aquatic Nuisance Species Management Plan ("ANSMP") is to prevent the introduction and/or spread of aquatic nuisance species in Project waters. The ANSMP is intended to be compatible with other aquatic nuisance species management plans in the Columbia River mainstem. Furthermore, the management plan is intended to be supportive of the Wells HCP, BTMP, PLMP, RFMP, WSMP, and Water Quality Management Plan by continuing to prevent the introduction and/or spread of aquatic nuisance species in Project waters. The measures presented within the ANSMP are designed to meet the following objectives: (1) implement best management practices to prevent Eurasian watermilfoil proliferation during in-water improvement activities at the Project; (2) continue participation in regional and state aquatic nuisance species efforts to prevent the introduction and spread of aquatic nuisance species; and (3) assess and monitor aquatic nuisance species in response to proposed changes in Project operations.

7. Water Quality Management Plan

The goal of the Water Quality Management Plan ("WQMP") is to protect the quality of the surface waters affected by the Project. Reasonable and feasible measures will be implemented in order to comply with the numeric criteria of the Washington WQS, Chapter 173-201A WAC. The measures within the WQMP are designed to meet the following objectives: (1) maintain compliance with the WQS for Total Dissolved Gas; if non-compliance is observed, the Aquatic SWG will identify reasonable and feasible measures, which will be implemented by Douglas PUD; (2) maintain compliance with the WQS for temperature; if information becomes available that suggests non-compliance is occurring or likely to occur, the Aquatic SWG will identify reasonable and feasible measures, which will be implemented by Douglas PUD; (3)

maintain compliance with the WQS for other numeric criteria; if information becomes available that suggests non-compliance is occurring or likely to occur, the Aquatic SWG will identify reasonable and feasible measures, which will be implemented by Douglas PUD; (4) operate the Project in a manner that will avoid, or where not feasible to avoid, will minimize the spill of hazardous materials and implement effective countermeasures in the event of a hazardous materials spill; and (5) participate in regional forums tasked with improving water quality conditions and protecting designated uses in the Columbia River basin.

Based on the foregoing, the Parties believe that the Aquatic Settlement Agreement is fair and reasonable and in the public interest. Accordingly, the Parties request the Commission to approve the Aquatic Settlement Agreement pursuant to Rule 602 of the Commission's Rules of Practice and Procedure.[14] In addition, the Parties request that the Commission adopt Attachments A through G of the Agreement, without modification, as conditions of the new license for the Project.

IV. STUDIES IN SUPPORT OF THE AQUATIC SETTLEMENT AGREEMENT

The Aquatic Settlement Agreement is fully supported by the extensive record developed in the ILP for relicensing the Project. Each of the six aquatic resource management plans contains a detailed review of the status of the resource within the Project area and the results of relevant relicensing studies. This information established the foundation for the development of goals and objectives by the Aquatic SWG as well as the related measures set forth in each resource management plan. Further support for the aquatic resource management plans is provided in Sections 3.3.2.1 through 3.3.2.9 of Exhibit E of Douglas PUD's Final License Application and in Section 2.5.1.2 of the draft Biological Assessment, which is included as

[14] 18 C.F.R. § 385.602 (2009).

Appendix E-2 to the Exhibit E. Lastly, the biological basis of the management plans is supported by the following study reports:

Bickford, S. and T. Skilingstad. 2000. Movements of Northern Squawfish in the reservoir, forebay, and tailrace of the Wells Hydroelectric Project, mid-Columbia River, Washington. Public Utility District No. 1 Douglas County, East Wenatchee, Washington.

BioAnalysts, Inc. 2004. Movement of Bull Trout within the Mid-Columbia River and Tributaries, 2001-2004. Prepared by BioAnalysts, Inc. , Eagle Rock, Idaho for Public Utility District No. 1 of Chelan County, Wenatchee, WA, Public Utility District No. 1 of Douglas County, East Wenatchee, WA, and Public Utility District No. 1 of Grant County, Ephrata, WA.

BioAnalyst, Inc. 2006. Aquatic Macroinvertebrate Inventory and RTE Assessment. Wells Hydroelectric Project, FERC No. 2149. Prepared for Public Utility District No. 1 of Douglas County, East Wenatchee, WA.

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CBE. 2004. Wells Dam Spillway Total Dissolved Gas Evaluation. Final Report. Prepared by Columbia Basin Environmental, The Dalles, Oregon for Public Utility District No. 1 of Douglas County, East Wenatchee, Washington.

CBE. 2006. Wells Dam Spillway Total Dissolved Gas Evaluation. Final Report. Prepared by Columbia Basin Environmental, The Dalles, Oregon for Public Utility District No. 1 of Douglas County, East Wenatchee, Washington.

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EES Consulting, J. Carroll, ENSR, and Parametrix. 2007. Total Dissolved Gas Production Dynamics Study. Wells Hydroelectric Project. FERC No. 2149. Prepared by EES Consulting, Joe Carroll, ENSR, and Parametrix. Prepared for Public Utility District No. 1 of Douglas County, East Wenatchee, WA.

EES Consulting, Inc. 2006. Comprehensive Limnological Investigation. Wells Hydroelectric Project FERC No. 2149. Prepared by EES Consulting, Bellingham, WA for Public Utility District No. 1 of Douglas County, East Wenatchee, Washington.

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Jacobs Engineering. 2007. Wells Hydroelectric Project: Spill Prevention Control and Countermeasure (SPCC) Plan. Prepared by Jacobs Engineering, Bellevue, WA. Prepared for Public Utility District No. 1 of Douglas County, East Wenatchee, WA.

Jerald, T. 2007. White Sturgeon (Acipenser transmontanus) Population Assessment in Wells Reservoir. MSc Thesis. Central Washington University, Ellensburg, WA.

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Lê, B. and S. Kreiter. 2005. Aquatic Macrophyte Identification and Distribution Study. Wells Hydroelectric Project, FERC NO. 2149. Public Utility District No. 1 of Douglas County, East Wenatchee, WA.

LGL (LGL Limited) and Douglas PUD. 2007. Wells Bull Trout Monitoring and Management Plan, 2006 Annual Report. Wells Hydroelectric Project FERC No. 2149.

LGL and Douglas PUD. 2008a. Adult Pacific Lamprey Passage Evaluation. Wells Hydroelectric Project. No. 2149. Prepared by LGL Limited, Ellensburg, WA. Prepared for Public Utility District No. 1 of Douglas County, East Wenatchee, WA.

LGL and Douglas PUD. 2008b. Bull Trout Monitoring and Management Plan, 2005-2008 Final Report. Wells Hydroelectric Project FERC No. 21. 49. Prepared for Public Utilities District No. 1 of Douglas County. East Wenatchee, Washington.

McGee, J. A. 1979. Fisheries Survey of Wells Reservoir. Public Utility District of Douglas County, East Wenatchee, Washington.

Murauskas, J. G. and P. N. Johnson. 2009. Assessment of Adult Pacific Lamprey Behavior in Response to Temporary Velocity Reductions at Fishway Entrances. Study plan prepared for the Aquatic Settlement Work Group, Wells Hydroelectric Project FERC No. 2149, with technical support from J. Skalski, R. Wielick, D. Allison, M. Hallock, and B. Le. East Wenatchee, Washington.

Parametrix, Inc. 2009. Continued Monitoring of DO, pH, and Turbidity in the Wells Forebay and Lower Okanogan River (DO, pH, and Turbidity Study). Wells Hydroelectric Project, FERC No. 2149. Initial Study Report required by FERC. Prepared for Public Utility District No. 1 of Douglas County. East Wenatchee, WA.

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Skalski, J. R. and R. L. Townsend. 2005. Analysis of the Douglas County Public Utility District #1 Sturgeon Mark-Recapture Study. Columbia Basin Research. School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA.

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V. PUBLIC NOTICE AND COMMENT

Douglas PUD has served copies of this Application on all entities listed on the attached Relicensing Distribution List in accordance with the Communication Protocol for the Wells ILP. The Parties respectfully request the Commission to issue a public notice of this offer of settlement pursuant to Rule 602 providing for initial comments within 20 days of the filing of the offer of settlement and reply comments within 30 days of such filing.

VI. CONCLUSION

WHEREFORE, the Parties respectfully request the Commission to approve the Aquatic Settlement Agreement and to adopt Attachments A through G thereof, without modification, as conditions of the new license for the Project.

Respectfully submitted,

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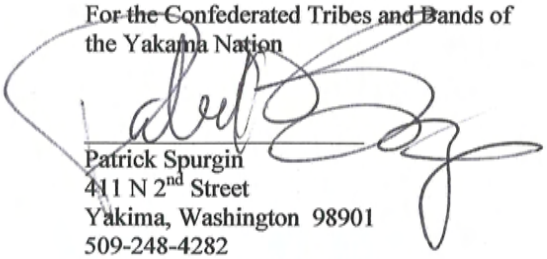

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Bickford, S. and T. Skillingstad. 2000. Movements of Northern Squawfish in the reservoir, forebay, and tailrace of the Wells Hydroelectric Project, mid-Columbia River, Washington.

MOVEMENTS OF NORTHERN PIKEMINNOW IN THE RESERVOIR, FOREBAY AND TAILRACE OF THE WELLS HYDROELECTRIC PROJECT COLUMBIA RIVER, WASHINGTON

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ABSTRACT

Northern pikeminnow have been identified as an important predator of juvenile salmonid downstream of hydroelectric dams. Interest in collecting pikeminnow behavior information focused on increasing the effectiveness of pikeminnow control programs conducted in the reservoir and tailrace of Wells Dam. Objectives of the study included qualitatively comparing pikeminnow movements to river condition, juvenile fish migrations and hatchery releases. Additional objectives included identifying feeding and spawning aggregations of pikeminnow in the Columbia River near Wells Dam.

Radio-telemetry was determined to be the most effective means to collect detailed information on pikeminnow behavior. A total of forty-one pikeminnow were surgically implanted with miniaturized radio-transmitters and released into the Columbia River near Wells Dam. Between May 20 and June 5, 1997, twenty-two adult pikeminnow were tagged and released below Wells Dam and sixteen pikeminnow were tagged and released in the reservoir above the dam. On June 26, 1997, three pikeminnow were collected in the Wells tailrace, tagged and relocated to release sites in Lake Pateros.

Radio-tagged pikeminnow averaged 405 mm long and weighed 649 g. Average age was estimated to be 8 years. Thirty-eight mobile telemetry surveys were conducted on the Columbia, Okanogan and Methow rivers. Surveys started in May and continued until August 1997.

On average, pikeminnow migrated 25.6 km during the three month study. Tailrace fish traveled an average of 26.4 km and reservoir fish averaged 26.3 km. Seven percent of the fish tagged in 1997 stayed within one km of the initial release site. Twenty-nine percent of the tagged fish migrated at least 40 km. Thirty-two percent of the tailrace and thirty-one percent of the reservoir fish migrated at least 40 km. Two fish (5%) tagged in the forebay of Wells Dam migrated over 80 km during the study. By August 1997, the distribution of tailrace released pikeminnow stretched from the mouth of the Entiat River to the tailrace of Chief Joseph Dam and included the lower 20 km of the Okanogan River.

Patterns in pikeminnow movements included a pronounced migration of tagged fish to Chelan Falls. This migration included both tailrace and reservoir released fish. The migration to Chelan Falls occurred during water temperatures between 15 and 17 C. Fifty-two percent of the tailrace and twenty percent of the reservoir fish migrated to Chelan Falls during June and July 1997. By the first week of August, there were no radio-tagged pikeminnow in the vicinity of Chelan Falls. After spawning, seventy-nine percent of the Chelan Falls spawners had moved back upstream toward Wells Dam. The remaining twenty-one percent of the Chelan Falls spawners were last detected downstream of Chelan Falls. Sixty-six percent of the reservoir and nine percent of the tailrace fish detected at Chelan Falls ascended Wells Dam and migrated into Lake Pateros.

Recaptures of radio-tagged pikeminnow occurred between June 1997 and August 1998. In that time, thirty-two percent of the total radio-tagged pikeminnow population was recaptured. Seven percent of the tags were recovered from osprey nests and twenty-four percent of the tags were recaptured by pikeminnow anglers.

In 1997 and 1998, anglers recaptured seven percent and seventeen percent of the total number of radio-tags released. A single radio-tagged pikeminnow was recaptured in 1999 however no tag specific information was provided to the authors. Pikeminnow anglers recaptured eleven percent of the reservoir and thirty-five percent of the tailrace pikeminnow. Upon recapture in 1998, radio-tagged fish had grown an average of 7.2% in length and 14.6% in weight.

Two spawning aggregations and one feeding aggregation of pikeminnow were discovered in 1997. Spawning aggregations were located at Chelan Falls and in the eastern portion of the Wells tailrace. The only feeding aggregation discovered in 1997 was located in the Wells Fish hatchery outfall. Both spawning locations have been successfully exploited during pikeminnow removal efforts conducted by Douglas PUD in 1998 and 1999.

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INTRODUCTION

Northern pikeminnow (*Pytchochelius oregonensis*) are omnivorous fish native to the lakes, streams and rivers of western North America. Northern pikeminnow have been identified as an important predator of juvenile salmonids particularly in association with large Columbia and Snake river hydroelectric projects (Poe et al., 1991). The diet of pikeminnow is rather diverse and often includes freshwater crustaceans and mollusks, aquatic and terrestrial insects and for larger sized pikeminnow, juvenile fishes are also frequently consumed (Wydoski and Whitney, 1979). In the Mid-Columbia River, juvenile fishes were the most abundant food item found in the stomachs of pikeminnow sampled in the spring of 1993 (Burley and Poe, 1994). Crayfish was the most abundant prey item found in the stomachs of pikeminnow sampled during the summer of 1993.

Adult Northern pikeminnow frequently congregate downstream of hydroelectric projects beginning in late April (Sims et al., 1977; Sims et al., 1978; Rieman et al. 1991). At times, juvenile salmonids can become stunned, disoriented or artificially concentrated as they pass through hydroelectric facilities. Aggregations of pikeminnow immediately downstream of hydroelectric dams can resultantly consume large numbers of migrating juvenile salmonids.

Large aggregations of pikeminnow have been observed in the tailraces of many Columbia River hydroelectric projects (Buchanan et al., 1981; Lynch, 1993; Gessel et al., 1994). Lynch (1993) estimated the population of pikeminnow present in the tailrace of The Dalles Dam to be between 1,743,339 to 162,748 fish when using the Peterson and Schnabel mark-recapture estimators. Gessel et al, (1994) estimated pikeminnow abundance at the forebay and reservoir of Bonneville Dam, using the Petersen, Schnabel and Schumacher-Eschmeyer estimators. Gessel et al. (1994) estimated that between 54,480 and 61,828 pikeminnow were present in the forebay and reservoir of Bonneville Dam. During both studies, the migratory behavior of pikeminnow potentially biased the resultant population estimates.

Pikeminnow removal efforts at the Wells Hydroelectric Project were initiated in 1995 based upon information collected during predator indexing studies in the Mid-Columbia River (Burley and Poe, 1994). The 1995 removal effort evaluated the effectiveness of using setlines, gillnets and sports angling equipment to remove adult pikeminnow from the Wells tailrace. Catch peaked during the first two weeks of July when water temperatures approached 15 degrees Celsius (C) (Bickford and Klinge, 1996). Population estimates in 1995 ranged from 17,892 to 10,761 pikeminnow when derived with the Peterson and Schnabel abundance estimators, respectively.

Removal efforts were expanded during the summer of 1996. Peterson and Schnabel population estimates were not estimable for the data collected during 1996. Consequently, a Modified Chapman Abundance Estimator was used to estimate the tailrace population of pikeminnow. The Chapman model estimated that 5,111 pikeminnow were present in the Wells tailrace during 1996. However, population estimates from 1995 and 1996 were likely biased as a result of tagged individuals immigrating from the sampling domain. Recaptures of tagged fish long distances from

the sampling domain indicated that adult pikeminnow had the potential to exhibit highly migratory behaviors below Wells Dam.

Trends in catch per unit effort may also be related to the movement of pikeminnow into and out of the Wells tailrace. Typically, catch rates increase during June and July and abruptly decrease during late July and early August (Bickford, 1997). Water temperature is thought to be the controlling factor for pikeminnow reproduction, migration and catchability (Wydoski and Whitney, 1979; Lynch, 1993; Burley and Poe, 1994; Jerald, 1999).

Interest in determining the mechanism behind pikeminnow behavior at Wells Dam revolved around the development of efficient pikeminnow removal efforts. In theory, the most effective population control program would emphasize control activities tailored to exploit the life history of pikeminnow.

To date, most pikeminnow behavior studies have focused on pikeminnow behavior relative to dam operations and major structural modifications at dams (Hansel et. al. 1993, Issak and Bjornn 1994). The 1997 pikeminnow telemetry program was designed to monitor pikeminnow behavior during the subyearling chinook outmigration (June 15 – August 15) and during pikeminnow spawning (July).

The primary goal of the pikeminnow behavior study was to increase the District's understanding of pikeminnow movement in the waters associated with Wells Dam. Radio-telemetry was selected as the most appropriate assessment tool. Objectives of the pikeminnow telemetry study included: 1) qualitatively assessing the behavior of pikeminnow at Wells Dam relative to juvenile salmonid migrations, river conditions and hatchery releases and 2) locating spawning aggregations of pikeminnow in the Mid-Columbia River.

METHODS

Study Area

The Wells Hydrocombine generating facility is located at R km 830.1 on the Columbia River (Figure 1). The Wells Hydrocombine, unlike typical Columbia River hydroelectric projects, efficiently combines generation, spill and fish facilities into one structure. The generation facilities at Wells Dam contain ten Kaplan turbines that have a generation capacity of 840,000 kilowatts of electricity. Juvenile fish are bypassed away from turbines via a highly effective surface collection system. The Wells bypass system provides a safe, non-turbine passage route through the dam for over 90% of the spring and summer migrants. Wells is the upper most generating project that adult anadromous chinook, steelhead and sockeye salmon migrate through on the Columbia River. The reservoir formed by Wells Dam is called Lake Pateros. The Methow and Okanogan rivers, located at R km 843.1 and 858.6, respectively flow directly into Lake Pateros (Figure 2).

The Methow and Okanogan rivers are important production areas for Columbia River anadromous salmonids including spring, summer and fall chinook (*Oncorhynchus tshawytscha*) summer steelhead (*O. mykiss*), and sockeye salmon (*O. nerka*). Northern pikeminnow can be found throughout the Wells tailrace, Lake Pateros and Lake Pateros tributary streams.

Collection of Study Animals

Adult pikeminnow were collected for tagging with sport fishing and commercial setline equipment. Both bait and lures were used to entice fish to bite. Collection areas included the Wells Fish Hatchery outfall channel, the Wells tailrace and forebay and various sites throughout Lake Pateros including inundated sections of tributary streams.

Biological Assessment

The Fulton-type condition factor formula was used to calculate the condition of each fish at the time of tagging and at the time of final recapture. The equation for condition factor was based on the following equation:

$$KTL = (W/L^3)X$$

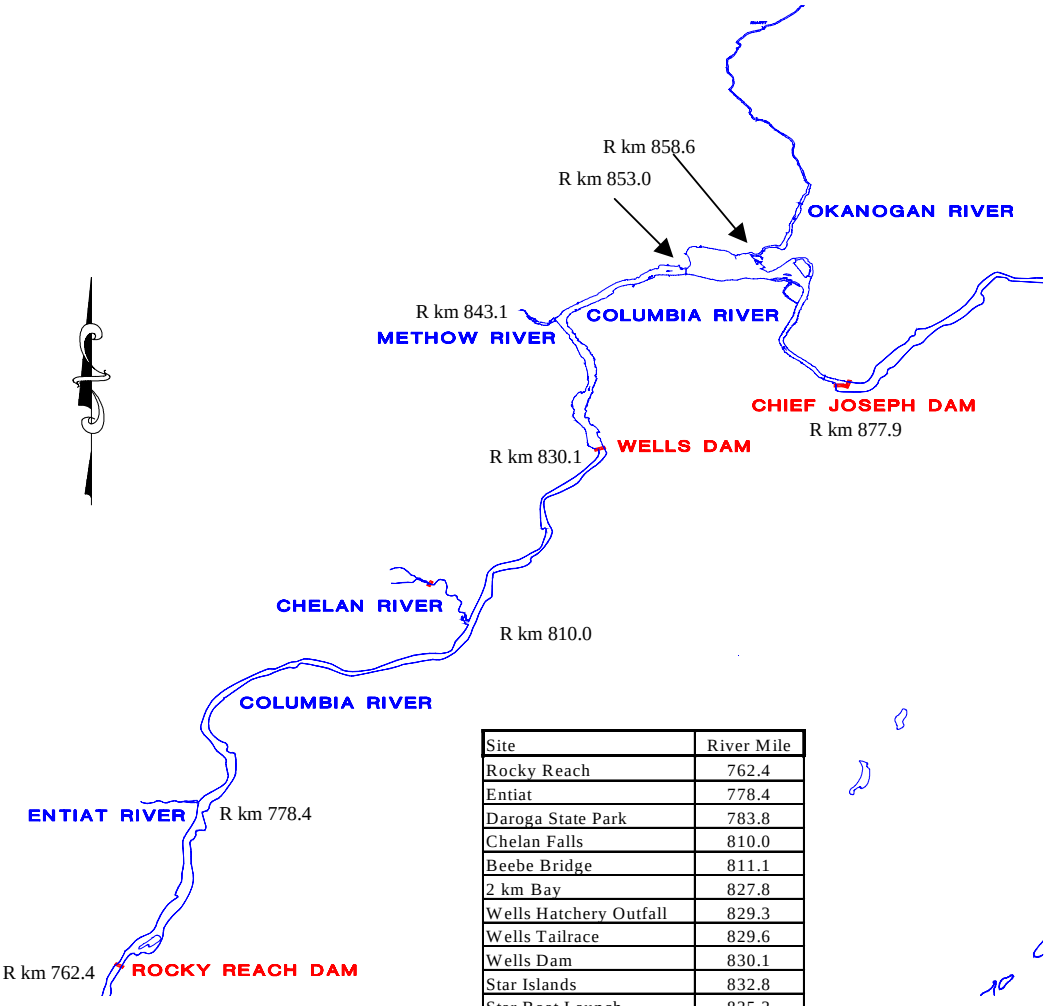
where

KTL = condition factor for metric units
W = weight of fish in grams
L = total length of fish in mm
$X = 10^5$ (arbitrary constant to increase KTL to a size of easier comprehension).

The age of each tagged pikeminnow was estimated based upon an existing fork length to age relationship developed by Wydoski and Whitney (1979) (Figure 3). When practical, the gender and sexual maturity of each fish was recorded at the time of tagging and upon recapture.

Figure 1. Mainstem Columbia and Snake rivers depicting important hydroelectric projects.

Figure 2. Important landmarks used during the 1997 Wells Pikeminnow telemetry study.



Site	River Mile
Rocky Reach	762.4
Entiat	778.4
Daroga State Park	783.8
Chelan Falls	810.0
Beebe Bridge	811.1
2 km Bay	827.8
Wells Hatchery Outfall	829.3
Wells Tailrace	829.6
Wells Dam	830.1
Star Islands	832.8
Star Boat Launch	835.3
Star Ranch	836.9
Pateros	843.1
Central Ferry Canyon	849.7
Brewster	853.0
Okanogan River	858.6
Park Island	867.4
Colville Tribal Hatchery	872.3
Bridgeport	873.9
Foster Creek	876.5
Chief Joseph Dam	877.9

Figure 3. Age at fork length relationship for northern pikeminnow collected from Idaho lakes and reservoirs (Widoski and Whitney, 1979).

Radio-Tagging

The procedure used to surgically implant miniaturized radio transmitters was similar to the techniques described by Hart and Summerfelt (1975), Bigood (1980), and Issak and Bjornn (1992). Disposable plastic surgical gloves were worn to prevent infection. All surgical equipment, including the transmitters, was sterilized in an aqueous solution containing 5% chlorhexidine prior to surgery. The fish were anesthetized in a tub containing 250mg/L of MS-222 for approximately 4 minutes or until the fish exhibited very slow gill aspiration rates. The weight (g) and fork length (mm) of each tagged pikeminnow was recorded prior to tag insertion. Pikeminnow smaller than 350g were not radio-tagged. At smaller fish weights, the radio-tag would have represented greater than 2% of the fish's total body weight (Winter, 1983). The tagged fish were then placed on an inverted V-board lined with wet paper towels. A scalpel was used to make the initial incision. The initial incision was made posterior of the mid-ventrally line, 2 cm anterior to the pelvic girdle. The incision was then finished with surgical scissors. The total length of the incision was 4 cm. A 16-gauge hypodermic needle, threaded with the tag's antenna and held in place with a steel rod extension, was guided into the incision and moved directly under the body wall until the antenna exit was reached. The antenna exit was located mid-ventrally directly between the pelvic fins and anus. The needle pierced the skin at the antenna exit site and the extension rod and antenna were pulled out of the exit hole. The antenna exit did not require stitches. The hypodermic needle and rod were then removed. The radio-tags were inserted through the incision into the body cavity. The transmitter was then positioned directly under the abdominal incision. The incision was closed with ETHICON synthetic absorbable sutures. Three simple interrupted surgical stitches were used to close the incision. A drop of oxytetracycline was applied to the surface of the incision and antenna exit hole. The tagged fish was then returned to a 115 liter (L) freshwater cooler for recovery. When the fish regained equilibrium and maintained an upright swimming position, it was returned to the river.

Radio Tracking

Mobile monitoring of radio-tagged pikeminnow was accomplished by foot, boat, truck and by airplane. The study area included the lower 20 km of the Methow River, the entire Okanogan River from the mouth to Zosel Dam, all of Lake Pateros and from the forebay of Rocky Reach Dam to the tailrace of Wells Dam.

Two SRX-400A telemetry receivers (Lotek Engineering Inc.) were used during the study. These receivers were connected to several different antenna arrays including a 4-element unidirectional yagi antenna, a 3-element fold down unidirectional yagi antenna and two bidirectional H-antennas. Noise attenuating headsets were also used during boat and aerial surveys to reduce audible noise. Forty digitally coded 3-volt Lotek MCFT-3B radio-transmitters were utilized during the study.

Each tag measured 43 mm in length and 11 mm in width and weighed 10.5 g in air and 4.3 g in water. Each tag emitted a uniquely coded signal once every five seconds. The minimum rated life span for each tag was 238 days with a 50% life expectancy of 358 days. The radio-tags operated at a frequency of 146 MHz spread across channels 1 (149.020MHz), 2 (149.040MHz), 3 (149.060MHz) and 4 (149.080MHz). Each channel contained 10 codes from code 21 through code 30. Once tagged, each pikeminnow was assigned a three-digit reference number that corresponded with the channels and codes of the tags used during the study (Table 1).

Lotek SRX-400A receivers were utilized for radio-transmitter interrogation. Upon locating and coding a tagged individual, the three digit fish number, time, date, location, depth, temperature and general habitat characteristics of the site were recorded.

Table 1: Radio-tagged pikeminnow numbering system based on tag frequency (channel) and code.

Channel:	Channel 1	Channel 2	Channel 3	Channel 4
Frequency:	149.020	149.040	149.060	149.080
Code	fish #	fish #	fish #	fish #
21	121	221	321	421
22	122	222	322	422
23	123	223	323	423
24	124	224	324	424
25	125	225	325	425
26	126	226	326	426
27	127	227	327	427
28	128	228	328	428
29	129	229	329	429
30	130	230	330	430

RESULTS

Collection of Study Animals

From May 15 to July 7, the pikeminnow telemetry crew fished for a total of 69 hours, capturing 43 northern pikeminnow for a catch-per-unit-effort (CPUE) of 0.6 (Table 2). Due to the lower densities of pikeminnow in Lake Pateros, commercial setlines were utilized. Setlines produced a catch of 20 fish during a total of 271 hours fishing for a CPUE of 0.1 (Table 3). The most productive fishing baits included lamprey ammocetes or juvenile smolts collected during fyke net sampling. Lures, clams, crayfish and worms were also used with limited success. No incidental fishes were captured during the 1997 pikeminnow telemetry study.

Biological Assessment

Of the 63 pikeminnow collected, 41 were of an appropriate size and condition to be candidates for tagging. The average weight of tagged fish was 694 g (range 375 – 1375g) with an average fork length of 405 mm (range 330 – 500mm) (Table 4). Condition factor for tagged pikeminnow ranged from 0.81 to 2.26 with an average of 1.03. The average age of each tagged fish was estimated based upon length at age data collected from rivers in Idaho (Wydoski and Whitney, 1979). The average age of fish tagged during the study was 8 years with a range of ages from 6 to over 10 years old (Table 4).

Radio-Tagging and Release

On average, radio-tagged pikeminnow were released within 15 minutes of initial capture. Exceptions included eleven pikeminnow captured on May 15 and 19, 1997. All eleven tagged fish were retained and observed for several days prior to being released back into the Columbia River. Fish retained for observation were released the week of May 20 –28, 1997. Other notable exceptions to the 15-minute collection, tag and release protocol included three pikeminnow that were captured in the Wells Hatchery outfall and relocated to reservoir release sites on June 26, 1997 (Table 5). Pikeminnow were relocated to provide information on home fidelity.

Pikeminnow behavior in the Wells tailrace was monitored through the collection, tagging and release of fish below the dam. The week of May 20 – 28, 1997 twenty pikeminnow were tagged and released at the Wells Hatchery outfall (Fish #122, #125, #127, #128, #130, #121, #123, #124, #126, #129, #222, # 221, #324, #329, #423, #224, #328, #421, #422 #427). Tag #427 was recovered on July 2, 1997 without the fish. Osprey predation was suspected. Tag #427 along with the single remaining unused radio-tag (Tag #330) were each individually implanted into new fish (Fish #427(2), #330) on July 7, 1997. Both tagged pikeminnow were released back into the hatchery outfall the same day that they were collected (Table 5). A total of 22 radio-tagged pikeminnow were released downstream of Wells Dam.

Pikeminnow behavior in Lake Patoros was monitored through the implantation of radio-tags into fish collected and released throughout the Wells reservoir. On May 27, June 9 and June 13, 1997 seven pikeminnow (Fish #425, #327, #227, #229, #426, #429, #430) were captured, tagged and released in Lake Pateros within 4.0 km of Wells Dam. On June 19 and 27, 1997, eight pikeminnow (Fish #225, #230, #321, #226, #228, #323, #325, #326) were captured, tagged and released in Lake Pateros, one km south of the Methow River. Fish #424 was collected and tagged in the tailrace of Chief Joseph, 67.6 km upstream from Wells. Fish #424 was collected and released on June 5, 1997. A total of 16 radio-tagged pikeminnow were collected, tagged and released into Lake Pateros.

In order to gain insight into pikeminnow homing fidelity, three pikeminnow were collected from the tailrace, tagged and released into Lake Pateros. All three fish were collected from the tailrace of Wells Dam on June 26, 1997. After being tagged, the three fish were transported by truck upstream to reservoir release sites. Two of the relocated fish (Fish #223, #322) were released into the Okanogan River, 2.4 km upstream of the confluence of the Okanogan and Columbia rivers. The remaining radio-tagged fish (Fish #428) was released into the Columbia River near Brewster (Table 5).

Table 2: Catch-per-unit-effort (CPUE) for pikeminnow collected with sport angling gear during the 1997 radio-tagging study.

Date	Location	Time (hours)	# of fish	CPUE	average CPUE
15-May	WHO	6	17	2.8	
19-May	WHO	2	8	4.0	
27-May	WHO	3	3	1.0	
28-May	WHO	5	5	1.0	
7-Jul	WHO	2	3	1.5	
26-Jun	TR	3	3	1.0	below dam 1.9
21-May	FB	8.5	1	0.1	
22-May	FB	8.5	0	0.0	
27-May	FB	2	1	0.5	
29-May	FB	7	0	0.0	
2-Jun	FB	4	0	0.0	
4-Jun	FB	2	1	0.5	
5-Jun	BRIDG	16	1	0.1	above dam 0.1
Total		69	43		0.6

Location codes below the dam: WHO (Wells Hatchery outfall), TR (tailrace).
Location codes above the dam: FB (forebay), BRIDG (Bridgeport).

Table 3: Catch-per-unit-effort (CPUE) for pikeminnow collected with setlines during the 1997 radio-tagging study.

Date	Location	Time (hours)	# of fish	CPUE	average CPUE
9-Jun	FB	4.5	1	0.2	
11-Jun	FB	8	0	0.0	
12-Jun	FB	72.5	8	0.1	
16-Jun	PAT	48	0	0.0	
17-Jun	PAT	54	0	0.0	
18-Jun	PAT	30	4	0.1	
23-Jun	PAT	28	1	0.0	
26-Jun	PAT	26	6	0.2	
Total		271	20		above dam 0.1

Location codes above the dam: FB (forebay), PAT (Pateros, mouth of the Methow River).

Table 4: Length, weight, condition factor and estimated age for forty-one pikeminnow radio-tagged at Wells Dam, 1997.

Fish # Channel/Code	FL (mm)	Weight (g)	Condition Factor	Estimated Age
121	380	1239	2.26	7
122	490	1375	1.17	10
123	400	1040	1.63	8
124	415	852	1.19	8
125	420	800	1.08	8
126	380	754	1.37	7
127	330	467	1.30	6
128	370	536	1.06	7
129	390	806	1.36	7
130	340	550	1.40	6
221	365	512	1.05	7
222	350	537	1.25	6
223	430	701	0.88	9
224	420	647	0.87	9
225	430	704	0.89	9
226	390	555	0.94	7
227	350	424	0.99	6
228	360	404	0.87	6
229	440	753	0.88	9
230	410	724	1.05	8
321	400	533	0.83	8
322	370	515	1.02	7
323	360	405	0.87	6
324	358	512	1.12	6
325	480	900	0.81	10
326	380	550	1.00	7
327	440	690	0.81	9
328	443	651	0.75	9
329	500	1135	0.91	10
330	390	375	0.63	6
421	335	365	0.97	6
422	470	1025	0.99	10
423	347	425	1.02	6
424	390	412	0.69	7
425	385	690	1.21	7
426	430	600	0.75	9
427	480	761	0.69	10
427’	460	950	0.98	10
428	480	1200	1.09	10
429	480	904	0.82	10
430	370	470	0.93	7
Average	405	694	1.03	8

Table 5: Capture, tagging and release information for radio-tagged pikeminnow, Wells Dam, 1997.

Tag #	Fish #	Capture Date	Capture Location	Date Tagged	Date Released	Release Location	Field Comments
			BELOW WELLS				
1	122	15-May	WHO	20-May	20-May	WHO	Lab surgery, female
2	125	15-May	WHO	21-May	21-May	WHO	Lab surgery
3	127	15-May	WHO	22-May	22-May	WHO	Lab surgery
4	128	15-May	WHO	22-May	22-May	WHO	Lab surgery
5	130	15-May	WHO	22-May	22-May	WHO	Lab surgery
6	121	19-May	WHO	20-May	20-May	WHO	Lab surgery, female
7	123	19-May	WHO	20-May	20-May	WHO	Lab surgery, female
8	124	19-May	WHO	20-May	20-May	WHO	Lab surgery
9	126	19-May	WHO	22-May	22-May	WHO	Lab surgery
10	129	19-May	WHO	22-May	22-May	WHO	Lab surgery
11	222	19-May	WHO	27-May	27-May	WHO	
12	221	27-May	WHO	27-May	27-May	WHO	
13	324	27-May	WHO	27-May	27-May	WHO	
14	329	27-May	WHO	27-May	27-May	WHO	Female
15	423	27-May	WHO	27-May	27-May	WHO	
16	224	28-May	WHO	28-May	28-May	WHO	
17	328	28-May	WHO	28-May	28-May	WHO	Scrapes, slow recovery
18	421	28-May	WHO	28-May	28-May	WHO	
19	422	28-May	WHO	28-May	28-May	WHO	Female
20	427	28-May	WHO	28-May	28-May	WHO	Tag recovered
21	330	7-Jul	WHO	7-Jul	7-Jul	WHO	
20’	427(2)	7-Jul	WHO	7-Jul	7-Jul	WHO	Male, tag re-used

Location codes below Wells: WHO (Wells Hatchery outfall), w (west), TR (Wells tailrace).
Location codes above Wells: e (east), w (west), FB (forebay), PAT (Pateros, Methow River mouth), BREW (Brewster), OK (mouth of Okanogan River), and BRIDG (Bridgeport).

Table 5: (Continued).

Tag #	Fish #	Capture Date	Capture Location	Date Tagged	Date Released	Release Location	Field Comments
			ABOVE WELLS				
22	425	27-May	eFB	27-May	27-May	eFB	
23	327	9-Jun	eFB	9-Jun	9-Jun	eFB	
24	227	13-Jun	eFB	13-Jun	13-Jun	eFB	
25	229	13-Jun	eFB	13-Jun	13-Jun	eFB	
26	426	13-Jun	eFB	13-Jun	13-Jun	eFB	
27	429	13-Jun	eFB	13-Jun	13-Jun	eFB	One eye
28	430	13-Jun	eFB	13-Jun	13-Jun	eFB	Male
29	225	19-Jun	wPAT	19-Jun	19-Jun	wPAT	Maxillary rip, slow recovery
30	230	19-Jun	ePAT	19-Jun	19-Jun	ePAT	
31	321	19-Jun	wPAT	19-Jun	19-Jun	wPAT	
32	226	27-Jun	ePAT	27-Jun	27-Jun	ePAT	Slow recovery
33	228	27-Jun	ePAT	27-Jun	27-Jun	ePAT	
34	323	27-Jun	ePAT	27-Jun	27-Jun	ePAT	Slow recovery
35	325	27-Jun	ePAT	27-Jun	27-Jun	ePAT	Slow recovery
36	326	27-Jun	ePAT	27-Jun	27-Jun	ePAT	
37	223	19-Jun	wTR	19-Jun	19-Jun	OK	Relocation
38	322	19-Jun	wTR	19-Jun	19-Jun	OK	Relocation
39	428	19-Jun	wTR	19-Jun	19-Jun	BREW	Relocation, female
40	424	5-Jun	BRIDG	5-Jun	5-Jun	BRIDG	

Location codes below Wells: WHO (Wells Hatchery outfall), w (west), TR (Wells tailrace).
Location codes above Wells: e (east), w (west), FB (forebay), PAT (Pateros, Methow River mouth), BREW (Brewster), OK (mouth of Okanogan River), and BRIDG (Bridgeport).

Radio Tracking

Forty-one Northern pikeminnow were radio-tagged and mobile tracked within Lake Pateros, Lake Entiat and the Methow and Okanogan rivers during 1997. Radio-tracking commenced on May 15, 1997 and continued five days per week until August 12, 1997. Various modes of transportation were utilized during radio-tracking including the use of a boat, a truck and an airplane. Each week the entire study area was surveyed at least once for a total of 38 surveys. Mobile tracking in the proximity of Wells Dam was conducted five days a week throughout the study. Tracking was conducted during both day and night. No differences were detected in the detection efficiency of nighttime versus daytime radio-tracking efforts.

Tag Recaptures

Recaptures of radio-tagged pikeminnow occurred over a fourteen month period beginning July 1997 and continuing until August 31, 1998. During that time, thirteen (32%) of the forty-one radio-tagged pikeminnow were recovered. Three (23%) of the recaptured radio-tags were found inside osprey nests during the summer of 1997. Ten (77%) of the recaptured radio-tagged pikeminnow were collected by anglers operating in the tailrace of Wells Dam. Anglers recaptured three radio-tagged fish in 1997 and seven in 1998. In addition to the thirteen radio-tags recaptured between July 1997 and August 1998, one additional radio-tag was recaptured in June 1999 by an angler operating in the Wells tailrace. Unfortunately, the tag channel and code from the single 1999 recapture was not reported to the District.

Eight (35%) of the radio-tagged pikeminnow released into the Wells tailrace were recaptured by anglers fishing in the tailrace during 1997 and 1998. During the same time period, two (11%) of the Lake Pateros radio-tagged pikeminnow were also recaptured by anglers fishing in the Wells tailrace. Specific details related to the movements of individual radio-tagged pikeminnow, including specific behaviors of recaptured fish, can be found in Appendix A.

Upon recapture, the weight and fork length of individual tagged pikeminnow was recorded when practical. Seven pikeminnow tagged in 1997 were recaptured in 1998. The average fork length and weight of these fish increased 7.2% and 14.6%, respectively (Table 6).

Table 6: Length, weight and condition factor for radio-tagged pikeminnow recaptured during 1997 and 1998 (no biological information collected during 1997).

Fish # Channel/ Code	Initial FL (mm)	Initial weight (g)	Initial Condition Factor	Recapture Date	Final FL (mm)	Final weight (g)	Final Condition Factor
121	380	1239	2.26	July 16, 1997	-	-	-
322	370	515	1.02	July 24, 1997	-	-	-
323	360	405	0.87	July 24, 1997	-	-	-
124	415	852	1.19	June 23, 1998	437	1104	1.32
224	420	647	0.87	June 25, 1998	489	1010	0.86
428	480	1200	1.09	July 2, 1998	501	1278	1.02
125	420	800	1.08	July 3, 1998	425	850	1.11
127	330	467	1.30	July 3, 1998	329	530	1.49
228	360	404	0.87	August 10, 1998	410	349	0.51
123	400	1040	1.63	August 16, 1998	431	1078	1.35
Average for fish Recaptured	403	773	1.18		432	886	1.09

Fish Movements
Movement Rates and Distances

Northern pikeminnow radio-tagged and released into the Wells tailrace and into Lake Pateros (n=41) migrated an average of 25.6 km during the summer of 1997 (May - August, 1997). On average, pikeminnow tagged in the Wells tailrace (n=22) traveled 26.4 km during the study. Pikeminnow tagged in Lake Pateros (n=16) traveled an average of 26.3 km during the study. The three fish transported from the Wells tailrace to Lake Pateros traveled an average of 15.6 km.

The range of distances traveled by all 41 fish included three (7%) fish (#121, #223 and #325) that did not leave their initial release sites and twelve (29%) fish (#123, #124, #125, #224, #227, #229, #230, #423, #425 #427, #427(2) and #430) that each migrated over 40 km during the study (Table 7). Thirty-two percent of the tailrace and thirty-one percent of the Lake Pateros radio-tagged pikeminnow migrated over 40 km.

Two (5%) of the more active pikeminnow (Fish #229 and #425) were collected, tagged and released in the forebay of Wells Dam. Both fish migrated downstream through Wells Dam and ended up at Chelan Falls during the spawning period (Appendix A). Both fish later ascended Wells Dam and by August 1997 both fish had arrived in the tailrace of Chief Joseph Dam. Both pikeminnow migrated over 80 km during the study.

Fish #229, was collected, tagged and released into the forebay of Wells Dam on June 13, 1997. This fish was later tracked to a shallow wetland near Starr Boat launch (R km 835.3) on June 18, 1997. Fish #229 then dropped below Wells Dam and was detected at Chelan Falls on July 2 and July 10, 1997. The fish was later detected in the tailrace of Wells Dam on July 17, 1997. Fish #229 was then detected near Bridgeport at R km 871 on July 24, 1997. Fish #229 was later observed in the tailrace of Chief Joseph Dam (R km 877). The last confirmed observation of Fish #229 was on July 28, 1997 at R km 867, 10.5 km downstream of Chief Joseph Dam near Park Island (R km 867.4). Fish #229 traveled over 106.6 km during the 46 day period that this fish was monitored. Fish #229 traveled an average of 2.3 km per day.

Fish #425 exhibited the second longest migration recorded with 84.3 km logged during 1997. Coincidentally #425 was also collected, tagged and released in the Wells forebay. Fish #425 was tagged on May 27, 1997 and was periodically detected near the Starr Boat Launch (R km 835) until June 16, 1997 when the fish disappeared. On June 24, 1997, #425 was tracked to a holding pool at the mouth of the Chelan River. No further observations of this fish were collected until July 28, 1997 when #425 was observed in the tailrace of Chief Joseph Dam (R km 877) along with #229.

Relationships between distances traveled and biological characteristics of pikeminnow were investigated. There were no significant ($p < 0.10$) relationships between the distance individual fish traveled and the length, weight, sex, condition factor and estimated age of the fish.

Table 7: Total distance traveled between reception dates for individual pikeminnow.

Fish #	Dates Tracked (1997)	Total km Traveled	General Movement Pattern
121+	5/21 –6/16	0.0	Wells hatchery outfall and tailrace
122	5/21 – 7/24	39.4	Wells Hatchery outfall to Chelan Falls
123*+	5/21 – 7/21	44.7	Wells Hatchery outfall to Okanogan River
124+	5/21 – 7/24	47.2	Wells Hatchery outfall to Entiat
125+	5/27 – 7/21	63.9	Wells tailrace to Chelan Falls (twice)
126	5/22 – 7/2	19.3	Wells tailrace to Chelan Falls
127+	5/22 – 7/9	19.3	Wells hatchery outfall to Chelan Falls
128	5/22 – 7/15	0.5	Wells hatchery outfall and tailrace
129	5/22 – 7/24	6.9	Wells hatchery outfall and tailrace
130	5/22 – 7/24	7.6	Wells hatchery outfall and tailrace
221	5/28 – 7/24	24.9	Wells tailrace to Beebe Bridge to Chelan Falls
222	5/28 – 7/9	39.6	Wells hatchery outfall to Chelan Falls to Wells tailrace
223	6/26 – 7/1	0.0	Relocated – Okanogan River
224+	5/28 – 7/24	43.9	Wells tailrace to Chelan Falls to Wells tailrace
225	6/19 – 6/27	6.3	Pateros
226	6/27 – 7/24	4.7	Pateros to Methow River
227	6/13 – 7/24	55.5	Wells forebay to Pateros to Okanogan River
228+	6/27 – 7/28	16.1	Pateros to Wells forebay to Pateros
229*	6/13 – 7/28	106.6	Wells forebay to Chelan Falls to Wells tailrace to Chief Joseph
230	6/19 – 7/28	46.7	Pateros to Wells forebay to Chief Joseph
321	6/19 – 6/27	1.6	Pateros and Methow River
322	6/26 – 7/28	10.5	Relocated – Okanogan and Columbia river confluence
323	7/7 – 7/28	9.7	Wells forebay to Pateros
324	5/28 – 7/1	0.5	Wells Hatchery outfall to tailrace
325	6/27	0.0	Wells tailrace
326	6/27 – 7/24	3.1	Pateros and Methow River
327*	6/17 – 7/24	5.8	Wells forebay to Wells tailrace and hatchery outfall
328+	5/28 – 7/24	1.6	Wells Hatchery outfall and tailrace
329+	5/28 – 7/17	2.1	Wells Hatchery outfall and tailrace

(*) Pikeminnow ascended or descended Wells Dam; (**) ascended or descended Wells Dam twice.

(+) Pikeminnow was recaptured during 1997 or 1998.

Table 7: (Continued).

330*	7/7 – 7/24	29.3	Wells tailrace to Bridgeport Bar
421	5/28 – 6/25	0.3	Wells hatchery outfall and tailrace
422	5/28 – 7/24	24	Wells hatchery outfall to Chelan Falls
423	5/28 – 7/12	58.4	Wells to Chelan Falls to Wells to Chelan Falls to Wells
424	6/9 – 7/16	12.1	Bridgeport and Chief Joseph
425**	5/28 – 7/24	84.3	Wells forebay to Chelan Falls to Chief Joseph
426	6/18 – 7/28	17.5	Forebay to Methow River to forebay
427	5/28 – 7/24	63.7	Wells hatchery outfall to Chelan Falls to hatchery outfall
427(2)	7/7 – 7/24	45.1	Wells hatchery outfall to Chelan Falls to hatchery outfall
428+	7/1 – 7/24	36.2	Relocated – Brewster to Pateros to Okanogan River
429	6/13 – 7/28	8.5	Wells Forebay
430	6/13 – 7/24	42.6	Wells forebay to Okanogan River

(*) Pikeminnow ascended or descended Wells Dam; (**) ascended or descended Wells Dam twice.

(+) Pikeminnow was recaptured during 1997 or 1998.

Pikeminnow Movement Patterns – Tailrace Tags

Patterns of movement for radio-tagged pikeminnow released into the Wells tailrace and hatchery outfall included a pronounced migration (12 fish or 52%) of fish to Chelan Falls during June and July. The peak of this movement took place at water temperatures between 15 and 17 C. In 1997, pikeminnow spawning was observed in the Wells tailrace at water temperatures between 15 to 17 C. Of the 22 pikeminnow tagged and released into the Wells tailrace, nine (41%) stayed within 5 km of the Wells tailrace during 1997. Fifty-two percent (n = 12) of the tailrace tagged pikeminnow made migrations to Chelan Falls in 1997. Seventy-five percent (n = 9), of the 12 fish that visited Chelan Falls, returned to the Wells tailrace by August 1997. One tagged fish (Fish #125) made two trips from the Wells tailrace to Chelan Falls during the span of the three month study (Appendix A).

Two (7%) of the fish that migrated to Chelan Falls, continued to move downstream after the spawn. One fish (Fish #124) migrated as far downstream as the Entiat River (R km 778.4) by August 1997. The following year (June 23, 1998) this same fish was recaptured in the Wells Hatchery outfall.

Two (9%) of the tailrace tagged pikeminnow ascended the fish ladders at Wells Dam (Fish #123 and #330). Fish #123 was tagged below Wells on May 19, 1997 and was last recorded on August 5, 1997; 14.5 km up the Okanogan River. Fish #330 was tagged below Wells on July 7, 1997. Fish #330 was last observed on August 12, 1997 when it was located near the confluence of the Okanogan and Columbia rivers (R km 858.6) (Appendix A).

Pikeminnow Movement Patterns – Lake Pateros Tags

Pikeminnow radio-tagged in Lake Pateros moved on average the same distances as fish tagged in the tailrace of Wells Dam (26.4 km tailrace versus 26.3 km Lake Pateros). No overriding migrating pattern was observed for pikeminnow released into Lake Pateros. In total, three (20%) of the fifteen reservoir radio-tagged pikeminnow (Fish #229, #327 and #425) migrated downstream through Wells Dam. Of these three fish, two (13%) (Fish # 229 and # 425) continued to move downstream and ended up at Chelan Falls during the spawning period (June 24 – July 10, 1997). Water temperatures during this period were between 15 and 17 C. The remaining reservoir fish (Fish #327) stayed within three miles of the Wells tailrace for the remainder of the study.

Interestingly, both Fish #229 and #425 migrated back upstream and over Wells Dam during late July 1997. Both fish were last observed in the tailrace of Chief Joseph Dam on July 28, 1997 (Appendix A).

Other interesting reservoir tagged pikeminnow included Fish #227 and #230. Fish #227 was tagged on June 13, 1997 within 4 km of forebay of Wells Dam. Fish #227 was last observed in the Okanogan River on August 3, 1997. This fish was documented migrating over 17.7 km up the Okanogan River (Appendix A).

Fish #230 was tagged near the Methow River on June 19, 1997. Fish #230 later dropped downstream to the forebay of Wells Dam on July 24, 1997 but migrated back upstream and was last observed in the tailrace of Chief Joseph Dam on August 12, 1997.

Two (13%) of the Lake Pateros radio-tagged pikeminnow were consumed by osprey. Conversely, only one (4.5%) of the tailrace released pikeminnow was consumed by an osprey.

Pikeminnow Movement Patterns – Relocated Tags

Three pikeminnow were radio-tagged and relocated to reservoir release sites during the 1997 telemetry study. All three fish were collected in the Wells tailrace. Only one (33%) of the three relocated pikeminnow successfully returned to the collection site, over 26 km downstream of the release site. Confirmation of the presence of this fish in the Wells tailrace was collected one year later by a pikeminnow angler. The fish was recaptured near the original collection site. The tag from the second relocated pikeminnow was collected from an osprey nest near the reservoir release site. The third relocated pikeminnow migrated over 20 km up the Okanogan River and was not observed again after August 7, 1997.

Pikeminnow Movement Patterns – Overall

Pikeminnow fishway counts and radio-tag movements were examined relative to river conditions, juvenile salmonid migrations and hatchery releases at Wells Dam. Relationships between river conditions and pikeminnow movements in 1997 indicate a pronounced increase in pikeminnow activity after water temperatures reached 16 C. Ladder counts of pikeminnow also appear to increase at water temperatures of 16 C (Figure 4).

The relationship between water temperature and pikeminnow ladder counts at Wells Dam was investigated. There appears to be a significant ($R^2 = 0.45$, $p < 0.01$) linear relationship between pikeminnow ladder counts and water temperatures between 15 and 18 C (Figure 5).

Pikeminnow fishway counts and radio-tag movements were compared to the 1997 Wells hydroacoustic index. Pikeminnow fishway counts were used as an index in fish activity. Pikeminnow counts were compared to trends in the hydroacoustic index (Figure 6). There was a significant ($p = 0.03$) negative linear relationship between pikeminnow counts and the Wells summer-time hydroacoustic index of juvenile salmonids (Figure 7). Radio-tag observations of pikeminnow movement in the Wells tailrace also qualitatively indicated an inverse relationship between the number of radio-tagged pikeminnow in the Wells tailrace and the hydroacoustic index of juvenile salmonid. In 1997, 52% of the tailrace radio-tagged pikeminnow were observed migrating downstream, away from the Wells tailrace, during the peak of the subyearling migration (as measured by hydroacoustic transducers). The majority of the pikeminnow that migrated downstream of Wells Dam during this period appeared to be making a spawning migration to Chelan Falls.

Figure 4. Wells fishway counts of pikeminnow relative to Columbia River water temperatures at Wells Dam, 1997.

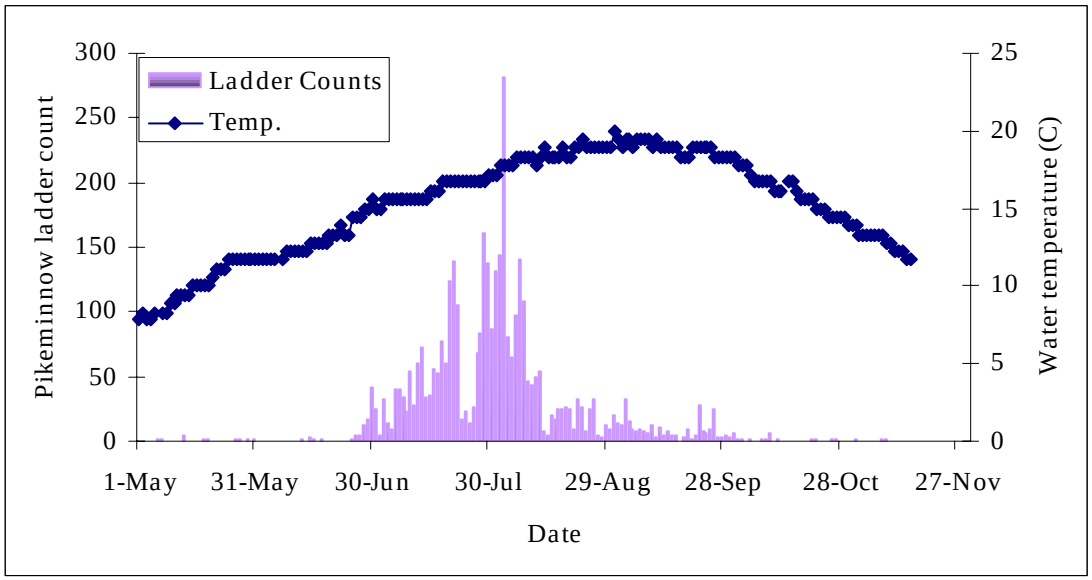


Figure 5. Regression plot of Wells Dam fishway counts of pikeminnow versus Columbia River water temperatures (15 – 18 C), Wells Dam 1997.

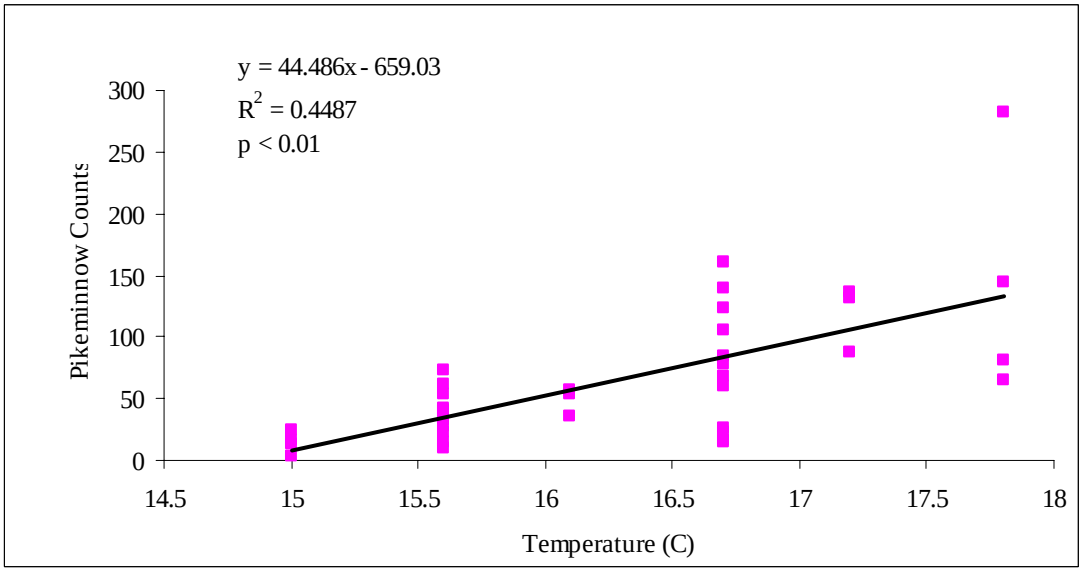


Figure 6. Wells fishway counts of pikeminnow relative to Wells juvenile salmonid hydroacoustic index, 1997.

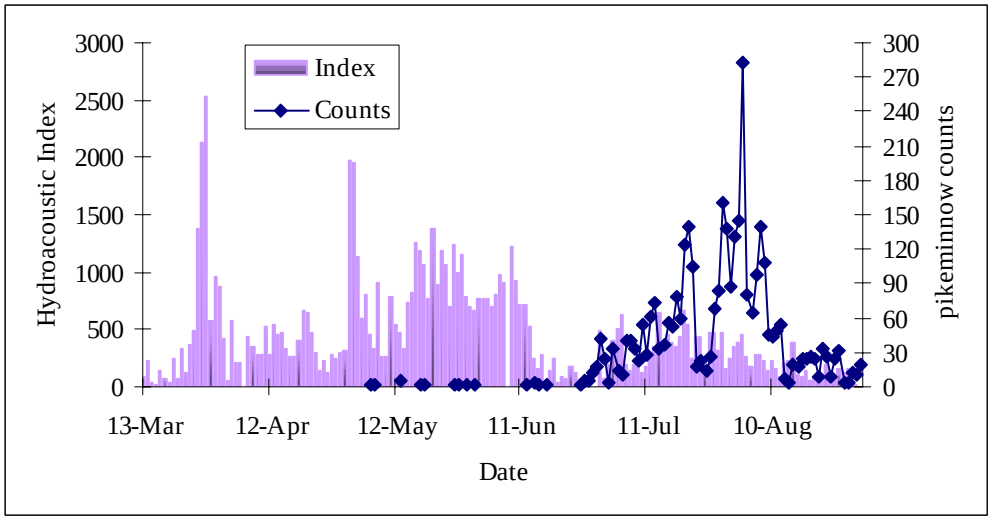
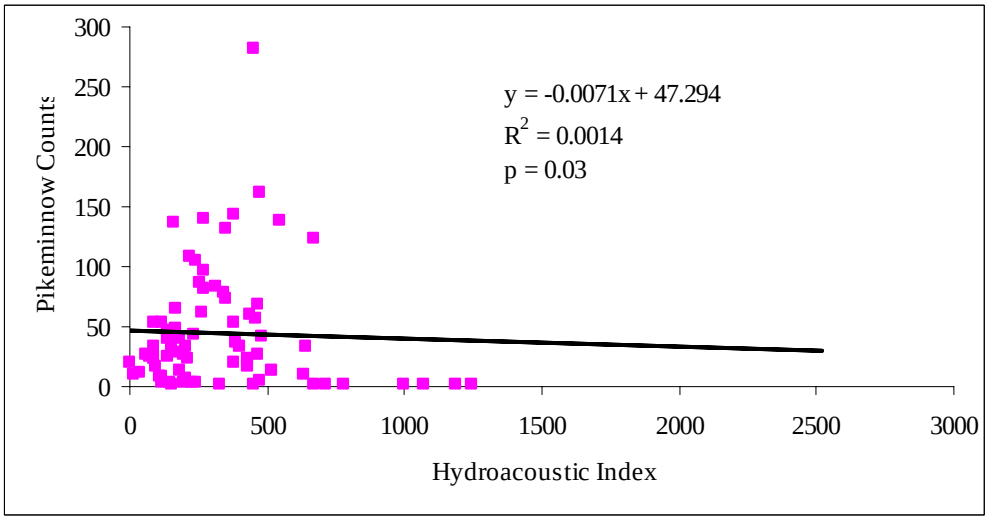


Figure 7. Regression plot of Wells Dam fishway counts of pikeminnow versus hydroacoustic index values, Wells Dam 1997.



DISCUSSION

The goal of the 1997 pikeminnow telemetry study was to increase the District's understanding of pikeminnow behavior in the waters associated with Wells Dam. Particular objectives of the study included; 1) locate spawning and feeding aggregations of pikeminnow in the Columbia River near Wells Dam and 2) qualitatively assess the behavior of pikeminnow relative to juvenile fish migrations, river conditions, and hatchery releases.

To accomplish these objectives, adult pikeminnow were surgically tagged with radio-transmitters and released into the Columbia River prior to the summer migration of juvenile salmonids and prior to the pikeminnow spawning period.

Forty-one radio-tagged pikeminnow were released throughout Lake Pateros and the Wells tailrace. Radio tracking took place during the months of May – August 1997. Tag recaptures continued until August 1999.

Tagged fish averaged 694 mm in length and 405 g in weight. The estimated average age of tagged fish was 8 years old. The majority of these fish were expected to be reproductively mature.

Survival through the tagging procedure was high with 100% of the fish released alive following surgery. Pikeminnow survival after tagging was excellent with all but one of the tagged fish observed on more than one occasion after release. The forty remaining radio-tags were successfully tracked at least twice. Each radio-tagged pikeminnow was observed an average of 11 times between May and August 1997.

Osprey predation was much higher than anticipated, as were rates of recapture by tailrace anglers. Thirteen percent (13%) of the reservoir released fish and four percent (4%) of the tailrace released fish were consumed by osprey. Pikeminnow anglers recaptured 35% of the tailrace released fish and 11% of the reservoir released fish. On average the size of fish radio-tagged in 1997 that were recaptured in 1998 increased in length by 29 mm (7.2%) and weight 133 g (14.6%).

Assuming 100% survival of radio-tagged pikeminnow from 1997 to 1998, a minimum pikeminnow exploitation rate by anglers operating in the Wells tailrace would be 35% in 1998. A minimum estimate of angler exploitation of Lake Pateros pikeminnow would be 11% during 1998.

Objective 1)
Locating spawning and feeding aggregations of pikeminnow in the Columbia River near Wells Dam

Spawning aggregations of pikeminnow were identified in two areas downstream of Wells Dam, one feeding aggregation was also observed in 1997 and a potential spawning site was identified in Lake Pateros. The largest and most interesting aggregation of spawning pikeminnow was located at the confluence of the Chelan and Columbia rivers. Fifty-two percent of the tailrace and thirteen percent of the reservoir released pikeminnow migrated to Chelan Falls during the spawning period.

It is hypothesized that the majority of these fish migrated to Chelan Falls as part of their reproductive cycle. All of the pikeminnow that migrated to Chelan Falls during June and July had left Chelan Falls by August 1997. The reservoir fish that migrated downstream through the dam to spawn at Chelan Falls during June and July all migrated back upstream by the end of August 1997. Two of these fish managed to migrate to Chief Joseph Dam by the end of August 1997.

The second spawning aggregation of pikeminnow was located 0.8 km downstream of Wells Dam on the eastern half of the river. Female radio-tagged pikeminnow arrived at this location during the appropriate spawning window. Thirty-nine percent of the tailrace tagged pikeminnow visited this spawning site in 1997. One tailrace released fish migrated from the Wells tailrace to Chelan Falls twice during the spawning period.

Since 1997, pikeminnow bounty fishermen have successfully exploited the tailrace spawning site during the peak of the spawn.

A feeding aggregation of pikeminnow was observed in the Wells hatchery outfall several days prior to the actual release of subyearling chinook from the Wells Fish Hatchery. Actual numbers of tagged individuals peaked after hatchery flows were increased in the channel to facilitate the collection of chinook broodstock.

The majority of the Lake Pateros released pikeminnow remained widely scattered with few discernable patterns or aggregations observed. However, a small spawning aggregation was observed in the vicinity of Bridgeport Bar. Three tagged pikeminnow converged on a reef near Park Island during the peak of the spawning periods. Verification of spawning at this site was difficult because water depth and shoreline access limited the tracking teams ability to precisely triangulate the position of the fish.

Objective 2)

Qualitatively assess the behavior of pikeminnow relative to juvenile fish migrations, river conditions and hatchery releases.

River temperature proved to be the best predictors of pikeminnow activity at Wells Dam. Radio-tagged pikeminnow activity peaked during the same time period as Wells pikeminnow ladder counts. A significant linear relationship between pikeminnow ladder counts and water temperatures was developed from data collected in 1997. Water temperatures increasing from 15 to 18 C displayed the highest correlation with pikeminnow activity at Wells Dam. This water temperature regime is also closely associated with the reproductive cycle of Columbia River pikeminnow. Peak radio-tagged fish movements, fishway counts, spawning and pikeminnow migrations to Chelan Falls were all highly correlated to water temperatures.

A negative relationship between the Wells hydroacoustic index and adult fishway counts was derived from data collected in 1997. Tailrace observations of tagged fish declined dramatically during the spawn. In 1997 the pikeminnow spawn took place during the peak of the summer subyearling migration through Wells Dam.

Below Wells Dam, pikeminnow activity was focused at the Wells Fish hatchery outfall. In 1997, pikeminnow began to congregate at the outfall two weeks prior to the release of subyearling summer chinook from the hatchery. Pikeminnow numbers continued to climb and peaked after flows into the outfall channel were increased to facilitate brood collection.

Higher water clarity and relatively slow water velocity likely increases the foraging success of pikeminnow aggregation within the vicinity of the Wells Hatchery oufall. Similar water chemistry and hydraulics are found in the Chelan River where water clarity, velocity and water temperatures are considerably different than those found in Lake Entiat. Clear, slow moving water appears to attract pikeminnow during June and July.

At Wells Dam, radio-tagged pikeminnow avoided areas immediately downstream of the powerhouse. Turbulence and a lack of significant velocity refuges appeared to prevent pikeminnow from remaining immediately downstream of Wells Dam. Instead, the majority of radio-tagged pikeminnow congregated near the hatchery outfall or in near shore areas where water velocities were slower relative to the boat restricted zone below Wells Dam.

In Lake Pateros, radio-tagged pikeminnow were frequently found in association with rip rap, boulders and gravel substrates. Few observations of tagged fish coincided with silted or sandy substrates. Interestingly, none of the 15 reservoir radio-tagged pikeminnow migrated into the Methow River. However, three radio-tagged pikeminnow migrated into the Okanogan River during 1997. One pikeminnow migrated over 20 km up the Okanogan and another was observed over 17 km up the Okanogan River.

Four tagged fish were detected in the tailrace of Chief Joseph Dam. Two of these fish were released into Lake Pateros and two were released into the tailrace of Wells Dam.

Movement patterns of tagged fish were similar for tailrace and Lake Pateros tagged fish. Both groups of fish displayed a net migration to the Chelan River during the spawning period followed by a net movement upstream in late July and August. Tailrace and reservoir released fish migrated almost identical distances after release. During the study, tailrace fish migrating 26.4 km and reservoir fish migrating 26.3 km.

There was no significant relationship between distances traveled and fish size, weight, sex, condition factor or fish age.

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APPENDIX A

Spatial depictions of radio-tagged pikeminnow tagged and tracked during 1997 and recaptured in 1998 and 1999 in the upper Mid-Columbia River, Washington. Observation dates and locations noted in maps contained within Appendix A only represent significant movements or changes in location of tagged fish.

Example 1. Fish 121 was observed on 12 occasions including the release and recapture episodes. Fish 121 was not detected outside the immediate hatchery outfall between May 20 and June 16, 1997.

Example 2. Fish 122 was observed on 22 occasions. The majority of these observations took place at the hatchery outfall between May 20, June 2 and July 1, 1997. This fish was also observed at three additional locations on July 24, August 5 and August 7, 1997.

Wells Dam Spillway Total Dissolved Gas Evaluation

27 May to 10 June 2003

FINAL REPORT

December 2003

Prepared for

Public Utility District No. 1 of Douglas County
1151 Valley Mall Parkway
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Preface

This document reports the findings of a study conducted at Wells Dam from 27 May to 10 June 2003. The study was conducted by Columbia Basin Environmental and funded by the Public Utility District No. 1 of Douglas County. The use of trade names in this document should not be interpreted as an endorsement by the District or CBE.

Summary

The Public Utility District No. 1 of Douglas County undertook a study at Wells Dam, located on the Columbia River, to describe total dissolved gas pressures resulting from spill operation by the dam. An array of water quality data loggers were installed in the Wells Dam tailwater for a period of two weeks between 27 May and 10 June, 2003 and programmed to record water temperatures and total dissolved gas pressures along a fifteen-minute interval.

Data indicated that total dissolved gas saturations measured approximately three miles downstream of the project were greater than would have been expected based on the volume of spill reported by the dam. It was estimated that gassing of turbine releases contributed an additional 1.3% to the downstream total dissolved gas saturation. This implied that rather than diluting spillway releases, thus redistributing the total dissolved gas mass, the total pressures of powerhouse releases were increased.

Tracing total dissolved gas saturations through the Wells Dam receiving waters indicated a rapid decrease in total pressures in the immediate tailrace (up to 1.7% decrease per mile for the first 3 miles) followed by a more gradual decrease (decrease of approximately 0.3% per mile) through the subsequent 36 mile long reservoir.

1.0. Introduction

The total dissolved gas (TDG) pressure of water describes the total pressure exerted by the constituent gasses as determined by their concentration and solubility. There are numerous natural and anthropogenic influences on dissolved gas concentrations and pressures including, but not limited to, community metabolism, heating, aeration devices, water falling over dams, weirs, or waterfalls, and turbine venting. It is possible for TDG pressures to exceed the equilibrium pressure resulting in TDG *supersaturation*. Supersaturated water will tend to lose gas to the atmosphere; however, this may be slow in the absence of turbulent flow.

The detrimental effects of the exposure of aquatic organisms to water characterized by elevated dissolved gas pressures were identified as early as 1905 (1905 Marsh and Gorham). Exposure to supersaturated water may result in *gas bubble trauma* (GBT), a condition similar to nitrogen narcosis ("the bends") in divers. As fish move vertically in the water column, gasses dissolved in the bloodstream under greater hydrostatic pressure may rapidly leave solution. This may lead to gill and skin blistering and "pop-eye". The presence of GBT has been documented throughout the Columbia River Basin, the most notable resulting in large fish kills at the John Day Dam (Beiningen and Ebel 1970).

1.1. Site Description

Wells Dam is located on the Columbia River near Azwel, Washington at river mile 515.8 (Figure 1). The project was built as a *hydrocombine* meaning that the spillway is situated directly over the powerhouse. The overall length of the dam is 4460 ft, of which the hydrocombine comprises 1130 ft. The project consists of eleven vertical lift spill gates and ten generating units with a maximum nameplate capacity of 774MW. The hydraulic capacity of the powerhouse is 220 kcfs and the maximum spillway capacity is 1180 kcfs.

Wells Dam spillway operation consists of *forced* spill (inflows exceed the capacity of the powerhouse) or *bypass* spill (spill of a portion of total river volume to assist the out migration of juvenile salmonids). Forced occurs any time the total river discharge exceeds the powerhouse's total capacity. Excess capacity results from low power demand, high total river flows (>220 kcfs at Wells Dam), or in the event of equipment failure. Bypass spill at Wells Dam typically occurs between April and September consisting of approximately 10 kcfs divided equally between Spillbays 2, 4, 6, 8, and 10.

1.2. Background

The water quality standard for TDG pressure for the state of Washington is as follows:

> *Total dissolved gas shall not exceed 110 percent of saturation at any point of sample collection.*

The National Oceanographic and Atmospheric Association Fisheries (formerly the National Marine Fisheries Service) has requested spill at selected hydroprojects within the Columbia River Basin to assist with juvenile salmonid out migrations. The state of Washington developed the following waiver to the aforementioned standard:

Special fish passage exemption for sections of the Snake and Columbia rivers: *When spilling water at dams is necessary to aid fish passage, total dissolved gas must not exceed an average of one hundred fifteen percent as measured at Camas/Washougal below Bonneville dam or as measured in the forebays of the next downstream dams. Total dissolved gas must also not exceed an average of one hundred twenty percent as measured in the tailraces of each dam. These averages are based on the twelve highest hourly readings in any one day of total dissolved gas. In addition, there is a maximum total dissolved gas one hour average of one hundred twenty-five percent, relative to atmospheric pressure, during spillage for fish passage.*

The DCPUD has maintained a permanent TDG fixed monitoring system (TDGFMS) consisting of two Hydrolab® MiniSonde® multiprobes that measure water temperature and TDG pressure throughout the bypass spill season at Wells Dam. The forebay probe (WEL) has been in operation since 1996 and the tailwater probe (WELW) since 1998. Atmospheric pressure data were collected via an aneroid barometer located on the surface deck of the dam. In addition to the TDGFMS, the DCPUD had collected grab data periodically to evaluate lateral and longitudinal distributions in TDG pressure. The results of these studies indicated minor gradients of less than 2% saturation across the width of the tailrace (Klinge 1998).

To better understand the distribution and fate of spilled water from Wells Dam, the Public Utility District No. 1 of Douglas County (DCPUD) undertook a study during the spring of 2003. This document describes the procedures, results, and conclusions of that work.

1.3. Objectives

The following objectives were identified:

1. determine the effectiveness of the tailwater fixed monitor location at representing TDG pressures in the Wells Dam tailwater

2. better define the relationship between spillway release and TDG production at Wells Dam to produce a TDG “rating curve”

3. estimate the degree to which powerhouse releases are impacted by spill

4. quantify the degassing rate of spilled water between the spillway and the tailwater monitor location

2.0. Methods

Deployment of the auxiliary probes was timed to coincide with the spring freshet to capture the widest range of discharges with the minimum impact to normal power generation.

2.1. Instrumentation

An array of Hydrolab® MiniSonde® multi-parameter data loggers were leased for the period of study. Each *sonde* was equipped with sensors for water temperature, TDG pressure, and sensor depth. Prior and subsequent to field deployment, each sonde was calibrated to NIST traceable standards for temperature and TDG pressure. Seven sondes were deployed, in addition to the existing permanent monitoring stations, and programmed to record data at fifteen-minute intervals. Atmospheric pressure data were collected at the forebay TDGFMS location and corrected for the tailwater elevation.

2.2. Field Deployment

Deployment sites were selected to maximize data resolution in key regions centered around the stilling basin and the tailwater TDG monitor location. The study area is depicted in Figure 2. Sondes were divided between two transects (T1 and T2) located approximately 800 feet and 2.9 miles downstream of the dam, respectively. The location of each deployment station was determined via global positioning system (GPS).

Transect 1 (Figure 3) consisted of four sondes leased for the study. Each was housed in a 200 lb. steel case that served to both anchor the station and protect the sonde. Anchors were attached to a series of surface floats via 5/16" diameter steel cables that allowed installation and retrieval by boat. Figure 4 provides an illustration of the deployment rigging used for Transect 1.

Transect 2 (Figure 5) consisted of three leased sondes and the Wells Dam tailwater TDGFMS sonde. Transect 1 was located in the boat restricted zone of the project; therefore, civilian boat traffic was not a concern. Recreational navigation was allowed at Transect 2; however, and the surface deployment method used for Transect 1 was inappropriate. To minimize danger to boat traffic, the sondes were strung across the river in a "necklace" configuration consisting of 5/16" diameter steel cable and 150 lb. steel anchors. Figure 6 provides an illustration of the deployment rigging used for Transect 2. The tailwater TDGFMS (WELW) was permanently deployed in a pipe that and transmitted real time data to the DCPUD headquarters in East Wenatchee, Washington.

A bathymetric survey was conducted using a Garmin® GPSMAP 168 GPS receiver/depth sounder. Data were collected by "cruising" from immediately downstream of Transect 2 upstream to Transect 1. Multiple lateral passes were conducted at Transects 1 and 2 to develop the weighting coefficients used to average water quality data (described in greater detail in Section 2.3).

2.3. Data Analysis

Data collected for the Wells Spillway study were obtained from the following sources:

1. field transect data – water temperature and TDG pressure (mm Hg) reported every fifteen minutes for nine sites (seven auxiliary sondes in addition to the forebay and tailwater TDGFMS)

2. CROHMS data – hourly project operation and water quality data from the Columbia River Operational HydroMet System maintained by the U.S. Army Corps of Engineers

3. fifteen minute project operations data – total project discharge, total spillway discharge, fishway discharge, individual spill gate opening, individual turbine output, and forebay and tailwater elevation reported every fifteen minutes

4. Wells Dam Spill Logs – control room log recording discrete operational changes and the time they occurred

5. bathymetric survey data – latitude, longitude, and depth information for the Wells Dam tailwater collected during boat cruise from Transect 2 (2.9 miles downstream) to Transect 1 (800 feet downstream).

A database was created to assemble the divergent datasets into a uniform format. The various datasets were synchronized, with some interpretation required to assign operation logs (recorded at time of occurrence, not necessarily on the quarter hour) and the regularly reported data for the continuous sets.

The sondes utilized pressure sensors to report the total pressure at the depth of sample collection. Water quality standards were written with respect to deleterious effects to biota and expressed TDG pressure as a percentage of surface saturation as

$$TDG_{sat} = \frac{TDG_i}{BP_i} \times 100$$

where

TDG_{sat} = TDG pressure expressed as percentage of surface saturation

TDG_i = TDG pressure at station i, mm Hg

BP_i = Atmospheric pressure at station i, mm Hg

Equation 1

Individual spillbay discharge was determined from the gate opening information as follows:

$$G_{Q_i} = G_{OP_i} \Big/ \sum_{i=1}^{11} G_{OP_i} \times \left(Q_{SP_f} + Q_{SP_F}\right)$$

where

G_{Q_i} = total discharge for gate i, kcfs

G_{OP_i} = total opening for gate i, ft

Q_{SP_f} = Wells Dam fish bypass spill, kcfs

Q_{SP_F} = Wells Dam forced spill, kcfs

Equation 2

Spill patterns were assigned based on the gate openings for the operating spillbays. It was necessary for the sondes of Transect 2 to reach equilibration so that relationships between water quality and Wells Dam operation could be identified. Equilibration depended on both the

travel time for water through the tailwater and the response time of the TDG sensors. Meeting these requirements meant that steady operation for not less than one hour was needed to reasonably expect equilibrated TDG pressures for all sites. Periods characterized by near uniform operation were segregated into *spill events*. These data were then filtered to select events of duration greater than one hour to yield the final data set for summarization.

Spill event data for Transects 1 and 2 were flow-weighted to provide a single average TDG pressure for each event. Flow-weighting sought to represent both the magnitude of the pressure and the volume of water it represented described as

$$TDG_{wt} = \frac{\sum TDG_i q_i}{Q_{tot}}$$

where

TDG_{wt} = flow - weighted average TDG pressure

TDG_i = TDG pressure at station i

q_i = discharge at station i

Q_{tot} = total river discharge

Equation 3

Station discharges were based on the percentage of the river cross-section represented by that station. Bathymetric survey data were analyzed for to determine the most logical flow apportionment for individual stations. The flow-weighting used in these analyses was; therefore, based on *area* rather than *discharge*, a relatively minor distinction that should not impact subsequent analysis.

In addition to guiding decisions for flow-weighting, bathymetric data were also used to construct an aerial approximation of the Wells Dam tailwater morphometry. The map created from those data identified the thalweg and provided an indication of the flow patterns through the tailwater.

3.0. Results

All of the sondes reported data for the entire period of study and all passed quality assurance/quality control tests conducted prior and subsequent to deployment. Station information and QA/QC data are summarized in Tables 1 and 2, respectively. High resolution operations data (fifteen-minute interval) were available for the entire study except for an approximate twenty hour interruption between June 4 at 1045 and June 5 at 0800 resulting from an unexplained equipment failure. Hourly operations data from the CROHMS were used to fill this gap. Table 3 summarizes the various data sets and their inclusive dates.

3.1. Hydrology

River flows were less than anticipated (Figure 7), ranging from a minimum daily average discharge of 85.1 kcfs on June 1 to a maximum of 162.0 kcfs on June 10. The vast majority of Wells Dam spill was manifested as standard fish bypass spill. The greatest hourly discharge of 223.4 kcfs was recorded on the morning of May 28 at 2145 with the maximum spill discharge of 96.5 kcfs occurring two hours later. A similar spill event occurred on the morning of June 7, although total flows were less peaking at 208.5 kcfs with a maximum spill discharge of 92.4 kcfs. Both events resulted in forced spill to pass water in excess of the powerhouse capacity, and neither was characterized by a sustained pattern. Since the duration of these events was insufficient to meet the filter criteria defining spill events (near static operation for at least one hour), they were necessarily excluded from flow-weighted analyses.

One short duration spill event occurred at Chief Joseph Dam, upstream of Wells, on 28 May from 1800 to 0000 with the total spillway discharge reaching a maximum of 30.8 kcfs. This represented the only spill at Chief Joseph Dam for the period of study, thus incoming pressures documented by the forebay TDGFMS represented ambient background pressures and were likely representative of the forebay as a whole (no lateral variation in TDG pressures).

3.2. Bathymetry

Tailwater morphometry was mapped using data adapted from GPS cruises. These data are depicted in the contour map in Figure 8. The degree to which the data were interpolated may be inferred from the distribution of sample points (unlabeled dots in Figure 8). From this representation, the proximity of the auxiliary and TDGFMS stations to the thalweg are readily identifiable. These data were used to develop the weighting coefficients (Table 4) which were subsequently utilized in developing transect average TDG pressures.

3.3. Fixed Monitor Data

Hourly water temperature data from the CROHMS for the four sites relevant to Wells Dam are presented in Figure 9. Temperatures (as measured by WEL) reflected diel warming and, at a larger scale seasonal warming, increasing from 10.9 ºC at deployment to 13.1 ºC two weeks later upon retrieval. Total dissolved gas pressure data for these sites are depicted in Figure 10. Note that WEL exhibited daily cycles of up to 2.5% saturation, regardless of spill operation at Chief Joseph Dam. This most likely resulted from localized surface warming at the TDGFMS. As temperatures increased, the pressures inside the TDG probe's membrane also increased (Charles' Law). The relatively slow diffusion rate of gasses across the silastic tubing that comprised it, resulted in a temporary increase in TDG pressure. This was likely an artifact of data collection and was not reflective of the actual Wells Dam forebay TDG pressures. Daily pressure fluctuations may also result from community metabolism; however, no data were available to support this. The single spill event at Chief Joseph resulted in TDG saturations of

approximately 118% at the tailwater site (CHQW), but were not reflected by saturations measured at WEL.

The two high spill events occurring on 28-29 May and 6-7 June were readily identified at both WELW and RRH (manifested as the distinct peaks in Figure 10). The dramatic contrast in the TDG pressures resulting from these events to the remaining study period allowed for an estimate of both the travel time and degassing rate for water traversing Lake Entiat. Note that the pressures measured at WELW were manifested as a sharp pressure spike occurring for less than two hours, while the elevated pressures measured at RRH are characterized by an attenuated peak occurring over several hours. Travel time estimation was, therefore, based on the arrival of the TDG *front* at RRH and not the peak value. Using the TDG pressure spikes of the high spill events to match the other operation events, the travel time for water through Lake Entiat was generally thirty to forty hours.

3.4. Transect Data

Auxiliary TDG data collected at Transects 1 and 2 are presented as Figures 11 and 12, respectively. The highest TDG saturations were reported at Transect 1, with station T1C typically exhibiting the maximum pressures. Transect 1 TDG saturations reached a maximum of 132.9% on May 29 at 0000, which were the highest documented. A lateral gradient ranging from of up to 12.5% saturation was consistent throughout the study. As previously noted, T1C generally represented the maximum pressures, although values for T1B were similar.

Data collected at Transect 2 exhibited lower TDG pressures than those measured along Transect 1, as expected given its greater distance from the spillway. The maximum pressure reported for Transect 2 was 128.7% occurring at station T2C on May 29 at 0030. As with Transect 1, at lateral gradient of up to 15.6% saturation was observed for most of the study, with the highest pressures measured at station T2C. The three auxiliary sites generally responded to changes in project operations simultaneously, while response by the tailwater FMS (WELW) lagged by up to forty-five minutes. In addition to longer response times, TDG pressures measured at WELW differed from those at T2C by as much as 5% saturation.

As previously noted, the duration of the high spill events was insufficient to allow equilibrated measurements at both transects, thus they were excluded from the mass balance analyses described in later sections. The dramatic, rapid increase in TDG saturations above those measured prior and subsequent to these events allowed the TDG *plumes* to be followed through the Wells Dam tailwater and the remainder of Lake Entiat.

Figure 13 depicts the TDG saturations and project operations for Transect 1 for the period of May 28-30, 2003. Data for Transect 2 for the same period are depicted in Figure 14. Station T1C recorded the highest TDG saturation of the study (132.9%) as Wells Dam total spillway discharge approached 100 kcfs (over 58% of the total river discharge). The highest TDG saturation at station T1A for the same event was 126.6% (6.3% less than T1C). Stations T1B and T1A peaked at TDG saturations of 131.8 and 131.3%, respectively. Transect 1 stations first indicated the arrival of the plume at 2245. The TDG front reached Transect 2 at 2315, indicating a travel time from Transect 1 to Transect 2 of approximately thirty minutes.

A lateral gradient in TDG pressure was observed (as with Transect 1) with the highest pressures again occurring near mid-river. Station T2C reached a maximum saturation of 128.7% with stations T2B and T2D peaking at 127.1 and 127.3%, respectively. The minimum pressures were measured at station T2A (WELW) which peaked at 124.5% saturation, some

thirty minutes after T2C. TDG pressures at both Transects decreased as quickly as they rose following passage of the TDG front, except for T2A (WELW), which took an additional forty-five minutes to return to pre-front levels.

The second high spill event of the study occurred on the morning of June 7, 2003 as depicted in Figures 15 and 16 for Transects 1 and 2, respectively. The total spillway discharge reached a maximum of 92.4 kcfs (~56% of the total river discharge) for approximately fifteen minutes. Despite the short duration of the event, its impact was seen throughout the tailwater as manifested by the sharp increase in TDG saturation at all stations. It was unlikely that the pressures recorded during this event represented equilibrated values, but they do support data collected for the prior high spill event.

With the exception of the high spill occurrences on the mornings of May 29 and June 7, no other operations resulted in TDG saturations greater than the 125% waiver to the Washington State water quality standard.

3.5. Spill Events

Data meeting the criteria outlined in Section 2.3 (periods characterized by at least one hour of relatively constant operation) were consolidated into 51 spill events. Of these, forty-six events were of sufficient duration to allow both Transect 1 and Transect 2 stations to reach equilibration. Event averaged data for the 46 events are summarized in Table 5.

Events ranged from one hour to over eighteen hours in duration. The minimum mean total river discharge of 25.1 kcfs occurred during Event 4, which also represented the minimum total spillway discharge of 2.7 kcfs. The maximum mean total river discharge of 194.8 kcfs occurred during Event 39, with a comparable discharge occurring during Event 7 (193.8 kcfs). The total spill discharge for both events was 11.0 kcfs, representing approximately 5.6-5.7% of the total discharge. Roughly 35% of the spill events had total spill discharges of 11.0 kcfs which represented from 5.6-9.8% of the total river flow.

The maximum TDG pressure of 114.2% was measured at station T1D during Spill Event 41. Stations T1B and T1C reported comparable values of 113.3 and 113.6%, respectively. Project output was similar for Spill Event 26, but TDG pressures for Transect 1 were 4.2 to 5.3% less than for Event 41. Background TDG pressures reported by the forebay FMS (WEL) were 107.3% for Spill Event 26, some 3.5% lower than the subsequent event, which may explain this apparent disparity. None of the spill events resulted in TDG saturations in excess of state of Washington water quality standards.

3.5.1. Flow-weighted Data

Transect TDG saturations were flow-weighted based on the weighting coefficients in Table 4. Flow-weighted averages yielded a single TDG pressure for each transect for each event, the results of which are presented in Table 6. Mean saturations for Transect 1 were up to 2.0% greater than for Transect 2, with the overall mean of 0.4%. Transect 2 mean saturations were up to 2.4% greater than those reported for the Wells Dam forebay. The overall contribution of TDG pressure for Wells Dam averaged 1.3% as determined from the forebay to Transect 2 change in saturation.

Comparing forebay TDG pressures to the flow-weighted pressures for Transects 1 and 2 provided an estimate of the change in mass (flux) of gasses resulting from Wells Dam. The difference between the forebay TDG saturation and the flow-weighted saturations for Transects

1 and 2 are plotted against spill from Wells Dam expressed as a percentage of the total river discharge in Figure 17.

Neither relationship exhibited a strong correlation, as evidenced by the low r^2 values; however both indicated a direct relationship with the percentage of the river passed as spill. Transect 1 TDG saturations were best described by a second order polynomial, indicating that the net increase in TDG pressures over forebay pressures became more dependent on spill as it increased as a percentage of the total flow. Transect 2 flux estimates were much less correlated with the percentage of spill ($r^2 = 0.28$). Increasing the complexity of the equation yielded no stronger relationship for the transect, which was best described by a simple linear relationship. These representations indicate that for every 5% increase in Wells Dam spill there was a corresponding increase of 0.5% in TDG flux.

3.5.2. TDG Mass Balance

Determining the fate of powerhouse release water, i.e. dilution of, or gassing by, spill release, required apportionment of the Wells Dam release waters and associated TDG saturations. Assuming the fate of powerhouse release water to be dilution of spill release, the flow-weighted TDG saturation for Transect 2 could be expressed

$$TDG_{wt} = \frac{(TDG_{PH} \times Q_{PH}) + (TDG_{SP} \times Q_{SP})}{(Q_{PH} + Q_{SP})}$$

where

TDG_{wt} = Flow - weighted TDG saturation for Transect 2

TDG_{PH} = TDG saturation of the powerhouse release water

TDG_{SP} = TDGsaturation of the spillway release water

Q_{PH} = total powerhouse discharge

Q_{SP} = total spillway discharge

Equation 4

If station T1C TDG saturations (typically the maximum pressures for Transect 1) represented TDG_{SP} and WEL saturations represented TDG_{PH}, then the weighted TDG saturation for Transect 2 could be computed using the operation logs from the dam to represent the discharge variables. These values are presented with their corresponding empirical values in Table 7.

Observed TDG saturations for Transect 2 consistently exceeded those derived from Equation 4, ranging from 0.5 to 2.2% higher with a mean difference of 1.2% saturation. A paired t-test indicated a that the mean values were significantly different ($p<0.05$). Saturations for the spillway release were estimated from station T1C data and, if underestimated, could have resulted in the relationships presented in Table 7. Substituting Transect 2 flow-weighted average TDG saturations for TDG_{wt}, Equation 4 was rearranged to solve for the mean spill TDG saturation as

$$TDG_{SP} = \frac{(TDG_{wt} \times (Q_{PH} + Q_{SP})) - (TDG_{PH} \times Q_{PH})}{Q_{SP}}$$

Equation 4a

Spillway TDG saturations computed via Equation 4a reached a maximum of 134.5% saturation, exceeding the maximum value for Transect 1 by 22.9%. The mean difference in the saturations derived from Equation 4a and those measured for T1C was 14.0%. The maximum saturation occurred during Event 42 characterized by low total river discharge (71.9 kcfs) and relatively modest spill (6.6 kcfs representing 9.2% of the total discharge). The maximum TDG saturation measured during the entire study (T1C, 133%) occurred during a spill event of nearly 100 kcfs representing 49% of the total river discharge.

Equation 4 was rearranged, again, to solve for TDG_{PH} as

$$TDG_{PH} = \frac{\left(TDG_{wt} \times \left(Q_{PH} + Q_{SP}\right)\right) - \left(TDG_{SP} \times Q_{SP}\right)}{Q_{PH}}$$

Equation 4b

The results of these calculations indicated that the TDG saturations for the powerhouse release water averaged 1.3% higher than those reported by WEL. Empirical and computed weighted average TDG pressures derived from Equations 4a and 4b are summarized in Table 8.

3.6. Daily 12 hour Average TDG Saturations

Daily averages of the twelve highest saturations for Transects 1 and 2 are presented in Table 9. Station averages for Transect 2 varied from 0.7 to 2.1% saturation, but would not have resulted in changes to the day's compliance evaluation as determined by the tailwater TDGFMS.

4.0. Conclusions

Although total flows for the middle Columbia River were less than forecasted, the results of this study provided valuable information regarding TDG distributions at Wells Dam. Based on comparisons of lateral TDG saturations at Transect 2, the tailwater TDGFMS does not represent the maximum values for that location. Although the daily averages represented little difference between the TDG saturations measured at WELW and the mid-river stations (T2B and T2C), this was likely due to the short duration of the few significant spill events. The tailwater TDGFMS is located on the eastern shore of the river in an eddy. Based on the shape of the response curves of Transect 2 TDG saturations, the eddy caused both a delay and attenuation in the response of WELW. While TDG saturations at WELW compared well to the other stations for the spill events, an additional thirty to forty-five minutes were required for equilibrated measurements. Determination of compliance with state of Washington water quality standards was the same for all of the Transect 2 stations.

The limited duration and frequency of high spill prevented the development of a useful TDG production curve for the Wells Dam spillway. Most data were collected under fish by-pass spill conditions consisting of spill through spillbays 2, 4, 6, 8, and 10 representing less than ten percent of the total river flow. Wells Dam spill and forebay to tailwater changes in TDG were weakly correlated, indicating an increasing trend. The longer response was likely a symptom of the TDGFMS location within the eddy, which required time to "flush" water from prior operations. The effect was manifested as a shift in both the leading and lagging edges of the TDG response curve. Numerous spikes in the TDG saturations at Transect 2 – the results of fleeting changes in the Wells Dam discharge – were not measured by the tailwater TDGFMS; however, there was no apparent impact to compliance evaluations.

The mass balance approach was confounded by the erratic nature of operation by Wells Dam, since accurate estimates depend on complete accounting of both the magnitude of the TDG pressure and the volume of water it represented. Despite this, results indicated that the average TDG saturations for Transect 2 were greater than would have been expected from Wells Dam spill, alone. Results indicated WEL underestimated the *effective* powerhouse TDG saturation by an average of 1.3%. Powerhouse releases should reflect forebay saturations and the consistent difference implied that powerhouse TDG pressures were influenced by turbine operation (unlikely given the powerhouse operation during this study) or spill.

Estimations of travel times through Lake Entiat generally agreed with estimates developed from the TDGFMS at Wells and Rocky Reach Dams. Tracing water from the forebay of Wells Dam to that of Rocky Reach Dam indicated that TDG pressures changed rapidly between the spillway and Transect 2, with reductions of up to 5% (or approximately -1.7% per mile). Reductions in TDG saturation between Transect 2 and the Rocky Reach forebay TDGFMS (RRH) indicated a TDG reduction of up to 12% (or about -0.3% per mile).

The conclusions drawn from this study are limited by the flow conditions occurring during data collection. Additional data collected under higher project discharges are needed to refine estimates the influence of spill operation to powerhouse release water and to explore ameliorative possibilities. The most desirable approach would include scheduled, steady state spill events designed to capture the widest river flows possible. Project operations should be held constant for at least two hours to allow equilibrated measurements for the entire tailwater. Data collection outside of the fish passage season would simplify data analysis, since forebay TDG pressures would not be influenced by upstream activities.

References

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Marsh, M.C. and F.P. Gorham. 1905. The Gas disease in fishes. Report of the United States Bureau of Fisheries for 1904:343-376.

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Tables

Table 1. Station information for water quality data collection

S/N	Transect	Station ID	Location		Depth (ft)
			Latitude	Longitude	
33254	N/A	WEL	47.94722	-119.86508	15
40857	T1	T1A	47.94455	-119.86244	50
39285	T1	T1B	47.94434	-119.86333	65
40862	T1	T1C	47.94399	-119.86420	65
40859	T1	T1D	47.94411	-119.86562	60
32639	T2	WELW	47.91309	-119.89625	20
40860	T2	T2B	47.91364	-119.89676	45
40861	T2	T2C	47.91463	-119.89668	50
40858	T2	T2D	47.91476	-119.89744	35

Table 2. Calibration summary information for water quality sensors

Calibration Type	S/N	Date	BP (mmHg)	Temperature (ºC)			TDG Pressure (mm Hg)			Deviation from TDG Standard (mm Hg)		
				Std	Probe	Diff	BP + 0	BP + 100	BP + 200	BP + 0	BP + 100	BP + 200
Pre-deployment	39285	05/26/03	756	17.7	17.7	0.0	756	856	956	0	0	0
Pre-deployment	40857	05/26/03	755	17.5	14.7	2.8	755	855	955	0	0	0
Pre-deployment	40858	05/26/03	756	17.5	17.4	0.1	756	856	956	0	0	0
Pre-deployment	40859	05/26/03	756	17.6	17.6	0.0	756	856	956	0	0	0
Pre-deployment	40860	05/26/03	756	17.5	17.4	0.1	755	855	955	-1	-1	-1
Pre-deployment	40861	05/26/03	756	17.5	17.5	0.0	755	855	956	-1	-1	0
Pre-deployment	40862	05/26/03	755	17.5	17.4	0.1	755	855	955	0	0	0
Pre-deployment	32639	05/27/03	749	11.4	11.3	0.1	750	850	950	1	1	1
Pre-deployment	33254	05/27/03	747	12.1	12.1	0.0	747	847	947	0	0	0
Post-deployment	39285	06/10/03	750	20.2	20.3	0.0	751	851	951	1	1	1
Post-deployment	40857	06/10/03	750	20.2	20.2	0.0	750	850	950	0	0	0
Post-deployment	40858	06/10/03	750	20.2	20.2	0.0	752	852	952	2	2	2
Post-deployment	40859	06/10/03	750	20.2	20.2	0.0	751	851	951	1	1	1
Post-deployment	40860	06/10/03	750	20.2	20.2	0.1	750	850	950	0	0	0
Post-deployment	40861	06/10/03	750	20.3	20.2	0.0	750	850	951	0	0	1
Post-deployment	40862	06/10/03	750	20.2	20.2	0.0	751	851	951	1	1	1
Post-deployment	32639	06/18/03	736	14.2	14.1	0.1	736	836	936	0	0	0
Post-deployment	33254	06/18/03	733	14.2	14.1	0.0	734	833	933	1	0	0

Table 3. Summary of Data Sets Included in Wells Dam Spillway Evaluation

Data Set	Provider	Inclusive Dates	Interval (hrs)	Description
Transect	CBE	May 27 – June 10, 2003	0.25	Water temperature (ºC), TDG pressure (mm Hg), sample depth (m) collected by leased Hydrolab® MiniSonde® multiprobes
CROHMS	Internet	May 27 – June 10, 2003	1.0	Water temperature (ºC), TDG pressure (mm Hg), atmospheric pressure (mm Hg), total project discharge (kcfs), total project spill discharge (kcfs), forebay elevation (ft MSL), tailwater elevation (ft MSL) queried from Columbia River Operational HydroMet System maintained by the U.S. Army Corps of Engineers
Wells Dam Operations	DCPUD	May 27 – June 4 June 5-10, 2003	0.25	Wells Dam total river discharge (kcfs), by-pass spill discharge (kcfs), forced spill discharge (kcfs), fishway discharge (kcfs), individual generator output (MW), individual spill gate openings (ft), forebay elevation (ft MSL), tailwater elevation (ft MSL)
Control Room Logs	DCPUD	May 27 – June 10, 2003	N/A	Spill gate openings (ft), and total spillway discharge (kcfs) reported at time of change
Wells Dam FMS	DCPUD	May 27 – June 5, 2003	0.25	Water temperature (ºC), TDG pressure (mm Hg), and atmospheric pressure (mm Hg) for the Wells Dam permanent TDG monitoring system
Wells Tailwater Bathymetry	CBE	May 27, 2003	N/A	Tailwater bathymetric survey data consisting of latitude, longitude, and river depth collected via mapping GPS during deployment of transect instruments.

Table 4. Transect Average TDG Weighting Coefficients

Transect	Station	Weighting Coefficient
Transect 1	T1A	0.35
Transect 1	T1B	0.20
Transect 1	T1C	0.20
Transect 1	T1D	0.25
Transect 2	T2A	0.10
Transect 2	T2B	0.35
Transect 2	T2C	0.35
Transect 2	T2D	0.20

Table 5. Spill Event Summary Information

Event	DateTime		Duration	Qtot	Qgen	Qsp	Percent	WEL	T1A	T1B	T1C	T1D	WELW	T2B	T2C	T2D
	Start	End		kcfs	kcfs	kcfs	Spill	%Sat	%Sat	%Sat	%Sat	%Sat	%Sat	%Sat	%Sat	%Sat
1	05/27/03 06:45	05/27/03 08:30	1.75	87.3	78.5	8.8	10.1	106.0	107.6	109.3	109.5	109.1	107.3	104.3	107.4	110.2
2	05/27/03 09:45	05/27/03 23:15	13.50	170.2	159.2	11.0	6.5	107.6	109.1	109.4	109.0	108.5	108.9	108.6	108.8	108.6
3	05/28/03 00:00	05/28/03 01:15	1.25	89.1	80.3	8.8	9.9	107.2	109.0	109.1	108.9	109.0	108.7	108.6	108.9	108.6
4	05/28/03 02:15	05/28/03 04:15	2.00	25.1	22.4	2.7	10.8	107.1	109.0	109.3	109.0	109.1	108.5	108.8	109.0	108.6
5	05/28/03 06:45	05/28/03 08:45	2.00	111.8	100.8	11.0	9.8	108.0	109.9	110.3	109.9	109.2	109.1	109.2	109.3	109.1
6	05/28/03 09:15	05/28/03 10:30	1.25	69.1	62.5	6.6	9.5	108.3	109.6	110.5	110.3	110.2	109.8	109.8	110.0	109.7
7	05/28/03 11:15	05/28/03 21:15	10.00	193.8	182.8	11.0	5.7	108.9	110.5	111.0	110.7	109.9	110.3	110.1	110.4	110.1
8	05/29/03 08:00	05/29/03 23:45	15.75	170.1	159.2	11.0	6.5	109.5	111.0	111.7	111.3	110.3	110.8	110.7	111.0	110.6
9	05/30/03 02:30	05/30/03 04:15	1.75	40.3	35.9	4.4	10.9	109.4	111.4	111.6	111.5	111.5	111.5	111.3	111.4	111.5
10	05/30/03 04:45	05/30/03 09:00	4.25	108.8	100.0	8.8	8.1	109.5	110.8	111.0	111.0	111.0	110.7	110.6	110.9	110.7
11	05/30/03 09:15	05/30/03 19:45	10.50	156.9	145.9	11.0	7.0	109.4	111.3	111.3	110.7	110.3	110.8	110.7	110.8	110.4
12	05/30/03 20:15	05/30/03 22:45	2.50	138.5	127.5	11.0	7.9	108.5	110.2	110.3	110.1	109.9	110.0	109.9	110.1	109.7
13	05/31/03 00:00	05/31/03 01:15	1.25	61.5	54.9	6.6	10.7	108.0	109.8	110.0	109.5	109.5	109.6	109.7	109.9	109.5
14	05/31/03 01:45	05/31/03 03:00	1.25	45.7	41.3	4.4	9.6	107.8	110.1	109.6	109.0	109.1	109.3	109.3	109.3	109.1
15	05/31/03 06:30	05/31/03 07:30	1.00	51.8	47.4	4.4	8.5	107.5	110.0	110.1	109.4	109.3	108.8	108.9	109.0	108.6
16	05/31/03 08:30	05/31/03 10:15	1.75	116.3	107.5	8.8	7.6	107.9	109.1	109.6	109.4	109.4	109.1	109.1	109.3	109.1
17	05/31/03 10:30	05/31/03 22:30	12.00	148.9	137.9	11.0	7.4	108.6	110.2	110.6	110.2	109.4	109.9	109.8	110.0	109.7
18	06/01/03 00:00	06/01/03 01:45	1.75	39.9	35.5	4.4	11.0	107.5	111.1	111.3	110.8	110.6	109.1	109.5	109.7	109.2
19	06/01/03 02:00	06/01/03 03:45	1.75	61.2	54.6	6.6	10.8	107.3	110.0	110.7	109.2	109.0	109.1	109.7	109.9	109.5
20	06/01/03 04:00	06/01/03 06:45	2.75	31.5	27.1	4.4	14.0	107.3	111.3	112.1	110.8	109.9	108.9	109.2	109.1	108.6
21	06/01/03 07:15	06/01/03 10:00	2.75	70.2	63.6	6.6	9.4	107.6	109.5	110.0	108.9	108.7	109.3	109.5	109.4	109.1
22	06/01/03 10:15	06/01/03 11:30	1.25	36.5	32.1	4.4	12.0	107.6	110.7	111.0	109.9	110.3	109.4	109.1	109.1	108.6
23	06/01/03 13:15	06/01/03 17:45	4.50	149.3	138.3	11.0	7.4	108.3	109.8	110.0	109.6	109.3	109.8	109.5	109.6	109.4
24	06/01/03 18:15	06/01/03 22:30	4.25	109.8	101.0	8.8	8.0	107.7	109.1	109.1	108.9	109.3	108.9	108.9	109.0	108.8
25	06/01/03 23:00	06/02/03 00:15	1.25	70.3	63.7	6.6	9.4	107.6	109.0	109.0	108.6	108.8	108.3	108.5	108.7	108.5
26	06/02/03 00:30	06/02/03 04:00	3.50	38.1	33.7	4.4	11.6	107.3	109.2	109.1	108.7	108.9	107.9	108.4	108.6	108.2
27	06/02/03 04:15	06/02/03 07:00	2.75	73.1	66.5	6.6	9.0	107.0	108.5	108.7	108.0	108.1	107.8	108.2	108.3	107.9
28	06/02/03 08:15	06/02/03 09:30	1.25	92.1	85.5	6.6	7.2	107.2	108.4	108.5	107.9	108.1	108.0	108.3	108.4	108.0
29	06/02/03 10:15	06/02/03 22:15	12.00	170.7	159.7	11.0	6.4	108.2	109.5	109.8	109.5	108.9	109.2	109.2	109.3	109.0
30	06/03/03 00:00	06/03/03 01:30	1.50	45.6	41.2	4.4	9.7	107.5	109.7	110.4	110.3	110.6	108.8	109.0	109.3	108.6
31	06/03/03 02:15	06/03/03 04:15	2.00	43.6	39.2	4.4	10.1	107.4	109.5	109.7	108.6	108.7	108.9	108.9	109.0	108.9
32	06/03/03 05:15	06/03/03 06:45	1.50	50.8	46.4	4.4	8.7	107.2	109.1	108.8	108.3	108.5	108.4	108.5	108.4	108.1
33	06/03/03 08:30	06/03/03 22:45	14.25	165.6	154.6	11.0	6.6	108.7	110.2	110.3	109.7	109.3	109.7	109.6	109.8	109.4
34	06/04/03 01:30	06/04/03 04:30	3.00	49.6	45.2	4.4	8.9	108.0	109.0	109.3	109.0	109.2	109.1	109.2	109.2	109.0
35	06/04/03 08:45	06/04/03 10:30	1.75	162.8	151.8	11.0	6.8	108.8	110.0	110.2	109.8	109.4	109.3	109.4	109.6	109.2
36	06/05/03 08:15	06/05/03 23:30	15.25	175.0	164.0	11.0	6.3	110.1	111.8	112.0	111.7	110.8	111.5	111.4	111.5	111.2
37	06/06/03 01:15	06/06/03 02:45	1.50	42.0	37.6	4.4	10.5	109.8	111.1	111.4	111.2	111.3	111.2	111.5	111.8	111.3
38	06/06/03 03:00	06/06/03 05:30	2.50	69.8	63.2	6.6	9.5	109.5	111.0	111.5	110.6	110.7	110.7	110.7	110.8	110.5
39	06/06/03 06:30	06/06/03 22:45	16.25	194.8	183.8	11.0	5.6	110.0	111.9	112.1	111.6	110.8	111.3	111.3	111.4	111.1
40	06/07/03 07:00	06/08/03 00:45	17.75	171.3	160.3	11.0	6.4	110.6	112.0	112.3	111.8	111.1	111.8	111.5	111.7	111.3
41	06/08/03 02:00	06/08/03 05:00	3.00	38.3	33.9	4.4	11.5	110.5	112.6	113.3	113.6	114.2	111.6	112.1	112.5	111.8
42	06/08/03 05:30	06/08/03 06:30	1.00	71.9	65.3	6.6	9.2	110.3	111.8	112.1	111.6	111.6	112.1	112.5	112.5	113.0
43	06/08/03 06:45	06/08/03 12:45	6.00	112.3	103.5	8.8	7.8	111.2	111.9	112.0	111.9	112.2	112.0	111.8	112.0	111.8
44	06/08/03 13:00	06/08/03 23:45	10.75	161.8	150.8	11.0	6.8	111.6	112.6	112.8	112.3	111.9	112.4	112.2	112.3	112.0
45	06/09/03 02:00	06/09/03 05:00	3.00	55.8	51.4	4.4	7.9	110.0	111.0	111.2	111.0	111.2	111.2	111.2	111.2	110.9
46	06/09/03 05:30	06/10/03 00:00	18.50	178.5	167.5	11.0	6.2	110.4	112.3	112.8	112.1	111.1	111.8	111.8	112.0	111.5

Table 6. Flow-weighted TDG Saturations by Spill Event

Event	WEL %Sat	T1wt %Sat	T2wt %Sat	T1-T2 %Sat	T2-WEL %Sat
1	106.0	108.7	106.9	1.8	0.9
2	107.6	109.0	108.7	0.2	1.1
3	107.2	109.0	108.7	0.3	1.5
4	107.1	109.1	108.8	0.3	1.7
5	108.0	109.8	109.2	0.6	1.2
6	108.3	110.0	109.9	0.2	1.5
7	108.9	110.5	110.2	0.3	1.3
8	109.5	111.1	110.8	0.3	1.3
9	109.4	111.5	111.4	0.1	2.0
10	109.5	110.9	110.7	0.2	1.2
11	109.4	110.9	110.7	0.2	1.3
12	108.5	110.2	109.9	0.2	1.5
13	108.0	109.7	109.7	0.0	1.7
14	107.8	109.5	109.2	0.3	1.4
15	107.5	109.7	108.9	0.9	1.4
16	107.9	109.4	109.2	0.2	1.3
17	108.6	110.1	109.8	0.2	1.2
18	107.5	111.0	109.5	1.5	2.0
19	107.3	109.7	109.7	0.0	2.4
20	107.3	111.0	109.0	2.0	1.7
21	107.6	109.3	109.4	-0.1	1.7
22	107.6	110.5	109.0	1.5	1.4
23	108.3	109.7	109.6	0.1	1.2
24	107.7	109.1	108.9	0.2	1.2
25	107.6	108.9	108.5	0.3	0.9
26	107.3	109.0	108.4	0.6	1.1
27	107.0	108.4	108.1	0.2	1.1
28	107.2	108.3	108.3	0.0	1.0
29	108.2	109.4	109.2	0.2	1.0
30	107.5	110.2	109.0	1.2	1.5
31	107.4	109.1	108.9	0.2	1.5
32	107.2	108.7	108.4	0.4	1.2
33	108.7	109.9	109.6	0.2	1.0
34	108.0	109.1	109.1	0.0	1.2
35	108.8	109.8	109.4	0.4	0.6
36	110.1	111.6	111.4	0.1	1.3
37	109.8	111.2	111.5	-0.3	1.7
38	109.5	111.0	110.7	0.3	1.2
39	110.0	111.6	111.3	0.3	1.3
40	110.6	111.8	111.6	0.2	1.0
41	110.5	113.3	112.1	1.2	1.6
42	110.3	111.8	112.5	-0.8	2.2
43	111.2	112.0	111.9	0.1	0.7
44	111.6	112.4	112.2	0.2	0.7
45	110.0	111.1	111.2	-0.1	1.1
46	110.4	112.1	111.8	0.3	1.4

Table 7. Empirical and Calculated Weighted Average TDG Saturations for Transect 2

Event	T2wt (Empirical) %Sat	T2wt (Calculated) %Sat	T2wte-T2wtc %Sat
1	59.2	106.4	0.5
2	60.2	107.7	1.0
3	60.4	107.4	1.4
4	60.7	107.3	1.5
5	61.5	108.2	1.0
6	62.0	108.5	1.4
7	62.7	109.0	1.2
8	63.3	109.6	1.2
9	63.7	109.6	1.8
10	64.0	109.6	1.1
11	64.3	109.5	1.2
12	64.2	108.6	1.3
13	64.3	108.2	1.5
14	64.5	107.9	1.3
15	64.8	107.7	1.2
16	65.2	108.0	1.2
17	66.0	108.8	1.1
18	66.1	107.8	1.6
19	66.2	107.5	2.2
20	66.8	107.8	1.2
21	66.9	107.7	1.6
22	67.5	107.9	1.1
23	67.9	108.4	1.1
24	67.9	107.8	1.1
25	68.2	107.7	0.8
26	68.5	107.5	0.9
27	68.6	107.1	1.0
28	69.0	107.3	1.0
29	69.9	108.2	1.0
30	70.2	107.7	1.2
31	70.3	107.5	1.4
32	70.5	107.3	1.1
33	71.6	108.7	0.9
34	71.5	108.0	1.1
35	72.3	108.9	0.6
36	73.4	110.2	1.2
37	73.6	110.0	1.6
38	73.8	109.6	1.1
39	74.5	110.1	1.2
40	75.1	110.7	0.9
41	75.7	110.9	1.2
42	75.7	110.4	2.1
43	76.4	111.3	0.6
44	76.9	111.6	0.6
45	76.5	110.1	1.1
46	77.2	110.5	1.3

Table 8. Empirical and Calculated TDG Saturations for Wells Dam Powerhouse and Spillway Release Water

Event	TDGspe (T1C) %Sat	TDGspc %Sat	Diff TDGsp %Sat	TDGphe (WEL) %Sat	TDGphc %Sat	Diff TDGph %Sat
1	109.5	114.9	5.4	106.0	106.6	0.6
2	109.0	124.3	15.3	107.6	108.7	1.1
3	108.9	122.7	13.8	107.2	108.7	1.5
4	109.0	123.1	14.1	107.1	108.8	1.7
5	109.9	120.3	10.4	108.0	109.1	1.1
6	110.3	124.5	14.2	108.3	109.8	1.5
7	110.7	132.1	21.4	108.9	110.2	1.3
8	111.3	129.2	17.9	109.5	110.7	1.2
9	111.5	127.7	16.1	109.4	111.4	2.0
10	111.0	124.7	13.7	109.5	110.7	1.2
11	110.7	128.0	17.3	109.4	110.7	1.3
12	110.1	126.9	16.8	108.5	109.9	1.4
13	109.5	123.8	14.3	108.0	109.7	1.7
14	109.0	122.6	13.6	107.8	109.3	1.5
15	109.4	123.5	14.1	107.5	108.8	1.3
16	109.4	124.6	15.2	107.9	109.2	1.2
17	110.2	124.8	14.6	108.6	109.8	1.2
18	110.8	125.5	14.7	107.5	109.3	1.8
19	109.2	129.2	20.1	107.3	109.8	2.4
20	110.8	119.5	8.7	107.3	108.7	1.4
21	108.9	126.1	17.2	107.6	109.4	1.8
22	109.9	119.1	9.1	107.6	108.9	1.3
23	109.6	125.0	15.4	108.3	109.6	1.2
24	108.9	122.5	13.5	107.7	108.9	1.2
25	108.6	117.5	8.9	107.6	108.5	0.9
26	108.7	116.4	7.7	107.3	108.3	1.0
27	108.0	119.5	11.5	107.0	108.1	1.1
28	107.9	121.4	13.4	107.2	108.3	1.0
29	109.5	124.2	14.8	108.2	109.2	1.0
30	110.3	123.2	12.9	107.5	108.9	1.4
31	108.6	122.3	13.7	107.4	109.0	1.5
32	108.3	121.4	13.1	107.2	108.4	1.2
33	109.7	123.3	13.6	108.7	109.6	1.0
34	109.0	121.3	12.3	108.0	109.1	1.2
35	109.8	118.2	8.4	108.8	109.4	0.6
36	111.7	131.3	19.6	110.1	111.4	1.3
37	111.2	126.1	14.9	109.8	111.6	1.7
38	110.6	121.9	11.4	109.5	110.7	1.2
39	111.6	132.7	21.1	110.0	111.3	1.3
40	111.8	125.7	13.9	110.6	111.6	1.0
41	113.6	124.2	10.6	110.5	111.9	1.4
42	111.6	134.5	22.9	110.3	112.6	2.3
43	111.9	119.8	7.9	111.2	111.9	0.7
44	112.3	121.2	8.9	111.6	112.2	0.7
45	111.0	124.6	13.6	110.0	111.2	1.2
46	112.1	132.7	20.5	110.4	111.8	1.3

Table 9. Daily Average of 12 Highest TDG Saturations

Date	CHQW	WEL	T1A	T1B	T1C	T1D	WELW	T2B	T2C	T2D	RRH
05/28/03	112.2	108.8	111.3	112.3	112.1	111.2	110.3	110.3	110.7	110.3	109.6
05/29/03	109.2	109.8	113.2	114.6	114.9	113.5	114.5	114.4	114.7	114.5	110.0
05/30/03	109.0	109.6	111.5	111.8	111.6	111.3	111.2	111.2	111.4	111.2	113.4
05/31/03	108.4	108.7	110.3	110.6	110.3	109.6	109.9	109.9	110.0	109.7	110.9
06/01/03	108.0	108.0	110.6	111.2	110.2	109.9	109.6	109.7	109.8	109.4	110.2
06/02/03	108.1	108.2	109.7	110.0	109.6	109.1	109.3	109.3	109.4	109.1	109.1
06/03/03	108.8	108.8	110.4	110.5	110.0	109.7	109.9	109.8	109.9	109.6	109.4
06/04/03	109.5	109.4	110.8	111.0	110.6	110.3	110.5	110.4	110.6	110.3	109.8
06/05/03	109.5	110.3	111.9	112.1	112.1	111.4	111.7	111.6	111.7	111.3	110.8
06/06/03	110.0	110.1	112.3	112.7	112.3	111.4	111.5	111.6	111.9	111.5	112.0
06/07/03	111.3	110.8	114.0	114.7	114.8	114.2	115.5	115.3	115.5	115.4	112.5
06/08/03	112.2	111.7	112.7	113.1	112.8	112.8	112.4	112.3	112.6	112.3	114.7
06/09/03	111.4	110.5	112.5	113.0	112.3	111.3	112.0	112.0	112.1	111.7	112.6

Figures

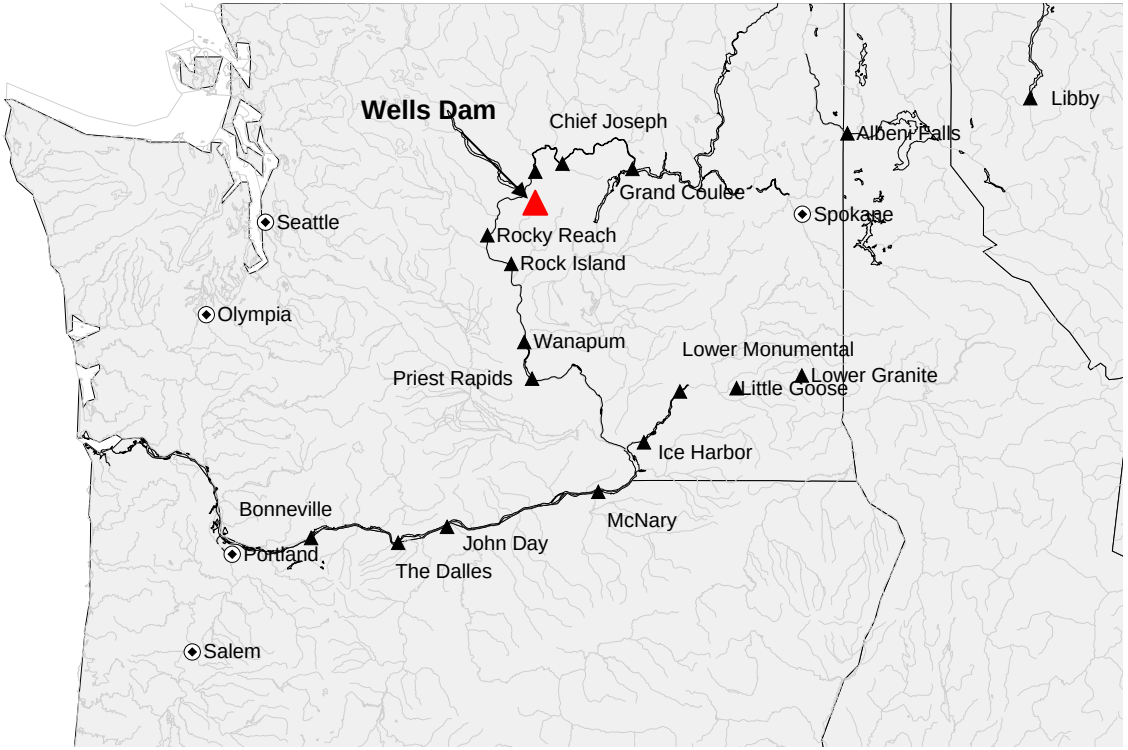


Figure 1. Regional map indicating location of Wells Dam.

Figure 2. Area map for Wells Dam spill evaluation indicating primary deployment transects.

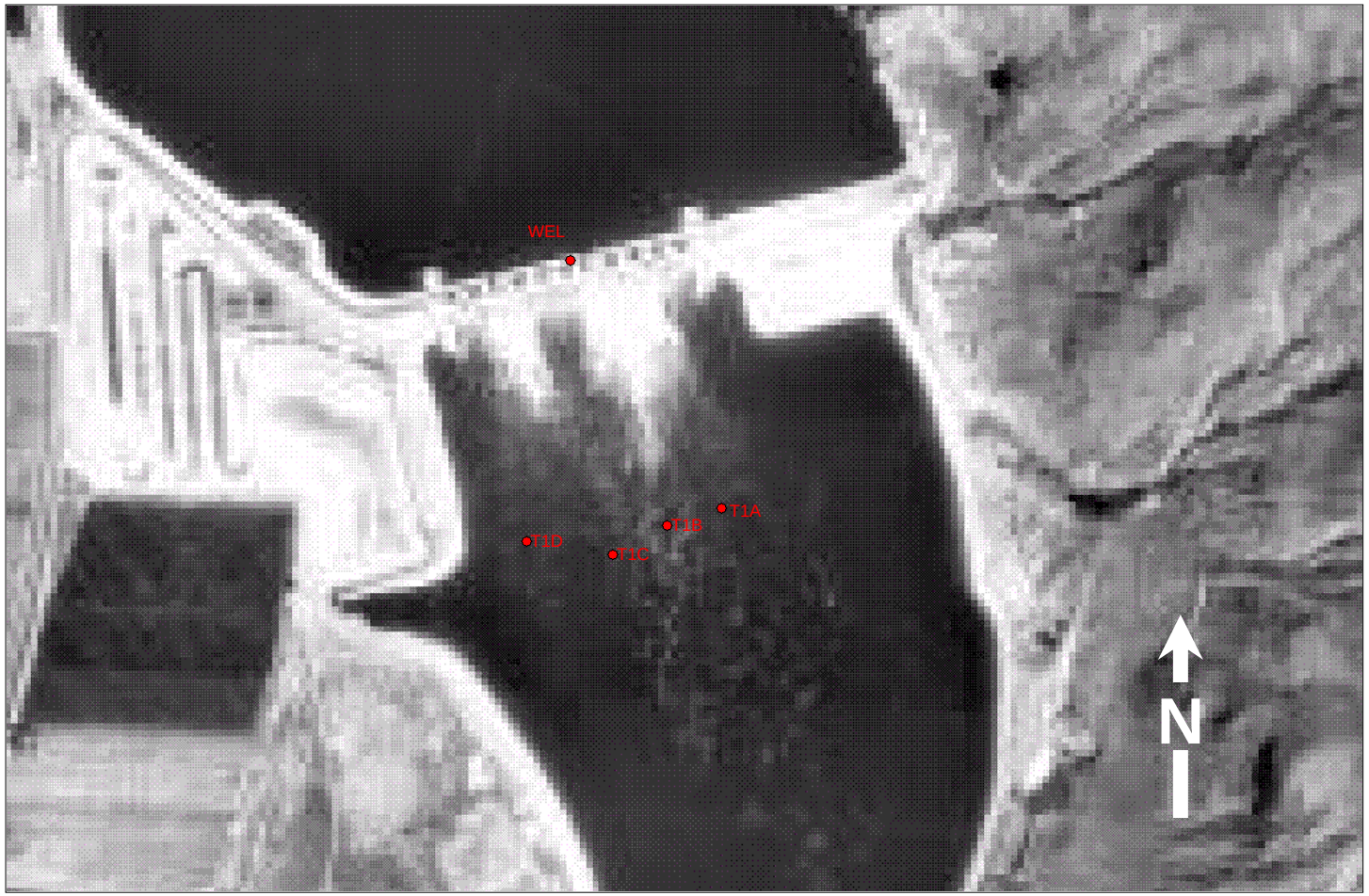


Figure 3. Transect 1 deployment locations.

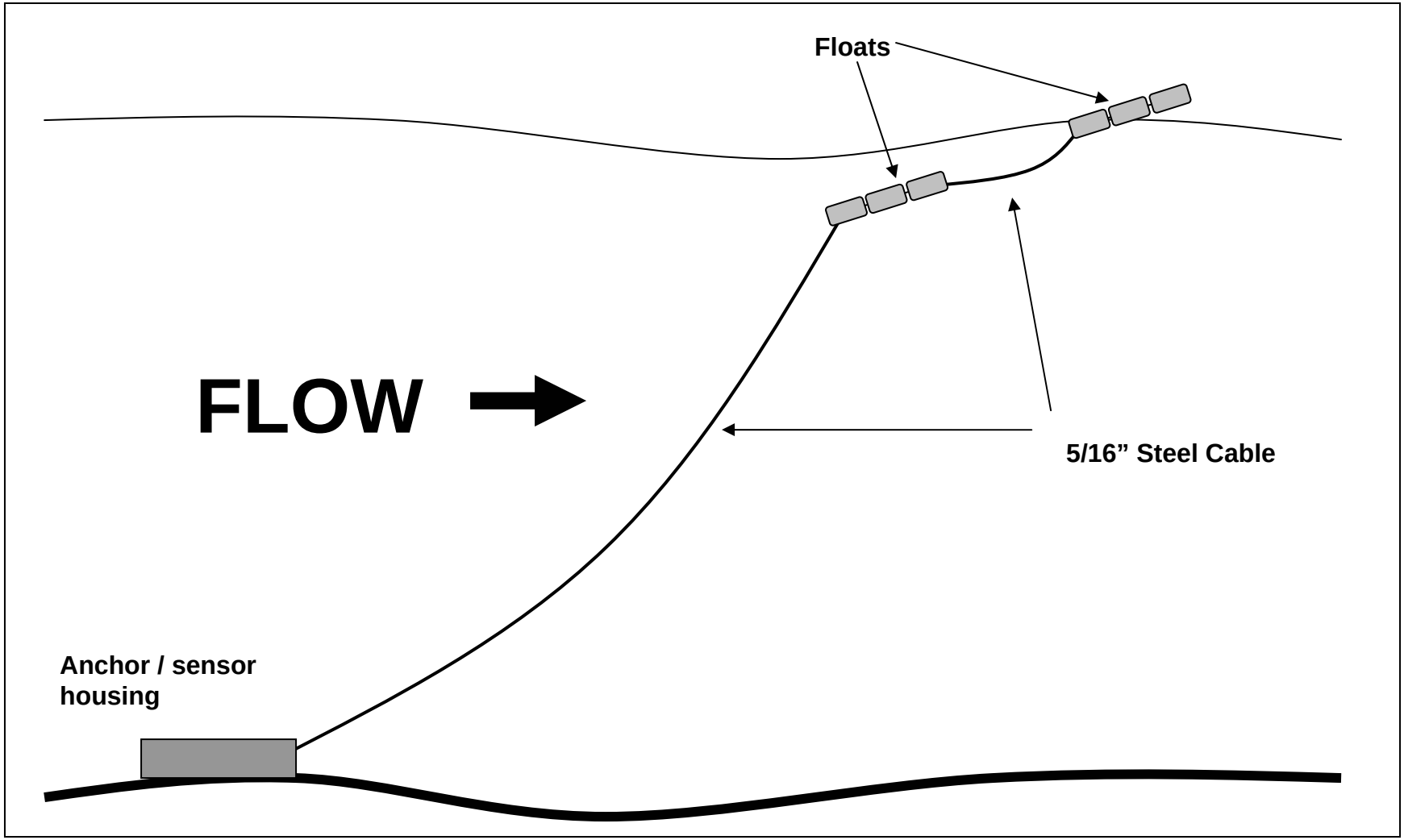


Figure 4. Schematic representation of Transect 1 deployment rigging.

Figure 5. Transect 2 deployment locations

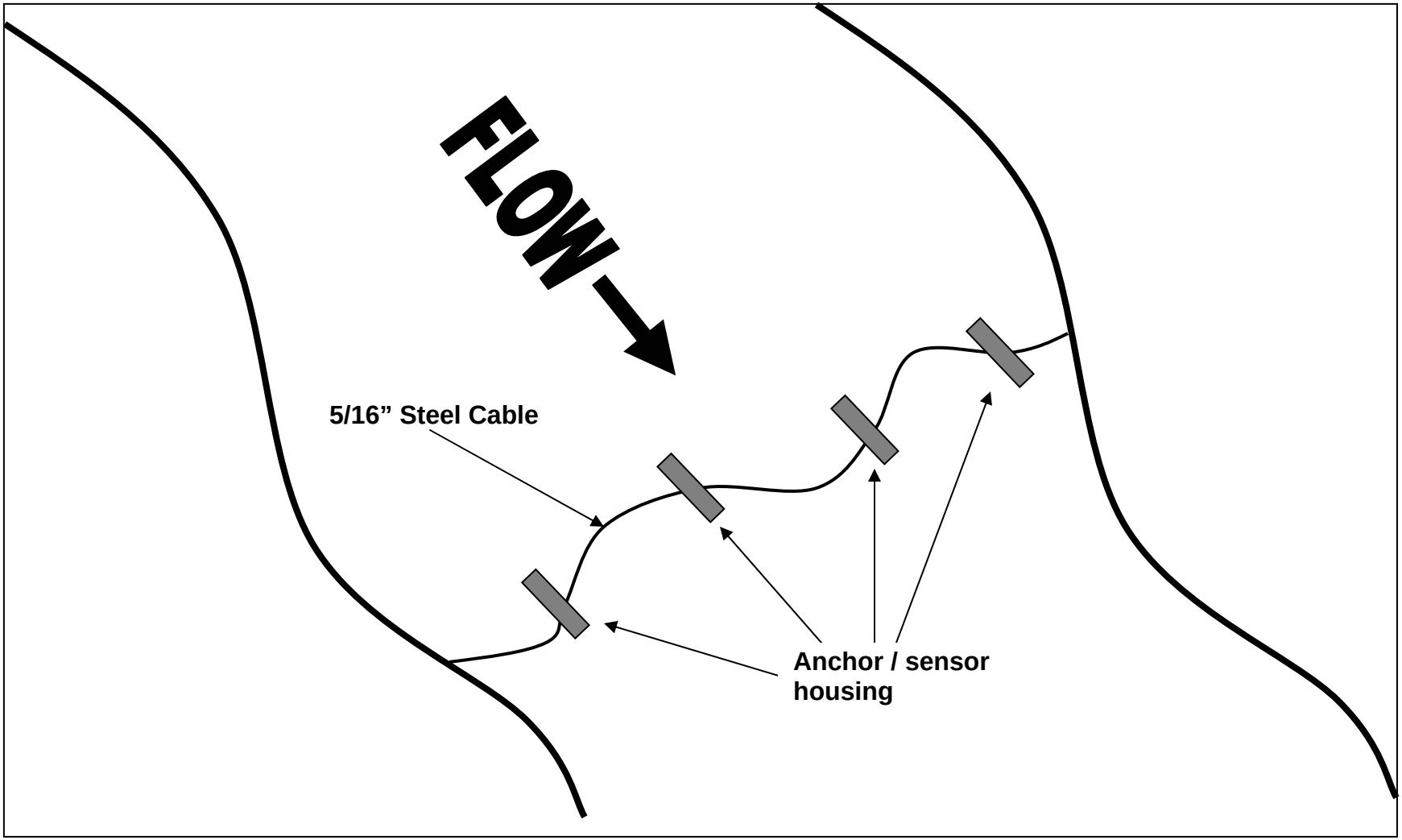


Figure 6. Schematic representation of Transect 2 deployment rigging.

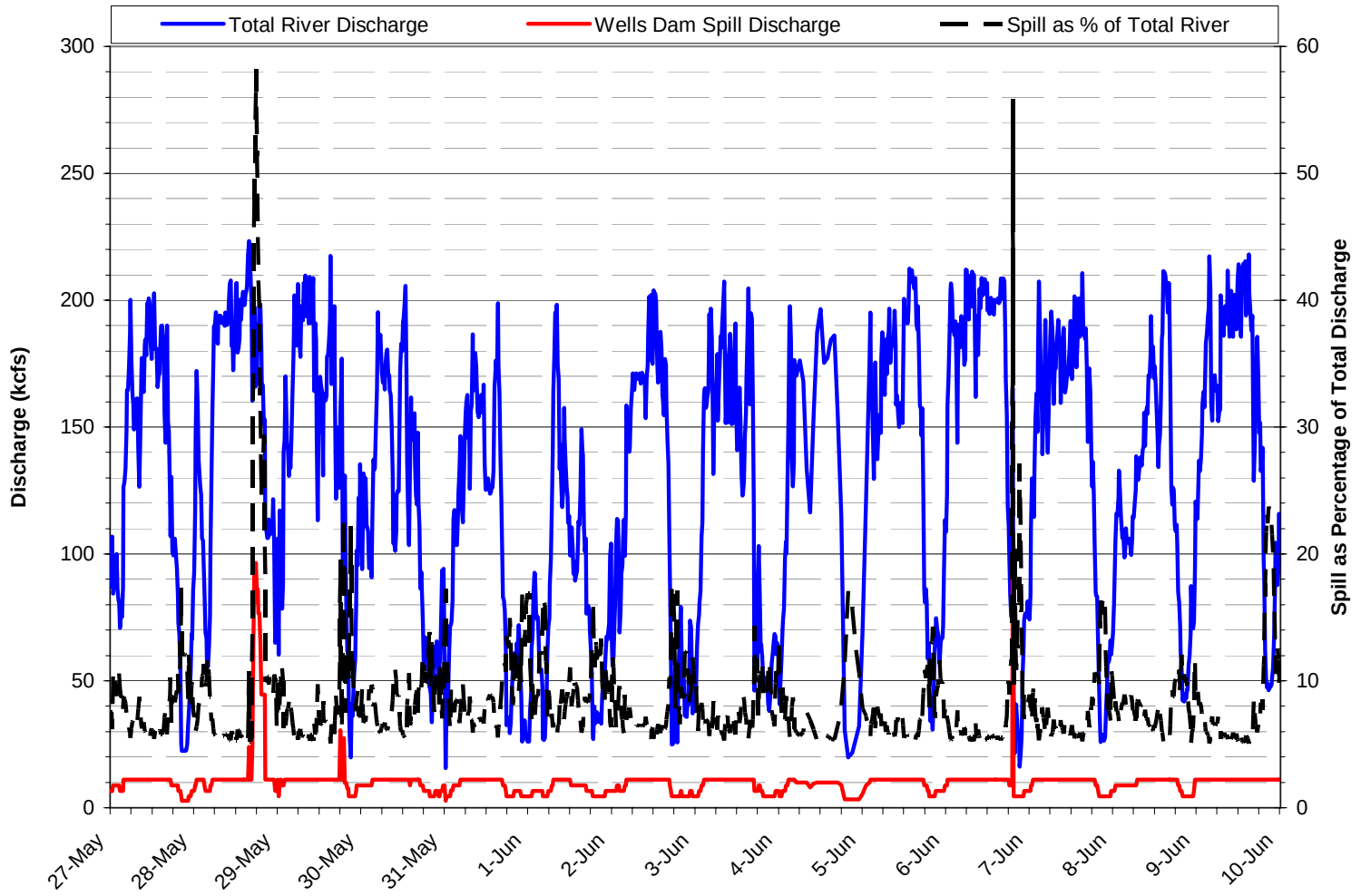


Figure 7. Wells Dam project discharge for the period of 27 May to 10 June 2003.

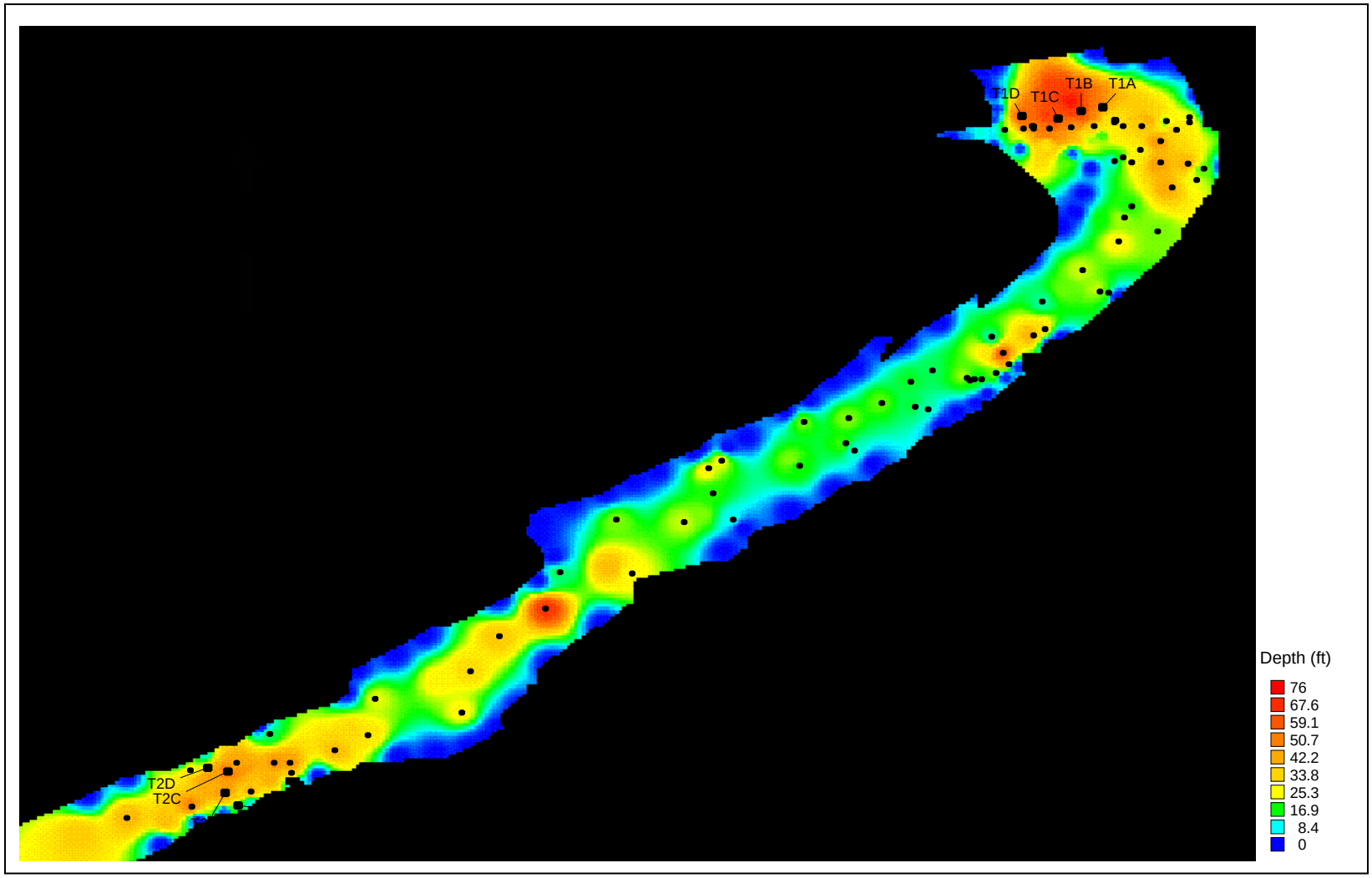


Figure 8. Contour map of Wells Dam tailwater morphometry developed from bathymetric cruise data.

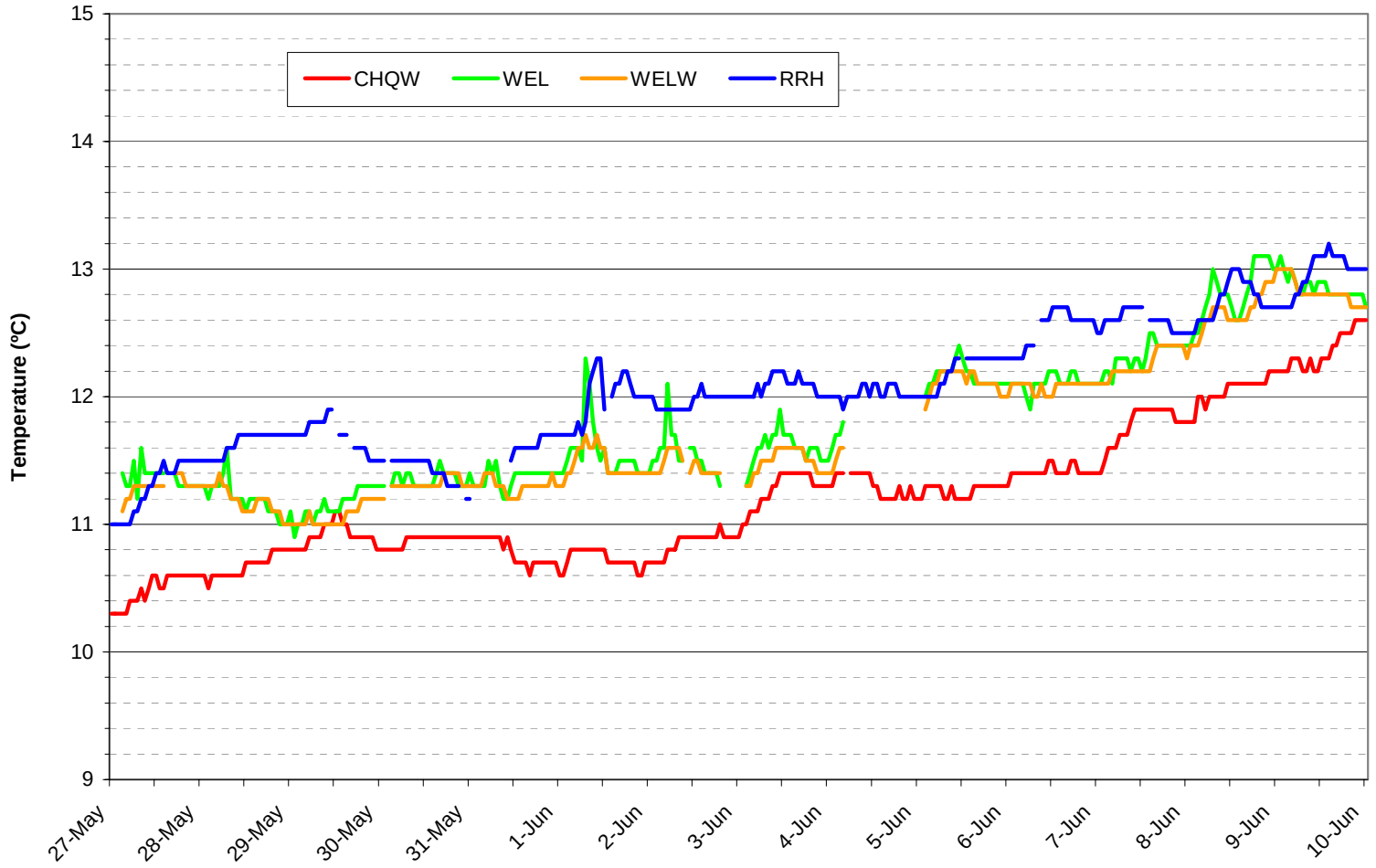


Figure 9. Water temperature data measured at Chief Joseph, Wells, and Rocky Reach Dams for the period of 27 May to 10 June 2003.

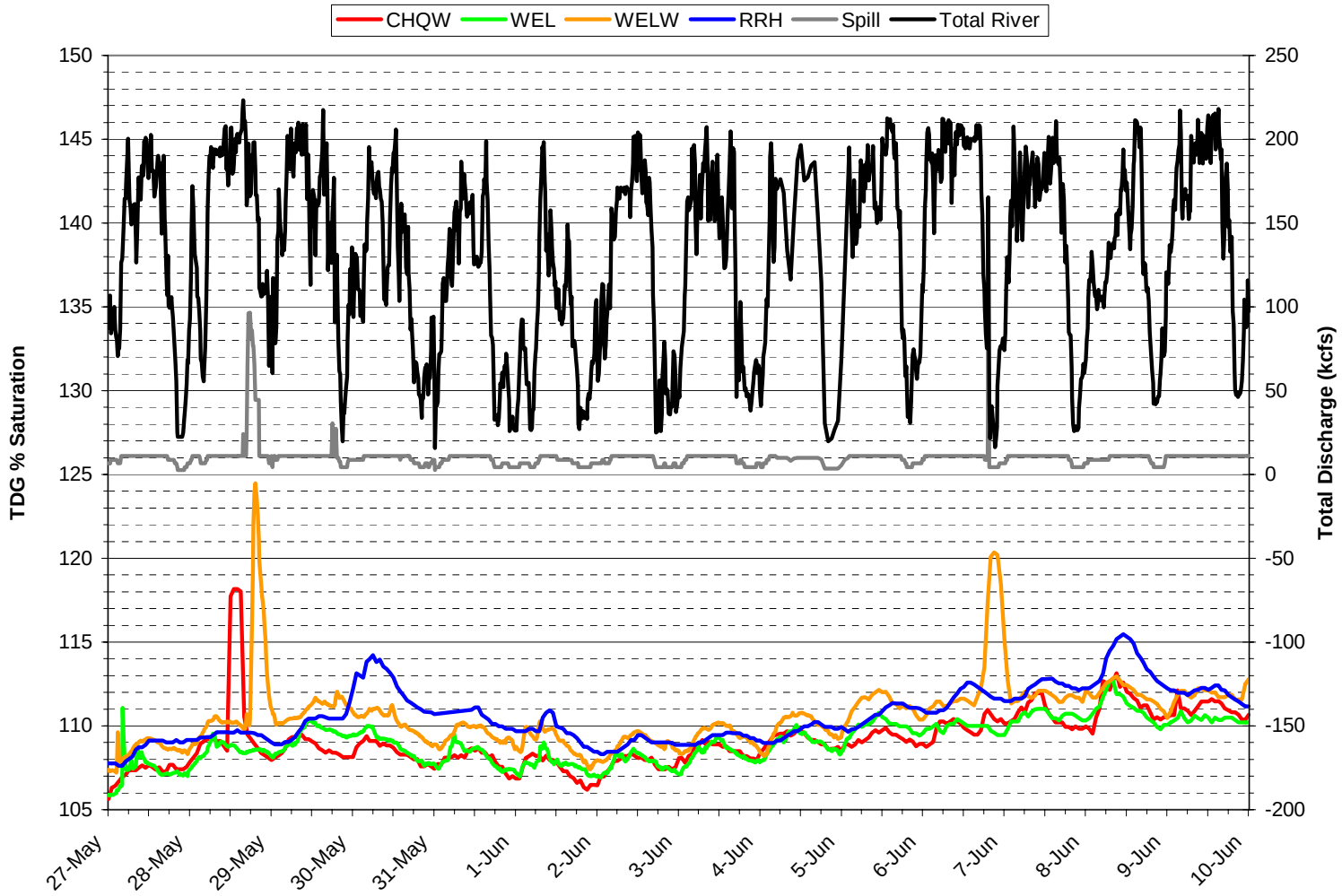


Figure 10. Total dissolved gas saturations measured at Chief Joseph, Wells, and Rocky Reach Dams for the period of 27 May to 10 June 2003 (River and spill discharge information are for Wells Dam).

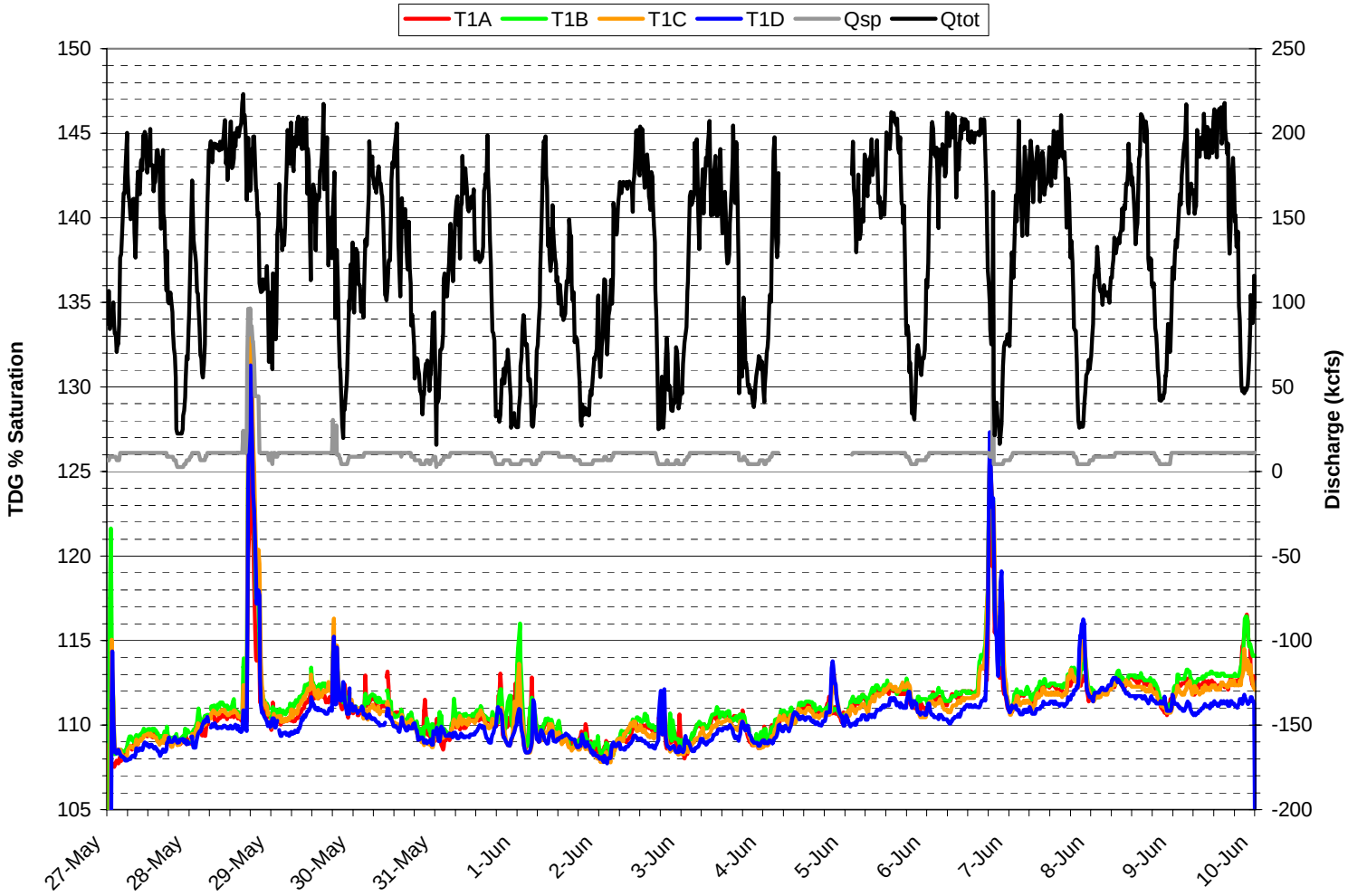


Figure 11. Wells Dam 15-minute operations data and Transect 1 TDG saturations for the period from 27 May to 10 June 2003.

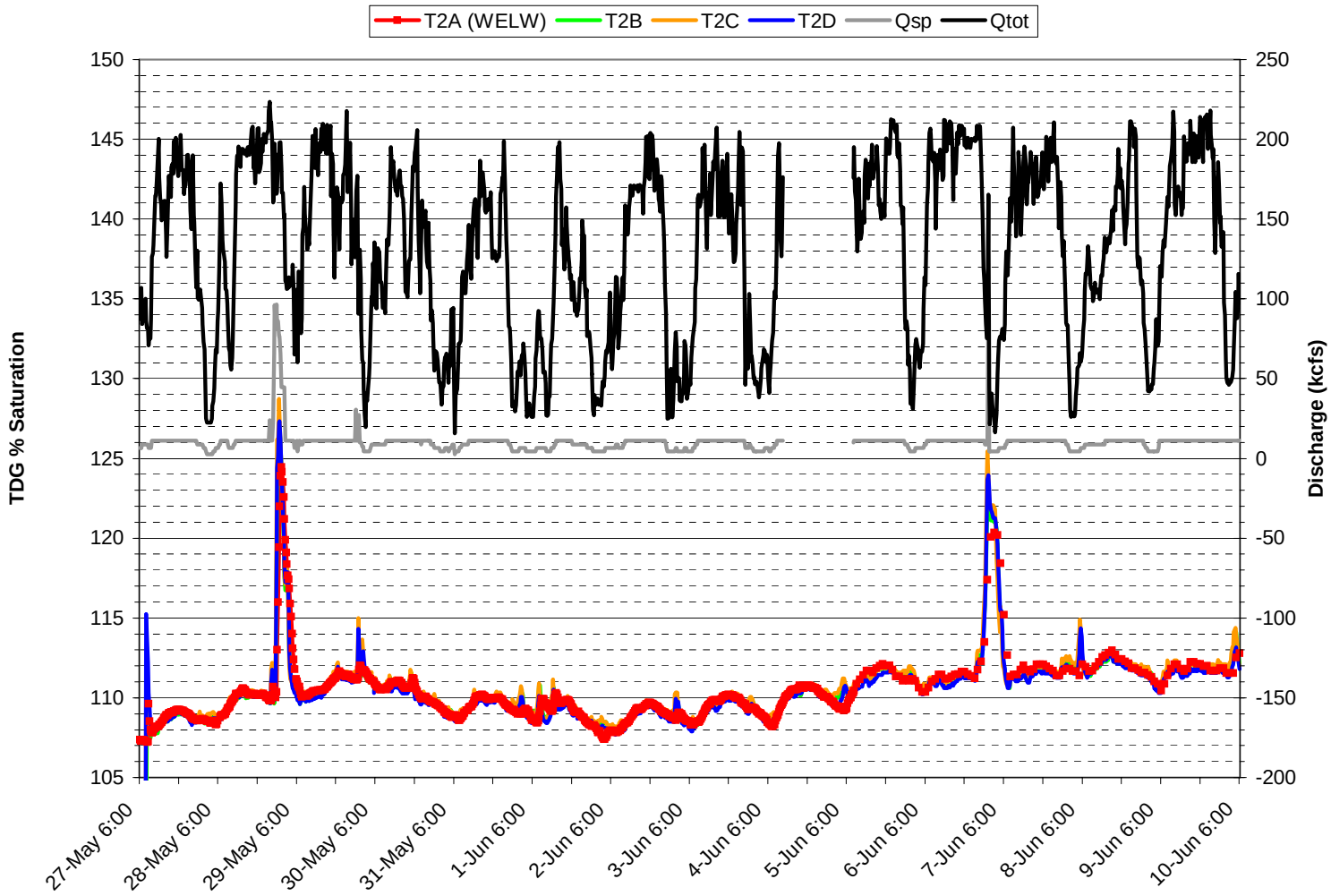


Figure 12. Wells Dam 15-minute operations data and Transect 2 TDG saturations for the period from 27 May to 10 June 2003.

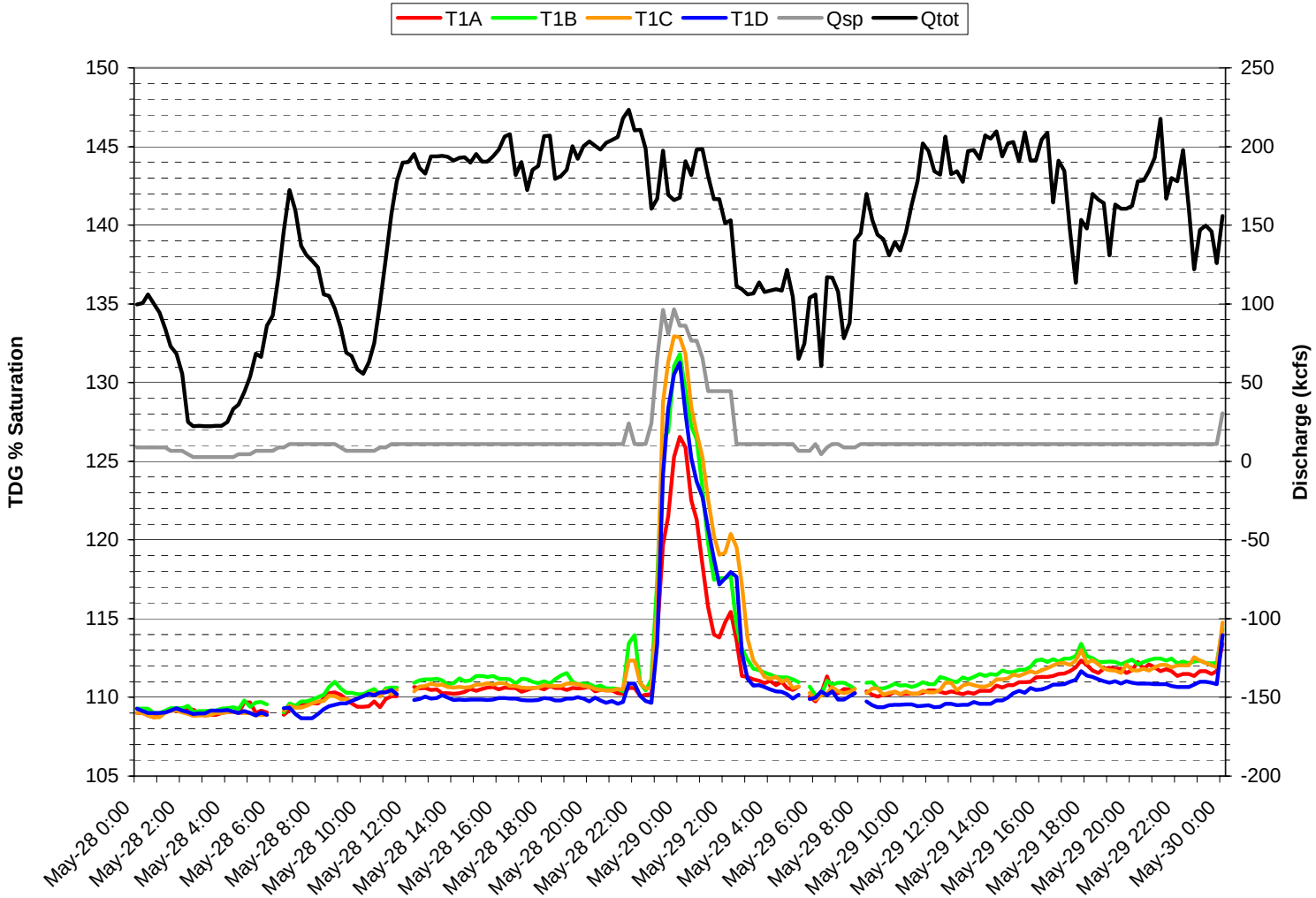


Figure 13. Wells Dam 15-minute operations data and Transect 1 TDG saturations for the period from 28 to 30 May 2003.

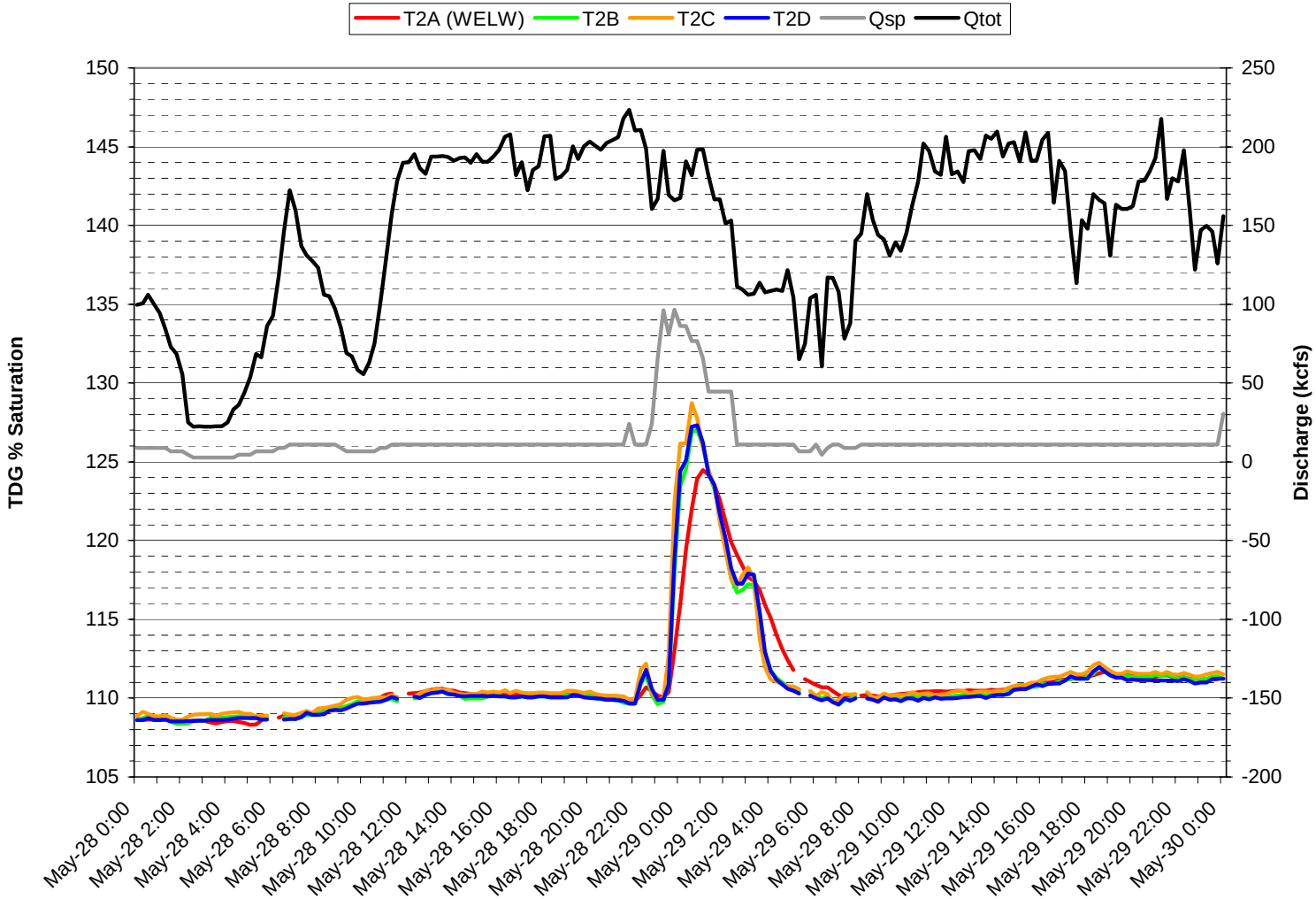


Figure 14. Wells Dam 15-minute operations data and Transect 2 TDG saturations for the period from 28 to 30 May 2003.

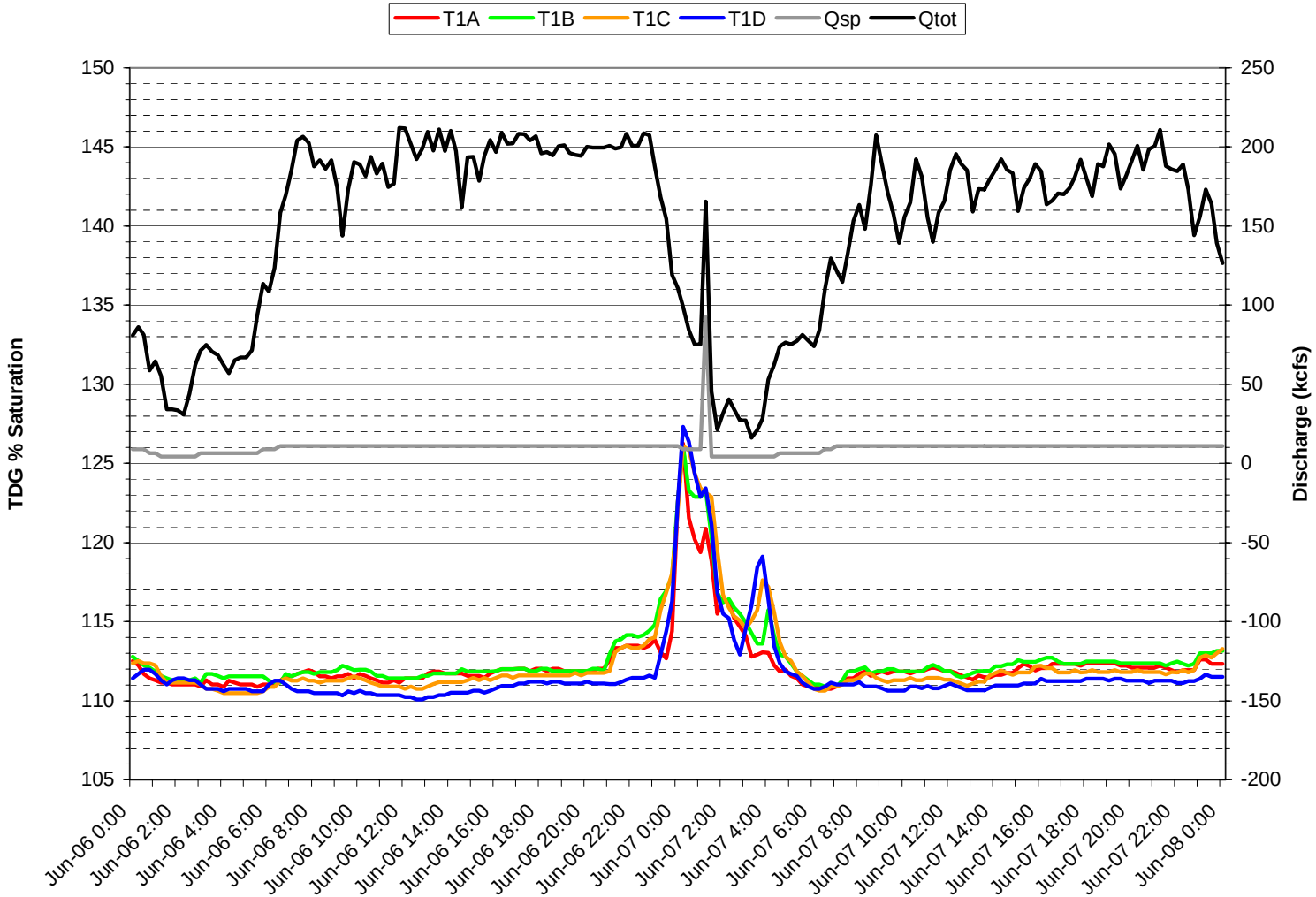


Figure 15. Wells Dam 15-minute operations data and Transect 1 TDG saturations for the period from 6 to 8 June 2003.

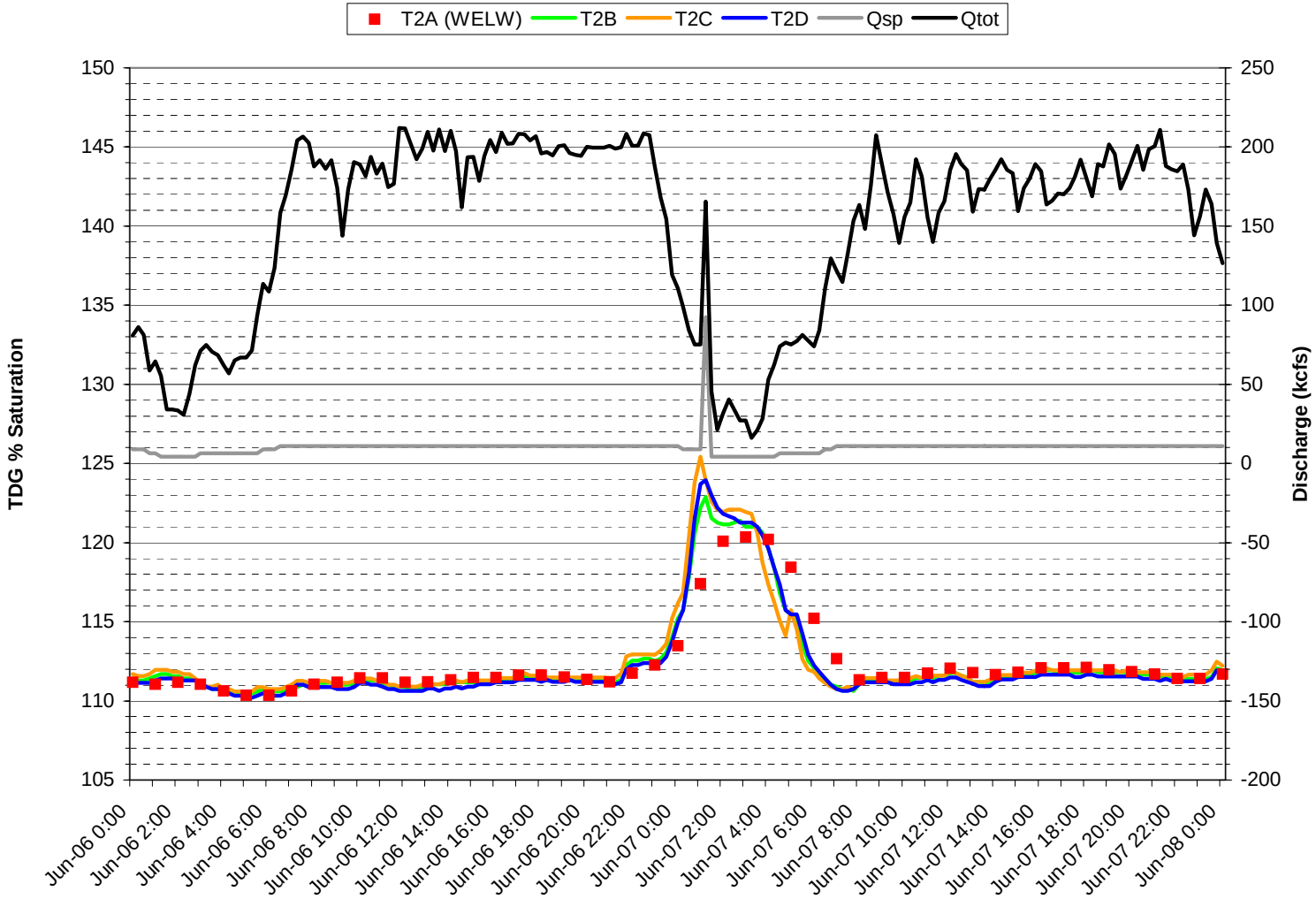
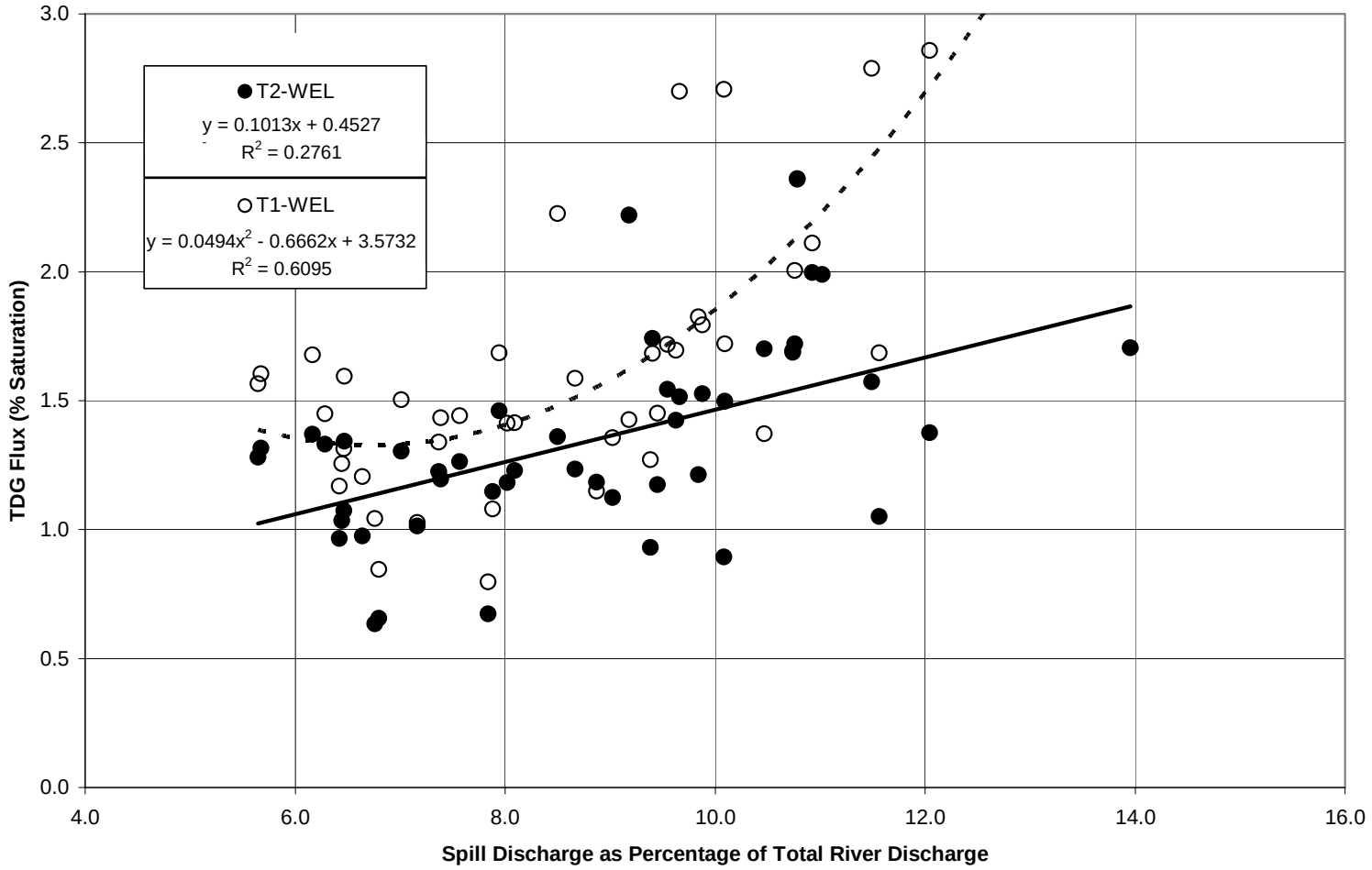


Figure 16. Wells Dam 15-minute operations data and Transect 2 TDG saturations for the period from 6 to 8 June 2003.



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BioAnalysts, Inc. 2004. Movement of Bull Trout within the Mid-Columbia River and Tributaries, 2001-2004. Prepared by BioAnalysts, Inc., Eagle Rock, Idaho for Public Utility District No. 1 of Chelan County, Wenatchee, WA, Public Utility District No. 1 of Douglas County, East Wenatchee, WA, and Public Utility District No. 1 of Grant County, Ephrata, WA.

MOVEMENT OF BULL TROUT WITHIN THE MID-COLUMBIA RIVER AND TRIBUTARIES, 2001-2004

Final

ROCKY REACH HYDROELECTRIC PROJECT
FERC Project No. 2145

ROCK ISLAND HYDROELECTRIC PROJECT
FERC Project No. 943

WELLS HYDROELECTRIC PROJECT
FERC Project No. 2149

PRIEST RAPIDS HYDROELECTRIC PROJECT
FERC Project No. 2114

May 26, 2004

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SECTION 1: INTRODUCTION

On 10 June 1998, the U.S. Fish and Wildlife Service (Service) listed bull trout (*Salvelinus confluentus*) within the Columbia River basin as threatened under the Endangered Species Act (ESA) (50 CFR 63(111)). Later (1 November 1999), the Service listed bull trout within the coterminous United States as threatened under the ESA (50 CFR 64(210)). The Service identified habitat degradation, fragmentation and alterations associated with dewatering, road construction and maintenance, mining, and grazing; blockage of migratory corridors by dams or other diversion structures; poor water quality; incidental angler harvest; entrainment into diversion channels; and introduced non-native species as major factors affecting the distribution and abundance of bull trout. They noted that dams (and natural barriers) have isolated population segments resulting in a loss of genetic exchange among these segments (50 CFR 63(111):31657). The Service believes many populations are now isolated and disjunct.

In a letter to the Federal Energy Regulatory Commission (FERC), the Service requested consultation under Section 7 of the ESA regarding the effects of hydroelectric project operations on bull trout in the Columbia River (letter from M. Miller, USFWS, to M. Robinson, FERC, dated 10 January 2000). The request for consultation was based on observations of bull trout in the study area. In its reply to the Service, the FERC noted that there was virtually no information on bull trout in the mainstem Columbia River.

Because bull trout within the mid-Columbia River[1] area are listed under the ESA (50 CFR 63(111):31651), and they may be affected by the operation of hydro-projects owned and operated by Chelan, Douglas, and Grant PUDs (Mid-Columbia PUDs), the Mid-Columbia PUDs initiated a multi-year evaluation of the status of bull trout in the project area. Currently, little is known about the life-history characteristics (e.g., movements, distribution, habitat use, etc.) of bull trout in the mid-Columbia River. Therefore, in order to assess the operational effects of hydroelectric projects on adult bull trout within the mid-Columbia, a total of 79 adult bull trout were radio-tagged during the 2001-2003 study period and tracked to describe their movements within the mid-Columbia Basin.

The specific objectives of the study were to: (1) describe the movements and migration of adult bull trout in the mid-Columbia system and (2) assess the effects of hydroelectric operations on the movement and migration patterns of adult bull trout in the mid-Columbia River. This report focuses primarily on the last two years of the study, because the first year of work has already been reported (BioAnalysts, Inc. 2002). However, for comparative purposes, the results for all three years of research have been included into one report. For additional information on the first year of this study, please refer to the publication BioAnalysts, Inc. (2002).

[1] In this document, the mid-Columbia River is defined as the area between the confluence of the Yakima and Columbia rivers and Chief Joseph Dam. NOAA Fisheries refers to this area as the upper-Columbia River.

SECTION 2: PROJECT AREA

The primary geographical area of interest was the mainstem Columbia River from Priest Rapids Dam to Chief Joseph Dam (Figure 1). It is within this area that the effects of Priest Rapids, Wanapum, Rock Island, Rocky Reach, and Wells dams were assessed regarding the movements and migration of adult bull trout. At these dams, fixed-site radio-telemetry systems were installed to monitor the movements of radio-tagged bull trout. The study area also included the four major tributaries to the mid-Columbia River; Wenatchee, Entiat, Methow, and Okanogan systems. Both fixed-site and mobile telemetry surveys monitored the movement of radio-tagged bull trout within each of the major tributary streams.

Columbia River flows in the project area during the period May through October 2001-2003 are shown in Figure 2, Figure 3, Figure 4, Figure 5 and Figure 6. Discharge at the mid-Columbia River projects was a combination of turbine generation and spill generally from the first of May to the end of August. However, minimal spill levels continued at Priest and Wanapum dams until the end of October. Similar spill operations did not occur at Wells, Rocky Reach and Rock Island dams. Migration of bull trout upstream through each of the projects was provided by a fishway ladder system. These ladder systems consist of one or more main entrances located in the tailrace of each project. Some projects (e.g., Priest Rapids, Wanapum, and Rocky Reach dams) also include orifice gates (O.G. gates) that are used to provide additional entrances to the collection channels of the main ladder system. Migration downstream past mid-Columbia River projects likely occurs through powerhouse or spillway passage routes and may also include juvenile bypass collection facilities.

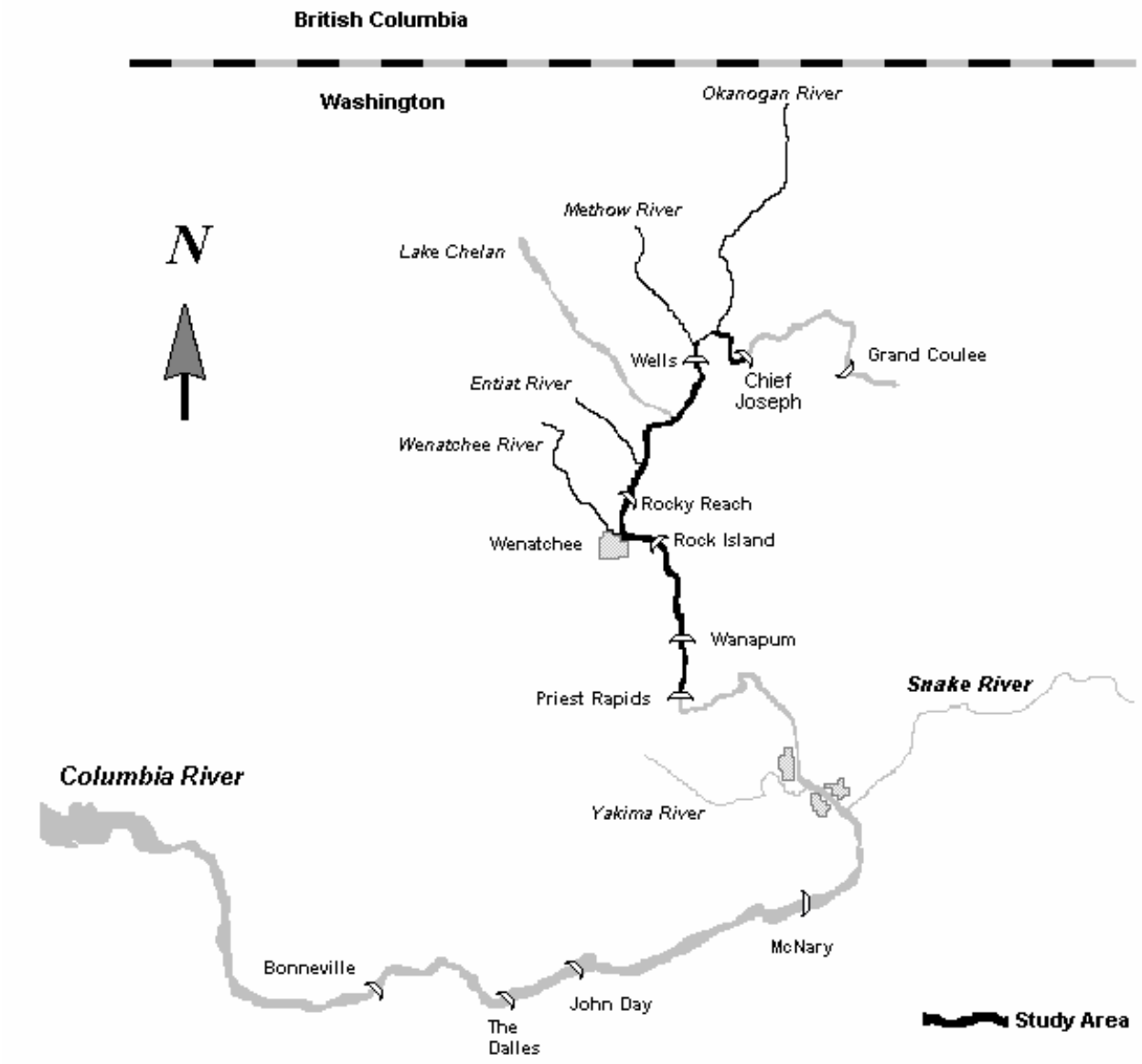

Figure 1: Study area for assessing migration patterns of bull trout in the mid-Columbia River. Fixed radio-telemetry sites monitored the movement of bull trout near Priest Rapids, Wanapum, Rock Island, Rocky Reach, and Wells dams. Fixed sites placed in the Wenatchee, Entiat, Methow, and Okanogan rivers monitored time of entry and exodus of bull trout in large tributaries of the mid-Columbia River.

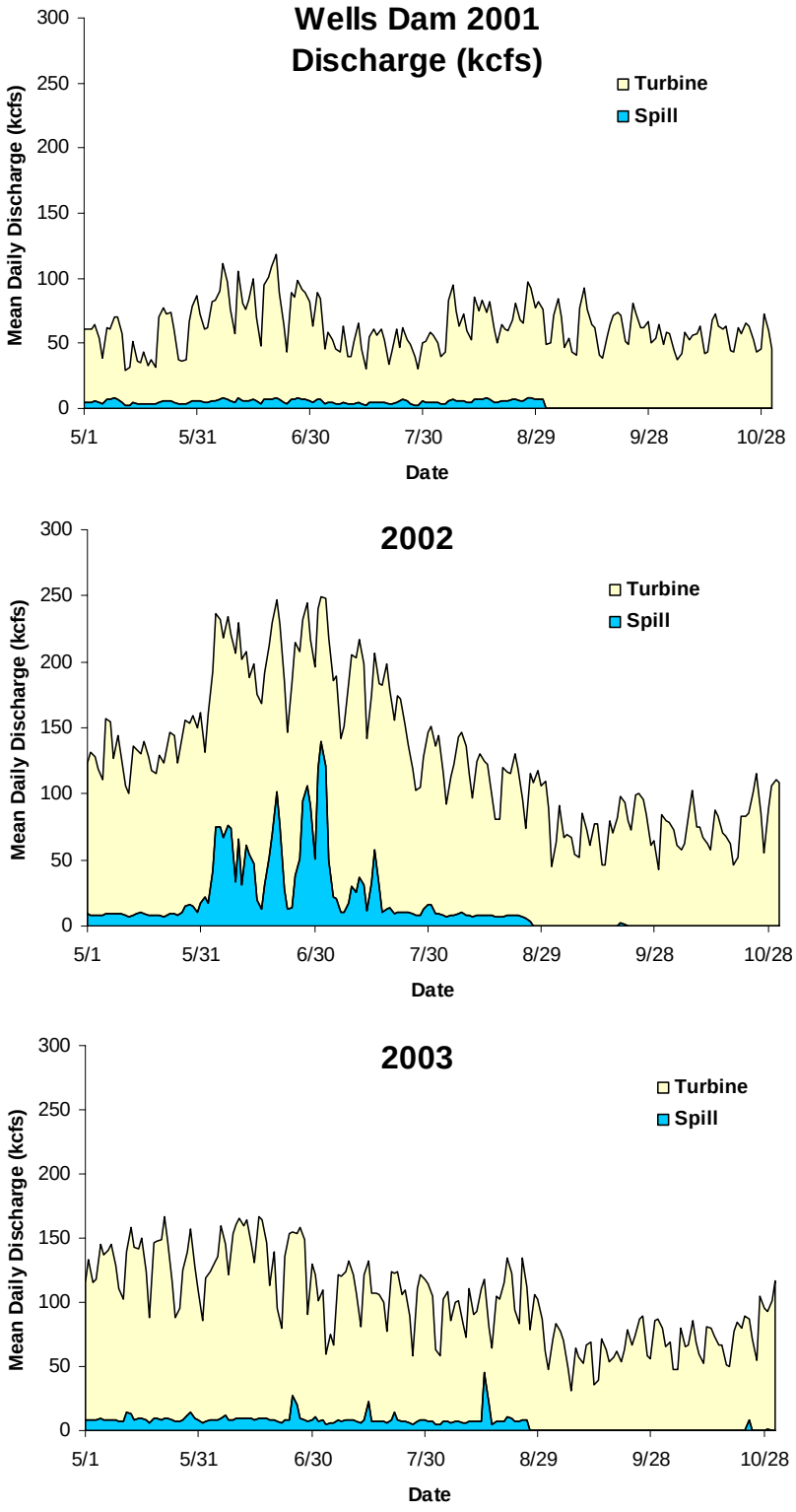

Figure 2: Columbia River flows passing through Wells Dam during the period May through October, 2001-2003.

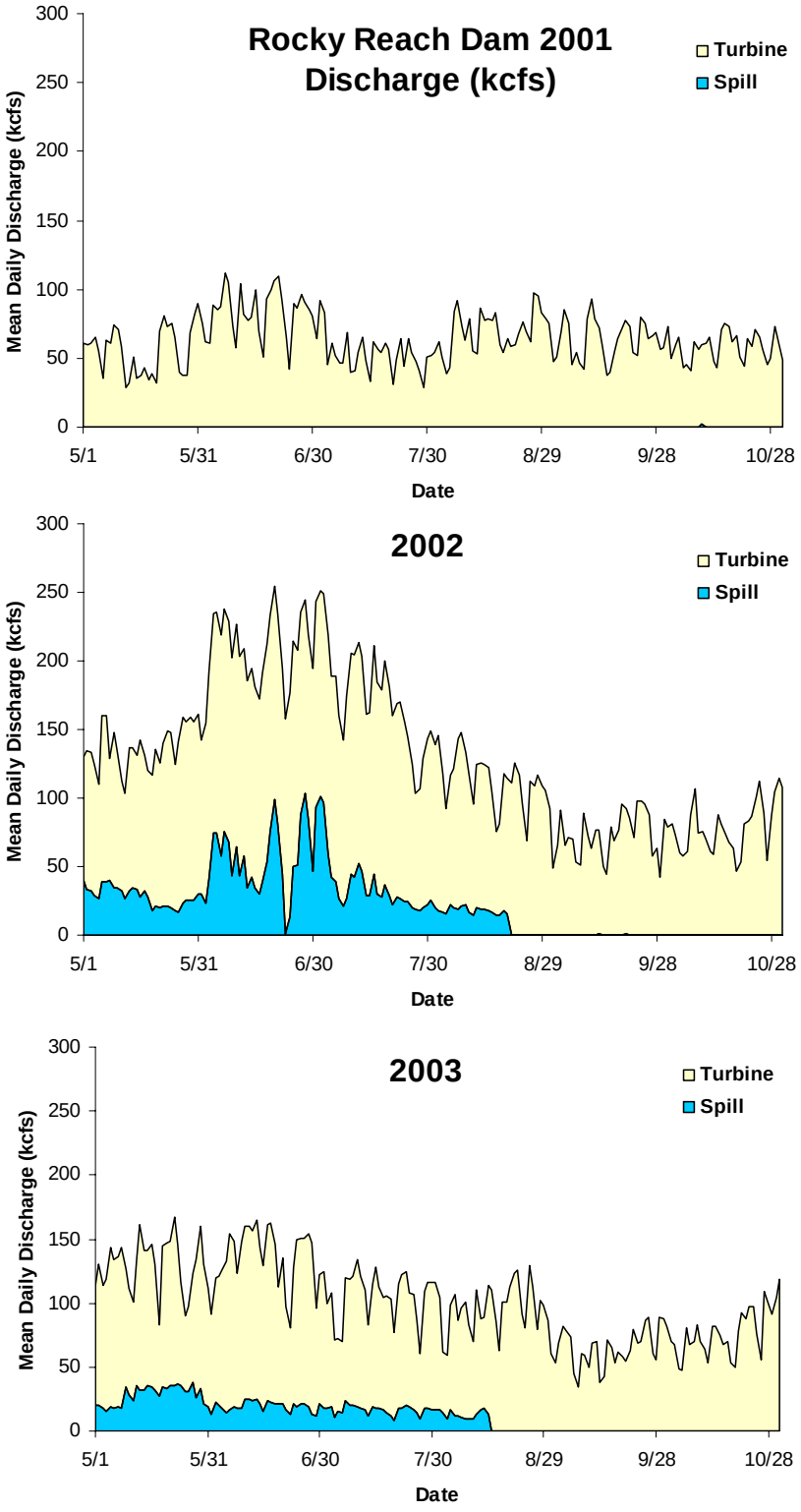

Figure 3: Columbia River flows passing through Rocky Reach dam during the period May through October, 2001-2003.

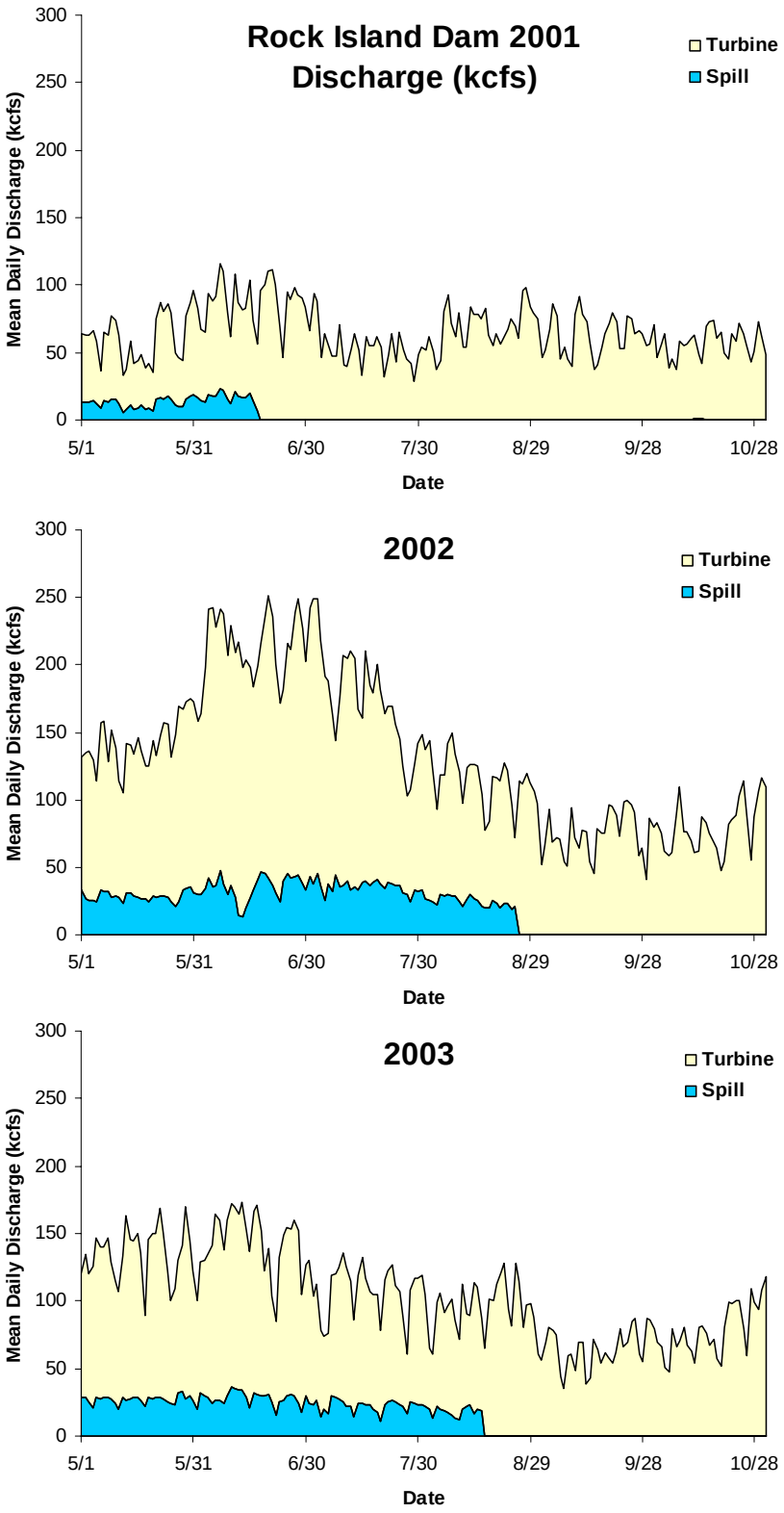

Figure 4: Columbia River flows passing through Rock Island dam during the period May through October, 2001-2003.

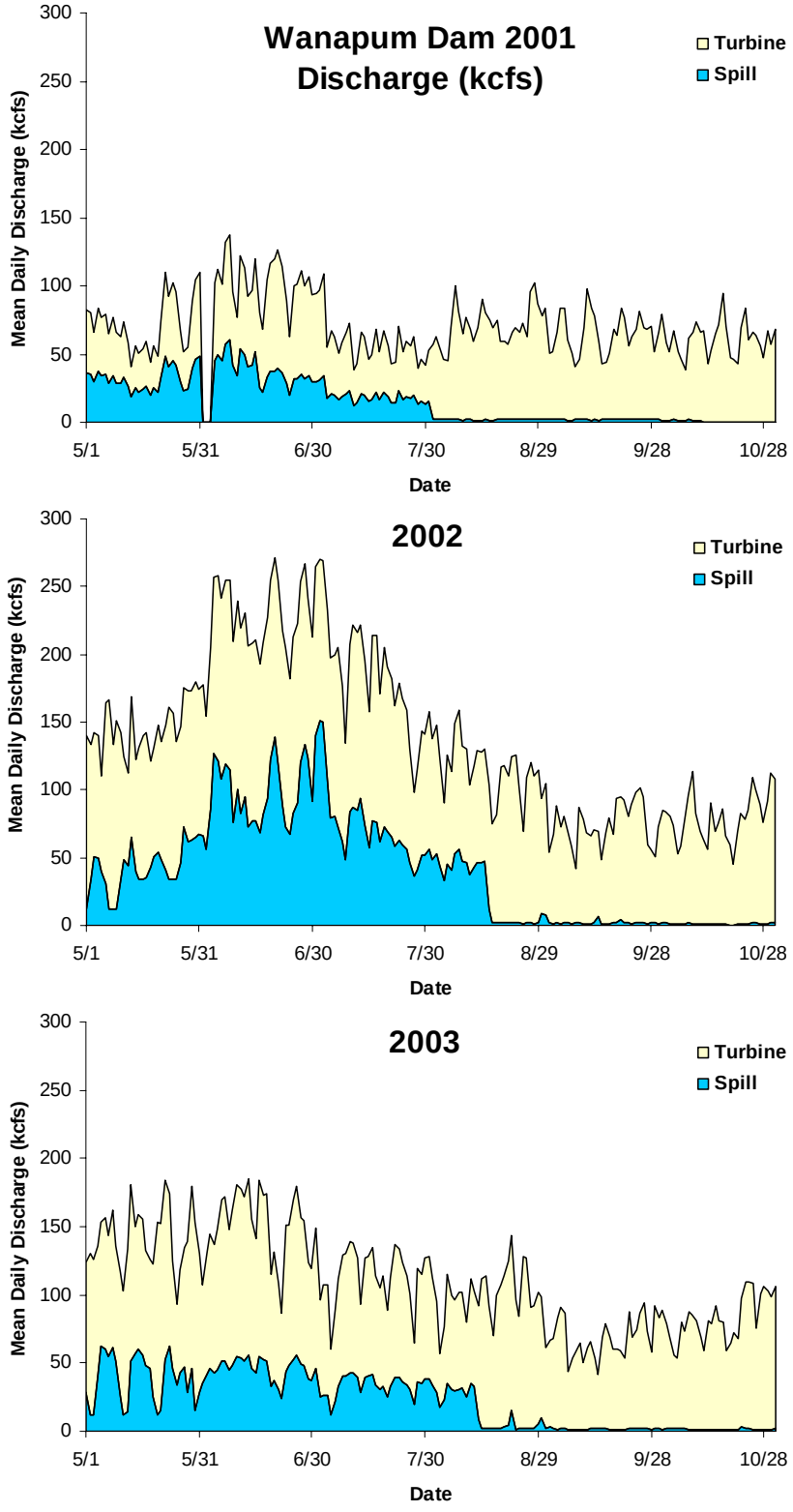

Figure 5: Columbia River flows passing through Wanapum dam during the period May through October, 2001-2003.

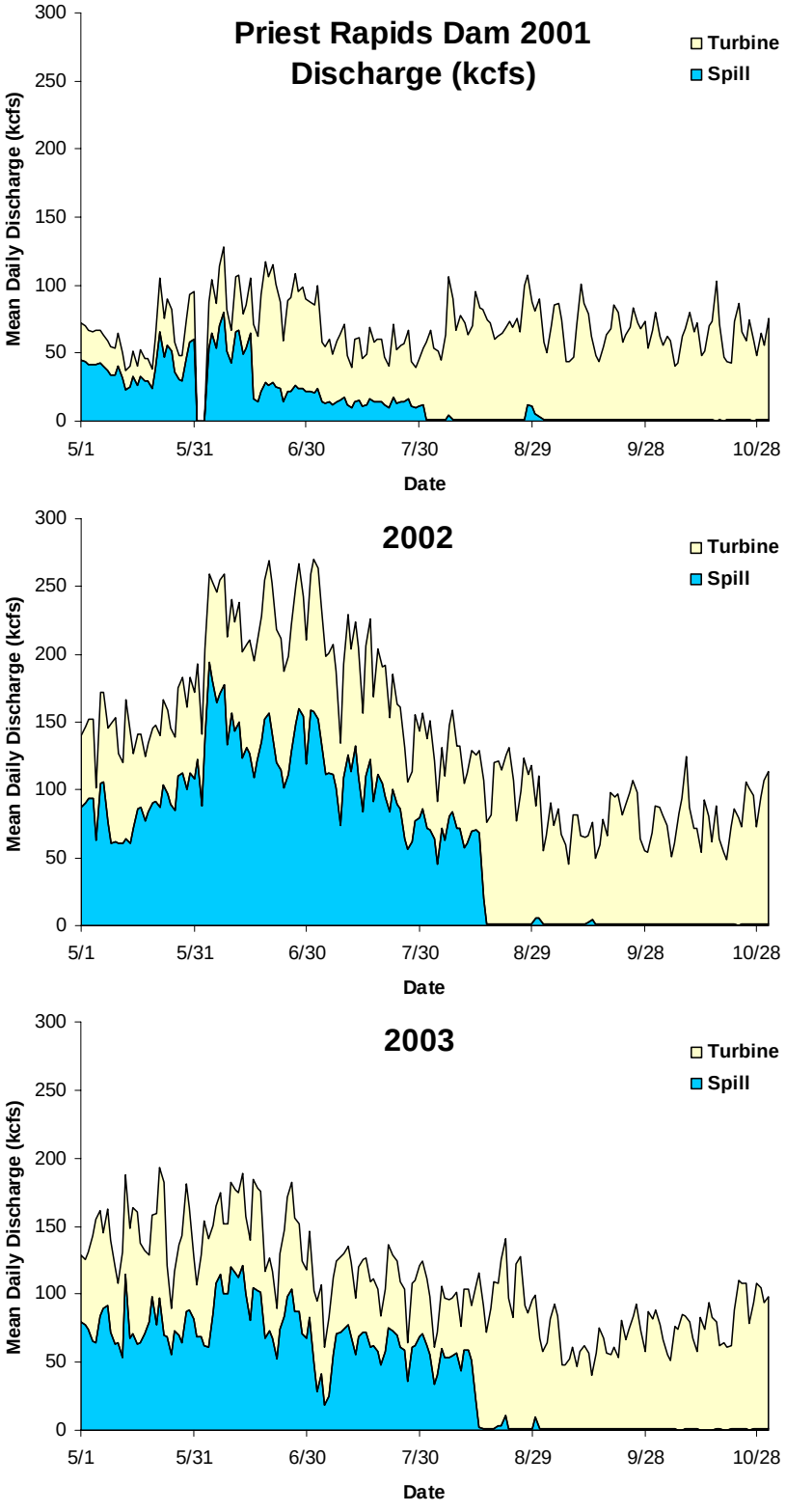

Figure 6: Columbia River flows passing through Priest Rapids dam during the period May through October, 2001-2003.

SECTION 3: METHODS

This study relied on radiotelemetry techniques to monitor the movements and migration patterns of adult bull trout in the mid-Columbia River. Below, is a description of the number of fish tagged in 2002, including the tagging procedures and monitoring systems used in 2002 and 2003. Study methods for the 2001 study period are summarized in BioAnalysts, Inc. (2002). However, it should be noted that all methods and monitoring systems were consistent in all three years of the study.

3.1 Number of Bull Trout Tagged

To assess the movements and migration of adult bull trout, the original proposal was to tag a total of 40 bull trout in the mid-Columbia River in 2002. This number was consistent with tagging efforts in 2001[2] and was based on discussions with the Service. This sample size represented about 20% of all bull trout counted at the dams in previous years. The number of trout to be collected and tagged at each dam was based on the proportion of fish that migrated past those dams in 2000. Because more bull trout pass Rocky Reach Dam than Rock Island or Wells dams, the target was to capture and tag 10 adult bull trout at Rock Island Dam, 20 at Rocky Reach Dam, and 10 at Wells Dam. Bull trout were sampled during mid-May to late-June, which coincides with the period when the most bull trout are observed passing through the three dams (Figure 7, Figure 8 and Figure 9). No attempts were made to tag at Priest or Wanapum dams because very few bull trout are observed moving past those projects.

To avoid a temporal bias in the sampling program, bull trout were collected throughout the spring migration period (20 May to 27 June) at Rocky Reach Dam by establishing weekly tagging targets. These weekly targets were based on the proportion of fish observed at Rocky Reach Dam in 2000 and 2001 (Table 1). That is, bull trout were captured throughout the passage period, but a greater number were collected and tagged during the period of peak passage.

In order to describe passage distribution, the number of bull trout passing Rocky Reach Dam during each week in 2000 and 2001 were compiled. From those data, the proportion of the total run that passed the project during each week was then calculated. The numbers of bull trout captured and tagged at the dam during each week of the 2002 sampling period was estimated from the product of the weekly proportions and total sample size (i.e., 20 fish at Rocky Reach) (Table 1). At most, five fish were to be collected and tagged during a given sampling week (Table 1). Because of the desire to maintain the predetermined tagging schedule, it was decided that if the weekly tagging quotas were not met at the project, the deficit would be carried into the following week.

Diel passage data for adult bull trout at Rocky Reach and Rock Island dams indicated that most bull trout passed the projects between 0800-2300 hours (Figure 10 and Figure 11). Since the upstream release of radio-tagged fish at Rocky Reach Dam required logistical support from Chelan PUD, it was decided to operate the traps between 0800-1700 hours.

[2] In 2001, only 39 adult bull trout were captured and tagged. Because of the low number of bull trout that passed Rock Island Dam, only seven fish were collected and tagged there. The deficit was partially made up at Rocky Reach Dam, where 22 adult trout were collected and tagged (two more than the target). The goal of 10 bull trout at Wells Dam in 2001 was met.

No weekly tagging goals were established for the collection of bull trout at Rock Island or Wells dams in 2002. In 2001 at Rock Island, it was difficult to meet tagging quotas near the end of the tagging period. Therefore, the decision was made to collect and tag all fish as they passed the project. At Wells Dam, the overall trap operation time was reduced to minimize the potential for delay and harassment to migrating ESA listed spring Chinook salmon and steelhead. At Wells, collection and tagging began on 21 May and continued through 19 June with trap operation typically Monday through Wednesday between 0900-1400 hours (Figure 12).

Table 1: Weekly adult bull trout tagging schedule for Rocky Reach Dam, 2002. The tagging schedule was based on the proportion observed (counted) during the same period during the 2000 and 2001 migrations.

		2000 and 2001	
Week	**Beginning**	**Observed Average**	**Tag**
1	13-May	30.5	4
2	20-May	41.5	5
3	27-May	32.5	4
4	03-June	18.0	2
5	10-June	14.5	2
6	17-June	11.5	2
7	24-June	10.0	1
	Totals	**158.5**	**20**

3.2 Trapping Facilities

3.2.1 Rocky Reach and Rock Island Dams

Trap facilities at Rocky Reach and Rock Island dams are integrated with the existing fish-viewing structures within the ladders (Figure 13 and Figure 14). Essentially, the fish-viewing guide wall extends upstream to the exit weir, where a pneumatically-activated gate guides fish into a collection area. On the other side of the pneumatic gate the collection area contains a removable capture vessel. As a bull trout entered the viewing area, a technician activated the pneumatic gate, which blocked passage into the forebay and diverted the bull trout into the collection area. Using an underwater camera, the technician could observe the bull trout enter the collection area, at which time the gate would be closed, trapping the bull trout. Non-target species and small bull trout (<40 cm fork length) were allowed to exit the ladder by simply not activating the pneumatic gate. After a bull trout was contained within the collection area, either an electric or hand-operated winch raised the collection vessel from the collection area up to the work-surface platform. As the vessel emerged from the water, a wooden cover was placed on top of the vessel to reduce stress to the fish and eliminate the possibility of the fish jumping out of the vessel.

The captured bull trout was then transferred from the collection vessel to the surgical facility. To facilitate transfer and reduce handling stress, the bull trout was sedated with tricaine

methanesulfonate (MS-222) at a concentration of 80 mg/L while the fish was contained in the collection vessel (see Surgical Techniques for detailed description of sedation). At Rocky Reach Dam, the collection vessel was moved laterally along an I-beam monorail close to the surgical facility located under the roadway of the ladder. The fish was then transferred by hand to the surgical table for processing. At Rock Island Dam, the surgical facility was located within a trailer about 10 m from the collection area. There, the fish was transferred in a rubber bladder filled with anesthetic water to the surgical facility.

3.2.2 Wells Dam

Bull trout at Wells Dam were trapped at the brood-stock collection facility located within the left bank ladder. The brood-stock collection facility is located at pool 40 about half way up the fish ladder. The trap is operated by placing a barrier fence across the entire width of pool. When the trap is in operation, all fish ascending the left bank ladder are blocked by the barrier fence and forced to ascend the off-ladder trap via a steep-pass denil that leads to an upwell enclosure. Once inside the upwell enclosure, fish move down a sorting chute by jets of water introduced near the top of the sorting chute. As the fish slide down the sorting chute, they are identified and either diverted into the holding tank or allowed to pass upstream of the trap. When a bull trout was observed in the chute, a technician activated a pneumatic gate diverting the fish into a 2,270-liter holding tank. Non-target species and small bull trout (<40 cm fork length) were shunted back to the ladder upstream of the trapping barrier. The fish ladder supplied the holding tank with freshwater at a rate of 114 to 151 L/hr to maintain adequate dissolved oxygen and temperature levels. At the time of tagging, bull trout were netted from the holding vessel and transferred to an anesthetic vessel containing an 80 mg/L solution of MS-222. Once anesthetized, fish were transferred to a mobile surgical station for further processing.

3.3 Tagging Procedures

3.3.1 Description of Radio Tags

Adult bull trout were implanted with digitally-encoded transmitters developed by Lotek Engineering. The transmitter, model MCFT-3A, was 16 mm in diameter, 46 mm long, and weighed 6.2 grams in water and 16.0 grams in air. With a 5.0-second burst rate, the estimated life of the transmitter was 761 days.

Winter (1983) identified a criterion of 2% for the ratio of transmitter to body weight (in air) as being acceptable. For transmitters used in this study, that criterion would allow the tagging of trout equal to or greater than 800 grams. However, more recent information suggests that a radio transmitter that is as much as 5-10% of the fish's body weight will not adversely affect fish behavior (Adams et al. 1998). Using the criterion of 5% would allow the tagging of fish as small as 320 grams, and 10% would allow the tagging of fish as small as 160 grams. Taking a conservative approach, a decision was made to only tag fish with a fork length greater than 40 cm (~650 grams). Based on this strategy, at most, the transmitter would amount to 2.5% of the fish's body weight.

3.3.2 Surgical Techniques

The surgical procedures employed are nearly identical to the methods described in Summerfelt and Smith (1990), with some modifications based on consultation with the Service. Bull trout were anesthetized in a pre-operative solution of MS 222 at a concentration of 80 mg/L. Service biologists

found that 80 mg/L of MS 222 for initial induction, followed by a concentration of 40 mg/L during surgery was adequate to maintain anesthesia during implantation of transmitters in bull trout (J. De La Vergne, USFWS, personal communication). Before preparation of the pre-operative solution of MS-222, the water was sampled for pH. If the solution was acidic (pH<7.0), it was buffered with sodium bicarbonate to maintain a pH of 7, thereby reducing physiological stress associated with anesthesia (Wedemeyer 1970). After sedation, the fish was weighed, measured, and a genetic sample was taken from the upper lobe of the caudal fin. In addition, several scales were collected for age analysis from all bull trout collected at Rock Island, Rocky Reach, and Wells dams. Scale analysis was performed by the Washington Department of Fish and Wildlife. Genetic samples were preserved and provided to the Service. Genetic characterization was not a task of this study; therefore, genetic results are not presented in this report.

After the fish was sedated, it was placed it on a V-shaped cradle in preparation for surgery. Throughout the procedure, a surgical assistant flushed the gills of the fish with a 40-mg/L solution of MS-222 using a large bulb-type syringe. During this process gill activity was monitored, and if necessary, either freshwater or a stronger solution of MS-222 (80 mg/L) was used to maintain the desired level of anesthesia. Before surgery, all surgical instruments and the radio-transmitter were sterilized in 100% ethyl alcohol, and then rinsed with a 3% solution of sodium chloride to prevent irritation at the incision site.

Before making the incision, the fish's tissue was swabbed with iodine to decrease the likelihood of post-operative infection. An incision about 2-cm long was made lateral to the linea alba and about 2 cm anterior of the pelvic girdle through the musculature of the fish. A 16-gauge cannula sheathed within a Teflon tube (to protect internal organs) was then inserted into the body cavity of the fish. The cannula was positioned at an angle 45 degrees to the medial line of the fish, and distal to the posterior end of the incision. Pressure was then applied to the cannula in order to penetrate the wall of the peritoneal cavity. Once the cannula penetrated the wall of the peritoneal cavity, the Teflon sheath was removed and the transmitter antenna was inserted into the cannula. The cannula was then removed, and the transmitter was inserted into the body cavity of the fish. The body cavity was closed with 3 to 4 internally-knotted absorbable sutures and swabbed with iodine. Veterinary tissue glue was applied to both the incision and the exit site of the transmitter antenna.

After surgery, the fish was transferred to a 49-liter cooler that was supplied with river water, and was held until equilibrium was achieved (typically 10 to 15 minutes). The same vessel was used for post-operative recovery, transport, and release. During the handling procedure, start and completion times were recorded for surgery, recovery, transport, and release. In addition, the water temperature within the recovery/transport vessel was monitored before transport and release.

3.4 Transport and Release

The same general transport procedures were used at the release sites near Rock Island and Wells dams. Typically, after the fish had recovered, the transport vessel containing the fish was loaded into a truck, was supplied with air delivered through an air stone, and was transported quickly to the release site. At the release site, the air stone was removed and the vessel was placed into the river. At the time of release, the water temperature within the vessel and also in the river was then recorded. The vessel was then gently rolled onto its side and the lid was opened allowing the fish to

swim free of the vessel. The swimming behavior of the fish was observed and any abnormalities were noted.

The transport procedures described above differed slightly for fish tagged and released at Rocky Reach Dam. Because the surgical station was located under a roadway within the fish ladder, it was not possible to carry the holding vessel to the upper deck for transport to the release site. For fish released into the tailrace of Rocky Reach Dam, the vessel was loaded into a boat and transported the vessel to the boat dock located about 50 m upstream from the dam on the right bank. A truck then transported the vessel from the dock to the release site downstream from the dam. For fish released upstream from the project, the vessel was loaded onto a boat and transported directly to the release site. The remaining release procedures were similar to those described above.

At the request of the Service, at each of the three dams half of the fish were released downstream from the dam and the other half were released upstream from the dam. The purpose of this release strategy was to increase the sample size of fish ascending the ladder systems at each of the projects where fish were collected and tagged. For fish released upstream from the dam, they were released as close to the dam as possible, but outside the influence of the forebay hydraulics (i.e., spill and bypass entrainment flows). Figure 15, Figure 16, and Figure 17 show specific release locations.

3.5 Fish Monitoring Systems

3.5.1 Fixed Telemetry

Multiple-telemetry techniques were used to assess the movement of tagged bull trout within the study area. At Priest Rapids, Wanapum, Rock Island, Rocky Reach, and Wells dams, a combination of aerial and underwater antennas were deployed. The primary purpose for these systems was to document the presence of bull trout at each project, specific to either the forebay or tailrace. In addition to these systems, a number of additional telemetry systems were deployed to address specific questions posed by Chelan and Douglas PUDs. At Rock Island, Rocky Reach, and Wells dams, additional systems were installed to identify tagged bull trout that could enter, ascend, and exit specific gates and fish ladders. At these projects, all possible access points to the adult fish ladders and the exits were monitored individually in 2002, allowing the route of passage to be determined as well as the ability to establish the exact time of entrance and exit from the ladder system. In 2003, however, only the tailrace and ladder exits were monitored at Rock Island and Rocky Reach dams, because of a lack of telemetry receivers. At Wells Dam in 2003, all systems were monitored. English et al. (1998, 2001) provided a detailed description of the telemetry systems at each of the dams and within the tributaries.

To assess movement within tributaries, both fixed-telemetry sites and aerial surveys were used within the Wenatchee, Entiat, Methow, and Okanogan rivers (see English et al. 1998, 2001). In the Wenatchee River basin, a single fixed-telemetry site was deployed at the Wenatchee River County Park (R.K. 12.5). In the Entiat River basin, a single system was deployed at R.K. 4.8. In the Methow basin two telemetry sites were established, one at R.K. 2.4 and the other at R.K. 17.5. In the Okanogan basin, a single system was installed at R.K. 9.0. At each of these locations, two 3- or 4-element Yagi antennas were deployed and monitored separately, with one antenna aimed downstream and the other upstream. This allowed us to assess the presence and direction of travel of bull trout at each site.

3.5.2 Aerial Surveys

Aerial surveys over the Columbia River (between Priest Rapids and Chief Joseph dams) were typically conducted on a monthly basis from April 2002 to the end of March 2003, and a semi-monthly basis from April 2003 to the end of March 2004. In addition, aerial surveys were conducted on the Wenatchee, Entiat, and Methow River systems. Because only two bull trout were detected at the fixed-telemetry site on the Okanogan River (and both later entered the Methow River), no aerial surveys were conducted in that basin. In the other basins, aerial surveys covered the mainstems to natural barriers or to points of safe access for fixed-wing aircraft. In addition, where possible, aerial surveys were conducted on smaller tributaries where bull trout presence was likely.

3.5.3 Boat Surveys

In 2001, boat surveys were used to assess general habitat use by tagged bull trout in the mainstem Columbia River. During that period, bi-weekly boat surveys were conducted in Rock Island and Rocky Reach reservoirs. This task was not repeated during the 2002 and 2003 study periods. Instead, boat surveys were used only to locate tagged fish that had not been detected for some time in the Columbia River and to pinpoint fish (or tags) that had not moved for an extended period of time. As such, only two boat surveys were conducted within Rock Island and Rocky Reach reservoirs in 2002 and three in 2003. Boat survey protocols followed those described in BioAnalysts, Inc. (2002).

During the period of 20 December 2001 to 31 March 2004, a total of 57 boat surveys were conducted within Wanapum and Priest Rapids reservoirs by Grant County PUD and LGL Limited personnel. Of the 57 surveys, 21 were conducted within Priest Rapids Reservoir and 36 within Wanapum Reservoir. Methods varied between surveys, but were typically conducted using either an aerial or underwater dipole antenna or both. These surveys provided detailed information as to the rearing location of tagged bull trout downstream from Rock Island Dam.

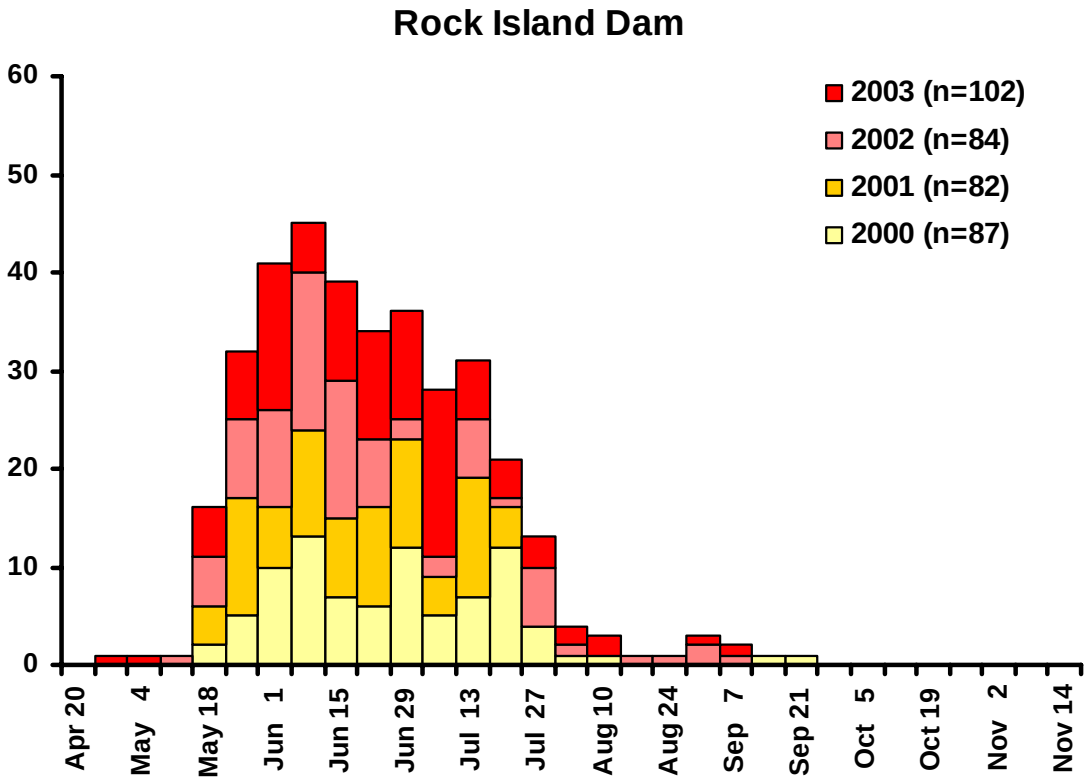

Figure 7: Passage distribution plotted by week for bull trout passing Rock Island Dam from 2000-2003.

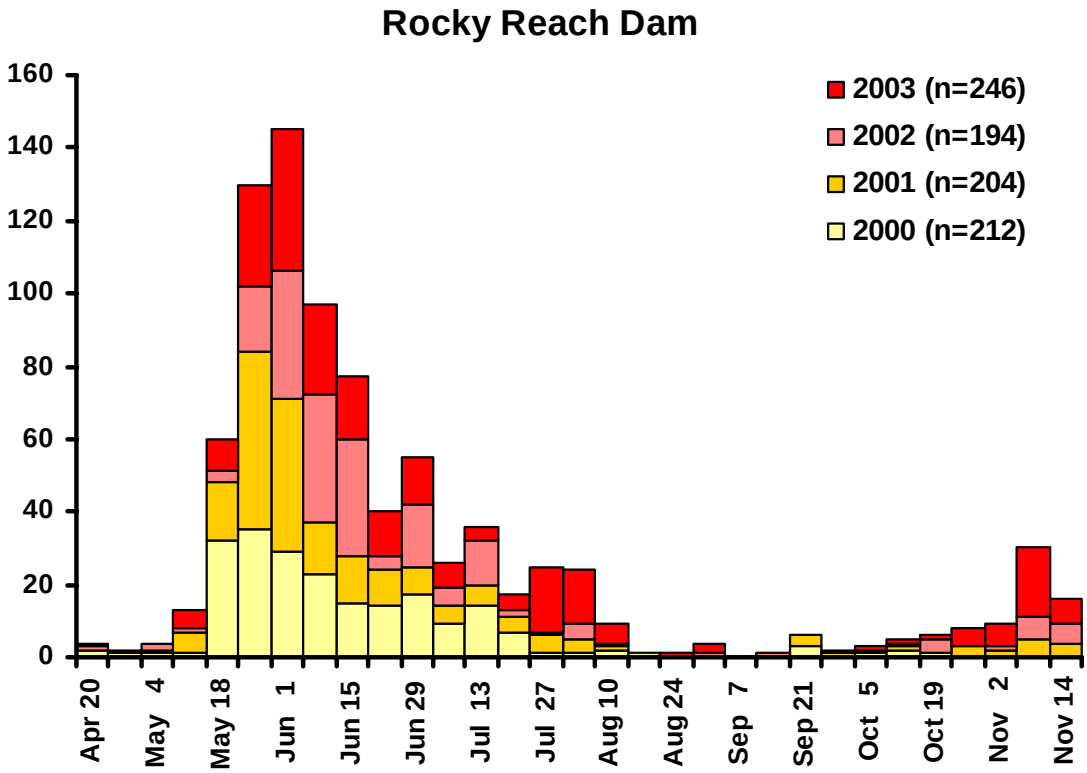

Figure 8: Passage distribution plotted by week for bull trout passing Rocky Reach Dam from 2000-2003.

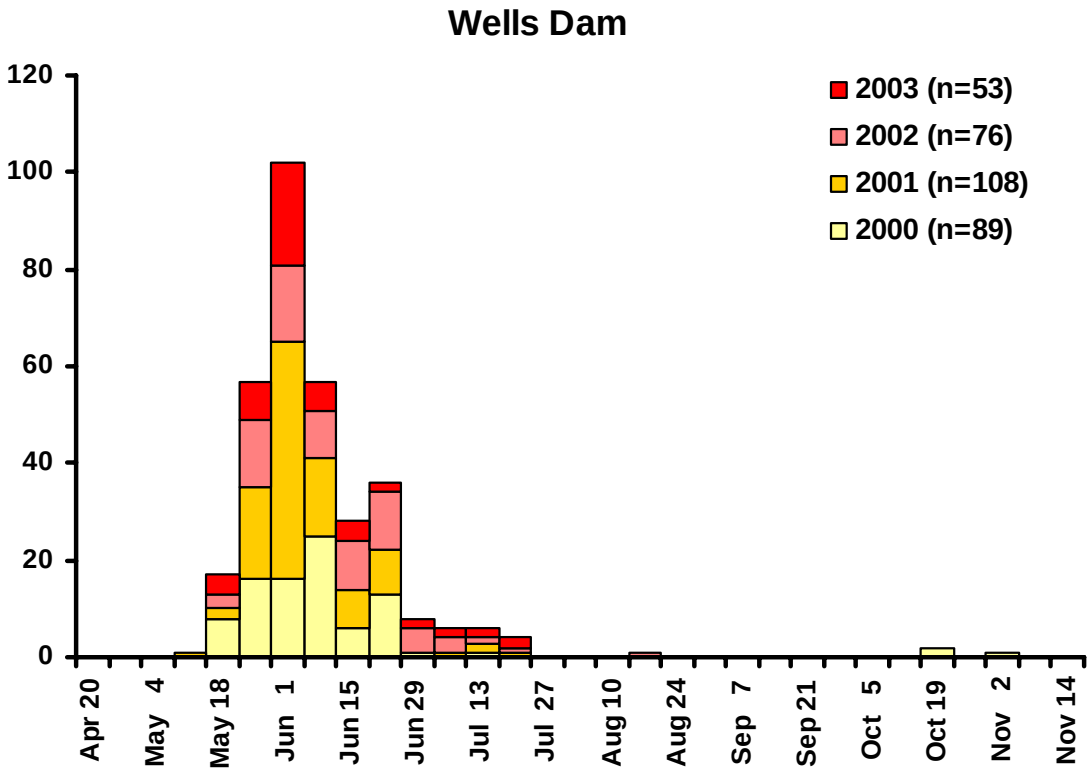

Figure 9: Passage distribution plotted by week for bull trout passing Wells Dam from 2000-2003.

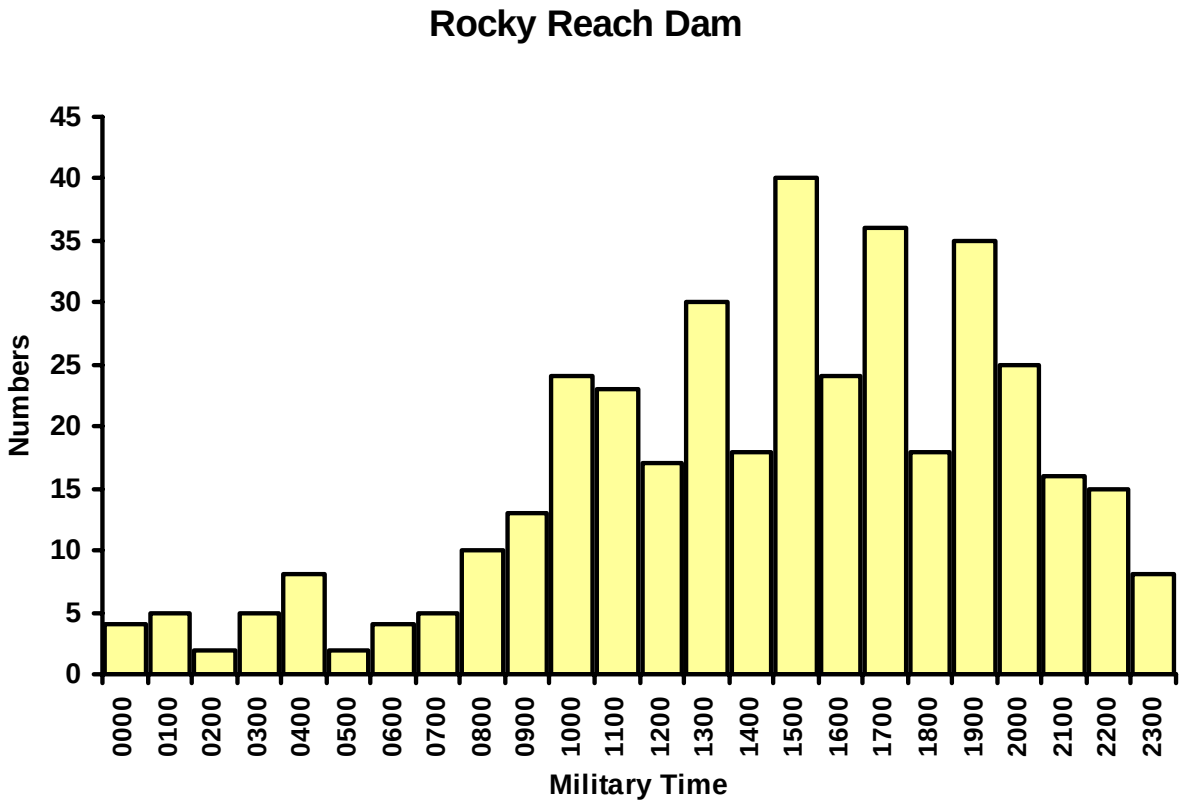

Figure 10: Time of passage for bull trout observed at Rocky Reach Dam ladder from 15 April to 31 November 2000 and 2001.

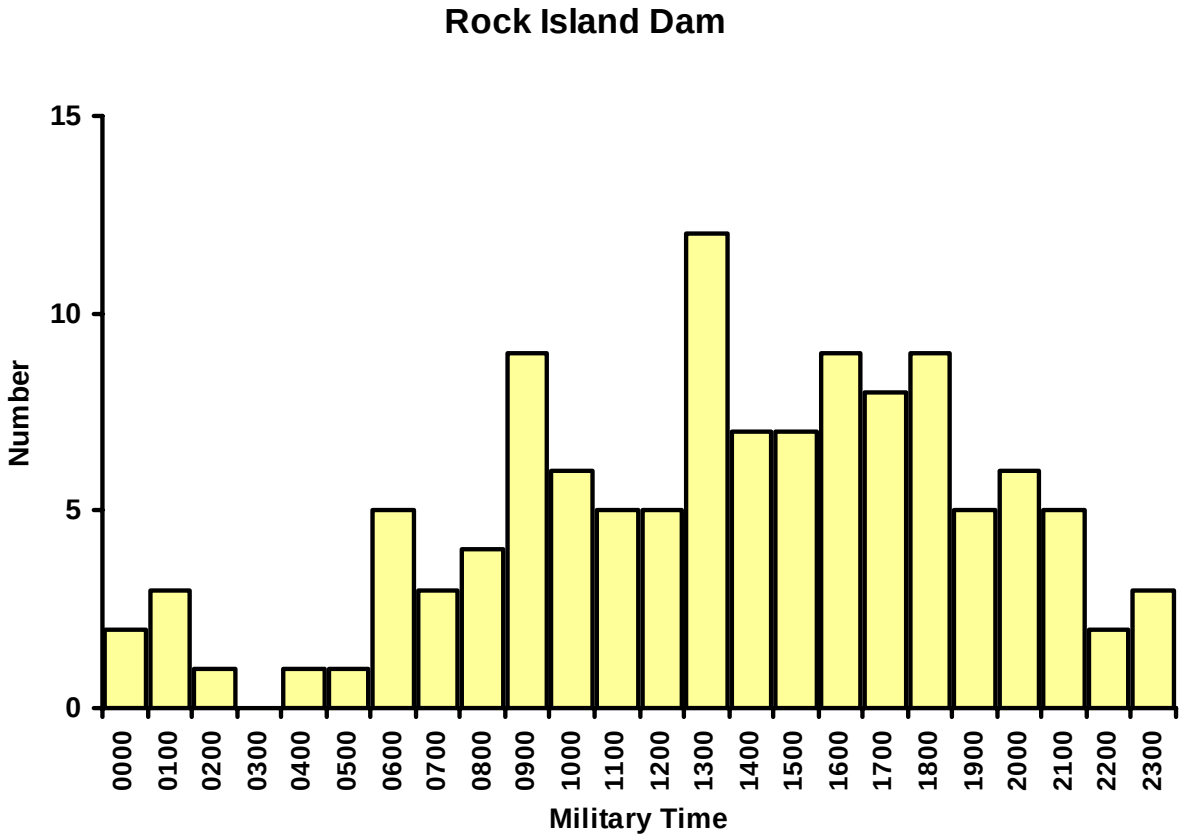

Figure 11: Time of passage for bull trout observed at Rock Island Dam ladders from 15 April to 31 November 2000 and 2001.

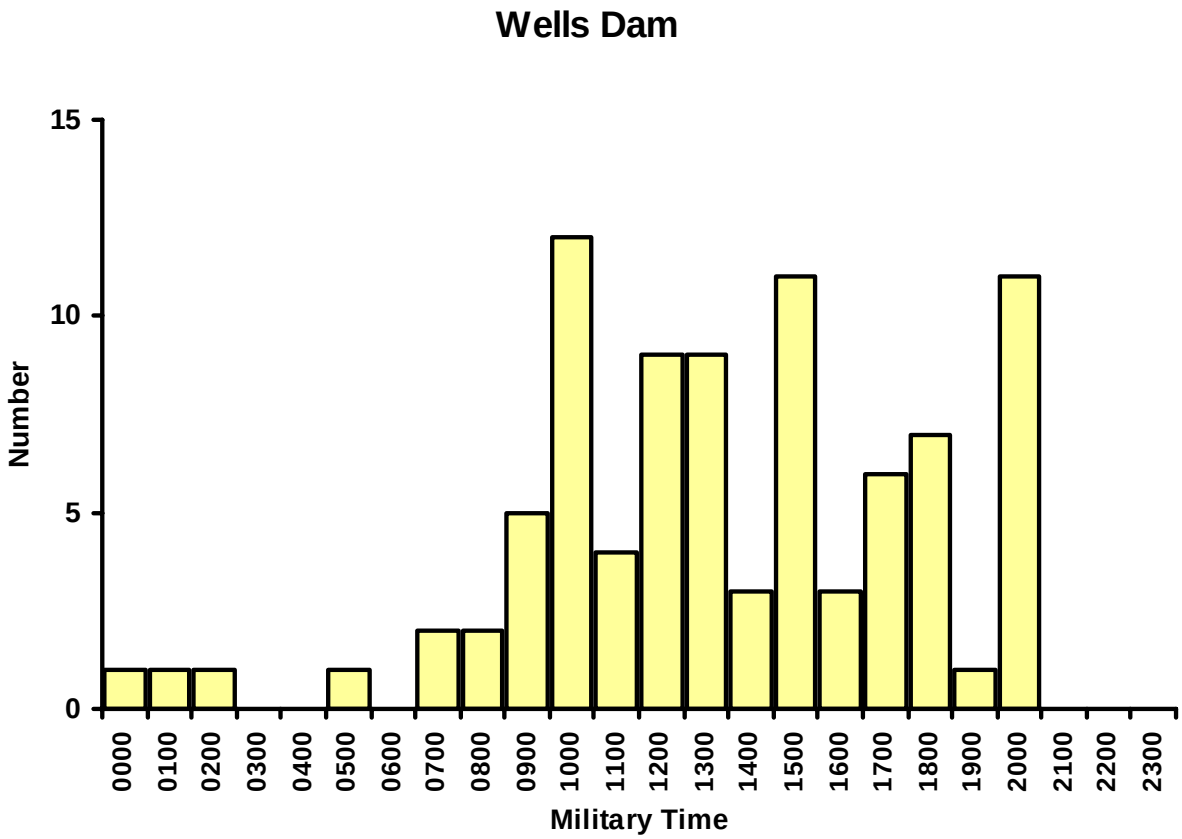

Figure 12: Time of passage for bull trout observed at Wells Dam ladders from 15 April to 31 November 2000.

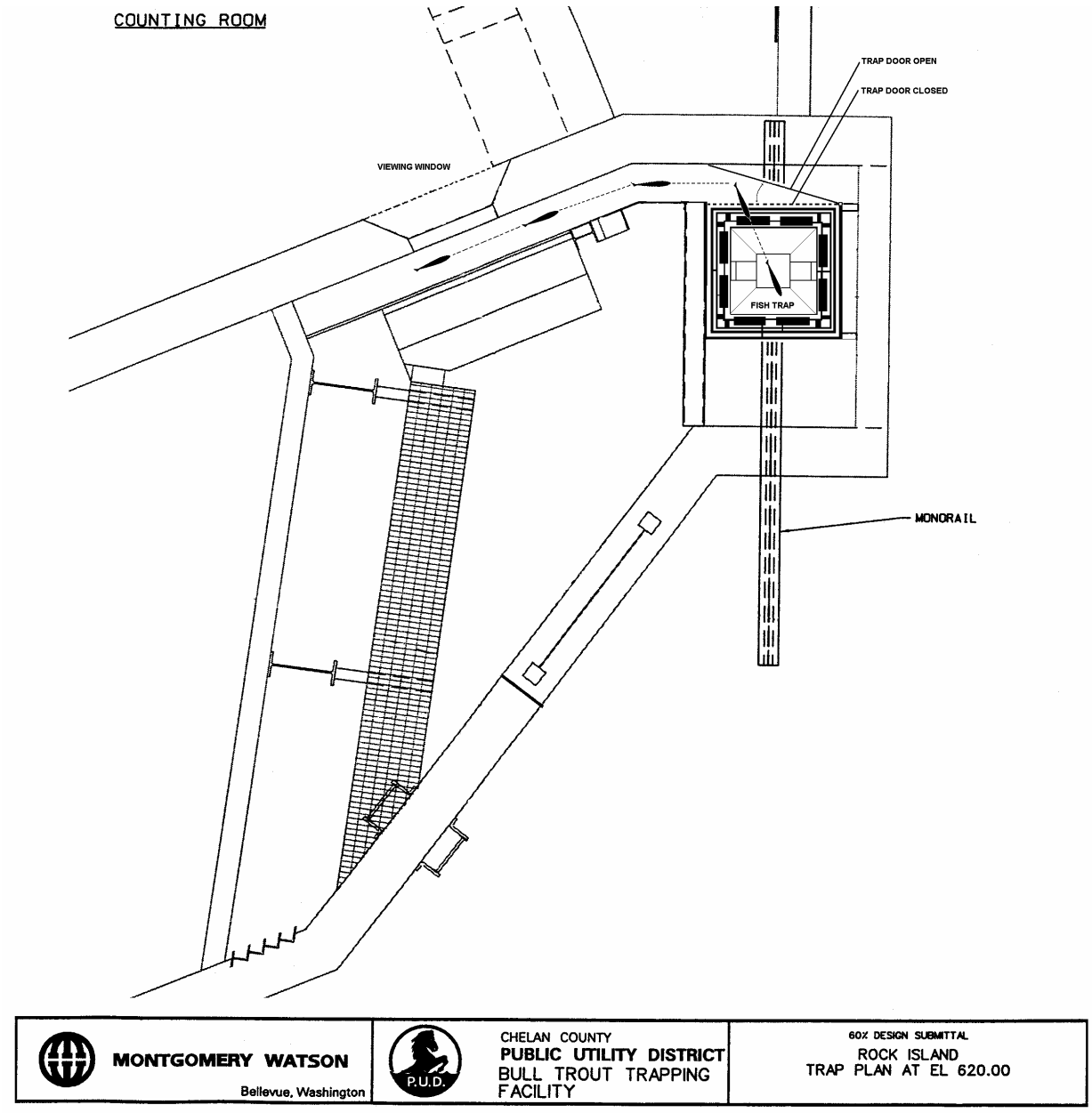

Figure 13: Plan view of Rock Island Dam fish trap showing movement of bull trout past the viewing window and the pneumatic gate open for entry into fish trap.

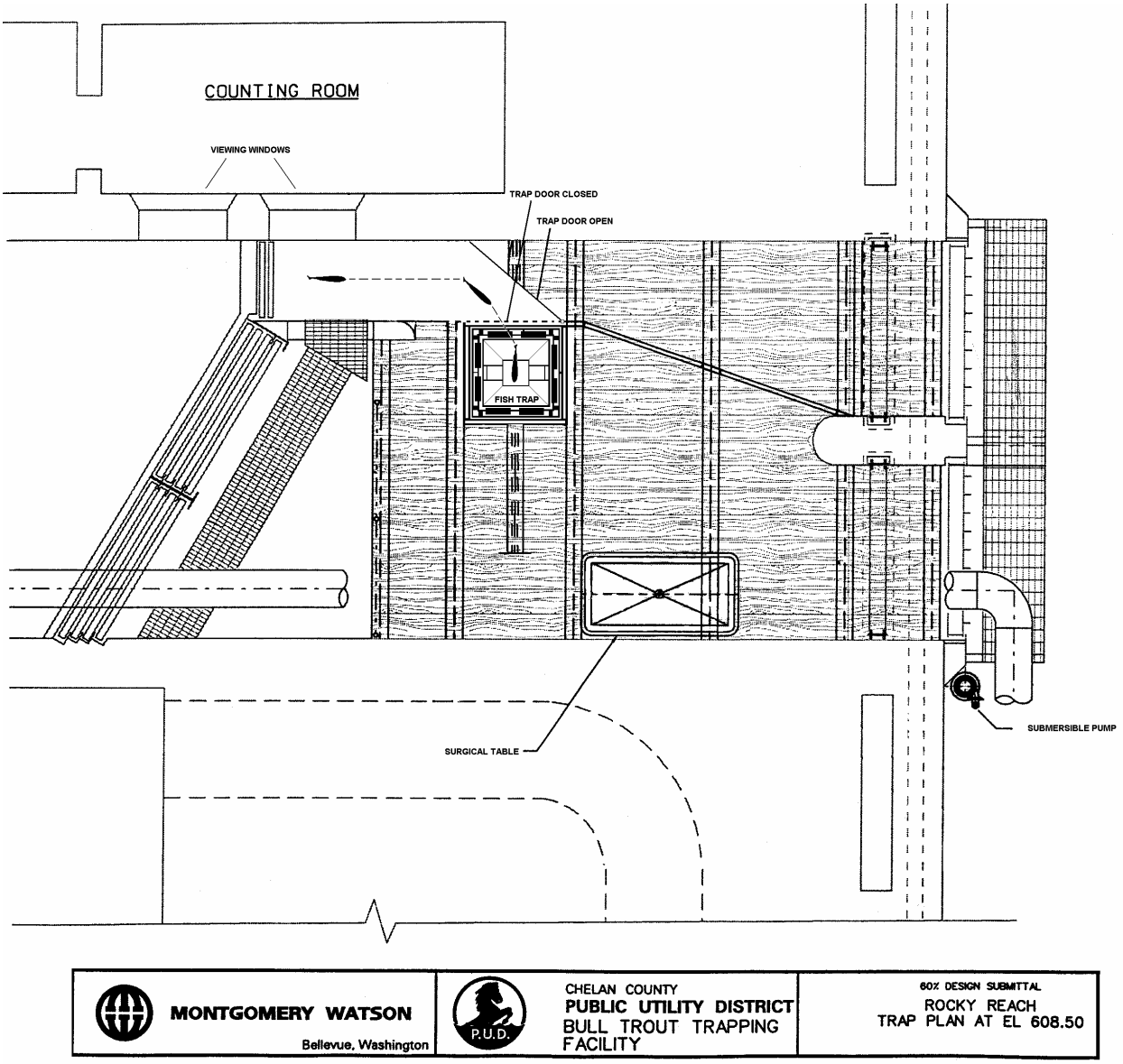

Figure 14: Plan view of Rocky Reach Dam trap showing movement of bull trout past the viewing window and the pneumatic gate open for entry into fish trap.

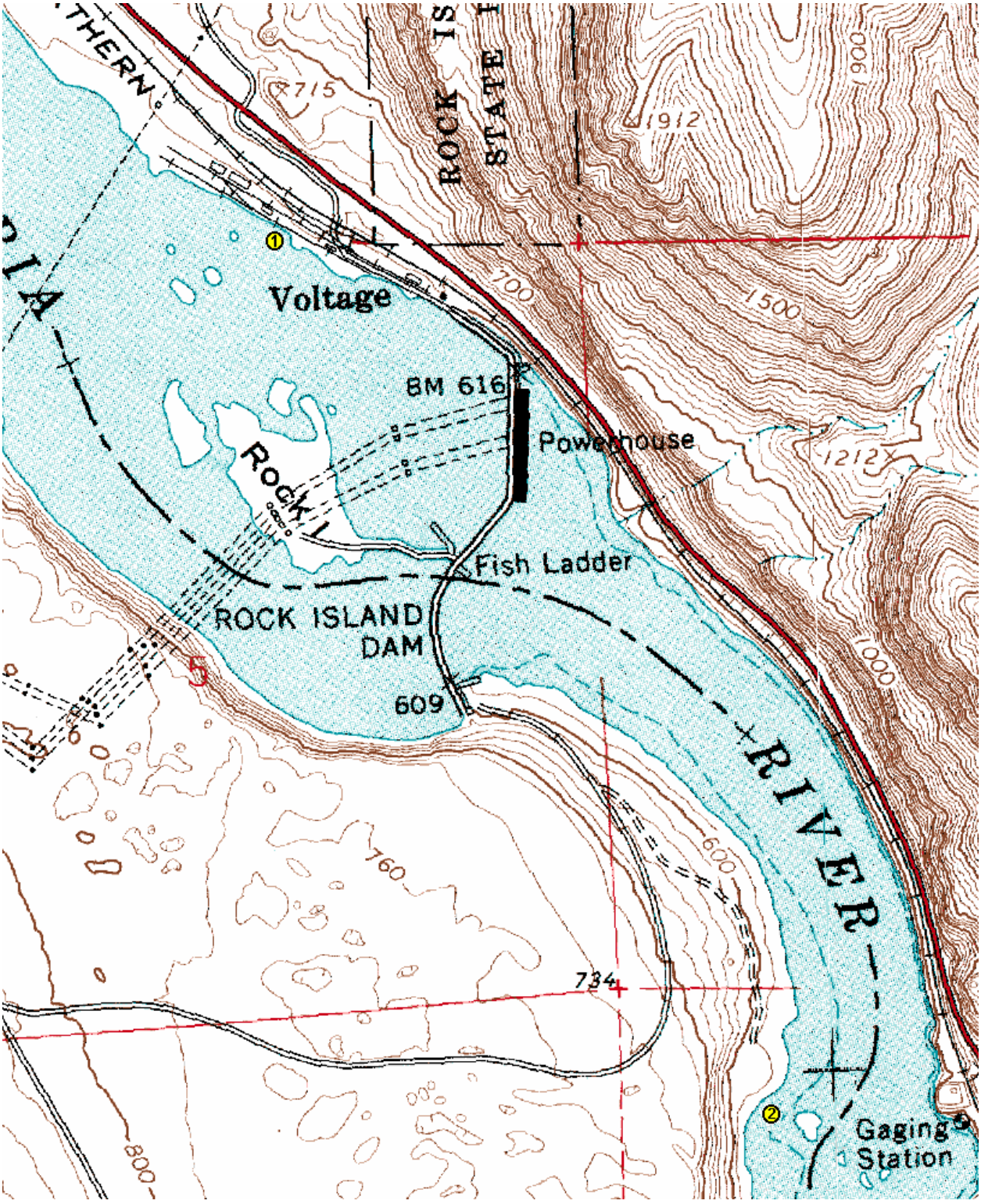

Figure 15: Bull trout release locations upstream (1) and downstream (2) of Rock Island Dam.

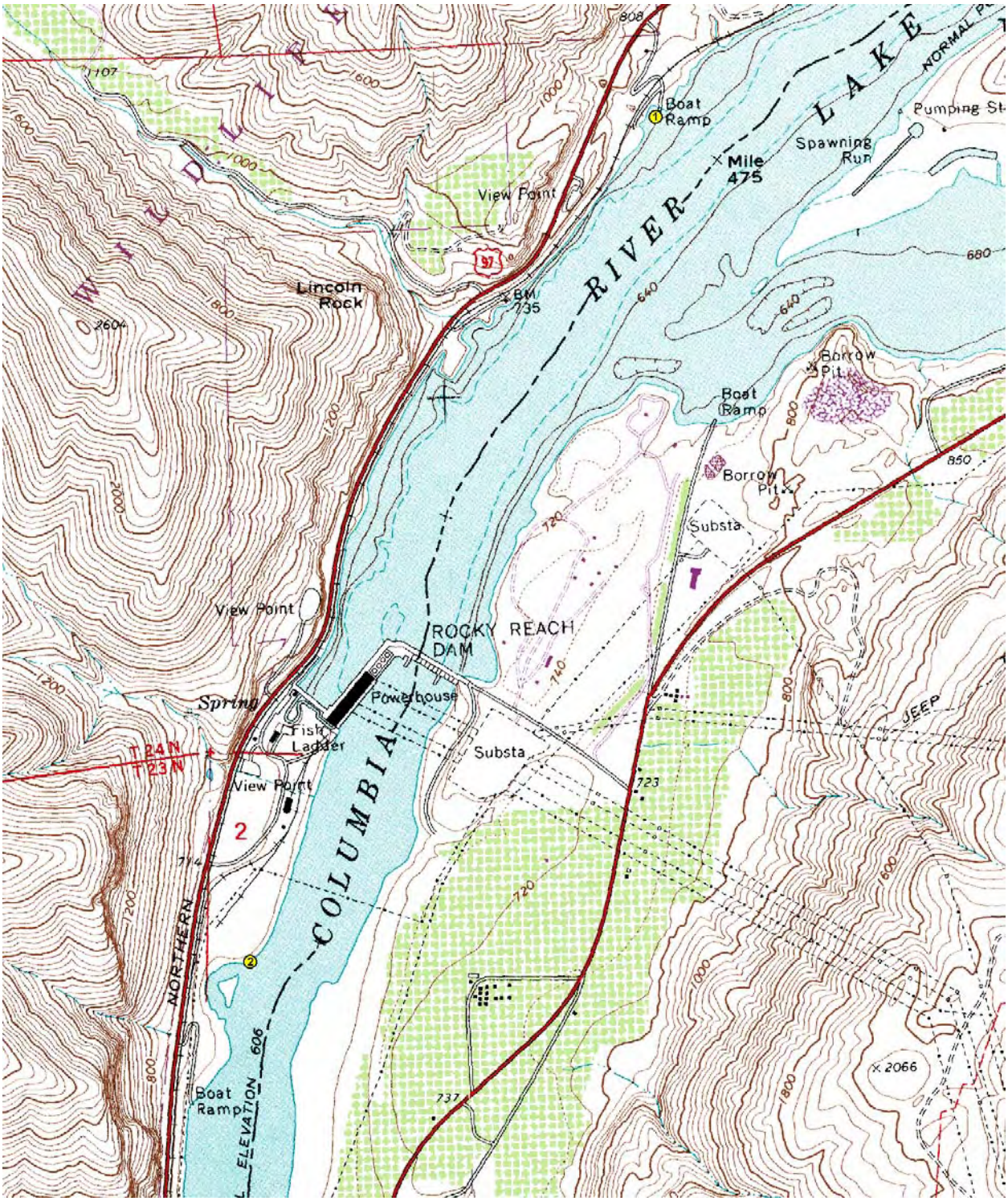

Figure 16: Bull trout release locations upstream (1) and downstream (2) of Rocky Reach Dam.

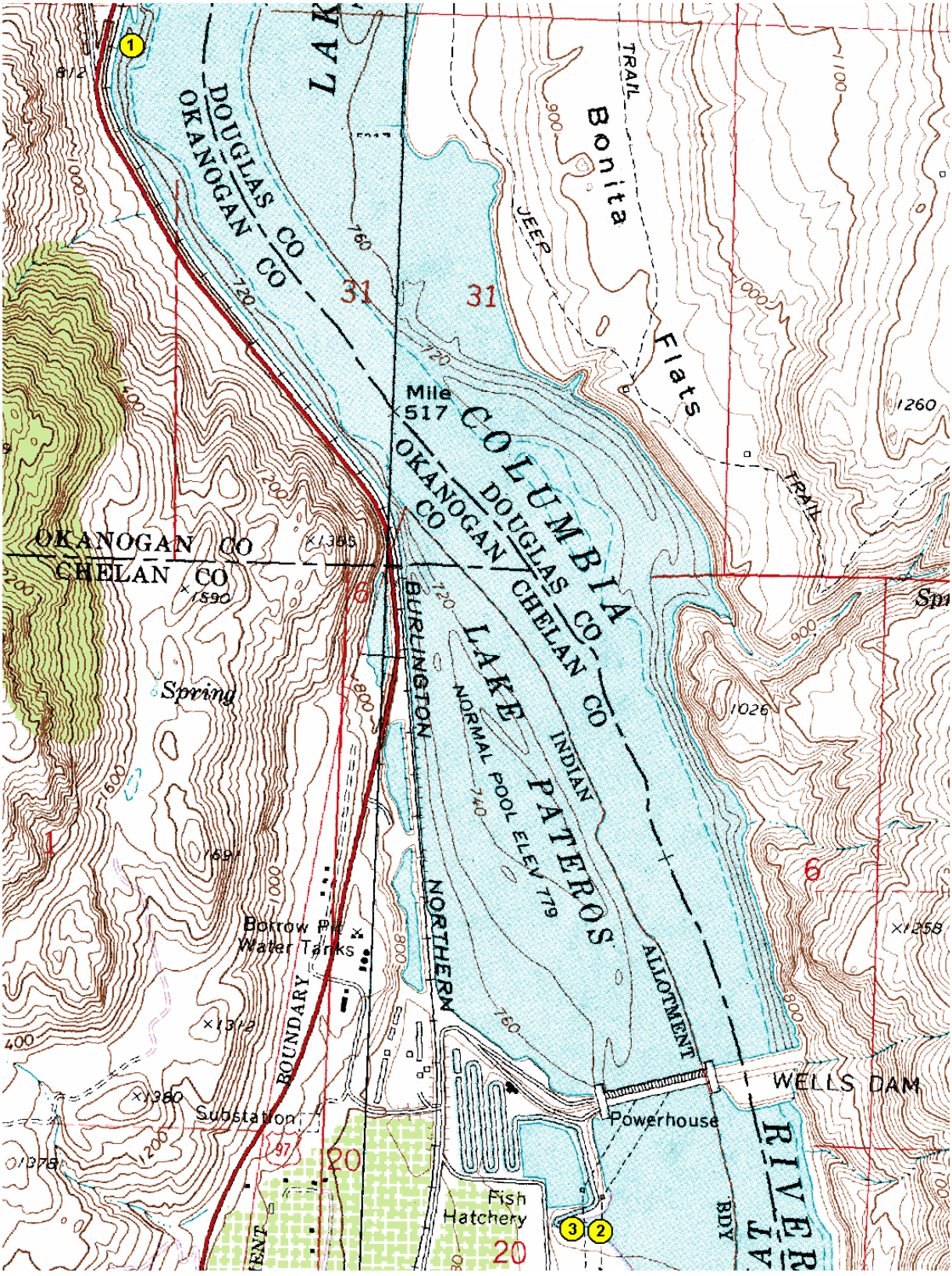

Figure 17: Bull trout release locations upstream (1) and downstream (2) of Wells Dam. Location of hatchery outfall (3) is also identified on the map.

SECTION 4: RESULTS AND DISCUSSION

A total of 79 adult bull trout were radio-tagged at three Columbia River dams during 2001 and 2002, with 39 adult bull trout tagged in 2001 (see results in BioAnalysts, Inc. 2002) and 40 in 2002 (Table 2). In 2002, the goal was to tag 10 fish at both Rock Island and Wells dams and 20 fish at Rocky Reach Dam. At Rock Island Dam in 2002, a total of eight bull trout were captured and tagged, with half released upstream and half downstream from the dam. At Wells Dam, nine adult bull trout were collected and tagged by 12 June, with five released upstream and four downstream from the dam. In an effort to capture and tag a total of 40 adult trout in 2002, the sampling period was extended at Rocky Reach Dam. There, 23 adult bull trout were captured and tagged, with 11 released upstream and 12 downstream from the dam.

The mean size of bull trout captured and tagged in 2002 tended to increase in an upstream direction, with the smallest fish collected at Rock Island Dam and the largest at Wells Dam (Table 2). Bull trout tagged at Rock Island Dam averaged 49.6-cm long (fork length) and weighed 1,325 g. Bull trout at Rocky Reach Dam averaged 55.1-cm long and weighed 1,967 g, while those at Wells averaged 57.3 cm and weighed 2,183 g. In total, the 40 bull trout averaged 54.5-cm long and weighed 1,888 g. Fish size also tended to increase in an upstream direction in 2001, although sizes of fish captured and tagged at Rock Island and Rocky Reach dams were similar (BioAnalysts, Inc. 2002).

The age analysis of fish collected in 2002 varied from the analysis in 2001. In 2002, age was partitioned into two stanzas based on life-history characteristics. For example, an age-5 bull trout could be categorized as a 3/2 fish, which means it spent three years in a cold-water environment (e.g., within a tributary of the mainstem Columbia River) and two years in a relatively warmer-water environment (e.g., the mainstem Columbia River). In 2002, age could be determined for 36 of 40 individuals. Four fish could not be aged because of scale regeneration. Of the 36 fish aged, 12 were 4 years of age (two were classified as 4/0 and ten as 3/1), 19 were 5 years of age (seven were classified as 4/1 and twelve as 3/2), three were 6 years of age (two were classified as 4/2 and one as 3/3), and two were 7 years of age (both were classified as 4/3). Five of the 36 fish had spawned previously on one or more occasion (Table 2). In 2001, only total age was determined for eight bull trout captured at Wells Dam. Of those fish, two were age-5 fish and six were age-6 fish.

For the 40 bull trout captured and tagged at the three collection locations, the mean surgical, recovery, and transport times were 4.7, 11.7, and 11.8 minutes, respectively. The surgical times at the three dams were similar, with the mean times varying by only 0.7 minutes. However, recovery and transport times for the different release sites varied somewhat. The mean recovery time varied between projects by 2.2 minutes, and was likely due to the time necessary to prepare the tagging facility for the next tagging event (this task was completed while the tagged fish recovered). Variability in transport times resulted from road conditions and distance traveled to the various release sites. Nevertheless, the mean overall time from start to finish (surgery, recovery, transport, and release) among tagging locations varied by only 8.3 minutes, with the Rock Island upstream releases requiring only 22.3 minutes and the Rocky Reach downstream releases requiring 30.6 minutes.

Water temperatures within the transport vessel changed little from the time of recovery to the time of release in the river. On only two occasions did the water temperature increase during the time the fish were held in the vessel. On both occasions the temperature increased 0.5°C; however, the increase in temperature during transport probably benefited the fish. That is, for these two fish, the temperature at the release site was higher than the water temperature at the collection site. The increase within the transport vessel served to acclimate fish to the higher temperature at the release location (in both cases, the temperature within the transport vessel at the time of release was the same as at the release site).

Differences in temperatures between the collection site and release site were common. For fish tagged and released at Rock Island and Rocky Reach dams (n = 31), differences in temperatures between the collection and release sites occurred on ten occasions (Table 2), but the difference in temperature never varied by more than 1°C. At Wells Dam, temperatures at the collection and release sites differed during the release of seven trout. Three trout released downstream from Wells Dam experienced temperature differences of 1.0 °C. Trout released upstream from the dam experienced differences that ranged between 0.5 and 3.0°C. While these temperature differences did not appear to affect survival or behavior of the fish exposed to them, it is possible that behavior immediately after release could have been affected. However, no abnormal behavior was observed immediately after release.

Table 2: Description of the 40 adult bull trout tagged in 2002 at Rock Island, Rocky Reach, and Wells dams from 20 May to 27 June 2002. An "s" after the age indicates previous spawning. Water temperatures represent the beginning and end of transport, and at the release site.

Collection		Transmitter		Fish Metrics (cm/g)			Elapsed Time (m)			Water Temp. (°C)			
Date	Time	Chan.	Code	Fork L.	Weight	Age	Surgery	Recovery	Transport	Begin	End	Rel.	Location
Rock Island Dam													
20-May	1555	14	97	53.0	1,700	3/1(s)	6	11	7	11.0	11.0	12.0	Up
23-May	1321	14	90	49.5	1,250	3/2	6	13	11	12.0	12.0	11.5	Down
04-Jun	0845	14	110	60.0	2,400	4/1	5	8	8	12.5	12.5	13.0	Up
04-Jun	1622	14	105	52.0	1,350	3/1	4	10	10	13.0	13.0	13.0	Down
07-Jun	1019	14	109	50.0	1,400	3/1	5	11	7	12.5	12.5	13.0	Up
07-Jun	1640	14	113	43.0	800	4/1	4	10	11	12.5	12.5	12.5	Down
12-Jun	0928	14	119	42.5	700	R	4	10	7	13.0	13.0	14.0	Up
12-Jun	1256	14	115	46.6	1,000	3/1	5	11	11	13.5	13.5	13.0	Down
			Mean:	**49.6**	**1,325**	**---**	**5**	**10**	**10**				
			Minimum:	**42.5**	**700**	**---**	**4**	**8**	**8**				
			Maximum:	**60.0**	**2,400**	**---**	**6**	**13**	**11**				
Rocky Reach Dam													
20-May	1445	14	88	65.5	3,200	R	6	14	10	11.0	11.0	11.0	Up
21-May	1737	14	89	63.0	2,950	3/2	6	20	11	11.0	11.0	11.0	Down
23-May	1413	14	92	50.5	1,950	3/2	5	16	11	11.0	11.0	11.0	Up
29-May	0858	14	95	57.0	2,100	3/2	6	13	14	12.0	12.0	12.0	Down
30-May	1057	14	98	57.0	1,950	3/2	4	14	10	12.0	12.0	12.0	Up
30-May	1409	14	104	56.0	2,000	3/2	6	13	12	12.0	12.0	12.0	Down
03-Jun	1310	14	108	62.0	2,350	4/1	5	6	13	12.0	12.0	12.0	Up
03-Jun	1416	14	101	55.3	1,950	R	5	6	13	12.0	12.0	12.0	Down
04-Jun	1212	14	100	52.5	1,700	3/2	4	7	11	12.5	12.5	12.5	Up
04-Jun	1427	14	111	56.5	2,200	R	5	17	13	12.0	125	12.5	Down
06-Jun	1017	14	103	61.4	3,300	4/3(s)	5	11	14	12.0	12.0	12.0	Up
06-Jun	1533	14	106	58.5	2,500	3/2(s)	3	16	14	12.0	12.0	12.0	Down
07-Jun	1413	14	121	48.1	1,350	3/1	5	18	11	12.5	12.5	12.5	Up
10-Jun	1200	14	114	54.0	1,700	3/2	4	14	11	12.0	12.0	12.5	Down
10-Jun	1656	14	116	60.8	2,850	4/1	6	17	11	12.0	12.0	12.0	Up
11-Jun	1406	14	118	46.0	950	3/1	4	11	12	12.5	12.5	13.0	Down
12-Jun	1337	14	122	59.7	2,100	3/2	5	10	13	13.0	13.0	13.0	Up
18-Jun	1040	14	126	60.4	2,300	3/3(s)	6	10	13	13.5	13.5	13.5	Down
21-Jun	1136	14	123	57.5	1,750	3/1	4	11	12	14.0	14.0	14.0	Up
24-Jun	1400	14	124	57.0	1,800	3/2	4	13	11	14.5	15.0	15.0	Up
26-Jun	0824	14	125	46.0	1,000	3/1	4	14	12	15.0	15.0	15.0	Down
27-Jun	1226	14	127	41.5	650	4/0	4	14	14	15.0	15.0	15.0	Down
27-Jun	1755	14	120	40.4	650	4/0	4	12	11	15.0	15.0	15.0	Down
			Mean:	**55.1**	**1,967**	**---**	**4**	**12**	**12**				
			Minimum:	**40.4**	**650**	**---**	**4**	**10**	**11**				
			Maximum:	**65.5**	**3,300**	**---**	**6**	**14**	**14**				
Wells Dam													
23-May	1530	14	91	69.9	4,250	4/3(s)	5	12	21	10.5	10.5	10.5	Up
28-May	1510	14	93	54.5	1,800	4/2	4	9	13	11.5	11.5	12.5	Down
03-Jun	0915	14	107	60.5	2,300	4/1	4	19	12	13.0	13.0	15.0	Up
03-Jun	1425	14	94	51.0	1,400	3/1	4	4	12	13.0	13.0	15.0	Up
03-Jun	1650	14	96	56.0	1,850	4/2	4	7	11	12.0	12.0	13.0	Down
04-Jun	0912	14	102	63.5	2,900	4/1	4	9	11	13.0	13.0	13.0	Down
04-Jun	1325	14	99	46.5	1,150	3/1	3	6	18	13.0	13.0	16.0	Up
11-Jun	1325	14	112	62.1	2,600	3/2	6	10	11	13.0	13.0	14.0	Down
12-Jun	1535	14	117	52.0	1,400	4/1	4	11	14	14.0	14.0	14.5	Up
			Mean:	**57.3**	**2,183**	**---**	**4**	**8**	**12**				
			Minimum:	**46.5**	**1,150**	**---**	**3**	**4**	**11**				
			Maximum:	**69.9**	**4,250**	**---**	**6**	**11**	**13**				

4.1 Mortalities

None of the 40 bull trout tagged in 2002 died during the period from capture to release. All 40 fish appeared to be healthy and exhibited normal behavior upon release. Most migrated to a tributary stream or moved several kilometers from a release area. During the monitoring phase of the study, however, a total of six transmitters were recovered within the study area during the period of April 2002 to March 2003 (2002 Study Period), and eight additional transmitters were recovered during the period of April 2003 to March 2004 (2003 Study Period). For those 14 fish, only one carcass was recovered with a transmitter.

Recovery of a transmitter without a carcass does not necessarily mean that the fish died. For example, a bull trout was captured at Rocky Reach Dam in 2002 that had scarring consistent with a transmitter that had been extruded through the musculature where the transmitter antenna exited the fish. Incision and suture scars were readily apparent on this fish as well as an "asterisk-shaped" scar where the antenna exited the body. It appears that this fish was captured and tagged the previous year, lost its transmitter, and survived. Other researchers have noted similar observations while tagging adult bull trout in the Tucannon and Touche rivers. One fish that was previously tagged, but was missing its transmitter, was recaptured as it entered the Touche River. This fish exhibited the same asterisk-shaped scar that was observed for the fish captured at Rocky Reach Dam (G. Mendel, WDFW, personal communication). Thus, it is possible that some of the recovered transmitters from this study may have been shed from live fish.

During the 2001 study period (May 2001 to March 2002), only one fish was confirmed to have died after release.[3] That fish was released upstream of Rock Island Dam on 3 July 2001 and was detected at Rocky Reach Dam two days later, where it was detected over the course of nine days. Thirteen days after the last detection at Rocky Reach, it was detected in the forebay of Rock Island Dam, where it was detected in the same location over the next 2.5 months. Inspection of the site revealed the skeletal remains and skin of a bull trout. The transmitter was detected about 3 meters from the carcass.

The fate and detailed detection histories of each of the 14 fish tagged in 2002 are presented in Appendix A, and therefore will not be presented in detail here. What follows is only a brief summary on the movements of the 14 fish.

Transmitter Recovery - 2002:

Four of the six transmitters recovered in 2002 were implanted in fish collected at Wells Dam. All four of these fish migrated into the Twisp River (a tributary to the Methow River) and the transmitters were recovered in that tributary upstream from a dewatered section in the fall of 2002. For one of these fish, both the carcass and transmitter were recovered together. The carcass was frozen in an area where there was little water within the stream channel. For another fish, the

[3] Fish tagged in 2001 carried transmitters with a one-year tag life. It is possible that some of these fish died or lost tags after the tag expired and therefore were not detected. Tags used in 2002 had a much longer tag life allowing the opportunity to document mortality or tag loss for a longer period of time.

transmitter was found on shore above the wetted channel. All four fish traveled 98 to 116 km from the release sites at Wells Dam to the Twisp River.

The fifth transmitter was recovered in the upper Entiat River onshore under a boulder. This transmitter was originally implanted into a fish collected at Rocky Reach Dam. This fish traveled 55 km before its transmitter was recovered. The U.S. Fish and Wildlife Service recovered the transmitter and noted that it was in a mink den. The transmitter had identifiable "cut" marks on the antenna resulting from predation or scavenging.

The sixth transmitter recovered in 2002 was implanted in a fish at Rock Island Dam. This fish did not spend any length of time in tributaries, as did other tagged trout. Instead, it moved upstream to Wells Dam, then back downstream to a location downstream from Rock Island Dam. The transmitter was located onshore above the high water mark under debris. This fish traveled about 322 km before its transmitter was recovered.

Transmitter Recovery - 2003:

A total of eight transmitters were recovered in 2003. Three were recovered in the Twisp River, with two originating from Rocky Reach Dam and the third from Wells Dam. One transmitter was recovered downstream of the Poplar Flat Campground, a second near the Scatter Creek Trailhead, and the third near Roads End. Two of the three tags were buried in gravel and the third was on a gravel bar about two feet from the waters edge. No carcasses were recovered with these transmitters.

Two transmitters were recovered in the Mad River (a tributary to the Entiat River), with one fish tagged at Rock Island Dam, the other at Rocky Reach. Both of these transmitters were recovered within 200 meters of each other, and were located about 7 km upstream of the Pine Flat Campground. Both transmitters were found in the water laying on the streambed. No carcasses were found at these sites.

The other three transmitters were recovered in the mainstem Columbia River near the Entiat River confluence. Two of these transmitters were implanted in fish at Rock Island Dam and the other at Rocky Reach. One transmitter was recovered near the east shore about 200 meters upstream of the Entiat River in water about 3.5 m deep. Another was recovered near the west shore at a depth of about 4.5 m, approximately 1.5 km downstream of the Entiat River. The third was recovered about 5 km downstream of the Entiat River near the east shore in 4-m deep water. No carcasses were recovered.

It is likely that five other fish may have died or shed their tags. Two are currently located about 100 m upstream of Box Canyon in the Entiat River, one is in the upper reaches of the Mad River, another is located within the boat restricted zone of Rocky Reach Dam near the east shore, and the fifth was last seen at Priest Rapids Dam. The first four fish have remained in the same location for several months, and the fifth fish has not been detected for some time. Attempts to locate these fish (or their transmitters) have been unsuccessful.

4.2 Migration Time and Downstream Movement

Because of the extensive deployment of telemetry systems at each mainstem dam and near the mouths of major tributaries, it was possible to document the length of time each fish spent within various areas at the dams, the elapsed time between dams, the time required to travel from a dam to the next upstream tributary, and whether bull trout migrated downstream past any of the projects within the study area. For some of the fish tagged in 2001, transmitters were still active as they migrated upstream in 2002. Therefore, these fish were included in the 2002 analysis. For the analysis of the 2003 migration period, only the transmitters for fish tagged in 2002 were active. It should be noted that the number of fish used to estimate the following residence times may be less than the total number of fish passing the dam of interest, or the reach of river upstream from the project. This is because of incomplete detection histories for some fish. For example, if a fish is not detected by the tailrace antenna array, the tailrace and overall dam passage time cannot be estimated.

Over the course of the study, a few modifications in the monitoring systems affected the extent the data could be analyzed. For the 2001 and 2002 migrations, all telemetry systems were operational. However, in 2003 the ladder entrances at Rock Island and Rocky Reach dams were not monitored. Therefore, only overall dam passage time could be ascertained at these projects. This happened because of a concurrent telemetry study conducted by Chelan PUD at the time bull trout were migrating upstream past Rock Island and Rocky Reach dams. As such, the entrance receivers were removed and used in that study. However, the second telemetry study provided telemetry coverage at all spillbays and powerhouse units at Rock Island and Rocky Reach dams. Coverage at these locations allowed detailed analysis of downstream movement through these units by bull trout in 2003.

For clarity, defined are the following terms.

- *Tailrace residence* is the elapsed time between the first detection by the tailrace array and the first detection upon final entrance into the ladder system.
- *Fishway residence* is the elapsed time between the first detection upon final entrance into the ladder system to the last detection at that ladder exit.
- *Elapsed time at the dam* is the sum of the tailrace and fishway times.
- *Elapsed time between dams* is the time from last detection at a ladder exit or from the time it was released to the time of first detection within the tailrace of the next upstream dam.
- *Elapsed time from a dam to an upstream tributary* is the time from last detection at the ladder exit or from the time it was released to the time of entry into an upstream tributary.

For all estimates, only fish that were actively migrating upstream have been included. For example, fish that were detected by the tailrace and ladder systems, but migrated downstream and entered a tributary were not used to calculate tailrace residence time. Downstream migration past a given project was assessed as the detection of a fish downstream from the dam after the fish had recently exited the ladder system.

4.2.1 Rock Island Dam

At Rock Island Dam eight adult bull trout were captured and tagged in 2002. All four of the fish released downstream from the project migrated upstream, with one fish passing the project through the left-bank ladder and the other three through the right-bank ladder. In addition, one fish tagged in 2001 (tag 14-7) passed Rock Island Dam through the right-bank ladder. For these five fish, the median tailrace residence time was 5.66 days, ranging from 0.43-16.43 days (Table 3). The median residence time through the right-bank and left-bank fishways was 0.85 days and 0.18 days, respectively. The median elapsed time at the dam for all five fish was 5.90 days and ranged from 1.21-17.35 days (Table 3). During the 2003 migration, two bull trout migrated upstream past Rock Island Dam. As mentioned previously, the ladder entrances were not monitored, and therefore, only overall dam passage times are available. For these two fish, the median passage time was 5.10 days with a range of 4.03 to 6.17 days (Table 4). In 2001, the median elapsed time at the dam was 2.28 days (Table 5). For the three years of passage at Rock Island Dam, no downstream movement of bull trout was observed after the fish exited the ladder systems.

The migration time for bull trout from Rock Island Dam to Rocky Reach Dam or to an upstream tributary was assessed in 2002 for the eight fish tagged and released at Rock Island Dam in 2002, plus one fish tagged in 2001. Of these nine bull trout, seven were detected in the tailrace of Rocky Reach Dam and the other two migrated into the Wenatchee River. The median time between projects was 2.78 days, ranging from 1.14-5.46 days, and the median elapsed time between detection at Rock Island Dam and the Wenatchee River was 5.99 days, ranging from 4.56 to 7.41 days (Table 3). In 2003, the migration time between Rock Island Dam and the upstream locations was assessed for two fish; with one migrating to Rocky Reach Dam and the other entering the Wenatchee River. For these fish, the elapsed time to Rocky Reach Dam and the Wenatchee River was 1.79 and 1.67 days, respectively (Table 4). In 2001, the median travel time between the two dams was 1.33 days, and the median travel time to the Wenatchee River was 1.39 days (Table 5).

Although elapsed times at Rock Island Dam were greater in 2002 and 2003 than in 2001, no evidence was found that indicated that the longer time periods had a negative impact on successful and timely entry into spawning tributaries.

4.2.2 Rocky Reach Dam

To assess the movement and behavior of bull trout at Rocky Reach Dam in 2002, 11 bull trout were tagged and released upstream and 12 downstream from the project for that year. Analysis of residence and passage times at this project also included fish tagged at Rock Island Dam and bull trout tagged in 2001 that passed the project during the 2002 study period. In sum, 21 tagged bull trout passed Rocky Reach Dam in 2002, eight released in Rocky Reach tailrace, one released in Rocky Reach forebay, six from Rock Island Dam, and six fish tagged in 2001. Two of the fish tagged in 2001 ascended the fishway more than once. One ascended the ladder three times; the other ascended the ladder twice. Unfortunately, during the upstream passage of one bull trout (released downstream from Rocky Reach Dam) the ladder exit receiver did not record the exit time. Therefore, a total of 23 passage events[4] were analyzed at Rocky Reach Dam in 2002.

[4] In this analysis, it is assumed that passage events were independent of each other. This may not be statistically valid because two bull trout ascended the ladder system more than once.

Fish could enter the ladder system at Rocky Reach Dam through a number of entrances or gates. Possible entrances included the right bank entrance, six O.G. gates, the left bank entrance, and the spillway entrance. During the 2002 study period, five tagged fish entered the spillway entrance, nine entered the left-ladder entrance, six entered one of the six O.G. gates, and four entered the right-ladder entrance. In 2001, seven ascended the ladder system through the left-ladder entrance and two entered the right-ladder entrance. In 2002, the median tailrace residence time was 4.44 days, ranging from 0.60-16.25 days (Table 3). The median fishway residence time was 0.28 days (range, 0.13-6.15 days). The median elapsed time at the dam was 4.86 days, ranging from 1.11-16.50 days (Table 3). In contrast, during the 2001 migration, the median time at the dam was 3.79 days, median tailrace time was 1.28 days, and the median fishway time was 1.92 days (Table 5). In general, fish spent more time in the tailrace of Rocky Reach Dam in 2002 than in 2001 (Table 5). In 2003 the ladder entrances were not monitored, and, as such, elapsed times at the dam cannot be partitioned into tailrace and ladder times. However, for the nine fish that passed upstream of Rocky Reach Dam, the overall median elapsed time at the dam was 4.68 days, ranging from 0.66-16.87 days (Table 4).

Further inspection of the data indicated that fish migrating upstream from Rock Island Dam moved through Rocky Reach Dam quicker than fish tagged at Rocky Reach and released into the tailrace. The median time spent in Rocky Reach tailrace for the eleven fish that migrated upstream from Rock Island Dam was 2.97 days, compared to 7.67 days for the eight fish tagged at Rocky Reach and released in the tailrace. A similar trend was observed during the 2001 study period. During that study period, the median tailrace time for fish migrating upstream from Rock Island was 0.85 days compared to 1.79 days for fish tagged at Rocky Reach and released into the tailrace. Once the fish were in the ladder system, little difference in median ladder times was observed between the two groups of fish.

Five downstream passage events were recorded at Rocky Reach Dam in 2002. These events were based on the movements of three bull trout, some of which moved through the project more than once. One fish (14-124) released upstream of Rocky Reach Dam was detected 15 hours later in the tailrace of the project. This fish re-ascended the ladder and entered the Entiat River, where it resided for five days. The following day this fish moved back downstream and passed through the dam a second time. A second fish (14-32) tagged in 2001 moved downstream through the project on two different occasions during an 18-day period. After ascending the ladder system the first time, this fish moved downstream through the powerhouse (unit 6 or 7) and began re-ascending the ladder within three hours. Eleven days after exiting the ladder system, it again moved downstream past Rocky Reach Dam (passage route unknown). It re-ascended the ladder, entered the Entiat River, and seven months later was detected in the tailrace of Wells Dam. Another trout (14-37) tagged in 2001 provided the last downstream event at Rocky Reach Dam in 2002. Within about 24 hours after initially ascending the ladder, this fish moved back downstream through the project (passage route unknown). The fish spent about four days in the tailrace before re-ascending the ladder. This fish was detected in the Entiat River 15 days later.

During the 2003 migration, three bull trout exhibited four downstream passage events at Rocky Reach Dam after exiting the fish ladder. One fish (14-99), resided within the Wenatchee River basin during the fall of 2002. It then moved into Rock Island pool, passed Rocky Reach Dam on 29 May 2003 and within 33 minutes moved back downstream through turbine unit 10. The fish re-ascended

the ladder and exited the system on 30 May. On 2 June it was detected at Wells Dam and migrated from there into the Methow River. The second fish (14-101) remained in the Entiat Basin during autumn 2002. It then moved into Rock Island pool, migrated downstream through Rock Island Dam, remained there for some time before moving upstream through the left-bank ladder on 12 June 2003. By 14 June, the fish moved into the Rocky Reach tailrace. It ascended the ladder and exited the system the following day and within 44 minutes the fish entered and passed through turbine unit 1. By 22 June the fish had moved into the Wenatchee River and was stationed near the town of Monitor. This bull trout remained in the Wenatchee system for four months, primarily in Ingalls Creek, a tributary to Peshastin Creek.

The third fish (14-114) exhibited two downstream movement events at Rocky Reach Dam during the 2003 migration. After residing in the Entiat Basin during autumn 2002, the fish moved into Rock Island pool and remained there for the first half of 2003. It then moved to Rocky Reach tailrace (29 May 2003), ascended and exited the ladder on 2 June, and after 27 minutes in the forebay it moved downstream through spillbay 2. By 4 June, the fish re-ascended the ladder and spent 30 minutes in the forebay before moving downstream through spillbay 4. The fish re-ascended and exited the ladder the following day and eventually entered the Entiat River basin where it resided for four months. These observations and those in 2002 indicate that the fish were not significantly harmed during their downstream movements through the dam.

In 2002, migration time was estimated for 30 bull trout from Rocky Reach Dam to either Wells Dam or to an upstream tributary (Entiat River). The 30 fish included eight bull trout released into the tailrace of Rocky Reach Dam, 11 released into the forebay, five tagged at Rock Island Dam, and six from the 2001 study. The median travel time for the 23 bull trout that moved from Rocky Reach to the Entiat River was 11.34 days, range 3.51-26.98 days (Table 3). For the seven fish that traveled to Wells Dam, the median elapsed time between projects was 2.03 days, range 1.09-3.71 days (Table 3). During the 2003 study period, a total of six tagged trout migrated into the Entiat River. For those fish, the median passage time between the dam and the Entiat River was 16.47 days, with a range of 15.18-21.98 days. One other fish migrated upstream to Wells Dam. For that fish, the elapsed time between dams was 1.73 days (Table 4).

Travel times to either the Entiat River or Wells Dam were greater in 2002 and 2003 than in 2001. In 2001, the median travel time between Rocky Reach Dam and the Entiat River was 7.20 days and 1.69 days from Rocky Reach to Wells Dam (Table 5).

4.2.3 Wells Dam

In 2002, nine adult bull trout were tagged and released at Wells Dam to assess movements and migration behavior there. For that year, a total of 11 tagged fish moved through Wells Dam, including five fish from Rocky Reach, the four released into the tailrace of Wells Dam in 2002, and two fish from the 2001 tagging period. One fish re-ascended the ladder twice. Therefore, a total of 12 passage events at Wells Dam were examined, with two bull trout ascending the right-bank ladder and 10 the left ladder. Unfortunately, during the course of the study, the DSP unit monitoring the left-bank ladder entrance malfunctioned, resulting in the detection of only one fish at the left-bank entrance. The absence of detection at this ladder entrance does not affect overall dam passage time (because the left-bank ladder exit monitor worked properly), but precludes estimates of variability of tailrace and ladder residence times.

At Wells Dam in 2002, the median tailrace residence time was 7.84 days, ranging from 1.64-18.35 days (Table 3). The median fishway residence time in the right bank ladder was 0.21 days (range, 0.20-0.23 days) and 0.32 days in the left-bank ladder. The overall elapsed time at the dam for the 12 passage events was 7.60 days and ranged from 1.83-24.87 days (Table 3). During the 2003 migration, only one tagged bull trout migrated upstream through Wells Dam (the left bank ladder). For this fish, the tailrace residence time was 1.0 day and the ladder residence time was 0.16 days. Overall, the elapsed time at Wells Dam was 1.16 days (Table 4).

The median tailrace time in 2002 exceeded those recorded in 2001 by about 6.3 days. However, the median passage times within the ladders as well as the overall dam passage time were less in 2002 than in 2001 (Table 5). For 2003, the tailrace time was similar to 2001, and the ladder time similar to 2002 (Table 5). A possible explanation for these observations is that spill in 2002 was far greater than what was observed in 2001 or 2003.

It is possible to compare elapsed time of fish released at Wells Dam with those released at downstream dams in 2002. The median elapsed time at the dam for the four fish released in the tailrace was 20.09 days, compared to 3.56 days for the seven fish that migrated upstream from downstream dams. A similar trend was observed in 2001 at Wells Dam. In 2001, the median tailrace time was 3.64 days for fish released into the tailrace and 1.04 days for fish that migrated upstream from downstream dams. Similar to observations at Rocky Reach Dam, it appears that releasing recently tagged bull trout immediately downstream from Wells Dam increases tailrace residence time, thereby exaggerating the actual tailrace residence and elapsed time at the dam. It is likely that a recovery period of a few days is needed before fish released in the tailrace behave like fully-recovered fish that migrated from downstream locations.

Of the bull trout that passed Wells Dam, or were released into the forebay of that project in 2002 (n=15), 11 were detected by the fixed-telemetry site near the mouth of the Methow River. Two other fish passed Wells Dam and were detected in the Methow River during aerial surveys, but were not detected at the fixed-telemetry site. The transmitter of another fish apparently died after exiting the left-bank ladder. This transmitter was implanted into a fish in 2001 and was nearly 400 days old, which exceeded the expected 360-day tag life. Finally, another fish (tag 14-108) entered the Okanogan River and shortly thereafter left that river and moved into the Methow River. The travel time between Wells Dam and the Okanogan River site was 3.37 days. For the 11 fish that entered the Methow River, the median travel time between the dam and the river was 2.78 days (range, 0.33-16.42 days; Table 3). In 2003, the single fish that migrated upstream of Wells Dam entered the Methow River, with an elapsed time of 1.09 days between the two sites. The elapsed time between Wells Dam and the Methow River for 2002 and 2003 was longer than in 2001 (0.40 days; Table 5).

Two tagged bull trout were detected as they moved downstream through Wells Dam in 2002. One fish (14-100), released into the forebay of Rocky Reach Dam, migrated upstream and ascended the right-bank ladder at Wells Dam. Within a nine hour period, this fish moved back downstream through the dam. Four days later, the fish had ascended the left-bank ladder and exited the ladder system. This fish eventually ended up in the Methow River. The second fish (14-99) was released upstream of Wells Dam and about five hours later was detected in the tailrace of the project. This fish migrated downstream, passed Rocky Reach Dam, and entered the Wenatchee River. No

evidence indicates that these fish were significantly harmed during their downstream passage through the dam. For the 2001 and 2003 migrations, no downstream passage events were observed.

Table 3: Summary of migration time (days) for adult radio-tagged bull trout that traveled between fixed station telemetry sites in 2002. Migration time was only assessed for actively migrating fish.

Location[1]	N	Mean	Median	Minimum	Maximum
Rock Island Dam					
Tailrace (A-B)	5	6.93	5.66	0.43	16.43
Left Fish Ladder (B-C)	1	0.18	0.18	0.18	0.18
Right Fish Ladder (B-C)	4	0.73	0.85	0.25	0.97
Elapsed Time at Dam (A-C)	5	7.55	5.90	1.21	17.35
Dam to Wenatchee River (C-D)	2	5.99	5.99	4.56	7.41
Dam to Rocky Reach Tailrace	7	2.70	2.78	1.14	5.46
Rocky Reach Dam					
Tailrace (A-B)	22	5.82	4.44	0.60	16.25
Fish Ladder (B-C)	23	0.59	0.28	0.13	6.15
Elapsed Time at Dam (A-C)	21	6.51	4.86	1.11	16.50
Dam to Entiat River (C-D)	23	12.26	11.34	3.51	26.98
Dam to Wells Tailrace	7	2.28	2.03	1.09	3.71
Wells Dam					
Tailrace (A-B)	3	9.27	7.84	1.64	18.35
Left Fish Ladder (B-C)	1	0.32	0.32	0.32	0.32
Right Fish Ladder (B-C)	2	0.21	0.21	0.20	0.23
Elapsed Time at Dam (A-C)	12	9.89	7.60	1.83	24.87
Dam to Methow River (C-D)	11	5.83	2.78	0.33	16.42

[1]Locations are defined as:

A First detection by tailrace system (300 meters downstream).

B First detection inside either ladder entrance.

C Last detection at either ladder exit.

D First detection at tributary site.

Table 4: Summary of migration time (days) for adult radio-tagged bull trout that traveled between fixed station telemetry sites in 2003. Migration time was only assessed for actively migrating fish.

Location[1]	N	Mean	Median	Minimum	Maximum
Rock Island Dam					
Tailrace (A-B)	---	---	---	---	---
Left Fish Ladder (B-C)	---	---	---	---	---
Right Fish Ladder (B-C)	---	---	---	---	---
Elapsed Time at Dam (A-C)	2	5.10	5.10	4.03	6.17
Dam to Wenatchee River (C-D)	1	1.67	1.67	1.67	1.67
Dam to Rocky Reach Tailrace	1	1.79	1.79	1.79	1.79
Rocky Reach Dam					
Tailrace (A-B)	---	---	---	---	---
Fish Ladder (B-C)	---	---	---	---	---
Elapsed Time at Dam (A-C)	9	5.46	4.68	0.66	16.87
Dam to Entiat River (C-D)	6	17.19	16.47	15.18	21.98
Dam to Wells Tailrace	1	1.73	1.73	1.73	1.73
Wells Dam					
Tailrace (A-B)	1	1.00	1.00	1.00	1.00
Left Fish Ladder (B-C)	1	0.16	0.16	0.16	0.16
Right Fish Ladder (B-C)	---	---	---	---	---
Elapsed Time at Dam (A-C)	1	1.16	1.16	1.16	1.16
Dam to Methow River (C-D)	1	1.09	1.09	1.09	1.09

[1]Locations are defined as:

A First detection by tailrace system (300 meters downstream).

B First detection inside either ladder entrance.

C Last detection at either ladder exit.

D First detection at tributary site.

Table 5: Summary of migration time in 2001, 2002, and 2003 (days) for adult radio-tagged bull trout that traveled between fixed station telemetry sites. Migration time was only assessed for actively migrating fish.

	2001		2002		2003	
Location[1]	**N**	**Median**	**N**	**Median**	**N**	**Median**
		Rock Island Dam				
Tailrace (A-B)	---	---	5	5.66	---	---
Left Fish Ladder (B-C)	---	---	1	0.18	---	---
Right Fish Ladder (B-C)	---	---	4	0.85	---	---
Elapsed Time at Dam (A-C)	3	2.28	5	5.90	2	5.10
Dam to Wenatchee River (C-D)	1	1.39	2	5.99	1	1.67
Dam to Rocky Reach Tailrace	4	1.33	7	2.78	1	1.79
		Rocky Reach Dam				
Tailrace (A-B)	9	1.28	22	4.44	---	---
Fish Ladder (B-C)	9	1.92	23	0.28	---	---
Elapsed Time at Dam (A-C)	9	3.79	21	4.86	9	4.68
Dam to Entiat River (C-D)	13	7.20	23	11.34	6	16.47
Dam to Wells Tailrace	6	1.69	7	2.03	1	1.73
		Wells Dam				
Tailrace (A-B)	10	1.53	3	7.84	1	1.00
Left Fish Ladder (B-C)	1	11.63	1	0.32	1	0.16
Right Fish Ladder (B-C)	7	5.45	2	0.21	---	---
Elapsed Time at Dam (A-C)	8	8.87	12	7.60	1	1.16
Dam to Methow River (C-D)	13	0.40	11	2.78	1	1.09

[1]Locations are defined as:

A First detection by tailrace system (300 meters downstream).
B First detection inside either ladder entrance.
C Last detection at either ladder exit.
D First detection at tributary site.

4.3 Tributary Selection and Residence

In 2001, all surviving adult bull trout tagged at each dam selected a major tributary for fall or fall-winter residence (Table 6). Major tributaries selected included the Wenatchee, Entiat, and Methow systems. One bull trout entered the Okanogan River (detected at the fixed-telemetry site at R.K. 9.0), but shortly thereafter migrated downstream and entered the Methow River. For many of these fish, it is not possible to establish the date of exodus from the tributary of residence. This is likely due to three factors. First, during the period when these fish may have exited the tributaries, the receivers monitoring those sites were also monitoring frequencies associated with other telemetry studies. As such, due to the extended receiver cycle time associated with this activity, fish may not have been detected as they passed the detection site. Second, for some of these fish, the transmitters may have failed by the time the fish exited the various basins. Finally, mobile survey efforts during the period following potential exodus had been reduced due to tagging efforts. However, based on detections within the mainstem at the various dams, five fish without tributary exit dates were confirmed to have exited the basin of residence (Table 6).

Of the 40 bull trout tagged at the three dams in 2002, 37 of them moved into tributaries for fall or fall-winter residence (Table 7). During 2002, the tributary residence of two fish tagged in 2001 was also documented. Other bull trout tagged in 2001 likely entered tributaries in fall 2002, but their transmitters had failed before it was possible to detect them in tributaries. For these 39 fish, their residence times and locations within tributaries have been summarized (Table 7).

Major tributaries selected by these fish included the Wenatchee, Entiat, and Methow River systems (Figure 18, Figure 19, and Figure 20)[5]. Entrance times of fish within the tributaries were based on the first detection at the fixed-sites within each tributary. All fish that entered tributaries were detected at the fixed sites. However, some fish were not detected at the fixed-sites during their exit from tributary streams. Therefore, aerial and boat surveys, as well as fixed-site telemetry data were used to determine tributary exit times for these fish.

Three fish tagged in 2002 did not enter tributaries. One fish (14-110) is likely dead. The transmitter of this fish was discovered downstream from Rock Island Dam on 22 August 2002. Before its transmitter was discovered, the fish had made brief forays into the Wenatchee and Entiat rivers. Another fish (14-124) remained between the Wenatchee River confluence and Rocky Reach Dam, while the third (14-127) resided between the Wenatchee River and Entiat River confluences.

During the fall of 2003, a total of 14 bull trout entered tributaries (Table 8). All of these fish were tagged in 2002. Of these fish, all but two exited tributaries by 23 November 2003, and all were detected by the fixed-sites as they exited the tributaries. The two fish (14-92 and 14-125) that remained in tributaries were last detected on 3 November 2003 during an aerial survey over the Mad River.

[5] These figures represent major tributaries selected, not specific locations within the major tributaries. Appendix B provides the locations where fish were detected during aerial surveys.

There is no indication that the hydro-system prevents bull trout from migrating into tributary streams. However, passage through the hydro-system may delay their entry into tributaries, causing them to miss their window for successful spawning. To address this we compared the timing of bull trout spawning in the basin with times at which tagged bull trout entered tributaries. The assumption is that if bull trout entered tributaries before the onset of spawning, then it is unlikely that the hydro-system prevented them from reaching their spawning areas in time to successfully spawn.

The literature indicates that bull trout spawn from August to November during periods of decreasing water temperatures (reviewed in Chapter 1 in the USFWS 2002 Draft Recovery Plan). In the Entiat Basin, based on over a decade of spawning surveys, median spawning times for bull trout ranged from mid- to late-September (data from P. Archibald, USFS). Our telemetry study indicates that most bull trout entered tributaries by the end of June, and aerial surveys detected tagged bull trout in possible spawning streams well before mid-September (Appendix B). Thus, there is no evidence that the hydro-system delayed the migration of bull trout to spawning areas in tributary streams. The following is a summary of tributary residence.

4.3.1 Wenatchee River

In 2001, of the 38 surviving bull trout, eight (21%) moved into the Wenatchee River basin. Of those fish, two were collected and tagged at Rock Island Dam. One of those came from a downstream release, while the other came from an upstream release. The other six fish that selected the Wenatchee basin were collected and tagged at Rocky Reach Dam and were released downstream from the dam (Table 6).

Aerial surveys were used to describe the location of seven of the eight fish in the Wenatchee system. Four fish remained within the Wenatchee River and did not move into tributaries. One resided about 1 km upstream from the mouth of the river, one near the town of Cashmere, and two in Tumwater Canyon (one near the lower end of the canyon and the other at the upstream end of the canyon). The other three fish resided in tributaries to the Wenatchee River. One fish was found in Peshastin Creek, one in the lower portion of Icicle Creek, and one in the lower portion of the Chiwawa River

In 2002, six tagged bull trout entered the Wenatchee River system (Table 7). These fish originated from releases at all three projects. Two were tagged at Rock Island Dam (Figure 18), three at Rocky Reach Dam (Figure 19), and one at Wells Dam (Figure 20). These fish entered and remained within the mainstem Wenatchee River. Aerial surveys located one near the town of Monitor, another near the town of Dryden, and two near the town of Leavenworth (Appendix B). The other two fish resided near the confluence of the Chiwawa River.

In 2003, three tagged bull trout entered the Wenatchee River system. One was tagged at Rock Island Dam and two at Rocky Reach Dam in 2002 (Table 8). All three of these fish resided within tributaries to the Wenatchee River (Appendix B). One fish resided within Ingalls Creek, which is a tributary to Peshastin Creek, and two resided within the Chiwawa River. The two fish that entered the Chiwawa River in 2003 resided in the Wenatchee basin in 2002 (Table 7 and Table 8; Appendix B). The third fish, which resided within Ingalls Creek in 2003, resided in the Mad River in 2002.

In 2001, bull trout that selected the Wenatchee Basin entered the system at different times. Five of the eight fish entered the Wenatchee River near the end of June 2001. The other three fish entered

the Wenatchee River on 16 July, 27 August, and 21 September 2001 (Table 6). The time of egress also varied. As of the end of March 2002, five fish remained in the Wenatchee system, and four did so until their transmitters failed. The fifth fish was detected at Rocky Reach Dam on 22 May 2002. The other three left the system between 2 November and 11 December 2001 (Table 6). Of the three bull trout that left the Wenatchee River, two remained within the Rock Island Pool and did not pass any dams. The other fish moved downstream through Rock Island Dam and later moved back upstream through the dam. It was last detected (1 April) in the forebay of Rock Island Dam.

Bull trout that selected the Wenatchee Basin in 2002 entered and exited the system at different times. Two entered the Wenatchee River by the end of June, three by mid-July, and the last one in early August 2002 (Table 7). The median date of entry was 3 July 2002. The time of tributary egress also varied. Four of the six fish exited the system by the first week of November 2002. The other two exited in mid-December and mid-January, respectively (Table 7). The median date of exodus was 6 November 2002. After leaving the Wenatchee River, four fish resided in the Columbia River between Rock Island Dam and the Wenatchee River confluence, another remained in the Rock Island Pool, and the sixth resided downstream from Rock Island Dam.

For the three fish that resided within the Wenatchee basin in 2003, the date of entry varied by only six days, spanning from 16-22 June. For these fish, the median date of entry was 18 June. The date of tributary egress spanned about five weeks, with the first fish exiting the basin on 17 October. The other two fish exited the Wenatchee basin on 21 and 22 November. For two of these fish, their location of residence after leaving the Wenatchee River was documented during either aerial or boat surveys. One fish migrated downstream of Rock Island Dam, the second is in the Rock Island pool between Rock Island Dam and the Wenatchee River confluence, and the location of the third fish remains unknown.

Tributary selection by bull trout may be influenced by release location. Combining data collected at the three projects during 2001 and 2002 reveals that 28% (11 of 39) of all fish released downstream from projects ended in tributaries downstream from release sites. In contrast, only 3% of the bull trout released upstream from projects ended in tributaries downstream from release sites. This pattern was most apparent at Rocky Reach Dam, where 43% (10 of 23) of the fish released in the tailrace during 2001 and 2002 ended in the Wenatchee River.

4.3.2 Entiat River

For the 2001 period of tributary residence, a total of 15 adult bull trout moved into the Entiat River during the study. Of those, two were tagged at Rock Island Dam (downstream releases), 12 at Rocky Reach (four released downstream and eight upstream), and one at Wells Dam (downstream release; **Table 6**). All fish in the Entiat system resided either in the Mad River (eight fish) or in the mainstem Entiat River (seven fish). Those in the Mad River selected locations upstream from the Pine Flat Campground, while those in the Entiat River resided upstream from the Mad River confluence (BioAnalysts, Inc. 2002).

A total of 21 bull trout entered the Entiat River in 2002. These fish originated from releases at Rock Island (5 fish) and Rocky Reach dams (16 fish) (Table 7; Figure 19). No fish released at Wells Dam ended up in the Entiat Basin (Table 7). All fish in the Entiat system resided in either the Mad River (11 fish) or the mainstem Entiat River (10 fish). Those in the Mad River occupied locations

upstream from the Pine Flat Campground (Appendix B). Of the ten fish that resided in the mainstem Entiat River, two were located downstream of the Mad River confluence, one between the confluences of the Mad River and Preston Creek, and seven upstream of Preston Creek (Appendix B).

In 2003, a total of 10 bull trout entered and resided within the Entiat basin (Table 8). Of these, seven occupied locations in the Mad River and three within the mainstem Entiat River (Appendix B). As in previous years, all of the bull trout that entered the Mad River resided upstream of the Pine Flat Campground. For the trout that resided within the mainstem of the Entiat River, all occupied locations upstream of Preston Creek. Of the ten bull trout that resided within the Entiat basin in 2003, seven also resided within that basin in 2002, with six selecting the same general area as the previous year (i.e., mainstem Entiat River or the Mad River). The other three fish in the Entiat basin in 2003 resided in either the mainstem Wenatchee River or in the Columbia River in 2002 (Table 7and Table 8).

All tagged bull trout that entered the Entiat River basin in 2001 did so relatively quickly after being released. The latest date of entry was 18 July, with the majority of the fish entering the system by the end of June (Table 6). The time of egress varied between fish in the Mad River and those in the Entiat River. All tagged fish that left the Entiat River did so by 11 November. Tagged fish in the Mad River remained there through winter and only one left the system by the end of March 2002. Two other fish that resided within the Mad River were detected in the mainstem Columbia River on 22 May and 6 June, 2002. Both of these fish were last detected in the forebay of Rocky Reach Dam. Of the eight adult bull trout that left the Entiat Basin during the study, four moved downstream through Rocky Reach Dam and resided in the Rock Island Pool. Two other bull trout moved downstream through both Rocky Reach and Rock Island dams, but did not pass Wanapum Dam. The remaining two bull trout moved into Rocky Reach Pool and passed no dams.

All tagged bull trout that entered the Entiat River basin in 2002 did so relatively quickly after being released. They entered the Entiat River from 6 June to 13 July with more than half of the fish entering the system by the end of June (Table 7). The median date of entry was 21 June 2002. The time of egress varied between fish in the Entiat River and those in the Mad River, with median tributary exit times of 4 September and 23 October, respectively. Of the 21 tagged fish that entered the Entiat Basin, 15 left the system by 17 December. Of those that remained in the system, three either died or shed their tags (14-88, 14-95 and 14-97), and three others may have died or shed their tags (14-119, 14-122 and 14-123). The 15 bull trout that left the Entiat Basin moved downstream into the Columbia River to reside in Rocky Reach, Rock Island, or Wanapum reservoirs. Ten fish moved into Rocky Reach pool, with seven located between Rocky Reach Dam and the Entiat River confluence and three between the Entiat River confluence and Wells Dam. Four bull trout moved downstream past Rocky Reach Dam and resided between the confluence of the Wenatchee River and Rocky Reach Dam. Finally, one bull trout migrated downstream past Rocky Reach and Rock Island dams and resided in the tailrace of Rock Island Dam.

Entry of bull trout into the Entiat Basin in 2003 spanned a period of ten weeks, with two fish entering that basin on 8 and 20 April and the last fish entering 22 June. However, the majority of the fish entered the Entiat River around mid-June, with a median date of entry of 13 June (Table 8). Of the ten fish that entered the Entiat River, eight exited that basin by the end of the study period (31

March 2004). For those fish, the median date of exodus was 21 October, with the first fish leaving the system on 4 October, and the last on 23 November. After exit from that basin, two fish resided within the Rock Island pool, five in Rocky Reach pool, and one downstream from Rock Island Dam.

4.3.3 Methow River

During the 2001 period of tributary residence, a total of 15 tagged adult bull trout moved into the Methow River. Two of those fish were tagged and released at Rock Island Dam (upstream releases), four at Rocky Reach Dam (one downstream release and three upstream releases), and nine at Wells Dam (four downstream releases and five upstream releases; Table 6). All of the fish entered the Methow basin by 11 June. By the end of March 2002, only four tagged bull trout had left the system. Those four had moved out of the system by 16 December 2001. Of the 11 tagged trout that did not leave the system by the end of the 2001 study period (31 March, 2002), eight remained in the Methow basin until their transmitters failed. For the other three, two were last detected in the tailrace of Wells Dam, and one upstream of that project.

During the 2002 study period, 12 adult bull trout entered the Methow River. These fish originated from releases at Rocky Reach and Wells dams (Table 7). Four bull trout were released at Rocky Reach Dam (Figure 19) and eight at Wells Dam (Figure 20). No fish tagged at Rock Island Dam moved into the Methow River (Table 7). Bull trout in the Methow system selected two primary areas, the mainstem Methow River and the Twisp River (Appendix B). Of the 12 fish that resided within the Methow basin, nine were located within the Twisp River upstream of Buttermilk Creek, and three appear to have resided upstream from the town of Winthrop. For the 2003 migration, only a single bull trout entered the Methow basin. That fish was initially tagged at Wells Dam in 2002, and resided in the mainstem Methow River near the Twisp River confluence (Table 8).

All bull trout that entered the Methow River in 2002 did so during the month of June (between 3 and 27 June). For those fish, their fates can be classified into four categories: 1) fish that exited the basin; 2) those that either died or shed their tags; 3) those that have not exited the basin but appear to be alive; and 4) fish whose fates are unknown.

The first category includes only a single fish (14-112). After entering the Methow River, this fish was not located over a 15 month period. During a routine aerial survey on 23 October 2003, it was located about 2 km downstream from the town of Winthrop and near the confluence of Gold Creek on 3 November. The last detection for this fish was 15 November 2003 at the fixed-telemetry site. As aerial surveys were typically terminated near the town of Winthrop, it is likely that this fish resided upstream of this location for an extended period of time. The second category of fish, those that either died or shed their tags, includes a total of seven fish. The transmitters for all seven fish were recovered in the tributary of residence (Table 7: Tributaries selected by adult bull trout tagged at Rock Island, Rocky Reach, and Wells dams and the dates they entered and left those tributaries, 2002.; Appendix A).

The third category, fish that have not exited the basin but appear to be alive, includes two fish. One fish (14-94) was not detected for 17 months after entering the Methow basin. During an aerial survey conducted by the USFWS on 18 December 2003, this fish was located upstream from the town of Winthrop. Another fish (14-116) has resided in both the mainstem Methow River and the Twisp River, and was most recently detected in Buttermilk Creek on 2 October 2003. This fish has

been in the Methow basin for over 16 months. The fate of the last two fish is unknown. One was last detected on 1 July 2002, the other 19 February 2003. For the single fish that entered the Methow basin in 2003, it exited that basin on 28 October 2003 after four and a half months at that location. In 2002, this fish resided within the Wenatchee River basin.

Table 6: Tributaries selected by adult bull trout tagged at Rock Island, Rocky Reach, and Wells dams and the dates they entered and left those tributaries, 2001.

Tagging Information			Tributary Residence			
Release	Code	Date	Entrance	Exit	Subbasin	Location
			Rock Island Dam			
Down	32	21-May-01	04-Jun-01	23-Nov-01	Entiat	Mad River
Down	55	19-Jun-01	28-Jun-01	---	Entiat	Mad River
Down	35	30-May-01	13-Jun-01	---	Wenatchee	Peshastin Creek
Up	48	03-Jul-01	NA	NA	Dead	
Up	4	17-May-01	30-May-01	---	Methow	Twisp River
Up	13	24-May-01	11-Jun-01	---	Methow	Twisp River
Up	36	13-Jun-01	21-Sep-01	02-Nov-01	Wenatchee	Mainstem Wenatchee River
			Rocky Reach Dam			
Down	29[1]	21-May-01	06-Jun-01	---	Entiat	Mad River
Down	18[1]	23-May-01	07-Jun-01	---	Entiat	Mad River
Down	15	25-May-01	06-Jun-01	02-Nov-01	Entiat	Mainstem Entiat River
Down	11	29-May-01	06-Jun-01	02-Nov-01	Entiat	Mainstem Entiat River
Down	54	30-May-01	11-Jun-01	---	Methow	Libby Creek
Down	8	11-Jun-01	30-Jun-01	---	Wenatchee	Chiwawa River
Down	46	18-Jun-01	23-Jun-01	11-Dec-01	Wenatchee	Icicle Creek
Down	5	17-May-01	30-May-01	---	Wenatchee	Mainstem Wenatchee River
Down	9	07-Jun-01	27-Aug-01	16-Nov-01	Wenatchee	Mainstem Wenatchee River
Down	25	25-Jun-01	29-Jun-01	---	Wenatchee	Mainstem Wenatchee River
Down	34[1]	10-Jul-01	16-Jul-01	---	Wenatchee	Mainstem Wenatchee River
Up	45	15-Jun-01	29-Jun-01	---	Entiat	Mad River
Up	47	19-Jun-01	01-Jul-01	---	Entiat	Mad River
Up	3	15-May-01	22-May-01	---	Entiat	Mad River
Up	24	22-May-01	04-Jun-01	---	Entiat	Mad River
Up	6	29-May-01	10-Jun-01	17-Oct-01	Entiat	Mainstem Entiat River
Up	7	04-Jun-01	08-Jun-01	11-Nov-01	Entiat	Mainstem Entiat River
Up	37	06-Jun-01	11-Jun-01	09-Nov-01	Entiat	Mainstem Entiat River
Up	50	13-Jul-01	18-Jul-01	24-Sept-01	Entiat	Mainstem Entiat River
Up	20	21-May-01	30-May-01	16-Dec-01	Methow	Twisp River
Up	12	24-May-01	10-Jun-01	07-Oct-01	Methow	Twisp River
Up	14	25-May-01	02-Jun-01	---	Methow	Twisp River
			Wells Dam			
Down	17	24-May-01	02-Jun-01	10-Aug-01	Entiat	Mainstem Entiat River
Down	22	29-May-01	08-Jun-01	---	Methow	Mainstem Methow River
Down	26	22-May-01	01-Jun-01	16-Dec-01	Methow	Twisp River
Down	19	22-May-01	01-Jun-01	---	Methow	Twisp River
Down	33	22-May-01	08-Jun-01	13-Apr-02	Methow	Twisp River
Up	28	22-May-01	24-May-01	---	Methow	Mainstem Methow River
Up	23[1]	29-May-01	01-Jun-01	---	Methow	Mainstem Methow River
Up	21	22-May-01	24-May-01	02-Nov-01	Methow	Twisp River
Up	31[1]	21-May-01	27-May-01	---	Methow	Buttermilk Creek
Up	16	23-May-01	25-May-01	---	Methow	Buttermilk Creek

[1] Based on detection histories for these fish, it appears that they exited the tributary of residence. However, due to a lack of detections at the fixed telemetry sites on the tributary of residence, a date of exodus can not be established.

Table 7: Tributaries selected by adult bull trout tagged at Rock Island, Rocky Reach, and Wells dams and the dates they entered and left those tributaries, 2002.

Tagging Information			Tributary Residence			
Release	Code	Date	Entrance	Exit	Subbasin	Location
			Rock Island Dam			
Down	105	04-Jun-02	27-Jun-02	17-Dec-02	Wenatchee	Mainstem Wenatchee River
Down	113	07-Jun-02	22-Jun-02	06-Nov-02	Wenatchee	Mainstem Wenatchee River
Down	90[3]	23-May-02	01-Jul-02	04-Sep-02	Entiat	Mainstem Entiat River
Down	115	12-Jun-02	01-Jul-02	04-Sep-02	Entiat	Mainstem Entiat River
Up	110[1]	04-Jun-02	---	---	Columbia River	---
Up	97[2]	20-May-02	19-Jun-02	---	Entiat	Mad River
Up	119[4]	12-Jun-02	29-Jun-02	---	Entiat	Mad River
Up	109[3]	07-Jun-02	20-Jun-02	17-Dec-02	Entiat	Mad River
			Rocky Reach Dam			
Down	127	27-Jun-02	---	---	Columbia River	---
Down	104	30-May-02	01-Jul-02	09-Oct-02	Wenatchee	Mainstem Wenatchee River
Down	125	26-Jun-02	06-Jul-02	06-Nov-02	Wenatchee	Mainstem Wenatchee River
Down	126	18-Jun-02	14-Jul-02	14-Jan-03	Wenatchee	Mainstem Wenatchee River
Down	101	03-Jun-02	25-Jun-02	06-Nov-02	Entiat	Mad River
Down	106	06-Jun-02	27-Jun-02	09-Oct-02	Entiat	Mainstem Entiat River
Down	111	04-Jun-02	18-Jun-02	06-Nov-02	Entiat	Mad River
Down	118	11-Jun-02	01-Jul-02	09-Oct-02	Entiat	Mainstem Entiat River
Down	114	10-Jun-02	01-Jul-02	09-Oct-02	Entiat	Mad River
Down	120	27-Jun-02	13-Jul-02	09-Oct-02	Entiat	Mad River
Down	95[1]	29-May-02	09-Jun-02	---	Entiat	Mainstem Entiat River
Down	89[2]	21-May-02	09-Jun-02	---	Methow	Twisp River
Down	46	18-Jun-01	04-Jul-02	01-Aug-02	Entiat	Mainstem Entiat River
Up	124	24-Jun-02	---	---	Columbia River	---
Up	103	06-Jun-02	21-Jun-02	09-Oct-02	Entiat	Mainstem Entiat River
Up	121	07-Jun-02	20-Jun-02	06-Nov-02	Entiat	Mad River
Up	88[2]	20-May-02	06-Jun-02	---	Entiat	Mad River
Up	92	23-May-02	19-Jun-02	04-Sep-02	Entiat	Mad River
Up	122[4]	12-Jun-02	20-Jun-02	---	Entiat	Mainstem Entiat River
Up	123[4]	21-Jun-02	01-Jul-02	---	Entiat	Mainstem Entiat River
Up	98[3]	30-May-02	12-Jun-02	09-Oct-02	Entiat	Mad River
Up	116	10-Jun-02	24-Jun-02	---	Methow	Twisp River
Up	100	04-Jun-02	27-Jun-02	---	Methow	Twisp River
Up	108[2]	03-Jun-02	23-Jun-02	---	Methow	Twisp River
Up	7	04-Jun-01	11-Jun-02	04-Aug-02	Entiat	Mainstem Entiat River
			Wells Dam			
Down	112	11-Jun-02	19-Jun-02	15-Nov-03	Methow	Mainstem Methow River
Down	93[1]	28-May-02	24-Jun-02	---	Methow	Twisp River
Down	96[1]	03-Jun-02	22-Jun-02	---	Methow	Twisp River
Down	102[2]	04-Jun-02	26-Jun-02	---	Methow	Twisp River
Up	99	04-Jun-02	01-Aug-02	06-Nov-02	Wenatchee	Mainstem Wenatchee River
Up	91	23-May-02	03-Jun-02	---	Methow	Mainstem Methow River
Up	94	03-Jun-02	20-Jun-02	---	Methow	Mainstem Methow River
Up	107[1]	03-Jun-02	09-Jun-02	---	Methow	Twisp River
Up	117[1]	12-Jun-02	21-Jun-02	---	Methow	Twisp River

[1] The transmitters for these fish were recovered at the tributary or location of residence during the 2002 study period.
[2] The transmitters for these fish were recovered at the tributary or location of residence during the 2003 study period.
[3] The transmitters for these fish were recovered after tributary exodus during the 2003 study period in the Columbia River.
[4] These fish are suspected of perishing or shedding their tags in the tributary of residence.

Table 8: Tributaries selected by adult bull trout tagged at Rock Island, Rocky Reach, and Wells dams and the dates they entered and left those tributaries, 2003.

Tagging Information			Tributary Residence			
Release	**Code**	**Date**	**Entrance**	**Exit**	**Subbasin**	**Location**
			Rock Island Dam			
Down	113	07-Jun-02	16-Jun-03	21-Nov-03	Wenatchee	Chiwawa River
			Rocky Reach Dam			
Down	101	03-Jun-02	22-Jun-03	17-Oct-03	Wenatchee	Peshastin Creek
Down	104	30-May-02	01-Jun-03	21-Oct-03	Entiat	Mainstem Entiat River
Down	106	06-Jun-02	20-Apr-03	23-Nov-03	Entiat	Mainstem Entiat River
Down	114	10-Jun-02	22-Jun-03	04-Oct-03	Entiat	Mad River
Down	118	11-Jun-02	08-Apr-03	17-Oct-03	Entiat	Mad River
Down	120	27-Jun-02	18-Jun-03	18-Nov-03	Entiat	Mad River
Down	125	26-Jun-02	18-Jun-03	---	Entiat	Mad River
Down	126	18-Jun-02	18-Jun-03	22-Nov-03	Wenatchee	Chiwawa River
Down	127	27-Jun-02	13-Jun-03	17-Oct-03	Entiat	Mad River
Up	92	23-May-02	14-Jun-03	---	Entiat	Mad River
Up	103	06-Jun-02	13-Jun-03	21-Oct-03	Entiat	Mainstem Entiat River
Up	121	07-Jun-02	08-Jun-03	21-Oct-03	Entiat	Mad River
			Wells Dam			
Up	99	04-Jun-02	03-Jun-03	28-Oct-03	Methow	Mainstem Methow River

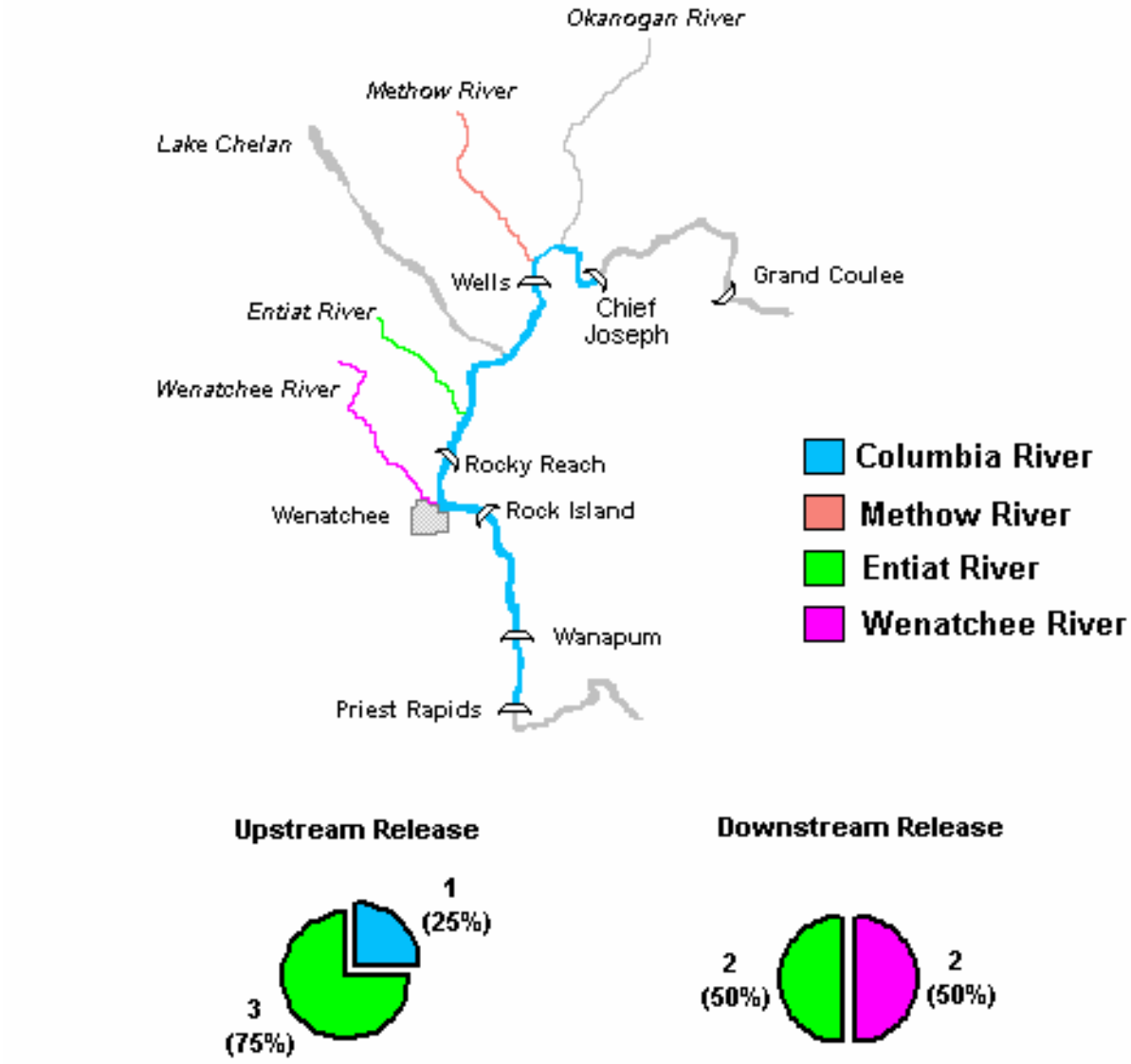

Figure 18: Mid-Columbia River tributaries selected by bull trout after they were released upstream and downstream from Rock Island Dam, 2002. Final destination for radio-tagged bull trout within each tributary is noted in Table 7.

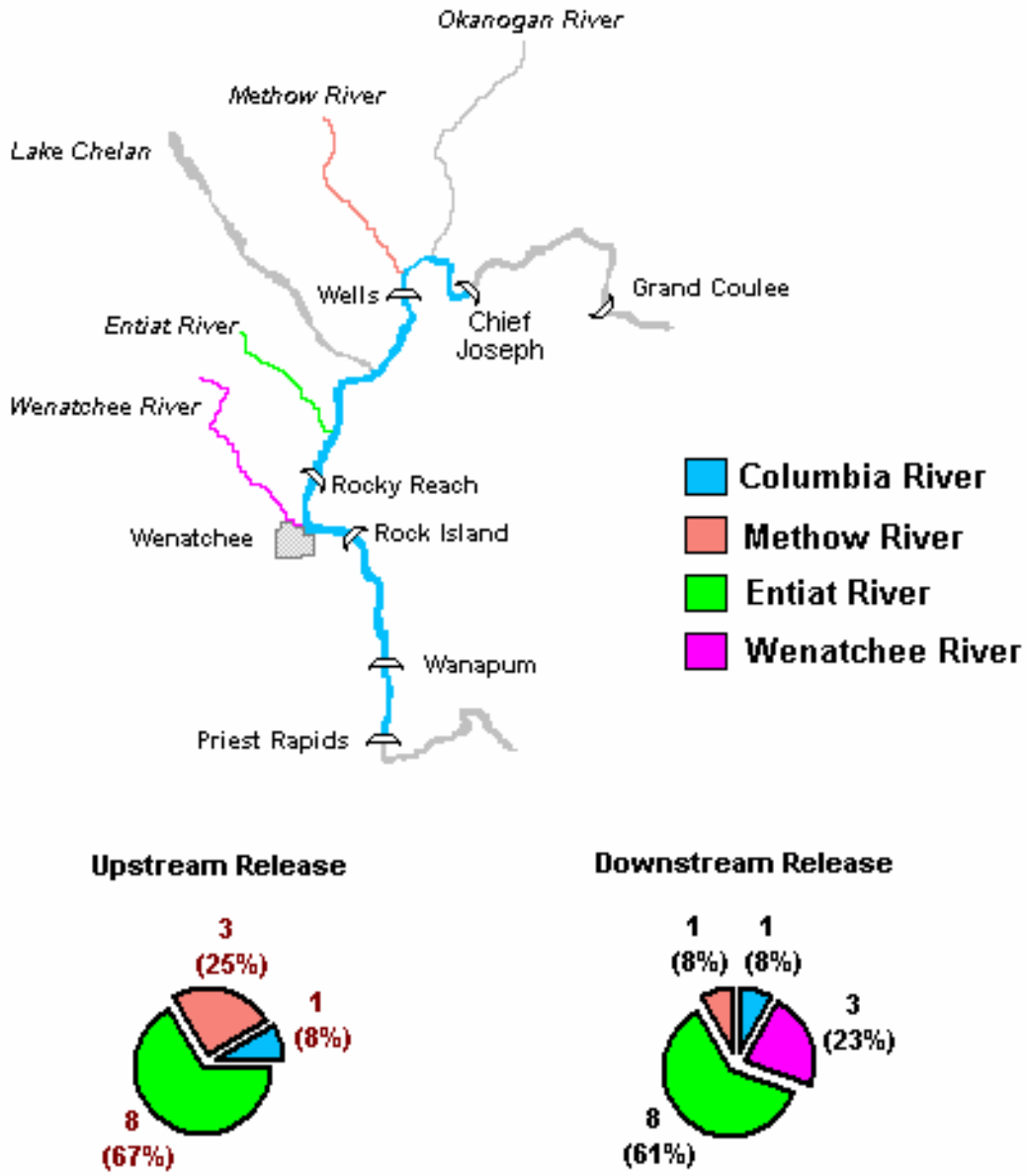

Figure 19: Mid-Columbia River tributaries selected by bull trout after they were released upstream and downstream from Rocky Reach Dam, 2002. Final destination for radio-tagged bull trout within each tributary is noted in Table 7.

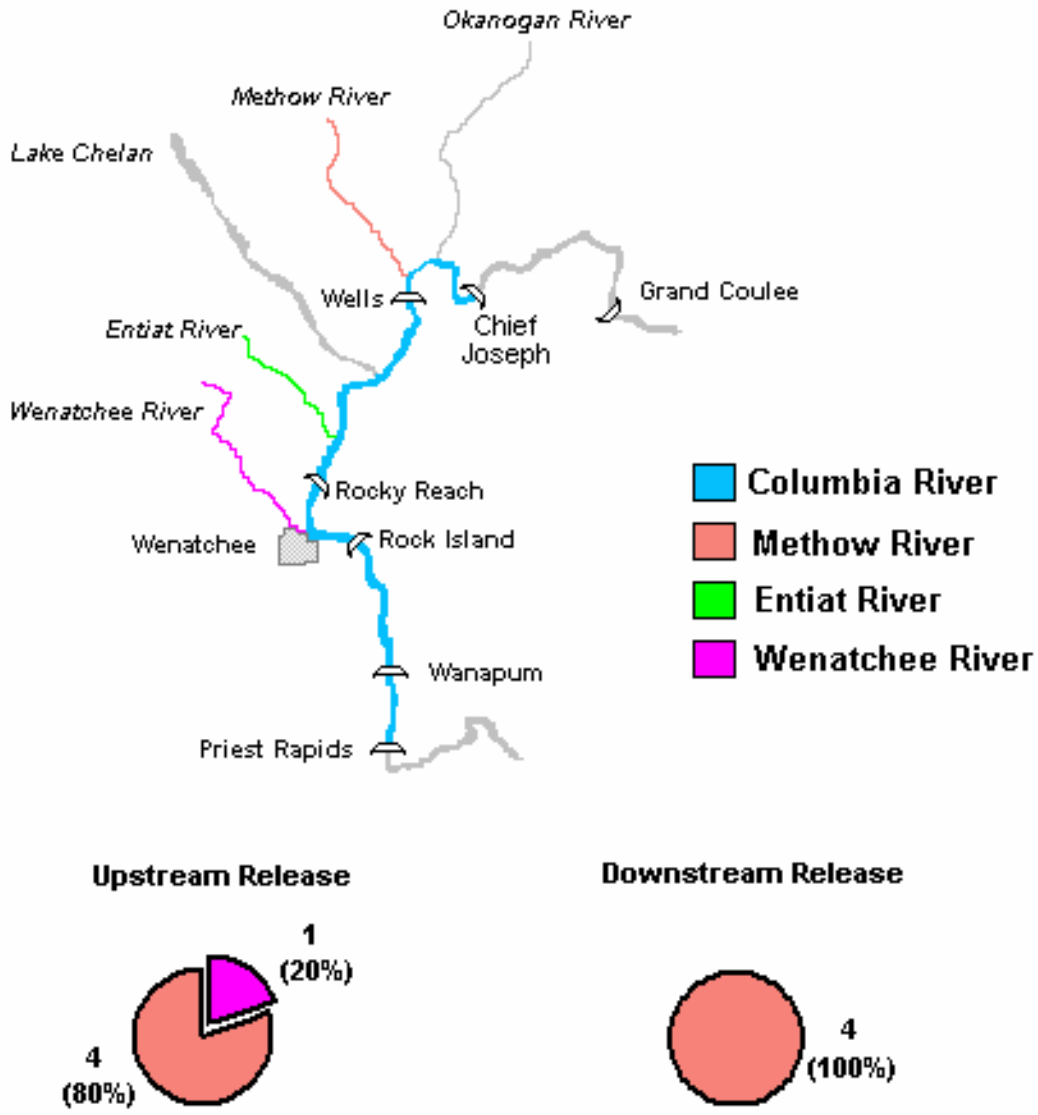

Figure 20: Mid-Columbia River tributaries selected by bull trout after they were released upstream and downstream from Wells Dam, 2002. Final destination for radio-tagged bull trout within each tributary is noted in Table 7.

4.4 Tributary and Mainstem Temperatures

To investigate the relationship between temperature and movement of bull trout in the mid-Columbia River, it is possible to compare temperatures at the time of entry into tributary streams with that of the Columbia River. For this analysis, the mean daily temperature of the Columbia River relative to the various tributaries at the time bull trout entered the Wenatchee, Entiat and Methow rivers have been compared. Where data were available, minimum, mean and maximum daily temperatures within the lower tributaries have been plotted. For fish entering the Wenatchee and Entiat rivers, tributary temperatures were compared to temperatures measured within the Rocky Reach tailrace. For fish entering the Methow River, tailrace temperatures measured at Wells Dam were used. For some fish, there is a history of tributary entrance on more than one occasion. That is, for some fish tagged in 2001, their transmitters were active long enough to document tributary entrance in both 2001 and 2002. Likewise, many fish tagged in 2002 also entered tributaries in 2003.

Temperature data for the various tributaries is in many cases incomplete. Temperature data collected from the Wenatchee, Methow, and Entiat rivers were all collected in the lower 4-kilometers of each stream. For the lower Wenatchee River, daily minimum, mean and maximum temperatures for 2001, and only mean temperatures for 2002 and 2003 were acquired. For the lower Methow River, only daily mean values were available for 2001 and 2003. No temperature data were available in 2002 for the Methow River. Temperature data for the Entiat River were the most complete with daily minimum, mean and maximum values recorded. However, for all three tributaries, data were only available through the latter part of August. However, to better understand mid-Columbia River temperatures and migration of bull trout, the first and last date of entry into each tributary were used, regardless if temperature data were available in the tributaries.

Seventeen bull trout entered the Wenatchee Basin during the spring and summer of a three year study period. There were no temperature data available in the lower Wenatchee River for three of those fish. Bull trout entered the Wenatchee River in June and July when the mean daily temperatures in the Wenatchee River ranged from 10.5 °C to 17.2 °C. In the Columbia River during that time the mean daily temperatures ranged from 11.2 °C to 19.6 °C (Figure 21).

There were forty-six radio-tagged bull trout that entered the Entiat basin from April to mid-July. Bull trout entered the Entiat River when the mean daily temperatures ranged from 7 .5 °C to 15.8 °C (Figure 22). Mean daily temperatures for the Columbia River during the migration period varied from 5.4 °C to 19.6 °C.

Collectively for the 2001-2003 study period 28 radio-tagged bull trout entered the Methow basin in May and June. However, due to sporadic stream temperature monitoring within the lower Methow River, it is only possible to document stream temperatures for six fish at the time of tributary entrance. Six bull trout entered the Methow River when the mean daily temperatures varied from 9.7 °C to 13.5 °C (Figure 23). For all bull trout that entered the Methow basin, mean daily temperatures for the Columbia River during the three year study period ranged from 10.1 °C to 14.9 °C.

For the three years of data regarding tributary entrance into the Wenatchee, Entiat and Methow rivers, a total of 91 tributary entrance events occurred. During the study period bull trout entered mid-Columbia tributaries from April to September but most (94%) entered tributaries during May, June and July. At the time bull trout entered tributary streams the mean daily temperatures in the mainstem Columbia River varied from 5.4 °C to 19.6 °C. Similarly, tributary mean daily temperatures ranged from 7.5 °C to 17.2 °C. Most bull trout (92.3%) entered tributaries before the Columbia River reached a mean temperature of 15 °C. The successful migration of bull trout into the various spawning streams of the Wenatchee, Entiat and Methow suggests that temperatures at the time of migration in the mid-Columbia River did not appear to limit the migration of radio-tagged bull trout.

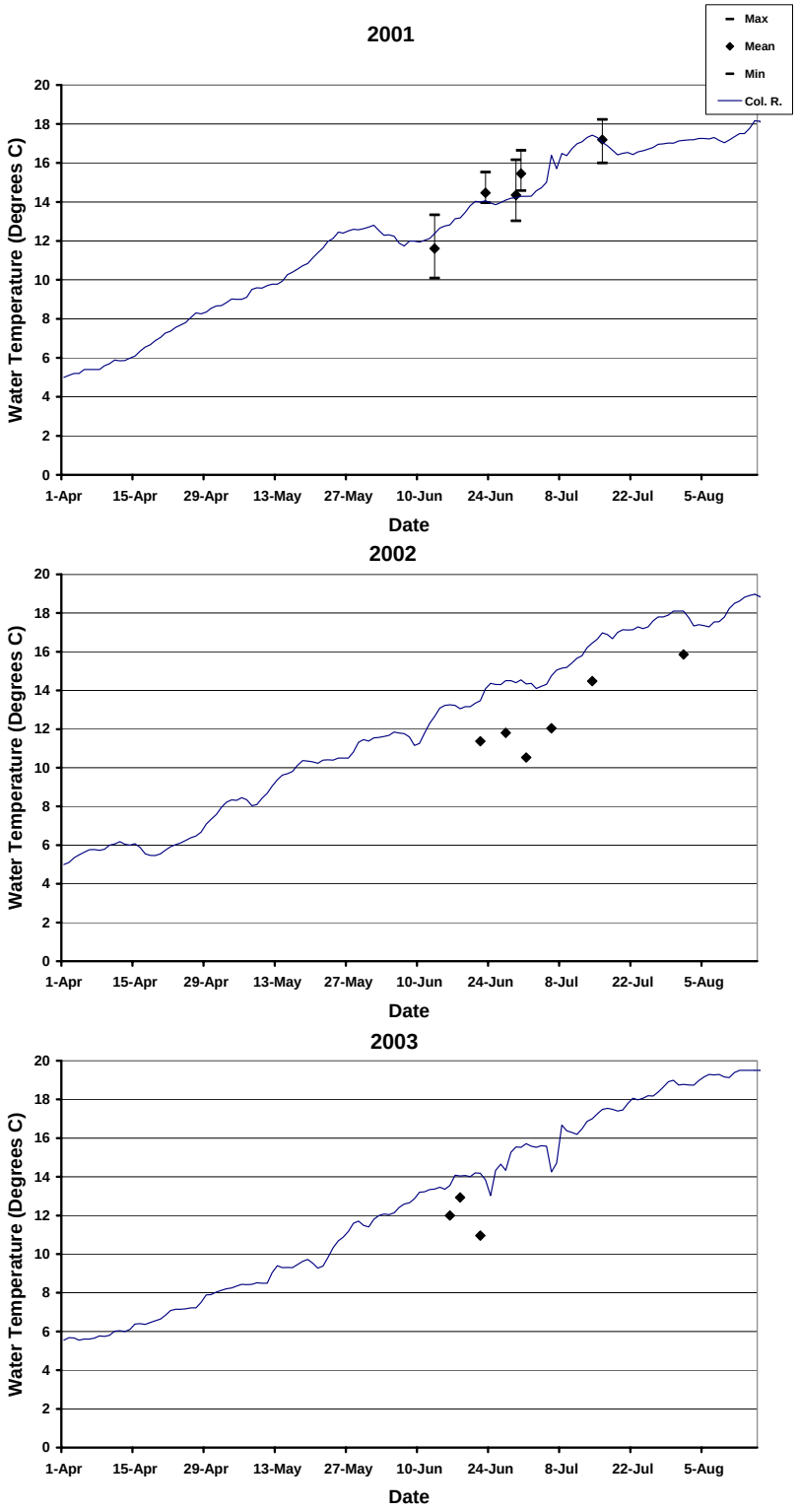

Figure 21: Wenatchee River temperatures at the time of tributary entrance relative to the Columbia River measured downstream of Rocky Reach Dam, 2001-2003. Daily minimum, mean and maximum Wenatchee River temperatures provided where data were available. Each data point represents an individual fish.

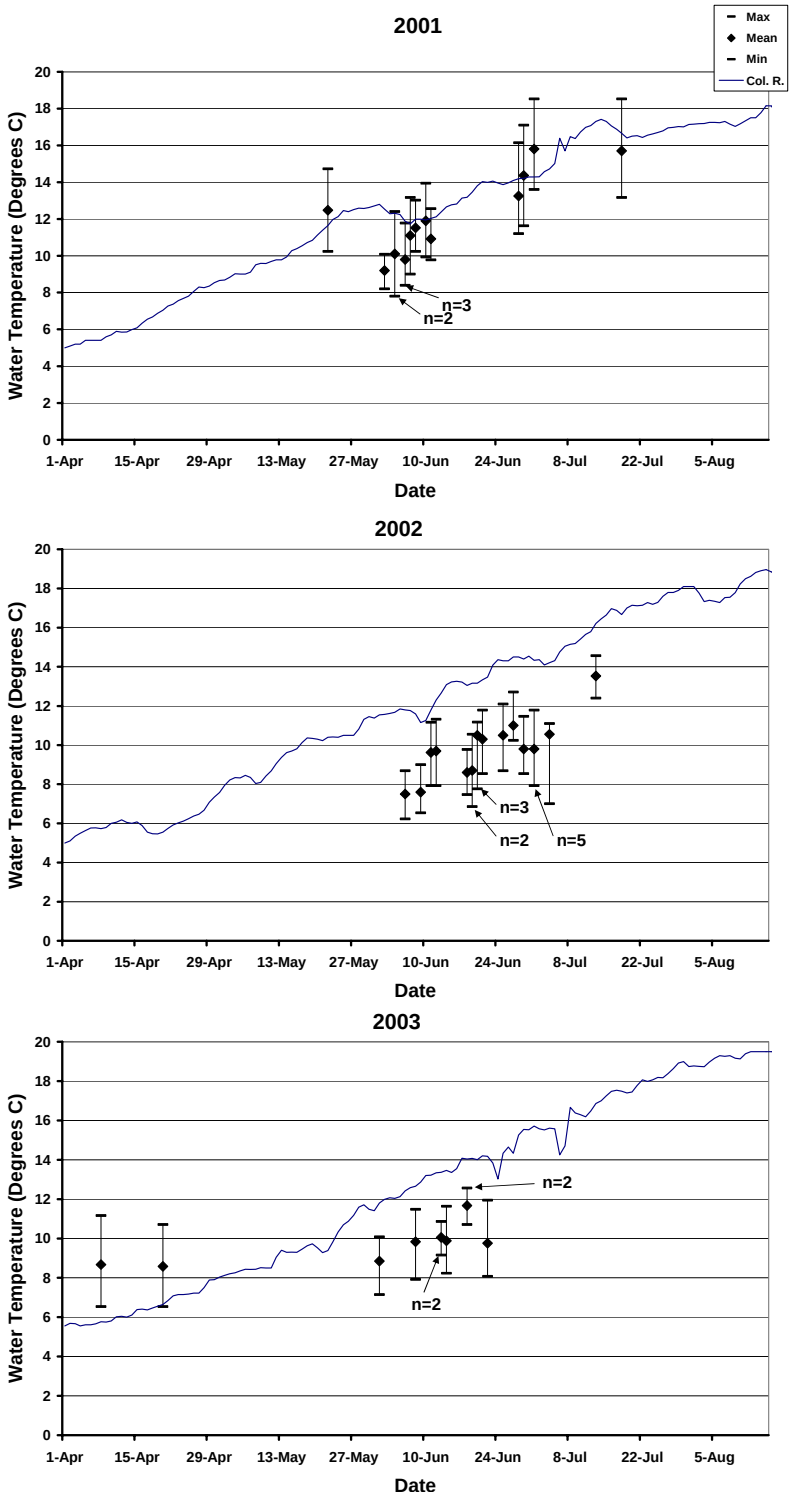

Figure 22: Entiat River temperatures at the time of tributary entrance relative to the Columbia River measured downstream of Rocky Reach Dam, 2001-2003. Daily minimum, mean and maximum Entiat River temperatures provided where data were available. Each data point represents an individual fish except where noted.

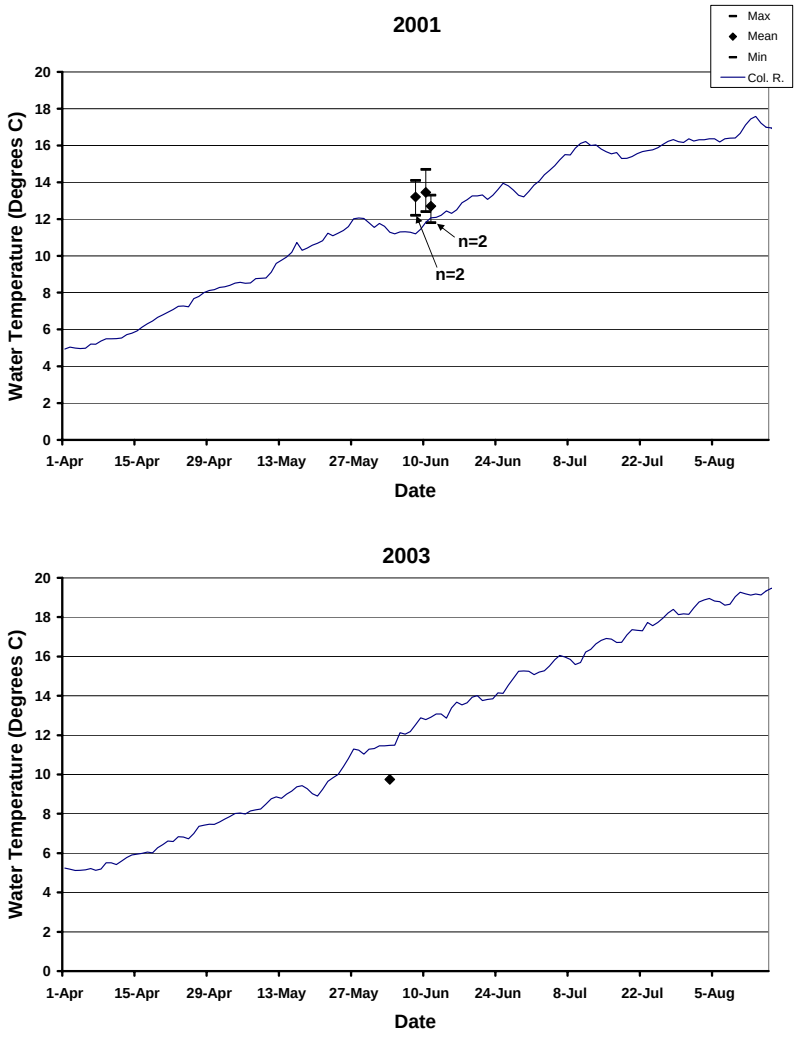

Figure 23: Methow River temperatures at the time of tributary entrance relative to the Columbia River measured downstream of Wells Dam, 2001and 2003. Daily minimum, mean and maximum Methow River temperatures provided where data were available. Each data point represents an individual fish.

4.5 Mainstem Habitat Use

During the 2001 study period, boat surveys were used to describe the general habitats used by tagged adult bull trout as they moved through Rock Island and Rocky Reach reservoirs. Similar surveys were not repeated in 2002 and 2003. For results from those efforts, refer to BioAnalysts, Inc. (2002). However, in addition to the mainstem habitat use assessments conducted by boat in 2001, an effort was also made to examine the extent that radio-tagged bull trout used the Wells Hatchery outfall and the mainstem Columbia River downstream from Rock Island Dam. The purpose of this work was to determine if bull trout used the Wells Hatchery outfall as temperature refugia and to assess the extent that bull trout used Wanapum and Priest Rapids reservoirs. What follows is a summary of those findings.

4.5.1 Wells Hatchery Outfall

To address this issue, an underwater telemetry system was deployed within the outfall channel downstream from the ladder system. In both 2001 and 2002, tagged bull trout were observed in the hatchery outfall. In 2003, a single bull trout was detected in the tailrace of Wells Dam, but it did not use the hatchery outfall. In 2001, of the 39 bull trout that were radio-tagged throughout the mid-Columbia River, a total of 11 (28.2%) were detected within the Wells Hatchery outfall (Table 9). Of the trout that were in the vicinity of Wells Dam and the outfall (12 tagged bull trout), all but one (92%) entered the hatchery outfall. Of those that entered the outfall, two were tagged at Rock Island, four at Rocky Reach, and five at Wells Dam.

The five fish tagged at Wells Dam that entered the outfall were all released downstream from the dam. Thus, their detection in the outfall was not surprising given that they were released about 20 m downstream from the underwater telemetry system. However, all five fish were detected multiple times, and one was detected on 13 separate occasions (Table 9). On average, fish were detected 6.6 times by the outfall underwater telemetry system with a total of 22.3 minutes per detection. The total elapsed time for fish detected at the outfall (i.e., the period of time between the first detection and the last detection for the first and last visits, respectively) averaged 5.6 days, with a range of several minutes to 15.4 days.

In 2002, of the 15 tagged bull trout that were in the vicinity of Wells Dam, ten were tagged in 2002 and five in 2001. Eight of the 15 fish visited the outfall (Table 10). Three were tagged at Rocky Reach and five were tagged at Wells Dam. Four of the five fish tagged at Wells Dam were fish released downstream of the dam in the immediate vicinity of the hatchery outfall, and as with the 2001 observations, it is not surprising that they were detected at the outfall. However, all of these fish were detected multiple times, with one detected on 24 separate occasions (Table 10). On average, fish visited the outfall 9.4 times and averaged 10.2 minutes per visit. The total elapsed time[6] for fish detected at the outfall averaged 6.0 days, ranging from several minutes to 15.5 days.

Bull trout were more likely to use the outfall during daylight hours than at night. Of the 73 detections for the 11 tagged bull trout that occurred in the outfall in 2001, 58 occurred during periods

[6] Total elapsed time is defined as the period of time between the first detection and the last detection for the first and last visits, respectively.

of daylight (0500-2100 hours), with an average of 3.6 detections per daylight hour. During periods of darkness, on average 1.9 detections per hour were observed (Figure 24). Similar to observations in 2001, bull trout in 2002 were more likely to use the outfall during daylight hours than at night. Of the 75 detections for the eight tagged bull trout that occurred in the outfall, 56 occurred during daylight, averaging 3.5 detections per daylight hour. During periods of darkness, an average 2.4 detections per hour were observed (n = 19; Figure 25).

There are several possible reasons why adult bull trout frequent the hatchery outflow, including using the area as a temperature refuge, seeking opportunistic feeding opportunities, or simply demonstrating exploratory behavior. With regard to the outflow providing bull trout with a temperature refuge, the hatchery operates June through August primarily on water diverted from the mainstem Columbia River. This water is supplemented with about 4 cfs of well water, which has a fairly constant temperature of 11.1°C. Although the well water may have some moderating effect on water temperature at the hatchery, overall a large difference in temperature between the outfall and the mainstem Columbia River would not be expected. Water temperatures recorded within the mainstem Columbia (recorded at Wells Dam) during the time period when bull trout were detected in the hatchery outfall (3-20 June) ranged between 10.1 and 13.3°C, which are within the thermal optima for adult bull trout (EPA 2001). Therefore, it is doubtful that bull trout used the hatchery outfall as a temperature refuge.

It is possible that the bull trout frequented the outfall in search of prey. Typical operation at the hatchery is to volitionally release yearling chinook smolts between 15 and 30 April, and subyearling chinook smolts in early June. These smolts migrate downstream through the hatchery outfall channel system and then enter the Columbia River. During the 2001 study period, bull trout were observed at the hatchery outfall between 17 May and 27 June. In 2002, detections occurred between 3 June and 20 June. Large numbers of smolts were routinely observed during the period when the bull trout frequented the outflow (Shane Bickford, DPUD, personal communication). Given that bull trout feed opportunistically (Goetz 1989), it is likely that the tagged bull trout were taking advantage of the large concentration of juvenile salmonids within the hatchery outfall system.

Table 9: Number of visits and length of time that eleven bull trout were detected within the Wells Hatchery outfall, 2001. The mean, minimum, maximum and total times are in hours and the elapsed time is in days. The elapsed time is defined as the period of time between the first and last detections at this location.

Release Location	Code	Number of Visits	Time				
			Mean	Min	Max	Total	Elapsed
Rock Island Dam							
Up	4	1	0:04:35	---	---	0:04:35	0.0
Up	13	15	0:54:34	0:00:12	12:03:18	13:38:25	8.6
Rocky Reach Dam							
Down	54	6	0:02:45	0:00:31	0:04:58	0:16:31	4.8
Up	12	13	0:09:41	0:01:14	0:22:23	2:05:51	10.3
Up	20	1	0:11:32	---	---	0:11:32	0.0
Up	47	4	0:02:11	0:00:18	0:04:34	0:08:43	2.4
Wells Dam							
Down	17	2	0:13:39	0:01:02	0:26:15	0:27:17	0.4
Down	19	8	0:29:43	0:00:51	1:59:32	3:57:43	3.6
Down	22	3	1:40:37	0:02:33	4:55:35	5:01:51	8.5
Down	26	13	0:03:21	0:00:30	0:13:47	0:43:38	7.8
Down	33	7	0:04:32	0:00:51	0:13:23	0:31:41	15.4

Table 10: Number of visits and length of time that eight bull trout were detected within the Wells Hatchery outfall, 2002. The mean, minimum, maximum and total times are in hours and the elapsed time is in days. The elapsed time is defined as the period of time between the first and last detections at this location.

Release Location	Code	Number of Visits	Time				
			Mean	Min	Max	Total	Elapsed
Rocky Reach Dam							
Up	100	9	0:06:41	0:00:18	0:32:41	1:00:08	4.16
Up	108	5	0:01:15	0:00:19	0:02:15	0:06:14	4.65
Up	116	7	0:03:08	0:00:15	0:16:59	0:21:59	2.87
Wells Dam							
Down	93	24	0:16:06	0:00:16	1:04:05	6:26:13	15.50
Down	96	17	0:05:19	0:00:16	1:12:57	1:30:24	14.60
Down	102	3	0:01:51	0:01:35	0:02:03	0:05:32	0.08
Down	112	4	0:04:32	0:00:19	0:07:43	0:18:08	4.74
Up	99	6	0:03:47	0:00:22	0:08:45	0:22:40	1.26

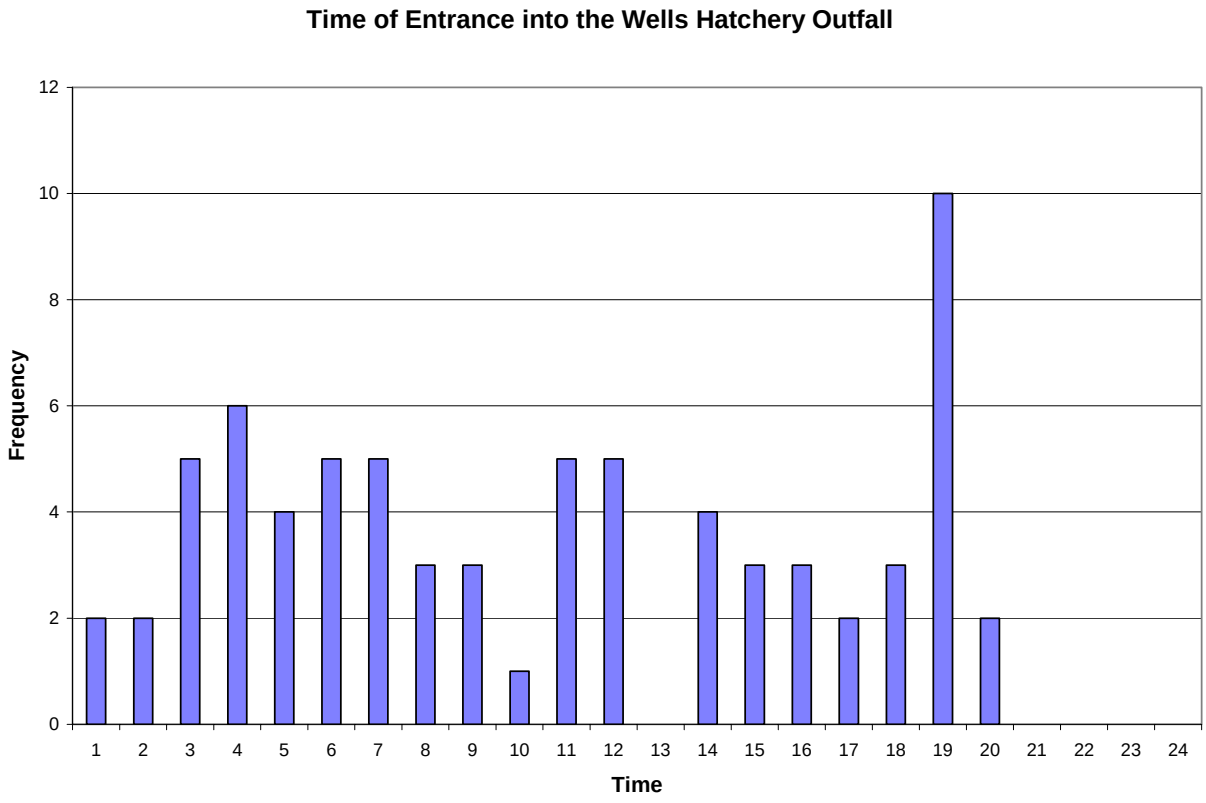

Figure 24: Diel pattern for 11 radio-tagged bull trout detected at the Wells hatchery outfall, 2001. There were 73 visits to the hatchery outfall, but most (58) occurred between 0500-2100 hrs.

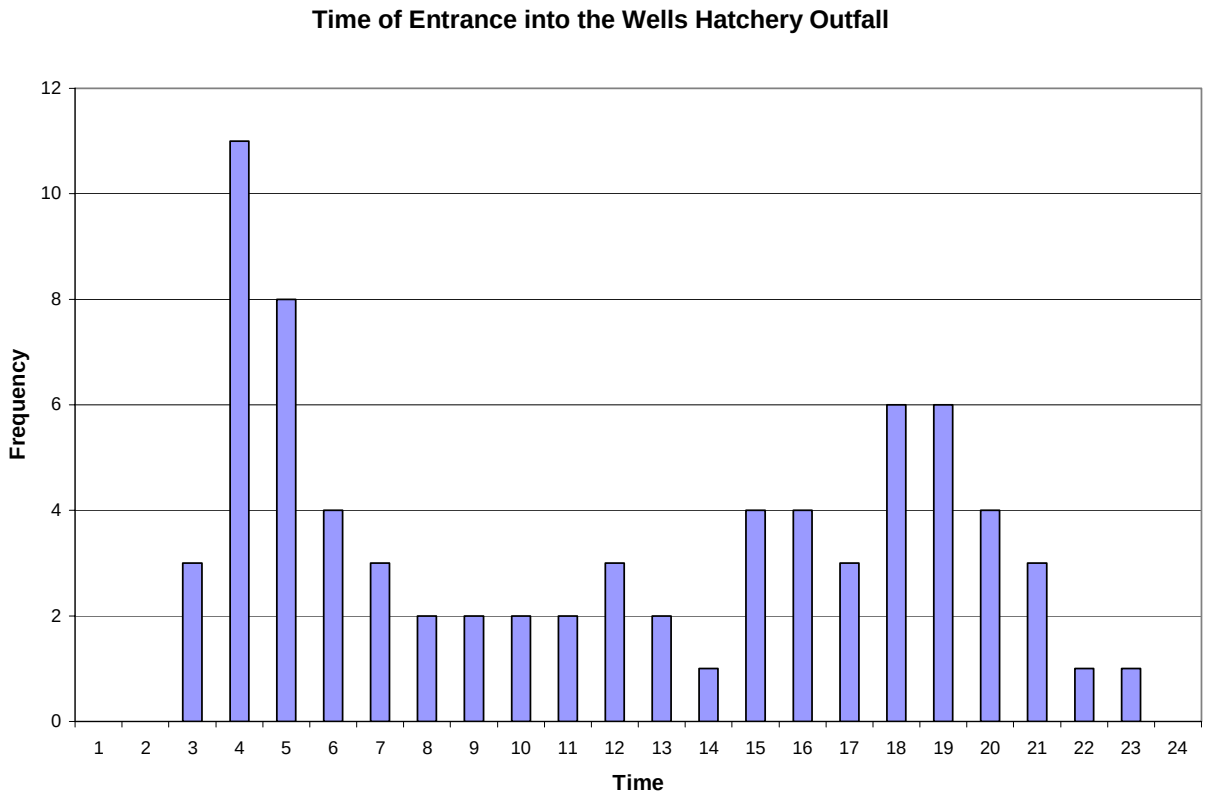

Figure 25: Diel pattern for eight radio-tagged bull trout detected at the Wells Hatchery outfall, 2002. There were 75 visits to the hatchery outfall, but most (56) occurred between 0500-2100 hrs.

4.5.2 Wanapum and Priest Rapids Reservoirs

The extent of movement observed for bull trout that migrated downstream of Rock Island Dam is based primarily on detection histories generated from fixed-site telemetry data collected at Priest Rapids, Wanapum, and Rock Island dams, as well as during mobile surveys. Telemetry data collected at Rocky Reach and Wells dams, as well as the tributary sites, have been integrated to aid in the removal of false records from the database. Collectively, ten radio-tagged bull trout migrated downstream of Rock Island Dam after spending time in tributaries. This represents 12.7% of the tagged population. One fish (14-101) moved downstream on two separate occasions. Only one of the ten fish was detected at Wanapum and Priest Rapids dams. Thus, the other nine remained in the Wanapum Reservoir and did not pass Wanapum or Priest Rapids dams.

In addition to the fixed-site telemetry data, aerial and boat surveys provided relatively accurate information on the location of tagged fish within Wanapum reservoir. During the course of the study, a total of 36 boat and 35 aerial surveys were conducted on Wanapum reservoir. The accuracy of aerial surveys was about 300 m, based on tests conducted by Chelan PUD in the Entiat Basin using ten test transmitters. The accuracy of boat surveys depended on the type of antenna used and the method of tracking. For detections using an underwater antenna, the accuracy was about 10 m. For aerial antennas using triangulation techniques, the accuracy was about 50 m. Simple detection with an aerial antenna was about 200 m.

No bull trout were found in Priest Rapids reservoir during 21 boat and 35 aerial surveys. One bull trout (14-105), however, was detected with fix-site systems at Wanapum and Priest Rapids dams on 26 and 28 May 2003, respectively. These results indicate that bull trout resided primarily in areas upstream of Wanapum Dam. While this observation is limited to only radio-tagged fish included in this study, additional data indicate that bull trout rarely use Priest Rapids Reservoir. Grant County PUD regularly conducts salvage operations of fish collected within gatewells at both Wanapum and Priest Rapids dams during the juvenile migration. For the years of 1997-2003, no bull trout were collected during salvage operations at Priest Rapids Dam. During fish-ladder maintenance at Priest Rapids Dam during 1996-2003, only one bull trout (36-cm long) was found and released alive (left-bank fish ladder; 8 December 2000; T. Dresser, Grant County PUD, personal communication). Additionally, during sampling efforts to document fish assemblages within the Priest Rapids Reservoir in 1999, only a single bull trout was captured, which was 28 cm in length (Pfeifer et al. 2001).

It was possible to document locations of the ten fish residing downstream from Rock Island Dam on several occasions using a variety of methods (i.e., aerial or boat surveys and fixed-telemetry sites). Four fish did not move beyond the tailrace of Rock Island Dam. Another fish (14-101), after moving from tributaries in 2002 and 2003, occupied a station about 2 km upstream of Tarpiscan Creek in both years. Four other fish resided between the I-90 Bridge and about 4 km upstream of Quilomene Island, or about 19 km upstream of Wanapum Dam (Figure 26). The tenth fish was detected at both Wanapum and Priest Rapids dams. What follows is a detailed summary of the detection history for each of the ten fish detected downstream from Rock Island Dam.

Code 6 Bull Trout – This fish was trapped and tagged at Rocky Reach Dam, released upstream of the project on 29 May 2001, and was 56.9-cm long (FL) and weighed 2,000 g. After release, this

trout migrated upstream and entered the Entiat River on 10 June 2001, where it resided until 17 October 2001, much of the time near the Silver Falls Campground. After migrating out of the Entiat River, this trout resided within the Columbia River between Rocky Reach Dam and the Entiat River confluence until it passed Rocky Reach Dam on 14 November 2001. During the period of 14 November 2001 to 17 April 2002, this fish was detected within the Rock Island reservoir and Rocky Reach tailrace by both fixed-telemetry sites and mobile surveys. On 3 June 2002, this fish was detected by the aerial array in the tailrace of Rock Island Dam over a seven hour period (Figure 26). This was the last contact with this fish.

Code 7 Bull Trout – This fish was trapped and tagged at Rocky Reach Dam, released upstream of the project on 4 June 2001, and was 48.5-cm long (FL) and weighed 1,150 g. After release, the fish was detected within the Rocky Reach forebay for about 1 day and then was detected at the Entiat River fixed-site (RK 4.8) on 8 June 2001. The fish migrated upstream and resided within the Entiat River upstream of Preston Creek. On 11 November 2001, this fish was again detected by the fixed-site on the lower Entiat River as the fish exited the tributary. The first detection in the tailrace of Rock Island Dam was on 18 November 2001, at which time it migrated downstream of Rock Island Dam to a point about 11 km upstream of Wanapum Dam. The fish remained within this area for about 2 months (28 February to 25 April 2002) (Figure 26). The fish then began an upstream migration and was last detected at the Rock Island and Rocky Reach ladder exits on 20 May and 25 May, respectively, and re-entered the Entiat River on 11 June where it resided between the Mad River confluence and Preston Creek until it exited the Entiat River on 4 August. This fish was last detected on 10 October 2002 between the Wenatchee River confluence and Rocky Reach Dam.

Code 15 Bull Trout – This trout was collected and tagged at Rocky Reach Dam and released into the tailrace of the project. The fish was released on 25 May 2001 and was 56.1-cm long and weighed 1,950 g. After release, this fish spent about 4 days in the tailrace and ladder system at Rocky Reach Dam. After exiting the ladder, it was detected on 6 June 2001 at the Entiat River fixed-telemetry site. From there it migrated upstream and resided upstream of Preston Creek in the Entiat River. During its migration downstream, it was detected in the lower Entiat River again by the fixed-telemetry site on 2 November 2001. On 10 November 2001, the bull trout was detected at Rocky Reach Dam where it resided in the mainstem Columbia River between Rock Island and Rocky Reach dams until 27 March 2002, when it was first detected in the tailrace of Rock Island Dam. This fish was located during four separate aerial surveys within the Rock Island tailrace and by the fixed-telemetry site at that location until 6 August 2002 (Figure 26). This fish was detected on multiple occasions in the tailrace of Wells Dam during the period of 16 December 2002 to 27 February 2003. Subsequent to detections at that location, this fish was detected in the tailrace of Rocky Reach Dam on 17 March 2003.

Code 36 Bull Trout – This bull trout was collected and tagged at Rock Island Dam on 13 June 2001 and released upstream of the project. It was 59.7-cm long and weighed 1,750 g. After release, this fish migrated upstream to Rocky Reach Dam, where it spent about 3 months within the area between the Wenatchee River confluence and the tailrace of Rocky Reach Dam. On 21 September 2001, this fish was detected within the lower 3 to 4 km of the Wenatchee River, where it remained for about 1.5 months. After exiting the Wenatchee River, it was first detected at Rock Island Dam on 1 December 2001 and later in the Rock Island tailrace during the period of 18-24 December 2001 (Figure 26). After exiting the Rock Island ladder, the fish again resided within the Rock Island

reservoir until it ascended and exited the Rocky Reach ladder on 2 July 2002. This fish was last detected at Wells Dam on 6 July 2002.

Code 99 Bull Trout – This bull trout was collected and tagged at Wells Dam on 4 June 2002 and released upstream of the project. It was 46.5-cm long and weighed 1,150 g. Five hours after release, this fish was detected in the tailrace of Wells Dam, where it was detected over an eight day period. This trout then migrated downstream and was detected in the tailrace of Rocky Reach Dam on 20 June 2002. The fish then migrated into the Wenatchee River, where it resided for 19 days between the Wenatchee River confluence and the town of Leavenworth. After migrating out of the Wenatchee River, it was detected in the tailrace of Rocky Reach Dam for a period of one day, beginning 11 July 2002, and was subsequently detected in the tailrace of Rock Island Dam on 13 July 2002 until 29 July 2002 (Figure 26). After ascending the Rock Island center fish ladder, this trout was detected in the Wenatchee River, where it resided until 6 November 2002. After migrating out of the Wenatchee River, this fish resided between Rock Island Dam and the Wenatchee River confluence. On 3 June 2003 it entered the Methow River where it remained until 28 October 2003. It then moved into the Entiat River and was last detected there on 3 November 2003 about 1 km upstream of the confluence.

Code 101 Bull Trout – This bull trout was collected and tagged at Rocky Reach Dam on 3 June 2002 and released downstream from the project. It was 55.3-cm long and weighed 1,950 g. After release, this fish ascended the Rocky Reach fish ladder and exited the system on 15 June 2002. Ten days later the fish was detected at the Entiat River fixed-telemetry site and eventually migrated upstream and resided within the Mad River. The fish exited the Entiat basin on 6 November 2002 and was detected in the tailraces of Rocky Reach and Rock Island dams on 15 January 2003 and 16 January 2003, respectively. This fish was later detected about 3 km upstream of Tarpiscan Creek on 18 March 2003 during an aerial survey, and later (28 March 2003) about 2 km upstream of Tarpiscan Creek near the right bank during a boat survey conducted by Grant County PUD (Figure 26). This trout then moved upstream, entered Rock Island Dam tailrace on 6 June 2003, and passed the dam (via the center ladder) on 12 June 2003. It continued upstream, passing Rocky Reach Dam on 15 June 2003. The fish then moved back downstream through the dam and entered the Wenatchee River on 22 June 2003, where it resided in Peshastin Creek for about four months. After leaving the Wenatchee basin, this fish once again moved downstream and passed Rock Island Dam on 20 October 2003, where it remained through the end of the study period (31 March 2004; Figure 26).

Code 105 Bull Trout – This bull trout was collected and tagged at Rock Island Dam on 4 June 2002 and released downstream of the project. It was 52.0-cm long and weighed 1,350 g. After release, this fish was detected over the course of 17 days in the tailrace of Rock Island Dam. On 22 June 2002, it exited the right bank ladder and migrated upstream where it entered the Wenatchee River five days later. Over the course of a five and a half month period of residence within the Wenatchee basin, this fish was only detected on one occasion; an aerial survey conducted shortly after it entered the Wenatchee River (1 July 2002). During that survey, the fish was detected near the town of Monitor, Washington. The location of residence for this fish while within the Wenatchee basin is largely unknown. After exiting the Wenatchee River, this fish resided primarily near the Wenatchee River confluence within the mainstem Columbia River over a period of approximately seven months. During the period of 22-24 May 2003, this fish was again detected at the fixed telemetry site on the Wenatchee River. After detection at this location, it was detected 15 hours later (24 May)

in the tailrace of Rock Island Dam. Subsequently, this fish was detected on 26 and 28 May in the forebays of Wanapum and Priest Rapids dams, respectively. These detections were the last contact with this fish. Efforts to locate this fish within the Priest Rapids pool have been unsuccessful, and as such, it is likely that this fish migrated downstream of Priest Rapids Dam. Its fate, whether alive or dead at this point, is unknown.

Code 110 Bull Trout – This bull trout was collected and tagged at Rock Island Dam on 4 June 2002 and is the only fish that may have died downstream from Rock Island Dam (see Section 4.1). The fish was released upstream of the project and was 60.0-cm long and weighed 2,400 g. After release, this fish was detected over a two-day period in the tailrace of Rocky Reach Dam beginning 6 June 2002. Subsequently, this fish migrated downstream and entered the Wenatchee River on 11 June 2002, where it resided between the town of Leavenworth and Tumwater Dam until 10 July. After leaving the Wenatchee River, this trout was detected once again in the tailrace of Rocky Reach Dam beginning 10 July 2002 for a 3-day period. After ascending the fish ladder, the trout was detected in the tailrace of Wells Dam on 14 July 2002 for one day. After migrating downstream, the fish entered the Entiat River on 18 July and remained near the fixed-telemetry site (R.K. 4.8) for two days. On 20 July, this fish was detected in the tailrace of Rocky Reach Dam and on 21 July in the tailrace of Rock Island Dam. The next contact with this fish was between 1 August and 22 August, when its transmitter was recovered (Figure 26).

Code 113 Bull Trout – This trout was captured and tagged at Rock Island Dam and released downstream from the project on 7 June 2002. The fish was 43.0-cm long and weighed 800 g. After release, the fish ascended the left-bank ladder and exited the system on 14 June 2002. Eight days later, this fish was detected at the fixed-telemetry site on the Wenatchee River and subsequently resided within the Wenatchee basin through 6 November 2002, much of that time near the confluence of the Chiwawa River. After leaving the Wenatchee basin, this fish moved downstream, passed Rock Island Dam, and remained near Sunland Bar (downstream from Quilomene Island) during 19 February to 28 March 2003. It then moved to a location about 2 km upstream of Tarpiscan Creek and remained there from 23 May to 3 June 2003 (Figure 26). This fish then migrated upstream, exited the Rock Island right-bank ladder on 14 June 2003, and entered the Wenatchee River on 16 June. It resided within the Wenatchee basin until 21 November, much of the time in Tumwater Canyon and in the Chiwawa River. This fish was last detected on 18 December 2003 in Rock Island reservoir.

Code 118 Bull Trout – This trout was captured and tagged at Rocky Reach Dam and released downstream from the project on 11 June 2002. The fish was 46.0-cm long and weighed 950 g. Twelve days after release, this fish exited Rocky Reach ladder and subsequently entered the Entiat River on 1 July 2002. This trout remained in the mainstem Entiat River downstream from the Mad River confluence until it left the river on 9 October 2002. The fish remained in the Columbia River upstream of Rocky Reach Dam until 8 April 2003, when it re-entered the Entiat River and migrated into the Mad River. After leaving the Entiat basin on 23 October 2003, it was detected in the tailraces of Rocky Reach and Rock Island dams on 5 and 13 November 2003, respectively. This fish has been detected on three occasions over a 3.5 month period downstream of Quilomene Island (Figure 26).

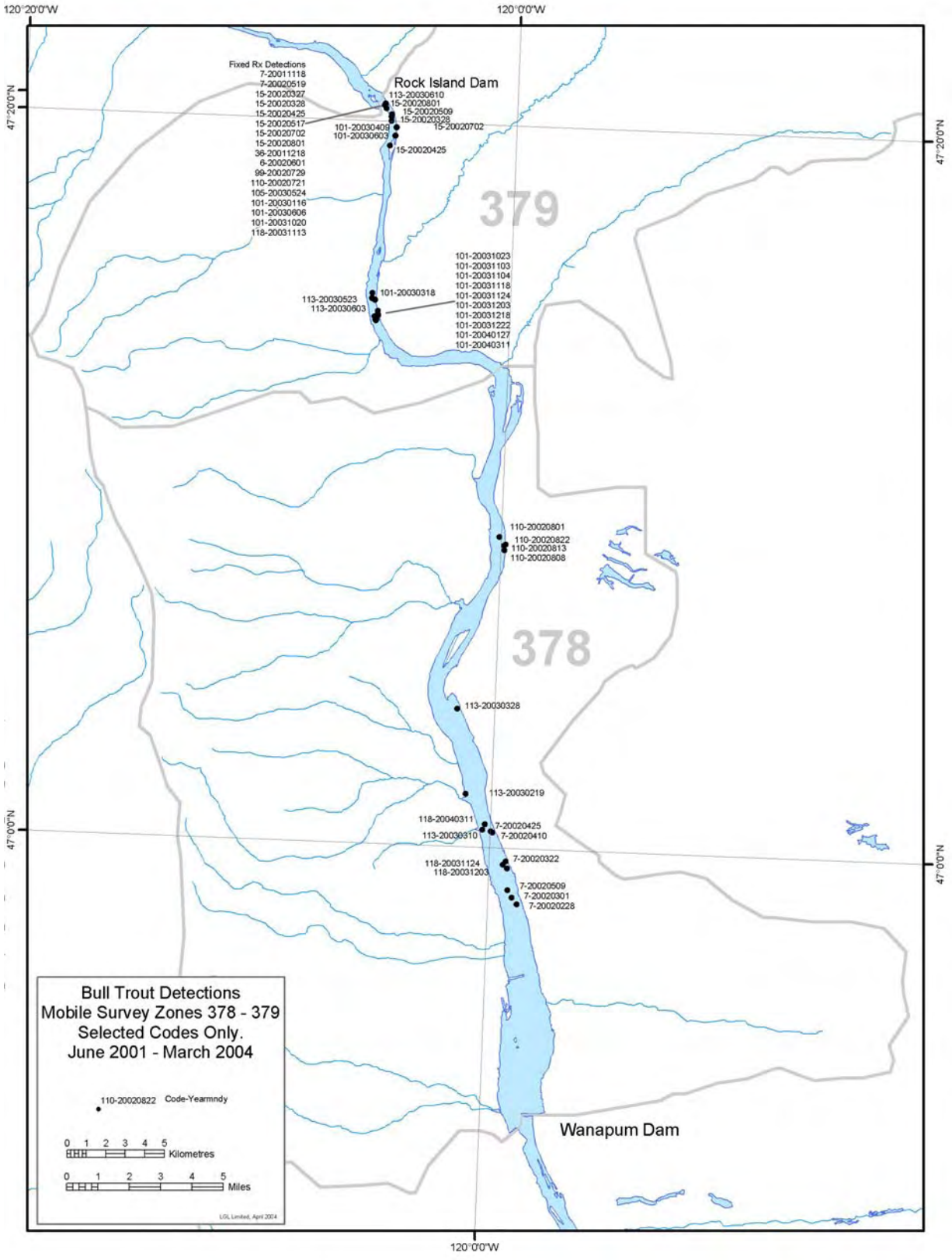

Figure 26: Map of bull trout detected downstream from Rock Island Dam.

SECTION 5: CONCLUSIONS

Based on the results from the 2001-2004 study, we offer the following conclusions.

1. Seventy-nine adult bull trout were successfully tagged with radio tags in 2001 and 2002. Of those, it appears that 15 may have died or shed their tags. However, there is no evidence that any of these potential deaths were the result of hydroelectric projects.
2. Based on data collected in 2001-2004, operations of hydroelectric facilities on the mid-Columbia River did not negatively affect the survival of adult bull trout. That is, no adult bull trout were killed during upstream or downstream passage through the mid-Columbia dams.
3. Although hydroelectric operations did not appear to affect the survival of adult bull trout, the presence of dams may have slowed migration times. On average, it took bull trout longer to pass dams than it did for them to move through reservoirs (i.e., from project to project). One reason for the possible delays is that bull trout found increased foraging opportunities in the tailraces. Additional work is needed to verify this possibility.
4. The overall dam passage time is considerably greater for fish tagged and released into the tailrace of a given project than it is for fish that migrated upstream after being released at downstream projects. The release location of future studies assessing passage rates at dams should be made upstream of the project or far enough downstream to allow adequate recovery following tagging.
5. At Rocky Reach Dam, the location where tagged fish are released appears to influence tributary selection. Of the tagged fish released downstream from the project in 2001, 55% (6 of 11) moved downstream and entered the Wenatchee River. In 2002, 33% (4 of 12) of the fish released downstream from Rocky Reach Dam entered the Wenatchee River. In contrast, only 3% of the fish released upstream from dams move downstream into tributaries.
6. There were nine downstream passage events observed at Rocky Reach Dam (5 in 2002 and 4 in 2003) and two at Wells Dam (2002). Of those, six occurred within 24 hours after exiting the ladder system(s), and two within 15 hours after the fish were released into the forebay (one at Rocky Reach and one at Wells Dam). These two events may be related to releasing the fish too close to the dam. For three fish, after exhibiting downstream movement behavior, two migrated into tributaries downstream of the given project, and one resided within the mainstem Columbia River. Future studies that include forebay releases should consider releasing fish further upstream from the projects to eliminate the effects of handling on downstream movement.
7. Bull trout entered tributaries shortly after release. They selected the Wenatchee, Entiat, and Methow systems. No bull trout selected the Okanogan system, although one entered the Okanogan River, it quickly left and moved into the Methow system. Most entered tributaries by the end of June and were found in possible spawning streams well before the initiation of spawning. Most tagged trout left tributary streams by late November.

8. For the three years of data regarding tributary entrance into the Wenatchee, Entiat and Methow rivers, a total of 91 tributary entrance events occurred. During the study period bull trout entered mid-Columbia tributaries from April to September but most (94%) entered tributaries during May, June and July. At the time bull trout entered tributary streams the mean daily temperatures in the mainstem Columbia River varied from 5.4 °C to 19.6 °C. Similarly, tributary mean daily temperatures ranged from 7.5 °C to 17.2 °C. Most bull trout (92.3%) entered tributaries before the Columbia River reached a mean temperature of 15 °C. The successful migration of bull trout into the various spawning streams of the Wenatchee, Entiat and Methow suggests that temperatures at the time of migration in the mid-Columbia River did not appear to limit the migration of radio-tagged bull trout.
9. Over half (53%) of the bull trout detected within the Wells Dam tailrace entered the hatchery outfall. Four of the five bull trout released downstream of the dam entered the outfall multiple times. Because there was little difference in temperature between the outfall and the mainstem Columbia River, it is unlikely that bull trout used the outfall as a temperature refuge. Instead, they may have used the outfall to increase feeding opportunities.
10. Of the 79 bull trout tagged in 2001 and 2002, ten (12.7%) moved downstream of Rock Island Dam after an extended stay in tributaries. At the conclusion of the study period (31 March 2004), one tagged bull trout had passed Wanapum Dam, and is presumed to have also passed Priest Rapids Dam.

SECTION 6: ACKNOWLEDGMENTS

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APPENDIX A: SUMMARY OF RECOVERED BULL TROUT TAGS

The purpose of this appendix is to provide a detection history for radio tags recovered from bull trout tagged in spring 2002 at Rock Island, Rocky Reach, and Wells dams. Efforts were made in the fall of 2002 and 2003 to recover those tags from bull trout that were suspected to have perished or shed their tags. The detection histories describe the extent of movement after the bull trout were released, but may not explain the circumstances surrounding the loss of the tagged fish.

All the bull trout were captured, tagged, and released in the spring of 2002 at Rock Island, Rocky Reach, or Wells dams. The bull trout were surgically implanted with radio tags and released either upstream or downstream of their respective projects. Fixed-station telemetry receivers at the projects and in the lower tributary rivers along with monthly aerial surveys provided the detection history for these bull trout. A detailed summary of the methods used to tag, release, and track bull trout can be found in BioAnalysts, Inc. (2002). In addition, the U.S. Fish and Wildlife Service provided information on the location for some of the bull trout while the trout resided in tributaries. Their efforts provided valuable information on the recovery of tags and the condition of the tributary streams.

In this summary, the discussion focuses on 14 of 40 (35%) tagged bull trout. For convenience, the bull trout have been separated by tagging location and each bull trout has been identified by the radio transmitter channel and code (e.g., 14-93) with a brief description of their movement after release. For all of these bull trout the tag was recovered but only one carcass was recovered. A map is provided to show the locations where the tags were recovered.

Wells Dam

Tag 14-93--The upstream movement of this bull trout suggests that it made a migration to a known spawning area in the Twisp River of the Methow Basin. A conservative estimate of this bull trout's migration is roughly 109 km (68 miles) from downstream of Wells Dam to the upper Twisp River and then back downstream within the Twisp River (Table A1).

This bull trout was tagged on 28 May at Wells Dam and was released downstream of the project near the west shoreline. Within hours of the release the bull trout had moved back upstream and was detected in the tailrace of Wells Dam. The bull trout was detected for a period of 14 days in the tailrace until it passed the project on 22 June. Two days later, 24 June, the bull trout was detected in the lower Methow River. By 1 July the bull trout was detected just downstream from McFarland Creek on the Methow River. One month later during an aerial survey on 1 August the fish was detected in the Twisp River upstream from the confluence of South Creek. By 4 September, the fish had moved downstream and was detected near the confluence of Reynolds Creek. The next month on 9 October the bull trout was detected even further downstream near the confluence of Scaffold Camp Creek. Finally on 31 October the tag for this fish was recovered near that location on an island gravel bar above the wetted channel and there was no carcass in the area (Figure A1).

Table A1: Summary information on radio tags recovered for bull trout tagged in the spring of 2002.

Tag	Tag Location	Release Location	Detections		Distance Traveled (km)	Tag Recovery	Carcass Recovered
			Basin	Subbasin			
14-093	Wells	Downstream (28-May)	Methow (24-June)	Twisp (1-August)	109	31 October 2002: Twisp R. Tag recovered on an island gravel bar above the wetted channel	No
14-096	Wells	Downstream (3-June)	Methow (22 June)	Twisp (1-August)	98	31 October 2002: Twisp R. Tag recovered mid-channel in a riffle	No
14-102	Wells	Downstream (4-June)	Methow (26-June)	Twisp (1-August)	117	12 September 2003: Twisp R. The tag was recovered on a gravel bar about two feet from waters edge	No
14-107	Wells	Upstream (3-June)	Methow (9-June)	Twisp (1-August)	116	26 November 2002: Twisp R. Tag and bull trout recovered in downstream area with little flow	Yes
14-117	Wells	Upstream (12-June)	Methow (21-June)	Twisp (1-August)	116	22 October 2002: Twisp R. Tag recovered in log jam	No
14-088	Rocky Reach	Upstream (20-May)	Entiat (16-June)	Mad (1-July)	44	16 September 2003: Mad R. The tag was recovered in about 6 inches of water downstream from a log jam	No
14-089	Rocky Reach	Downstream (21-May)	Methow (9-June)	Twisp (1-July)	181	12 September 2003: Twisp R. Tag was buried in six inches of pea gravel below a logjam.	No
14-095	Rocky Reach	Downstream (29-May)	Entiat (9-June)	Up. Entiat (1-August)	55	7 November 2002: Up Entiat R. Tag recovered on shore inside a hole under a boulder. Cut marks were observed on the antenna.	No
14-098	Rocky Reach	Upstream (30-May)	Entiat (12-June)	Mad (1-August)	65	15 September 2003: Columbia R. Tag recovered at a depth of 3 meters in aquatic vegetation	No
14-108	Rocky Reach	Upstream (3-June)	Methow (23-June)	Twisp (1-August)	211	12 September 2003: Twisp R. Tag found by edge of a pool under cobble and gravel	No
14-090	Rock Island	Downstream (23-May)	Entiat (1-July)	Up. Entiat (1-August)	164	15 September 2003: Columbia R. Tag recovered at a depth of 4 meters	No
14-097	Rock Island	Upstream (20-May)	Entiat (19-June)	Mad (Sept.)	81	16 September 2003: Mad R. Tag recovered in stream in about ten inches of water	No
14-109	Rock Island	Upstream (7-June)	Entiat (19-June)	Mad (4 -Sept.)	98	15 September 2003: Columbia R. The tag recovered at a depth of 4 meters on a steeply sloped bank.	No
14-110	Rock Island	Upstream (4-June)	Columbia	Wenatchee Entiat (July)	322	22 August 2002: Columbia R. Tag recovered 10-15 feet from waters edge under a pile of debris	No

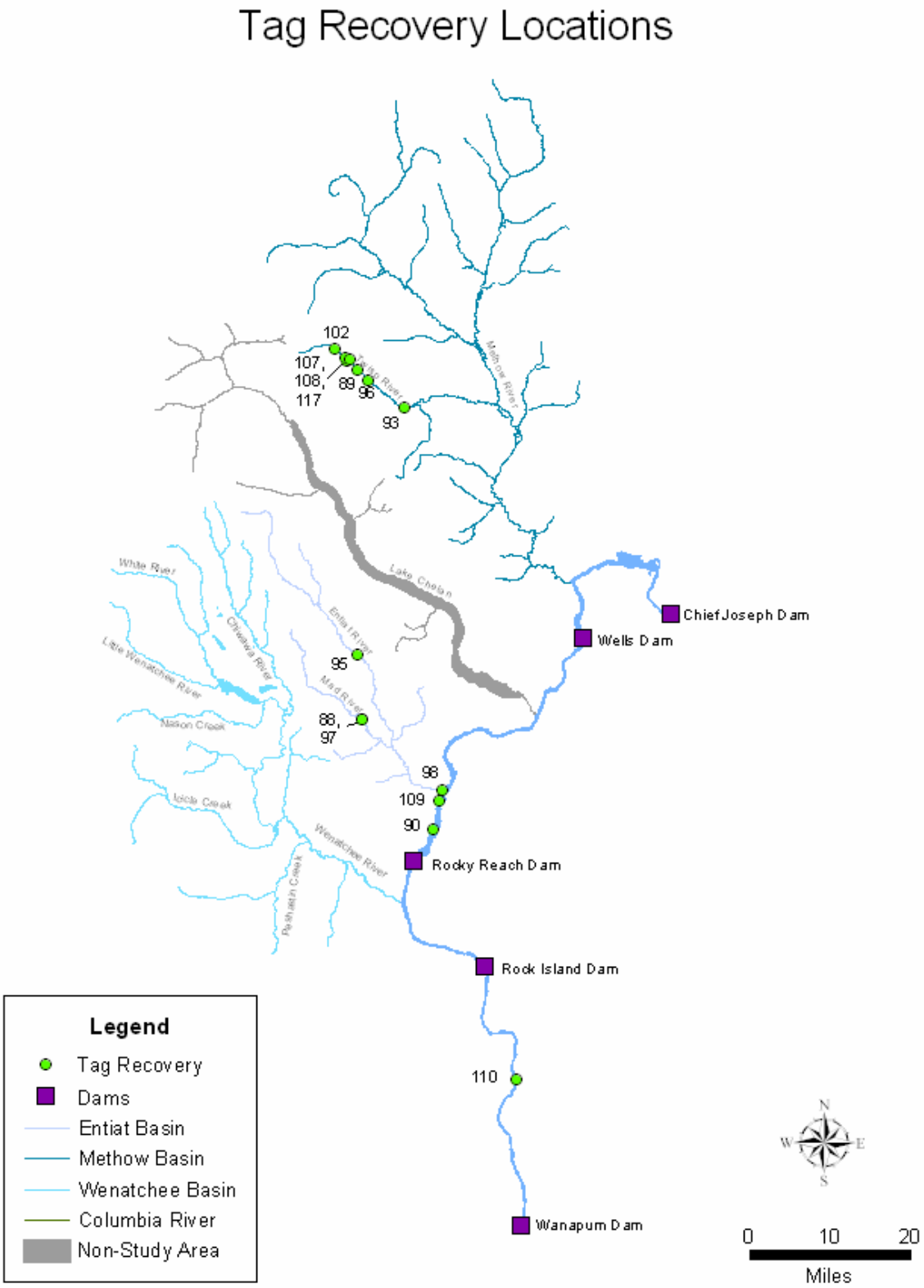


Figure A1: Location and code for radio tags recovered from bull trout tagged at mid-Columbia River projects in spring of 2002.

Tag 14-96--This bull trout migrated to a known spawning area in the Twisp River of the Methow Basin (Figure A1). The bull trout migrated about 98 km (61 miles) from downstream of Wells Dam to the upper Twisp River (Table A1).

The bull trout was tagged on 3 June and was released downstream of Wells Dam near the west shoreline. The bull trout was detected in the tailrace of the project for a period of12 days until it passed on 22 June. Within ten hours after ascending the fish ladder at Wells Dam, the fish was detected in the lower Methow River the same day (22 June). The bull trout was again detected in the lower Methow River on 1 July near Black Canyon Creek. By 1 August, the fish had entered the Twisp River and was detected upstream from the confluence of Williams Creek. The fish was detected at this location on 4 September and again on 9 October. On 31 October, personnel from the US Fish and Wildlife Service recovered the radio tag near this location mid-channel in a riffle (Figure A1). No carcass was found at the location.

Tag 14-102--This bull trout migrated to a known spawning area in the Twisp River of the Methow Basin. The bull trout migrated about 117 km (73 miles) from downstream of Wells Dam to the upper Twisp River (Table A1).

This bull trout was tagged on 4 June 2002 at Wells Dam and was released downstream of the project near the west shoreline. Within hours of the same day the bull trout was detected in the tailrace of Wells Dam and was detected at the project for a period of 12 days until it passed on 26 June. Within ten hours of ascending the fish ladder at Wells Dam, the fish was detected in the lower Methow River the same day (26 June). The bull trout was again detected in the lower Methow River on 1 July during an aerial survey. An aerial survey on 1 August revealed that the fish had migrated to the Twisp River and was upstream from the confluence of South Creek. On 4 September the bull trout was detected further upstream in the Twisp River near Road End Campground. U.S. Fish and Wildlife Service personnel tracked the bull trout to a log jam in the Twisp River near the location it was observed on 9 October. Their last ground survey on 27 November 2002 revealed that the fish had not moved from the location. The tag (no carcass) was recovered on a gravel bar about two feet from waters edge on 12 September 2003 (Figure A1).

Tag 14-107--This bull trout migrated to a known spawning area in the Twisp River of the Methow Basin (Figure A1). The bull trout had traveled about 116 km (72 miles) from upstream of Wells Dam to the upper Twisp River (Table A1).

This bull trout was tagged on 3 June and was released upstream of Wells Dam. The bull trout was detected in the lower Methow River on 9 June. On 1 July the bull trout was detected upstream from Gold Creek on the Methow River. By 1 August the bull trout had migrated to the upper Twisp River upstream from South Creek. In early November flows in the Twisp River came up and portions of the formerly dry channel were now wetted. The bull trout moved downstream during the increased flow. However, the increased flow was not sufficient enough to re-water the entire dry section of the Twisp River. As flow receded the bull trout remained downstream. On 26 November the U. S Fish and Wildlife Service personnel recovered the tagged bull trout carcass (frozen) in this downstream area (Figure A1). Another tagged bull trout (14-116) was captured alive in this area and was transported downstream to where the stream began to flow again.

Tag 14-117--This bull trout migrated to a known spawning area in the Twisp River of the Methow Basin (Figure A1). The bull trout had traveled about 116 km (72 miles) from upstream of Wells Dam to the upper Twisp River (Table A1).

The bull trout was tagged on 6 June at Wells Dam and was released upstream of the project on the west shoreline. The fish then migrated to the Methow River and was detected in the lower river on 21 June. More than a week later on 1 July the fish had ascended the rapids in the lower Methow River and was detected just upstream from French Creek on the Methow River. By 1 August, the bull trout had migrated to the Twisp River and was detected several miles upstream from the confluence of South Creek. U.S. Fish and Wildlife Service personnel observed this fish alive on 25 September in a logjam near a redd. On 9 October the bull trout had moved downstream near the confluence of South Creek. Later, on 22 October the tag but no carcass was recovered in a log jam near that same location (Figure A1).

Rocky Reach Dam

Tag 14-88--This bull trout migrated to a known spawning area in the Mad River of the Entiat Basin. The bull trout migrated approximately 44 km (28 miles) from its release location at Rocky Reach Dam into the Mad River (Table A1).

This bull trout was tagged on 20 May 2002 at Rocky Reach Dam, and was released upstream of the project near the west shoreline. Seventeen days after release, this fish was detected at the fixed-telemetry site on the Entiat River. Upstream movement was documented during a series of aerial surveys; with the fish being detected on 1 July approximately 1.5 km upstream of Pine Flat Campground, on 1 August approximately 1.5 km upstream of Hornet Creek, and on 9 October approximately 1 km downstream from Windy Creek. The fish was detected on four more occasions during the period of December 2002 to March 2003. However, during this period, the transmitter was located at the same location as on 9 October. The transmitter (no carcass) for this fish was recovered on 16 September 2003 at this location in approximately 6 inches of water downstream from a log jam (Figure A1).

Tag 14-089--This bull trout migrated to a known spawning area in the Twisp River of the Methow Basin. A minimum estimate of this bull trout's migration is about 181 km (112 miles) from downstream of Rocky Reach Dam to the upper Twisp River (Table A1).

This bull trout was tagged on 21 May 2002 at Rocky Reach Dam and was released downstream. The next day the bull trout was detected in the tailrace of Rocky Reach Dam. The bull trout passed Rocky Reach Dam 15 days later on 6 June 2002. The next day, 7 June, the fish was detected in the tailrace of Wells Dam. The bull trout passed Wells Dam two days later on 9 June and had moved into the Methow River the same day. On 1 July the bull trout had moved into the Twisp River downstream from the mouth of Buttermilk Creek. Later, on 1 August the fish had moved further upstream in the Twisp River upstream from the confluence of Buttermilk Creek. The fish remained in this area over an extended time until the tag was recovered on 12 September 2003 just downstream of Poplar Flats campground (Figure A1). The tag was buried in

approximately six inches of loose pea gravel on the downstream side of a logjam. No carcass was recovered nor were there any obvious signs of predation visible on the radio tag or antenna.

Tag 14-95--This bull trout migrated into the upper Entiat River to a potential spawning area. The bull trout migrated about 55 km (34 miles) from its release location at Rocky Reach Dam to the upper Entiat River (Table A1).

This bull trout was tagged on 29 May at Rocky Reach Dam and was released downstream near the west shoreline. The fish moved back into the tailrace the same day and re-ascended the fish ladder and was last detected at the project four days later exiting the ladder on 4 June. Five days later, on 9 June, the bull trout had migrated to and was detected in the lower Entiat River. The bull trout was detected upstream in the Entiat River between the confluences of Mad and Preston creeks on 1 July. More than a month later (1 August) the bull trout had migrated upstream and was detected upstream from Preston Creek. The bull trout was detected three more times (4 Sept, 9 Oct and 6 Nov) in the same general area on the Entiat River upstream near the confluence of McCrea Creek. Finally on 7 November the tag was recovered by USFWS personnel on the shore inside a hole under a boulder (Figure A1). The tag had obvious scratch marks, and USFWS personnel speculated that the marks were caused by mink (*Mustela vison*) predation or scavaging.

14-098--This bull trout migrated into the Mad River of the Entiat Basin. This fish migrated about 65 km (41 miles) from its release location upstream from Rocky Reach Dam to the Mad River and back downstream into the Columbia River where the tag was found (Table A1).

The bull trout was tagged at Rocky Reach Dam on released upstream of the project on 30 May 2002. The bull trout moved into the Entiat River on 12 June. Later, on 1 July the fish was detected again in the Entiat River from confluence to Mad River. By 1 August the fish had moved into the Mad River. On 9 October 2002 the fish was detected downstream in the Entiat River. By 1 January 2003 the fish had moved downstream and was detected in the Columbia River. The tag but not carcass for this fish was recovered on 15 September 2003 just upstream from the mouth of the Entiat River about 200 meters on west shore (Figure A1). Divers that recovered the tag noted that the tag was found at a depth of about 3 meters in an area of dense aquatic macrophytes with a mud and silt bottom.

Tag 14-108--This bull trout migrated upstream to a spawning area in the Twisp River of the Methow Basin. The fish made a brief excursion to the Okanogan River before heading up the Methow River. This fish traveled about 211 km (131 miles) from upstream of Rocky Reach Dam to the Okanogan River and back down to the Methow River and finally into the headwaters of the Twisp River (Table A1).

The bull trout was tagged on 3 June 2002 at Rocky Reach Dam and was released upstream from the project. The fish then moved upstream and was detected in the tailrace of Wells Dam on 6 June. The bull trout passed Wells Dam on 18 June and was detected in the Okanogan River on 22 June. The next day the bull trout was detected at the mouth of the Methow River on 23 June. The fish was observed again in Methow River between mouth and Libby Creek on 1 July. By 1 August the bull trout had moved into the headwaters of the Twisp River upstream of Buttermilk Creek. The tag for this bull trout was recovered on 12 September 2003 just downstream of the Scatter Creek Trailhead

on the edge of a pool under cobble and gravel (Figure A1). There were no obvious signs of predation and no carcass was found.

Rock Island Dam

Tag 14-90--This bull trout migrated to a known spawning area in the Entiat River. The bull trout migrated approximately 164 km (102 miles) from its release location to the spawning area, then back to the Columbia River (Table A1).

This fish was released downstream of Rock Island Dam on 23 May 2002 near the west shore. After release, the fish migrated past the dam through the right bank fish ladder, and exited that system on 8 June. The next day this fish was detected in the tailrace of Rocky Reach Dam, and three days later was detected at the ladder exit at that project. On 1 July, this fish was detected at the fixed-telemetry site on the Entiat River. Subsequently, this fish migrated upstream to a location approximately 1 km downstream from Entiat Falls (1 August 2002), then downstream where it was detected on 4 September approximately 3 km upstream of Preston Creek. The next detection of this fish was in the Columbia River on 17 December 2002, where it was located over the course of approximately 10 months on 11 separate occasions. The transmitter (no carcass) of this fish was recovered on 15 September 2003, and was located approximately 8 km downstream of the Entiat River confluence (Figure A1). The transmitter was in approximately 4 meters of water, and was located near the west shore.

Tag 14-97--This bull trout migrated to a known spawning area in the Mad River of the Entiat Basin. The bull trout migrated approximately 81 km (50 miles) from its release location at Rocky Reach Dam into the Mad River (Table A1).

This fish was tagged on 20 May 2002, and was released upstream of Rock Island Dam near the east shore. Six days after release, this fish was detected in the tailrace of Rocky Reach Dam, and four days later it exited the ladder system at that project. On 19 June 2002, this fish was detected at the fixed-telemetry site located at RK 4.8 of the Entiat River. During the next aerial survey (1 July 2002), it was detected in the lower Entiat River approximately 1 km upstream of the Entiat National Fish Hatchery. During the period of September 2002 to September 2003, this fish was located on nine separate occasions, all during routine aerial surveys. The location of this fish for those surveys was the same, which was approximately 1 km downstream of Windy Creek within the Mad River (Figure A1). The transmitter for this fish was recovered at that location on 16 September 2003 without a carcass.

Tag 14-109--This bull trout migrated into the Mad River of the Entiat Basin. This fish migrated about 98 km (61 miles) from its release location upstream from Rock Island Dam to the Mad River and back downstream into the Columbia River where the tag was found (Table A1).

This bull trout was tagged at Rock Island Dam and released upstream from the project on 7 June 2002. Three days later, 10 June, the fish had moved into the tailrace of Rocky Reach Dam and passed the project on 12 June. The bull trout moved upstream and entered the Entiat River on 19 June. The fish was detected again in the Entiat River on 1 July downstream from confluence of Mad River. The bull trout was detected in the Mad River on 4 September and remained there until 17

December when it was detected back in the Entiat River. The fish moved back downstream into the Columbia River by 14 January 2003 upstream from the confluence of the Entiat River. On 19 February 2003 the fish was detected in the Columbia River back downstream near the confluence of Entiat River. The tag was recovered in the Columbia River on 15 September 2003 about 1.6 kilometers downstream from mouth of Entiat River on the west shore (Figure A1). The radio tag was found in water at a depth of 4 meters on a steeply sloped bank. Divers that recovered the tag noted that the bank was rocky with old trees and lots of fishing line.

Tag 14-110--The movements of this bull trout were mostly within the Columbia River and do not appear to suggest a spawning migration. The bull trout migrated about 322 km (200 miles) from it release location to the tailrace of Rocky Reach, into the Wentachee River, back to the Columbia River and upstream to the tailrace of Wells dam and eventually back downstream of Rock Island Dam (Table A1).

The bull trout was tagged at Rock Island Dam on 4 June and was released upstream of the project. Within two days the fish was detected upstream in the tailrace of Rocky Reach Dam. The fish was detected in the tailrace three consecutive days (6-8 June) until it moved downstream to the Wenatchee River. It moved up the Wenatchee River and was detected near the town of Monitor on 11 June. During an aerial survey on 1 July, this bull trout had migrated upstream in the Wenatchee River and was detected downstream of Tumwater Canyon near the town of Leavenworth. Nine days later on 10 July the fish was detected in the Wenatchee River back downstream near the town of Monitor. That same day, approximately 11 hours later, the fish had moved back into the Columbia River and upstream to the tailrace of Rocky Reach Dam. The bull trout remained in the tailrace four days until it passed the project on 13 July. On 14 July the fish had migrated upstream and was detected in the tailrace of Wells Dam. The fish remained in the tailrace for one day then moved downstream in the Columbia River and was detected in the Entiat River on 18 July. The bull trout then moved further downstream in the Columbia River, passing both Rocky Reach and Rock Island dams on 20 and 21 July, respectively. The bull trout was detected again during an aerial survey on 1 August downstream of Rock Island Dam near Quilomene Island on the Columbia River. Later, the fish was detected upstream 1.5 miles from Quilomene Island in the same location during boat surveys on the Columbia River on 8, 13, 22 August. The tag (no carcass) was found 10-15' from the waters edge under a pile of debris on 22 August (Figure A1).

DISCUSSION

The detection history of most of the bull trout prior to the recovery of the transmitters suggests that they migrated to spawning areas in the Methow and Entiat basins where bull trout are known to spawn (Table A1). The one exception is tag 14-110 that was recovered downstream of Rock Island Dam.

The bull trout reviewed in this summary did not originate from a single tag or release location and were not tagged by a single person, which suggests that these factors did not influence fish survival or tag expulsion. Six of the bull trout were released downstream of mid-Columbia River projects and eight were released upstream. Bull trout released at Wells Dam were detected in the Methow River in June 2002. Those bull trout were later detected in the Twisp River by 1 August 2002. Bull trout released near Rocky Reach Dam entered the Methow and Entiat rivers in June and were detected in the upper Entiat, Mad, and Twisp rivers in July and August. These dates appear to agree with the general migration timing for bull trout (Brown 1994; USFS 2001).

The migration distance for these bull trout from June to September ranged from about 44 km to about 322 km. Assuming that successive detection in different upstream areas means that fish were alive and actively migrating, then most of the fish survived about two months after they were tagged. That length of time between when the fish were tagged to their entry in a tributary stream suggests that the bull trout did not suffer an acute or debilitating injury associated with tagging nor did dam passage have an immediate affect on survival.

In general, observations made on bull trout tagged by the USFWS and BioAnalysts, Inc. revealed that most of the bull trout only had creases or slight wear marks associated with the external antenna (Per. Comm., Mark Nelson, USFWS). The tags in two bull trout may have shifted internally, resulting in the antenna protruding from the body at a right angle. The one bull trout that was recovered (14-107) in the Twisp River did not have any obvious injuries and the incision healed completely.

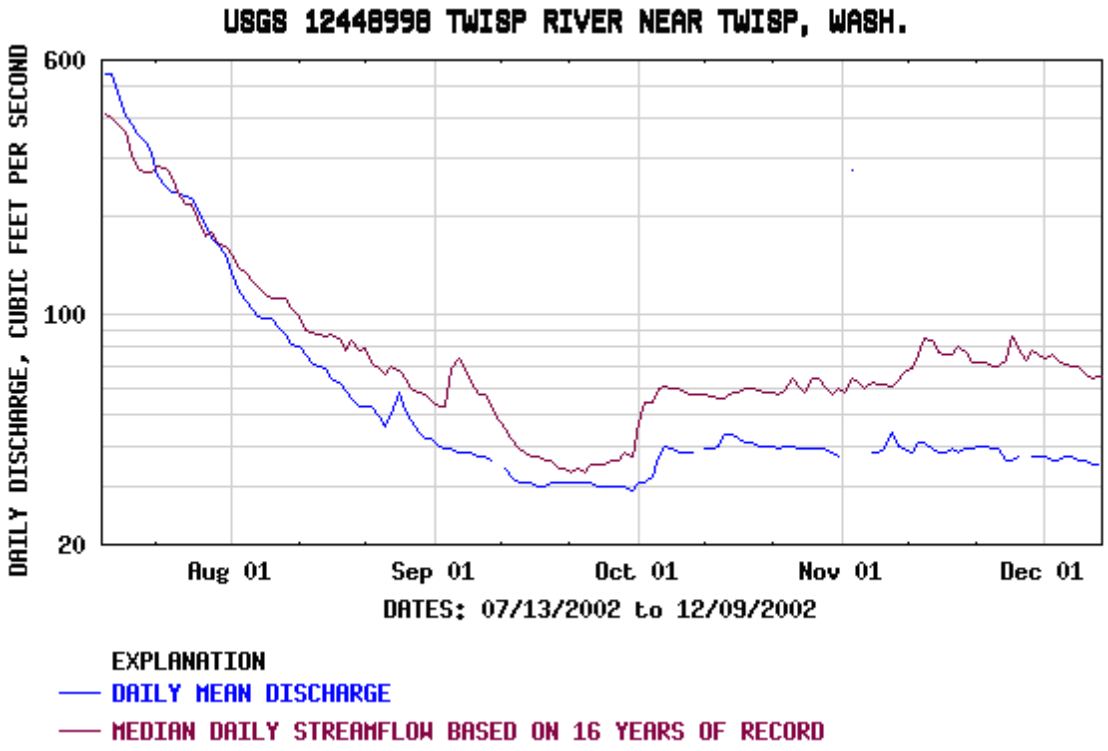
The location where four tags were recovered suggests that the fish may have been removed from the water (Table A1). Clearly, tags found above the wetted channel in the tributaries during low flow periods of late summer and fall suggest some method of transport. Some researchers have noted that predation, angling/poaching, and shed tags are the suspected causes of tag loss (Elle 1995; Swanberg 1997; Chandler et al. 2001). The U.S. Fish and Wildlife Service suspect that some of their bull trout tagged in 2002 perished (20% of tagged fish). Some of their tags have been recovered onshore away from the river.

Predation may have played an important role in the disappearance of tagged bull trout. One tag (14-95) had cut marks on the antenna portion of the radio tag (Table A1). Here, the observer noted that the tag was recovered on the shore inside a hole under a boulder perhaps only big enough for a mink. Chandler et al. (2001) and Elle (1995) both noted that mink preyed on their bull trout. The bull trout with tag 14-110 made extensive movement both upstream and downstream in the Columbia River. That tag was finally recovered downstream of Rock Island Dam about 10-15 feet from the waters

edge under a pile of debris that had floated in during high water. The observers noted that it was common to see hawks and eagles in this area. Three other tags (14-98, 14-90, and 14-109) were recovered without a carcass in the Columbia River. These fish migrated to spawning areas in the Entiat basin before their tags were found.

Harsh stream conditions in the fall may have contributed to the loss of some bull trout. Both the Twisp and Entiat rivers experienced very low flow conditions in fall 2002 compared to the period of record (Figure A2). Low flows in the Twisp River created a dry stream channel in fall, which prevented adults from migrating downstream, presumably after they had spawned. This condition has been observed in the Twisp River the past two years. Increased flows in late fall, particularly in small tributaries, may be an important cue that triggers downstream movement of adult bull trout. Two bull trout migrated downstream when flows increased in the Twisp River in November 2002. However, the increased flow was not sufficient to provide complete passage downstream to the Methow River. One bull trout died (14-107) after it had moved downstream and became stranded. That bull trout was recovered during a survey conducted by the U.S. Fish and Wildlife Service. Another tagged bull trout (14-116) was rescued and returned downstream along with one untagged bull trout. Swanberg and Burns (1997) observed a similar situation for a bull trout in the upper Blackfoot River. In their study they found a bull trout that became isolated in a large ice-covered pool just upstream of a dry section of Landers Fork. That fish froze seven days later.

Most of the bull trout that were tracked migrated to spawning areas in the Entiat and Methow basins. Although multiple spawning has been reported for bull trout, relatively high mortality (67%) for spawning bull trout has also been noted (Schill et al. 1994). Elle (1998) reported a lower range of mortalities (26% to 36%) for spawning adults. He noted that there was no difference in survival during spawning between radio-tagged and untagged bull trout. This information suggests that the fall spawning period may be a time when adult bull trout are likely to perish. The loss of tagged bull trout, however unfortunate to this study, provides a more complete picture of the life history for bull trout in the mid-Columbia region.



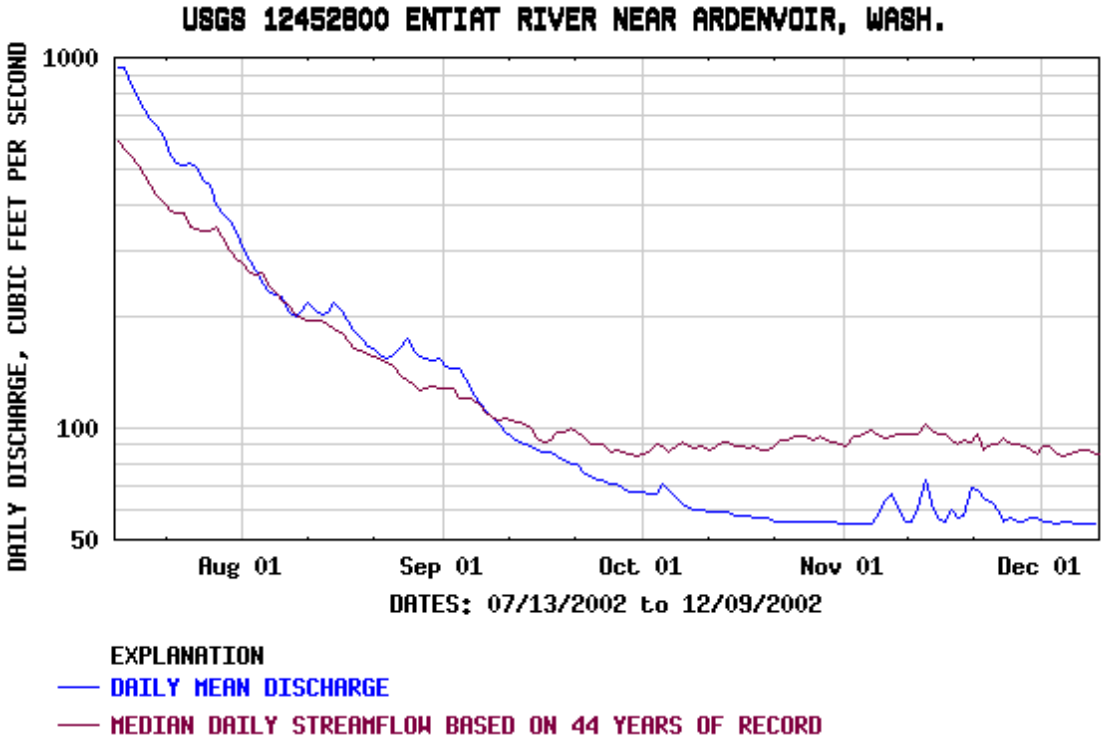


Figure A2: Stream discharge (cfs) in the Twisp and Entiat rivers from August to December, 2002.

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APPENDIX B: BULL TROUT DETECTION MAPS

Available Upon Request

BioAnalysts, Inc. 2006. Aquatic Macroinvertebrate Inventory and RTE Assessment. Wells Hydroelectric Project, FERC No. 2149. Prepared for Public Utility District No. 1 of Douglas County, East Wenatchee, WA.

AQUATIC MACROINVERTEBRATE INVENTORY AND RTE ASSESSMENT

WELLS HYDROELECTRIC PROJECT

FERC NO. 2149

June, 2006

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APPENDIX C MOLLUSK FAUNA ABUNDANCE AND DIVERSITY

ABSTRACT

This study was initiated to provide baseline information on the aquatic macroinvertebrate fauna and mollusks in the Wells Project. This aquatic macroinvertebrate inventory was conducted in order to characterize the aquatic macroinvertebrate and mollusk assemblage found within the Wells Project and in order to provide information on the possible occurrence of rare, threatened and endangered (RTE) macroinvertebrate species potentially occurring within the Wells Project. Additional objectives of the study include describing habitat associations and qualitative abundance for various species categories of macroinvertebrates.

In order to achieve these objectives, benthic macroinvertebrates were sampled within representative habitats throughout the Wells Project. The abundance and richness of the aquatic macroinvertebrate fauna varied according to habitat. There were eighty-eight different taxa observed in the study area with the most abundant and diverse taxa observed in littoral areas of fast and slow water habitats. Fast water areas were more abundant but generally had the same taxa richness as slow water habitat. Macroinvertebrate abundance in slow water littoral areas varied from 231 to 683 organisms per sample and fast water varied from 5,224 to 9,184 organisms per sample. Deepwater site abundance in the Columbia River ranged from 5 to 295 organisms per sample. In littoral areas, chironomids were consistently one of the most dominant taxa but other taxa were also important such as Gastropoda, Annelida, Crustacea, and Trichoptera. Similar taxa were important in the Methow and Okanogan rivers.

There were seventeen different mollusk species identified in the Wells Project. Of these seventeen species, nine were gastropods and eight were bivalves. The gastropods included eight native species and one non-native snail. The bivalves included seven native species and one non-native clam. There were two Washington State candidate species, the Columbia River spire snail and Columbia River limpet, found in the Methow River in relatively clean and complex substrate. The Columbia spire snail was also found in the Okanogan River in areas that once appeared to be riffle habitat. At these locations the water was approximately 2-meters deep and the substrate was mostly sand with fines, gravel, and cobble. These mollusks were not abundant at either site and in most instances were identified from shell fragments or dead organisms. No Federal ESA listed or Federal candidate macroinvertebrates or mollusks were found during the study.

1.0 INTRODUCTION

1.1 General Description of the Wells Hydroelectric Project

The Wells Hydroelectric Project is located at river mile (RM) 515.8 on the Columbia River in the State of Washington. Wells Dam is located approximately 30 river miles downstream from the Chief Joseph Project, owned and operated by the United States Army Corps of Engineers, and 42 miles upstream from the Rocky Reach Hydroelectric Project owned and operated by Chelan County PUD. The nearest town is Pateros, Washington, which is located approximately 8 miles upstream from the Wells Dam.

The Wells Project is the chief generating resource for Douglas PUD. It includes ten generating units with a nameplate rating of 774,300 kW and a peaking capacity of approximately 840,000 kW. The design of the Wells Project is unique in that the generating units, spillways, switchyard, and fish passage facilities were combined into a single structure referred to as the hydrocombine. Fish passage facilities reside on both sides the hydrocombine, which is 1,130 feet long, 168 feet wide, with a crest elevation of 795 feet in height.

The Wells Reservoir is approximately 30 miles long. The Methow and Okanogan rivers are tributaries of the Columbia River within the Wells Reservoir. The Wells Project boundary extends approximately 1.5 miles up the Methow River and approximately 15.5 miles up the Okanogan River. The normal maximum surface area of the reservoir is 9,740 acres with a gross storage capacity of 331,200 acre-feet and usable storage of 97,985 acre feet at elevation of 781. The normal maximum water surface elevation of the reservoir is 781 feet (Figure 1.1-1).

The purpose of this study is to provide biological information as a baseline inventory on aquatic macroinvertebrates in the Wells Project. This study is one of several studies that have been implemented in order to assess baseline environmental conditions prior to relicensing the Wells Project.

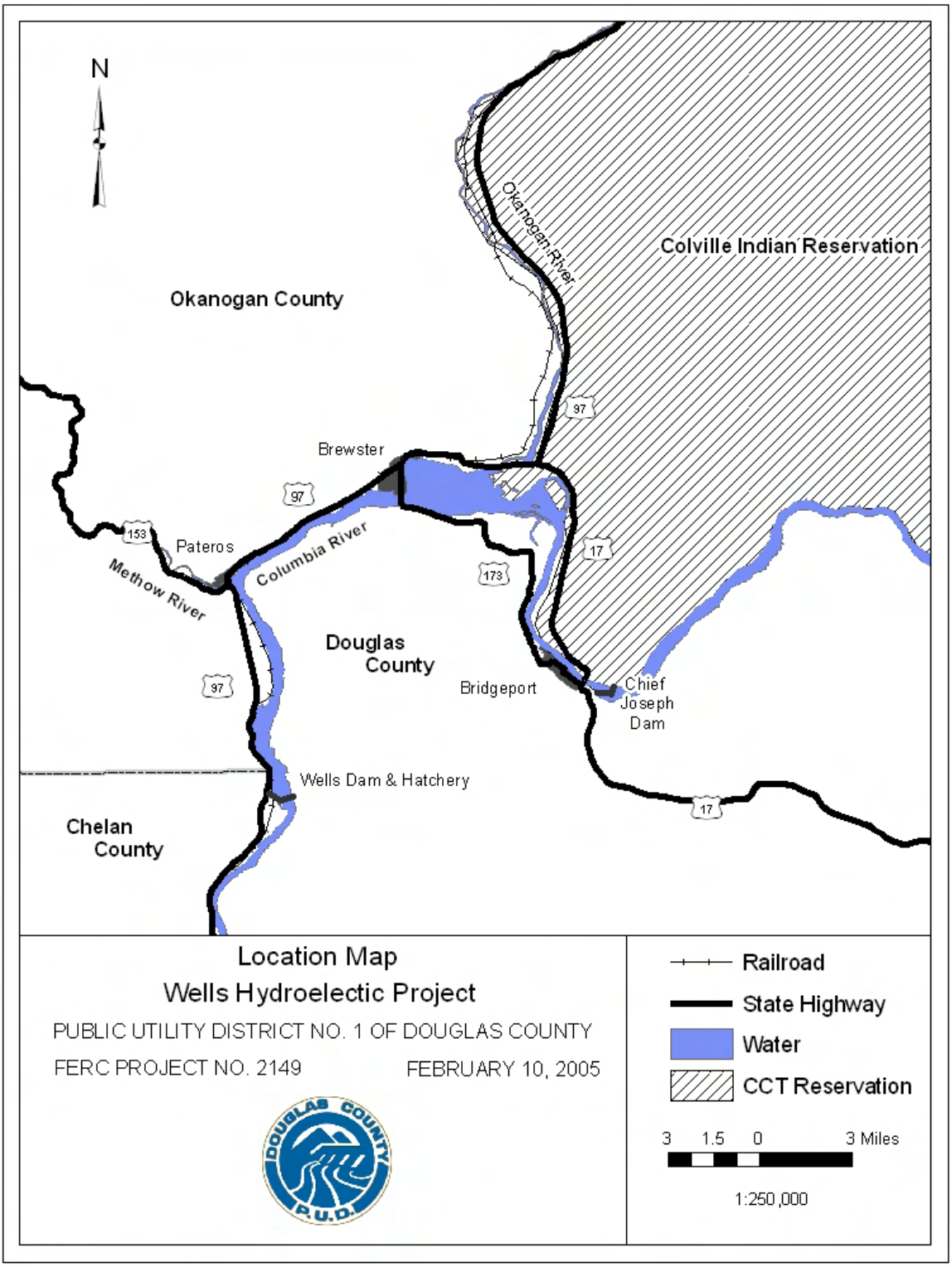

Figure 1.1-1 Location Map of the Wells Project

2.0 GOALS AND OBJECTIVES

The purpose of this study is to provide biological information as a baseline inventory on aquatic macroinvertebrates in the Wells Project. This study is one of several studies that have been implemented in order to assess baseline environmental conditions prior to relicensing the Wells Project. The goal of this study is to determine the current aquatic macroinvertebrate assemblage in the Wells Project. Specific objectives include:

1. Implement a rare, threatened, and endangered (RTE) species assessment in the Wells Project.
2. Collect aquatic macroinvertebrates from representative habitats within the Wells Project.
3. Identify aquatic macroinvertebrates (e.g. bivalves, gastropods, and insects) to the genus taxonomic level.
4. Provide habitat associations for aquatic macroinvertebrates by descriptive and quantitative measures of physical habitat characteristics (i.e., velocity, substrate, depth, etc).
5. Provide qualitative abundance (i.e., rare, common, abundant) for species categories within the Wells Project.

Based on literature review, there are three mollusks species that may occur in the Wells Project that have been listed as species of concern in Washington State. State and Federal status are provided in Table 2.0-1. An RTE assessment will provide a better understanding of the occurrence and habitat requirements of these species in the Wells Project.

Table 2.0-1 State and Federal status for mollusks that may occur in the Wells Project Area

Common Name(s)[1]	Scientific Name[2]	Status	
		State	Federal
Giant Columbia River Limpet Shortface Lanx	*Fisherola nutalli*	State Candidate	None
Giant Columbia Spire Snail Columbia Pebblesnail Ashy Pebblesnail	*Fluminicola columbiana =(fuscus)*	State Candidate	Species of Concern
California Floater	*Anodonta californiensis*	State Candidate	Species of Concern

[1] . Other common names for the Columbia River Limpet and Columbia Spire Snail are provided.

[2] . *Fluminicola columbiana* is now recognized as *F. fuscus* (Turgean et al. 1998).

3.0 STUDY AREA

The study area includes the Wells Reservoir from Wells Dam to the tailrace of Chief Joseph Dam. The Wells Reservoir is approximately 30 miles long extending from the forebay of Wells Dam to the tailrace of Chief Joseph Dam on the Columbia River and includes 1.5 miles of the lower Methow River and 15.5 miles of the lower Okanogan River. The tailrace waters just downstream from Wells Dam are included in the study area; however, the analysis of aquatic macroinvertebrates will primarily rely on data collected in the tailrace as part of a previous study (DE&S and RL&L, 2000).

4.0 BACKGROUND AND EXISTING INFORMATION

Aquatic macroinvertebrates are organisms like aquatic insects, worms, clams, snails, and other animals without backbones that can be seen without the aid of a microscope. Aquatic macroinvertebrates can inhabit a diverse array of habitats including streams, wetlands, springs, lakes, and reservoirs. The abundance and diversity of aquatic macroinvertebrates has been used as an indicator of ecosystem health and of local biodiversity (Plotnikoff and Ehinger 1997).

There is limited information on the RTE species that may occur in the Wells Project. There has been some baseline inventory information collected on aquatic macroinvertebrates in the upper Columbia River in the Rocky Reach reservoir (DE&S and RL&L 2000). There were no RTE species found in Rocky Reach reservoir. However, recent surveys in the Methow and Okanogan rivers, upstream from the Wells Project, have confirmed the presence of the Columbia pebblesnail and the shortface lanx (Neitzel and Frest 1990). Most collections of these mollusks have occurred in only a few sites: the Hanford Reach of the Columbia River, Washington; Black Canyon of the Payette River, Idaho; and the Deschutes River, Oregon. The Columbia pebblesnail is mostly found living in oligotrophic, hard-substrate, swift-flowing habitats, mostly in larger streams. Similarly, the shortface lanx is found mostly on boulders and cobbles in clear, cold, swift, and large streams.

The California Floater is declining throughout much of its former range and the species current distribution is not well known (Larsen et al. 1995). There have been only a few sites from which there are recent records of live California floaters and they include: portions of the Columbia and Okanogan rivers, Curlew Lake (Frest and Johannes 1993), and several ponds adjacent to the Columbia River downstream from the Hanford reactor sites (Pauley and Nakatani 1968). None of these locations include the Wells Project. The California Floater is mostly reported in rivers or river lakes in relatively stable, oxygenated mud, sand, or fine gravel beds, often located in pools just downstream from rapids. Larsen et al. (1995) suggest that the California Floater requires a relatively stable substrate so it is not buried and/or suffocated by shifting sediments.

5.0 METHODOLOGY

In autumn 2005, aquatic macroinvertebrate fauna were sampled throughout the Wells Project. Sample sites were selected to represent a variety of habitats and physical attributes. These habitats and physical attributes were selected within three major geographic areas of the Wells Project. These three areas were all within the Wells Reservoir and consisted of the Columbia

River portion of the Wells Reservoir and the inundated portions of the Methow and Okanogan rivers.

5.1 Site Description

Onsite field reconnaissance and bathymetric maps were used to select sampling stations among the diverse habitats of the Wells Project. Sampling areas were selected in the field to describe potential communities based on physical attributes (i.e., depth, substrate, and velocity) that might dictate the diversity and abundance of benthic macroinvertebrates and mollusks. The major geographic areas of the Wells Project were further stratified into zones such as littoral, pelagic/profundal, and riverine. The littoral zone was characterized as areas that extended from the shore just above the influence of waves and spray to a depth where light was insufficient for rooted aquatic vegetation (Goldman and Horne 1983). The pelagic or profundal zone was characteristic of deep water areas that extend beyond the littoral zone. The section of the Methow and Okanogan rivers within the Wells Project boundary was described as riverine because there was less variation in depth.

Another major difference in habitat is often associated with water velocity that can be described as fast water and slow water habitat types. To describe the immediate sampling area, Hawkins et al. (1993) level I classification was used to characterize stream habitat as either fast water or slow water areas. In general, fast-water areas tend to have larger substrate, more turbulence, a narrower stream channel, and higher stream gradient. Conversely, slow-water areas tend to be less turbulent, have smaller substrate, and a wider stream channel. Substrate composition was visually estimated based on the percentage of different size categories (Peck et al. 2001). The size categories used to describe the diameter of the substrate were: fines (<0.06mm), sand (0.06-2.0mm), gravel (2-64mm), cobble (64-250mm), and boulder (250-4000mm). In addition, at each sampling station water column depth, water temperature (°C), and the presence of aquatic macrophytes was noted.

A Hydrolab minisonde multimeter was used to collect basic water quality information during the study. This on-site information was augmented with more detailed information from the implementation of the Wells Project Comprehensive Limnological Investigation (EES Consulting, 2006) which was conducted during the same time period. In the following sections, the sampling areas and techniques used to assess aquatic macroinvertebrate assemblages in the Wells Project are described.

5.2 Benthic Macroinvertebrates

Benthic macroinvertebrate fauna were sampled in the Wells Project with colonization baskets, petite ponar grabs, and a suction device. Colonization baskets were placed at five locations throughout the Columbia River in late September to sample littoral areas of the Wells Project (Table 5.1-1). The colonization baskets were constructed similar to other baskets used in a previous study to sample macroinvertebrate fauna in the Rocky Reach Reservoir (DE&S and RL&L 2000). Each square basket was made of semi-rigid plastic mesh netting that measured 15x15x15 cm. The baskets were filled with gravel and cobble substrate. At each sample location, five substrate filled baskets were placed in a straight line extending out from the

shoreline perpendicular to stream flow. The baskets were placed in good contact with the local substrate and evenly spaced to allow water flow around each basket. Placement of the colonization baskets on the river bottom allowed bottom-dwelling invertebrates as well as drifting animals to colonize the substrates. Flagging was attached to at least one basket to help SCUBA divers retrieve the baskets at a later date. Colonization baskets were retrieved in late October approximately 35 days after they were deployed. All five baskets were retrieved and placed in a large bucket where the substrate and baskets were scrubbed to remove aquatic macroinvertebrate fauna. The sample material was then sieved (500 μm) and preserved with 70% ethyl alcohol.

Petite ponar samples were taken from six stations throughout the Wells Project (Table 6.1-1). Petite ponar samples were taken at either deep or slow water habitats where silt and sand were the dominant substrate types. At each location, five petite ponar grabs were combined as one sample for each station. The petite ponar sampler used in this study had a maximum sample volume of 2.4 liters so the maximum volume of substrate sampled at each station was approximately 12 liters. Each petite ponar grab was placed into a bucket and sieved through a 500 μm mesh. After all five petite ponar grabs were sieved; benthic macroinvertebrates were combined into one sample and placed into a labeled sample bottle prepared with 70% ethyl alcohol. Substrate composition was qualitatively estimated from the material retrieved from all ponar grabs collected at each station. Depth (meters) was reported from a depth sounder when the boat was positioned at the sampling station.

A suction device was used to sample benthic macroinvertebrates within a one square meter area quadrat to a depth of approximately 15 cm below the sediment-water interface. Aluminum conduit about 2 cm in diameter was cut and bent to form a single square meter sampling quadrat. This active sampling technique was used at three of the five stations where colonization baskets were deployed to provide complimentary information on mollusks and other benthic macroinvertebrates. The suction device consisted of an aluminum pipe 3.8 cm in diameter and 68.5 cm long. One end (the extraction end) of the aluminum pipe was cut at a 45º angle and the other end was fitted with a cam-lock to extend the tube if needed. A handle was attached to the body of the device to help control the movement and a valve was used to regulate the amount of air infused into the pipe. A portable air compressor supplied air through a hose that was coupled to the suction device. At the distal end of the pipe a fine-mesh collection bag held the sample. Small substrates (fines and sand) were suctioned from the quadrat and screened through the sample bag while larger substrate was held up to the nozzle of the suction device and scrubbed with a hand brush. The total volume of substrate sampled equaled approximately 0.15 cubic meters. All benthic macroinvertebrate samples were internally-tagged and shipped to the processing laboratory (EcoAnalysts, Moscow, ID). Analytical results are presented in Appendix A and B for benthic macroinvertebrate sampling locations.

5.3 Mollusks

To accomplish the RTE assessment portion of the study, mollusks were sampled in the Columbia, Okanogan and Methow rivers with an airlift suction device. The same suction device that was used to provide complimentary information at colonization basket sites was used to sample mollusks. However, the suction device was used more intensively to search for RTE

species. Instead of a single 1 square meter sample quadrat there were seven randomly selected quadrats used for collecting mollusks along a 40-meter transect. These seven randomly selected quadrats were intensively sampled by removing the top 15 cm of substrate with the suction device. In addition, SCUBA divers collected other visible mollusks as they inspected areas adjacent to each transect.

Sample locations for mollusks were based on general habitat preferences noted in the literature for Washington state candidate species and Federal species of concern (pebblesnail, California floater, and shortface lanx). The information suggested that stable environments with clean, flowing, well-oxygenated water were important (Neitzel and Frest 1990; Larsen et al. 1995; Clarke 1981). Preferences for substrate appeared to vary depending on the organism or life stage but typically gravels, boulders, and sand/mud were noted depending on how the organism was attached or secured to the bottom and the method of feeding (filtering or scraping). Snorkeling and SCUBA observations provided useful information on different habitat attributes within the Wells Project. Final selection of all areas was based on habitat and some evidence of mollusks (live specimens or shells).

Mollusk samples were collected at two sites each in the Columbia, Methow and Okanogan rivers within the Wells Project. Samples from each transect were sieved (500 micron screen), combined, preserved in 70% ethyl alcohol, and sent to the processing laboratory (Deixis Consulting, Seattle, WA). Analytical results are presented in Appendix C.

5.4 Field and Laboratory Techniques

Field collection methods followed procedures outlined in Plotnikoff and White (1996) to ensure that all samples were collected with the greatest quality assurance (QA). Because the purpose of this study was to provide a qualitative assessment of aquatic macroinvertebrates in the Wells Project, artificial substrate sampling procedures also included collections by SCUBA divers. These collections were used to enhance taxa representativeness by sampling within the substrate, which could reveal distinct or less abundant organisms in the substrate. QA/QC procedure was also important for sample processing, handling, sorting, preserving, identifying, and storing samples to meet or exceed guidelines established by federal and state agencies (Plotnikoff and White 1996; Plotnikoff and Ehinger 1997).

Aquatic macroinvertebrate samples were sent to different analytical laboratories. Benthic macroinvertebrate samples were sent to EcoAnalysts, Inc. in Moscow, ID. Mollusk samples were sent to Dr. Terrence Frest at Deixis Consulting in Seattle, WA. In both laboratories, all samples were inspected to make sure the containers were intact and properly preserved. The samples were inventoried and checked against the sample collection list.

For benthic macroinvertebrates, all materials from a sample were combined in a Caton tray and floated in water. A Caton tray is a large sampling tray with grids and a sieve bottom. Large debris was rinsed, inspected for macroinvertebrates, and discarded after being inspected by another technician. The remainder of the sample was repeatedly rinsed and sifted to remove macroinvertebrates and organic matter from inorganic sediments. The material was then sifted through a 500 micron sieve and any remaining inorganic sediments were inspected for

macroinvertebrates too heavy to float off (e.g. mollusks, snails, stone-cased Trichoptera). Sample material was then evenly distributed throughout a sampling tray and inspected to determine the relative organism abundance. Samples with relatively few individuals were completely sorted. Samples with abundant organisms were subsampled by randomly selected squares. In subsampling, the fraction of squares sorted was recorded. The samples were sorted using a dissecting microscope (10X minimum magnification). Extracted macroinvertebrates were placed in labeled vials containing 70% ethanol and stored pending identification. Macroinvertebrates were identified to the lowest possible taxonomic level and counted (see Appendix A). Biological metrics (richness, community composition, taxa dominance, and biotic indices) were also calculated (see Appendix B).

At the laboratory, mollusk samples were sifted through a series of Taylor standard brass sieves to 40 mesh (<0.5mm). Mollusks were removed under a Leica Mz 7.5 binocular dissecting scope and retained in 95% ethanol. Picking was done at low power and the residues, insects, etc. retained under alcohol. Mollusks were segregated by species, identified, and stored in labeled bottles. After identification and enumeration, all material, including substrate, insects, mollusks, etc. were returned to the original sample bottles and stored in the original preserving fluid.

5.5 Data Analysis

For benthic macroinvertebrates, samples were analyzed to determine their abundance, taxa richness, community composition, and biotic indices (see Appendix B). For mollusks, species richness and qualitative abundance was provided for each sample site from both live and dead intact organisms as well as partial shell fragments (see Appendix C).

6.0 RESULTS

6.1 Benthic Macroinvertebrates

6.1.1 Site Descriptions

Habitat varied by depth, velocity, substrate, and presence of aquatic macrophytes in sampling sites of the Columbia River. Table 6.1-1 presents habitat features noted at each sampling site. Five sites were located in the Columbia River in the shallow littoral zone of the reservoir. Essentially, these sites were located in the zone that extends from the shore just above the influence of waves and spray to a depth where light is insufficient for rooted aquatic vegetation (Goldman and Horne 1983). Three sites were located in slow water depositional areas dominated by small substrates and extensive aquatic macrophyte beds. These three sites were indicative of most of the reservoir downstream from the confluence of the Okanogan River. The two remaining sites were located in fast water areas dominated by larger substrate with little or no aquatic macrophytes. These sites typify the area downstream from Chief Joseph Dam to the confluence of the Okanogan River. Two additional sites in the Columbia River were located in the deep water areas of the reservoir. These sites were characteristic of the pelagic/profundal zone or deep-water areas that extend beyond the littoral zone. Four sites were sampled in the riverine habitat of the Methow and Okanogan rivers. At these sites, major differences in habitat were associated with substrate composition and the presence of aquatic macrophytes.

Information collected from the 2005 comprehensive limnological study was used to describe water quality at the time benthic surveys were conducted (EES Consulting, 2006). During the study, mean September water temperature in the Wells Project was 18.9°C in the Columbia River and 18.8°C in the Okanogan River. Water temperature data was unavailable in the Methow River for September. Stream temperature in the Columbia River was fairly uniform and did not stratify with depth (EES Consulting, 2006). Likewise, dissolved oxygen (DO) did not appear to vary much with depth. Mean dissolved oxygen remained above 8.0 mg/l for September in littoral (8.7-10.1 mg/l) and pelagic (9.0-9.1 mg/l) areas (EES Consulting, 2006). Mean DO measurements in September for the Okanogan and Methow rivers were 9.0 mg/l and 9.7 mg/l, respectively (EES Consulting, 2006). In the Wells Project, mean pH readings for September were fairly uniform at 7.5 to 8.3.

Table 6.1-1 Information on benthic macroinvertebrate sample sites in the Columbia, Methow, and Okanogan river sections of the Wells Project

			Physical Attributes										
								Substrate (%)[3]					
Station	Location	Method[1]	Depth (m)	Aquatic Macrophytes	Stream Habitat[2]	Hydrology	Zone	W	F	S	G	C	B
1	Columbia R.	CB, SD	2.4	Present	Slow	Depositional	Littoral	0	10	20	40	30	0
2	Columbia R.	CB	1.8	Present	Slow	Depositional	Littoral	0	10	40	30	20	0
3	Columbia R.	CB, SD	1.8	Present	Slow	Depositional	Littoral	0	15	50	25	10	0
4	Columbia R.	CB	2.4	Absent	Fast	Erosional	Littoral	0	10	10	10	70	0
5	Columbia R.	CB, SD	3.0	Absent	Fast	Erosional	Littoral	0	0	10	10	80	0
6	Methow R.	PG	2.1	Absent	Slow	Depositional	Riverine	0	10	75	15	0	0
7	Methow R.	PG	3.0	Present	Slow	Depositional	Riverine	5	75	15	5	0	0
8	Columbia R.	PG	21.3	Absent	Slow	Depositional	Pelagic	0	0	100	0	0	0
9	Columbia R.	PG	18.3	Absent	Slow	Depositional	Pelagic	5	75	20	0	0	0
10	Okanogan R.	PG	2.4	Present	Slow	Depositional	Riverine	0	40	60	0	0	0
11	Okanogan R.	PG	4.0	Absent	Slow	Depositional	Riverine	5	55	40	0	0	0

[1.] Method used at sampling station: CB=Colonization Baskets: SD=Suction Device; PG=Petite Ponar Grab.

[2.] Stream habitat characterized as either fast or slow water areas (Hawkins et al. 1993).

[3.] Substrate Categories: W= Wood and organic debris; F=Fines (<0.06mm); S= Sand (0.06-2.0mm); G=Gravel (2-64 mm); C= Cobble (64- 250mm); B= Boulder (250-4000mm) (From Peck et al. 2001).

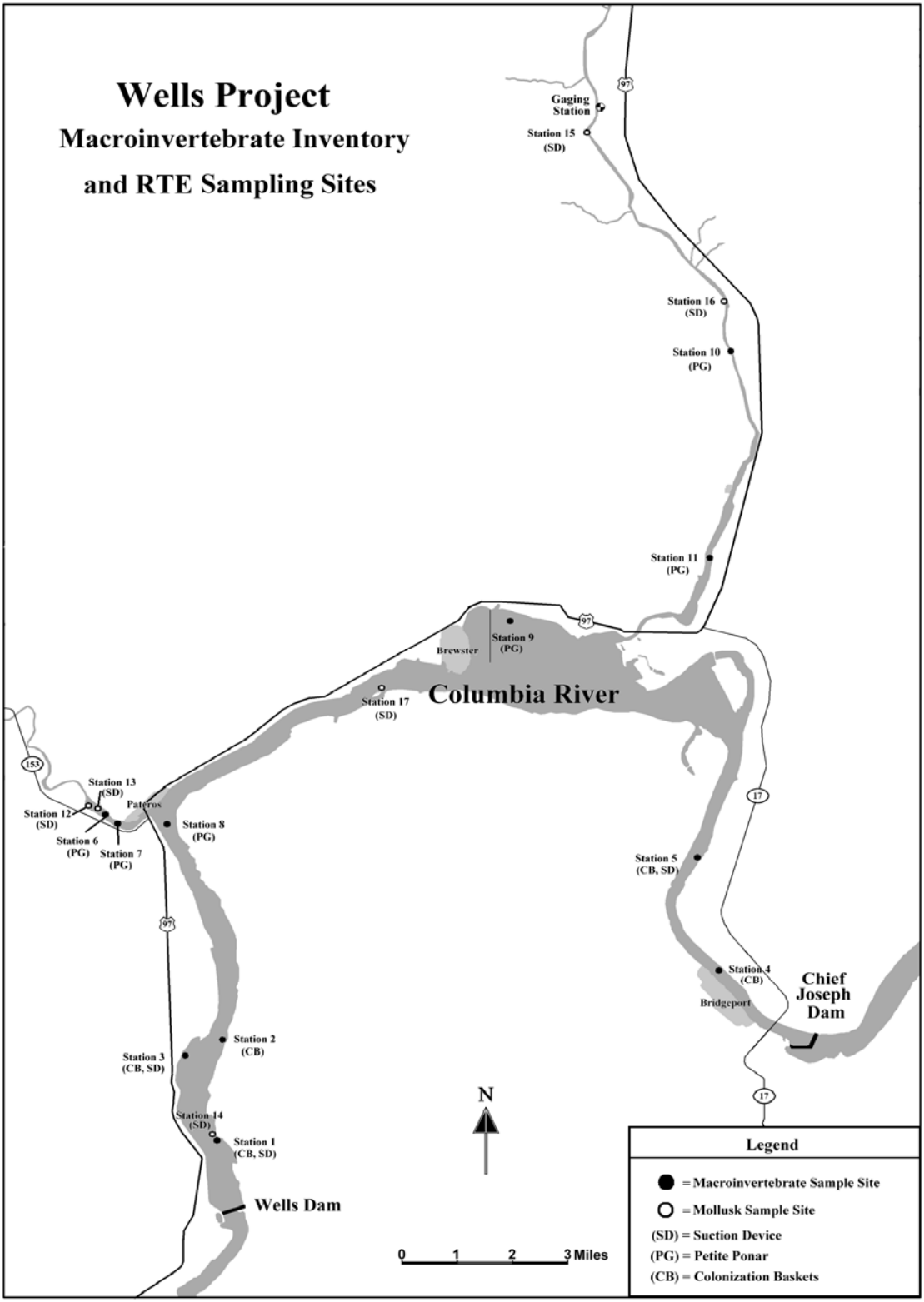

Figure 6.1-1 Wells Project macroinvertebrate inventory and mollusk RTE sampling sites

6.1.2 Abundance and Taxa Richness

Eighty-eight different taxonomic groups were identified in the Wells Project. Seventy-two taxa were identified downstream in the Rocky Reach Project (DE&S and RL&L 2000). Appendix A provides a complete taxa list and count for benthic fauna collected at each station. In general, higher abundance and taxa richness appeared to be associated with littoral areas of the reservoir (stations 1-5) (Table 6.1-1; Table 6.1-2). When comparing riverine locations, sample taxa richness was slightly higher in the Okanogan River (21 and 23 taxa) compared to the Methow River (19 and 21 taxa) (Table 6.1-2). Total taxa richness was 33 in the Okanogan River and 29 in the Methow River and both rivers had four distinct taxa. Distinct taxa at a station are organisms that were not observed at any other sampling station in the Wells Project. In the deep water, fine sediment habitat stations of the Columbia River (8 and 9), taxa richness varied from 5 to 17. The low taxa richness observed at station eight in the Columbia River might be explained by the unstable shifting sands associated with the alluvial fan located near the confluence of the Methow River. In comparison, taxa richness was much higher at station nine in deep water where the substrate was more diverse. Sampling in deep water did not reveal any distinct taxa that were not observed at other stations in the littoral areas. Mean taxa richness downstream in the Rocky Reach project varied from 9 to 24 per sample location (DE&S 2000).

In the littoral areas of the Columbia River, sample taxa richness observed from the colonization baskets varied from 19 to 25 taxa (Table 6.1-2). Complimentary samples obtained at stations 1, 3, and 5 with the suction device had a taxa richness that ranged from 17 to 28 taxa. When the sampling techniques were combined at these stations, the range in taxa richness increased (28-35 taxa) (Table 6.1-2). Complimentary sampling with the suction device enhanced taxa richness and distinct taxa observations at stations 1, 3, and 5. That is, the suction device sampled several organisms within the substrate that were not represented in the colonization baskets. The increase in taxa richness generally was observed from organisms (mollusks, annelids, and crustacean) living deeper in the substrate.

Benthic fauna abundance within the Wells Project varied from 5 to 9,184 organisms per sample and was generally the most abundant at fast water stations (4 and 5). Similar to taxa richness, macroinvertebrate fauna were the least abundant at station eight. Macroinvertebrates were the most abundant at station five. The relatively low abundance and taxa richness observed with the suction device at station 5 may, in part, be due to difficulties associated with collecting samples in very fast waters.

Table 6.1-2 Taxa richness and abundance for benthic fauna samples collected in the Wells Project

Sampling Location	Columbia								Methow		Columbia		Okanogan	
Collection Method[1]	CB	SD	CB	CB	SD	CB	CB	SD	PG	PG	PG	PG	PG	PG
Station	1	1	2	3	3	4	5	5	6	7	8	9	10	11
Abundance	683	1,092	339	231	697	5,224	9,184	79	801	1,788	5	295	152	334
Distinct Taxa	2	2	0	1	5	3	2	2	2	2	0	0	1	3
Sample Taxa Richness	25	23	23	19	28	25	22	17	21	19	2	16	21	23
Total Taxa Richness	35		23	35		25	28		29		17		33	

[1.] Method used at sampling station: CB=Colonization Baskets: SD=Suction Device; PG=Petite Ponar Grab.

6.1.3 Community Composition and Taxa Dominance

Benthic fauna in littoral areas was diverse with apparent differences in community composition observed between fast and slow water areas. Community composition observed from sample stations in the Wells Project are presented in Table 5.1-3 and Table 5.1-4. At stations four and five, which were in the narrower, swifter currents of the Wells Reservoir, chironomids and trichopterans were the most abundant taxa and made up 65 to 71 percent of the sample, respectively (Table 5.1-3; Appendix B). At these stations, there were larger substrate (gravels and cobbles) mixed with sand and aquatic macrophyte beds were absent. In the slow water littoral areas (stations 1-3), chironomids and trichopterans were also abundant but gastropods made up the largest percentage of the organisms identified (Table 5.1-3: Appendix B). Flatworms and isopods were also a large percentage of the taxa identified at stations one and two, respectively. These stations were in close proximity to aquatic macrophyte beds where the majority of the substrate was sand and silt with less large substrate such as cobbles and gravels. Comparative sampling conducted with the suction device showed a community composition of benthic organisms dominated by Acari (water mites) and Odonata (damselflies and dragonflies), which are typically found down within the sediments.

The benthic macroinvertebrate community downstream in the Rocky Reach Project was dominated by chironomids, trichopteran, crustacea, bivalvia, gastropoda, acari, and segmented worms. Combined, these taxa contributed 95% to the total number of animals in the samples collected. Chironomid larvae were the most prevalent of taxa, accounting for between 21% and 92% of the animals at a given site.

Table 6.1-3 Community composition in percent for dominant taxa collected in the Columbia River of the Wells Project with colonization baskets and a suction device

	Colonization Baskets (%)					Suction Device (%)		
Taxanomic Group	**1**	**2**	**3**	**4**	**5**	**1**	**3**	**5**
Ephemeroptera (Mayflies)	0.0	0.0	0.9	0.0	0.0	0.0	4.3	0.0
Trichoptera (Caddisflies)	1.2	24.8	9.9	6.0	9.1	8.2	10.8	43.0
Lepidoptera (Butterflies and Moths)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3
Coleoptera (Beetles)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diptera-Chironomidae (Chironomid Flies)	29.6	2.9	32.9	88.2	85.2	2.6	2.6	32.9
Diptera (Flies)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Odonata (Damselflies and Dragonflies)	0.0	0.3	0.9	0.0	0.0	0.0	0.2	0.0
Gastropoda (Snails and Limpets)	8.4	46.6	47.2	0.5	0.0	5.0	29.9	10.1
Bivalvia (Clams and Mussels)	0.5	5.9	0.0	0.0	0.0	12.8	1.5	1.3
Acari (Mites)	1.3	0.9	0.9	2.4	3.1	1.1	8.9	3.8
Crustacea (Crayfish, isopods)	7.0	17.4	6.9	0.3	0.3	69.4	39.0	6.3
Annelida (Segmented Worms)	4.8	1.2	0.4	2.1	1.9	0.4	2.8	0.0
Nematoda (Roundworms)	0.0	0.0	0.0	0.5	0.4	0.5	0.0	1.3
Tubellaria (Flatworms)	47.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0

In the deep water or fine bottom substrate habitats segmented worms, clams, and chironomids were the most dominant taxa (Table 6.1-3; Appendix B). In the deep water habitat of the Columbia River (stations 8 and 9), benthic fauna consisted mostly of clams and roundworms. At these stations, the sediment was mostly sand and silt with some organic debris found at station nine. In the Methow River samples, segmented worms, chironomids, and clams were the most dominant taxa. Habitat in the Methow River differed in the amount of sand and silt contained in the substrate and the presence of aquatic macrophytes at station seven (Table 6.1-1). Clams and segmented worms were more dominant in the silt substrate with the aquatic macrophytes along the channel margins at station seven, while chironomids were more dominant in the sandy substrate near the main channel. In the Okanogan River, coleopterans, trichopterans, and chironomids were abundant at station ten, which was located along the channel margin among aquatic macrophytes and sand dominated substrate. At station eleven, located near the main channel, clams, segmented worms, and chironomids were the most dominant taxa. At this station, the substrate was mostly silt with sand and some organic material. The introduced Asian clam (*Corbicula fluminea)* was the dominant bivalve noted at most of the stations.

6.2 Mollusks

6.2.1 Site Descriptions

Sites selected for mollusk sampling were based on literature review and conversations with Dr. Terrence Frest, a regional expert on mollusks. The areas finally selected for intensive sampling were based predominantly on the presence of diverse habitat (substrate and velocity) to enhance the possibility of collecting rare, threatened or endangered (RTE) mollusks in the Wells Project. Snorkel surveys helped refine sampling areas by exploring different habitats and finding areas where at least shell fragments or live specimens of mollusks were present.

Sampling sites for mollusk surveys were in slow water depositional areas with fairly diverse substrate in the Columbia, Methow and Okanogan rivers. Table 6.2-1 presents habitat features noted at each sampling site. In the Columbia River, the sites were located in the shallow littoral zone. Station 17 was located just downstream from the town of Brewster near a series of three small islands (RM 528.5). Station 14 was located further downstream near Bonita Flats (RM 517.0). Both sites were depositional areas dominated by sand and gravel substrates that were close to aquatic macrophyte beds.

Sites selected in the Methow and Okanogan rivers were also in slow water depositional areas dominated by small substrates (Table 6.2-1). In the Methow River, stations 12 and 13 were located in the North and South channels of the river in depths less than 2 meters as it transitions from the free flowing river into the reservoir. In the Okanogan River, station 15 and 16 were located in areas that appeared to be old riffle habitat on the bend of the river at depths less than 2.5 meters. At these stations there were some large cobbles and boulders partially exposed from the bottom sediments but the dominant substrate was sand with fines and gravel as subdominant.

Table 6.2-1 Habitat information on mollusk sample sites in the Columbia, Methow, and Okanogan rivers

			Physical Attributes										
			Depth	Aquatic	Stream			Substrate (%)[3]					
Station	Location	Method[1]	(m)	Macrophytes	Habitat[2]	Hydrology	Zone	W	F	S	G	C	B
12	Methow R.	SD	1.7	Absent	Slow	Depositional	Riverine	0	10	40	40	10	0
13	Methow R.	SD	1.5	Absent	Slow	Depositional	Riverine	0	20	50	20	10	0
14	Columbia R.	SD	1.8	Present	Slow	Depositional	Littoral	0	10	40	20	10	0
15	Okanogan R.	SD	2.2	Absent	Slow	Depositional	Riverine	0	20	50	20	10	0
16	Okanogan R.	SD	2.4	Absent	Slow	Depositional	Riverine	0	30	50	10	10	0
17	Columbia R.	SD	2.1	Present	Slow	Depositional	Littoral	0	10	60	20	10	0

[1.] Method used at sampling station: CB=Colonization Baskets: SD=Suction Device; PG=Petite Ponar Grab.

[2.] Stream habitat characterized as either fast or slow water areas (Hawkins et al. 1993).

[3.] Substrate Categories: W= Wood and organic debris; F=Fines (<0.06mm); S= Sand (0.06-2.0mm); G=Gravel (2-64 mm); C= Cobble (64- 250mm); B= Boulder (250-4000mm) (From Peck et al. 2001).

6.2.2 Abundance, Taxa Richness, and RTE Assessment

There were 17 mollusk taxa identified from sample stations in the Wells Project. The number of mollusks identified at each station is presented in Appendix C. In summary, there were nine gastropod taxa and eight bivalve taxa identified in the Wells Project. The gastropods included eight native species and one introduced (*Radix auricularia*). The bivalves included seven native species and one non-native corbiculid (*Corbicula fluminea*). The number of mollusks found in the Wells Project is more than twice that observed within the Rocky Reach Reservoir with only eight mollusks (3 bivalves and 5 gastropods) found within the Rocky Reach Project (DE&S and RL&L 2000). The level of diversity (mean=9 taxa) also is similar with freshwater mollusk faunas previously reported from the Methow, Okanogan, and Columbia rivers by Taylor (1993), Neitzel & Frest (1993) and generally from the Columbia system by Neitzel & Frest (1993), and Frest & Johannes (1995, 2003, 2005).

In Washington, there are several mollusks that are state candidates and some that are Federal species of concern that may occur in the Wells Project. The ashy pebblesnail (*Fluminicola fuscus*) is a Washington State candidate species and was a former candidate species for Federal listing under the name Giant Columbia Spire Snail (*F. Columbiana*) in 1989. It is also commonly referred to as the Columbia pebblesnail (Frest and Johannes 1995). It was determined that the ashy pebblesnail did not require Federal protection and is no longer a Federal candidate species but is still a species of concern. The Giant Columbia Spire snail is mostly found living in oligotrophic, hard-substrate, swift-flow habitats, mostly in larger streams.

The Giant Columbia River Limpet (*Fisherola nuttalli*) is also known as the shortface lanx and is a Washington State candidate species. The limpet was under consideration as a Federal listing candidate in 1989 but was removed from the candidate list. This large limpet is found mostly on boulders and cobbles in clear, cold, swift, and large streams. It has been reported historically in the Methow, Okanogan, and Columbia rivers, and a few other Washington streams (Neitzel & Frest, 1993).

The California Floater (*Anodonta californiensis)* is a Washington State candidate species and is no longer a Federal candidate for listing but is still considered a Federal species of concern. The California Floater is most commonly reported from rivers or river lakes in relatively stable, oxygenated mud, sand, or fine gravel beds, often located in pools just downstream from rapids. Since it is unable to move rapidly across or through benthic materials, this clam requires a relatively stable substrate so it is not buried and/or suffocated by shifting sediments (Larsen et. al 1995).

Stations in the Methow River were located in the inundated portion of North and South channels where the substrate was fairly diverse and in close proximity to large cobbles and boulders located along the shoreline. There was noticeable current at both sites although the habitat was considered slow water habitat. Downstream from these sites the Methow River is dominated by silt and sand and snorkel surveys in this area revealed very little evidence of a diverse mollusk community. In the Methow River, there were 10 different mollusk species identified with the ridgebeak peaclam and remnants of the Columbia Spire Snail as the most abundant specimens found at the sampling sites (Table 6.2-2; Appendix C). Evidence of the Columbia Spire Snail

and Columbia River Limpet were limited mostly to dead organisms and shell fragments. Only one live specimen of the Columbia Spire Snail was found.

Mollusks in the Methow River that were alive at time of collection were dominated by bivalves with few live gastropods. The patchy mollusk composition observed at the two Methow River sites is common to mollusk communities. The two sites (12 and 13) were very similar with little differences in habitat descriptors (Table 6.2-1) yet mollusk communities were very different. Site 12 was dominated by *Fluminicula fuscus* (84 individuals) with full ontogeny while Site 13 was dominated by *Pisidium compressum* (40 individuals), again with full ontogeny. No whole shells of *F. fuscus* were found at Site 13. It is likely that the apparent mollusk communities at these two Methow sites were shaped by both drift of dead shells from upstream areas and habitat conditions at the sites.

In the Okanogan River, most of the stream is dominated by sand and silt. Water velocity and depth appeared to be fairly uniform within the inundated portion of the Okanogan River. Thus, stations selected in the Okanogan River were much less based on substrate or velocity but more on direct observations from snorkelers who found live specimens. The sampling areas appeared to be old riffle habitat on the bend of the river because there were some large cobbles and boulders partially exposed from the bottom sediments. In the Okanogan River there were nine mollusks species identified (Table 6.3-1). Recently, dead and live specimens of the Columbia Spire Snail were found in the Okanogan River. No other Washington state candidate or Federal ESA listed species was observed.

In contrast to Methow sites, Okanogan mollusk sites were much further downstream from the free-flowing Okanogan River and more shaped by on-site habitat conditions rather than by drift from upstream areas. Dominant mollusks at these sites were mostly live bivalves with large numbers of the very large, *Gonidea angulata* and the small fingernail clam, *Sphaerium striatinum.* In the more lacustrine Okanogan sites, gastropods were in low numbers although diversity was high. It is noteworthy that the introduced clam, *Corbicula fluminea,* so dominant at Columbia River sites was nearly absent in the Okanogan sites with only one individual found.

Stations selected in the Columbia River were also based on prior snorkeling and SCUBA diving. Observations in littoral areas of slow water habitat with diverse substrate and some water current showed considerable evidence of mollusks. Fast water areas upstream and in close proximity to Chief Joseph Dam did not show as much evidence of a diverse mollusk community. This observation was confirmed when the suction device was used to collect benthic macroinvertebrates. In slow water habitat at stations 1 and 3 there were at least seven mollusks observed compared to the three mollusks observed in fast water in the Chief Joseph tailrace (see Appendix A). Investigators found no mollusks in the tailrace of Wells Dams during surveys of Rocky Reach reservoir (DE&S and RL&L 2000).

There was nine mollusk species identified in the Columbia River. At Columbia River sites the Western Floater, Ridgebeak Peaclam, and Asian Clam were well represented. Gastropods were also diverse with large numbers of individuals found. High diversity, high numbers of individuals and a tendency for complete ontogeny of both bivalves and gastropods all indicate

more stable environments at the Columbia River sites. No state candidate or Federal ESA listed species were observed in the Columbia River (Table 6.2-2).

Table 6.2-2 Mollusks observed in the Methow, Okanogan, and Columbia rivers in the Wells Project

Mollusks	Methow	Okanogan	Columbia
Bivalves			
Western Pearlshell *Margaritinopsis falcata*	Present		
Asian Clam *Corbicula fluminea**		Present	Present
Western Floater *Anodonta kennerlyi*	Present		Present
Ridgebeak Peaclam *Pisidium compressum*	Present	Present	Present
Ubiquitous Peaclam *Pisidium casertanum*		Present	
Western Lake Fingernail Clam *Musculium raymondi*	Present	Present	
Western Ridge Mussel *Gonidea angulata*		Present	
Striate Fingernail Clam *Sphaerium striatinum*		Present	
Gastropods			
Three Ridge Valvata *Valvata tricarinata*			Present
Giant Columbia River Spire Snail *Fluminicola fuscus***	Present	Present	
Giant Columbia River Limpet *Fisherola nuttalli***	Present		
Big-ear Radix *Radix auricularia**	Present		Present
Golden Fossaria *Fossaria obrussa*	Present		Present
Prairie Fossaria *Fossaria (Bakerilymnaea) bulimoides*	Present		Present
Ash Gyro *Gyraulus parvus*	Present	Present	Present
Fragile Ancylid *Ferrissia californica*		Present	
Rocky Mountain Physa *Physella propinqua propinqua*			Present

*Introduced Species

**State Candidate or Federal Species of Concern

7.0 DISCUSSION

Macroinvertebrate communities varied in abundance and taxa richness based on differences in habitat and proximity to macrophyte beds. Macroinvertebrate communities in the Wells Project vary with substrate, depth, and velocity. Dominant taxa such as round worms (Nematoda) or segmented worms (Annelida) showed definite preferences for fine substrates while caddisflies (Trichoptera) were more abundant in more complex, coarser substrates. Still other taxonomic groups like chironomids (Diptera) appeared to have a wide distribution throughout the Wells Project. Observations suggested that taxa richness appeared to increase with habitat complexity. This was seen in the littoral areas of the reservoir where substrate and velocity varied but also when aquatic macrophytes were present. Mollusks appeared to need varied substrate to suit different modes of feeding (filtering and scraping), or the demands of different life stages.

Mollusks in the Wells Project were more diverse than areas noted downstream (DE&S and RL&L 2000). Samples collected in the Methow and Okanogan rivers showed that some State and Federal species of concern exist within the Wells Project. Areas where the Columbia River Spire Snail and Columbia River Limpet were found suggest that areas with complex habitat (more varied substrate, water velocity, and proximity to plant beds) provide more cover and feeding opportunities. Large expansive areas of sand and silt were not favorable habitat for mollusks. Perhaps areas with more complex substrate are more stable and mollusks in these areas are less likely to be buried or dislodged with variations in water velocity. Taxa present in the littoral areas of the Wells Project, which were formerly terrestrial habitat, suggests that numerous macroinvertebrates and several native mollusks have been able to exploit and disburse throughout these new submerged habitats.

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Appendix A

Benthic Macroinvertebrate Fauna Abundance and Diversity

Appendix A1. Abundance of different taxa counted from colonization baskets deployed in the Columbia River. Numbers in parenthesis represent percent subsampled.

		Station				
Taxanomic Groups	**Taxa**	**1 (88%)**	**2 (100%)**	**3 (100%)**	**4 (12.5%)**	**5 (6.3%)**
Ephemeroptera	*Caenis sp.*	0	0	2	0	0
Odonata	*Aeshna sp.*	0	1	2	0	0
Diptera-Chironomidae	*Cricotopus bicinctus gr.*	0	0	0	75	16
	Cricotopus sp.	0	0	0	21	9
	Dicrotendipes sp.	40	2	20	143	117
	Nilothauma sp.	1	0	0	0	0
	Orthocladius Complex	45	1	0	190	155
	Orthocladius annectens	0	0	0	1	0
	Orthocladius sp.	0	0	0	15	6
	Parakiefferiella sp.	1	0	0	2	0
	Paratanytarsus sp.	84	5	56	95	140
	Polypedilum sp.	1	1	0	0	0
	Potthastia longimana gr.	3	0	0	0	0
	Psectrocladius sp.	0	0	0	0	1
	Pseudochironomus sp.	1	0	0	0	0
	Rheotanytarsus sp.	0	0	0	0	1
	Synorthocladius sp.	1	0	0	28	16
	Tanytarsus sp.	0	1	0	6	28
Trichoptera	*Cheumatopsyche sp.*	0	0	0	0	4
	Hydroptila sp.	1	4	0	12	24
	Leptoceridae	0	0	1	0	0
	Mystacides sp.	3	0	0	0	0
	Nectopsyche sp.	0	0	2	0	0
	Ochrotrichia sp.	2	80	20	0	0
	Oecetis sp.	1	0	0	0	0
	Polycentropus sp.	0	0	0	27	18
	Psychomyia sp.	0	0	0	0	6
Gastropoda	*Fossaria sp.*	43	107	70	0	0
	Gyraulus sp.	2	21	15	3	0
	Lymnaeidae	0	1	1	0	0
	Physa (Physella) sp.	5	9	10	0	0
	Promenetus umbilicatellus	0	6	1	0	0
	Radix auricularia	0	0	4	0	0
	Valvata tricarinata	0	14	8	0	0
Bivalvia	*Corbicula sp.*	3	17	0	0	0
	Pisidium sp.	0	3	0	0	0
Annelida	*Alboglossiphonia heteroclita*	1	1	0	0	0
	Enchytraeidae	0	0	0	1	0
	Helobdella sp.	0	3	1	0	0
	Nais barbata	0	0	0	1	0
	Nais bretscheri	0	0	0	4	6
	Nais communis	0	0	0	1	0
	Nais pardalis	0	0	0	1	0
	Nais variabilis	28	0	0	4	4
	Pristina sp.	0	0	0	2	1
Acari	*Acari*	0	0	1	0	0
	Hygrobates sp.	0	2	0	0	0
	Lebertia sp.	8	1	1	3	3
	Limnesia sp.	0	0	0	11	11
	Oribatei	0	0	0	2	4
Crustacea	*Caecidotea sp.*	16	53	15	0	0
	Crangonyx sp.	20	0	0	0	0
	Hyalella sp.	1	3	0	2	2
	Ostracoda	0	3	0	0	0
	Pacifastacus leniusculus	5	0	1	0	0
Other Organisms	*Nematoda*	0	0	0	3	2
	Turbellaria	283	0	0	0	0
Total Organisms	**Subsample Abundance**	**599**	**339**	**231**	**653**	**574**
	Corrected Abundance	**683**	**339**	**231**	**5224**	**9184**

Appendix A2. Abundance of different taxa counted from petite ponar grabs at stations in the Wells Project. Numbers in parenthesis represent percent subsampled.

		Stations					
		6	**7**	**8**	**9**	**10**	**11**
Taxanomic Groups	**Taxa**	**(66%)**	**(33%)**	**(100%)**	**(100%)**	**(100%)**	**(100%)**
Diptera-Chironomidae	*Apedilum sp.*	2	0	0	0	0	0
	Chironomini	0	0	0	0	1	0
	Chironomus sp.	112	72	0	3	0	9
	Cladopelma sp.	0	1	0	2	0	1
	Cladotanytarsus sp.	3	2	0	0	0	0
	Cricotopus bicinctus gr.	0	3	0	0	0	0
	Cricotopus sp.	0	0	0	0	3	0
	Cryptochironomus sp.	8	3	0	2	0	3
	Harnischia sp.	0	0	0	1	0	10
	Microtendipes pedellus gr.	1	0	0	0	2	0
	Monodiamesa sp.	0	1	0	0	0	0
	Orthocladius annectens	0	22	0	0	5	0
	Paracladopelma sp.	0	1	0	0	0	0
	Paratanytarsus sp.	0	0	0	0	1	0
	Phaenopsectra sp.	5	6	0	1	0	0
	Polypedilum sp.	0	0	0	0	1	3
	Procladius sp.	2	0	0	1	0	2
	Psectrocladius sp.	0	0	0	0	3	0
	Stempellinella sp.	0	0	0	0	0	2
	Stictochironomus sp.	0	6	0	0	0	3
	Tanytarsini	1	0	0	0	0	0
	Tanytarsus sp.	75	48	0	4	0	45
Trichoptera	*Hydroptila sp.*	1	0	0	0	2	0
	Nectopsyche sp.	0	0	0	1	27	2
	Ochrotrichia sp.	0	0	1	0	5	0
	Oecetis sp.	0	0	0	14	1	10
Coleoptera	*Dubiraphia sp.*	0	0	0	0	72	24
Diptera	*Ceratopogoninae*	0	0	0	0	0	2
Lepidoptera	*Petrophila sp.*	0	0	0	0	0	0
Gastropoda	*Gyraulus sp.*	0	1	0	0	0	0
	Physa (Physella) sp.	0	0	0	0	1	1
Bivalvia	*Anodonta sp.*	0	0	0	1	0	0
	Corbicula sp.	33	86	4	131	0	97
	Sphaeriidae	0	0	0	0	1	0
Annelida	*Enchytraeidae*	0	0	0	2	0	0
	Limnodrilus hoffmeisteri	264	316	0	0	13	54
	Nais variabilis	1	0	0	0	0	0
	Tubificidae w/ cap setae	11	18	0	0	1	29
Acari	*Acari*	1	1	0	0	5	4
	Hygrobates sp.	0	4	0	2	0	1
	Lebertia sp.	0	0	0	1	1	0
	Limnesia sp.	1	4	0	0	1	1
	Neumania sp.	0	0	0	0	0	18
Crustacea	*Caecidotea sp.*	2	1	0	0	0	0
	Hyalella sp.	1	0	0	1	0	0
	Ostracoda	1	0	0	0	3	8
Other Organisms	*Nematoda*	1	0	0	128	3	5
	Turbellaria	1	0	0	0	0	0
Total Organisms	**Subsample Abundance**	**527**	**596**	**5**	**295**	**152**	**334**
	Corrected Abundance	**801**	**1788**	**5**	**295**	**152**	**334**

Appendix A3. Abundance of different taxa counted from suction dredge samples collected in the Columbia River. Numbers in parenthesis represent percent subsampled.

		Station		
		1	3	5
Taxonomic Group	Taxa	(50%)	(77%)	(100%)
Ephemeroptera	*Caenis sp.*	0	23	0
Odonata	*Coenagrion/Enallagma sp.*	0	1	0
Diptera-Chironomidae	*Cricotopus sp.*	0	0	2
	Dicrotendipes sp.	12	6	14
	Orthocladius Complex	0	0	3
	Paratanytarsus sp.	0	2	7
	Psectrocladius sp.	1	0	0
	Pseudochironomus sp.	1	4	0
Trichoptera	*Hydroptila sp.*	1	0	18
	Mystacides sp.	35	7	0
	Nectopsyche sp.	1	0	0
	Ochrotrichia sp.	6	43	0
	Oecetis sp.	0	3	0
	Oxyethira sp.	0	5	0
	Polycentropus sp.	1	0	13
	Psychomyia sp.	1	0	3
Lepidoptera	*Petrophila sp.*	0	0	1
Gastropoda	*Fossaria sp.*	10	1	0
	Gyraulus sp.	12	66	1
	Lymnaeidae	0	3	0
	Physa (Physella) sp.	3	18	0
	Radix auricularia	1	0	0
	Stagnicola sp.	0	0	7
	Valvata tricarinata	1	72	0
Bivalvia	*Anodonta sp.*	0	2	0
	Corbicula sp.	39	0	0
	Pisidium sp.	31	6	0
	Sphaeriidae	0	0	1
Annelida	*Alboglossiphonia heteroclita*	0	1	0
	Eclipidrilus sp.	1	0	0
	Enchytraeidae	0	2	0
	Helobdella sp.	0	12	0
	Helobdella stagnalis	1	0	0
Acari	*Arrenurus sp.*	0	1	0
	Hygrobates sp.	0	3	0
	Lebertia sp.	6	32	2
	Limnesia sp.	0	12	1
Crustacea	*Amphipoda*	0	3	0
	Caecidotea sp.	371	204	2
	Crangonyx sp.	6	0	2
	Hyalella sp.	2	1	1
	Ostracoda	0	1	0
Other Organisms	*Nematoda*	3	0	1
Total Organisms	**Subsample Abundance**	**546**	**536**	**79**
	Corrected Abundance	**1092**	**697**	**79**

Appendix B

Benthic Macroinvertebrate Fauna Biological Metrics

Appendix B1. Biological metrics for macroinvertebrate fauna collected from colonization baskets at five locations in the Wells Project

	Station				
	1	**2**	**3**	**4**	**5**
Abundance Measures					
Corrected Abundance	682.86	339.00	231.00	5224.00	9184.00
EPT Abundance	7.98	84.00	25.00	312.00	832.00
Dominance Measures					
1st Dominant Taxon	*Turbellaria*	*Fossaria sp.*	*Fossaria sp.*	*Orthocladius Complex*	*Orthocladius Complex*
2nd Dominant Taxon	*Paratanytarsus sp.*	*Ochrotrichia sp.*	*Paratanytarsus sp.*	*Dicrotendipes sp.*	*Paratanytarsus sp.*
3rd Dominant Taxon	*Orthocladius Complex*	*Caecidotea sp.*	*Ochrotrichia sp.*	*Paratanytarsus sp.*	*Dicrotendipes sp.*
1st Dominant Abundance	322.62	107.00	70.00	1520.00	2480.00
2nd Dominant Abundance	95.76	80.00	56.00	1144.00	2240.00
3rd Dominant Abundance	51.30	53.00	20.00	760.00	1872.00
Percent 1st Dominant Taxon	47.25	31.56	30.30	29.10	27.00
Percent 2nd Dominant Taxon (cumulative)	61.27	55.16	54.55	51.00	51.39
Percent 3rd Dominant Taxon (cumulative)	68.78	70.80	63.20	65.54	71.78
Richness Measures					
Species Richness	25.00	23.00	19.00	25.00	22.00
EPT Richness	4.00	2.00	4.00	2.00	4.00
Ephemeroptera Richness	0.00	0.00	1.00	0.00	0.00
Plecoptera Richness	0.00	0.00	0.00	0.00	0.00
Trichoptera Richness	4.00	2.00	3.00	2.00	4.00
Chironomidae Richness	9.00	5.00	2.00	10.00	10.00
Oligochaeta Richness	1.00	0.00	0.00	7.00	3.00
Non-Chiro. Non-Olig. Richness	15.00	18.00	17.00	8.00	9.00
Rhyacophila Richness	0.00	0.00	0.00	0.00	0.00
Community Composition (%)					
Ephemeroptera	0.00	0.00	0.87	0.00	0.00
Plecoptera	0.00	0.00	0.00	0.00	0.00
Trichoptera	1.17	24.78	9.96	5.97	9.06
EPT	1.17	24.78	10.82	5.97	9.06
Coleoptera	0.00	0.00	0.00	0.00	0.00
Diptera	29.55	2.95	32.90	88.21	85.19
Oligochaeta	4.67	0.00	0.00	2.14	1.92
Baetidae	0.00	0.00	0.00	0.00	0.00
Brachycentridae	0.00	0.00	0.00	0.00	0.00
Chironomidae	29.55	2.95	32.90	88.21	85.19
Ephemerellidae	0.00	0.00	0.00	0.00	0.00
Hydropsychidae	0.00	0.00	0.00	0.00	0.70
Odonata	0.00	0.29	0.87	0.00	0.00
Perlidae	0.00	0.00	0.00	0.00	0.00
Pteronarcyidae	0.00	0.00	0.00	0.00	0.00
Simuliidae	0.00	0.00	0.00	0.00	0.00

Appendix B1. Concluded.

	Station				
	1	**2**	**3**	**4**	**5**
Functional Group Composition					
Filterer Richness	1.00	3.00	0.00	1.00	3.00
Gatherer Richness	14.00	7.00	6.00	15.00	10.00
Predator Richness	3.00	3.00	3.00	5.00	5.00
Scraper Richness	3.00	4.00	4.00	1.00	1.00
Shredder Richness	1.00	1.00	1.00	2.00	2.00
Piercer-Herbivore Richness	1.00	1.00	0.00	1.00	1.00
Unclassified	1.00	4.00	3.00	0.00	0.00
Percent Filterers	0.5	6.19	0.00	0.92	5.75
Percent Gatherers	41.07	43.36	49.35	75.04	78.05
Percent Predators	48.75	1.18	1.73	7.04	6.62
Percent Scrapers	8.35	40.71	41.56	0.46	1.05
Percent Shredders	0.17	0.29	0.87	14.70	4.36
Percent Piercer-Herbivores	0.17	1.18	0.00	1.84	4.18
Percent Unclassified	0.17	7.08	4.33	0.00	0.00
Diversity/Evenness Measures					
Shannon-Weaver H' (log 10)	0.82	0.90	0.91	0.92	0.91
Shannon-Weaver H' (log 2)	2.74	3.00	3.02	3.07	3.03
Shannon-Weaver H' (log e)	1.90	2.08	2.10	2.13	2.10
Margalef's Richness	3.68	3.78	3.31	2.80	2.30
Pielou's J'	0.59	0.66	0.71	0.66	0.68
Simpson's Heterogeneity	0.74	0.81	0.83	0.83	0.82
Biotic Indices					
Percent Individuals with HBI Value	98.00	87.02	93.51	97.55	96.86
Hilsenhoff Biotic Index (HBI)	5.40	6.06	6.31	6.48	6.34
Percent Individuals with MTI Value	81.14	83.78	91.77	54.21	64.63
Metals Tolerance Index (MTI)	3.66	3.42	3.12	3.71	3.31
Percent Individuals with FSBI Value	0.17	1.18	0.00	1.84	4.88
Fine Sediment Biotic Index (FSBI)	5.00	5.00	-99.00	5.00	7.00
FSBI – average	0.20	0.22	-99.00	0.20	0.32
FSBI - weighted average	5.00	5.00	-99.00	5.00	4.57
Percent Individuals with TPM Value	8.01	2.95	0.00	46.86	41.64
Temperature Preference Metric (TPM) - average	0.48	0.61	-99.00	0.72	1.00
TPM - weighted average	5.75	2.40	-99.00	4.44	4.63
Karr BIBI Metrics					
Long-Lived Taxa Richness	2.00	3.00	2.00	0.00	0.00
Clinger Richness	6.00	7.00	7.00	6.00	7.00
Percent Clingers	8.35	63.42	48.92	22.05	17.42
Intolerant Taxa Richness	0.00	0.00	0.00	0.00	1.00
Percent Tolerant Individuals	7.92	30.17	18.52	0.29	0.08
Percent Tolerant Taxa	28.00	26.09	21.05	36.00	22.73
Coleoptera Richness	0.00	0.00	0.00	0.00	0.00

Appendix B2. Biological metrics for macroinvertebrate fauna collected from petite ponar grabs at six locations in the Wells Project.

	Stations					
	6	**7**	**8**	**9**	**10**	**11**
Abundance Measures						
Corrected Abundance	801.04	1788.00	5.00	295.00	152.00	334.00
EPT Abundance	1.52	0.00	1.00	15.00	35.00	12.00
Dominance Measures						
1st Dominant Taxon	*Limnodrilus hoffmeisteri*	*Limnodrilus hoffmeisteri*	*Corbicula sp.*	*Corbicula sp.*	*Dubiraphia sp.*	*Corbicula sp.*
2nd Dominant Taxon	*Chironomus sp.*	*Corbicula sp.*	*Ochrotrichia sp.*	*Nematoda*	*Nectopsyche sp.*	*Limnodrilus hoffmeisteri*
3rd Dominant Taxon	*Tanytarsus sp.*	*Chironomus sp.*		*Oecetis sp.*	*Limnodrilus hoffmeisteri*	*Tanytarsus sp.*
1st Dominant Abundance	401.28	948.00	4.00	131.00	72.00	97.00
2nd Dominant Abundance	170.24	258.00	1.00	128.00	27.00	54.00
3rd Dominant Abundance	114.00	216.00	0.00	14.00	13.00	45.00
Percent 1st Dominant Taxon	50.09	53.02	80.00	44.41	47.37	29.04
Percent 2nd Dominant Taxon (cumulative)	71.35	67.45	100.00	87.80	65.13	45.21
Percent 3rd Dominant Taxon (cumulative)	85.58	79.53	100.00	92.54	73.68	58.68
Richness Measures						
Species Richness	21.00	19.00	2.00	16.00	21.00	23.00
EPT Richness	1.00	0.00	1.00	2.00	4.00	2.00
Ephemeroptera Richness	0.00	0.00	0.00	0.00	0.00	0.00
Plecoptera Richness	0.00	0.00	0.00	0.00	0.00	0.00
Trichoptera Richness	1.00	0.00	1.00	2.00	4.00	2.00
Chironomidae Richness	9.00	11.00	0.00	7.00	7.00	9.00
Oligochaeta Richness	3.00	2.00	0.00	1.00	2.00	2.00
Non-Chiro. Non-Olig. Richness	9.00	6.00	2.00	8.00	12.00	12.00
Rhyacophila Richness	0.00	0.00	0.00	0.00	0.00	0.00
Community Composition (%)						
Ephemeroptera	0.00	0.00	0.00	0.00	0.00	0.00
Plecoptera	0.00	0.00	0.00	0.00	0.00	0.00
Trichoptera	0.19	0.00	20.00	5.08	23.03	3.59
EPT	0.19	0.00	20.00	5.08	23.03	3.59
Coleoptera	0.00	0.00	0.00	0.00	47.37	7.19
Diptera	39.66	27.68	0.00	4.75	10.53	23.95
Oligochaeta	52.37	56.04	0.00	0.68	9.21	24.85
Baetidae	0.00	0.00	0.00	0.00	0.00	0.00
Brachycentridae	0.00	0.00	0.00	0.00	0.00	0.00
Chironomidae	39.66	27.68	0.00	4.75	10.53	23.35
Ephemerellidae	0.00	0.00	0.00	0.00	0.00	0.00
Hydropsychidae	0.00	0.00	0.00	0.00	0.00	0.00
Odonata	0.00	0.00	0.00	0.00	0.00	0.00
Perlidae	0.00	0.00	0.00	0.00	0.00	0.00
Pteronarcyidae	0.00	0.00	0.00	0.00	0.00	0.00
Simuliidae	0.00	0.00	0.00	0.00	0.00	0.00

Appendix B2. Concluded.

	Stations					
	6	**7**	**8**	**9**	**10**	**11**
Functional Group Composition						
Filterer Richness	20.87	22.48	80.00	46.10	1.97	42.51
Gatherer Richness	74.95	73.83	20.00	3.05	68.42	41.92
Predator Richness	2.66	2.01	0.00	50.17	7.24	13.77
Scraper Richness	0.95	1.17	0.00	0.34	0.66	0.30
Shredder Richness	0.00	0.50	0.00	0.34	20.39	1.50
Piercer-Herbivore Richness	0.19	0.00	0.00	0.00	1.32	0.00
Unclassified	0.38	0.00	0.00	0.00	0.00	0.00
Percent Filterers	4.00	2.00	1.00	3.00	2.00	2.00
Percent Gatherers	8.00	10.00	1.00	5.00	9.00	9.00
Percent Predators	6.00	4.00	0.00	6.00	5.00	9.00
Percent Scrapers	1.00	2.00	0.00	1.00	1.00	1.00
Percent Shredders	0.00	1.00	0.00	1.00	3.00	2.00
Percent Piercer-Herbivores	1.00	0.00	0.00	0.00	1.00	0.00
Percent Unclassified	1.00	0.00	0.00	0.00	0.00	0.00
Diversity/Evenness Measures						
Shannon-Weaver H' (log 10)	0.66	0.69	0.22	0.54	0.84	1.01
Shannon-Weaver H' (log 2)	2.20	2.31	0.72	1.79	2.78	3.34
Shannon-Weaver H' (log e)	1.53	1.60	0.50	1.24	1.93	2.31
Margalef's Richness	2.99	2.40	0.62	2.64	3.98	3.79
Pielou's J'	0.50	0.54	0.72	0.45	0.63	0.74
Simpson's Heterogeneity	0.68	0.67	0.40	0.61	0.74	0.85
Biotic Indices						
Percent Individuals with HBI Value	93.17	84.23	20.00	54.58	98.68	64.97
Hilsenhoff Biotic Index (HBI)	9.23	9.32	4.00	5.60	5.89	8.00
Percent Individuals with MTI Value	40.04	22.65	20.00	52.88	80.26	32.93
Metals Tolerance Index (MTI)	3.66	3.64	3.00	4.67	3.89	3.58
Percent Individuals with FSBI Value	0.19	0.00	0.00	0.00	1.32	0.00
Fine Sediment Biotic Index (FSBI)	5.00	-99.00	-99.00	-99.00	5.00	-99.00
FSBI – average	0.24	-99.00	-99.00	-99.00	0.24	-99.00
FSBI - weighted average	5.00	-99.00	-99.00	-99.00	5.00	-99.00
Percent Individuals with TPM Value	14.61	8.56	0.00	1.69	51.32	22.16
Temperature Preference Metric (TPM) -	0.29	0.16	-99.00	0.25	0.48	0.48
TPM - weighted average	2.00	1.94	-99.00	2.00	1.19	1.78
Karr BIBI Metrics						
Long-Lived Taxa Richness	1.00	1.00	1.00	2.00	1.00	1.00
Clinger Richness	6.00	5.00	1.00	4.00	9.00	7.00
Percent Clingers	15.56	9.23	20.00	6.78	77.63	29.34
Intolerant Taxa Richness	0.00	0.00	0.00	0.00	0.00	0.00
Percent Tolerant Individuals	37.52	22.31	0.00	10.56	12.67	47.00
Percent Tolerant Taxa	42.86	42.11	0.00	50.00	28.57	47.83
Coleoptera Richness	0.00	0.00	0.00	0.00	1.00	1.00

Appendix B3. Biological metrics for macroinvertebrate fauna collected by suction dredge at three locations in the Wells Project.

	Station		
	1	**3**	**5**
Abundance Measures			
Corrected Abundance	1092.00	696.80	79.00
EPT Abundance	90.00	105.30	34.00
Dominance Measures			
1st Dominant Taxon	*Caecidotea sp.*	*Caecidotea sp.*	*Hydroptila sp.*
2nd Dominant Taxon	*Corbicula sp.*	*Valvata tricarinata*	*Dicrotendipes sp.*
3rd Dominant Taxon	*Mystacides sp.*	*Gyraulus sp.*	*Polycentropus sp.*
1st Dominant Abundance	742.00	265.20	18.00
2nd Dominant Abundance	78.00	93.60	14.00
3rd Dominant Abundance	70.00	85.80	13.00
Percent 1st Dominant Taxon	67.95	38.06	22.78
Percent 2nd Dominant Taxon (cumulative)	75.09	51.49	40.51
Percent 3rd Dominant Taxon (cumulative)	81.50	63.81	56.96
Richness Measures			
Species Richness	23.00	28.00	17.00
EPT Richness	6.00	5.00	3.00
Ephemeroptera Richness	0.00	1.00	0.00
Plecoptera Richness	0.00	0.00	0.00
Trichoptera Richness	6.00	4.00	3.00
Chironomidae Richness	3.00	4.00	4.00
Oligochaeta Richness	1.00	1.00	0.00
Non-Chiro. Non-Olig. Richness	19.00	23.00	13.00
Rhyacophila Richness	0.00	0.00	0.00
Community Composition (%)			
Ephemeroptera	0.00	4.29	0.00
Plecoptera	0.00	0.00	0.00
Trichoptera	8.24	10.82	43.04
EPT	8.24	15.11	43.04
Coleoptera	0.00	0.00	0.00
Diptera	2.56	2.61	32.91
Oligochaeta	0.18	0.37	0.00
Baetidae	0.00	0.00	0.00
Brachycentridae	0.00	0.00	0.00
Chironomidae	2.56	2.61	32.91
Ephemerellidae	0.00	0.00	0.00
Hydropsychidae	0.00	0.00	0.00
Odonata	0.00	0.19	0.00
Perlidae	0.00	0.00	0.00
Pteronarcyidae	0.00	0.00	0.00
Simuliidae	0.00	0.00	0.00

Appendix B3. Concluded.

	Station		
	1	**3**	**5**
Functional Group Composition			
Filterer Richness	12.82	1.49	1.27
Gatherer Richness	79.67	55.60	45.57
Predator Richness	2.01	9.70	21.52
Scraper Richness	4.76	16.42	6.33
Shredder Richness	0.18	0.00	2.53
Piercer-Herbivore Richness	0.18	0.93	22.78
Unclassified	0.18	15.86	0.00
Percent Filterers	2.00	2.00	1.00
Percent Gatherers	9.00	12.00	7.00
Percent Predators	4.00	6.00	4.00
Percent Scrapers	4.00	4.00	3.00
Percent Shredders	1.00	0.00	1.00
Percent Piercer-Herbivores	1.00	1.00	1.00
Percent Unclassified	1.00	3.00	0.00
Diversity/Evenness Measures			
Shannon-Weaver H' (log 10)	0.60	0.95	1.01
Shannon-Weaver H' (log 2)	1.98	3.16	3.35
Shannon-Weaver H' (log e)	1.37	2.19	2.32
Margalef's Richness	3.14	4.12	3.66
Pielou's J'	0.44	0.66	0.82
Simpson's Heterogeneity	0.52	0.81	0.88
Biotic Indices			
Percent Individuals with HBI Value	91.39	75.19	96.20
Hilsenhoff Biotic Index (HBI)	7.43	7.28	6.32
Percent Individuals with MTI Value	83.88	72.57	88.61
Metals Tolerance Index (MTI)	4.69	4.11	3.36
Percent Individuals with FSBI Value	0.18	0.00	22.78
Fine Sediment Biotic Index (FSBI)	5.00	-99.00	5.00
FSBI – average	0.22	-99.00	0.29
FSBI - weighted average	5.00	-99.00	5.00
Percent Individuals with TPM Value	0.55	0.19	30.38
Temperature Preference Metric (TPM) –	0.17	0.07	0.88
TPM - weighted average	2.00	2.00	2.75
Karr BIBI Metrics			
Long-Lived Taxa Richness	2.00	2.00	1.00
Clinger Richness	7.00	5.00	5.00
Percent Clingers	5.86	21.64	44.30
Intolerant Taxa Richness	1.00	0.00	1.00
Percent Tolerant Individuals	38.98	56.50	5.26
Percent Tolerant Taxa	30.43	35.71	23.53
Coleoptera Richness	0.00	0.00	0.00

Appendix C

Mollusk Fauna Abundance and Diversity

Appendix C1. Mollusks identified from surveys in the Methow River.

Location	Taxon	Common Name(s)	Specimens	Comments
Station # 12 Methow River	*Margaritinopsis falcata*	Western Pearlshell	3	> 3 < 5 years old
	Corbicula sp.		Fragments only	Identified from fragments; rare
	Sphaerium striatinum	Striate Fingernail Clam	Fragments only	Identified from fragments; rare
	Pisidium compressum	Ridgebeak Peaclam	7	Most specimen were dead; rare
	Musculium raymondi	Western Lake Fingernail Clam	1	One live specimen
	Fisherola nuttalli	Giant Columbia River Limpet or Shortface Lanx	12	Most adults all dead
	Fluminicola fuscus	Giant Columbia River Spire Snail or Ashy Pebblesnail	84	Most found dead; 1 live specimen; size range from small to gerontic; several operculi also (from live specimens)
Station # 13 Methow River	*Margaritinopsis falcata*	Western Pearlshell	7	All <10 years old
	Anodonta kennerlyi	Western Floater	3	All <5 years old
	Pisidium compressum	Ridgebeak Peaclam	40	Full ontogeny, including dead
	Pisidium casertanum	Ubiquitous Peaclam	11	Range but not full ontogeny; all live
	Radix auricularia	Big-ear Radix	6	Immature
	Fossaria obrussa	Golden Fossaria	1	Immature
	Fossaria (Bakerilymnaea) bulimoides	Prairie Fossaria	1	Adult
	Gyraulus parvus	Ash Gyro	1	Adult
	Fluminicola fuscus	Giant Columbia River Spire Snail or Ashy Pebblesnail	Fragments only	Fragmentary only (dead); very rare

Appendix C2. Mollusks identified from two stations in the Okanogan River.

Location	Taxon	Common Name(s)	Specimens	Comments
Station # 15 Okanogan River	*Gonidea angulata*	Western Ridgemussel	36	Essentially complete ontogeny; all live
	Sphaerium striatinum	Striate Fingernail Clam	108	Complete ontogeny but most adult, live
	Pisidium compressum	Ridgebeak Peaclam	10mni[3]	Rare; most adult; ½ dead
	Pisidium casertanum	Ubiquitous Peaclam	4mni	Rare; live
	Corbicula fluminea	Asian Clam	1mni	Rare; live
	Fluminicola fuscus	Giant Columbia River Spire Snail or Ashy Pebblesnail	16	All live or recent dead; none more than ½ grown; may include 1 or 2 small Fluminicola n. sp.
	Ferrissia californica	Fragile Ancylid	2	Very rare; small
	Physella sp.		2	Very rare; juvenile
	Gyraulus parvus	Ash Gyro	1	Very rare; half grown
Station # 16 Okanogan River	*Gonidea angulata*	Western Ridgemussel	35	Common; Full ontogeny but most <5 years old; includes dead, but mostly as small fragments
	Anodonta sp.		1	Very young juvenile; likely kennerlyi, judging from beak sculpture
	Sphaerium striatinum	Striate Fingernail Clam	10	Rare; most adult
	Pisidium compressum	Ridgebeak Peaclam	66mni	Common; full ontogeny but many small; some recent and long-dead
	Musculium raymondi	Western Lake Fingernail Clam	1	One live
	Fluminicola fuscus	Giant Columbia River Spire Snail or Ashy Pebblesnail	1	One long dead, small
	Physella sp.	Rocky Mountain Physa	8	Several live; most very young; but likely *propinqua*
	Gyraulus parvus	Ash Gyro	1	Rare, live
	Ferrissia californica	Fragile Ancylid	1	Rare, recently dead

[1] mni= minimum number of individuals.

Appendix C3. Mollusks identified from two stations in the Columbia River.

Location	Taxon		Specimens	Comments
Station # 14 Columbia River	*Anodonta kennnerlyi*	Western Floater	7	Rare; all young (<5 years old)
	Corbicula fluminea	Asian Clam	703	Abundant; but small only (<15 mm) except for 1 or 2
	Pisidium compressum	Ridgebeak Peaclam	306	Abundant; full ontogeny, common dead also
	Valvata tricarinata	Three Ridge Valvata	45	Uncommon; first 2/3 ontogeny
	Physella propinqua propinqua	Rocky Mountain Physa	72	Common, but all small (<1/6 adult size), live
	Gyraulus parvus	Ash Gyro	157	Nearly complete ontogeny but lacking largest; some recently dead
	Fossaria (F.) obrussa	Golden Fossaria	6	Very rare; immature; 5 dead
	Fossaria (Bakerilymnaea) bulimoides	Prairie Fossaria	90	Common live, full ontogeny; also dead
	Radix auricularia	Big-ear Radix	27	Uncommon live & dead; full ontogeny to ½ adult size
Station # 17 Columbia River	*Anodonta kennerlyi*	Western Floater	24	Common; nearly complete ontogeny, except for very old
	Corbicula fluminea	Asian Clam	256	Abundant; but small only (<15 mm); w/only 1 > 15mm & 1< 4mm
	Pisidium compressum	Ridgebeak Peaclam	117	Abundant; full ontogeny
	Valvata tricarinata	Three Ridge Valvata	114	Common; first 2/3 ontogeny
	Physella propinqua propinqua	Rocky Mountain Physa	4	Very rare; <1/3 grown; but very likely this species
	Gyraulus parvus	Ash Gyro	41	Nearly complete ontogeny, including some dead
	Fossaria (F.) obrussa	Golden Fossaria	1	Very rare; immature
	Fossaria (Bakerilymnaea) bulimoides	Prairie Fossaria	67	Common live, full ontogeny; also dead
	Radix auricularia	Big-ear Radix	24	Common live & dead; mostly to ½ grown

Bonneville Power Administration. 2010. Columbia River High-Water Operations, June 1-14, 2010. Final Report.

September 2010

Columbia River high-water operations

[June 1–14, 2010]

The Federal Columbia River Power System is operated for multiple public purposes, including flood control, irrigation, power production, navigation, recreation and municipal water supply. The system is also operated to protect the river's fish, including salmon, steelhead, sturgeon and bull trout listed as threatened or endangered under the Endangered Species Act. The U.S. Army Corps of Engineers and Bureau of Reclamation, which own the federal dams, operate them within constraints established to assure the requirements of all the multiple purposes are met.

The Bonneville Power Administration markets power from the federal dams within the constraints and requirements for other river purposes. Flood control, protection of fish listed under the Endangered Species Act, compliance with the Clean Water Act and other requirements take precedence over power production.

As part of its mission to market federal hydropower, BPA is the primary high-voltage transmission provider in the Columbia River Basin. Consistent with Federal Energy Regulatory Commission policies for open-access, non-discriminatory high-voltage transmission, BPA integrates new power sources into its transmission grid that request such service.[1] In the past few years, there has been remarkable growth in wind power projects interconnecting to BPA's transmission grid, driven by renewable portfolio standards in Washington and Oregon and increasingly by California's 33 percent renewable portfolio standard.[2] As a result, generating capacity is being developed in the Northwest far in advance of regional power demand.

Due to the wide seasonal and annual variations in Columbia River streamflows and the high variability of wind power output, BPA has been aware for some time that a combination of high streamflows and high wind could pose new challenges for Columbia River system operations. This expectation was fulfilled when high streamflows emerged for a short period this June in an otherwise low-water year. The June high-water event was likely a preview of situations BPA and the region will face again and for longer periods, particularly during years of heavy snowpack.

This paper describes how system operators managed through this first coincidence of high wind and high streamflows. In addition to actions within the hydro system itself, these steps included reducing nuclear plant output, storing water in Canadian reservoirs, providing power at little or no cost to utilities to displace operation of their thermal power plants, and temporarily reducing amounts of balancing reserves provided to wind power projects.

Many parties are involved in some aspect of these operations, but few see the actions of all. This overview is intended to provide a common context for regional conversations on additional approaches BPA and others might take to respond to future high-water events as the multiple demands on the river evolve and the region's wind generating capacity grows.

The Endangered Species Act, Clean Water Act and Biological Opinion on FCRPS operations are binding constraints on federal power production. With the growing imbalance in Northwest power supply and demand, new protocols, policies and tools may be needed to assure reliable and equitable power operation within the physical limits of this highly interdependent system.

1 For details, see *www.bpa.gov/corporate/pubs/fact_sheets/09fs/factsheet_-_Investing_in_the_NW_transmission_system.pdf.*

2 For details, go to *www.bpa.gov/go/wind.*

BACKGROUND

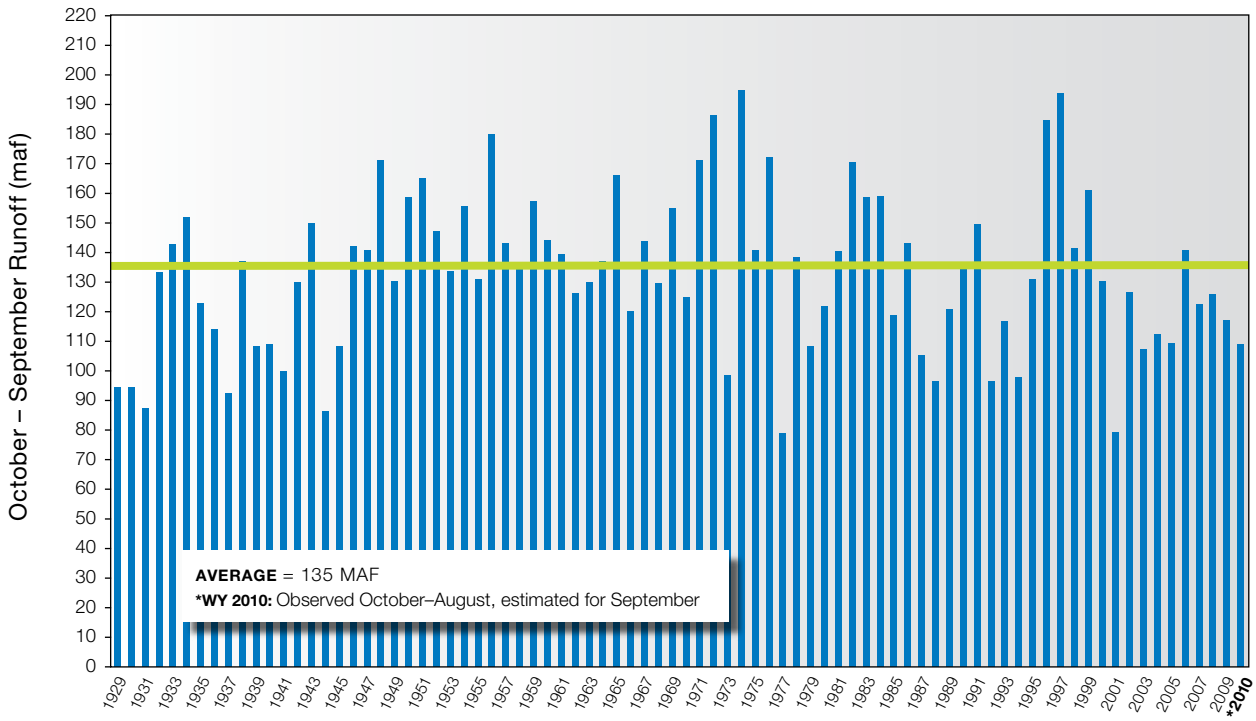
Responding to the unexpected

The Columbia River system typically sees periods of high flows in spring as the weather warms and snowpack melts. After a dry winter, spring 2010 river flows were expected to stay fairly low. Throughout April and May, FCRPS operation focused on providing enough river flow and spill to meet objectives designed to protect endangered juvenile salmon migrating to the Pacific and on refilling reservoirs in Idaho, Montana and Washington by July.

In early June, however, a strong Pacific jet stream brought storm systems with heavy precipitation and flooding in some areas. This was the first significant high-water event in several years. Snake River flows nearly tripled from 80,000 cubic feet per second (80 kcfs) to 210 kcfs in five days. Inflows into Lake Roosevelt behind Grand Coulee Dam rose 70 percent. The January through July water supply forecast for the Columbia River Basin increased nearly 10 million acre-feet as measured at The Dalles, Ore. — from about two-thirds to about three-fourths of average — between mid-May (71.2 maf) and mid-June (80.9 maf).

These flows were more than adequate to meet flow and spill objectives for fish passage. Operators' focus shifted to developing strategies and modifying operations to reduce excess spill and keep total dissolved gas (nitrogen saturation) at levels safe for fish. Meeting this objective involved numerous actions quickly taken by many parties, including BPA, the Corps, Reclamation, Energy Northwest, and utilities and independent power producers in the Northwest, British Columbia and California.

Columbia River water year runoff at The Dalles, Ore.
[1929–2010]



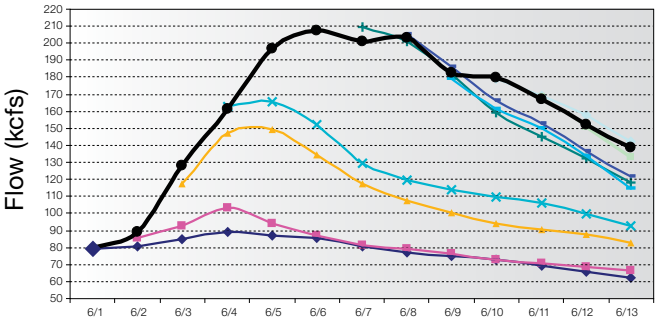
Overall, the 2009–2010 water year was another low-water year in a low-water decade.

Day-average inflows

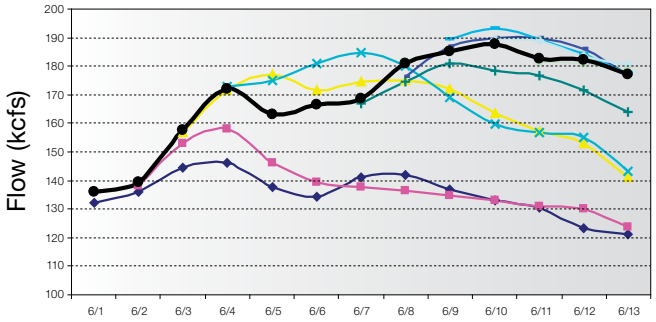
[modeled and actual June 1–13]

These graphs show how fast, hard and unexpectedly high water hit the Columbia River system. They measure successive streamflow forecasts and actual streamflows at Lower Granite Dam on the lower Snake River, Grand Coulee Dam on the mainstem Columbia, and at McNary dam, which lies below the confluence of the Snake and Columbia rivers. The dark blue and magenta lines depict what forecasters expected to see as of June 1 and 2. The heavy black lines are what actually happened. Other lines correspond to updated flow forecasts.

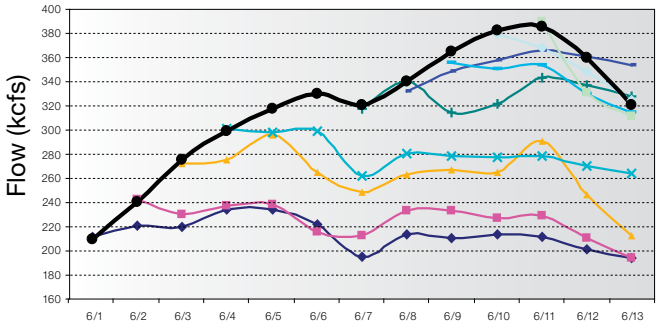
LOWER GRANITE DAM

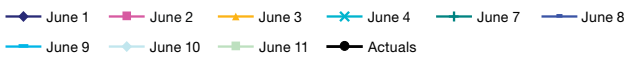


GRAND COULEE DAM



MCNARY DAM





HIGH FLOWS AND THE COLUMBIA RIVER SYSTEM

High flows in the Columbia River system are not rare; there is a one-in-three chance of flows at least as high as those of early June 2010 occurring in any year and lasting for one month or more.

The Columbia River system has an exceptionally wide range of high and low flows, with a historic minimum to maximum flow ratio of 1 to 35 (compared to 1 to 5 for the Mississippi). Flood control is a significant purpose of many of the Northwest's federal dams. The Vanport Flood of 1948 spurred reservoir development in the upper Columbia and was a major impetus for the Columbia River Treaty with Canada in 1964, which doubled Columbia reservoir storage. Even with the Treaty reservoirs, the federal system can store less than 40 percent of an average year's 134 million acre-feet of runoff.[3]

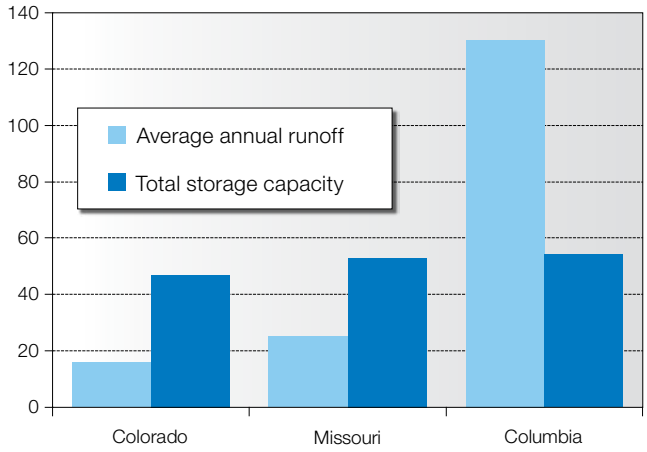
All dams in the Columbia River system are highly interdependent — water released from a headwaters dam can affect flows at up to 19 dams downstream. Northwest utilities coordinate power plant operations to make the best use of this interdependent hydropower under the Pacific Northwest Coordination Agreement[4] established in 1964. Transmission is also an important aspect of this interdependent system. Power generation opportunities can be constrained by transmission availability, and BPA Transmission Services relies heavily on federal hydropower to provide reserves that keep the electrical system in balance and operating reliably.

Water that cannot be stored necessarily flows downstream. Since the 1970s, BPA and other Northwest hydro producers have routinely sold surplus power produced during times of high streamflows at very low rates to utilities in the Northwest and California to encourage operators

3 As traditionally measured at The Dalles, Ore.

4 For details, see, *Columbia River System: The Inside Story*.

Columbia River runoff and storage compared to the Colorado and Missouri rivers



The Columbia River system has limited reservoir storage.

of coal, oil, natural gas and other power plants to reduce output of their plants and replace it with surplus hydropower when available.

In recent years, three new factors have been added to this equation.

1) The wholesale power market was deregulated in the 1990s, and power generation functionally separated from wholesale transmission. This has added numerous market participants such as independent power producers as well as complexities in the relationships among the players. In some circumstances, power generators may not want their generation displaced, because they may have economic incentives or reliability requirements that cause them to continue to generate, even if BPA offers hydro power at $0 per megawatt-hour.

2) Flow augmentation requirements for Columbia and Snake River salmon and steelhead listed under the Endangered Species Act have dramatically changed the way the reservoirs are managed, generally reducing storage space in reservoirs. Operators seek to refill system reservoirs by late June. If the runoff pattern is "flashy" with large surges of runoff, a higher proportion of the runoff may be forced through the system quickly due to lack of available reservoir storage.

3) About 3,000 megawatts of wind power generators have connected to BPA's transmission grid in the Columbia River Basin, adding highly variable renewable generation to the hydro base of the Columbia River system. This growth has been driven by Renewable Portfolio Standard requirements in Oregon, Washington and California, where an executive order would increase the state's current 20 percent RPS to 33 percent by 2020. One of the key variables is the quantity of renewable energy California utilities can provide from out of state resources. The ultimate decision on this issue could have a significant impact on the Northwest and other regions with large renewable resource endowments.

4) The rapid increase in wind power in the Northwest has increased the Northwest power system's maximum generation output significantly, but also requires providing balancing reserves to the wind generators, which now consumes a significant portion of the operating flexibility of the FCRPS. Wind generating capacity connected to BPA's transmission grid is expected to double by 2013. Regionally, including areas outside BPA's balancing authority, more than 5,000 MW of wind generation are currently installed. This also is expected to increase significantly by 2013.

FISH PROTECTION REQUIREMENTS AND SPILL

Juvenile fish migrating downstream in the Columbia and Snake rivers pass through up to eight federal dams.

Under the 2008 Federal Columbia River Power System Biological Opinion for protection of salmon and steelhead listed under the Endangered Species Act, certain amounts of water are required to be spilled at the eight mainstem projects rather than

passed through their turbines for fish passage each spring and summer.

However, excessive spill can result in high levels of total dissolved gas in the water, which can cause gas bubble trauma in fish — similar to the bends in divers. To protect fish from gas bubble trauma, state water quality standards under the Clean Water Act limit allowable levels of total dissolved gas to 110 percent saturation at any point of collection on the river.

In some cases, the amount of voluntary spill required for ESA-listed fish under the 2008 BiOp exceeds the limit allowed by the state water quality standards. The states of Washington and Oregon have authorized exceptions to these standards for the purpose of providing improved fish passage. The Corps submits a Gas Abatement Plan to the Department of Ecology of the state of Washington to request an adjustment to the state water quality standards that would allow total dissolved gas levels up to 120 percent of normal gas saturation levels in the tailraces of the eight mainstem dams and 115 percent saturation in their forebays. Additionally, a waiver is requested from the state of Oregon's Department of Environmental Quality to allow total dissolved gas levels up to 120 percent saturation in the tailraces of the eight mainstem dams.

In addition to voluntary spill for fish passage, involuntary spill can occur during high streamflows when all turbines at a dam are running at capacity or when insufficient market for power reduces use of some turbines and there is inadequate reservoir storage available. When this occurs, spill is added incrementally across all federally owned projects to prevent excessively high total dissolved gas levels. While not part of the criteria adjustment requested for the eight mainstem fish passage projects, the Gas Abatement Plan includes spill at Grand Coulee and Chief Joseph dams as operational measures to manage total dissolved gas levels in the Columbia River that result from involuntary spill.

The amount of total spill that can pass the eight mainstem dams without causing dangerous levels of total dissolved gas today is higher than in past decades, because flow deflectors or "flip lips" have been installed on all lower Snake and Columbia federal dams plus Chief Joseph Dam. Flow deflectors allow the energy in the spill to be dissipated closer to the water surface, allowing more of the gas in the spill to dissipate rather than dissolve in the water. Flow deflectors at Chief Joseph Dam, for example, increased allowable spill from 20 kcfs to 100 kcfs.

When flow goes above about 150 kcfs in the Snake River, total dissolved gas levels can no longer be managed to meet the 120 percent limit, where applicable, even with all turbines running at full output. Snake River flows peaked on June 6 at 207 kcfs and remained above 200 kcfs through June 9. At this point, half of the river was flowing through the powerhouse and the other half through the spillway. Because flows were above the project's powerhouse capacity, total dissolved gas levels in the water below Lower Granite Dam reached 130 percent saturation.

The lower Columbia River can sustain much higher flows before reaching total dissolved gas levels above 120 percent. Peak flows during the period were near 400 kcfs in the lower river, but the lower Columbia River dams experienced lower total dissolved gas levels, with elevated levels only at McNary and Bonneville dams. Total dissolved gas levels[5] just below McNary Dam peaked near 122 percent on June 10–11. Total dissolved gas levels peaked at 116 percent June 6, at 117 percent June 12 and 13 and at 118 percent June 23 in the forebay of Bonneville Dam.

Juvenile fish monitored, tested

The Pacific States Marine Commission regularly monitors the condition of migrating salmon smolts. During the first two weeks of June 2010, tests occurred at Lower Granite, Little Goose, Lower Monumental, McNary and Bonneville dams. Of 2,238 fish tested between June 1 and June 22, only 31 fish showed any symptoms of gas bubble trauma. Of these, 23 were

5 Total dissolved gas levels by dam, by hour, are posted at: *www.nwd-wc.usace.army.mil/tmt/wcd/tdg/months.html#L*.

ranked at the mildest level. Only one showed severe symptoms of gas bubble trauma. At these levels of detection, the effects of gas bubble trauma on smolts throughout the first three weeks of June appear to have been minimal.

FEDERAL ACTIONS TAKEN

Generation: less thermal, more hydro

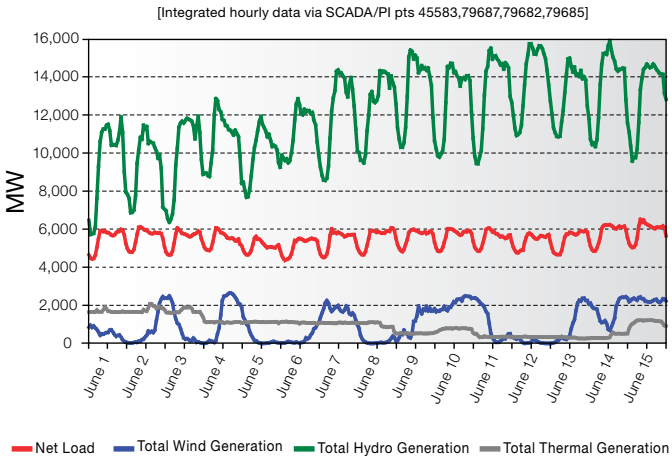
To minimize excess spill, federal hydro generators produced at times more than twice as much power as needed to meet BPA loads. Since generation must equal load, BPA provided power to other utilities to keep as many of the available hydro generators on line as possible. BPA used as much of its Northwest transmission network and interregional intertie transmission as possible to provide surplus hydro power to displace others' generation. BPA sold this power at prices down to $0/MWh to reduce excess spill and manage total dissolved gas levels. Hydropower output reflected the maximum possible production, limited by transmission availability and the market for power at zero cost.

During the event, regional thermal generation significantly declined as utilities consumed very low or no cost BPA hydropower instead. Loads remained fairly flat and low due to cool weather. Wind power fluctuated between zero and almost full output as storms blew through the region.

This graph at left shows the load (red line) and power generation within BPA's balancing authority in the high-flow period, regardless of ownership. The hydro (green line) is primarily federal hydropower; thermal generation (grey line) includes the Columbia Generating Station nuclear plant and resources operated by independent power producers; wind generation (blue line) comes from wind projects with a combined generating capacity of 2,830 MW, primarily east of the Columbia River Gorge, also owned by independent power producers.

BPA balancing authority load, total wind, hydro and thermal generation

[June 1–15, 2010]



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Other steps to reduce excess spill

Maximizing hydropower generation was not enough to manage the high flows and prevent reservoirs from overfilling. Additional water was spilled at several hydro projects to keep reservoirs from getting too full. This additional spill is called lack-of-market spill, since it would not have been necessary had there been additional market for power.

During this period, BPA, the Corps and Reclamation took the following actions to minimize dissolved gas levels while providing other system services, including wind balancing reserves:

- Canceled or delayed all non-essential generating unit outages on the Snake and Columbia dams until flows subsided.
- Moved spill to Grand Coulee, Chief Joseph, Dworshak and Willamette River dams and moved generation to the fish-passage projects.

- Reduced flows at Albeni Falls Dam as much as possible.
- Arranged with the Corps to use 2 feet of flood control space in John Day reservoir to reduce spill and prevent flooding in the lower Columbia (i.e., additional water could be stored behind the dam).
- Shaped as much Hungry Horse Dam and Dworshak Dam generation as possible into hours of heavy electricity use.

Seeking further ways to minimize dissolved gas levels by working with other regional partners, BPA also:

- Asked Energy Northwest to limit the output of the Columbia Generating Station nuclear plant to the lowest possible level that would not risk its ability to return to full power.
- Asked B.C. Hydro to reduce flows at Arrow Dam from 25 kcfs on June 9 to 20 kcfs on June 11 and through the rest of the high-flow period.
- Reduced wind balancing reserves for a few days in an attempt to minimize spill caused by unscheduled energy produced by wind generators.
- Suspended transmission control system maintenance to keep all possible transmission lines in service through the high-flow period.
- Worked with neighboring utilities to defer their non-emergency transmission maintenance, including intertie maintenance, throughout the high-flow period.
- Moved generation around the system to minimize capacity reductions on intertie lines to California while maintaining transmission reliability.

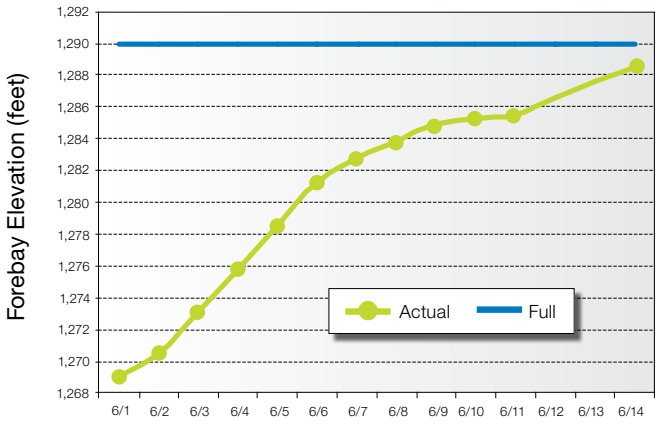
The following sections describe some of these efforts in more detail.

Reservoirs filled quickly

During the event, three of the five large federal Columbia River system reservoirs filled quickly,

Grand Coulee Dam refill

[June 1–14]



Grand Coulee Dam filled quickly to reduce streamflows downstream.

and a fourth was already close to full. The three Columbia River Treaty dams in Canada owned by B.C. Hydro — Mica, Duncan and Arrow — were all full by June 15.

Grand Coulee Dam's Lake Roosevelt filled as much as 2 feet a day in the first half of June and reached full in the third week of June. Grand Coulee Dam in Washington and Dworshak Dam in Idaho each filled about 19 feet during the period. Hungry Horse Dam in Montana filled 11.5 feet. All were near full by the end of the period.[6] Dworshak Dam, which had not been expected to refill this year, filled 2 feet a day and was approaching full by June 8, requiring higher outflows than planned at that reservoir. Albeni Falls was close to full on June 1 and remained so.

The exception was Libby Dam in Montana. Libby was operating to provide flows and spill for endangered Kootenai River white sturgeon and was not available to refill at that time to reduce streamflows downstream.

6 Coulee was 96.1, Horse 94.3 and Dworshak 99.1 percent full by the end of June 13.

Nuclear plant output reduced

The Columbia Generating Station nuclear plant is owned by Energy Northwest, a consortium of Washington state utilities, and its output is marketed by BPA. It was scheduled to reduce its output on June 4 to repair a condenser leak, which it did. The plant had been scheduled to return to full output on June 7. Instead, at BPA's request, Energy Northwest reduced generation, first to 30 percent on June 8 and then, from June 11 until flows subsided, to less than 20 percent of full output, the lowest level possible without taking the plant to cold restart (a lengthy and risky process). As high flows continued after the peak period passed, Columbia Generating Station continued to cycle from 100 percent output during the day to 85 percent output at night, when loads drop significantly, through June and into July.

Note that "cycling a nuclear plant" — reducing its generation for economic or environmental dispatch — is not normal utility practice and not something BPA takes lightly or recommends as regular utility practice. Nuclear plants are most efficient at steady full output. Because Columbia Generating Station is the sole thermal project in BPA's resource base, BPA has worked with Energy Northwest to develop dispatch protocols to reduce nuclear output during high water when necessary.

Other thermal generation unknown

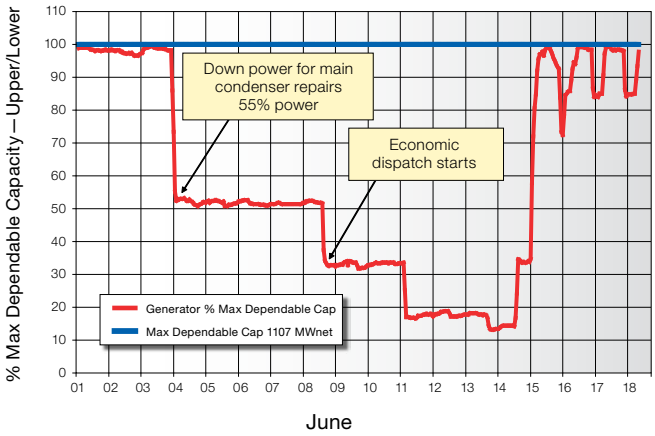
The thermal generation within BPA's balancing authority area was at very low levels during this period, as shown in the grey line in the graph on page 6.

This graph shows only load and generation in BPA's balancing authority area. BPA's knowledge of specific generation operating outside its balancing authority is limited and in large part anecdotal or inferred from transmission scheduled on BPA lines. Only the Western Electricity Coordinating Council System Coordinator has complete information on which specific resources outside the BPA balancing authority area are running in real time.

Columbia Generating Station

NUCLEAR PLANT

[June 2010 power history]



Nuclear output was reduced.

Balancing reserves to wind generators reduced

Most of the wind generation located in BPA's transmission grid is owned or under contract to non-federal utilities throughout the Northwest and California. Only about 20 percent is consumed by utilities in BPA's balancing authority. The remaining 80 percent uses BPA transmission capacity to move wind energy to purchasing utilities elsewhere. A key BPA role is to provide transmission services and balancing reserves to the wind generators in BPA's area, regardless of where the wind power is used. Balancing reserves correct for deviations between scheduled and actual wind output within each hour.

Columbia River Gorge wind patterns are extremely variable. Storms passing through the gorge cause very large up and down ramps that are hard to predict with precision. To provide balancing reserves for the roughly 3,000 MW of wind power currently interconnected to the federal system, BPA now sets aside about 850 average megawatts of hydro capability to provide incremental reserves and about 1,050 aMW to provide decremental reserves.[7] That is, BPA runs hydro generation 1,050 MW higher

7 For details, see *www.bpa.gov/corporate/pubs/fact_sheets/10fs/BPA_Wind_Power_Efforts_March_2010.pdf.*

than minimum generation at all times so as to stand ready to reduce hydro generation (dec) if the wind picks up and wind power suddenly increases above its schedule. BPA also runs hydro generation roughly 850 MW below maximum generation at all times to stand ready to increase hydro output (inc) instantly if the wind dies off and wind generation falls below its schedule within an hour.[8] These same inc and dec reserves are also used to account for variations of load in the BPA balancing authority. Gaps between scheduled and actual output are called station control error.

The red lines in the graphs at right show the station control error and how much federal balancing reserve the wind fleet was consuming at any given time, up (inc) or down (dec), on June 1–14. In setting rates for 2010–2011, BPA established amounts of reserves BPA would provide in this rate period. The green and blue lines show the reserve levels.

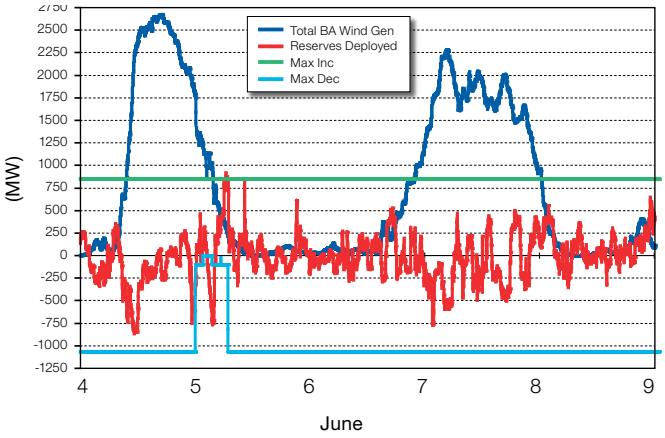
If wind generation deviation from schedule goes beyond these levels in either direction, BPA dispatchers instruct the wind generators to reduce their output (feather their blades) or BPA curtails their transmission to limit the amount of additional hydro generation provided. These operating directives are administered under BPA's Dispatcher's Standing Order 216 (DSO 216).[9]

In establishing DSO 216 and rates for 2010–2011, BPA informed wind project owners that there might be times when BPA would have to reduce its balancing reserves temporarily, in case of power system, transmission system or hydro operation requirements such as fish protection. Such reductions, predominantly in dec reserve levels, occurred on June 5 and June 9–13 and can be seen in the changes to the green and light blue lines in the graphs. DSO 216 triggered 24 times in this period, which can be seen on the graphs wherever the red line exceeds either the green or light blue line. A lower dec reserve level meant there was less chance that significant changes in the generation level of the wind fleet would cause reductions in hydro generation that would result in additional spill.

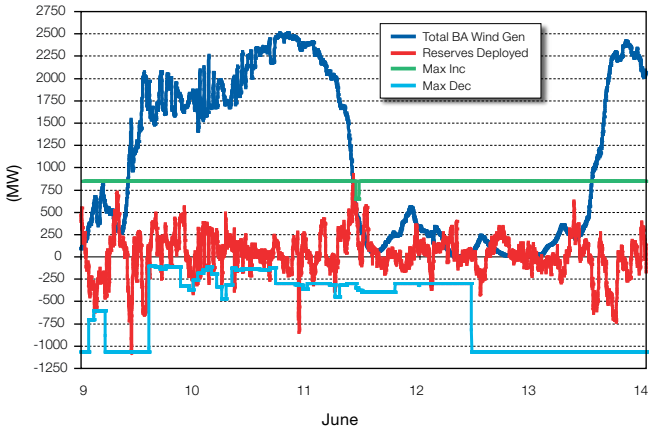
In short, to help meet fish protection requirements at the height of the high water event, BPA reduced balancing reserves that serve wind power projects (light blue and green lines).

BPA balancing authority wind data

[June 4–8, 2010]



[June 9–13, 2010]



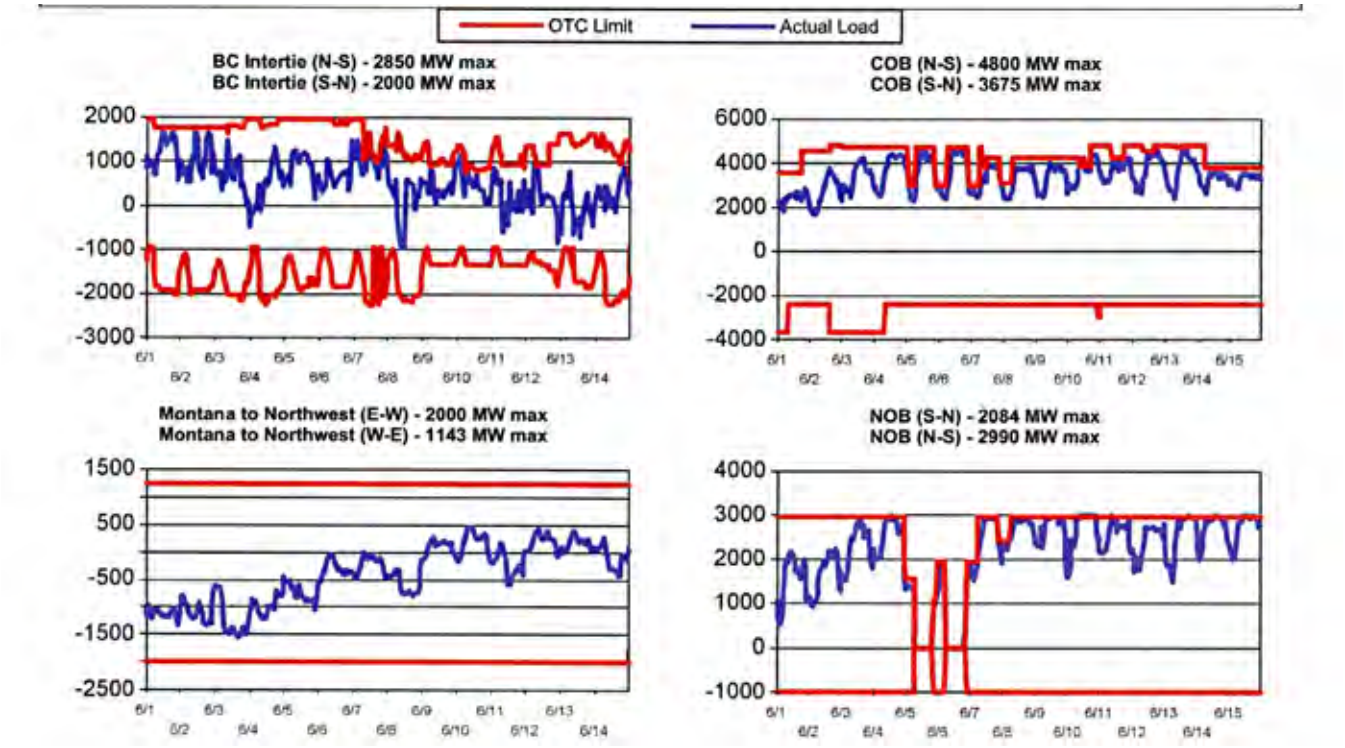
To help meet fish protection requirements at the height of the high water event, BPA reduced balancing reserves that serve wind power projects (light blue and green lines). Only reserves were reduced. All wind power that was scheduled and generated was delivered (dark blue line). The red line shows BPA reserves actually deployed.

8 BPA's Wind Integration Team initiatives are designed to reduce these reserve requirements on the federal system and help reduce the operating requirements and impacts of forecast errors. See *www.bpa.gov/corporate/WindPower/wit.cfm.*

9 For details, see *www.transmission.bpa.gov/wind/op_controls/default.cfm.*

Transmission flowgate use and availability

[June 1–15]



Transmission availability limited federal hydropower generation.

Importantly, during this period of reduced reserves, all wind generation that was scheduled and produced was delivered. Reducing balancing reserves affected only wind generation in excess of that scheduled and wind generation scheduled but not produced. Overall wind production in June was high, operating above a 33 percent capacity factor.

Transmission operations

Because federal hydropower was generating so far in excess of BPA loads, and wind power and other resources also required transmission, the high water also stressed the transmission grid. Conversely, transmission availability significantly limited opportunities for increasing hydropower generation to diminish dissolved gas levels in the river.

BPA owns and operates three-fourths of the high-voltage transmission in the Pacific Northwest, but is just one of 19 balancing authorities in the greater Northwest Power Pool region. As transmission availability permits, BPA and other Northwest utilities transmit surplus power between regions over intertie transmission lines to northern and southern California, British Columbia, and eastward to Montana and through Idaho to the inland Southwest.

During the high-water period, both the 4,800 MW capacity alternating current intertie to Northern California and the 3,100 MW direct current intertie to Los Angeles experienced intermittent outages and reduced capacity. The DC intertie was restored to full capacity June 8 and the AC on June 10. The somewhat smaller northern intertie to British Columbia saw intermittent 25 percent deratings due to British Columbia Transmission Corporation and

Puget Sound Energy maintenance outages through June 13. Theses reductions in transmission availability limited federal hydropower generation and contributed to the need to spill.

Transmission stresses within the Northwest also affected generation options. Diminished thermal generation shifted the patterns of where generation was occurring, which changed the loading on specific transmission paths.

The complex interdependencies of the Columbia River power and transmission system produced some unexpected outcomes that required adjustments as they became clear. For example, the high flows in the Snake River necessitated backing off Grand Coulee and Chief Joseph flows as much as possible to avoid too much water arriving at one time at McNary Dam at the confluence of the Snake and Columbia. When this occurred at night — when little electricity is used — it meant reducing generation at Grand Coulee and Chief Joseph dams. That, in turn, meant those two dams were no longer providing 600 MW of generation that could be dropped instantly if a transmission line fault occurred, which was required to maintain the carrying capacity of the intertie lines to California. Absent the generation at Grand Coulee and Chief Joseph, the intertie capacity had to be reduced by 600 MW, which reduced the amount of generation BPA could export and thereby increased spill. Once alerted to the problem, BPA transmission and power staff reprioritized where hydro generation would occur to restore the intertie capacity.

On June 11, BPA declared a "no touch" condition for the control center automation used by power system dispatchers, which means no computer system updates or testing took place to ensure no interruption to the computer systems used by dispatchers to monitor, operate and control the power system. The no touch rule ended June 14.

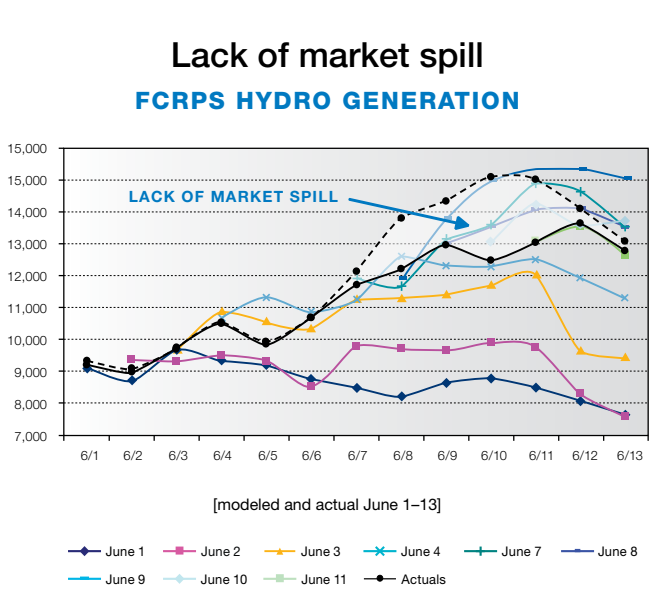
Wholesale power market conditions

Throughout June, BPA conducted forced marketing — sales of surplus power specifically to meet fish protection requirements. The solid black line on the graph below delineates BPA's success in increasing hydro generation as much as possible during the high-flow period. The light-shaded area shows lack-of-market spill, water spilled rather than directed through hydro turbines for lack of power market and/or transmission to reach potential markets.

Power markets were saturated across the West Coast. Clearing Up, an industry newsletter, reported that on June 7, power traded below $0/MWh for the first time since June 26, 2008, at the Mid-Columbia wholesale power trading hub. It said negative prices at that hub reached -$5.50/MWh on June 11.[10] The California Independent System Operator reported negative prices during the period exceeding -$20/ MWh.

BPA did not pay purchasers to take power, but gave power away even during heavy load hours. During the two-week period, BPA disposed of more than 50,000 megawatt-hours of electricity for free or for less than the cost of associated transmission.

10 "Spot Prices Below Water For a Spell." Clearing Up, June 28, 2010. Pg. 6.



The shaded light area shows lack-of-market spill — water that could have been used to generate power and reduce excess spill had a market for power and/or transmission to reach market been available.

Clearing Up concluded, "The irony of free hydropower in a statistically low water-supply year speaks volumes to the limitations of cumulative statistics and the challenges of managing the Columbia system."[11]

By June 12, while lack of market spill declined, BPA was still trying to find markets at $0/MWh. BPA continued to experience lack-of-market spill and sales below variable transmission costs through the rest of June. Total lack of market spill during the event was about 223,000 MWh. For the month, lack-of-market spill was about 745,000 MWh, or about 1,000 aMW.

CONCLUSIONS AND SUMMARY

Through a combination of regional cooperation and extensive urgent efforts, federal operators took action to protect threatened and endangered species in the Columbia River system this June. The Northwest federal hydropower system succeeded in managing through two weeks of high water to minimize effects from gas bubble trauma for endangered and threatened fish in the Columbia River system.

The Corps, Reclamation, BPA and many others participated in this effort. All parties "pulled out all the stops" — used every tool available in existing protocols and arrangements — to manage through the month.

There has been only one above average water year in the Columbia River system in the last decade. The last water year that was significantly above average was 1999, when very little commercial wind generation was on line in the Northwest. This year, the existing tools for addressing high water were stretched to manage successfully through a relatively short high-water period in an otherwise dry year.

Before a prolonged high-water event occurs, it would be well to consider what additional tools, policies and protocols might be developed to assure reliable and equitable power production in the interdependent Columbia River system within the constraints for other river uses.

11 Ibid.

CBE (Columbia Basin Environmental). 2003. Wells Dam Spillway Total Dissolved Gas Evaluation. Final Report. Prepared by Columbia Basin Environmental, The Dalles, Oregon for Public Utility District No. 1 of Douglas County, East Wenatchee, Washington.

Wells Dam Spillway Total Dissolved Gas Evaluation

27 May to 10 June 2003

FINAL REPORT

December 2003

Prepared for

Public Utility District No. 1 of Douglas County
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Preface

This document reports the findings of a study conducted at Wells Dam from 27 May to 10 June 2003. The study was conducted by Columbia Basin Environmental and funded by the Public Utility District No. 1 of Douglas County. The use of trade names in this document should not be interpreted as an endorsement by the District or CBE.

Summary

The Public Utility District No. 1 of Douglas County undertook a study at Wells Dam, located on the Columbia River, to describe total dissolved gas pressures resulting from spill operation by the dam. An array of water quality data loggers were installed in the Wells Dam tailwater for a period of two weeks between 27 May and 10 June, 2003 and programmed to record water temperatures and total dissolved gas pressures along a fifteen-minute interval.

Data indicated that total dissolved gas saturations measured approximately three miles downstream of the project were greater than would have been expected based on the volume of spill reported by the dam. It was estimated that gassing of turbine releases contributed an additional 1.3% to the downstream total dissolved gas saturation. This implied that rather than diluting spillway releases, thus redistributing the total dissolved gas mass, the total pressures of powerhouse releases were increased.

Tracing total dissolved gas saturations through the Wells Dam receiving waters indicated a rapid decrease in total pressures in the immediate tailrace (up to 1.7% decrease per mile for the first 3 miles) followed by a more gradual decrease (decrease of approximately 0.3% per mile) through the subsequent 36 mile long reservoir.

1.0. Introduction

The total dissolved gas (TDG) pressure of water describes the total pressure exerted by the constituent gasses as determined by their concentration and solubility. There are numerous natural and anthropogenic influences on dissolved gas concentrations and pressures including, but not limited to, community metabolism, heating, aeration devices, water falling over dams, weirs, or waterfalls, and turbine venting. It is possible for TDG pressures to exceed the equilibrium pressure resulting in TDG *supersaturation*. Supersaturated water will tend to lose gas to the atmosphere; however, this may be slow in the absence of turbulent flow.

The detrimental effects of the exposure of aquatic organisms to water characterized by elevated dissolved gas pressures were identified as early as 1905 (1905 Marsh and Gorham). Exposure to supersaturated water may result in *gas bubble trauma* (GBT), a condition similar to nitrogen narcosis ("the bends") in divers. As fish move vertically in the water column, gasses dissolved in the bloodstream under greater hydrostatic pressure may rapidly leave solution. This may lead to gill and skin blistering and "pop-eye". The presence of GBT has been documented throughout the Columbia River Basin, the most notable resulting in large fish kills at the John Day Dam (Beiningen and Ebel 1970).

1.1. Site Description

Wells Dam is located on the Columbia River near Azwel, Washington at river mile 515.8 (Figure 1). The project was built as a *hydrocombine* meaning that the spillway is situated directly over the powerhouse. The overall length of the dam is 4460 ft, of which the hydrocombine comprises 1130 ft. The project consists of eleven vertical lift spill gates and ten generating units with a maximum nameplate capacity of 774MW. The hydraulic capacity of the powerhouse is 220 kcfs and the maximum spillway capacity is 1180 kcfs.

Wells Dam spillway operation consists of *forced* spill (inflows exceed the capacity of the powerhouse) or *bypass* spill (spill of a portion of total river volume to assist the out migration of juvenile salmonids). Forced occurs any time the total river discharge exceeds the powerhouse's total capacity. Excess capacity results from low power demand, high total river flows (>220 kcfs at Wells Dam), or in the event of equipment failure. Bypass spill at Wells Dam typically occurs between April and September consisting of approximately 10 kcfs divided equally between Spillbays 2, 4, 6, 8, and 10.

1.2. Background

The water quality standard for TDG pressure for the state of Washington is as follows:

> *Total dissolved gas shall not exceed 110 percent of saturation at any point of sample collection.*

The National Oceanographic and Atmospheric Association Fisheries (formerly the National Marine Fisheries Service) has requested spill at selected hydroprojects within the Columbia River Basin to assist with juvenile salmonid out migrations. The state of Washington developed the following waiver to the aforementioned standard:

Special fish passage exemption for sections of the Snake and Columbia rivers: *When spilling water at dams is necessary to aid fish passage, total dissolved gas must not exceed an average of one hundred fifteen percent as measured at Camas/Washougal below Bonneville dam or as measured in the forebays of the next downstream dams. Total dissolved gas must also not exceed an average of one hundred twenty percent as measured in the tailraces of each dam. These averages are based on the twelve highest hourly readings in any one day of total dissolved gas. In addition, there is a maximum total dissolved gas one hour average of one hundred twenty-five percent, relative to atmospheric pressure, during spillage for fish passage.*

The DCPUD has maintained a permanent TDG fixed monitoring system (TDGFMS) consisting of two Hydrolab® MiniSonde® multiprobes that measure water temperature and TDG pressure throughout the bypass spill season at Wells Dam. The forebay probe (WEL) has been in operation since 1996 and the tailwater probe (WELW) since 1998. Atmospheric pressure data were collected via an aneroid barometer located on the surface deck of the dam. In addition to the TDGFMS, the DCPUD had collected grab data periodically to evaluate lateral and longitudinal distributions in TDG pressure. The results of these studies indicated minor gradients of less than 2% saturation across the width of the tailrace (Klinge 1998).

To better understand the distribution and fate of spilled water from Wells Dam, the Public Utility District No. 1 of Douglas County (DCPUD) undertook a study during the spring of 2003. This document describes the procedures, results, and conclusions of that work.

1.3. Objectives

The following objectives were identified:

1. determine the effectiveness of the tailwater fixed monitor location at representing TDG pressures in the Wells Dam tailwater

2. better define the relationship between spillway release and TDG production at Wells Dam to produce a TDG “rating curve”

3. estimate the degree to which powerhouse releases are impacted by spill

4. quantify the degassing rate of spilled water between the spillway and the tailwater monitor location

2.0. Methods

Deployment of the auxiliary probes was timed to coincide with the spring freshet to capture the widest range of discharges with the minimum impact to normal power generation.

2.1. Instrumentation

An array of Hydrolab® MiniSonde® multi-parameter data loggers were leased for the period of study. Each *sonde* was equipped with sensors for water temperature, TDG pressure, and sensor depth. Prior and subsequent to field deployment, each sonde was calibrated to NIST traceable standards for temperature and TDG pressure. Seven sondes were deployed, in addition to the existing permanent monitoring stations, and programmed to record data at fifteen-minute intervals. Atmospheric pressure data were collected at the forebay TDGFMS location and corrected for the tailwater elevation.

2.2. Field Deployment

Deployment sites were selected to maximize data resolution in key regions centered around the stilling basin and the tailwater TDG monitor location. The study area is depicted in Figure 2. Sondes were divided between two transects (T1 and T2) located approximately 800 feet and 2.9 miles downstream of the dam, respectively. The location of each deployment station was determined via global positioning system (GPS).

Transect 1 (Figure 3) consisted of four sondes leased for the study. Each was housed in a 200 lb. steel case that served to both anchor the station and protect the sonde. Anchors were attached to a series of surface floats via 5/16" diameter steel cables that allowed installation and retrieval by boat. Figure 4 provides an illustration of the deployment rigging used for Transect 1.

Transect 2 (Figure 5) consisted of three leased sondes and the Wells Dam tailwater TDGFMS sonde. Transect 1 was located in the boat restricted zone of the project; therefore, civilian boat traffic was not a concern. Recreational navigation was allowed at Transect 2; however, and the surface deployment method used for Transect 1 was inappropriate. To minimize danger to boat traffic, the sondes were strung across the river in a "necklace" configuration consisting of 5/16" diameter steel cable and 150 lb. steel anchors. Figure 6 provides an illustration of the deployment rigging used for Transect 2. The tailwater TDGFMS (WELW) was permanently deployed in a pipe that and transmitted real time data to the DCPUD headquarters in East Wenatchee, Washington.

A bathymetric survey was conducted using a Garmin® GPSMAP 168 GPS receiver/depth sounder. Data were collected by "cruising" from immediately downstream of Transect 2 upstream to Transect 1. Multiple lateral passes were conducted at Transects 1 and 2 to develop the weighting coefficients used to average water quality data (described in greater detail in Section 2.3).

2.3. Data Analysis

Data collected for the Wells Spillway study were obtained from the following sources:

1. field transect data – water temperature and TDG pressure (mm Hg) reported every fifteen minutes for nine sites (seven auxiliary sondes in addition to the forebay and tailwater TDGFMS)

2. CROHMS data – hourly project operation and water quality data from the Columbia River Operational HydroMet System maintained by the U.S. Army Corps of Engineers

3. fifteen minute project operations data – total project discharge, total spillway discharge, fishway discharge, individual spill gate opening, individual turbine output, and forebay and tailwater elevation reported every fifteen minutes

4. Wells Dam Spill Logs – control room log recording discrete operational changes and the time they occurred

5. bathymetric survey data – latitude, longitude, and depth information for the Wells Dam tailwater collected during boat cruise from Transect 2 (2.9 miles downstream) to Transect 1 (800 feet downstream).

A database was created to assemble the divergent datasets into a uniform format. The various datasets were synchronized, with some interpretation required to assign operation logs (recorded at time of occurrence, not necessarily on the quarter hour) and the regularly reported data for the continuous sets.

The sondes utilized pressure sensors to report the total pressure at the depth of sample collection. Water quality standards were written with respect to deleterious effects to biota and expressed TDG pressure as a percentage of surface saturation as

$$TDG_{sat} = \frac{TDG_i}{BP_i} \times 100$$

where

TDG_{sat} = TDG pressure expressed as percentage of surface saturation

TDG_i = TDG pressure at station i, mm Hg

BP_i = Atmospheric pressure at station i, mm Hg

Equation 1

Individual spillbay discharge was determined from the gate opening information as follows:

$$G_{Q_i} = G_{OP_i} \Big/ \sum_{i=1}^{11} G_{OP_i} \times \left(Q_{SP_f} + Q_{SP_F}\right)$$

where

G_{Q_i} = total discharge for gate i, kcfs

G_{OP_i} = total opening for gate i, ft

Q_{SP_f} = Wells Dam fish bypass spill, kcfs

Q_{SP_F} = Wells Dam forced spill, kcfs

Equation 2

Spill patterns were assigned based on the gate openings for the operating spillbays. It was necessary for the sondes of Transect 2 to reach equilibration so that relationships between water quality and Wells Dam operation could be identified. Equilibration depended on both the

travel time for water through the tailwater and the response time of the TDG sensors. Meeting these requirements meant that steady operation for not less than one hour was needed to reasonably expect equilibrated TDG pressures for all sites. Periods characterized by near uniform operation were segregated into *spill events*. These data were then filtered to select events of duration greater than one hour to yield the final data set for summarization.

Spill event data for Transects 1 and 2 were flow-weighted to provide a single average TDG pressure for each event. Flow-weighting sought to represent both the magnitude of the pressure and the volume of water it represented described as

$$TDG_{wt} = \frac{\sum TDG_i q_i}{Q_{tot}}$$

where

TDG_{wt} = flow - weighted average TDG pressure

TDG_i = TDG pressure at station i

q_i = discharge at station i

Q_{tot} = total river discharge

Equation 3

Station discharges were based on the percentage of the river cross-section represented by that station. Bathymetric survey data were analyzed for to determine the most logical flow apportionment for individual stations. The flow-weighting used in these analyses was; therefore, based on *area* rather than *discharge*, a relatively minor distinction that should not impact subsequent analysis.

In addition to guiding decisions for flow-weighting, bathymetric data were also used to construct an aerial approximation of the Wells Dam tailwater morphometry. The map created from those data identified the thalweg and provided an indication of the flow patterns through the tailwater.

3.0. Results

All of the sondes reported data for the entire period of study and all passed quality assurance/quality control tests conducted prior and subsequent to deployment. Station information and QA/QC data are summarized in Tables 1 and 2, respectively. High resolution operations data (fifteen-minute interval) were available for the entire study except for an approximate twenty hour interruption between June 4 at 1045 and June 5 at 0800 resulting from an unexplained equipment failure. Hourly operations data from the CROHMS were used to fill this gap. Table 3 summarizes the various data sets and their inclusive dates.

3.1. Hydrology

River flows were less than anticipated (Figure 7), ranging from a minimum daily average discharge of 85.1 kcfs on June 1 to a maximum of 162.0 kcfs on June 10. The vast majority of Wells Dam spill was manifested as standard fish bypass spill. The greatest hourly discharge of 223.4 kcfs was recorded on the morning of May 28 at 2145 with the maximum spill discharge of 96.5 kcfs occurring two hours later. A similar spill event occurred on the morning of June 7, although total flows were less peaking at 208.5 kcfs with a maximum spill discharge of 92.4 kcfs. Both events resulted in forced spill to pass water in excess of the powerhouse capacity, and neither was characterized by a sustained pattern. Since the duration of these events was insufficient to meet the filter criteria defining spill events (near static operation for at least one hour), they were necessarily excluded from flow-weighted analyses.

One short duration spill event occurred at Chief Joseph Dam, upstream of Wells, on 28 May from 1800 to 0000 with the total spillway discharge reaching a maximum of 30.8 kcfs. This represented the only spill at Chief Joseph Dam for the period of study, thus incoming pressures documented by the forebay TDGFMS represented ambient background pressures and were likely representative of the forebay as a whole (no lateral variation in TDG pressures).

3.2. Bathymetry

Tailwater morphometry was mapped using data adapted from GPS cruises. These data are depicted in the contour map in Figure 8. The degree to which the data were interpolated may be inferred from the distribution of sample points (unlabeled dots in Figure 8). From this representation, the proximity of the auxiliary and TDGFMS stations to the thalweg are readily identifiable. These data were used to develop the weighting coefficients (Table 4) which were subsequently utilized in developing transect average TDG pressures.

3.3. Fixed Monitor Data

Hourly water temperature data from the CROHMS for the four sites relevant to Wells Dam are presented in Figure 9. Temperatures (as measured by WEL) reflected diel warming and, at a larger scale seasonal warming, increasing from 10.9 ºC at deployment to 13.1 ºC two weeks later upon retrieval. Total dissolved gas pressure data for these sites are depicted in Figure 10. Note that WEL exhibited daily cycles of up to 2.5% saturation, regardless of spill operation at Chief Joseph Dam. This most likely resulted from localized surface warming at the TDGFMS. As temperatures increased, the pressures inside the TDG probe's membrane also increased (Charles' Law). The relatively slow diffusion rate of gasses across the silastic tubing that comprised it, resulted in a temporary increase in TDG pressure. This was likely an artifact of data collection and was not reflective of the actual Wells Dam forebay TDG pressures. Daily pressure fluctuations may also result from community metabolism; however, no data were available to support this. The single spill event at Chief Joseph resulted in TDG saturations of

approximately 118% at the tailwater site (CHQW), but were not reflected by saturations measured at WEL.

The two high spill events occurring on 28-29 May and 6-7 June were readily identified at both WELW and RRH (manifested as the distinct peaks in Figure 10). The dramatic contrast in the TDG pressures resulting from these events to the remaining study period allowed for an estimate of both the travel time and degassing rate for water traversing Lake Entiat. Note that the pressures measured at WELW were manifested as a sharp pressure spike occurring for less than two hours, while the elevated pressures measured at RRH are characterized by an attenuated peak occurring over several hours. Travel time estimation was, therefore, based on the arrival of the TDG *front* at RRH and not the peak value. Using the TDG pressure spikes of the high spill events to match the other operation events, the travel time for water through Lake Entiat was generally thirty to forty hours.

3.4. Transect Data

Auxiliary TDG data collected at Transects 1 and 2 are presented as Figures 11 and 12, respectively. The highest TDG saturations were reported at Transect 1, with station T1C typically exhibiting the maximum pressures. Transect 1 TDG saturations reached a maximum of 132.9% on May 29 at 0000, which were the highest documented. A lateral gradient ranging from of up to 12.5% saturation was consistent throughout the study. As previously noted, T1C generally represented the maximum pressures, although values for T1B were similar.

Data collected at Transect 2 exhibited lower TDG pressures than those measured along Transect 1, as expected given its greater distance from the spillway. The maximum pressure reported for Transect 2 was 128.7% occurring at station T2C on May 29 at 0030. As with Transect 1, at lateral gradient of up to 15.6% saturation was observed for most of the study, with the highest pressures measured at station T2C. The three auxiliary sites generally responded to changes in project operations simultaneously, while response by the tailwater FMS (WELW) lagged by up to forty-five minutes. In addition to longer response times, TDG pressures measured at WELW differed from those at T2C by as much as 5% saturation.

As previously noted, the duration of the high spill events was insufficient to allow equilibrated measurements at both transects, thus they were excluded from the mass balance analyses described in later sections. The dramatic, rapid increase in TDG saturations above those measured prior and subsequent to these events allowed the TDG *plumes* to be followed through the Wells Dam tailwater and the remainder of Lake Entiat.

Figure 13 depicts the TDG saturations and project operations for Transect 1 for the period of May 28-30, 2003. Data for Transect 2 for the same period are depicted in Figure 14. Station T1C recorded the highest TDG saturation of the study (132.9%) as Wells Dam total spillway discharge approached 100 kcfs (over 58% of the total river discharge). The highest TDG saturation at station T1A for the same event was 126.6% (6.3% less than T1C). Stations T1B and T1A peaked at TDG saturations of 131.8 and 131.3%, respectively. Transect 1 stations first indicated the arrival of the plume at 2245. The TDG front reached Transect 2 at 2315, indicating a travel time from Transect 1 to Transect 2 of approximately thirty minutes.

A lateral gradient in TDG pressure was observed (as with Transect 1) with the highest pressures again occurring near mid-river. Station T2C reached a maximum saturation of 128.7% with stations T2B and T2D peaking at 127.1 and 127.3%, respectively. The minimum pressures were measured at station T2A (WELW) which peaked at 124.5% saturation, some

thirty minutes after T2C. TDG pressures at both Transects decreased as quickly as they rose following passage of the TDG front, except for T2A (WELW), which took an additional forty-five minutes to return to pre-front levels.

The second high spill event of the study occurred on the morning of June 7, 2003 as depicted in Figures 15 and 16 for Transects 1 and 2, respectively. The total spillway discharge reached a maximum of 92.4 kcfs (~56% of the total river discharge) for approximately fifteen minutes. Despite the short duration of the event, its impact was seen throughout the tailwater as manifested by the sharp increase in TDG saturation at all stations. It was unlikely that the pressures recorded during this event represented equilibrated values, but they do support data collected for the prior high spill event.

With the exception of the high spill occurrences on the mornings of May 29 and June 7, no other operations resulted in TDG saturations greater than the 125% waiver to the Washington State water quality standard.

3.5. Spill Events

Data meeting the criteria outlined in Section 2.3 (periods characterized by at least one hour of relatively constant operation) were consolidated into 51 spill events. Of these, forty-six events were of sufficient duration to allow both Transect 1 and Transect 2 stations to reach equilibration. Event averaged data for the 46 events are summarized in Table 5.

Events ranged from one hour to over eighteen hours in duration. The minimum mean total river discharge of 25.1 kcfs occurred during Event 4, which also represented the minimum total spillway discharge of 2.7 kcfs. The maximum mean total river discharge of 194.8 kcfs occurred during Event 39, with a comparable discharge occurring during Event 7 (193.8 kcfs). The total spill discharge for both events was 11.0 kcfs, representing approximately 5.6-5.7% of the total discharge. Roughly 35% of the spill events had total spill discharges of 11.0 kcfs which represented from 5.6-9.8% of the total river flow.

The maximum TDG pressure of 114.2% was measured at station T1D during Spill Event 41. Stations T1B and T1C reported comparable values of 113.3 and 113.6%, respectively. Project output was similar for Spill Event 26, but TDG pressures for Transect 1 were 4.2 to 5.3% less than for Event 41. Background TDG pressures reported by the forebay FMS (WEL) were 107.3% for Spill Event 26, some 3.5% lower than the subsequent event, which may explain this apparent disparity. None of the spill events resulted in TDG saturations in excess of state of Washington water quality standards.

3.5.1. Flow-weighted Data

Transect TDG saturations were flow-weighted based on the weighting coefficients in Table 4. Flow-weighted averages yielded a single TDG pressure for each transect for each event, the results of which are presented in Table 6. Mean saturations for Transect 1 were up to 2.0% greater than for Transect 2, with the overall mean of 0.4%. Transect 2 mean saturations were up to 2.4% greater than those reported for the Wells Dam forebay. The overall contribution of TDG pressure for Wells Dam averaged 1.3% as determined from the forebay to Transect 2 change in saturation.

Comparing forebay TDG pressures to the flow-weighted pressures for Transects 1 and 2 provided an estimate of the change in mass (flux) of gasses resulting from Wells Dam. The difference between the forebay TDG saturation and the flow-weighted saturations for Transects

1 and 2 are plotted against spill from Wells Dam expressed as a percentage of the total river discharge in Figure 17.

Neither relationship exhibited a strong correlation, as evidenced by the low r^2 values; however both indicated a direct relationship with the percentage of the river passed as spill. Transect 1 TDG saturations were best described by a second order polynomial, indicating that the net increase in TDG pressures over forebay pressures became more dependent on spill as it increased as a percentage of the total flow. Transect 2 flux estimates were much less correlated with the percentage of spill ($r^2 = 0.28$). Increasing the complexity of the equation yielded no stronger relationship for the transect, which was best described by a simple linear relationship. These representations indicate that for every 5% increase in Wells Dam spill there was a corresponding increase of 0.5% in TDG flux.

3.5.2. TDG Mass Balance

Determining the fate of powerhouse release water, i.e. dilution of, or gassing by, spill release, required apportionment of the Wells Dam release waters and associated TDG saturations. Assuming the fate of powerhouse release water to be dilution of spill release, the flow-weighted TDG saturation for Transect 2 could be expressed

$$TDG_{wt} = \frac{(TDG_{PH} \times Q_{PH}) + (TDG_{SP} \times Q_{SP})}{(Q_{PH} + Q_{SP})}$$

where

TDG_{wt} = Flow - weighted TDG saturation for Transect 2

TDG_{PH} = TDG saturation of the powerhouse release water

TDG_{SP} = TDGsaturation of the spillway release water

Q_{PH} = total powerhouse discharge

Q_{SP} = total spillway discharge

Equation 4

If station T1C TDG saturations (typically the maximum pressures for Transect 1) represented TDG_{SP} and WEL saturations represented TDG_{PH}, then the weighted TDG saturation for Transect 2 could be computed using the operation logs from the dam to represent the discharge variables. These values are presented with their corresponding empirical values in Table 7.

Observed TDG saturations for Transect 2 consistently exceeded those derived from Equation 4, ranging from 0.5 to 2.2% higher with a mean difference of 1.2% saturation. A paired t-test indicated a that the mean values were significantly different ($p<0.05$). Saturations for the spillway release were estimated from station T1C data and, if underestimated, could have resulted in the relationships presented in Table 7. Substituting Transect 2 flow-weighted average TDG saturations for TDG_{wt}, Equation 4 was rearranged to solve for the mean spill TDG saturation as

$$TDG_{SP} = \frac{(TDG_{wt} \times (Q_{PH} + Q_{SP})) - (TDG_{PH} \times Q_{PH})}{Q_{SP}}$$

Equation 4a

Spillway TDG saturations computed via Equation 4a reached a maximum of 134.5% saturation, exceeding the maximum value for Transect 1 by 22.9%. The mean difference in the saturations derived from Equation 4a and those measured for T1C was 14.0%. The maximum saturation occurred during Event 42 characterized by low total river discharge (71.9 kcfs) and relatively modest spill (6.6 kcfs representing 9.2% of the total discharge). The maximum TDG saturation measured during the entire study (T1C, 133%) occurred during a spill event of nearly 100 kcfs representing 49% of the total river discharge.

Equation 4 was rearranged, again, to solve for TDG_{PH} as

$$TDG_{PH} = \frac{\left(TDG_{wt} \times \left(Q_{PH} + Q_{SP}\right)\right) - \left(TDG_{SP} \times Q_{SP}\right)}{Q_{PH}}$$

Equation 4b

The results of these calculations indicated that the TDG saturations for the powerhouse release water averaged 1.3% higher than those reported by WEL. Empirical and computed weighted average TDG pressures derived from Equations 4a and 4b are summarized in Table 8.

3.6. Daily 12 hour Average TDG Saturations

Daily averages of the twelve highest saturations for Transects 1 and 2 are presented in Table 9. Station averages for Transect 2 varied from 0.7 to 2.1% saturation, but would not have resulted in changes to the day's compliance evaluation as determined by the tailwater TDGFMS.

4.0. Conclusions

Although total flows for the middle Columbia River were less than forecasted, the results of this study provided valuable information regarding TDG distributions at Wells Dam. Based on comparisons of lateral TDG saturations at Transect 2, the tailwater TDGFMS does not represent the maximum values for that location. Although the daily averages represented little difference between the TDG saturations measured at WELW and the mid-river stations (T2B and T2C), this was likely due to the short duration of the few significant spill events. The tailwater TDGFMS is located on the eastern shore of the river in an eddy. Based on the shape of the response curves of Transect 2 TDG saturations, the eddy caused both a delay and attenuation in the response of WELW. While TDG saturations at WELW compared well to the other stations for the spill events, an additional thirty to forty-five minutes were required for equilibrated measurements. Determination of compliance with state of Washington water quality standards was the same for all of the Transect 2 stations.

The limited duration and frequency of high spill prevented the development of a useful TDG production curve for the Wells Dam spillway. Most data were collected under fish by-pass spill conditions consisting of spill through spillbays 2, 4, 6, 8, and 10 representing less than ten percent of the total river flow. Wells Dam spill and forebay to tailwater changes in TDG were weakly correlated, indicating an increasing trend. The longer response was likely a symptom of the TDGFMS location within the eddy, which required time to "flush" water from prior operations. The effect was manifested as a shift in both the leading and lagging edges of the TDG response curve. Numerous spikes in the TDG saturations at Transect 2 – the results of fleeting changes in the Wells Dam discharge – were not measured by the tailwater TDGFMS; however, there was no apparent impact to compliance evaluations.

The mass balance approach was confounded by the erratic nature of operation by Wells Dam, since accurate estimates depend on complete accounting of both the magnitude of the TDG pressure and the volume of water it represented. Despite this, results indicated that the average TDG saturations for Transect 2 were greater than would have been expected from Wells Dam spill, alone. Results indicated WEL underestimated the *effective* powerhouse TDG saturation by an average of 1.3%. Powerhouse releases should reflect forebay saturations and the consistent difference implied that powerhouse TDG pressures were influenced by turbine operation (unlikely given the powerhouse operation during this study) or spill.

Estimations of travel times through Lake Entiat generally agreed with estimates developed from the TDGFMS at Wells and Rocky Reach Dams. Tracing water from the forebay of Wells Dam to that of Rocky Reach Dam indicated that TDG pressures changed rapidly between the spillway and Transect 2, with reductions of up to 5% (or approximately -1.7% per mile). Reductions in TDG saturation between Transect 2 and the Rocky Reach forebay TDGFMS (RRH) indicated a TDG reduction of up to 12% (or about -0.3% per mile).

The conclusions drawn from this study are limited by the flow conditions occurring during data collection. Additional data collected under higher project discharges are needed to refine estimates the influence of spill operation to powerhouse release water and to explore ameliorative possibilities. The most desirable approach would include scheduled, steady state spill events designed to capture the widest river flows possible. Project operations should be held constant for at least two hours to allow equilibrated measurements for the entire tailwater. Data collection outside of the fish passage season would simplify data analysis, since forebay TDG pressures would not be influenced by upstream activities.

References

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Marsh, M.C. and F.P. Gorham. 1905. The Gas disease in fishes. Report of the United States Bureau of Fisheries for 1904:343-376.

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Tables

Table 1. Station information for water quality data collection

S/N	Transect	Station ID	Location		Depth (ft)
			Latitude	Longitude	
33254	N/A	WEL	47.94722	-119.86508	15
40857	T1	T1A	47.94455	-119.86244	50
39285	T1	T1B	47.94434	-119.86333	65
40862	T1	T1C	47.94399	-119.86420	65
40859	T1	T1D	47.94411	-119.86562	60
32639	T2	WELW	47.91309	-119.89625	20
40860	T2	T2B	47.91364	-119.89676	45
40861	T2	T2C	47.91463	-119.89668	50
40858	T2	T2D	47.91476	-119.89744	35

Table 2. Calibration summary information for water quality sensors

Calibration Type	S/N	Date	BP (mmHg)	Temperature (ºC)			TDG Pressure (mm Hg)			Deviation from TDG Standard (mm Hg)		
				Std	Probe	Diff	BP + 0	BP + 100	BP + 200	BP + 0	BP + 100	BP + 200
Pre-deployment	39285	05/26/03	756	17.7	17.7	0.0	756	856	956	0	0	0
Pre-deployment	40857	05/26/03	755	17.5	14.7	2.8	755	855	955	0	0	0
Pre-deployment	40858	05/26/03	756	17.5	17.4	0.1	756	856	956	0	0	0
Pre-deployment	40859	05/26/03	756	17.6	17.6	0.0	756	856	956	0	0	0
Pre-deployment	40860	05/26/03	756	17.5	17.4	0.1	755	855	955	-1	-1	-1
Pre-deployment	40861	05/26/03	756	17.5	17.5	0.0	755	855	956	-1	-1	0
Pre-deployment	40862	05/26/03	755	17.5	17.4	0.1	755	855	955	0	0	0
Pre-deployment	32639	05/27/03	749	11.4	11.3	0.1	750	850	950	1	1	1
Pre-deployment	33254	05/27/03	747	12.1	12.1	0.0	747	847	947	0	0	0
Post-deployment	39285	06/10/03	750	20.2	20.3	0.0	751	851	951	1	1	1
Post-deployment	40857	06/10/03	750	20.2	20.2	0.0	750	850	950	0	0	0
Post-deployment	40858	06/10/03	750	20.2	20.2	0.0	752	852	952	2	2	2
Post-deployment	40859	06/10/03	750	20.2	20.2	0.0	751	851	951	1	1	1
Post-deployment	40860	06/10/03	750	20.2	20.2	0.1	750	850	950	0	0	0
Post-deployment	40861	06/10/03	750	20.3	20.2	0.0	750	850	951	0	0	1
Post-deployment	40862	06/10/03	750	20.2	20.2	0.0	751	851	951	1	1	1
Post-deployment	32639	06/18/03	736	14.2	14.1	0.1	736	836	936	0	0	0
Post-deployment	33254	06/18/03	733	14.2	14.1	0.0	734	833	933	1	0	0

Table 3. Summary of Data Sets Included in Wells Dam Spillway Evaluation

Data Set	Provider	Inclusive Dates	Interval (hrs)	Description
Transect	CBE	May 27 – June 10, 2003	0.25	Water temperature (ºC), TDG pressure (mm Hg), sample depth (m) collected by leased Hydrolab® MiniSonde® multiprobes
CROHMS	Internet	May 27 – June 10, 2003	1.0	Water temperature (ºC), TDG pressure (mm Hg), atmospheric pressure (mm Hg), total project discharge (kcfs), total project spill discharge (kcfs), forebay elevation (ft MSL), tailwater elevation (ft MSL) queried from Columbia River Operational HydroMet System maintained by the U.S. Army Corps of Engineers
Wells Dam Operations	DCPUD	May 27 – June 4 June 5-10, 2003	0.25	Wells Dam total river discharge (kcfs), by-pass spill discharge (kcfs), forced spill discharge (kcfs), fishway discharge (kcfs), individual generator output (MW), individual spill gate openings (ft), forebay elevation (ft MSL), tailwater elevation (ft MSL)
Control Room Logs	DCPUD	May 27 – June 10, 2003	N/A	Spill gate openings (ft), and total spillway discharge (kcfs) reported at time of change
Wells Dam FMS	DCPUD	May 27 – June 5, 2003	0.25	Water temperature (ºC), TDG pressure (mm Hg), and atmospheric pressure (mm Hg) for the Wells Dam permanent TDG monitoring system
Wells Tailwater Bathymetry	CBE	May 27, 2003	N/A	Tailwater bathymetric survey data consisting of latitude, longitude, and river depth collected via mapping GPS during deployment of transect instruments.

Table 4. Transect Average TDG Weighting Coefficients

Transect	Station	Weighting Coefficient
Transect 1	T1A	0.35
Transect 1	T1B	0.20
Transect 1	T1C	0.20
Transect 1	T1D	0.25
Transect 2	T2A	0.10
Transect 2	T2B	0.35
Transect 2	T2C	0.35
Transect 2	T2D	0.20

Table 5. Spill Event Summary Information

Event	DateTime		Duration	Qtot	Qgen	Qsp	Percent	WEL	T1A	T1B	T1C	T1D	WELW	T2B	T2C	T2D
	Start	End		kcfs	kcfs	kcfs	Spill	%Sat	%Sat	%Sat	%Sat	%Sat	%Sat	%Sat	%Sat	%Sat
1	05/27/03 06:45	05/27/03 08:30	1.75	87.3	78.5	8.8	10.1	106.0	107.6	109.3	109.5	109.1	107.3	104.3	107.4	110.2
2	05/27/03 09:45	05/27/03 23:15	13.50	170.2	159.2	11.0	6.5	107.6	109.1	109.4	109.0	108.5	108.9	108.6	108.8	108.6
3	05/28/03 00:00	05/28/03 01:15	1.25	89.1	80.3	8.8	9.9	107.2	109.0	109.1	108.9	109.0	108.7	108.6	108.9	108.6
4	05/28/03 02:15	05/28/03 04:15	2.00	25.1	22.4	2.7	10.8	107.1	109.0	109.3	109.0	109.1	108.5	108.8	109.0	108.6
5	05/28/03 06:45	05/28/03 08:45	2.00	111.8	100.8	11.0	9.8	108.0	109.9	110.3	109.9	109.2	109.1	109.2	109.3	109.1
6	05/28/03 09:15	05/28/03 10:30	1.25	69.1	62.5	6.6	9.5	108.3	109.6	110.5	110.3	110.2	109.8	109.8	110.0	109.7
7	05/28/03 11:15	05/28/03 21:15	10.00	193.8	182.8	11.0	5.7	108.9	110.5	111.0	110.7	109.9	110.3	110.1	110.4	110.1
8	05/29/03 08:00	05/29/03 23:45	15.75	170.1	159.2	11.0	6.5	109.5	111.0	111.7	111.3	110.3	110.8	110.7	111.0	110.6
9	05/30/03 02:30	05/30/03 04:15	1.75	40.3	35.9	4.4	10.9	109.4	111.4	111.6	111.5	111.5	111.5	111.3	111.4	111.5
10	05/30/03 04:45	05/30/03 09:00	4.25	108.8	100.0	8.8	8.1	109.5	110.8	111.0	111.0	111.0	110.7	110.6	110.9	110.7
11	05/30/03 09:15	05/30/03 19:45	10.50	156.9	145.9	11.0	7.0	109.4	111.3	111.3	110.7	110.3	110.8	110.7	110.8	110.4
12	05/30/03 20:15	05/30/03 22:45	2.50	138.5	127.5	11.0	7.9	108.5	110.2	110.3	110.1	109.9	110.0	109.9	110.1	109.7
13	05/31/03 00:00	05/31/03 01:15	1.25	61.5	54.9	6.6	10.7	108.0	109.8	110.0	109.5	109.5	109.6	109.7	109.9	109.5
14	05/31/03 01:45	05/31/03 03:00	1.25	45.7	41.3	4.4	9.6	107.8	110.1	109.6	109.0	109.1	109.3	109.3	109.3	109.1
15	05/31/03 06:30	05/31/03 07:30	1.00	51.8	47.4	4.4	8.5	107.5	110.0	110.1	109.4	109.3	108.8	108.9	109.0	108.6
16	05/31/03 08:30	05/31/03 10:15	1.75	116.3	107.5	8.8	7.6	107.9	109.1	109.6	109.4	109.4	109.1	109.1	109.3	109.1
17	05/31/03 10:30	05/31/03 22:30	12.00	148.9	137.9	11.0	7.4	108.6	110.2	110.6	110.2	109.4	109.9	109.8	110.0	109.7
18	06/01/03 00:00	06/01/03 01:45	1.75	39.9	35.5	4.4	11.0	107.5	111.1	111.3	110.8	110.6	109.1	109.5	109.7	109.2
19	06/01/03 02:00	06/01/03 03:45	1.75	61.2	54.6	6.6	10.8	107.3	110.0	110.7	109.2	109.0	109.1	109.7	109.9	109.5
20	06/01/03 04:00	06/01/03 06:45	2.75	31.5	27.1	4.4	14.0	107.3	111.3	112.1	110.8	109.9	108.9	109.2	109.1	108.6
21	06/01/03 07:15	06/01/03 10:00	2.75	70.2	63.6	6.6	9.4	107.6	109.5	110.0	108.9	108.7	109.3	109.5	109.4	109.1
22	06/01/03 10:15	06/01/03 11:30	1.25	36.5	32.1	4.4	12.0	107.6	110.7	111.0	109.9	110.3	109.4	109.1	109.1	108.6
23	06/01/03 13:15	06/01/03 17:45	4.50	149.3	138.3	11.0	7.4	108.3	109.8	110.0	109.6	109.3	109.8	109.5	109.6	109.4
24	06/01/03 18:15	06/01/03 22:30	4.25	109.8	101.0	8.8	8.0	107.7	109.1	109.1	108.9	109.3	108.9	108.9	109.0	108.8
25	06/01/03 23:00	06/02/03 00:15	1.25	70.3	63.7	6.6	9.4	107.6	109.0	109.0	108.6	108.8	108.3	108.5	108.7	108.5
26	06/02/03 00:30	06/02/03 04:00	3.50	38.1	33.7	4.4	11.6	107.3	109.2	109.1	108.7	108.9	107.9	108.4	108.6	108.2
27	06/02/03 04:15	06/02/03 07:00	2.75	73.1	66.5	6.6	9.0	107.0	108.5	108.7	108.0	108.1	107.8	108.2	108.3	107.9
28	06/02/03 08:15	06/02/03 09:30	1.25	92.1	85.5	6.6	7.2	107.2	108.4	108.5	107.9	108.1	108.0	108.3	108.4	108.0
29	06/02/03 10:15	06/02/03 22:15	12.00	170.7	159.7	11.0	6.4	108.2	109.5	109.8	109.5	108.9	109.2	109.2	109.3	109.0
30	06/03/03 00:00	06/03/03 01:30	1.50	45.6	41.2	4.4	9.7	107.5	109.7	110.4	110.3	110.6	108.8	109.0	109.3	108.6
31	06/03/03 02:15	06/03/03 04:15	2.00	43.6	39.2	4.4	10.1	107.4	109.5	109.7	108.6	108.7	108.9	108.9	109.0	108.9
32	06/03/03 05:15	06/03/03 06:45	1.50	50.8	46.4	4.4	8.7	107.2	109.1	108.8	108.3	108.5	108.4	108.5	108.4	108.1
33	06/03/03 08:30	06/03/03 22:45	14.25	165.6	154.6	11.0	6.6	108.7	110.2	110.3	109.7	109.3	109.7	109.6	109.8	109.4
34	06/04/03 01:30	06/04/03 04:30	3.00	49.6	45.2	4.4	8.9	108.0	109.0	109.3	109.0	109.2	109.1	109.2	109.2	109.0
35	06/04/03 08:45	06/04/03 10:30	1.75	162.8	151.8	11.0	6.8	108.8	110.0	110.2	109.8	109.4	109.3	109.4	109.6	109.2
36	06/05/03 08:15	06/05/03 23:30	15.25	175.0	164.0	11.0	6.3	110.1	111.8	112.0	111.7	110.8	111.5	111.4	111.5	111.2
37	06/06/03 01:15	06/06/03 02:45	1.50	42.0	37.6	4.4	10.5	109.8	111.1	111.4	111.2	111.3	111.2	111.5	111.8	111.3
38	06/06/03 03:00	06/06/03 05:30	2.50	69.8	63.2	6.6	9.5	109.5	111.0	111.5	110.6	110.7	110.7	110.7	110.8	110.5
39	06/06/03 06:30	06/06/03 22:45	16.25	194.8	183.8	11.0	5.6	110.0	111.9	112.1	111.6	110.8	111.3	111.3	111.4	111.1
40	06/07/03 07:00	06/08/03 00:45	17.75	171.3	160.3	11.0	6.4	110.6	112.0	112.3	111.8	111.1	111.8	111.5	111.7	111.3
41	06/08/03 02:00	06/08/03 05:00	3.00	38.3	33.9	4.4	11.5	110.5	112.6	113.3	113.6	114.2	111.6	112.1	112.5	111.8
42	06/08/03 05:30	06/08/03 06:30	1.00	71.9	65.3	6.6	9.2	110.3	111.8	112.1	111.6	111.6	112.1	112.5	112.5	113.0
43	06/08/03 06:45	06/08/03 12:45	6.00	112.3	103.5	8.8	7.8	111.2	111.9	112.0	111.9	112.2	112.0	111.8	112.0	111.8
44	06/08/03 13:00	06/08/03 23:45	10.75	161.8	150.8	11.0	6.8	111.6	112.6	112.8	112.3	111.9	112.4	112.2	112.3	112.0
45	06/09/03 02:00	06/09/03 05:00	3.00	55.8	51.4	4.4	7.9	110.0	111.0	111.2	111.0	111.2	111.2	111.2	111.2	110.9
46	06/09/03 05:30	06/10/03 00:00	18.50	178.5	167.5	11.0	6.2	110.4	112.3	112.8	112.1	111.1	111.8	111.8	112.0	111.5

Table 6. Flow-weighted TDG Saturations by Spill Event

Event	WEL %Sat	T1wt %Sat	T2wt %Sat	T1-T2 %Sat	T2-WEL %Sat
1	106.0	108.7	106.9	1.8	0.9
2	107.6	109.0	108.7	0.2	1.1
3	107.2	109.0	108.7	0.3	1.5
4	107.1	109.1	108.8	0.3	1.7
5	108.0	109.8	109.2	0.6	1.2
6	108.3	110.0	109.9	0.2	1.5
7	108.9	110.5	110.2	0.3	1.3
8	109.5	111.1	110.8	0.3	1.3
9	109.4	111.5	111.4	0.1	2.0
10	109.5	110.9	110.7	0.2	1.2
11	109.4	110.9	110.7	0.2	1.3
12	108.5	110.2	109.9	0.2	1.5
13	108.0	109.7	109.7	0.0	1.7
14	107.8	109.5	109.2	0.3	1.4
15	107.5	109.7	108.9	0.9	1.4
16	107.9	109.4	109.2	0.2	1.3
17	108.6	110.1	109.8	0.2	1.2
18	107.5	111.0	109.5	1.5	2.0
19	107.3	109.7	109.7	0.0	2.4
20	107.3	111.0	109.0	2.0	1.7
21	107.6	109.3	109.4	-0.1	1.7
22	107.6	110.5	109.0	1.5	1.4
23	108.3	109.7	109.6	0.1	1.2
24	107.7	109.1	108.9	0.2	1.2
25	107.6	108.9	108.5	0.3	0.9
26	107.3	109.0	108.4	0.6	1.1
27	107.0	108.4	108.1	0.2	1.1
28	107.2	108.3	108.3	0.0	1.0
29	108.2	109.4	109.2	0.2	1.0
30	107.5	110.2	109.0	1.2	1.5
31	107.4	109.1	108.9	0.2	1.5
32	107.2	108.7	108.4	0.4	1.2
33	108.7	109.9	109.6	0.2	1.0
34	108.0	109.1	109.1	0.0	1.2
35	108.8	109.8	109.4	0.4	0.6
36	110.1	111.6	111.4	0.1	1.3
37	109.8	111.2	111.5	-0.3	1.7
38	109.5	111.0	110.7	0.3	1.2
39	110.0	111.6	111.3	0.3	1.3
40	110.6	111.8	111.6	0.2	1.0
41	110.5	113.3	112.1	1.2	1.6
42	110.3	111.8	112.5	-0.8	2.2
43	111.2	112.0	111.9	0.1	0.7
44	111.6	112.4	112.2	0.2	0.7
45	110.0	111.1	111.2	-0.1	1.1
46	110.4	112.1	111.8	0.3	1.4

Table 7. Empirical and Calculated Weighted Average TDG Saturations for Transect 2

Event	T2wt (Empirical) %Sat	T2wt (Calculated) %Sat	T2wte-T2wtc %Sat
1	59.2	106.4	0.5
2	60.2	107.7	1.0
3	60.4	107.4	1.4
4	60.7	107.3	1.5
5	61.5	108.2	1.0
6	62.0	108.5	1.4
7	62.7	109.0	1.2
8	63.3	109.6	1.2
9	63.7	109.6	1.8
10	64.0	109.6	1.1
11	64.3	109.5	1.2
12	64.2	108.6	1.3
13	64.3	108.2	1.5
14	64.5	107.9	1.3
15	64.8	107.7	1.2
16	65.2	108.0	1.2
17	66.0	108.8	1.1
18	66.1	107.8	1.6
19	66.2	107.5	2.2
20	66.8	107.8	1.2
21	66.9	107.7	1.6
22	67.5	107.9	1.1
23	67.9	108.4	1.1
24	67.9	107.8	1.1
25	68.2	107.7	0.8
26	68.5	107.5	0.9
27	68.6	107.1	1.0
28	69.0	107.3	1.0
29	69.9	108.2	1.0
30	70.2	107.7	1.2
31	70.3	107.5	1.4
32	70.5	107.3	1.1
33	71.6	108.7	0.9
34	71.5	108.0	1.1
35	72.3	108.9	0.6
36	73.4	110.2	1.2
37	73.6	110.0	1.6
38	73.8	109.6	1.1
39	74.5	110.1	1.2
40	75.1	110.7	0.9
41	75.7	110.9	1.2
42	75.7	110.4	2.1
43	76.4	111.3	0.6
44	76.9	111.6	0.6
45	76.5	110.1	1.1
46	77.2	110.5	1.3

Table 8. Empirical and Calculated TDG Saturations for Wells Dam Powerhouse and Spillway Release Water

Event	TDGspe (T1C) %Sat	TDGspc %Sat	Diff TDGsp %Sat	TDGphe (WEL) %Sat	TDGphc %Sat	Diff TDGph %Sat
1	109.5	114.9	5.4	106.0	106.6	0.6
2	109.0	124.3	15.3	107.6	108.7	1.1
3	108.9	122.7	13.8	107.2	108.7	1.5
4	109.0	123.1	14.1	107.1	108.8	1.7
5	109.9	120.3	10.4	108.0	109.1	1.1
6	110.3	124.5	14.2	108.3	109.8	1.5
7	110.7	132.1	21.4	108.9	110.2	1.3
8	111.3	129.2	17.9	109.5	110.7	1.2
9	111.5	127.7	16.1	109.4	111.4	2.0
10	111.0	124.7	13.7	109.5	110.7	1.2
11	110.7	128.0	17.3	109.4	110.7	1.3
12	110.1	126.9	16.8	108.5	109.9	1.4
13	109.5	123.8	14.3	108.0	109.7	1.7
14	109.0	122.6	13.6	107.8	109.3	1.5
15	109.4	123.5	14.1	107.5	108.8	1.3
16	109.4	124.6	15.2	107.9	109.2	1.2
17	110.2	124.8	14.6	108.6	109.8	1.2
18	110.8	125.5	14.7	107.5	109.3	1.8
19	109.2	129.2	20.1	107.3	109.8	2.4
20	110.8	119.5	8.7	107.3	108.7	1.4
21	108.9	126.1	17.2	107.6	109.4	1.8
22	109.9	119.1	9.1	107.6	108.9	1.3
23	109.6	125.0	15.4	108.3	109.6	1.2
24	108.9	122.5	13.5	107.7	108.9	1.2
25	108.6	117.5	8.9	107.6	108.5	0.9
26	108.7	116.4	7.7	107.3	108.3	1.0
27	108.0	119.5	11.5	107.0	108.1	1.1
28	107.9	121.4	13.4	107.2	108.3	1.0
29	109.5	124.2	14.8	108.2	109.2	1.0
30	110.3	123.2	12.9	107.5	108.9	1.4
31	108.6	122.3	13.7	107.4	109.0	1.5
32	108.3	121.4	13.1	107.2	108.4	1.2
33	109.7	123.3	13.6	108.7	109.6	1.0
34	109.0	121.3	12.3	108.0	109.1	1.2
35	109.8	118.2	8.4	108.8	109.4	0.6
36	111.7	131.3	19.6	110.1	111.4	1.3
37	111.2	126.1	14.9	109.8	111.6	1.7
38	110.6	121.9	11.4	109.5	110.7	1.2
39	111.6	132.7	21.1	110.0	111.3	1.3
40	111.8	125.7	13.9	110.6	111.6	1.0
41	113.6	124.2	10.6	110.5	111.9	1.4
42	111.6	134.5	22.9	110.3	112.6	2.3
43	111.9	119.8	7.9	111.2	111.9	0.7
44	112.3	121.2	8.9	111.6	112.2	0.7
45	111.0	124.6	13.6	110.0	111.2	1.2
46	112.1	132.7	20.5	110.4	111.8	1.3

Table 9. Daily Average of 12 Highest TDG Saturations

Date	CHQW	WEL	T1A	T1B	T1C	T1D	WELW	T2B	T2C	T2D	RRH
05/28/03	112.2	108.8	111.3	112.3	112.1	111.2	110.3	110.3	110.7	110.3	109.6
05/29/03	109.2	109.8	113.2	114.6	114.9	113.5	114.5	114.4	114.7	114.5	110.0
05/30/03	109.0	109.6	111.5	111.8	111.6	111.3	111.2	111.2	111.4	111.2	113.4
05/31/03	108.4	108.7	110.3	110.6	110.3	109.6	109.9	109.9	110.0	109.7	110.9
06/01/03	108.0	108.0	110.6	111.2	110.2	109.9	109.6	109.7	109.8	109.4	110.2
06/02/03	108.1	108.2	109.7	110.0	109.6	109.1	109.3	109.3	109.4	109.1	109.1
06/03/03	108.8	108.8	110.4	110.5	110.0	109.7	109.9	109.8	109.9	109.6	109.4
06/04/03	109.5	109.4	110.8	111.0	110.6	110.3	110.5	110.4	110.6	110.3	109.8
06/05/03	109.5	110.3	111.9	112.1	112.1	111.4	111.7	111.6	111.7	111.3	110.8
06/06/03	110.0	110.1	112.3	112.7	112.3	111.4	111.5	111.6	111.9	111.5	112.0
06/07/03	111.3	110.8	114.0	114.7	114.8	114.2	115.5	115.3	115.5	115.4	112.5
06/08/03	112.2	111.7	112.7	113.1	112.8	112.8	112.4	112.3	112.6	112.3	114.7
06/09/03	111.4	110.5	112.5	113.0	112.3	111.3	112.0	112.0	112.1	111.7	112.6

Figures

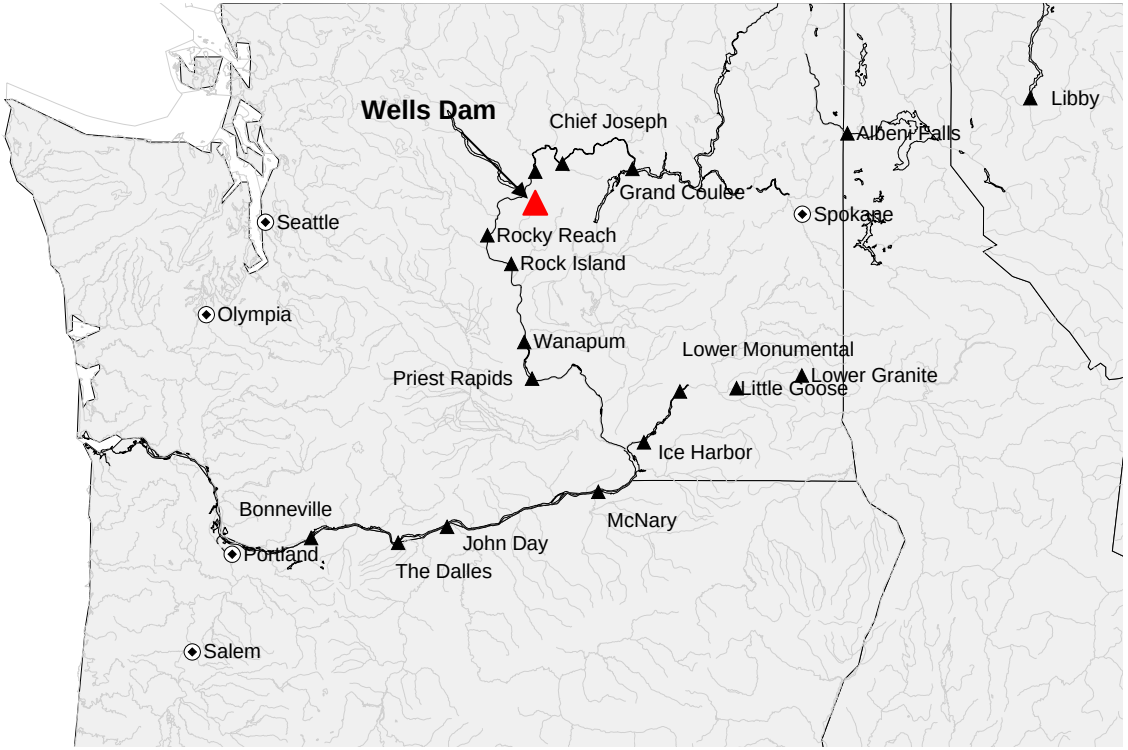

Figure 1. Regional map indicating location of Wells Dam.

Figure 2. Area map for Wells Dam spill evaluation indicating primary deployment transects.

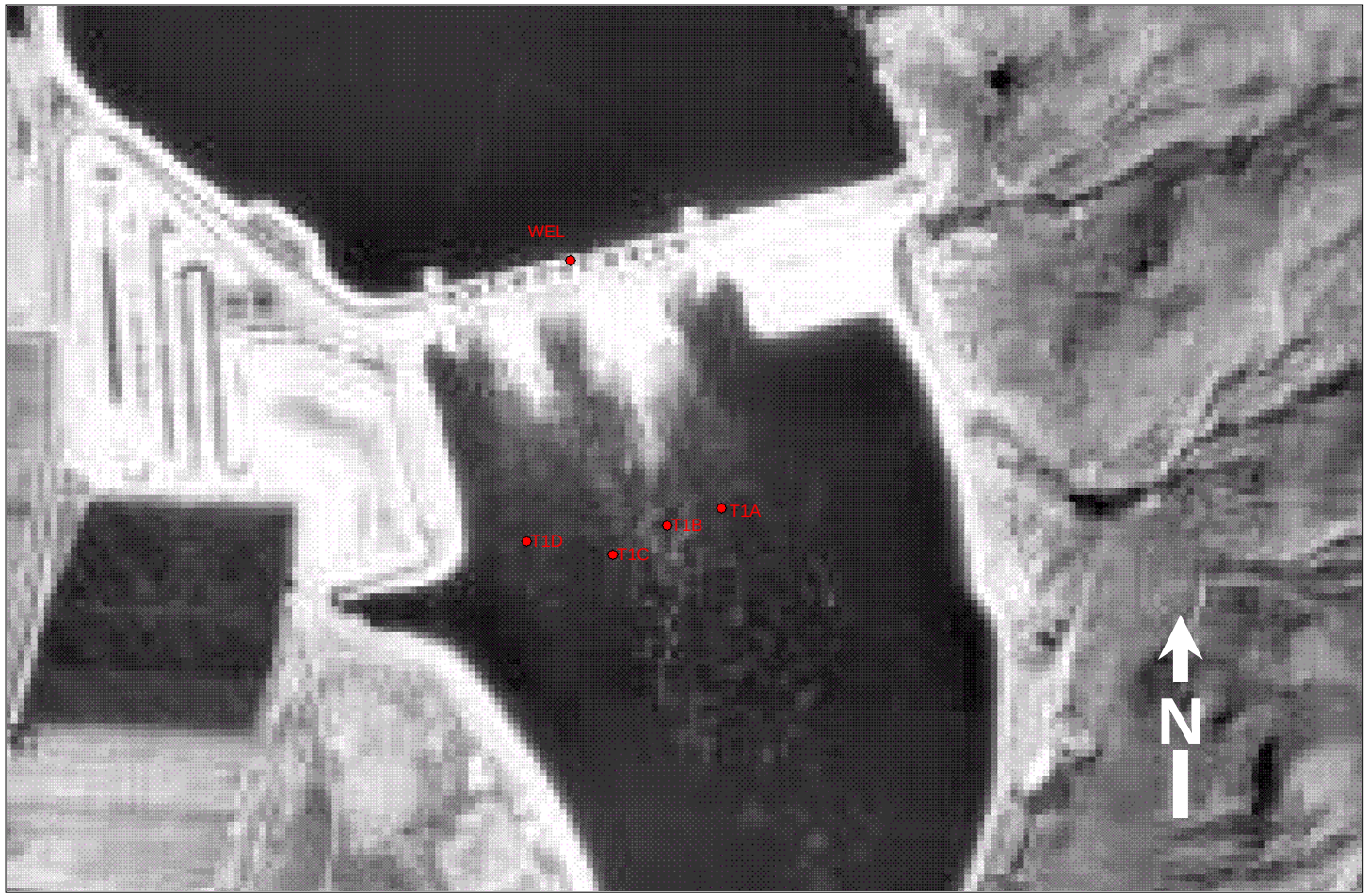

Figure 3. Transect 1 deployment locations.

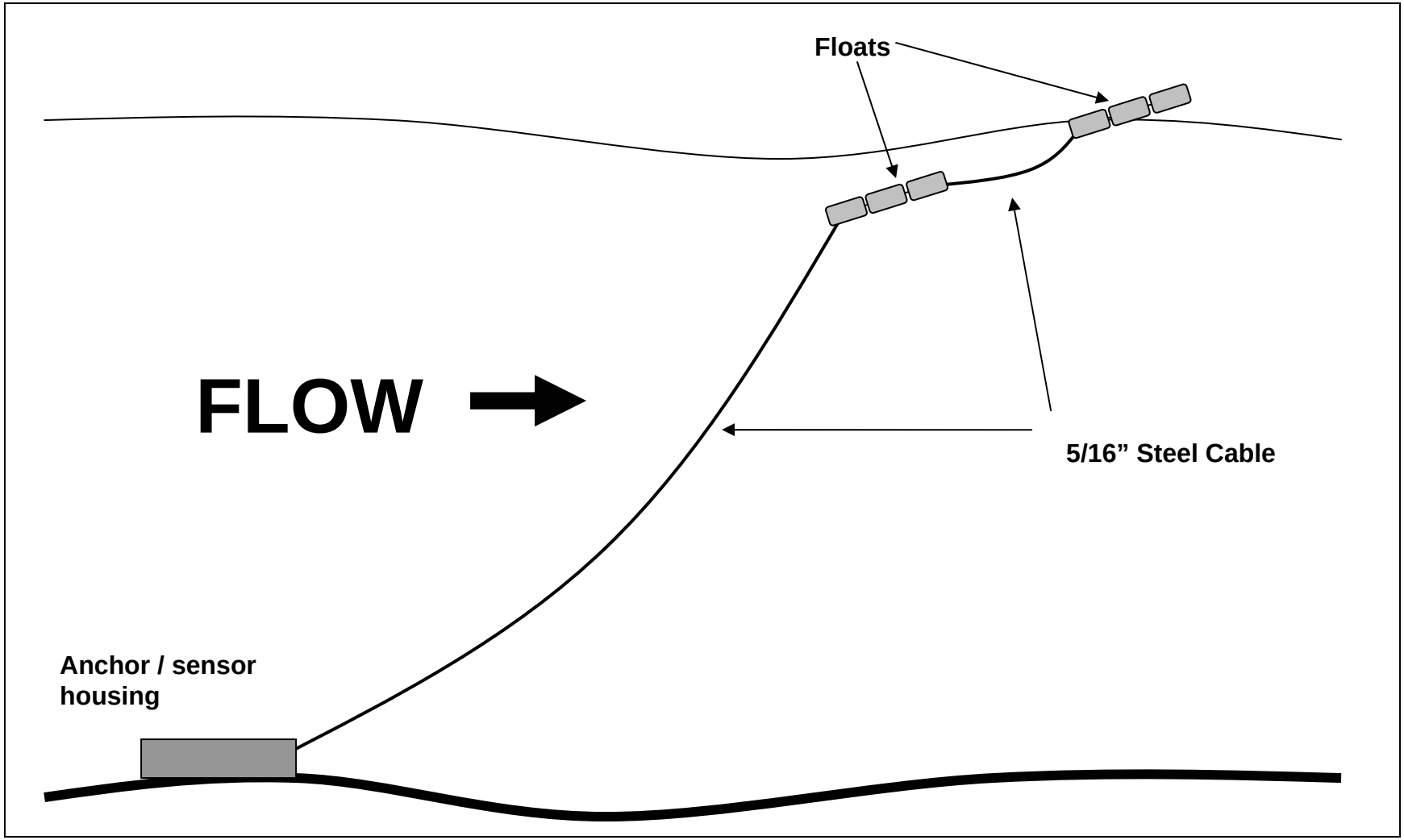

Figure 4. Schematic representation of Transect 1 deployment rigging.

Figure 5. Transect 2 deployment locations

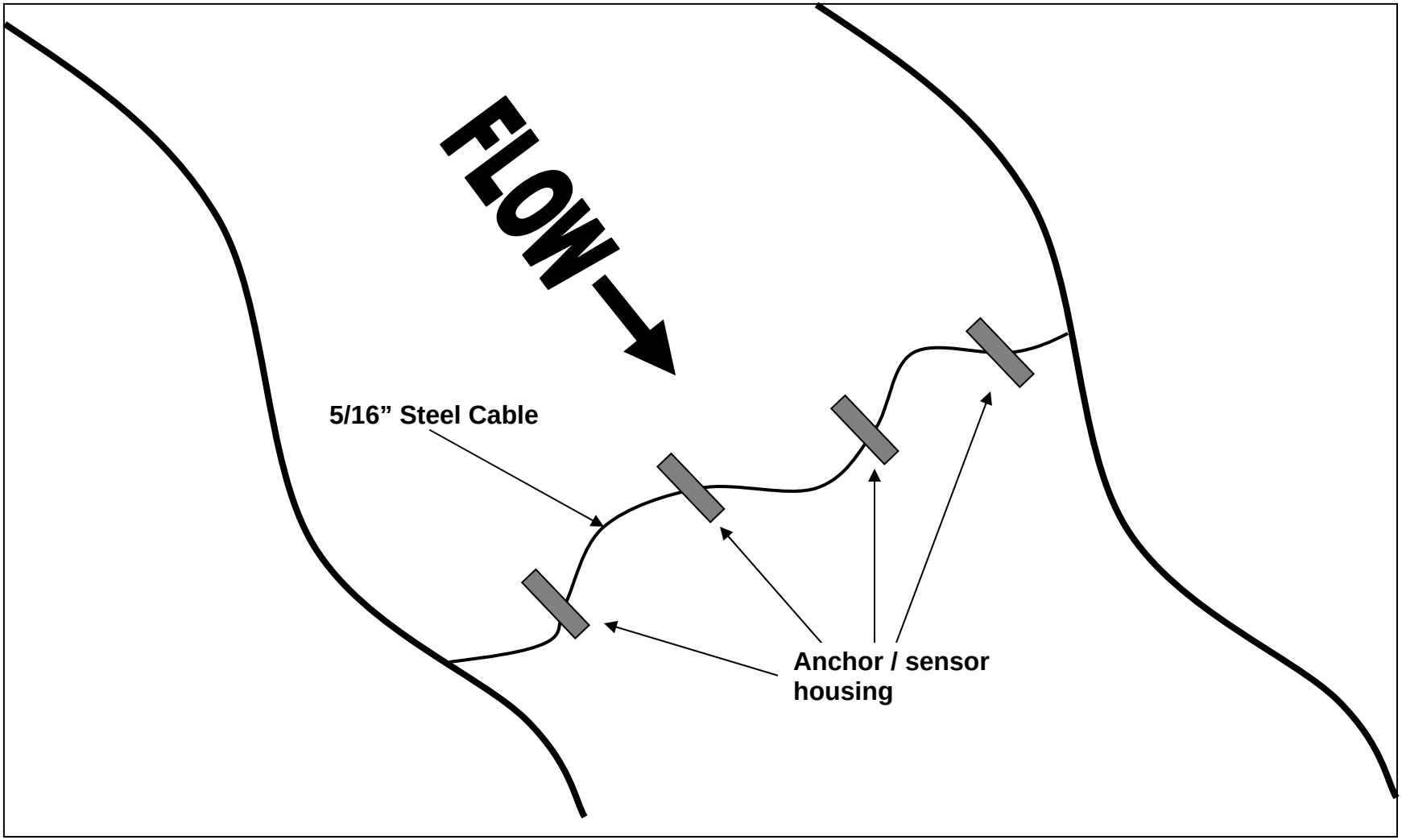

Figure 6. Schematic representation of Transect 2 deployment rigging.

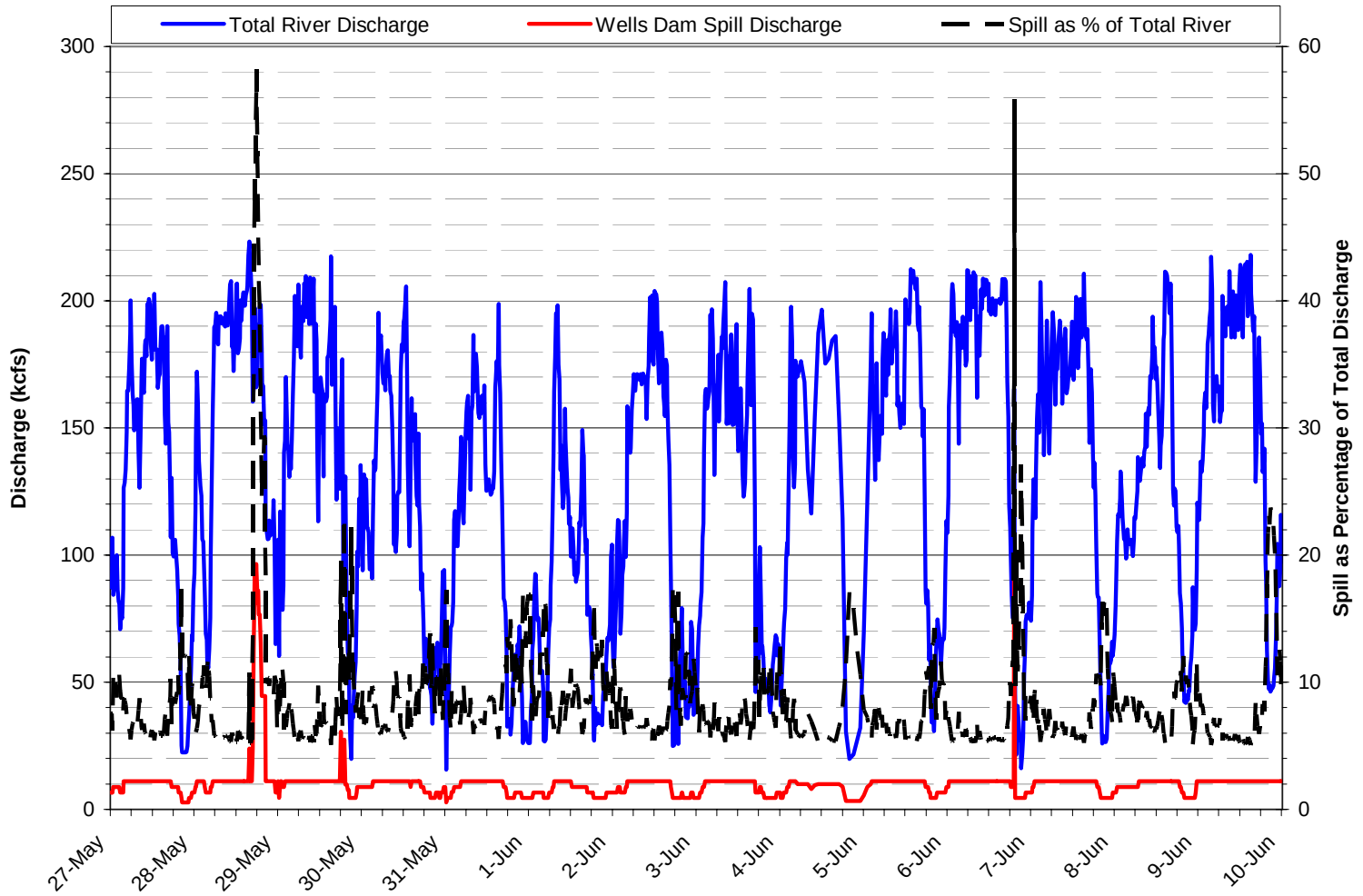

Figure 7. Wells Dam project discharge for the period of 27 May to 10 June 2003.

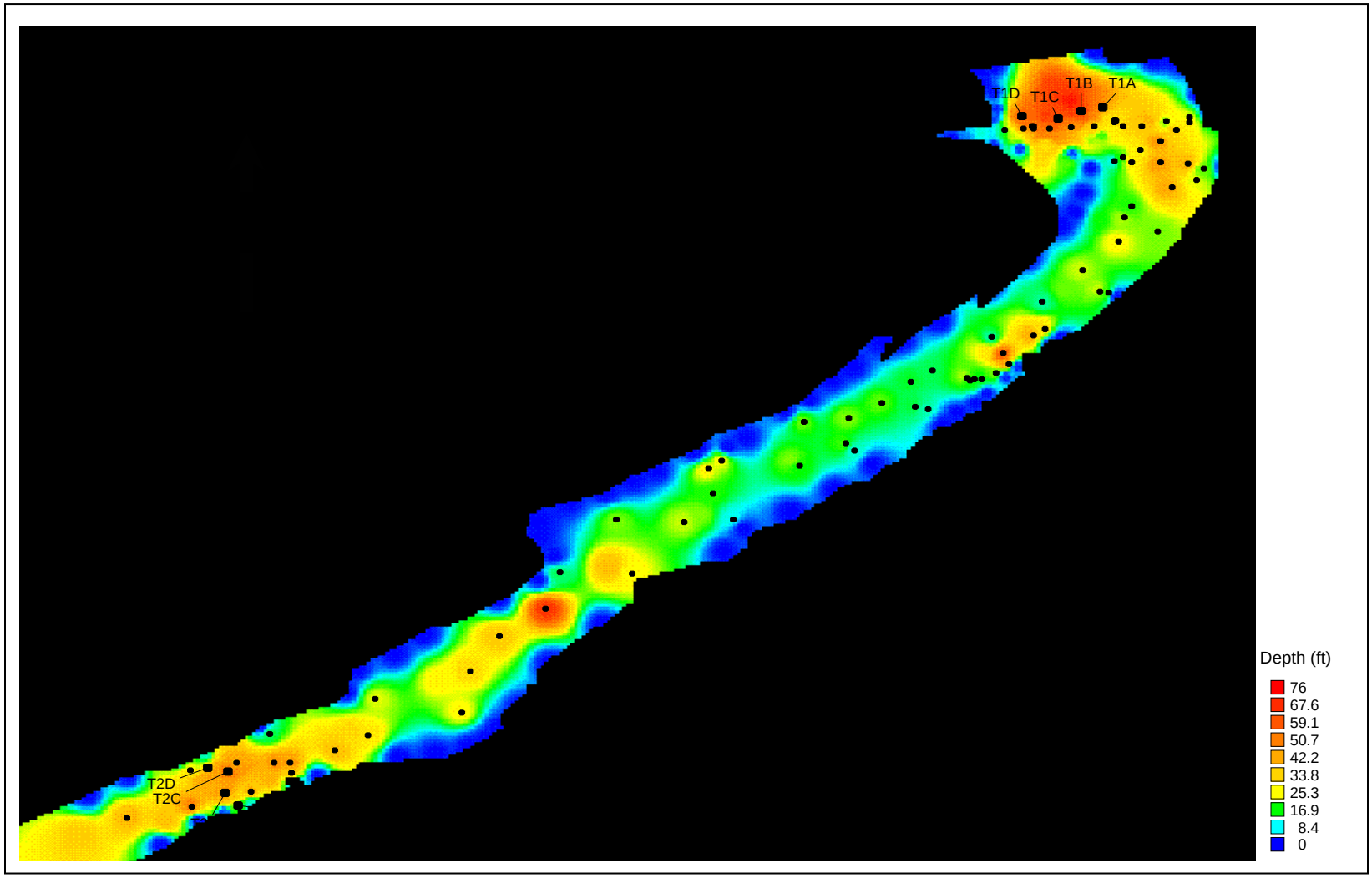

Figure 8. Contour map of Wells Dam tailwater morphometry developed from bathymetric cruise data.

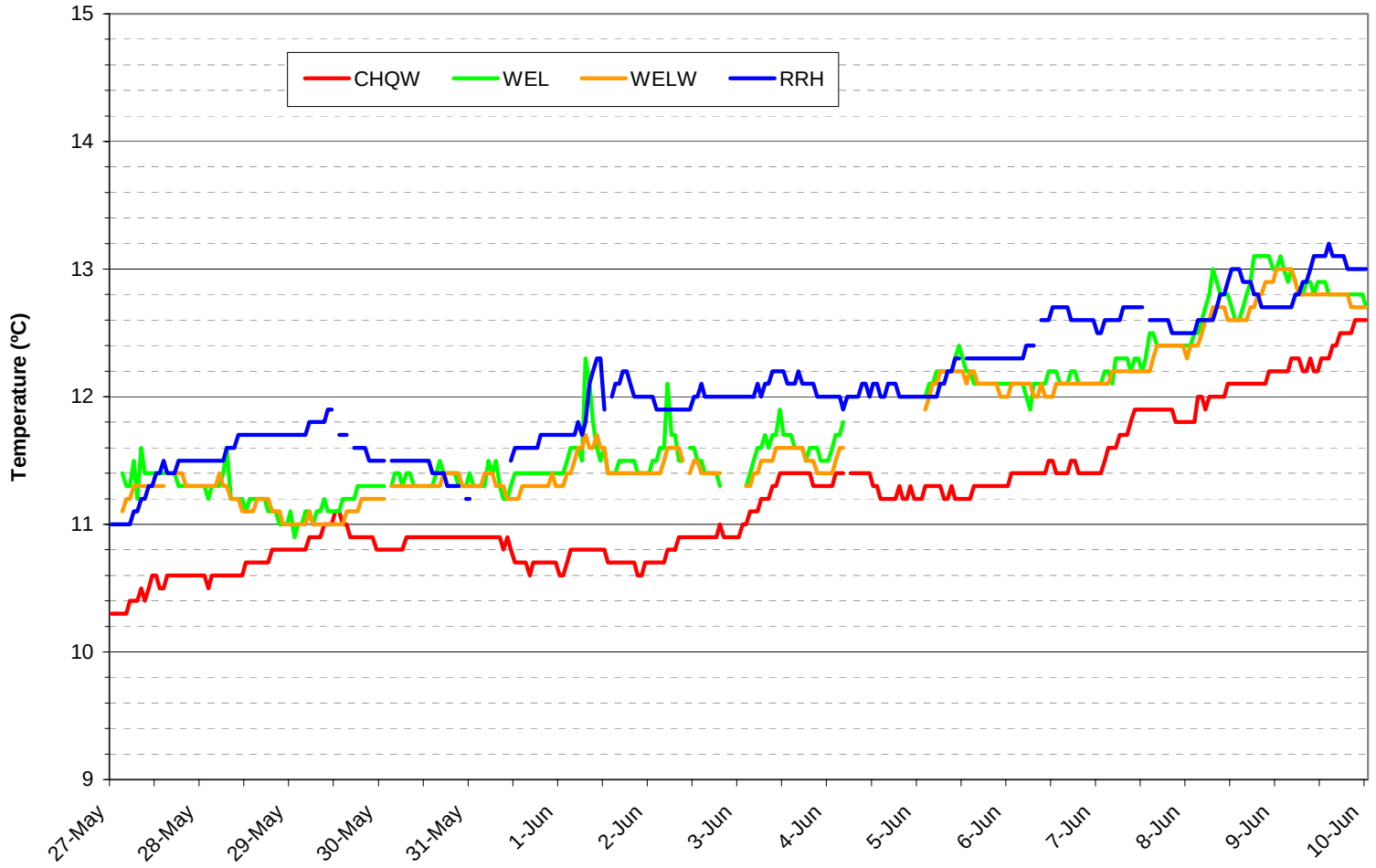

Figure 9. Water temperature data measured at Chief Joseph, Wells, and Rocky Reach Dams for the period of 27 May to 10 June 2003.

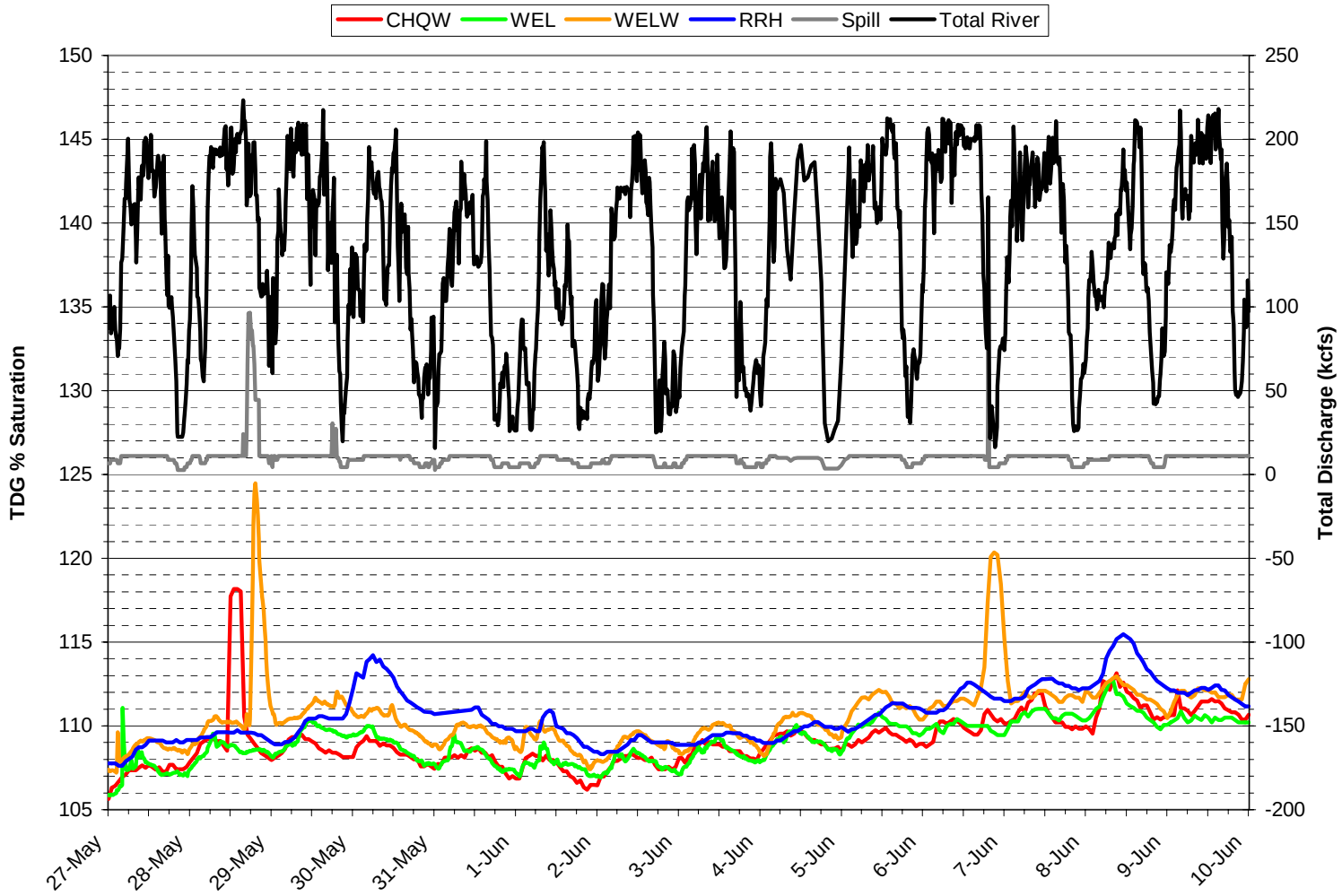

Figure 10. Total dissolved gas saturations measured at Chief Joseph, Wells, and Rocky Reach Dams for the period of 27 May to 10 June 2003 (River and spill discharge information are for Wells Dam).

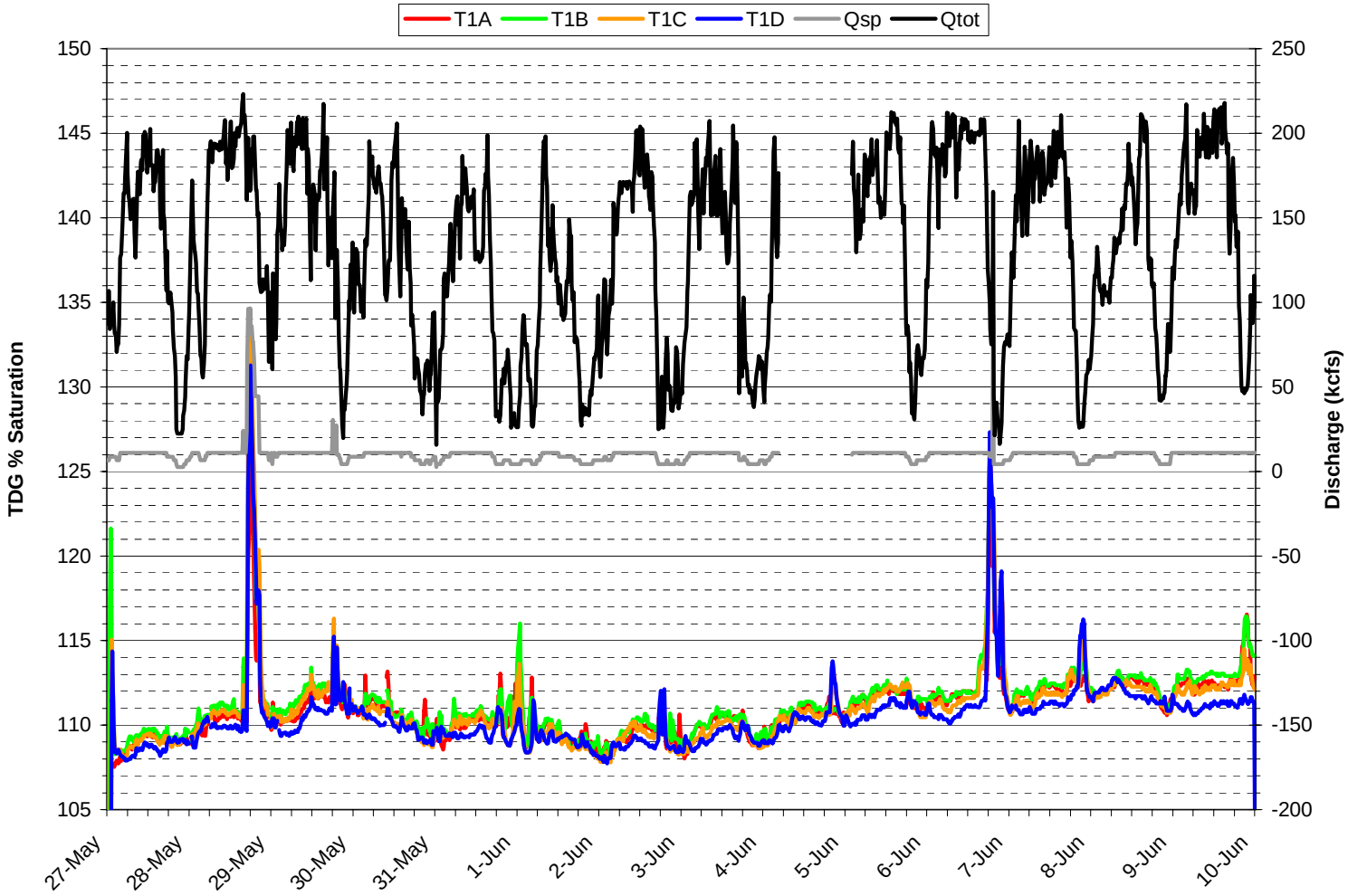

Figure 11. Wells Dam 15-minute operations data and Transect 1 TDG saturations for the period from 27 May to 10 June 2003.

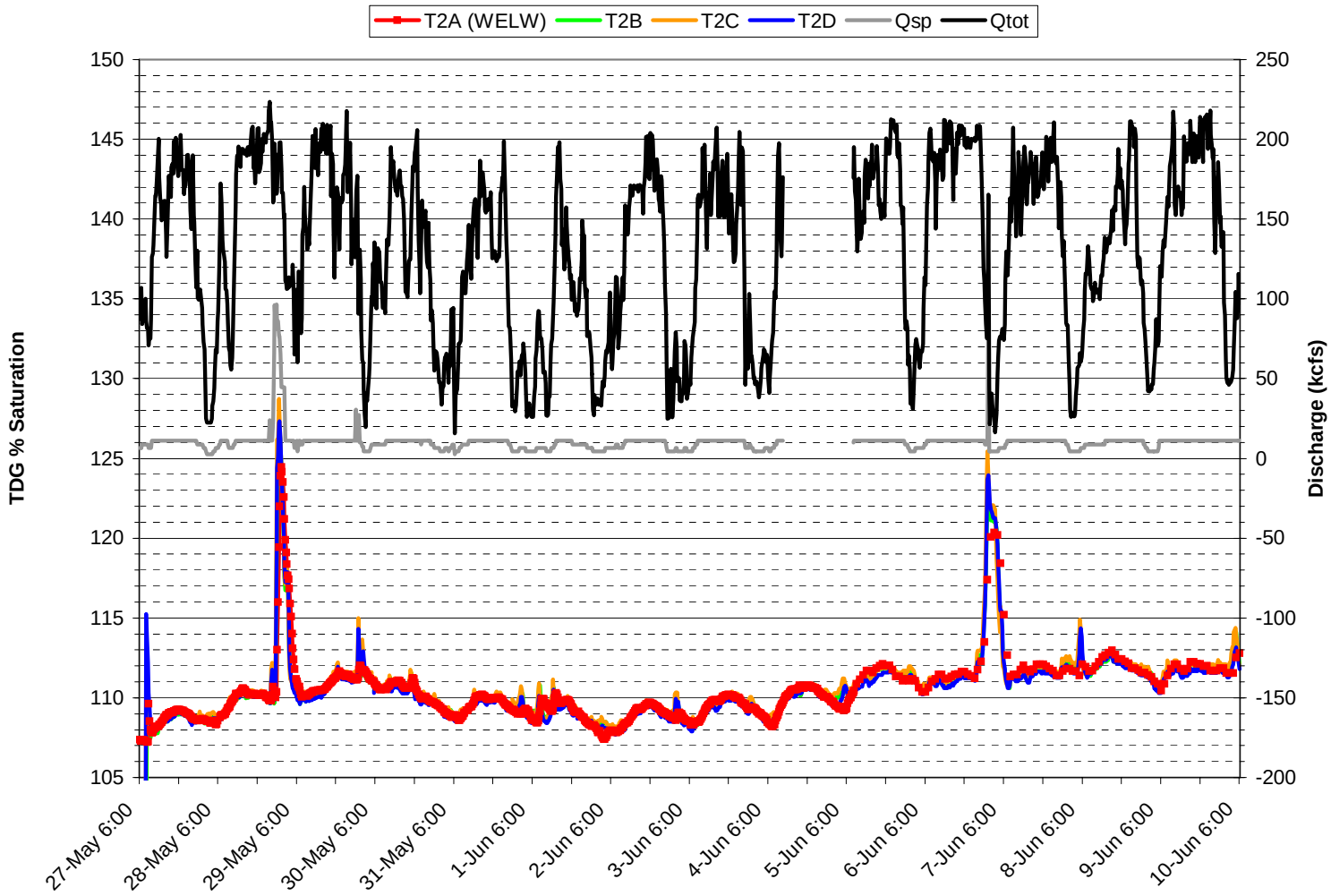

Figure 12. Wells Dam 15-minute operations data and Transect 2 TDG saturations for the period from 27 May to 10 June 2003.

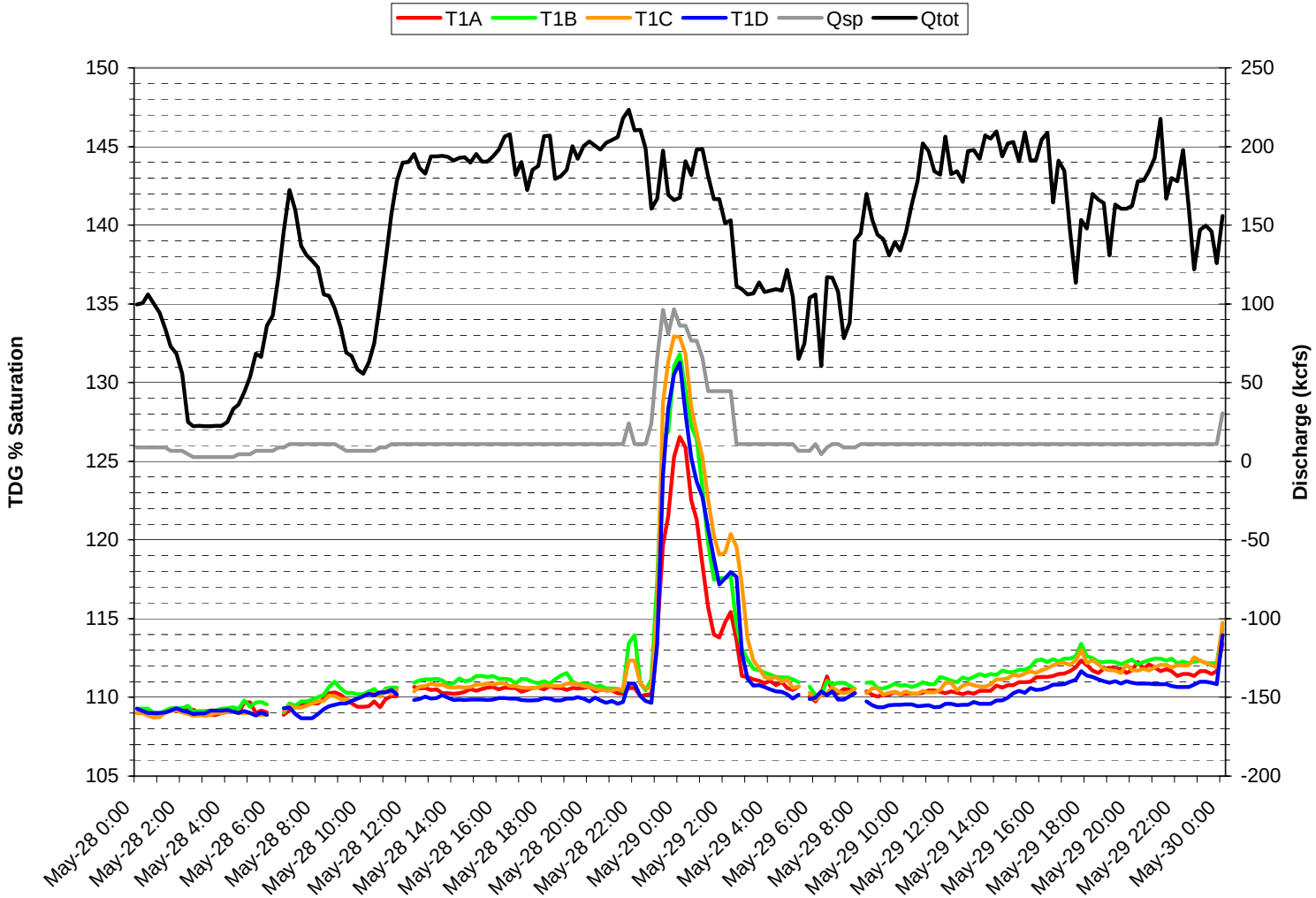

Figure 13. Wells Dam 15-minute operations data and Transect 1 TDG saturations for the period from 28 to 30 May 2003.

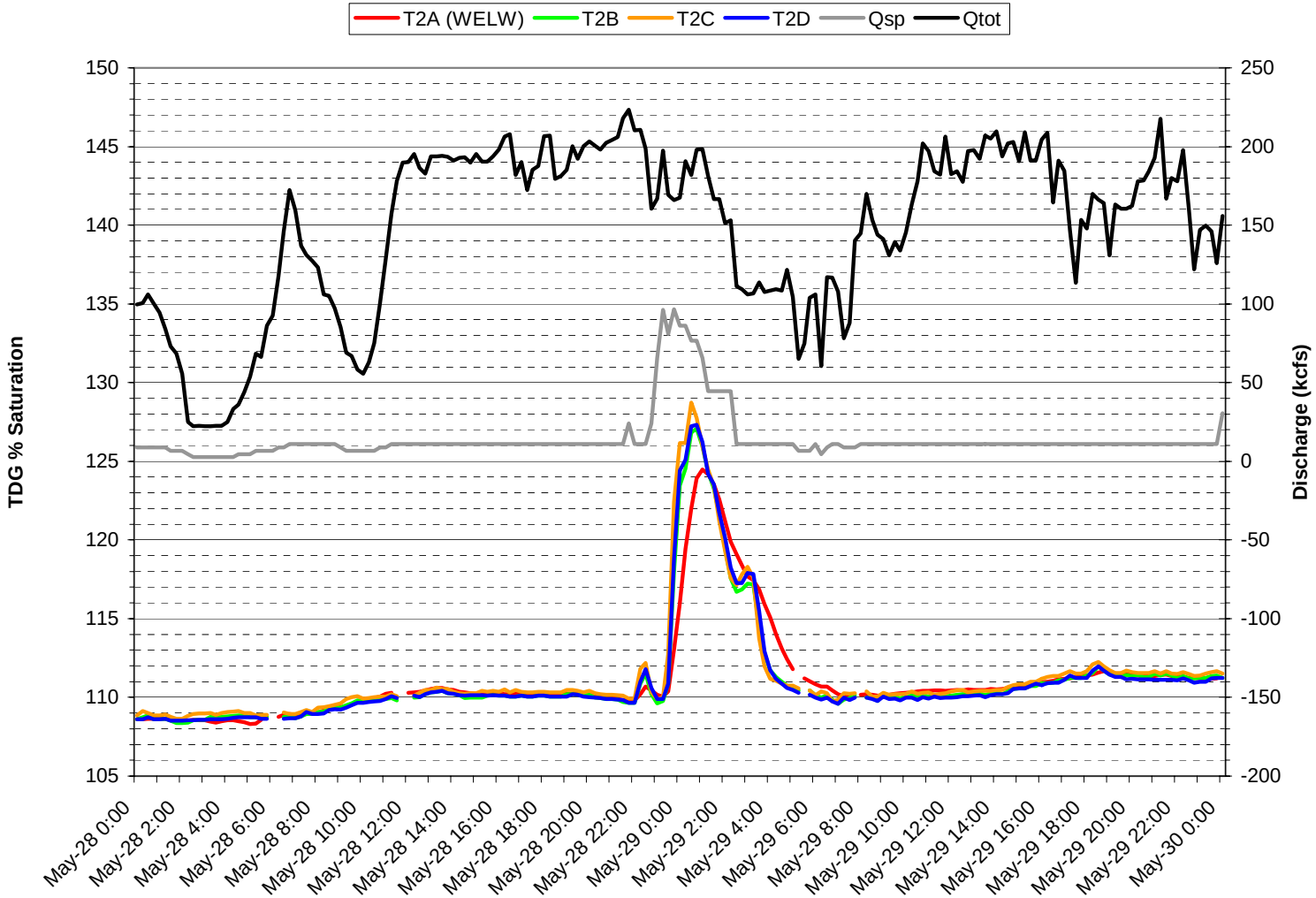

Figure 14. Wells Dam 15-minute operations data and Transect 2 TDG saturations for the period from 28 to 30 May 2003.

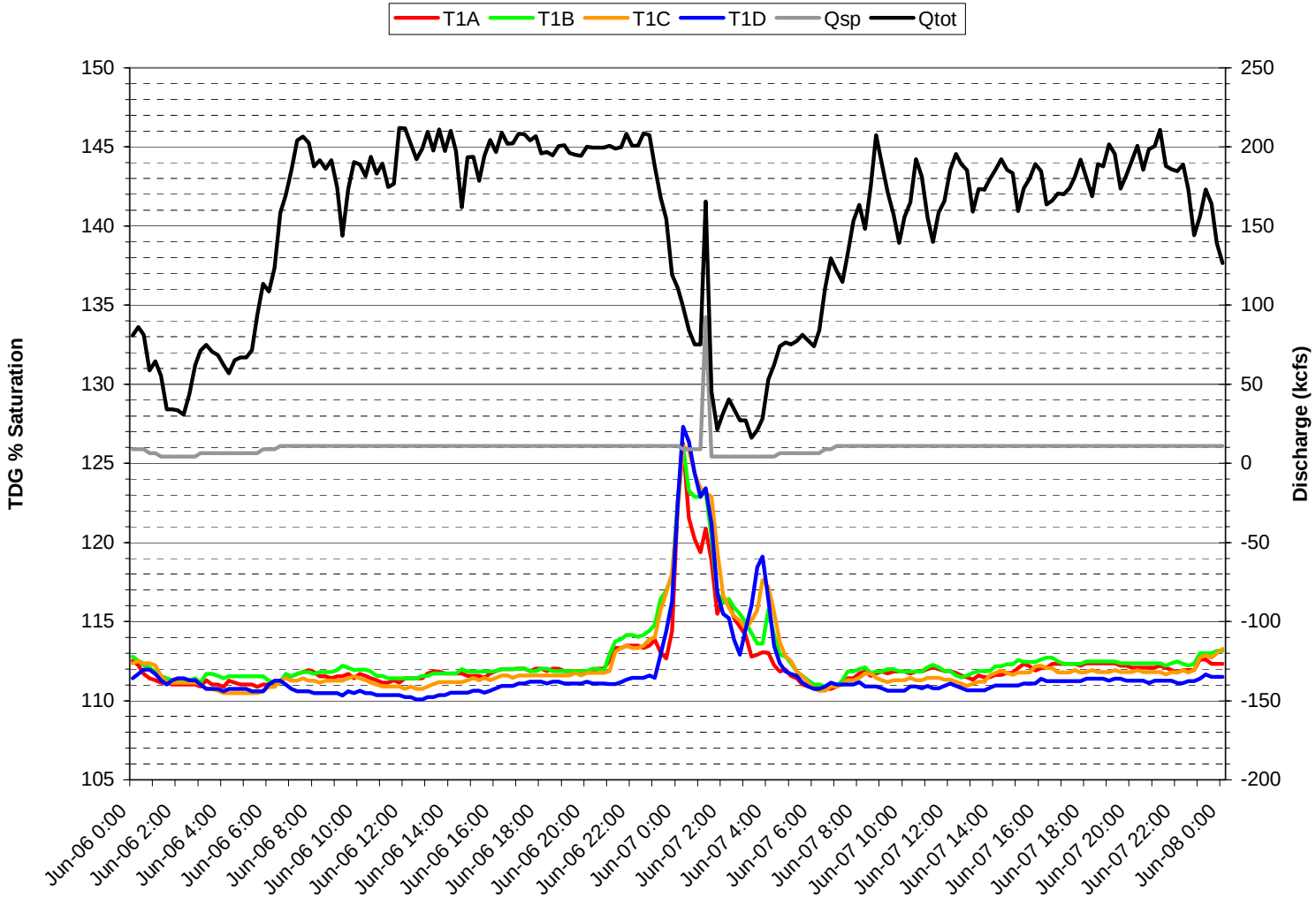

Figure 15. Wells Dam 15-minute operations data and Transect 1 TDG saturations for the period from 6 to 8 June 2003.

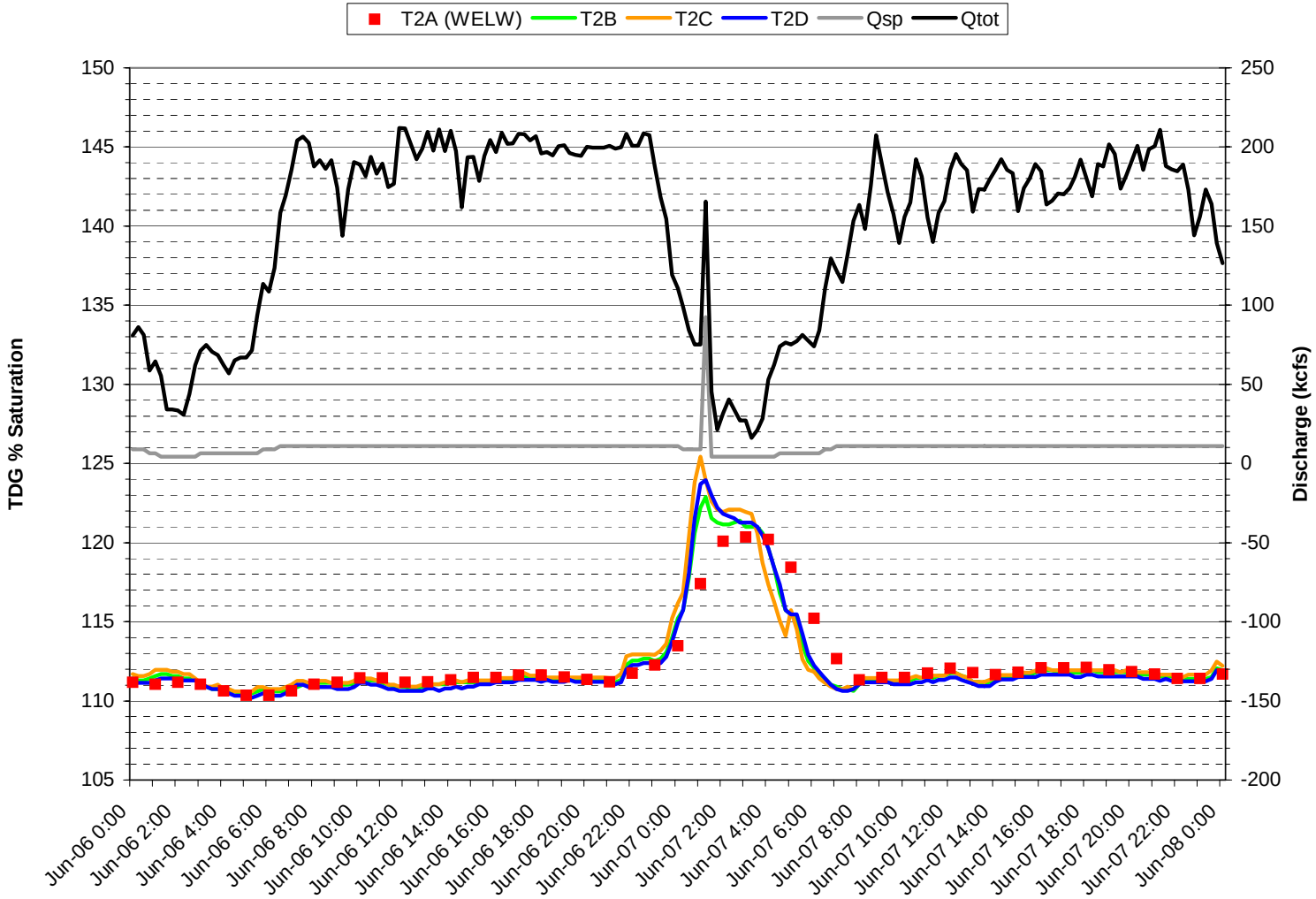

Figure 16. Wells Dam 15-minute operations data and Transect 2 TDG saturations for the period from 6 to 8 June 2003.

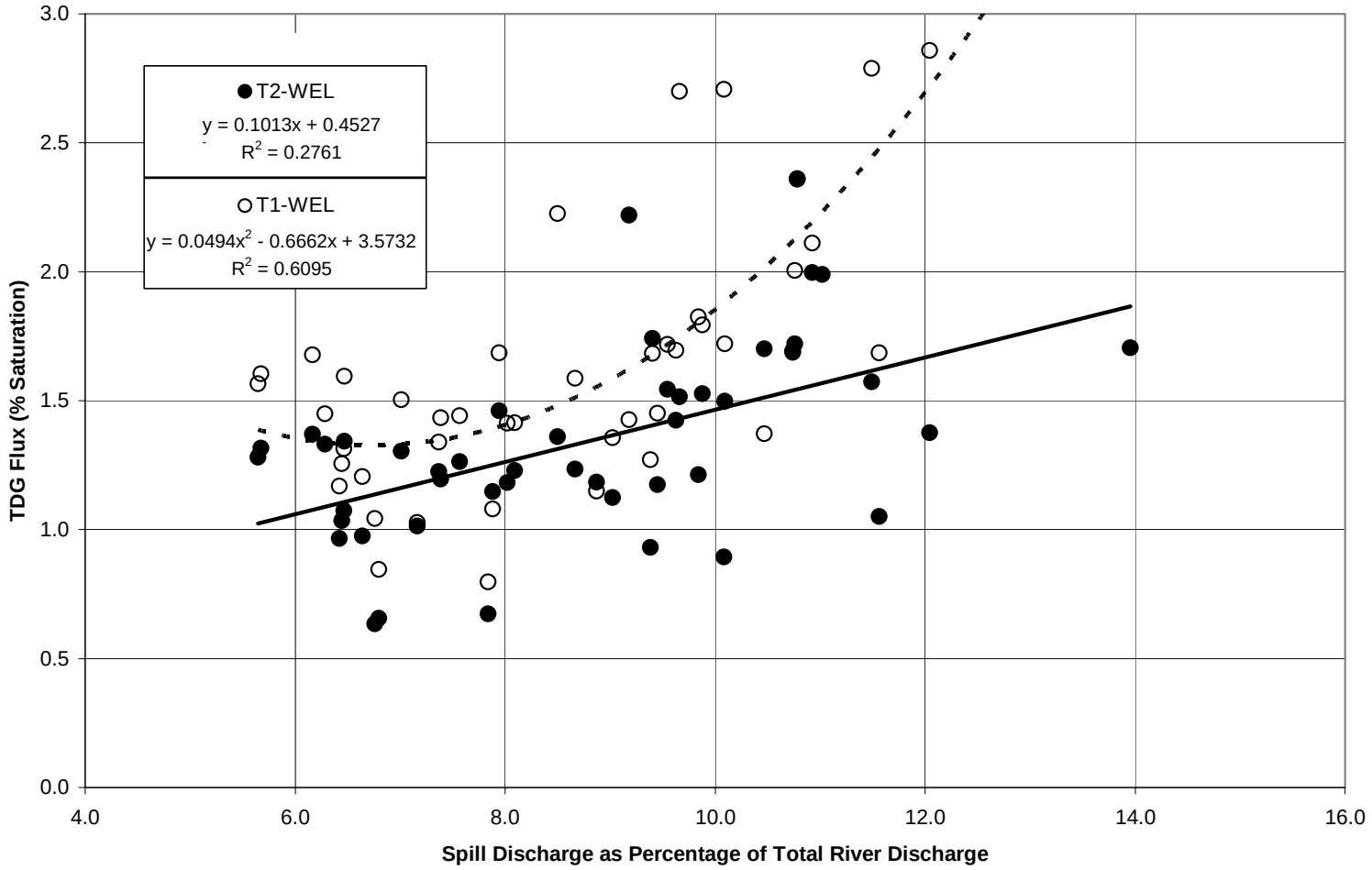

Figure 17. Wells Dam TDG flux determined from comparing forebay and tailwater pressures.

CBE. 2004. Wells Dam Spillway Total Dissolved Gas Evaluation. Final Report. Prepared by Columbia Basin Environmental, The Dalles, Oregon for Public Utility District No. 1 of Douglas County, East Wenatchee, Washington.

Wells Dam Spillway Total Dissolved Gas Evaluation

23 May to 6 June 2004

FINAL REPORT

December 2004

Prepared for

Public Utility District No. 1 of Douglas County
1151 Valley Mall Parkway
East Wenatchee, Washington 98802

Prepared by

Columbia Basin Environmental
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Preface

This document reports the findings of a study conducted at Wells Dam from 23 May to 6 June 2004. The study was conducted by Columbia Basin Environmental and funded by the Public Utility District No. 1 of Douglas County. The use of trade names in this document should not be interpreted as an endorsement by either party.

This document contains hyperlinks indicated by blue text. Click highlighted word to follow link.

Summary

The Public Utility District No. 1 of Douglas County undertook a study at Wells Dam, located on the Columbia River, to describe total dissolved gas pressures resulting from spill operation by the dam. An array of water quality data loggers were installed in the Wells Dam tailwater for a period of two weeks between 23 May and 6 June, 2004. Each was programmed to record water temperatures and total dissolved gas pressures along a ten-minute interval.

Both the forebay and tailwater fixed monitors were compared to adjacent sites. Based on criteria for compliance with state water quality standards, both sites effectively represented the water quality associated with operation of Wells Dam. The forebay monitor location exhibited greater daily temperature fluctuations than the two test locations. This may have resulted from localized influences resulting from its proximity to the project; however, this could not be determined from the available data.

Comparisons of upstream and downstream flow-weighted TDG saturations implied that the Wells tailwater monitor tended to under represent the total contribution of TDG by Wells Dam. The most likely explanation was that powerhouse release water was gassed by spilled water, effectively increasing the percentage of spilled water. Similar data collected under higher spill volumes may help verify the existence and degree of powerhouse gassing.

Given the relative ambiguity of the results, no definitive recommendations for monitor placement were forthcoming. Although instantaneous data comparisons between existing and alternate sites indicated differences, daily summaries did not.

1.0. Introduction

The total dissolved gas (TDG) pressure of water describes the total pressure exerted by the constituent gasses as determined by their concentration and solubility. There are numerous natural and anthropogenic influences on dissolved gas concentrations and pressures including, but not limited to, community metabolism, heating, aeration devices, water falling over dams, weirs, or waterfalls, and turbine venting. It is possible for TDG pressures to exceed the equilibrium pressure resulting in TDG *supersaturation*. Supersaturated water will tend to lose gas to the atmosphere; however, this may be slow in the absence of turbulent flow.

The detrimental effects of the exposure of aquatic organisms to water characterized by elevated dissolved gas pressures were identified as early as 1905 (Marsh and Gorham 1905). Exposure to supersaturated water may result in *gas bubble trauma* (GBT), a condition similar to nitrogen narcosis ("the bends") in divers. As fish move vertically in the water column, gasses dissolved in the bloodstream under greater hydrostatic pressure may rapidly leave solution. This may lead to gill and skin blistering and "pop-eye." The presence of GBT has been documented throughout the Columbia River Basin, the most notable resulting in large fish kills at the John Day Dam (Beiningen and Ebel 1970).

1.1. Site Description

Wells Dam is located on the Columbia River near Azwel, Washington at river mile 515.8 (Figure 1) and is owned and operated by the Public Utility District No. 1 of Douglas County (District). Wells Dam was built as a *hydrocombine* such that the spillway was situated directly over the powerhouse. This design was thought to reduce the plunge depth of spilled water by utilizing the force of the powerhouse release to essentially shallow the stilling basin (Klinge 1998). The overall length of the dam is 4460 ft, of which the hydrocombine comprises 1165 ft. The project consists of eleven vertical lift spill gates and ten generating units with a maximum nameplate capacity of 840 megawatts (MW). The hydraulic capacity of the powerhouse is 220 kcfs and the maximum spillway capacity is 1180 kcfs.

Wells Dam spillway operation consists of *forced* spill (inflows exceed the capacity of the powerhouse) or *bypass* spill (spill of a portion of total river volume to assist the out migration of juvenile salmonids). Forced occurs any time the total river discharge exceeds the powerhouse's total capacity. Excess capacity may result from restricted power transmission (e.g. power generation in excess of power demand), high total river flows (>220 kcfs at Wells Dam), or in the event of equipment failure. Bypass spill at Wells Dam typically occurs between April and August comprising a percentage of the total project discharge divided equally between Spillbays 2, 4, 6, 8, and 10.

1.2. Background

1.2.1. Water quality regulations

The water quality standard for TDG pressure for the state of Washington is as follows:

> *Total dissolved gas shall not exceed 110 percent of saturation at any point of sample collection.*

The National Oceanographic and Atmospheric Association (NOAA) Fisheries has requested spill at selected hydroprojects within the Columbia River Basin to assist with juvenile salmonid

out migrations. The state of Washington developed the following waiver to the aforementioned standard:

> ***Special fish passage exemption for sections of the Snake and Columbia rivers:*** *When spilling water at dams is necessary to aid fish passage, total dissolved gas must not exceed an average of one hundred fifteen percent as measured at Camas/Washougal below Bonneville dam or as measured in the forebays of the next downstream dams. Total dissolved gas must also not exceed an average of one hundred twenty percent as measured in the tailraces of each dam. These averages are based on the twelve highest hourly readings in any one day of total dissolved gas. In addition, there is a maximum total dissolved gas one hour average of one hundred twenty-five percent, relative to atmospheric pressure, during spillage for fish passage.*

1.2.2. Previous studies

The District has maintained a permanent TDG fixed monitoring system (TDGFMS) consisting of two Hydrolab® MiniSonde® multiprobes that measure water temperature and TDG pressure throughout the bypass spill season at Wells Dam. The forebay probe (WEL) has been in operation since 1996 and the tailwater probe (WELW) since 1998. Atmospheric pressure data are collected via an aneroid barometer located on the surface deck of the dam. In addition to the TDGFMS, the District has collected periodic grab data to evaluate lateral and longitudinal distributions in TDG pressure. The results of these studies indicated minor gradients of less than 2% saturation across the width of the tailrace (Klinge 1998).

The District undertook an intensive study to evaluate spill at Wells Dam during 2003. The 2003 study employed an array of data loggers arranged in a grid in the Wells Dam tailwater. The findings of that effort were summarized in a report for the District (CBE 2003). The previous study indicated that the tailwater FMS (WELW) exhibited a delayed response to operational changes by Wells Dam when compared to mid- and upstream locations. Despite this delay, averages of the twelve highest daily TDG saturations (the compliance measure used by the State of Washington) varied little between stations.

The 2003 study also attempted to determine the fate of powerhouse release water by comparing up- and downstream volume weighted TDG saturations. The results of these efforts were limited by the range of tested flow conditions, but implied that the TDG pressures of powerhouse release water may have been influenced by spillway operation (CBE 2003).

1.3. Objectives

This study sought to expand the findings of previous work at Wells Dam with the following two primary objectives:

1. determine the effectiveness of the present FMS locations at representing water temperature and TDG pressures in the Wells Dam forebay and tailwater

and

2. define the relationship between spillway release and power generation with TDG production at Wells Dam.

2.0. Methods

As with prior studies, sensor deployment was timed to coincide with the spring freshet to maximize the opportunity to sample high spillway discharges without negatively impacting power generation.

2.1. Instrumentation

Ten Hydrolab® MiniSonde® multi-parameter data loggers (sondes) were leased for the period of study in addition to one auxiliary probe and two permanent instruments owned by the District. Each sonde was equipped with sensors for water temperature, TDG pressure, and sonde depth. Prior and subsequent to field deployment, all probes were calibrated to NIST traceable standards for temperature and TDG pressure. Eleven auxiliary sondes were deployed, in addition to the permanent monitoring stations, and programmed to record data every ten minutes. Atmospheric pressure data were collected at the forebay TDGFMS location and corrected to the tailwater elevation for the downstream sites.

2.2. Field Deployment

Deployment sites were selected to maximize data resolution in key regions from the stilling basin downstream to the tailwater TDGFMS. Sondes were distributed in transects of three instruments distributed evenly across the river. Sondes were positioned in locations used in previous studies with the inclusion of an additional transect both upstream and downstream. Figure 2 depicts the transect locations for the 2004 study. The location of each deployment site was determined via global positioning system (GPS). Deployment information is summarized in Table 1.

2.2.1. Forebay

The forebay transect (FB, Figure 3) consisted of two sondes leased for the study and the forebay FMS (WEL). The leased probes (FB1 and FB2) were suspended from the boat restriction buoys flanking the project at a depth of approximately 12 m (40 ft). The forebay FMS was permanently deployed in a perforated pipe attached to the face of the dam at a depth of 4.5 m (15 ft).

2.2.2. Transect A

Transect A consisted of three leased probes located approximately 1000 ft. downstream of the dam (A1, A2, and A3 in Figure 3). Each was housed in a 200 lb. steel case that served to both anchor the station and protect the sonde. Anchors were attached to a series of surface floats via 5/16” diameter steel cables that allowed installation and retrieval by boat. Figure 4 provides an illustration of the deployment rigging used for Transect A.

2.2.3. Transect B

Transect B was also comprised of three leased sondes and was positioned about one mile downstream of the dam. To minimize danger to boat traffic, the sondes were strung across the river in a “necklace” configuration consisting of 5/16” diameter steel cable and 150 lb. steel anchors as depicted in Figure 5.

2.2.4. Transect C

Transect C consisted of two leased sondes and the tailwater TDGFMS (WELW) located about three miles downstream of the dam. The leased probes were installed in a manner similar

to Transect B (depicted in Figure 5) while the TDGFMS was permanently installed in a perforated pipe on the river's eastern shore. An additional sonde (WELWa in Figure 3) was deployed approximately 750 ft. upstream of the tailwater TDGFMS (WEL).

2.3. Data Analysis

Data collected for the Wells Spillway study were obtained from the following sources:

1. field transect data – water temperature and TDG pressure (mm Hg) reported every ten minutes for eleven sites (the forebay and tailwater TDGFMS and nine of eleven auxiliary sites)

2. Columbia River Operational HydroMet System (CROHMS) data – web-based database of hourly project operation and water quality data maintained by the U.S. Army Corps of Engineers

3. ten minute project operations data – total project discharge, total spillway discharge, turbine output by unit, and pool elevations for the forebay and tailwater reported every ten minutes provided by the DPUD Power Operations Database

4. bathymetric survey data – latitude, longitude, and depth information for the Wells Dam tailwater collected during four boat cruises conducted on 5 May and 10 June 2003 and on 23 May and 6 June 2004.

The sondes utilized TDG sensors that reported the total pressure at the depth of sample collection. Pressures were converted to TDG pressure as a percentage of surface saturation as

$$TDG_{sat} = \frac{TDG_i}{BP_i} \times 100$$

where

TDG_{sat} = TDG pressure expressed as percentage of surface saturation

TDG_i = TDG pressure at station i, mm Hg

BP_i = Atmospheric pressure at station i, mm Hg

Equation 1

2.3.1. Mass balance analysis

Data for the two-week study were visually filtered to select periods of relatively constant project discharge of duration sufficient to allow equilibrated measurements at all tailwater stations. The TDG exchange at Wells Dam was simplified as

$$TDG_{Wells} = \frac{(Q_{PH} \times TDG_{PH}) + (Q_{SP} \times TDG_{SP})}{(Q_{PH} + Q_{SP})}$$

where

TDG_{Wells} = the flow - weighted average TDG saturation measured at the Wells tailwater FMS

Q_{PH} = the total powerhouse discharge

TDG_{PH} = the average TDG saturation of powerhouse release water

Q_{SP} = the total spillway discharge

TDG_{SP} = the average TDG saturation of the spillway release water

Equation 2

Equation 2 assumed that the TDG saturation of water passing through turbines was unaffected; therefore, forebay TDG saturations were substituted for TDG_{PH}. Assuming that the powerhouse release water was unaffected by the presence of spill and that average TDG saturations measured at Transect C were representative of the weighted average saturations for the river, Equation 2 could be rearranged to solve for TDG_{SP} as

$$TDG_{SP} = \frac{((Q_{PH} + Q_{SP}) \times TDG_{Wells}) - (Q_{PH} \times TDG_{PH})}{Q_{SP}}.$$

Equation 3

Empirical data collected via the tailwater sensor array were substituted into Equation 3 and the calculated spill values were compared to those collected within the array.

3.0. Results

Data were available for eleven of the thirteen sites. The sonde at station B2 became entangled and was irretrievable despite repeated efforts to free it. No data were recorded for station C2 due to instrument malfunction. Of the remaining sondes, all reported data for the entire period of study and passed quality assurance/quality control protocols. Calibration data for the 2004 study are summarized in Table 2. Table 3 summarizes the type and inclusive dates for the datasets described in the subsequent analyses. Daily summaries for the Wells Dam Hydroproject are included as Table 4.

3.1. Hydrology

River flows were below average, ranging from a minimum daily average discharge of 62.5 kcfs on 6 June 2004 to a maximum of 147.3 kcfs on June 4. Spillway discharge consisted of standard fish bypass spill through Gates 2, 4, 6, 8, and 10. No other spill gates were operated with the exception of Gates 3 and 5 which were opened on 23 May 2004 for about ten minutes. The maximum spill discharge was 27.2 kcfs, occurring the same evening between 22:10 and 22:30. Mean daily river flow and spillway discharge for Wells Dam for the 2004 study are presented in Figure 6.

One short duration spill event occurred at Chief Joseph Dam, approximately 20 miles upstream of Wells Dam, on 30 May between 12:00 and 19:00 averaging about 5 kcfs. This represented the only spill at Chief Joseph Dam occurring during the study and had little apparent impact on Wells Forebay TDG pressures.

3.2. Bathymetry

Field survey data, reported as depth in feet, were combined with project tailwater stage data, reported as feet above mean sea level (ft. MSL), to determine the bottom elevations throughout the Wells tailwater. River depths at minimum and maximum tailwater elevations are displayed in Figures 7 and 8, respectively. Wells tailwater elevations varied up to 13 ft. depending on the total project discharge, ranging from a minimum of 705.3 to a maximum of 718.6 ft. MSL. The largest difference was realized at the near-dam transects A and B since the channel between Transects B and C was relatively uniform exhibiting minor changes with tailwater elevation. Station B3 exhibited the most dramatic difference with respect to tailwater fluctuation, with depths at low tailwater elevations less than 20 ft.

3.3. CROHMS

Hourly water temperatures for Wells, Chief Joseph, and Rocky Reach dams are displayed in Figure 9. The Wells forebay FMS (WEL) displayed the greatest daily fluctuation in water temperature when compared to both of the other CROHMS sites. Temperatures for WEL ranged from a minimum of 11.1 ºC on the morning of 23 May 2004 to a maximum of 13.0 ºC on the afternoon of 6 June 2004. Temperatures for the RRH forebay were approximately 0.2 ºC greater than those at the Wells tailwater, in contrast to the differences of up to 0.5 ºC between the Chief Joseph tailwater and the Wells forebay. The temperature “spikes” for WEL, apparent in Figure 9, were less pronounced in the hourly data and accounted for one or two consecutive measurements. Possible explanations will be discussed in a later section.

Total dissolved gas saturations exhibited daily cycles in response to hydroproject operations and *in situ* processes as displayed in Figure 10. The single 5 kcfs spill event at Chief Joseph Dam appears as the increase in TDG saturation for CHQW on 31 May 2004. The TDG

saturations at the RRH forebay exceeded saturations measured at the Wells tailwater for two distinct periods, as depicted in Figure 10, even when travel time was allowed for.

3.4. Fixed Monitor Evaluation

3.4.1. Forebay (WEL)

Water temperatures and TDG saturations for the Wells Dam forebay are depicted in Figure 11 and Figure 12, respectively. As previously stated, water temperatures measured at WEL fluctuated more widely than those at the ancillary stations varying by a daily minimum range of 0.2 ºC to a daily maximum of 1.7 ºC. Daily temperature summaries for all sites are presented in Table 5. Despite the relatively large daily fluctuations, there was not a significant difference between the average water temperatures for WEL, FB1, and FB2. The ancillary forebay stations were located 700 ft. upstream of the dam, while the forebay FMS was located on the upstream face of the dam. It is possible that the proximity of the WEL site to the dam resulted in measurements that were influenced by surface flows along the dam; therefore, not reflecting the overall temperature in the Wells forebay. Water temperatures for the tailwater site were included in Figure 11 to highlight the similarity between it and temperatures at FB1 and FB2.

The State of Washington measures compliance with water quality standards for TDG saturation by averaging the twelve highest hourly values for a given day. The daily twelve-hour averages for all stations are presented in Table 6. Comparisons between WEL and the auxiliary forebay stations again failed to identify a statistically significant difference. As depicted in Figure 12, there was good agreement between the forebay sites (data for WELW were excluded from this depiction, as they more reflected spill operation). Both minimum and maximum saturations occurred at WEL, although differences were typically less than 0.5% and not significant.

3.4.2. Tailwater (WELW)

Transect A TDG saturations are summarized in Figure 13 with the remaining tailwater TDG saturations presented in Figure 14. The peak tailwater TDG saturations occurred on the morning of 29 May 2004. Total dissolved gas saturations for Transect A measured on 28 and 29 May 2004 are depicted in Figure 15 with those for Transects B and C for the same period depicted in Figure 16. The maximum TDG saturation for the entire study was 125.7% as measured at station B3. The relatively low spillway discharge of 5.6 kcfs coincided with total river flows approaching 16.0 kcfs, thus spill discharge represented up to 30% of the total river flow, thus accounting for the higher TDG saturations.

As was documented in previous studies, WELW exhibited a delayed response to operational changes at the dam (up to one hour). The alternate monitor location (WELWa) also demonstrated a response delay, although typically less than that at WELW by about thirty minutes. Saturations at WELW and WELWa were less than those measured across the river at C3; however, elevated pressures persisted longer at both of the east shore sites. It is important to note that no data were available for either site B2 or C2. Since these sites were positioned at the deepest point along each transect, their loss meant that the bulk of the flow for these transects may have been unmeasured.

Neither daily averaged water temperatures (Table 5) nor daily twelve-hour averaged TDG saturations (Table 6) for WELW and WELWa demonstrated a significant difference from the other tailwater sites.

3.5. Mass Balance

The mass balance approach designed to quantify TDG production by Wells Dam was predicated on stable operations by the dam for a period sufficient for equilibrated TDG pressures to be realized at all sites. Previous studies indicated that this required up to three hours of steady state operation for the extreme downstream sensors at WELW. Based on these conditions, 29 spill events were visually identified from the two-week study as identified in Table 7. The mean project outflows and TDG saturations for each site are summarized by event in Table 8. Events ranged in duration from 2 to 19 hours and represented total average spillway discharges from 1.7 to 10.0 kcfs.

The highest TDG saturations were consistently measured at station A2 ranging from a minimum of 107.3% for Spill Event 14 to a maximum of 114.8% saturation for Spill Event 9. Data from Table 8 were applied to Equation 3 to calculate the estimated TDG saturation for spilled water. Data for the WELW and C3 site were averaged to represent the weighted TDG saturation for Wells Dam. Wells forebay values were represented by averaging data for stations FB1 and FB2. Equation 3 was further simplified by substituting weighting coefficients for powerhouse and spillway discharges based on the percentage of total project discharge represented by generation and spillway flows, respectively. The results of these exercises are presented in Table 9.

Estimated spill TDG saturations, based on this simplified mass balance approach, exceeded empirical values for every event. The maximum difference occurred for Spill Event 6 characterized by an average spill of 3.4 kcfs, or about 2% of the total river flow. Flow-weighted TDG saturations for Transect C indicated that for that volume of spilled water, TDG saturations of over 175% would be needed to affect the TDG_{WELLS} estimate. Actual TDG saturations, as summarized in Table 8, were closer to 110% and were fairly uniform throughout the tailwater ranging from a minimum of 108.5% at station A1 to 110.8% at A2. Transect C TDG saturations were typically highest at station C3, which averaged 0.4% saturation for the 29 spill events. Figure 17 depicts the difference in TDG saturations measured at station C3 and WELW plotted against the percentage spill for all spill events. The trend described by the equation in Figure 17 indicated an increase in the lateral difference in TDG saturations with increasing spill volumes. Although the correlation was not strong ($R^2 = 0.61$), saturations were consistently greater at station C3 than at WELW.

4.0. Conclusions

Water temperatures and, to a lesser degree TDG saturations, measured at WEL demonstrated greater daily fluctuations than at the two auxiliary forebay sites. This was less pronounced at the end of the study due to the overall increase in the minimum daily temperatures as the river underwent seasonal warming. It was possible that the present location of the forebay TDGFMS was influenced by surface water pulled to depth by project operations. Because the auxiliary stations were situated deeper in the water column and upstream of the dam, they would not have been affected by surface water. Despite the apparent differences in the ten-minute data; however, there was no significant difference between the daily averaged temperatures or the twelve-hour high average TDG saturations for the three forebay sites.

Data for the Wells Tailwater generally agreed with previous findings, being characterized by lower TDG saturations than ancillary stations. For the sole “high” spill event on 29 May, WELW responded over one hour later than station C3 along the west shore. In addition to a slower response, peak TDG saturations were over 3 % less than C3 (111.7 % at WELW vs. 115.0 % at C3) with elevated pressures persisting for over three hours at WELW and less than one hour at C3. The alternate tailwater TDGFMS site (WELWa) displayed a nearly identical trend to WELW, but responded about 30 minutes sooner than WELW. Comparisons of mean daily temperatures and daily twelve-hour high average TDG saturations between WELW and WELWa indicated no significant difference.

Mass balance analyses suffered due to the loss of data at key locations (stations B2 and C2) but indicated that data collected at the tailwater site under represented the average TDG saturation attributable to Wells Dam spill. As with the 2003 attempt with this approach, results were ambiguous owing to the relatively narrow range of spill volumes and wide range of powerhouse total discharges for a given event. Rocky Reach forebay TDG saturations exceeded those for the Wells tailwater for two extended periods during the study (Figure 10). This tended to corroborate the mass balance findings that a greater volume of water was influenced by Wells Spill than indicated by the tailwater FMS.

The results of this study tended to support the findings of previous work that suggested some gassing of powerhouse release water by spill. It is not known the degree to which this would occur at higher spill volumes. Future studies should attempt to sample a wider range of spill volumes with tighter control over powerhouse discharge. It is likely that TDG dynamics in the Wells tailwater are influenced by the total volume of spill and the number and/or location of the operating spillbays; therefore, future studies should exercise greater control over ancillary variables.

References

Beiningen, K.T. and W.J. Ebel. 1970. Effect of John Day Dam on dissolved nitrogen concentrations and salmon in the Columbia River. Transactions of the American Fisheries Society 99:664-671.

Columbia Basin Environmental. 2003. Wells Dam Spillway Total Dissolved Gas Evaluation, 27 May to 10 June 2003. Report prepared for Public Utility District No. 1 of Douglas County.

Klinge, Rick. 1998. Dissolved Gas Monitoring at Wells Dam Forebay and Tailrace, 1997. Public Utility District No. 1 of Douglas County.

Marsh, M.C. and F.P. Gorham. 1905. The Gas disease in fishes. Report of the United States Bureau of Fisheries for 1904:343-376.

State of Washington. “Water Quality Standards for Surface Waters of the State of Washington”. Chapter WAC 173-201A-180.

Tables

Table 1. Station information for water quality data collection

Serial No.	Station ID	Location (WGS-84)	
		Latitude	Longitude
40952	FB1	47.94938	-119.86255
38552	FB2	47.94902	-119.86719
33254	WEL	47.94722	-119.86508
408582	A1	47.94438	-119.85927
40862	A2	47.94438	-119.86202
40858	A3	47.94398	-119.86548
40120	B1	47.93493	-119.86342
40247	B2	47.93552	-119.86529
40860	B3	47.93602	-119.86652
39285	WELWa	47.91447	-119.89403
40739	C2	47.91409	-119.89693
40857	C3	47.91476	-119.89744
32639	WELW	47.91304	-119.89625

Table 2. Calibration summary information for water quality sensors

Calibration Type	S/N	Date	BP (mmHg)	Temperature (ºC)			TDG Pressure (mm Hg)				Deviation from TDG Standard (mm Hg)			
				Std	Probe	Diff	BP + 0	BP + 100	BP + 200	BP + 300	BP + 0	BP + 100	BP + 200	BP + 300
Pre-deployment	38552	05/22/04	748	17.3	17.2	0.1	748	848	948	1048	0	0	0	0
Pre-deployment	39285	05/22/04	748	17.4	17.4	0.0	749	849	949	1049	-1	-1	-1	-1
Pre-deployment	40120	05/22/04	750	16.7	16.7	0.0	749	849	949	1049	1	1	1	1
Pre-deployment	40247	05/22/04	750	16.8	16.8	0.0	750	850	950	1050	0	0	0	0
Pre-deployment	40739	05/22/04	749	17.1	17.1	0.0	749	849	949	1049	0	0	0	0
Pre-deployment	40857	05/22/04	750	16.8	16.8	0.0	750	850	950	1050	0	0	0	0
Pre-deployment	40858	05/22/04	750	17.0	17.0	0.0	750	850	950	1050	0	0	0	0
Pre-deployment	40860	05/22/04	749	17.2	17.1	0.1	749	849	949	1049	0	0	0	0
Pre-deployment	40862	05/22/04	750	16.9	16.9	0.0	750	850	950	1050	0	0	0	0
Pre-deployment	40952	05/22/04	749	17.2	17.1	0.1	749	849	949	1049	0	0	0	0
Pre-deployment	408582	05/22/04	749	17.0	17.0	0.0	749	849	949	1049	0	0	0	0
Pre-deployment	32639	05/23/04	740	13.1	13.0	0.1	740	839	939	1040	0	1	1	0
Pre-deployment	33254	05/23/04	738	12.4	12.4	0.0	739	838	939	1039	-1	0	-1	-1
Post-deployment	38552	06/07/04	751	17.8	17.8	0.0	750	850	950	1050	-1	-1	1	1
Post-deployment	40120	06/07/04	751	17.9	17.9	0.0	751	851	950	1050	0	0	1	1
Post-deployment	40739	06/07/04	751	No data due to probe malfunction.										
Post-deployment	40857	06/07/04	750	17.4	17.4	0.0	751	851	951	1051	1	1	-1	-1
Post-deployment	40858	06/07/04	751	18.0	18.0	0.0	752	852	952	1052	1	1	-1	-1
Post-deployment	40860	06/07/04	751	18.0	17.9	0.1	751	851	951	1051	0	0	0	0
Post-deployment	40862	06/07/04	751	17.9	17.9	0.0	751	851	951	1051	0	0	0	0
Post-deployment	40952	06/07/04	750	17.5	17.4	0.1	751	851	951	1051	1	1	-1	-1
Post-deployment	408582	06/07/04	751	18.1	18.1	0.0	750	850	950	1050	-1	-1	1	1

Table 3. Summary of Data Sets Included in Wells Dam Spillway Evaluation

Data Set	Provider	Inclusive Dates	Interval	Description
Transect	CBE	May 23 – June 6, 2004	10 min.	Water temperature (ºC), TDG pressure (mm Hg), sample depth (m) collected by leased Hydrolab® MiniSonde® multiprobes
CROHMS	Internet	May 23 – June 7, 2004	60 min.	Water temperature (ºC), TDG pressure (mm Hg), atmospheric pressure (mm Hg), total project discharge (kcfs), total project spill discharge (kcfs), forebay elevation (ft MSL), tailwater elevation (ft MSL) queried from Columbia River Operational HydroMet System maintained by the U.S. Army Corps of Engineers
Wells Dam Operations	DCPUD	May 23 – June 6, 2004	10 min.	Wells Dam total river discharge (kcfs), by-pass spill discharge (kcfs), forced spill discharge (kcfs), fishway discharge (kcfs), individual generator output (MW), individual spill gate openings (ft), forebay elevation (ft MSL), tailwater elevation (ft MSL)
Control Room Logs	DCPUD	May 23 – June 6, 2004	N/A	Spill gate openings (ft), and total spillway discharge (kcfs) reported at time of change
Wells Dam FMS	DCPUD	May 23 – June 6, 2003	10 min.	Water temperature (ºC), TDG pressure (mm Hg), and atmospheric pressure (mm Hg) for the Wells Dam permanent TDG monitoring system
Wells Tailwater Bathymetry	CBE	May 27, 2003; May 23, 2004; June 6, 2004	N/A	Tailwater bathymetric survey data consisting of latitude, longitude, and river depth collected via mapping GPS during deployment of transect instruments.

Table 4. Daily summaries for Wells Dam project operation for 23 May to 6 June 2004.

Date	Pool Elevation (ft msl)						Wells Dam Discharge (kcfs)								
	Forebay			Tailwater			Total			Spill			Power		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
05/23/04	781.0	779.6	780.3	179.0	706.2	710.4	190.0	20.5	85.5	27.2	3.4	5.5	179.0	16.1	78.0
05/24/04	780.9	778.7	780.0	182.9	705.4	712.6	193.9	13.6	115.8	10.0	3.4	7.4	182.9	10.9	107.2
05/25/04	780.9	779.1	779.9	187.7	706.2	712.9	198.7	24.8	121.7	7.8	3.4	5.6	187.7	20.4	112.9
05/26/04	780.8	777.8	779.8	181.1	706.1	713.1	192.1	26.3	125.4	3.4	3.4	3.4	181.1	21.9	116.0
05/27/04	780.9	778.9	780.0	192.1	706.8	713.8	203.1	28.3	133.4	7.8	3.4	7.0	192.1	23.9	123.8
05/28/04	780.4	778.9	779.8	184.9	706.6	712.3	195.9	24.2	111.4	7.8	3.4	4.0	184.9	19.8	102.3
05/29/04	780.7	778.2	779.8	185.6	706.0	711.5	196.6	16.0	100.8	7.8	3.4	5.5	185.6	11.6	92.8
05/30/04	780.6	779.1	780.0	172.6	706.8	712.2	183.6	33.8	112.1	10.0	5.6	7.6	172.6	29.4	103.1
05/31/04	780.4	778.8	779.7	151.8	706.0	710.9	162.8	34.1	97.8	10.0	3.4	8.3	151.8	29.7	89.4
06/01/04	780.6	777.9	779.7	167.3	708.1	712.1	178.3	59.4	112.9	10.0	7.8	8.9	167.3	52.8	103.6
06/02/04	780.8	778.9	779.9	197.7	706.4	713.3	208.7	34.7	129.2	10.0	3.4	8.3	197.7	30.3	120.0
06/03/04	780.9	778.9	779.8	201.9	706.0	714.3	212.9	30.8	143.1	10.0	5.6	7.9	201.9	26.4	133.2
06/04/04	780.9	778.6	780.0	199.4	707.5	714.7	210.4	45.4	147.3	7.8	5.6	5.8	199.4	41.0	137.4
06/05/04	780.7	778.8	779.8	184.3	705.3	712.0	195.3	13.3	107.6	10.0	1.7	7.2	184.3	10.6	99.0
06/06/04	780.4	778.8	779.5	129.7	706.6	708.7	138.5	35.1	62.5	10.0	3.4	4.6	129.7	30.7	56.8

Table 5. Daily summaries for water temperatures reported by the Wells FMS and selected comparison sites.

Date	Temperature (ºC)														
	FB1			FB2			WEL			WELWa			WELW		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
23-May-04	11.3	11.1	11.2	11.3	11.1	11.2	12.8	11.1	11.4	11.4	11.3	11.4	11.4	11.1	11.2
24-May-04	11.6	11.3	11.4	11.5	11.3	11.4	12.2	11.4	11.6	11.7	11.4	11.5	11.7	11.3	11.5
25-May-04	11.4	11.2	11.3	11.3	11.2	11.3	11.5	11.3	11.4	11.5	11.3	11.4	11.4	11.3	11.4
26-May-04	11.4	11.2	11.3	11.4	11.1	11.2	11.8	11.3	11.4	11.5	11.3	11.4	11.4	11.2	11.3
27-May-04	11.4	11.3	11.4	11.4	11.3	11.3	11.6	11.4	11.4	11.5	11.4	11.5	11.4	11.4	11.4
28-May-04	11.5	11.4	11.4	11.5	11.4	11.4	11.9	11.4	11.6	11.7	11.4	11.6	11.7	11.3	11.5
29-May-04	11.7	11.4	11.5	11.7	11.4	11.5	12.8	11.4	11.7	11.9	11.5	11.7	11.8	11.4	11.6
30-May-04	11.9	11.6	11.8	11.9	11.6	11.7	12.2	11.7	11.9	12.1	11.7	11.9	12.1	11.6	11.8
31-May-04	12.0	11.7	11.8	12.1	11.7	11.8	12.5	11.8	12.0	12.1	11.8	11.9	12.0	11.7	11.9
01-Jun-04	12.1	11.9	12.0	12.0	11.8	11.9	12.7	11.9	12.1	12.2	12.0	12.1	12.1	11.9	12.0
02-Jun-04	12.2	11.9	12.0	12.1	11.9	12.0	12.6	12.0	12.2	12.3	12.1	12.2	12.2	11.9	12.1
03-Jun-04	12.2	11.9	12.1	12.1	11.9	12.0	12.7	12.0	12.2	12.3	12.1	12.2	12.3	12.0	12.1
04-Jun-04	12.5	11.9	12.1	12.5	11.8	12.0	12.7	11.9	12.2	12.6	12.0	12.2	12.5	11.9	12.1
05-Jun-04	12.8	12.5	12.6	12.9	12.5	12.5	12.9	12.6	12.7	12.8	12.6	12.7	12.7	12.5	12.6
06-Jun-04	12.8	12.7	12.8	12.9	12.7	12.8	13.0	12.8	12.9	13.0	12.8	12.9	12.9	12.7	12.8

Table 6. Daily Average of 12 Highest TDG Saturations

Date	FB1	FB2	WEL	A1	A2	A3	B1	B3	C3	WELWa	WELW
05/23/04	106.8*	106.8*	107.4	107.5*	110.1*	108.7*	108.8*	108.2*	108.4*	108.2*	107.8
05/24/04	107.1	107.0	107.1	108.2	110.2	109.0	109.5	108.5	108.8	108.7	108.3
05/25/04	107.6	107.5	107.4	108.3	110.8	109.0	109.9	108.4	108.9	108.9	108.7
05/26/04	107.8	107.8	107.8	108.8	110.9	109.3	110.3	108.8	109.3	109.4	109.1
05/27/04	107.7	107.6	107.4	108.4	110.7	109.6	110.0	108.9	109.1	109.0	108.7
05/28/04	107.4	107.3	107.1	108.4	111.7	109.4	110.3	108.8	109.0	108.7	108.5
05/29/04	106.4	106.4	106.4	109.4	113.0	111.3	110.8	110.1	110.4	109.7	109.5
05/30/04	106.6	106.7	106.7	107.4	109.4	108.1	108.8	107.7	108.1	108.0	107.8
05/31/04	106.8	106.8	106.8	107.6	109.5	108.5	109.0	108.2	108.5	108.2	108.0
06/01/04	107.1	107.1	107.2	107.8	110.0	108.8	109.3	108.3	108.7	108.6	108.4
06/02/04	107.7	107.7	107.9	108.2	110.8	109.3	109.7	108.8	109.3	109.1	109.0
06/03/04	107.9	107.9	107.9	108.4	110.9	109.6	109.9	109.0	109.5	109.5	109.3
06/04/04	108.5	108.5	108.6	109.2	111.5	110.5	110.6	109.8	110.2	110.1	109.9
06/05/04	109.0	108.9	108.6	109.5	111.6	110.5	110.8	110.0	110.0	109.8	109.7
06/06/04	107.7	107.5	107.3	108.7	111.3	109.6	110.1	109.1	108.9	109.0	108.7

*Less than 12 hrs. data, straight average.

Table 7. Time periods for spill events identified from Wells Dam operations for the period from 23 May – 6 June 2004.

Spill Event	Start Time		End Time	
1	05/23	18:10	05/23	22:00
2	05/24	00:40	05/24	03:50
3	05/24	06:40	05/24	09:00
4	05/24	12:00	05/24	20:50
5	05/25	13:00	05/25	19:30
6	05/26	12:00	05/26	21:30
7	05/27	11:00	05/27	21:10
8	05/28	11:00	05/28	22:50
9	05/28	23:00	05/29	06:50
10	05/29	11:00	05/29	22:50
11	05/29	23:20	05/30	02:10
12	05/30	02:20	05/30	13:50
13	05/30	14:00	05/30	22:30
14	05/31	03:50	05/31	06:40
15	05/31	07:50	05/31	13:40
16	05/31	13:50	05/31	18:50
17	05/31	20:00	05/31	22:50
18	05/31	23:00	06/01	11:40
19	06/01	11:50	06/02	00:30
20	06/02	00:40	06/02	05:50
21	06/02	07:30	06/03	02:20
22	06/03	02:30	06/03	06:50
23	06/03	07:00	06/03	10:20
24	06/03	10:30	06/04	02:20
25	06/04	07:00	06/04	23:10
26	06/05	01:30	06/05	08:10
27	06/05	08:20	06/05	11:20
28	06/05	11:30	06/05	23:50
29	06/06	02:50	06/06	04:40

Table 8. Wells Dam project operation and water quality data summarized by spill event.

Spill Event	n	Discharge (kcfs)		TDG % Saturation										
		Project	Spill	FB1	FB2	WEL	A1	A2	A3	B1	B3	WELWa	WELW	C3
1	24	148.0	10.0	106.9	106.9	106.7	107.3	110.0	108.6	108.8	108.1	108.2	107.8	108.4
2	20	27.5	3.4	106.7	106.6	106.2	108.5	110.3	109.5	109.6	108.6	108.8	108.4	109.2
3	15	116.1	5.6	106.3	106.3	106.1	107.1	108.3	107.6	108.3	107.5	107.6	107.4	107.6
4	54	168.6	10.0	107.1	107.1	107.2	107.7	109.9	108.5	109.2	108.1	108.5	108.2	108.5
5	40	164.4	5.6	107.6	107.5	107.5	108.1	110.6	108.8	109.7	108.3	109.0	108.8	108.8
6	58	167.5	3.4	107.8	107.8	107.7	108.5	110.8	109.0	110.2	108.6	109.4	109.2	109.2
7	62	176.8	7.8	107.6	107.5	107.5	108.1	110.7	109.2	109.7	108.6	109.0	108.8	109.1
8	72	145.1	3.4	106.9	106.8	106.7	107.5	109.8	108.4	109.0	107.9	108.2	108.0	108.4
9	48	39.1	5.6	106.2	106.1	105.6	110.0	114.8	112.7	111.9	111.1	109.1	108.7	110.7
10	72	146.0	5.6	106.3	106.4	106.4	106.9	109.0	108.0	108.3	107.6	107.6	107.4	107.8
11	18	94.5	7.8	106.3	106.3	106.0	106.8	109.2	107.5	108.2	107.2	107.2	107.0	107.4
12	70	95.4	5.6	106.5	106.5	106.4	107.2	108.8	107.6	108.5	107.3	107.3	107.2	107.5
13	52	147.1	10.0	106.5	106.4	106.3	107.4	109.5	108.1	108.7	107.6	107.9	107.8	108.0
14	18	46.5	3.4	105.7	105.6	105.1	106.2	107.3	106.7	107.3	106.3	105.8	105.8	106.1
15	36	103.2	7.8	106.1	106.1	106.0	106.7	108.0	107.8	108.0	107.9	107.0	106.8	107.6
16	31	132.6	10.0	106.9	107.0	107.2	107.6	109.6	108.8	109.0	108.4	108.3	108.1	108.7
17	18	127.8	10.0	106.8	106.8	106.5	107.7	109.6	108.3	109.1	107.8	108.1	107.9	108.1
18	77	84.7	7.8	106.4	106.3	106.2	107.1	108.8	107.5	108.4	107.2	107.4	107.2	107.5
19	77	137.5	10.0	107.1	107.0	107.1	107.8	110.0	108.8	109.2	108.2	108.5	108.3	108.7
20	32	47.9	3.4	106.7	106.6	106.1	107.5	108.6	107.6	108.5	107.2	107.5	107.5	107.6
21	114	156.1	10.0	107.5	107.5	107.5	108.0	110.5	109.2	109.5	108.7	108.8	108.6	109.0
22	27	60.7	5.6	107.5	107.5	107.1	108.3	110.3	108.9	109.5	108.3	108.2	108.3	108.6
23	21	129.4	10.0	107.6	107.6	107.5	108.4	110.2	109.2	109.8	108.7	108.7	108.5	108.9
24	96	166.7	7.8	108.0	107.9	107.9	108.4	110.9	109.6	110.0	109.0	109.4	109.2	109.5
25	98	175.0	5.6	108.4	108.3	108.4	109.0	111.2	110.2	110.5	109.6	109.9	109.7	110.0
26	41	45.4	1.7	108.9	108.8	108.2	109.5	111.7	110.5	110.8	109.5	109.5	109.5	109.7
27	19	112.3	7.8	109.0	109.0	108.6	109.3	111.3	110.2	110.5	110.3	109.6	109.3	109.8
28	75	144.3	10.0	108.4	108.3	108.2	109.1	111.4	109.8	110.4	109.4	109.7	109.5	109.8
29	12	38.9	3.4	107.3	107.2	107.0	108.2	110.7	109.3	109.2	108.3	108.3	108.2	108.1

Table 9. Spill event summary information and results of mass balance calculations.

Spill Event	n	Discharge (kcfs)		Flow-weighting coefficients		TDG % Saturations		
		Project	Spill	Spill	Powerhouse	TDG_{WELLS}	Wells FB	Est. Spill
1	24	148.0	10.0	6.8%	93.2%	108.1	106.9	125.6
2	20	27.5	3.4	12.3%	87.7%	108.8	106.6	123.9
3	15	116.1	5.6	4.8%	95.2%	107.5	106.3	130.9
4	54	168.6	10.0	5.9%	94.1%	108.4	107.1	127.6
5	40	164.4	5.6	3.4%	96.6%	108.8	107.6	143.1
6	58	167.5	3.4	2.0%	98.0%	109.2	107.8	175.5
7	62	176.8	7.8	4.4%	95.6%	108.9	107.6	138.4
8	72	145.1	3.4	2.3%	97.7%	108.2	106.8	163.9
9	48	39.1	5.6	14.3%	85.7%	109.7	106.2	130.6
10	72	146.0	5.6	3.8%	96.2%	107.6	106.4	138.7
11	18	94.5	7.8	8.3%	91.7%	107.2	106.3	117.4
12	70	95.4	5.6	5.9%	94.1%	107.3	106.5	120.8
13	52	147.1	10.0	6.8%	93.2%	107.9	106.4	127.6
14	18	46.5	3.4	7.3%	92.7%	105.9	105.6	109.8
15	36	103.2	7.8	7.6%	92.4%	107.2	106.1	119.9
16	31	132.6	10.0	7.5%	92.5%	108.4	106.9	126.8
17	18	127.8	10.0	7.8%	92.2%	108.0	106.8	122.3
18	77	84.7	7.8	9.2%	90.8%	107.3	106.3	117.1
19	77	137.5	10.0	7.3%	92.7%	108.5	107.0	127.2
20	32	47.9	3.4	7.1%	92.9%	107.6	106.6	119.7
21	114	156.1	10.0	6.4%	93.6%	108.8	107.5	127.4
22	27	60.7	5.6	9.2%	90.8%	108.5	107.5	118.0
23	21	129.4	10.0	7.7%	92.3%	108.7	107.6	122.0
24	96	166.7	7.8	4.7%	95.3%	109.3	107.9	137.7
25	98	175.0	5.6	3.2%	96.8%	109.8	108.3	154.9
26	41	45.4	1.7	3.7%	96.3%	109.6	108.8	129.1
27	19	112.3	7.8	6.9%	93.1%	109.6	109.0	117.6
28	75	144.3	10.0	6.9%	93.1%	109.6	108.4	126.4
29	12	38.9	3.4	8.7%	91.3%	108.2	107.3	117.5

Figures

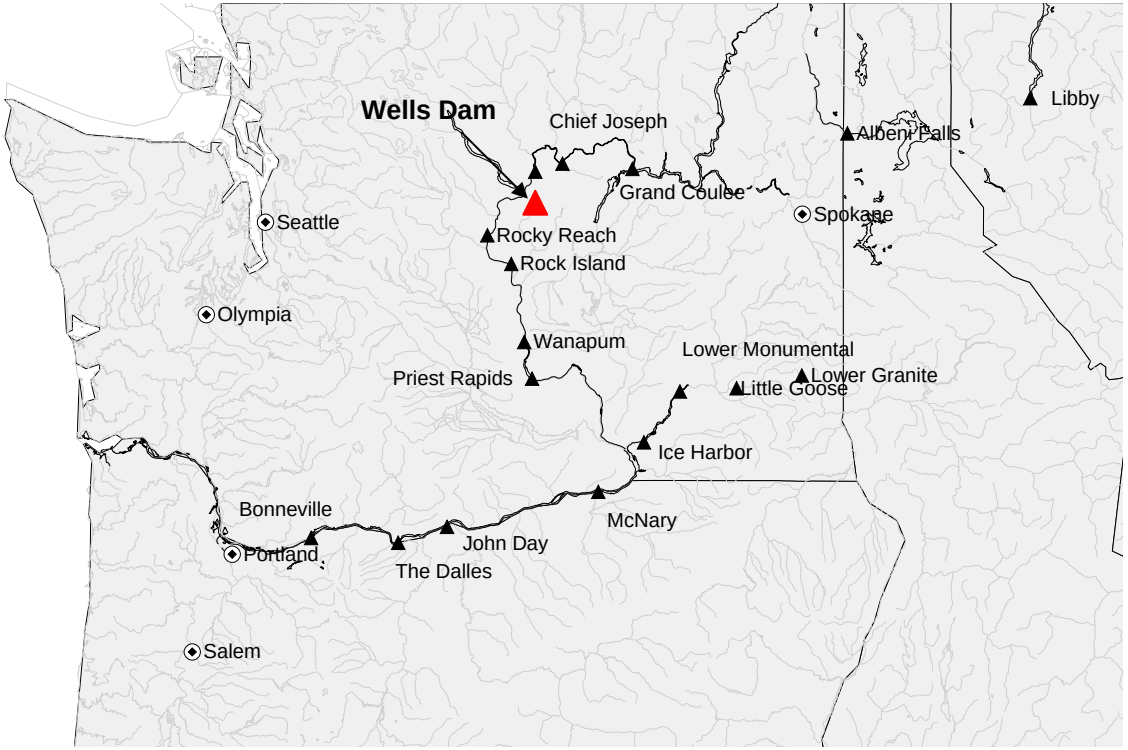

Figure 1. Regional map indicating location of Wells Dam.

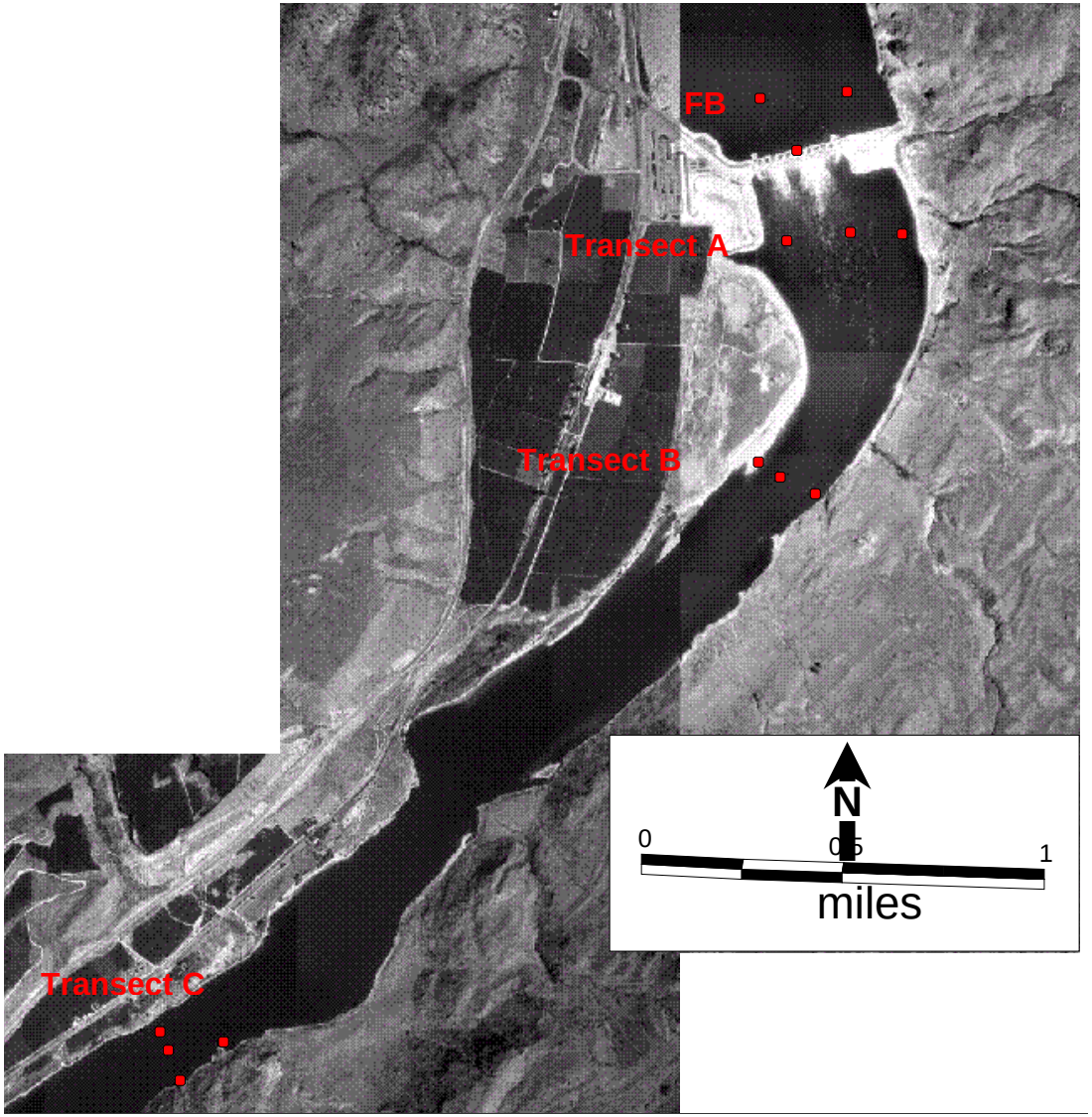

Figure 2. Area map for Wells Dam spill evaluation indicating primary deployment transects.

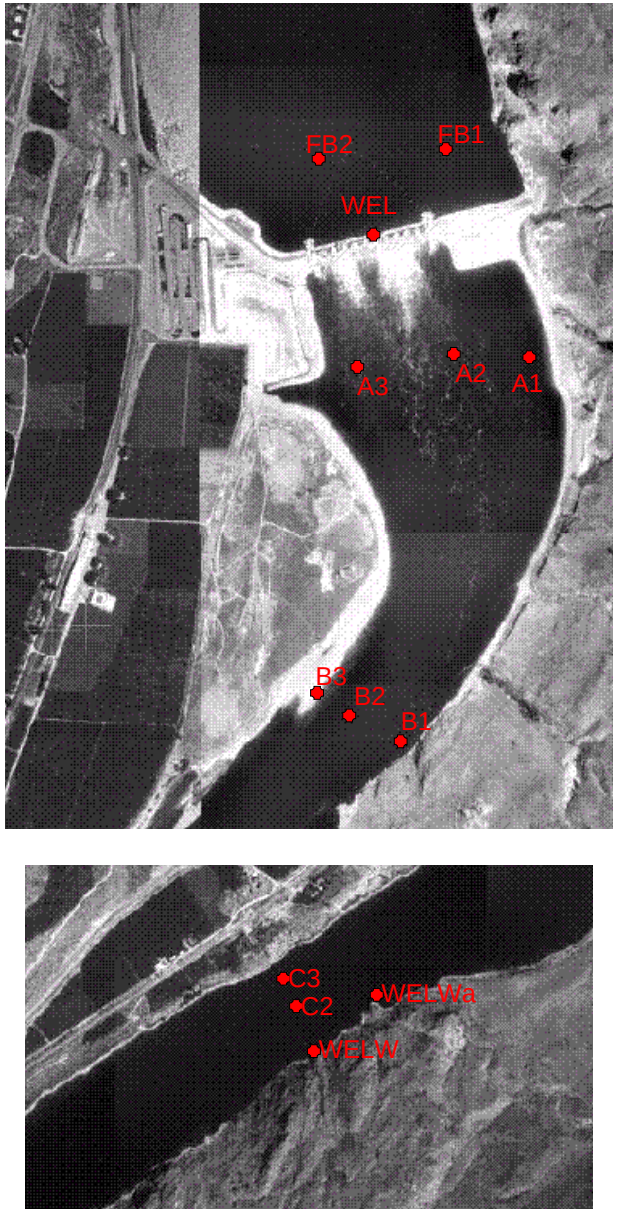

Figure 3. Station locations along primary transects.

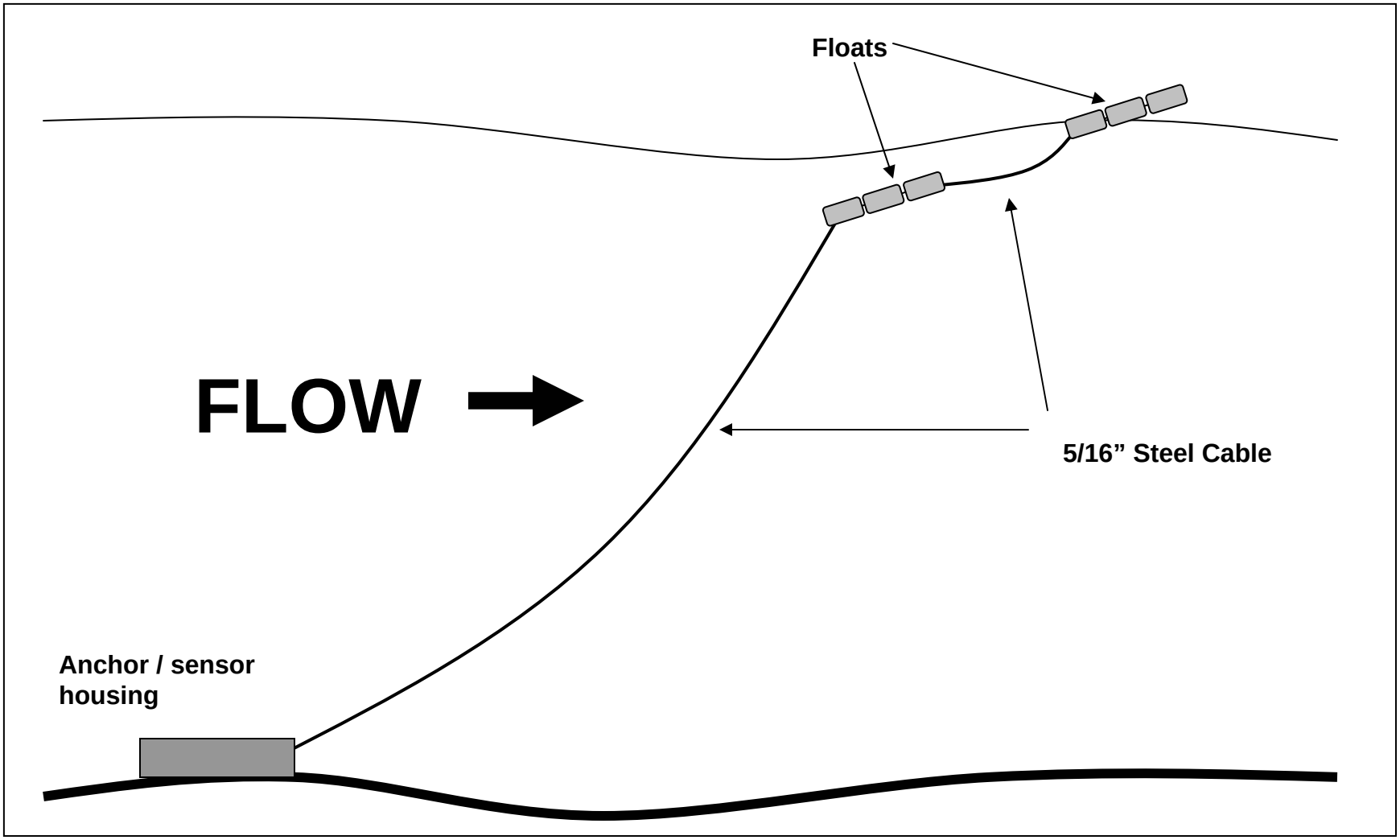

Figure 4. Schematic representation of Transect A deployment rigging.

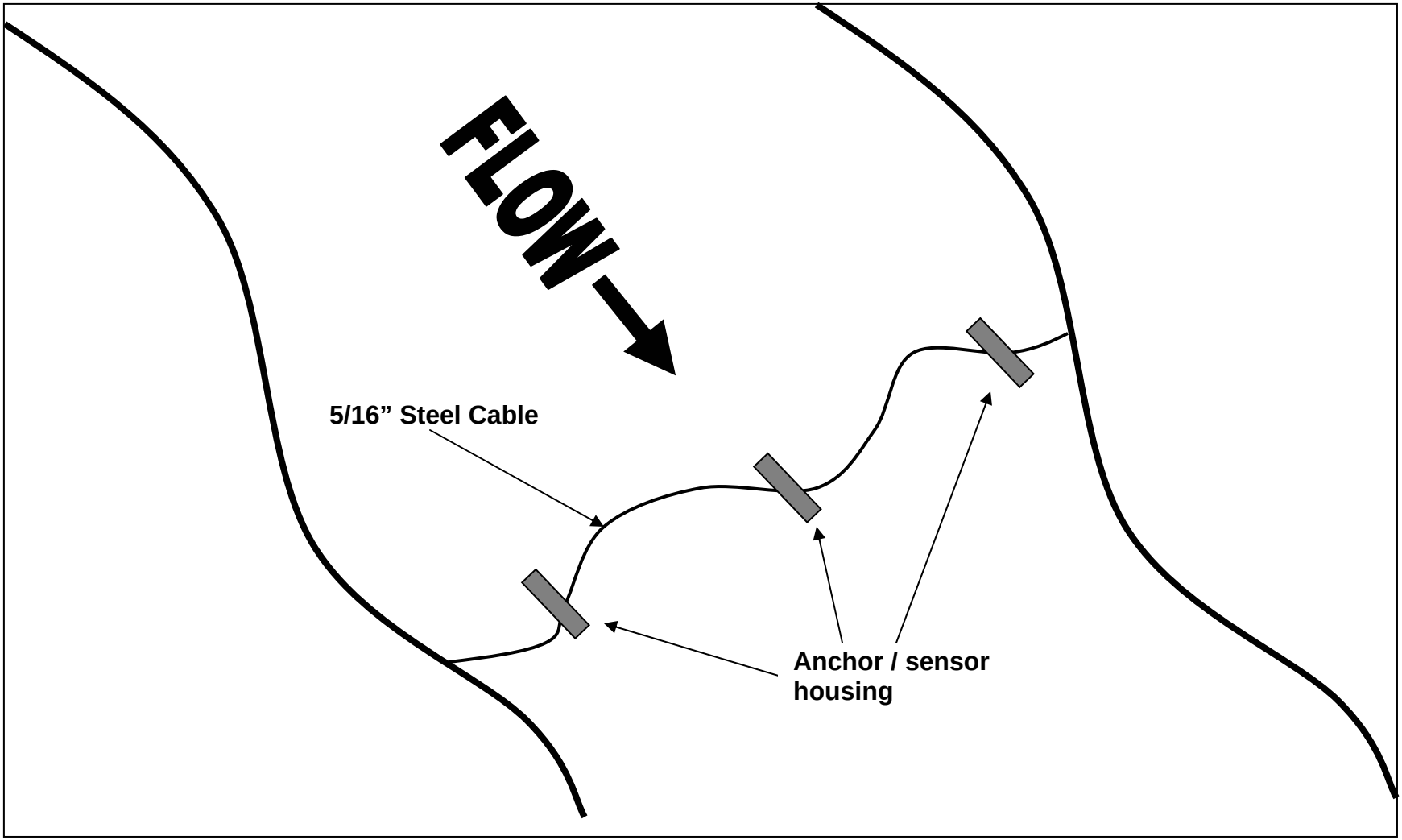

Figure 5. Schematic representation of Transects B and C deployment rigging.

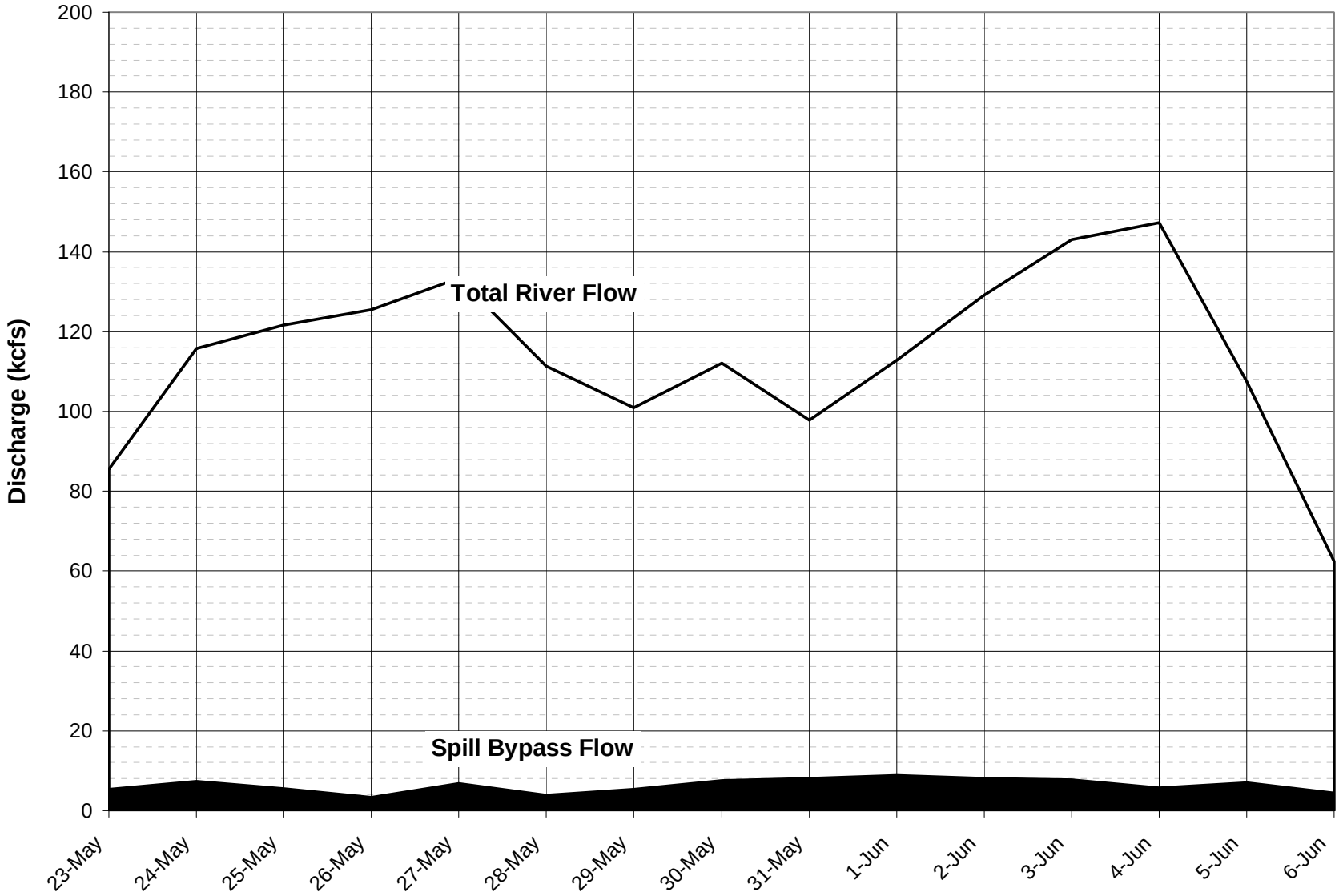

Figure 6. Daily average discharge at Wells Dam for the period of 23 May to 6 June 2004.

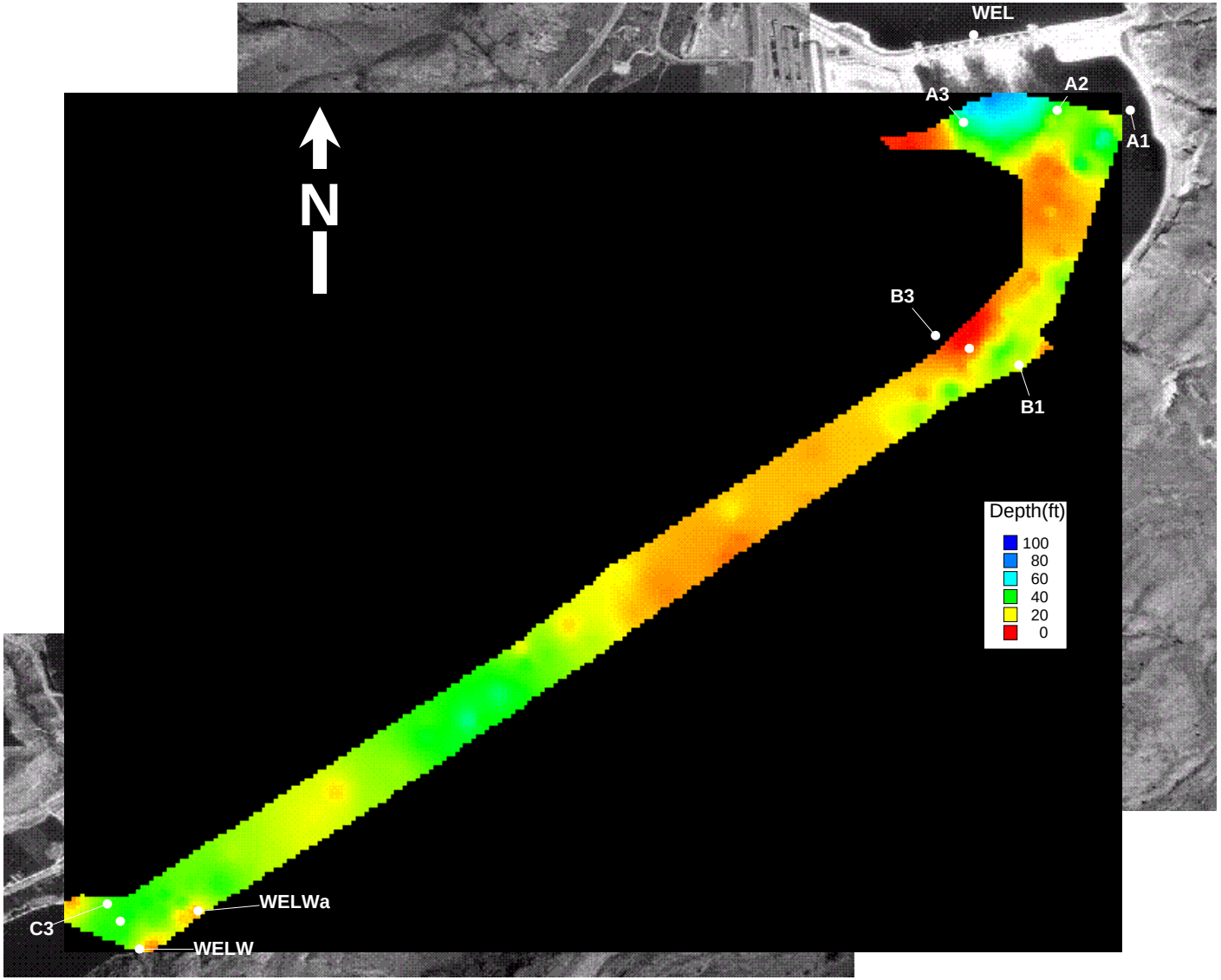

Figure 7. Wells Dam tailwater morphometry at minimum tailwater elevation developed from georeferenced depth sounder data collected on 23 May and 6 June 2004.

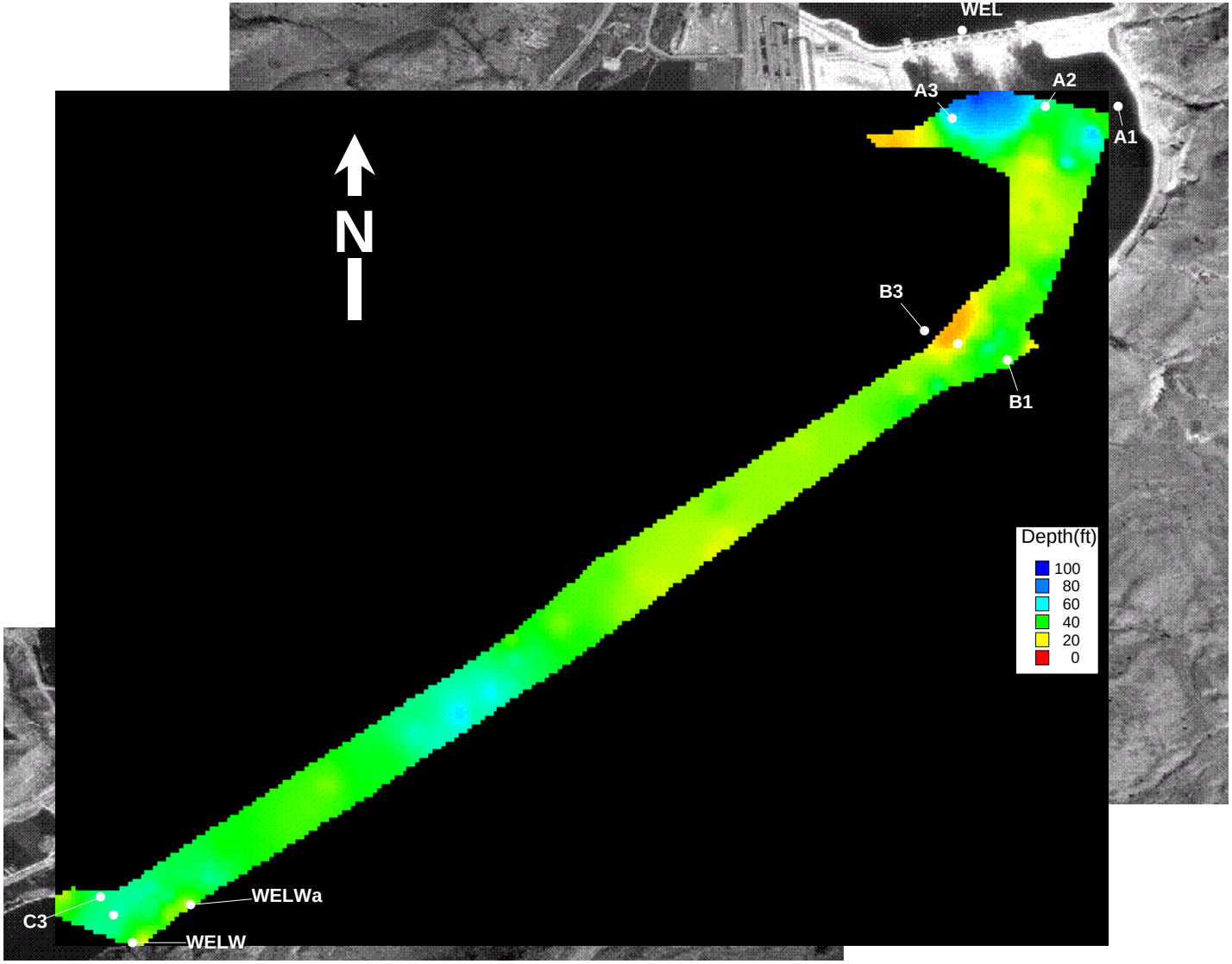

Figure 8. Wells Dam tailwater morphometry at maximum tailwater elevation developed from georeferenced depth sounder data collected on 23 May and 6 June 2004.

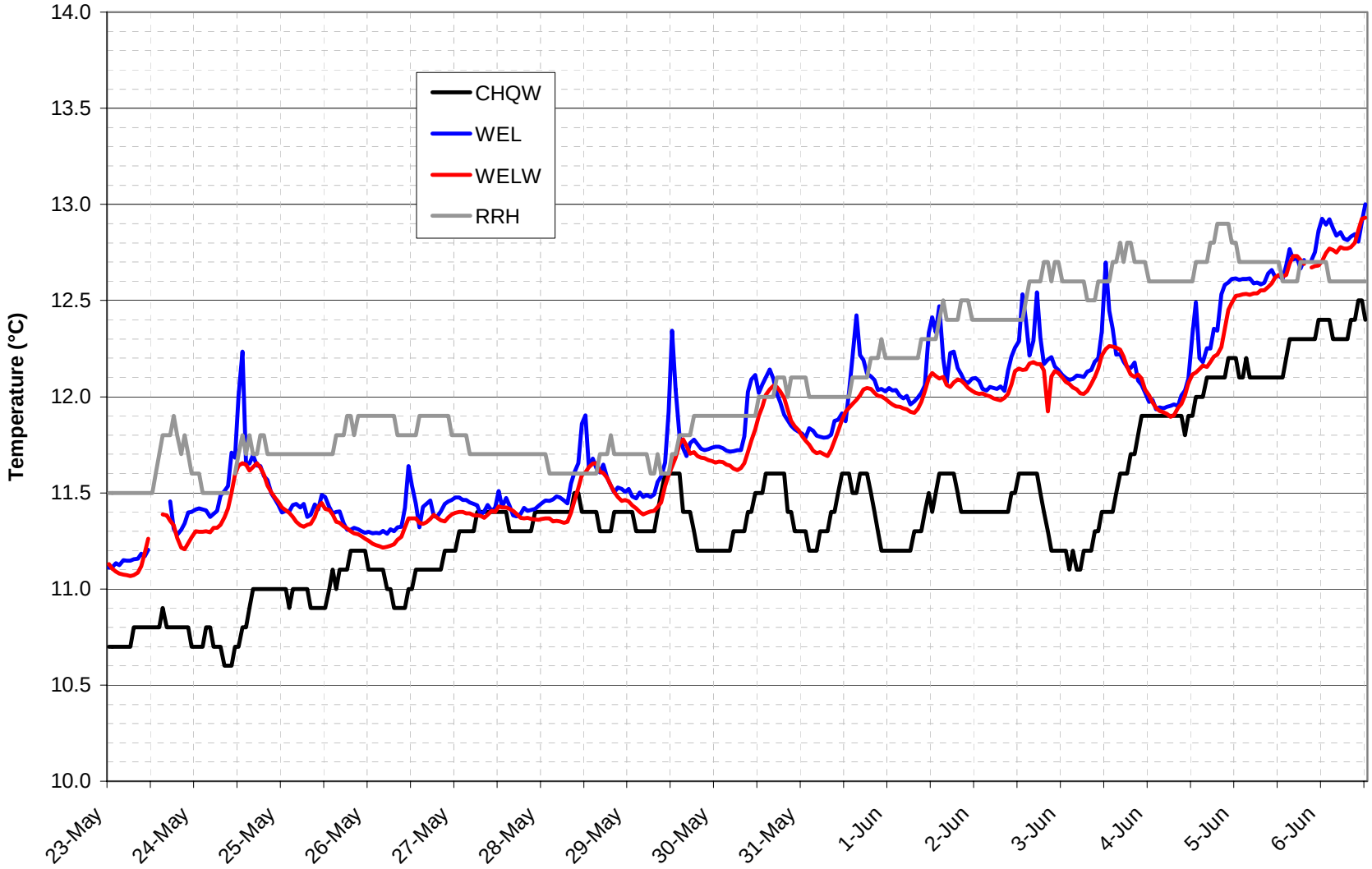

Figure 9. Water temperature data measured at Chief Joseph, Wells, and Rocky Reach Dams for the period of 23 May to 6 June 2004.

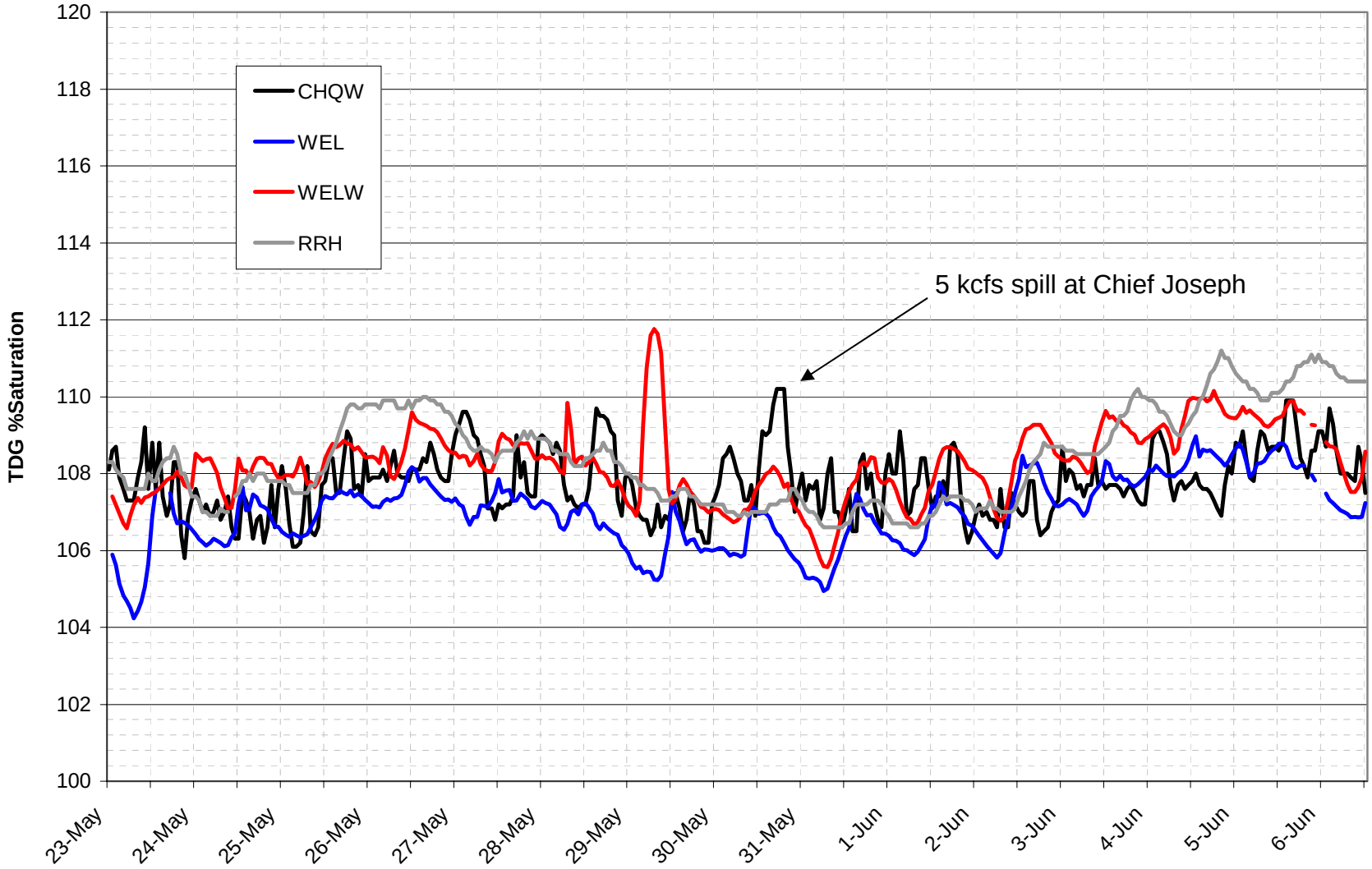

Figure 10. Total dissolved gas saturations measured at Chief Joseph, Wells, and Rocky Reach Dams for the period of 23 May to 6 June 2004.

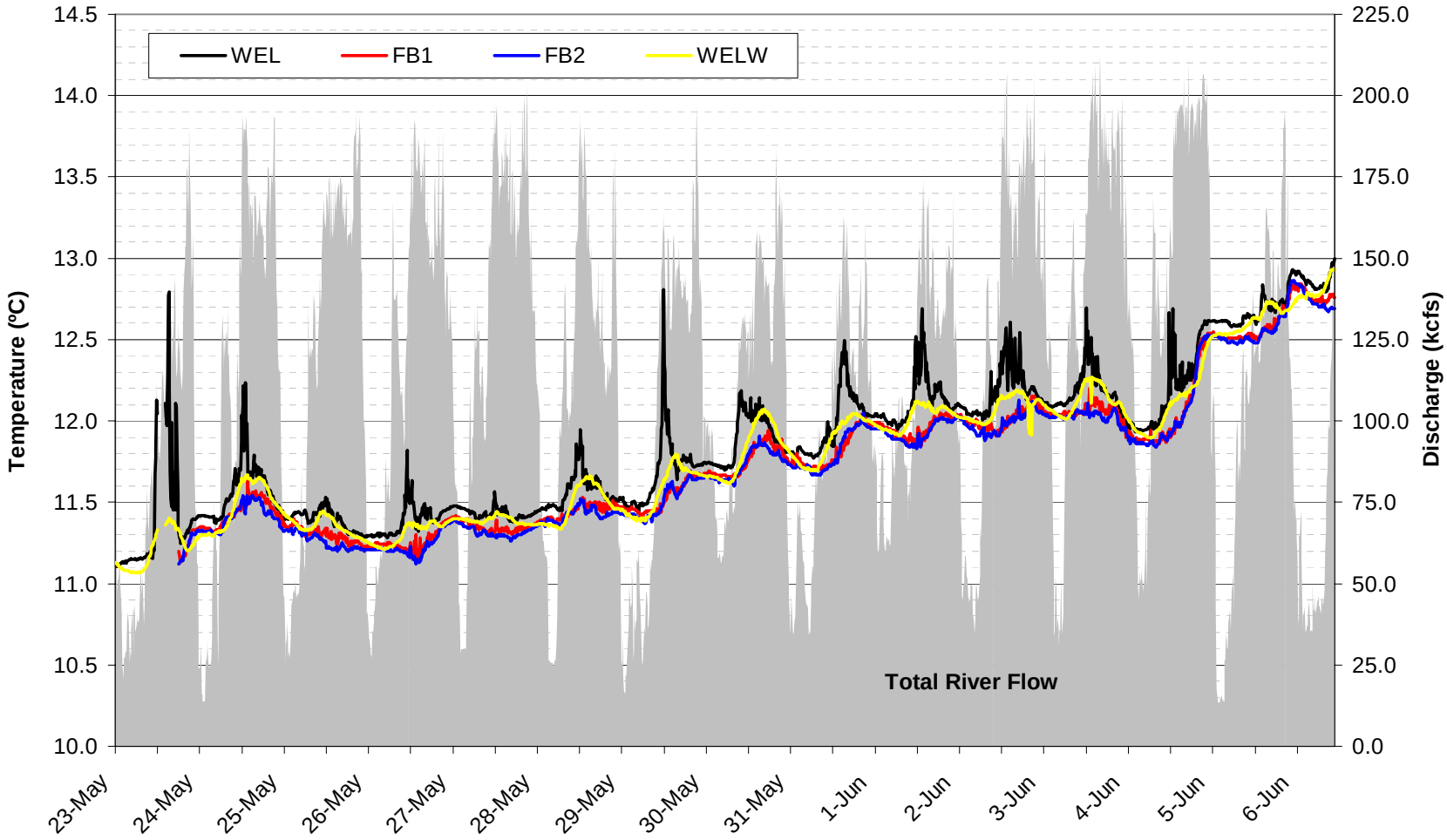

Figure 11. Water temperatures and river discharge for the Wells Dam Forebay for the period of 23 May to 6 June 2004.

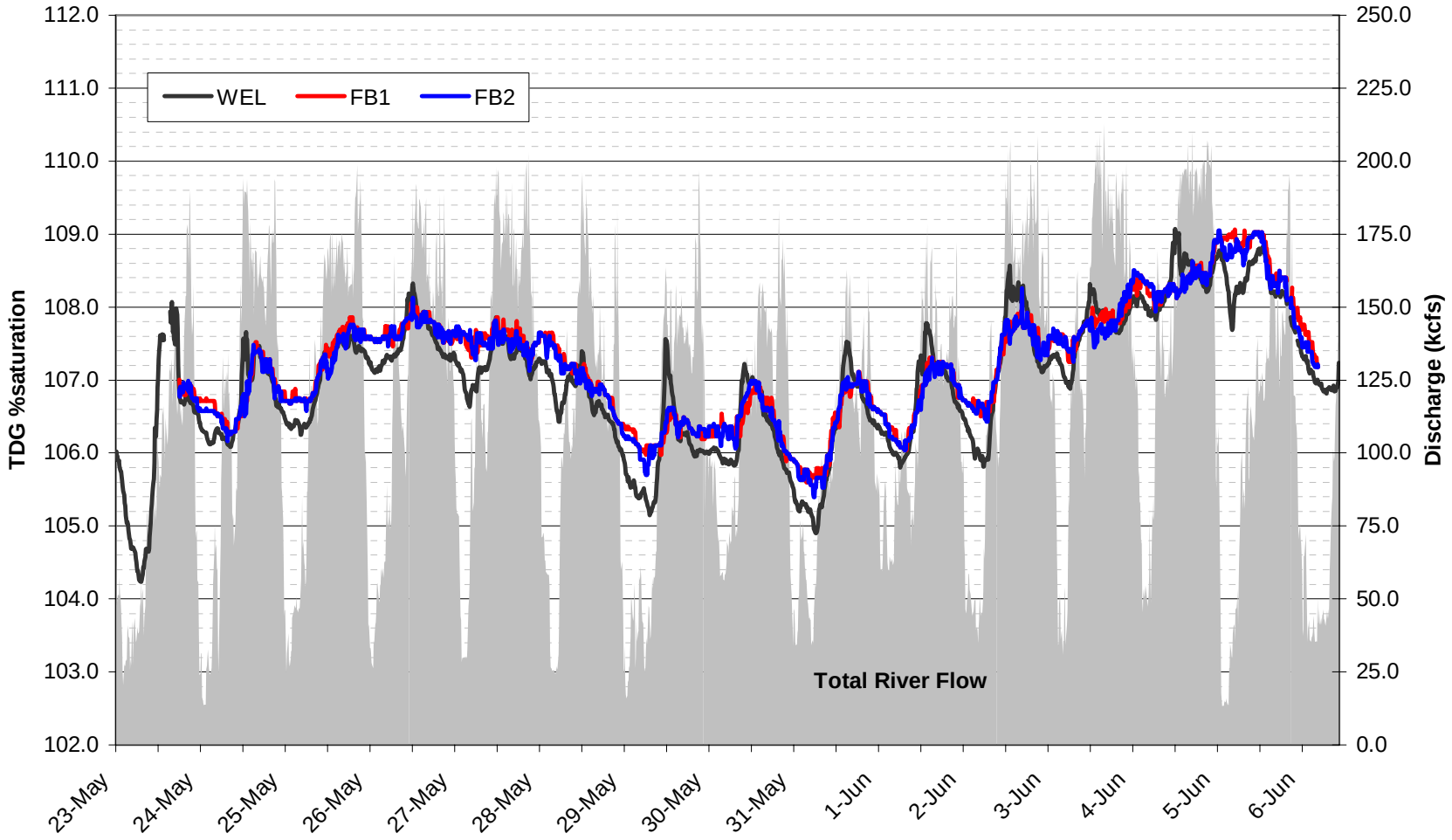

Figure 12. Total dissolved gas saturations and river discharge for the Wells Dam Forebay for the period of 23 May to 6 June 2004.

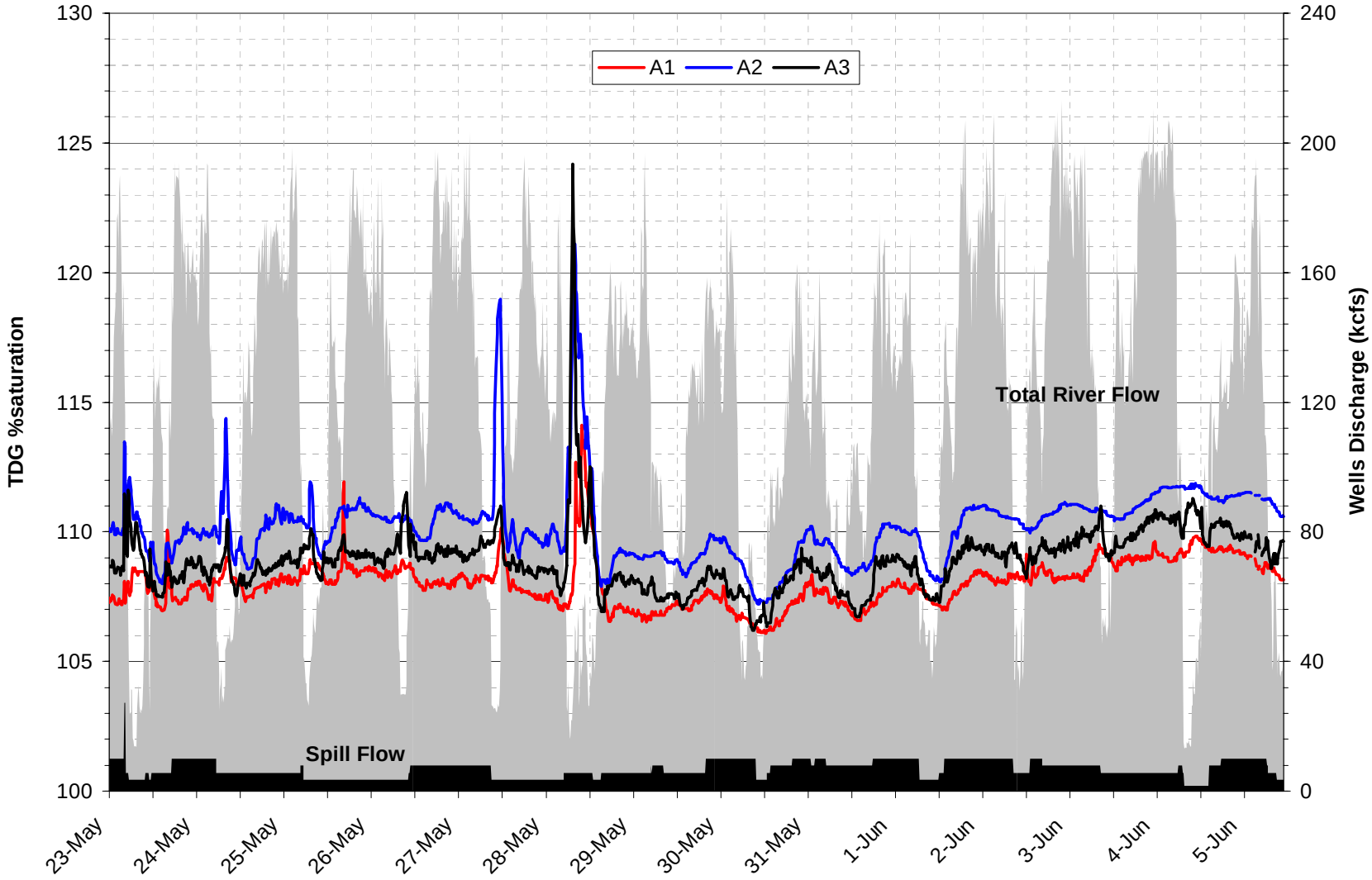

Figure 13. Wells Dam project discharge and Transect A TDG saturations for the period from 23 May to 6 June 2004.

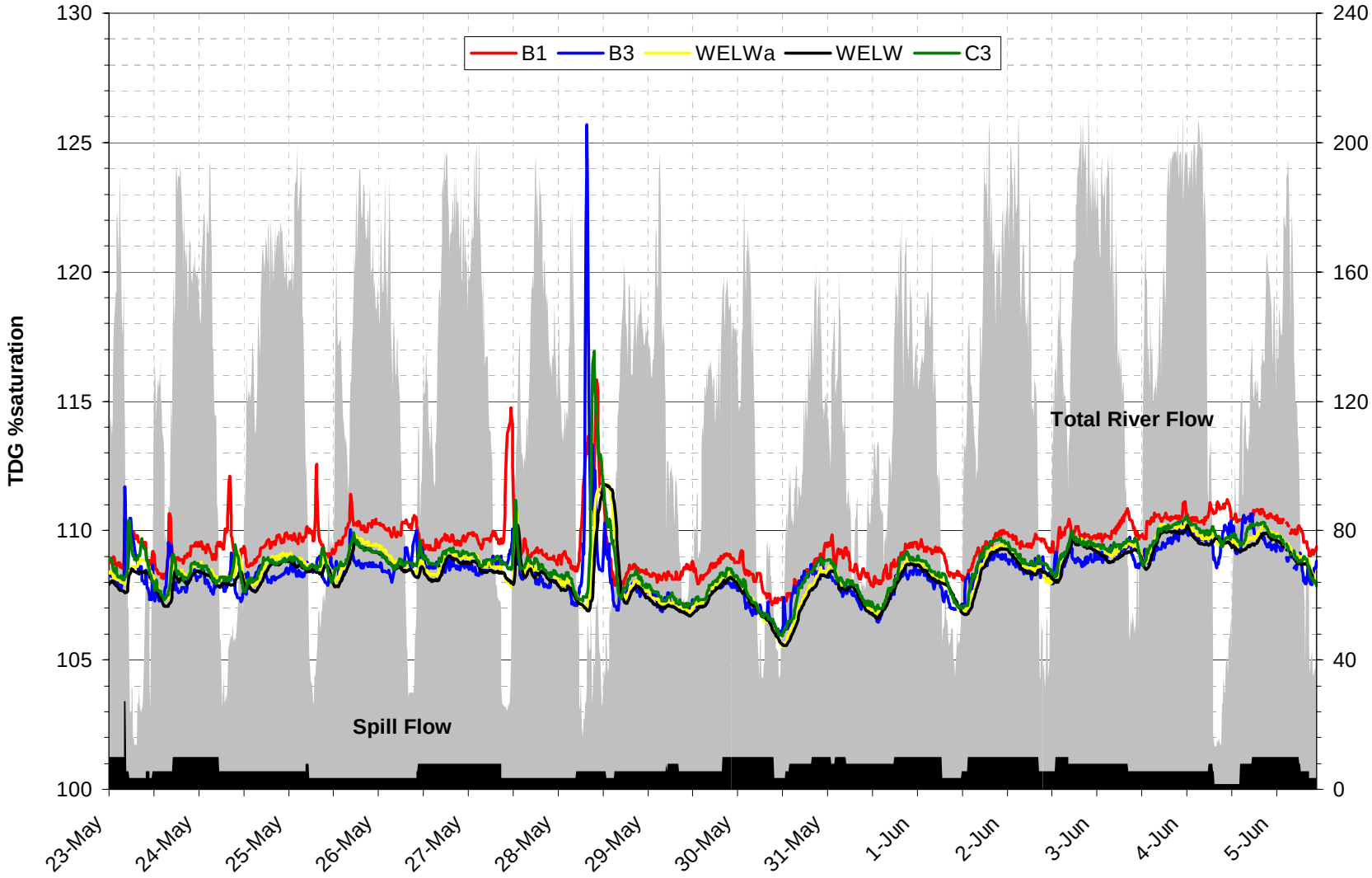

Figure 14. Wells Dam project discharge and Transect B and C TDG saturations for the period from 23 May to 6 June 2004.

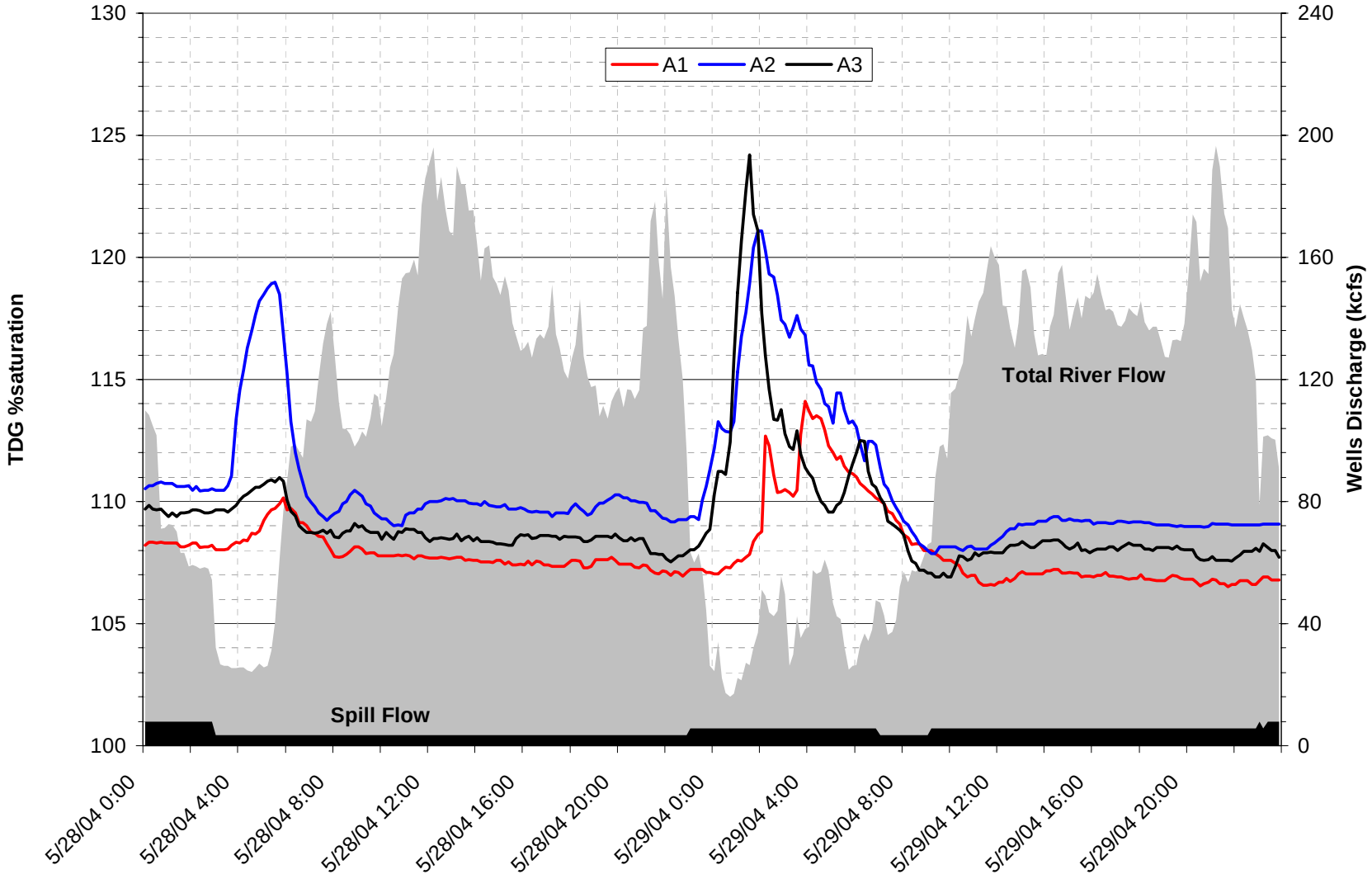

Figure 15. Wells Dam project discharge and Transect A TDG saturations for the period from 28 to 29 May 2004.

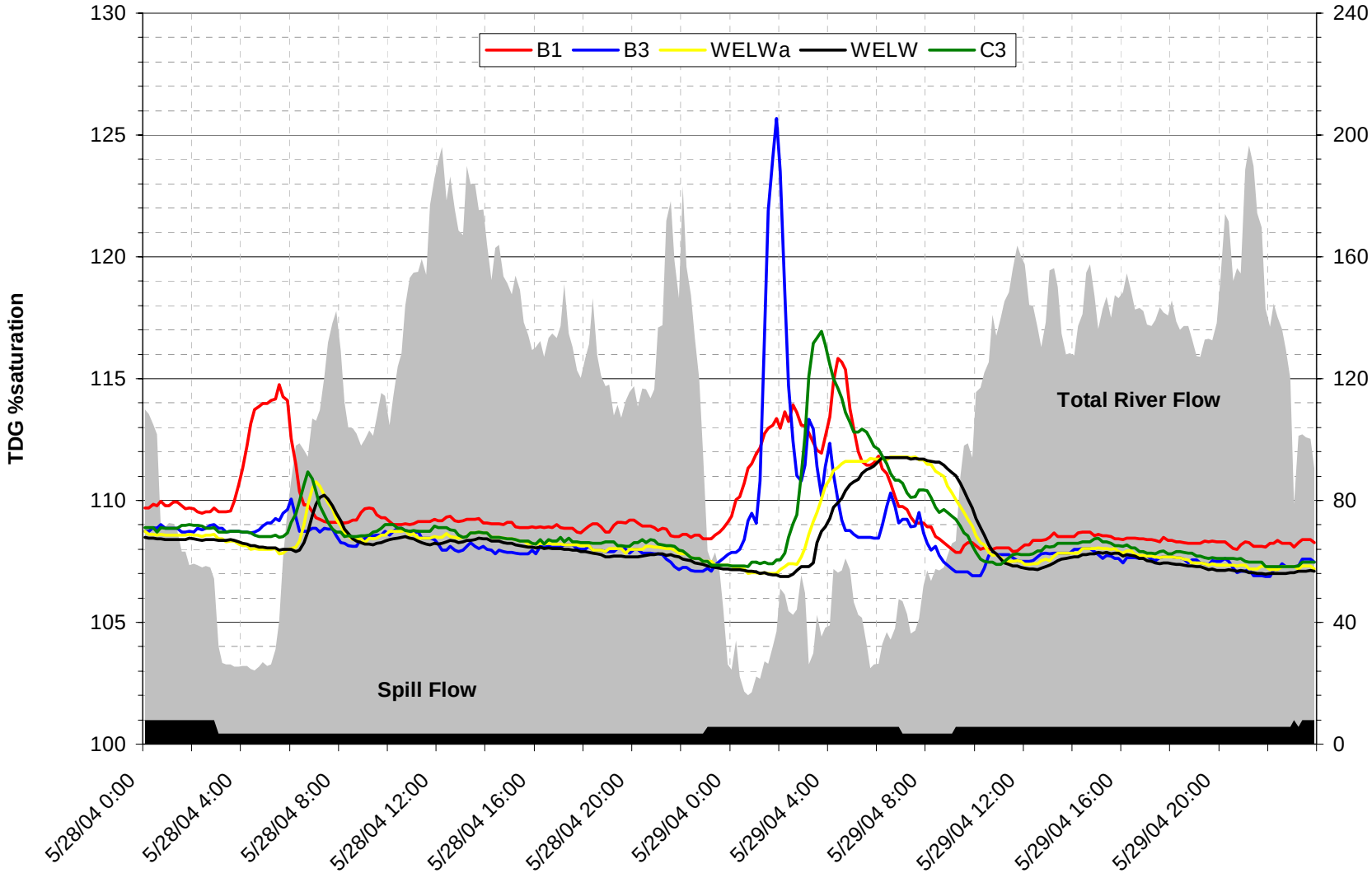

Figure 16. Wells Dam project discharge and Transect B and C TDG saturations for the period from 28 to 29 May 2004.

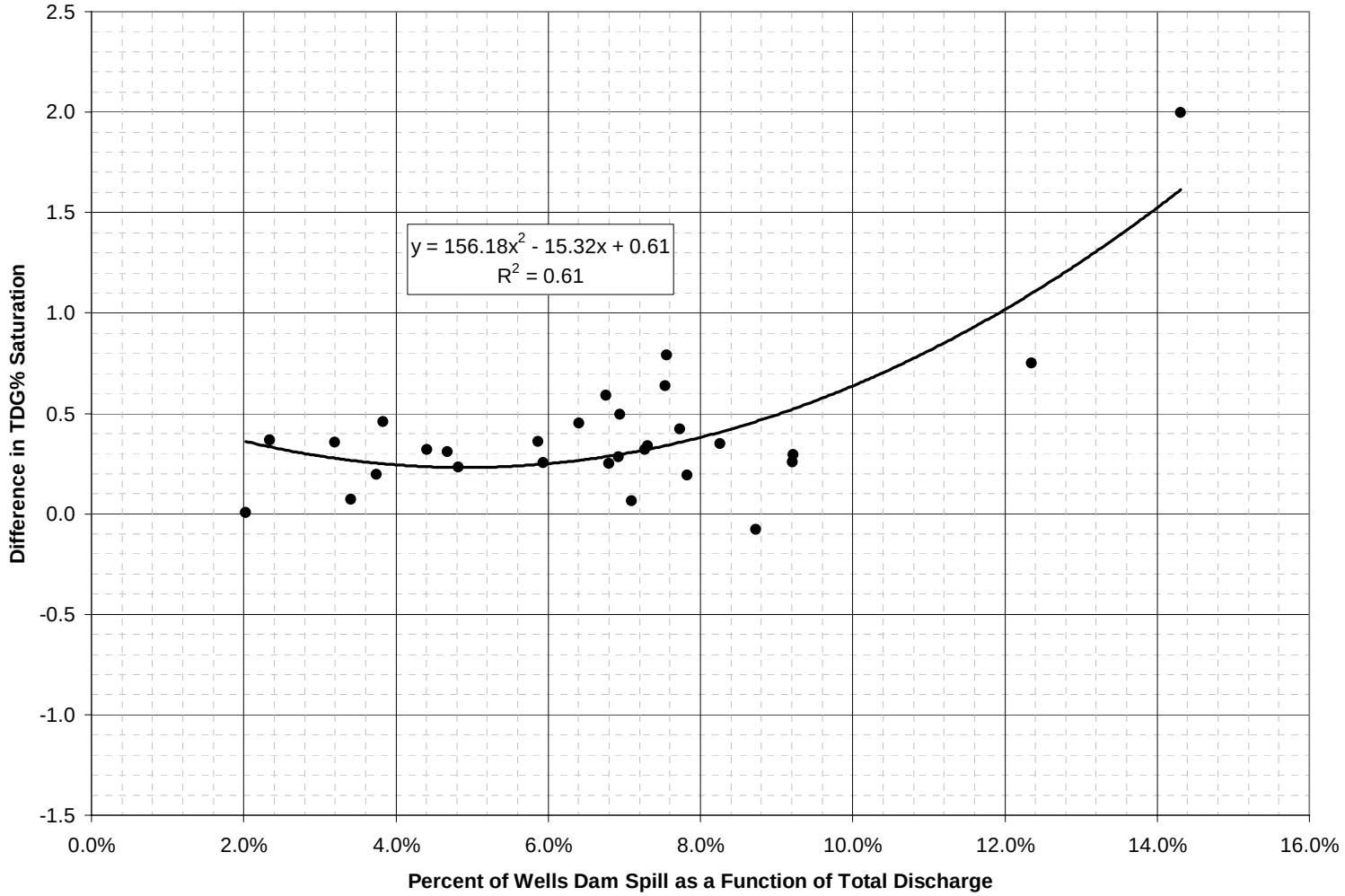

Figure 17. Difference in mean spill event TDG saturations for WELW and C3 plotted against mean spill from Wells Dam expressed as a percentage of the total project discharge.

CBE. 2006. Wells Dam Spillway Total Dissolved Gas Evaluation. Final Report. Prepared by Columbia Basin Environmental, The Dalles, Oregon for Public Utility District No. 1 of Douglas County, East Wenatchee, Washington.

Wells Dam Spillway Total Dissolved Gas Evaluation

23 May to 6 June 2005

FINAL REPORT

February 2006

Prepared for

Public Utility District No. 1 of Douglas County
1151 Valley Mall Parkway
East Wenatchee, Washington 98802

Prepared by

Columbia Basin Environmental
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Preface

This document reports the findings of a study conducted at Wells Dam from 23 May to 6 June 2005. The study was conducted by Columbia Basin Environmental and funded by the Public Utility District No. 1 of Douglas County. The use of trade names in this document should not be interpreted as an endorsement by either party.

This document contains hyperlinks indicated by blue text.
Click highlighted word to follow link.

Summary

During the spring of 2005, the Public Utility District No. 1 of Douglas County commissioned a total dissolved gas (TDG) study at the Wells Hydroelectric Project (FERC No. 2149) located at river mile 515.8 on the Columbia River. The study was implemented by Columbia Basin Environmental and was designed to describe total dissolved gas pressures resulting from eight pre-arranged spill scenarios consisting of different combinations of spillway and powerhouse operating conditions. An array of water quality data loggers were installed in the tailrace of Wells Dam for a period of two weeks between 23 May and 6 June, 2005. Each water quality logger was programmed to record water temperature and TDG pressure at ten-minute intervals. To better understand TDG dynamics at Wells Dam, the powerhouse and spillway were operated through a predetermined range of operational scenarios that varied the total flow, total spill, generation output, and location of the spillway discharge.

Total spillway discharges ranged from 26-38% of the total project discharge and were considered inadequate for developing TDG production curves for the spillway. An examination of historical data collected between 1998 and 2005 by the Wells Dam forebay and tailwater permanent monitors indicated that tailwater TDG saturations were dependent on both forebay TDG saturations and the total spillway discharge. The results indicated that an increase of 1 kcfs in spill resulted in a corresponding increase in tailwater saturations of 0.1%.

A simple mass balance approach was used to predict mean downstream TDG saturations. This approach assumed that powerhouse release waters diluted spill flows, rather than being gassed by spill. Comparisons of estimated and empirical tailwater TDG saturations indicated that powerhouse releases water exited the stilling basin with an increase of 3.9-8.0% in TDG saturation over forebay values. The trend was consistent across all eight scheduled tests. Operational patterns consisting of spill over generating turbines resulted in higher increases than other configurations.

Spill from the west side of the spillway resulted in consistently higher TDG saturations than similar spill discharges from the east side. This may have resulted from the greater depth in the west side of the stilling basin. Flat spill patterns consisting of near equal distribution of spill across the entire spillway yielded higher TDG saturations than crowned spill for similar total project discharges. This supported the idea of gassed powerhouse discharge since flat spill patterns involved more spill over generating units than did crowned spills.

The Wells Dam forebay monitor exhibited diel temperature cycles of over 1 C that were not reflected by the tailwater stations. This may have been the result of surface flows trained along the face of the dam and likely did not reflect the overall forebay temperature. Because of the relationships between temperature and TDG pressure, it was recommended that the forebay monitor be repositioned to a location upstream of the dam.

1.0. Introduction

The total dissolved gas (TDG) pressure of water describes the total pressure exerted by the constituent gasses as determined by their concentration and solubility. There are numerous natural and anthropogenic influences on dissolved gas concentrations and pressures including, but not limited to, community metabolism, heating, aeration devices, water falling over dams, weirs, or waterfalls, and turbine venting. It is possible for TDG pressures to exceed the equilibrium pressure resulting in TDG *supersaturation*. Supersaturated water will tend to lose gas to the atmosphere; however, this may be slow in the absence of turbulent flow.

The detrimental effects of the exposure of aquatic organisms to water characterized by elevated dissolved gas pressures were identified as early as 1905 (Marsh and Gorham 1905). Exposure to supersaturated water may result in *gas bubble trauma* (GBT), a condition similar to nitrogen narcosis ("the bends") in divers. As fish move vertically in the water column, gasses dissolved in the bloodstream under greater hydrostatic pressure may rapidly leave solution. This may lead to gill and skin blistering and "pop-eye." The presence of GBT has been documented throughout the Columbia River Basin, the most notable occurrence resulting in large fish kills at the John Day Dam (Beiningen and Ebel 1970).

This document summarizes the results of the latest in a series of studies undertaken by the Public Utility District No. 1 of Douglas County to better understand how operations at the Wells Hydroelectric Project affect downstream TDG saturations.

1.1. Site Description

The Wells Hydroelectric Project (FERC No. 2149) is located on the Columbia River near Azwel, Washington at river mile 515.8 (Figure 1) and is owned and operated by the Public Utility District No. 1 of Douglas County (District). The Wells Hydroelectric Facility is a hydrocombine meaning that the powerhouse, spillway, switchyard, fish ladders, and fish bypass system are integrated into a single structure with the spillways situated directly above the turbine intakes and draft tubes. The overall length of the dam is 4,460 feet, of which the hydrocombine comprises 1,165 feet. The project consists of eleven vertical lift spill gates and ten generating units with a maximum nameplate capacity of 840 MW. The hydraulic capacity of the powerhouse is 220 kcfs and the maximum spillway capacity is 1,180 kcfs. The project operates with a head ranging from 65 to 72 feet and is affected by the backwater of the Rocky Reach Hydroelectric Project (FERC No. 2145) located approximately 36.1 miles downstream.

Wells Dam spillway operations consist of *forced* spill (inflows in excess of powerhouse capacity) and *bypass* spill (spill of a portion of the total river volume to assist the out migration of juvenile salmonids). Forced spill occurs any time the total river discharge exceeds the powerhouse's total capacity. Excessive flows may result from low demands for power, high total river flows (>220 kcfs at Wells Dam), or in the event of equipment failure. Bypass spill at Wells Dam typically occurs between April and August comprising a percentage of the total project discharge divided between Spillbays 2, 4, 6, 8, and 10 as a function of the operating turbines. Bypass spill is dependent on project operations and total river flow and generally results in spills of 5-12% of the total project

discharge. Spillbays 2 and 10 have top-spill gates, while the remaining bays have underflow gates.

1.2. Background

1.2.1. Water Quality Regulations

The water quality standard for TDG pressure for Class A waters in the state of Washington is as follows:

> *Total dissolved gas shall not exceed 110 percent of saturation at any point of sample collection* (WAC 173-201A-030 (2) (iii)).

The National Oceanographic and Atmospheric Association (NOAA) Fisheries has requested spill at selected hydroprojects within the Columbia River Basin to assist with juvenile salmonid out migrations. The state of Washington developed the following waiver to the aforementioned standard:

> ***Special fish passage exemption for sections of the Snake and Columbia rivers:*** *When spilling water at dams is necessary to aid fish passage, total dissolved gas must not exceed an average of one hundred fifteen percent as measured at Camas/Washougal below Bonneville dam or as measured in the forebays of the next downstream dams. Total dissolved gas must also not exceed an average of one hundred twenty percent as measured in the tailraces of each dam. These averages are based on the twelve highest hourly readings in any one day of total dissolved gas. In addition, there is a maximum total dissolved gas one hour average of one hundred twenty-five percent, relative to atmospheric pressure, during spillage for fish passage.*

In addition to the waiver for fish passage, the state of Washington allows for the following consideration for flood control:

> *The water quality criteria herein established for total dissolved gas shall not apply when the stream flow exceeds the seven-day, ten-year frequency flood* (WAC 173-201A-060 (4) (a)).

1.2.2. Historical Data

The District has maintained a permanent TDG fixed monitoring system (TDGFMS) consisting of two Hydrolab® MiniSonde® multiprobes that measure water temperature and TDG pressure throughout the fish bypass spill season at Wells Dam. The TDGFMS is typically in service from 1 April until 15 September, which allows for an additional two weeks of data collection before and after the juvenile salmonid migration. The forebay probe (WEL) has been in operation since 1996 and the tailwater probe (WELW) since 1998. Atmospheric pressure data are collected via an aneroid barometer located on the surface deck of the dam. In addition to the TDGFMS, the District has collected periodic grab data to evaluate lateral and longitudinal distributions in TDG pressure. The results of these studies indicated minor gradients of less than 2% saturation across the width of the tailrace (Klinge 1998).

The District undertook more intensive studies to evaluate spill at Wells Dam during the 2003 and 2004 fish passage seasons. Both studies employed an array of data loggers arranged in a grid throughout the Wells Dam tailwater. The findings of those efforts were summarized in reports for the District (CBE 2003, 2004). The previous studies indicated that the tailwater TDGFMS (WELW) exhibited a delayed response to operational changes by Wells Dam when compared to mid- and upstream locations. Despite this delay, averages of the twelve highest daily TDG saturations (the compliance measure used by the State of Washington) varied little between stations.

The 2003 study also attempted to determine the fate of powerhouse release water by comparing upstream and downstream volume weighted TDG saturations. The results of these studies were limited by the range of flow conditions tested, but implied that the TDG pressures of powerhouse release water may have been influenced by spill. The 2004 study generally supported previous findings, indicating that Wells Powerhouse release water was gassed by spilled water. Temperature spikes apparent at the WEL site were not measured 800 feet upstream of the dam. This implied that the WEL site may have been influenced by surface flows and, therefore, may not have been representative of overall forebay temperatures and TDG pressures.

1.3. Objectives

This study sought to expand the findings of previous work at Wells Dam with the following primary objectives:

1. to determine the degree to which Wells Powerhouse release water is influenced by spillway operation, i.e. dilution or adsorption,

and

2. to explore ameliorative operational scenarios for reducing TDG production.

1.4. Approach

Previous studies required no special operations by the project, instead allowing flows to proceed based on power and fish passage requirements. Occasionally, high flows were measured; however, the distribution of flow was typically varied between turbines and spillways such that downstream probes rarely reached equilibrated values for a given flow condition.

1.4.1. Spill Shaping

The 2005 study requested three hours of static operation for each test condition to allow steady state conditions to be reached throughout the study area and to allow all probes to reach equilibration. Two principle test scenarios were devised to address the requirements of this study. Series one tests sought to examine the interaction of Wells Dam powerhouse and release flows by dividing flows between the east and west sides of the dam. Because the Wells Dam powerhouse and spillway were configured as a hydrocombine, it was difficult to sample undiluted powerhouse and spill release during normal operation. Dividing powerhouse and spillway flows provided the best opportunity to measure undiluted spillway TDG saturations. Water was spilled on both generating and

non-generating units by shifting powerhouse and spillway discharge between opposite sides of the dam.

Series two tests examined TDG production under different spill configurations for moderate and high flow spill events. Spillway discharges were shaped in a uniform (flat) or non-uniform (crowned) configuration for relatively moderate and high total river flows. Flat spills were characterized by near equal distribution of the total spillway discharge between all of the bays, while crowned spill more closely represented the spillway patterns employed by Wells for the same total flows. High and moderate flows were simulated by increasing total project discharge. Table 1 summarizes the test matrix for this study.

1.4.2. Mass Balance

To evaluate the impact of Wells Dam operations on downstream water quality, mean TDG saturations were compared using an upstream/downstream approach first developed by H.T. Odum to determine the influence of community metabolism on dissolved oxygen concentrations in flowing waters and a Florida turtle-grass community (Odum 1956, 1957).

The approach described herein attempted to reflect both the TDG saturation and volume of water affected and provided a simple way of evaluating the performance of the Wells Spillway under different operational scenarios. More importantly, this approach allowed indirect inferences about the influence of Wells Powerhouse flows on tailwater TDG saturations, i.e. dilution or adsorption. If spill and powerhouse TDG saturations were sufficiently represented, the mean tailwater TDG saturation for a given condition could be estimated. Since degassing was not considered and it was assumed there was no gas adsorption by powerhouse release water, estimated TDG saturations should have been less than or equal to empirical values. This may be restated in the form of testable hypotheses as

$$H_0 : TDG_{est} - TDG_{obs} \leq 0$$

$$H_a : TDG_{est} - TDG_{obs} > 0.$$

2.0. Methods

As with past studies, sensor deployment was timed to coincide with the spring freshet to maximize the opportunity to sample high spillway discharges without negatively impacting power generation. Test conditions were designed to target spill patterns thought to have the best chance of improving spill to TDG production ratios. Each test condition was held at, or near, steady state conditions for a period of at least three hours.

The original study plan included two transects, each consisting of three sensors distributed laterally across the width of the river. Transect A would be approximately 1100 feet downstream of the dam with Transect B about three miles downstream at the location of the tailwater TDG monitor (WELW). At the request of the Washington Dept. of Ecology, a third transect was to be included at a future potential compliance zone located approximately 2500 feet downstream. A problem with the equipment supplier reduced the probes available for the study, therefore Transect A was installed 2500 feet downstream and the near-dam transect was omitted.

2.1. Instrumentation

Five Hydrolab® multi-parameter data loggers (sondes) were utilized for the period of study plus the two seasonal fixed monitor instruments operated by the District. Each sonde was equipped with sensors for water temperature, TDG pressure, and depth. All probes were calibrated to NIST traceable standards for temperature and TDG pressure both prior and subsequent to field deployment following the methodologies outlined in Appendix A. Data were recorded along a ten-minute interval for the period of study. Atmospheric pressure data were collected at the Wells Dam forebay TDGFMS location and corrected to the tailwater elevation for the downstream sites. Hourly data for water quality and operations were obtained for ancillary hydroprojects from the Columbia River Operational HydroMet System (CROHMS) operated by the U.S. Army Corps of Engineers, Northwest Division. Probes at these sites also consisted of Hydrolab® sondes maintained as described in Appendix A.

2.2. Field Deployment

Sondes were distributed in two downstream transects of three instruments distributed across the lateral width of the river. Station locations based on GPS coordinates collected at the time of deployment and retrieval are depicted in Figure 2. Table 2 summarizes the deployment information for the 2005 study.

2.2.1. Forebay

The forebay TDGFMS (WEL) was permanently deployed in a perforated pipe attached to the face of the dam at a depth of approximately 4.5 m (15 feet). This probe served to represent background TDG saturations for the Wells forebay.

2.2.2. Transect A

Transect A consisted of three probes and was located approximately 2500 ft. downstream of the dam (A1, A2, and A3 in Figure 2). Each probe was housed in a 200 lb. steel case that served to both anchor the station and protect the sonde. Anchors were attached to a series of surface floats via 5/16" diameter steel cables that allowed

installation and retrieval by boat. Figure 3 illustrates the deployment rigging used for Transect A.

2.2.3. Transect B

Transect B consisted of two sondes in addition to the tailwater TDGFMS (WELW) located about three miles downstream of the dam. Probes were installed in a manner similar to Transect A (depicted in Figure 3) while the TDGFMS was permanently installed in a perforated pipe on the river's east bank (Figure 4).

2.3. Data Analysis

Data collected for the Wells Spillway study were obtained from the following sources:

1. field transect data – water temperature and TDG pressure (mm Hg) reported every ten minutes for seven sites (the forebay and tailwater TDGFMS and five auxiliary sites)

2. CROHMS data – web-based database of hourly project operation and water quality data maintained by the U.S. Army Corps of Engineers, Northwest Division

3. ten minute project operations data – total project discharge, total spillway discharge, turbine output by unit, and pool elevations for the forebay and tailwater reported every ten minutes from the District Power Operations Database

4. control room operator logs – individual spill gate settings recorded at the time of occurrence

The sondes utilized TDG sensors that reported the total pressure at the depth of sample collection. Pressures were converted to TDG pressure as a percentage of surface saturation as

$$TDG_{sat} = \frac{TDG_i}{BP_i} \times 100$$

where

TDG_{sat} = TDG pressure expressed as percentage of surface saturation

TDG_i = TDG pressure at station i, mm Hg

BP_i = Atmospheric pressure at station i, mm Hg

Equation 1

2.3.1. Data Preparation

Data for the various data sets were merged by date and time. Control room operator logs were used to identify study events and determine individual spill gate discharges. Spill levels were reported as discharge (kcfs) for Bays 2 and 10 and as gate opening (feet) for the remaining spillbays. Individual spillbay discharge was necessary for

analyses; therefore, gate openings were converted to discharge using the following relationship developed from data provided by the District:

$$Q_G = 0.2TW + 1.7G - 154.6$$

where

Q_G = discharge of spillway G, kcfs

TW = tailwater elevation, ft above MSL

G = spillgate G opening, ft

Equation 2

Total discharge estimates based on Equation 2 disagreed slightly with the electronic data set. These discrepancies were reconciled by determining the percentage each spillbay contributed to the total spill based on Equation 2 estimates and then applying those percentages to the ten-minute data sets.

Wells Powerhouse generator output was reported in megawatts. The percentage each generator contributed to the total power output was applied to total powerhouse flow estimates (computed as total project flow less estimated spill flow) to approximate individual turbine discharges.

Once the data sets were merged, individual test events were identified. Data for each test were visually inspected to select equilibrated values to be used in subsequent analyses. Figure 5 depicts data for Test 1D collected at Transect A to illustrate typical TDG senor response and equilibration times. Equilibrated data were then summarized by test condition for subsequent data analyses.

2.3.1. Mass balance analysis

To examine the influence of powerhouse and spillway release water, upstream and downstream TDG saturations were compared using the simplified mass balance approach used in prior studies. The forebay TDGFMS (WEL) represented background TDG saturations, or 100% of the upstream flow, which were assumed to be unaffected by Wells Dam operations. Downstream flows were assumed to consist of both powerhouse (background) and spillway water, each characterized by different TDG saturations. It was assumed that water passed through the powerhouse unchanged, thus WEL data represented powerhouse release TDG saturations. The TDG saturations of spilled water should vary with pattern and volume spilled. The highly turbulent flows characteristic of the stilling basin promoted gas exchange, both with air entrained by spill and lost to the atmosphere. Upon exiting the stilling basin, off gassing occurred much more slowly, thus more closely approximating "equilibrated" spill TDG saturations.

Assuming that spill and powerhouse flows were adequately reflected by data collected at Transects A and B, the estimated mean downstream TDG saturation could then be represented as

$$TDG_{Wells} = \frac{(Q_{PH} \times TDG_{PH}) + (Q_{SP} \times TDG_{SP})}{(Q_{PH} + Q_{SP})}$$

where

TDG_{Wells} = the flow - weighted average TDG saturation exiting the Wells tailwater (μTransect B)

Q_{PH} = the total powerhouse discharge

TDG_{PH} = the average TDG saturation of powerhouse release water (WEL)

Q_{SP} = the total spillway discharge

TDG_{SP} = the average TDG saturation of the spillway release water.

Equation 3

Substituting mean Transect B values for TDG_{Wells}, Equation 3 could be rearranged to solve for TDG_{SP} as

$$TDG_{SP} = \frac{((Q_{PH} + Q_{SP}) \times TDG_{Wells}) - (Q_{PH} \times TDG_{PH})}{Q_{SP}}.$$

Equation 4

Comparisons of actual and calculated values for TDG_{Wells} and TDG_{SP} were used to evaluate the performance of the different spill scenarios and to indirectly determine the effect of powerhouse flows, i.e. dilution or adsorption.

3.0. Results and Discussion

All eight of the pre-arranged spill scenarios were achieved during the study. Start and end times for the eight spill tests are presented in Table 3. Mean generator and spillbay discharges are summarized by unit in Table 4. In addition to the eight scheduled tests, an unplanned high spill event occurred between 26 and 27 May 2005. This event was unscheduled and occurred during relatively minor power demand. Flow distributions varied between turbines and gates; therefore, these data were excluded from mass balance analyses but included in the final dataset as they represented the highest spill levels of the study (100 kcfs representing 50% of total project flow). Graphical representations of the turbine and spillway patterns for the eight spill scenarios are included as Appendix B.

Data were available for all sites and pre and post study calibrations indicated that all probes performed within acceptable limits, as presented in Table 5. Equilibrated data for each test were summarized by station. Tables 6 and 7 depict test summaries for temperatures and TDG saturations, respectively. Mean tailwater elevations and sensor depths for each site are plotted by test as Figure 6. Sensor depth was highly correlated with tailwater elevation with the deepest values corresponding to the higher flow events. The mean tailwater elevation for the eight scheduled tests ranged from 710.6 feet above mean sea level (feet MSL) during Test 1B to 716.4 feet MSL during Test 2C. The maximum tailwater elevation for the entire study period of 719.8 feet MSL occurred on 25 May 2005 with a total project discharge of 225.5 kcfs.

Table 7 presents test averages for the 2005 spill study. These data represented equilibrated values and were utilized in subsequent analyses.

3.1. Hydrology

River flows were below average compared to historical values, ranging from a maximum daily average discharge of 177.2 kcfs on 27 May 2005 to a minimum of 41.1 kcfs on 5 June. Figure 7 displays daily average flows at Wells Dam for the 1997, 2001, and 2005 water years. These data were selected from the CROHMS dataset (1995-present) to illustrate flows for relatively high (1997) and low (2001) river conditions.

Spillway discharges occurring outside of the requested test periods consisted of standard fish bypass spill through Gates 2, 4, 6, 8, and 10. The maximum spill discharge of 100 kcfs occurred during the aforementioned unscheduled spill event on 27 May 2005. Daily average spills ranged from a minimum of 5.8 kcfs to a maximum of 26.1 kcfs occurring on 5 June and 27 May 2005, respectively.

One significant spill event averaging 27.8 kcfs occurred at Chief Joseph Dam, approximately 29.5 miles upstream of Wells Dam, on 25 May between 14:00 and 23:00. This was followed by a short term spill event lasting for two hours around 0:00 on 27 May 2005. Chief Joseph operations and downstream TDG saturations are presented in Figure 8. With the notable exception of 25 May, TDG saturations measured at the Chief Joseph tailwater FMS (CHQW) generally reflected upstream values with no clear influence by the dam on downstream TDG saturations measured at CHQW or WEL.

As previously discussed, tailwater elevations ranged from 704.8 to 719.8 feet MSL during the 2005 study. Wells tailwater elevations typically fluctuated by about ten feet during an operational day, mainly as a function of the total project discharge. Figure 9 depicts the bathymetry for the Wells Hydroproject from immediately upstream of the dam to approximately 2,700 feet downstream. The Wells Dam stilling basin is relatively deep to allow for the draft tube outlets and, presumably, as a result of scouring from spill. The thalweg follows the east side of the river until about 0.5 miles downstream, where the channel begins to exhibit a more uniform morphometry.

Because the sensors were anchored to the river bottom, their depth varied with variations in tailwater elevation as seen in Figure 6. This was more apparent at the shallower sites along Transect A than Transect B, which had a relatively wide, deep channel.

3.2. Temperature

Hourly water temperatures for Wells, Chief Joseph, and Rocky Reach dams are displayed in Figure 10 with hourly TDG saturations presented in Figure 11. Both the Wells (WEL) and Rocky Reach (RRH) forebay TDGFMS exhibited large daily fluctuations in water temperature when compared to the other sites. Temperatures measured at the WEL site ranged from a minimum of 10.9 C on the morning of 23 May 2005 to a maximum of 14.2 C on the afternoon of 29 May 2005. Temperature may significantly affect the TDG saturation of surface waters, as mentioned in Section 1.0. Figure 12 depicts water temperatures and TDG saturations for the Wells fixed monitoring stations reported every ten minutes for the same period shown in Figures 9 and 10. Note that temperatures measured by the forebay probe were more erratic than those downstream. The highest temperatures typically coincided with low project discharges during off peak hours – generally characterized by lesser flows throughout the Columbia River system.

The contrast between forebay and tailwater temperatures apparent in Figure 12 highlighted a potential problem with the forebay sensor location. The WEL probe was secured in a pipe attached to the upstream face of the dam. Figure 13 depicts temperature data collected upstream of the dam during the 2004 study. Note that temperatures measured approximately 800 feet upstream (FB1 and FB2) closely matched data collected downstream (WELW), without the relatively dynamic temperature fluctuations reported by the forebay TDGFMS (WEL). Forebay TDG saturations displayed a strong correlation with temperature as demonstrated by the relationships in Figure 14. The data points circled in Figure 14 represented the 25 May Chief Joseph Dam spill event. When these data were excluded, the correlation between temperature and TDG saturation was stronger (R^2=0.72).

3.3. TDG Production Curves

Historical TDGFMS data for Wells Dam collected between 1998 and 2005 indicated a relatively weak (R^2=0.67) linear relationship between WELW and WEL as depicted in Figure 15. When total spill was considered, a stronger linear relationship was described as

$$WELW = 0.89(WEL) + 0.14(Q_{SP}) + 12.42$$

$$R^2 = 0.91$$

where

$WELW$ = Wells tailwater TDG saturation

WEL = Wells forebay TDG saturation

Q_{SP} = Total discharge of the Wells Spillway (kcfs).

Equation 5

Figure 16 presents WELW TDG saturations predicted from Equation 5 plotted against actual values collected from 1998-2005. Values predicted from Equation 5 closely matched actual values and indicated an increase of approximately 0.7 % saturation for every 5 kcfs increase in Wells total spill, or 0.1 % per 1 kcfs increase in spill. If the percentage of the total project flow consisting of spilled water were substituted for total spill, mean tailwater TDG saturations were best predicted as

$$WELW = 0.90(WEL) + 0.27(P_{SP}) + 9.98$$

$$R^2 = 0.88$$

where

$WELW$ = Wells tailwater TDG saturation

WEL = Wells forebay TDG saturation

P_{SP} = Spillway discharge as a percentage of the total project flow.

Equation 6

Residual analyses revealed a stronger correlation between predicted TDG saturations and the percentage of spill than with total spill. Therefore, Equation 5 was deemed the more appropriate representation.

3.4. Spill Shaping

Previous studies had not requested specific spill patterns and normal project operation (spill over load) made it difficult to estimate distinct TDG saturations for spill and powerhouse releases. During the 2005 effort, tests 1B and 1C separated spill flows in an attempt to measure undiluted spillway and powerhouse TDG saturations.

The Wells Dam spillway consists of both top-spill and underflow gates; however, assuming there was no difference in the TDG exchange characteristics for the different spillway designs, a simple method for reducing maximum downstream TDG saturations could be a uniform (or flat) spill pattern. By distributing the total spillway discharge across all bays, the total discharge by any one bay was reduced. This had often resulted in lesser overall downstream TDG saturations during studies at other regional dams, albeit potentially expanding the total volume of water influenced by spill.

The Series 2 tests examined the difference between uniform and non-uniform spill distributions for moderate and high total project discharges. Figures 17 through 24 depict TDG saturations for paired tests measured at Transects A and B.

3.4.1. Loaded versus unloaded spill

Series 1 testing explored the potential differences between spill over generating and non-generating turbines for both the east and west sides of the dam. Tests 1A and 1B examined spill from the east side of the spillway over generating (1A) and non-generating (1B) units and the results of these tests for Transects A and B are depicted in Figures 17 and 18, respectively. Test 1A resulted in a gradient of 5% across Transect A with the highest values measured along the west bank. The gradient persisted all the way to Transect B with east bank values equal to those at Transect A, and mid-channel stations that were nearly equal. In contrast, Test 1B resulted in less of a gradient at Transect A with the highest values along the west half of the river. Transect B TDG saturations were nearly uniform for Test 1B.

Tests 1C and 1D represented spill from the west side of the spillway over generating and non-generating units, respectively. As demonstrated by Figures 19 and 20, a gradient of nearly 8% TDG saturation was observed at Transect A with the west bank stations displaying the highest values for test 1C at both transects. As with Test 1A, the gradient persisted to Transect B, although the east station (WELW) yielded higher values than east river (A1) values measured upstream. Test 1D resulted in near uniform values at Transects A (Figure 19) and B (Figure 20). The maximum TDG saturations were less for both transects than those for Test 1C. The volume of water influenced by spill was greater as indicated by the elevated saturations at all stations for Test 1D in contrast to the more localized influence indicated for Test 1C.

Spill from the west side of the spillway resulted in higher average TDG saturations for both transects and appeared to be independent of generation. Average TDG saturations were identical for the paired tests (1A/1B and 1C/1D) as summarized in Table 8.

3.4.2. Crowned versus Flat Spill

Series 2 tests explored the influence of shaping spill at moderate and high flows. Figures 21 and 22 display TDG saturations measured for crowned (or non-uniform) and flat (or uniform) spills at moderate flows for Transects A and B. A TDG gradient of 3.5% saturation was observed for Test 2A at Transect A, with the highest values represented by the mid-channel and west bank stations. The gradient was apparent, though less pronounced, at Transect B, with little change from upstream values. Test 2B resulted in near uniform TDG saturations across each transect, although the outer stations demonstrated slightly higher saturations than the mid-channel station for Transect A.

The trends observed at moderate flows were also expressed at higher flows, with a persistent gradient across both transects (Figures 23 and 24). West river TDG saturations were higher for both patterns and characterized by little change from the upstream transect. Uniform spill patterns resulted in higher TDG saturations than non-uniform patterns for both flow conditions. Differences between mean Transect A and B TDG saturations were generally less for the Series 2 tests than for the Series 1 tests. Figure 25 displays TDG saturations for Transect A, Transect B and WEL averaged by spill

test. Note that there was little difference in mean TDG saturations for Tests 1A/1B and 1C/1D, while uniform spill tests 2B and 2D resulted in higher TDG saturations than the corresponding non-uniform tests (2A and 2C in Figure 25).

Figure 26 depicts both the average TDG saturations measured for the forebay and tailwater stations (left axis) and the average change in TDG saturations from upstream to downstream as the difference in WEL and Transect B (right axis). Tests 1A, 1C, 1D, 2B, 2C, and 2D all resulted in an increase of around 7% saturation over forebay values. Tests 1B and 2A resulted in increases of 4.2% and 5.6%, respectively.

3.5. Mass Balance

Values from Table 8 were substituted into Equation 3 to solve for TDG_{Wells} by allowing the maximum TDG saturation for Transect A to represent TDG_{spill}. Allowing TDG saturations for the forebay (WEL) to represent TDG_{PH} assumed that powerhouse release water was not gassed by spill, but instead served to dilute spilled releases. Predicted and actual mean Transect B TDG saturations are plotted by test as Figure 27. In all tests, actual Transect B values exceeded predicted TDG saturations. A t-test analysis indicated that there was sufficient evidence at the 0.05 level of significance to reject the null hypothesis that the estimated Transect B TDG saturations were less than or equal to observed values.

Substituting Table 8 values into Equation 4 to solve for TDG_{SP} again demonstrated marked differences from actual values as seen in Figure 28. Given the significant differences evident in Figures 27 and 28, Equations 3 and 4 did not fully describe TDG processes.

If one assumed that the powerhouse release was gassed by spill, the mass balance approach described by Equation 3 would underestimate downstream values. To explore this concept further, the minimum Transect A saturation was substituted for TDG_{PH} in Equation 3 and used to compute mean Transect B values. When this estimate was compared to observed values, there was insufficient evidence at the 0.05 level of significance to reject the hypothesis that there was no difference between the two. The results of this approach are summarized in Figure 29. Results for all of the mass balance analyses are summarized in Table 9.

3.6. Compliance with water quality standards

Table 10 summarizes TDG saturations as the average of the twelve highest daily values, used as one measure of compliance with state water quality standards. The only value to exceed this standard was measured in the Rocky Reach forebay for 28 May 2005, one day after the unscheduled high spill event of 27 May. The twelve hour average for RRH was 120.4%, some 5.4% higher than the allowable limit. Instantaneous TDG saturations at or above 125% were measured throughout the Wells tailwater for a period about three hours with a total spillway discharge of 100.0 kcfs, which represented approximately 50% of the total project flow.

4.0. Conclusions

Total river flows at Wells Dam for 2005 were moderate and comparable to flows during the 2003 and 2004 studies. The average daily discharge at Wells Dam peaked at 178.7 kcfs on 27 May 2005. This was similar to the maximum daily average flows for 2003 (167.3 kcfs on 22 May 2003) and 2004 (170.1 kcfs on 29 June 2004), but represented only about 50% of the maximum daily average for 1997 (364.1 kcfs on 12 June 1997), which had the highest flows for the last ten years. Total spillway discharges for the 2005 study ranged from 26.0% to 37.7% of the total project flow. At 7Q10 flows (246 kcfs for Wells Dam) spill would represent approximately 11.6%, assuming the powerhouse were operating at full capacity (220 kcfs). It is more likely that power demand and mechanical constraints would preclude such operation, thus requiring additional spill. The higher background TDG saturations (upstream spill), deeper tailwater, and more turbulent flows experienced during 7Q10 discharges may reduce the ability to extrapolate from the 2005 study results.

Diel temperature cycles were much more pronounced at the Wells forebay monitor site than at the tailwater station (Figure 12). This was consistent with the results of the 2004 study (Figure 13) which had indicated that temperatures measured at the same depth (15 feet) approximately 800 feet upstream of the dam were up to 1 C less than at the forebay station and tracked with tailwater values. One explanation is that surface flows due to spill and/or generation train warmer waters past the forebay probe. Temperatures measured under this scenario would reflect the relatively thin surface layer of water rather than the bulk of the forebay. For the same concentration of a dissolved gas (or gasses) an increase in temperature results in a comparable increase in total gas pressure (Henry's Law). The silastic tubing used for TDG membranes allows diffusion of gasses while excluding the effects of hydrostatic pressure and is the limiting factor in the rapidity of the TDG probe's response to changes. If a TDG sensor is allowed to equilibrate to a given pressure and then heated, TDG pressures will rise quickly as the gasses within the membrane expand. This continues until the probe reaches the new equilibration point for the warmer temperature. Because ancillary probes did not exhibit similar temperature fluctuations, it is likely that the forebay site was not always representative of actual forebay conditions. The simplest solution to this problem would be to relocate the forebay monitor to a location upstream and away from the face of the dam.

Spillway discharges for the eight test events of this study ranged from about 26% to 38% of the total project flow. Spill over a wider range of flows would be needed to develop meaningful TDG production equations for the Wells Spillway. An examination of historical data collected by the Wells TDGFMS indicated that tailwater TDG saturations (WELW) were best explained as a function of background TDG pressures (WEL) and total spill as described by Equation 5. This relationship indicated that every 1 kcfs of additional spill corresponded to an increase of 0.1 % saturation in the tailwater. Previous work indicated that each 5% increase in Wells spill as a percentage of the total project discharge corresponded to a 0.5% in mean downstream TDG saturations (CBE 2003). Past research indicated a 1% increase in TDG saturation for every 4% increase in spill, as determined from the Wells TDGFMS (Klinge 1998). Additional data collected under a wider range of spills will be needed to refine and consolidate these estimates.

Spill from the west spillbays led to higher TDG saturations than similar spill volumes from the east spillbays. This trend was independent of which side of the powerhouse was operating. Lateral gradients observed along Transect A and Transect B indicated that powerhouse flows may have trained spillway releases with gradients of up to 5% saturation persisting to Transect B, approximately 3 miles downstream of the spillway. The west side of the Wells Dam stilling basin is deeper by 10 to 20 feet than the east side and is fairly uniform to the west shore. In contrast, the east side of the stilling basin is adjacent to the earthen portion of Wells Dam and gradually shallows toward the east shore. The deeper channel promotes a greater plunge depth for spilled water and, as a result, may promote gas adsorption.

Crowned spill events resulted in lower TDG saturations than flat spill events for the same total spill and total project discharges. Test 2B (flat spill, moderate flow) yielded TDG saturations approximating Test 2C (crowned spill, high flow) even though the latter test was characterized by higher total river and spill flows, in addition to a deeper tailwater. Flat spill events added spillbays to evenly distribute total spill, thus all operating turbines released water directly into spill. This was in contrast to the crowned spill events, where some bays and generators were idle. This may have effectively increased the volume of water spilled, thus increasing average downstream TDG saturations.

Mass balance analyses indicated that Wells Dam powerhouse release water was gassed by spill at the dam. Data consistently indicated a greater volume of water affected by the Wells Dam spillway than could be explained by the volume of water and TDG saturations measured for the spillway. Relationships between flow-weighted values indicated that the effective TDG saturation of powerhouse release waters was between 3.9-8.0% higher than reported by the forebay monitor. The greatest discrepancies occurred during the spill over load (1A and 1D) and flat spill tests (2B and 2D). These tests included more spill over generating units than the other tests allowing more direct interaction between the different flows.

It is important to note that the mass balance approach was highly dependent on forebay TDG saturations to represent background (i.e. powerhouse) values. It was possible that potential problems with the forebay station location may have magnified (or lessened) the perceived impact of different tests. Upstream spill from Chief Joseph Dam also influenced Wells Forebay TDG saturations. Despite these problems, the consistency and statistical significance of these results indicated that 100% of the Wells Powerhouse release waters were gassed by spill. This supported findings from prior studies that had indicated powerhouse flows were gassed by spill rather than diluting it.

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Tables

Table 1. Test Matrix for 2005 Wells Dam Spill Evaluation

Test	Description
1A	Spill over load, east spill/east generation
1B	Divided spill load, east spill/west generation
1C	Divided spill load, west spill/east generation
1D	Spill over load, west spill/west generation
2A	Crowned spill, modest flow
2B	Flat spill, modest flow
2C	Crowned spill, high flow
2D	Flat spill, high flow

Table 2. Deployment locations for 2005 Wells Dam Spillway Evaluation.

Serial No.	Station ID	Location (WGS-84)	
		Latitude	Longitude
42187	A1	47.93971	-119.85968
42200	A2	47.94063	-119.86141
42195	A3	47.94124	-119.86393
42188	B2	47.91400	-119.89700
32707	B3	47.91464	-119.89799
33254	WEL	47.94722	-119.86508
32639	WELW	47.91304	-119.89625

Table 3. Test Dates and Times for 2005 Wells Dam Spillway Evaluation

Test	Start Time	End Time	Duration (min.)	n
1A	5/24/05 22:00	5/25/05 1:00	180	19
1B	6/1/05 2:00	6/1/05 5:00	180	19
1C	6/1/05 22:00	6/2/05 1:00	180	19
1D	6/3/05 23:00	6/4/05 3:00	240	25
2A	5/23/05 8:00	5/23/05 11:00	180	19
2B	5/25/05 8:00	5/25/05 11:00	180	19
2C	5/23/05 13:00	5/23/05 16:00	180	19
2D	5/26/05 13:00	5/26/05 16:00	180	19

Table 4. Mean Unit Discharge for the Wells Dam 2005 Spillway Evaluation

		Discharge (kcfs)											
Test		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
1A	Spillbay	0.0	1.1	0.0	2.1	0.0	3.4	4.6	5.8	4.6	5.2	4.6	31.3
	Generator	0.0	0.0	0.0	0.0	0.0	0.0	15.8	15.9	15.6	15.9		63.2
1B	Spillbay	0.0	1.8	0.0	3.0	0.0	4.4	5.4	4.4	5.4	3.5	5.4	33.5
	Generator	0.0	16.1	16.2	16.0	15.9	0.0	0.0	0.0	0.0	0.0		64.2
1C	Spillbay	6.4	3.4	6.4	4.7	4.7	4.7	0.0	2.9	0.0	3.4	0.0	36.6
	Generator	0.0	0.0	0.0	0.0	0.0	0.0	15.1	15.2	14.9	15.3		60.5
1D	Spillbay	5.9	1.6	5.9	4.3	5.9	4.3	0.0	4.3	0.0	1.6	0.0	33.8
	Generator	0.0	16.0	16.1	16.2	15.9	0.0	0.0	0.0	0.0	0.0		64.2
2A	Spillbay	0.0	1.3	0.0	3.3	8.3	6.2	8.3	3.3	0.0	1.3	0.0	32.0
	Generator	0.0	0.0	15.2	15.1	15.0	15.2	15.2	15.3	0.0	0.0		91.0
2B	Spillbay	4.1	1.6	2.9	4.3	2.9	4.3	2.9	4.3	2.9	3.4	4.1	37.5
	Generator	0.0	0.0	14.4	14.3	14.2	14.4	14.4	14.5	0.0	0.0		86.3
2C	Spillbay	0.0	2.3	0.0	5.4	11.3	6.9	11.3	6.9	0.0	2.3	0.0	46.3
	Generator	0.0	16.0	16.1	15.9	15.9	16.1	16.0	16.2	15.9	0.0		128.0
2D	Spillbay	5.3	1.8	5.0	4.6	5.0	4.6	5.0	4.6	5.0	3.4	0.0	44.1
	Generator	0.0	15.4	15.5	15.3	15.2	15.4	15.6	15.5	15.2	1.7		124.9

Table 5. Water Quality Sensor Calibration Data for 2005 Wells Dam Spillway Evaluation

S/N	Date	BP (mmHg)	Temperature (°C)			TDG Pressure (mm Hg)				Deviation from TDG Standard (mm Hg)			
			Std	Probe	Diff	BP + 0	BP + 100	BP + 200	BP + 300	BP + 0	BP + 100	BP + 200	BP + 300
32707	05/21/05	759	15.5	15.4	0.1	758	858	958	1058	1	1	1	1
42187	05/21/05	759	15.5	15.5	0.0	758	858	958	1058	1	1	1	1
42188	05/21/05	759	15.6	15.6	0.0	759	859	959	1059	0	0	0	0
42195	05/21/05	759	15.4	15.4	0.0	759	859	959	1059	-1	-1	-1	-1
42200	05/21/05	759	15.5	15.5	0.0	759	859	959	1059	0	0	0	0
32639	05/22/05	744	10.9	10.8	0.1	743	843	943	1042	1	1	1	2
33254	05/22/05	743	11.0	11.0	0.0	742	842	942	1043	1	1	1	0
32707	06/06/05	752	16.4	16.4	0.0	751	851	951	1051	-1	-1	1	1
42187	06/06/05	752	16.4	16.4	0.0	751	851	951	1051	-1	-1	1	1
42188	06/06/05	752	16.3	16.2	0.1	751	851	952	1052	-1	-1	0	0
42195	06/06/05	752	16.3	16.3	0.0	752	851	951	1051	0	-1	1	1
42200	06/06/05	752	16.4	16.4	0.0	757	857	958	1058	-5	-5	-6	-6
32639	06/05/05	735	12.9	12.8	0.1	734	834	934	1034	-1	-1	1	1
33254	06/05/04	734	13.1	13.1	0.0	734	834	934	1034	0	0	0	0

Table 6. Summary Data for Water Temperatures for the Wells Dam 2005 Spillway Evaluation

	Test	Water Temperature (ºC)						
		WEL	WELW	A1	A2	A3	B2	B3
Mean	1A	11.1	11.0	11.1	11.1	11.1	11.1	11.1
	1B	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	1C	12.6	12.6	12.7	12.7	12.7	12.6	12.7
	1D	13.0	12.9	13.0	13.0	12.9	12.9	12.9
	2A	11.1	10.9	11.0	11.0	11.0	11.0	11.1
	2B	11.3	11.2	11.2	11.2	11.2	11.2	11.2
	2C	11.3	11.2	11.2	11.2	11.3	11.2	11.3
	2D	11.3	11.2	11.2	11.2	11.2	11.1	11.2
Maximum	1A	11.2	11.1	11.1	11.1	11.1	11.1	11.1
	1B	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	1C	12.6	12.6	12.7	12.7	12.7	12.7	12.7
	1D	13.0	12.9	13.0	13.0	13.0	12.9	12.9
	2A	11.2	10.9	11.0	11.1	11.1	11.0	11.1
	2B	11.3	11.2	11.2	11.2	11.2	11.2	11.2
	2C	11.3	11.3	11.3	11.3	11.3	11.2	11.3
	2D	11.5	11.2	11.2	11.2	11.2	11.2	11.2
Minimum	1A	11.1	11.0	11.1	11.1	11.1	11.1	11.1
	1B	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	1C	12.6	12.6	12.7	12.6	12.6	12.6	12.7
	1D	13.0	12.9	13.0	13.0	12.9	12.9	12.9
	2A	11.1	10.9	11.0	11.0	11.0	11.0	11.0
	2B	11.3	11.2	11.2	11.2	11.2	11.2	11.2
	2C	11.3	11.2	11.2	11.2	11.3	11.2	11.3
	2D	11.3	11.2	11.1	11.1	11.2	11.1	11.2

Table 7. Summary Data for TDG Saturations for the Wells Dam 2005 Spillway Evaluation

	Test	BP (mmHg)	TDG %Saturation						
		WEL	WEL	WELW	A1	A2	A3	B2	B3
Mean	1A	752.7	105.6	111.3	111.3	113.7	116.3	113.2	114.0
	1B	741.0	108.6	112.3	114.3	114.0	112.5	113.7	112.3
	1C	742.3	107.6	112.4	111.9	116.7	119.3	115.5	116.8
	1D	741.5	107.8	114.2	115.8	115.7	116.8	115.7	115.2
	2A	748.5	105.4	109.7	109.3	112.2	112.8	111.2	112.0
	2B	753.4	106.4	112.7	114.4	113.1	115.4	113.5	114.2
	2C	746.8	106.6	113.0	112.0	114.7	116.1	114.2	115.5
	2D	747.2	109.1	115.1	114.9	115.6	117.6	115.7	116.7
Maximum	1A	752.9	105.7	111.5	111.3	113.7	116.4	113.2	114.1
	1B	741.2	108.6	113.0	114.3	114.2	112.6	113.9	112.6
	1C	742.4	107.7	112.8	112.1	117.1	119.5	116.1	116.9
	1D	741.7	107.8	114.4	115.8	115.8	116.9	115.7	115.3
	2A	748.8	105.6	110.2	109.5	112.4	112.9	111.5	112.4
	2B	753.6	106.4	113.0	114.5	113.2	115.6	113.6	114.3
	2C	747.0	106.7	113.1	112.2	114.8	116.1	114.2	115.6
	2D	747.5	109.1	115.3	115.0	115.7	117.9	115.8	116.8
Minimum	1A	752.6	105.5	111.1	111.3	113.7	116.1	113.1	113.9
	1B	740.9	108.5	111.3	114.2	113.9	112.3	113.6	111.6
	1C	742.2	107.6	111.8	111.4	116.2	119.0	115.0	116.8
	1D	741.4	107.7	113.9	115.8	115.7	116.7	115.7	115.1
	2A	748.3	105.1	109.2	109.2	111.9	112.6	111.0	111.8
	2B	753.4	106.3	112.4	114.4	113.0	115.3	113.4	114.1
	2C	746.8	106.6	112.8	111.9	114.6	115.9	114.1	115.4
	2D	747.0	109.0	114.7	114.8	115.5	117.3	115.6	116.6

Table 8. Project Operation and TDG Saturation Spill Test Means

Test	n*	Discharge (kcfs)				Elevation (ft MSL)		TDG %Saturation						
		Project	Spill	Power	%Spill	Forebay	Tailwater	WEL	WELW	A1	A2	A3	B2	B3
1A	4	94.5	31.2	63.2	33.1%	778.8	710.8	105.6	111.3	111.3	113.7	116.3	113.2	114.0
1B	9	97.6	33.4	64.2	34.2%	778.4	710.6	108.6	112.3	114.3	114.0	112.5	113.7	112.3
1C	5	97.1	36.6	60.5	37.7%	778.9	710.6	107.6	112.4	111.9	116.7	119.3	115.5	116.8
1D	5	98.2	34.0	64.2	34.6%	778.6	710.8	107.8	114.2	115.8	115.7	116.8	115.7	115.2
2A	7	122.9	31.9	91.0	26.0%	778.9	712.5	105.4	109.7	109.3	112.2	112.8	111.2	112.0
2B	4	123.8	37.6	86.3	30.3%	780.3	712.5	106.4	112.7	114.4	113.1	115.4	113.5	114.2
2C	5	174.4	46.4	128.0	26.6%	778.8	716.4	106.6	113.0	112.0	114.7	116.1	114.2	115.5
2D	7	168.9	43.9	124.9	26.0%	780.2	716.0	109.1	115.1	114.9	115.6	117.6	115.7	116.7

*Refers to equilibrated values.

Table 9. Summary Data from Mass Balance Analyses

Test	TDG %Saturation						
	Empirical				Predicted		
	Avg Transect A TDG	Avg Transect B TDG	Max Transect A TDG	Min Transect A TDG	Avg Transect B TDG (assumes no change to powerhouse release)	Avg TDG of Spilled release	Avg Transect B TDG (assumes PH release gassed to Min Transect A)
1A	113.8	112.8	116.3	111.3	109.1	127.4	113.0
1B	113.6	112.8	114.3	112.5	110.5	120.8	113.1
1C	116.0	114.9	119.3	111.9	112.0	126.9	114.7
1D	116.1	115.0	116.8	115.7	110.9	128.8	116.1
2A	111.4	111.0	112.8	109.3	107.3	127.0	110.2
2B	114.3	113.5	115.4	113.1	109.1	129.8	113.8
2C	114.3	114.2	116.1	112.0	109.1	135.2	113.1
2D	116.0	115.8	117.6	114.9	111.3	135.0	115.6

Table 10. Average of 12 Highest Daily TDG Saturations

Date	CHQW	WEL	WELW	A1	A2	A3	B2	B3	RRH
5/23/2005	107.0	106.2	110.1	109.3	111.5	111.3	110.7	111.4	107.0
5/24/2005	107.5	105.9	108.5	109.1	109.7	108.0	108.9	108.1	107.2
5/25/2005	116.1	106.7	111.6	111.6	112.5	114.0	112.1	113.2	109.0
5/26/2005	107.4	108.4	113.4	113.2	115.0	115.7	114.1	114.7	110.9
5/27/2005	108.5	108.0	116.7	114.7	117.6	117.8	117.1	118.2	113.9
5/28/2005	110.4	109.4	110.0	109.4	111.2	112.2	110.5	111.5	120.4
5/29/2005	111.2	110.7	110.6	110.1	111.4	112.5	110.9	111.8	114.1
5/30/2005	111.1	109.7	110.9	110.4	112.4	112.3	111.5	111.8	112.1
5/31/2005	109.2	109.4	111.0	111.2	112.2	112.3	111.4	111.7	111.3
6/1/2005	110.1	108.8	111.8	112.4	112.7	111.7	112.1	111.4	110.6
6/2/2005	109.6	108.5	112.1	111.8	112.9	113.1	112.7	113.6	110.6
6/3/2005	109.5	108.5	110.1	110.1	111.4	110.7	110.6	110.3	111.6
6/4/2005	110.0	109.0	112.8	112.4	113.1	112.9	113.3	112.8	111.9

Figures

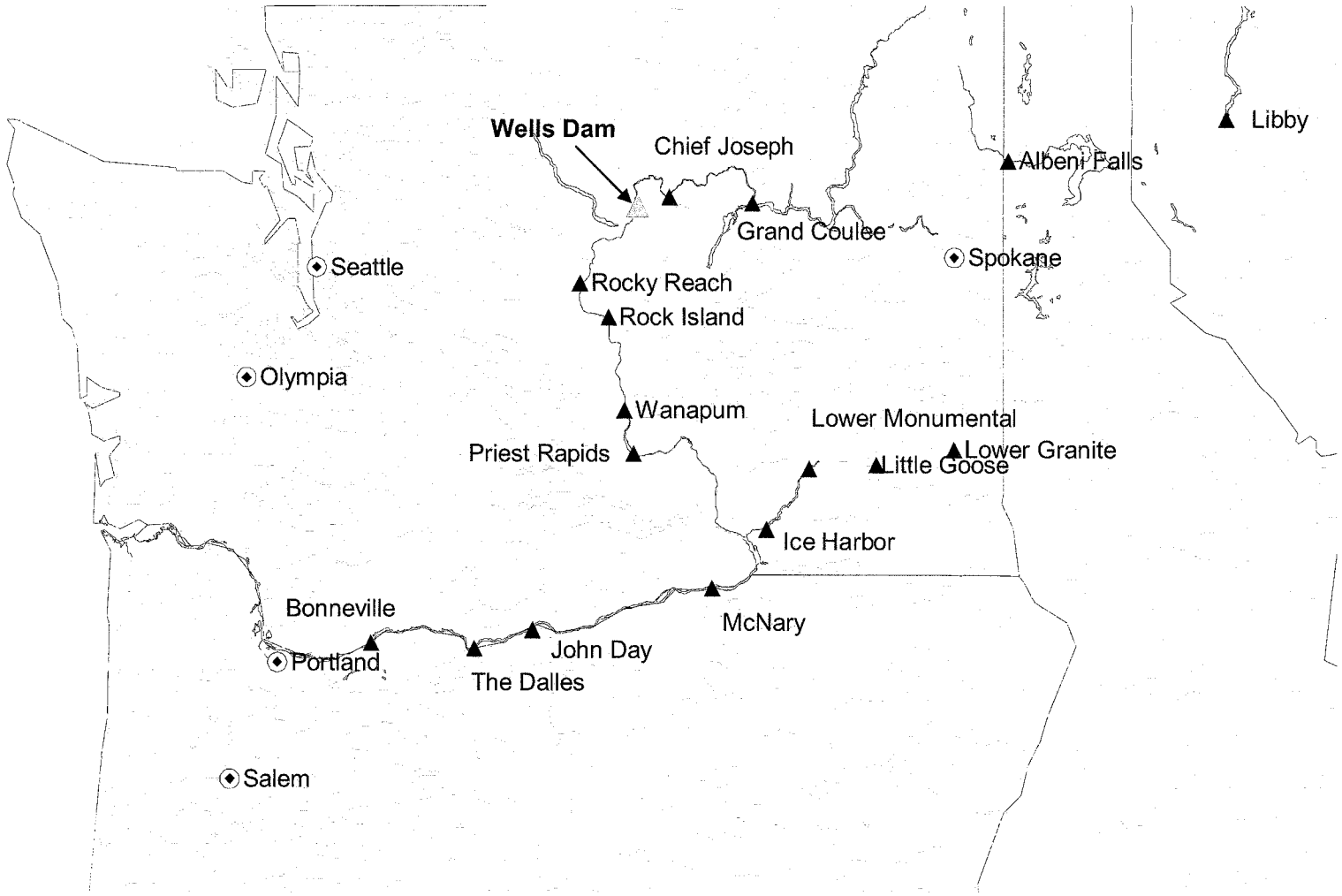

Figure 1. Regional map indicating location of Wells Dam.

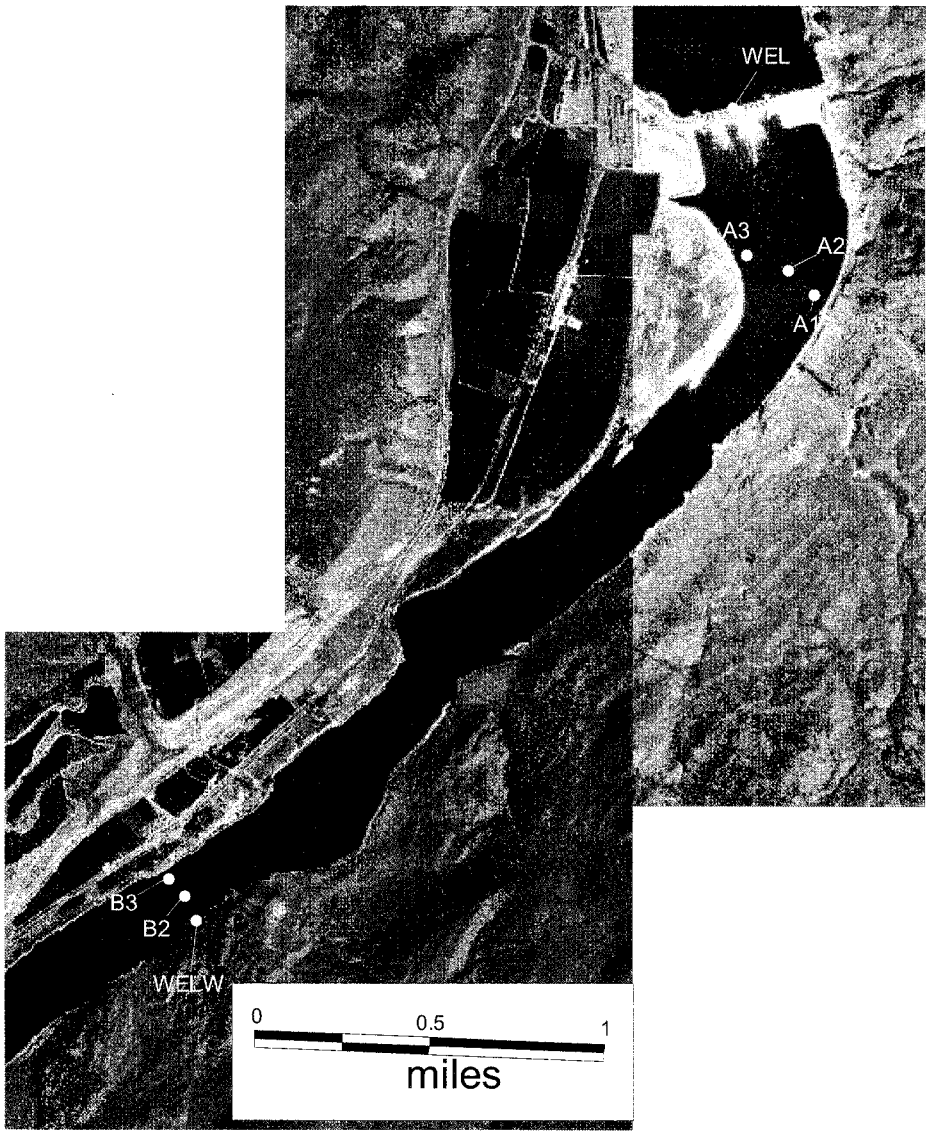

Figure 2. Deployment locations for 2005 Wells Dam Spillway evaluation.

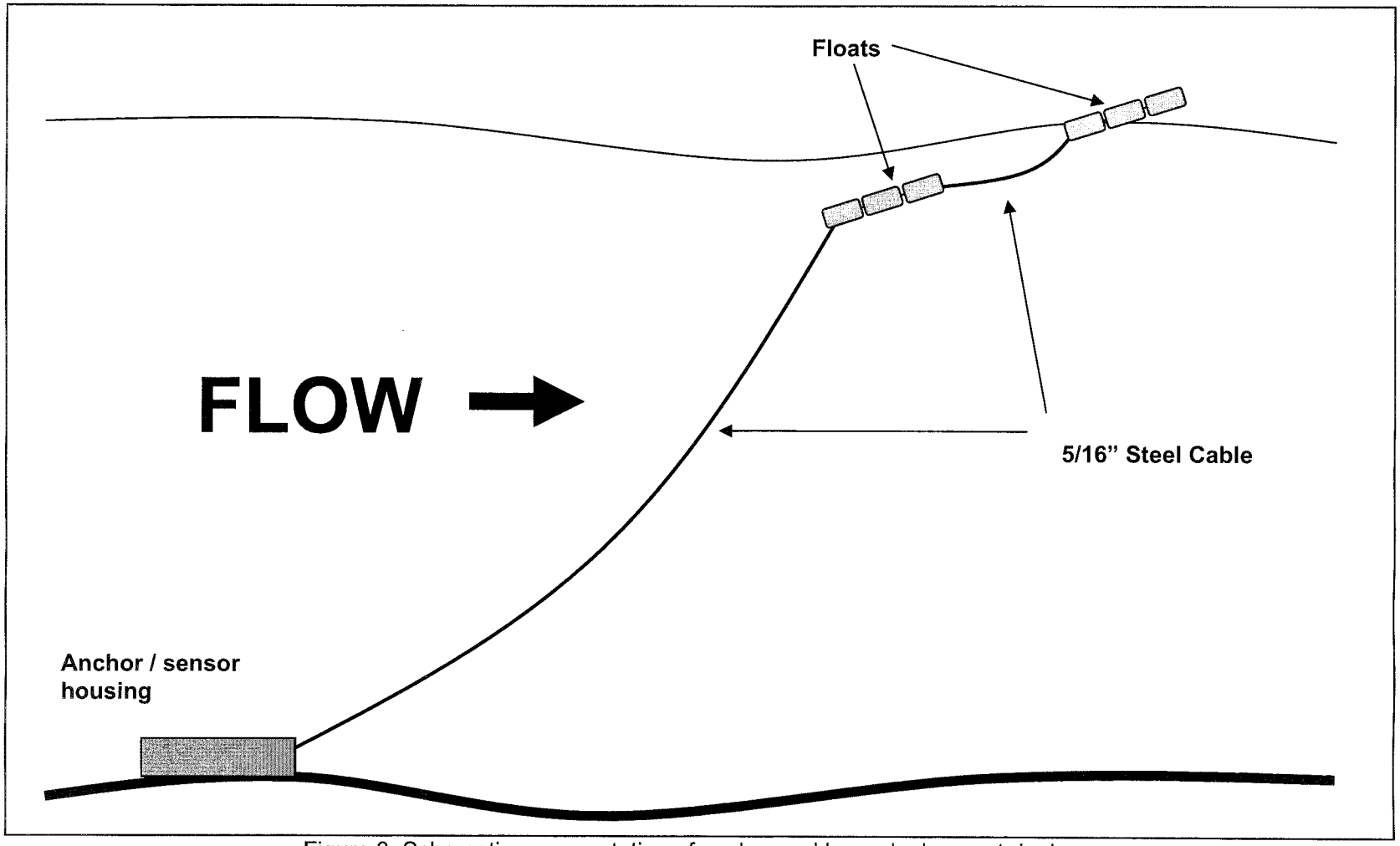

Figure 3. Schematic representation of anchor and buoy deployment rigging.

Figure 4. Wells Dam tailwater fixed water quality monitoring station.

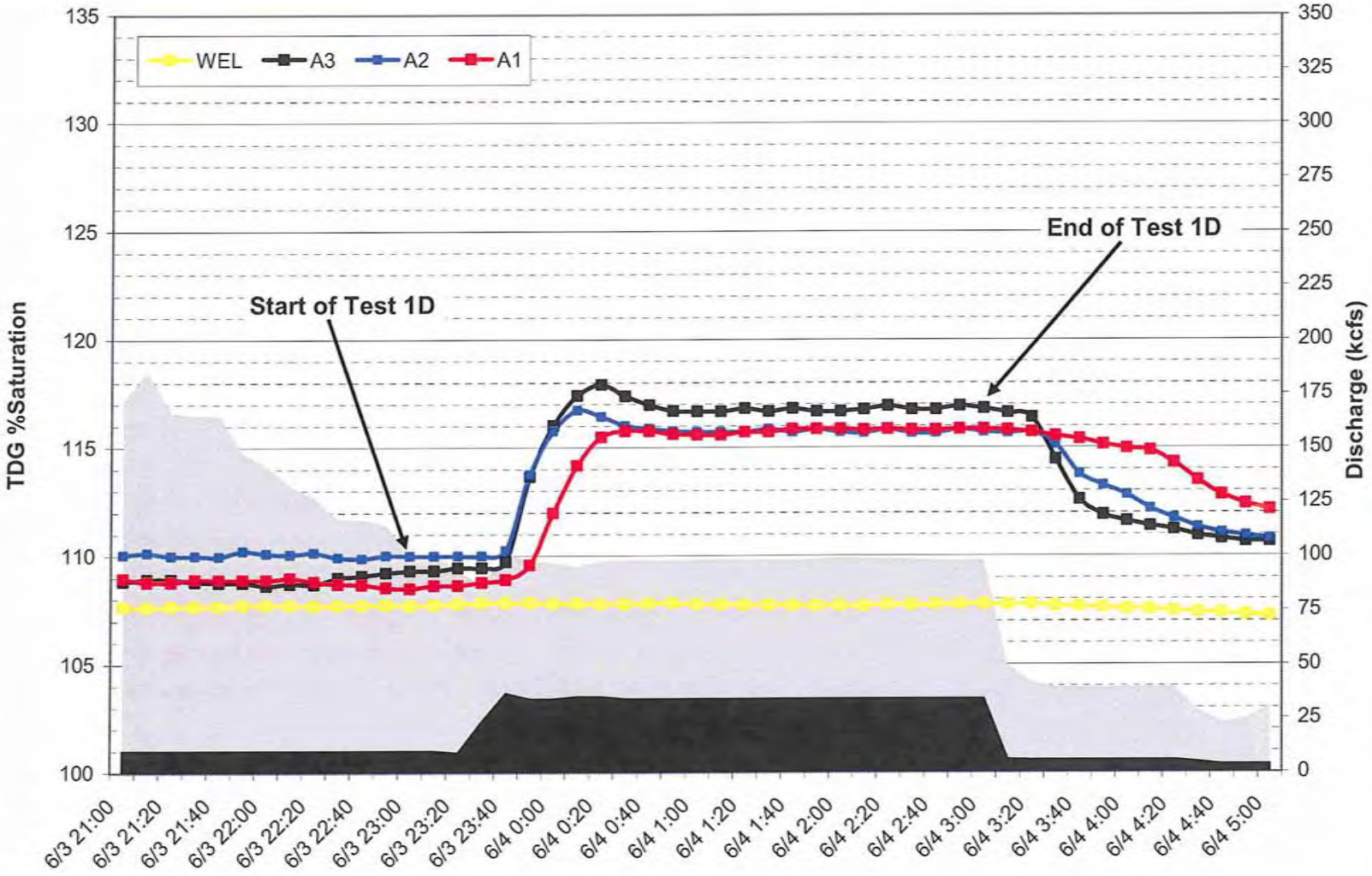

Figure 5. Transect A TDG saturations for Spill Test 1D, 3 June 23:00 to 4 June 03:00 2005.

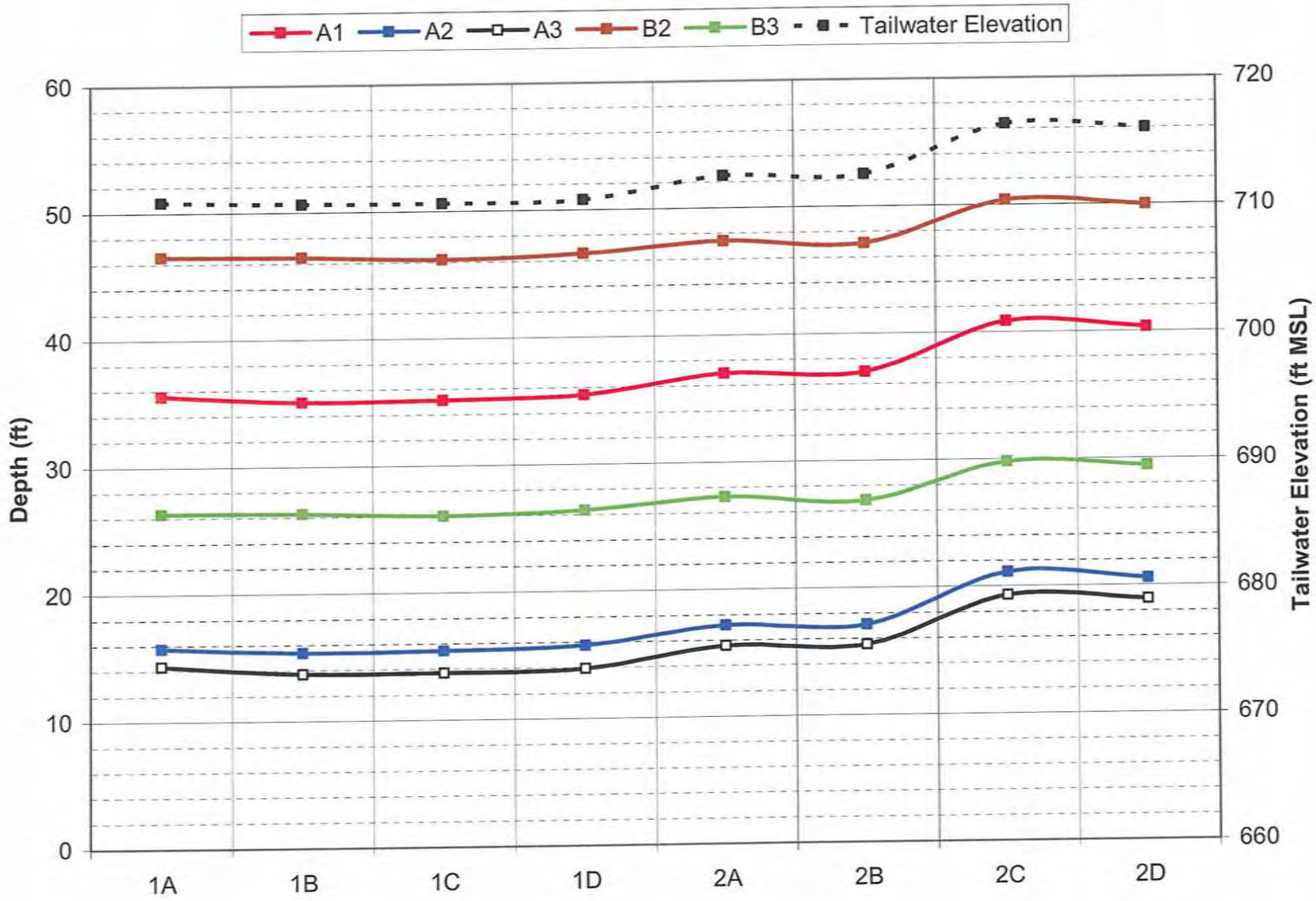

Figure 6. TDG probe depths and tailwater elevations averaged by test.

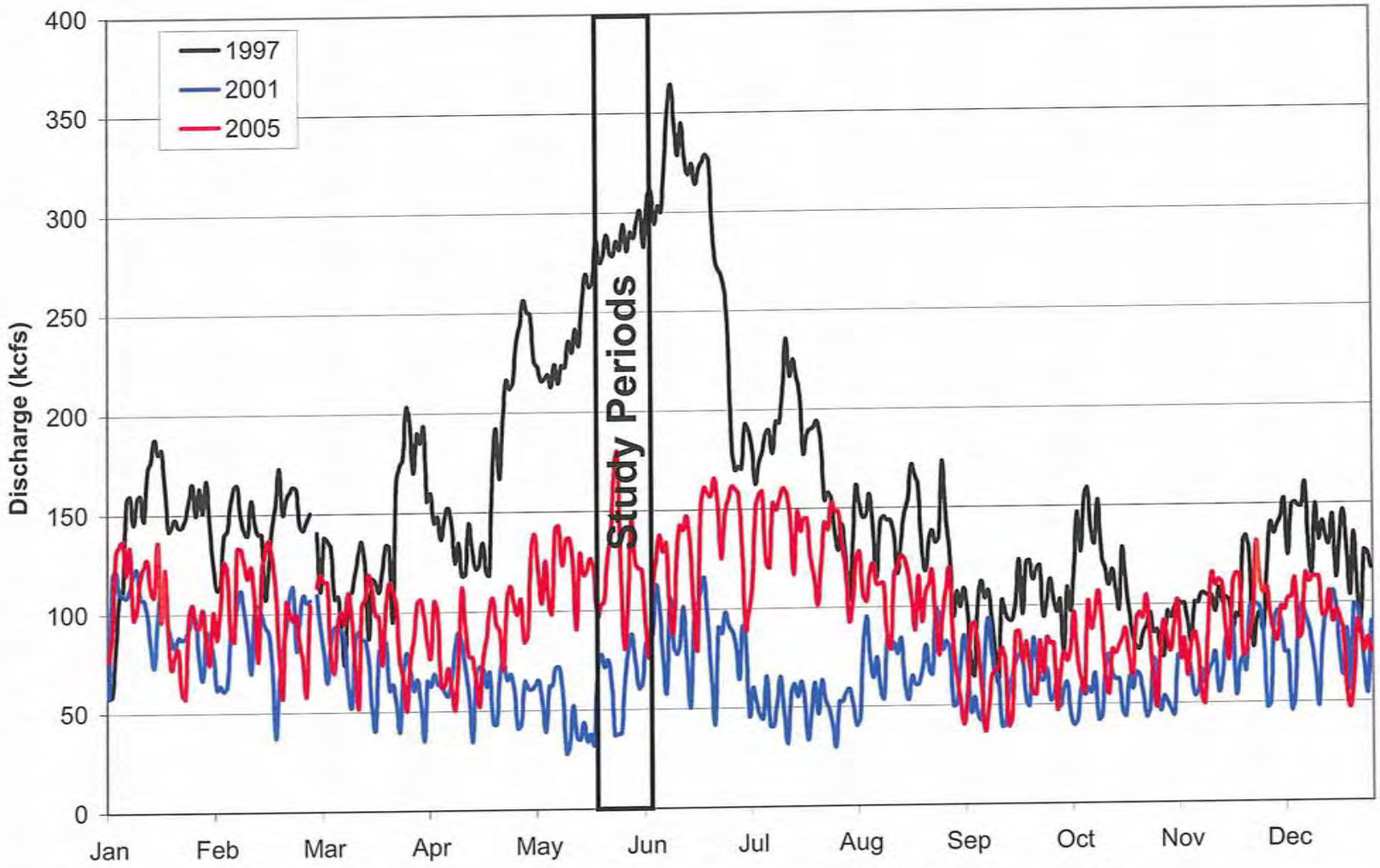

Figure 7. Mean daily discharge for Wells Dam for the years 1997, 2001, and 2005.

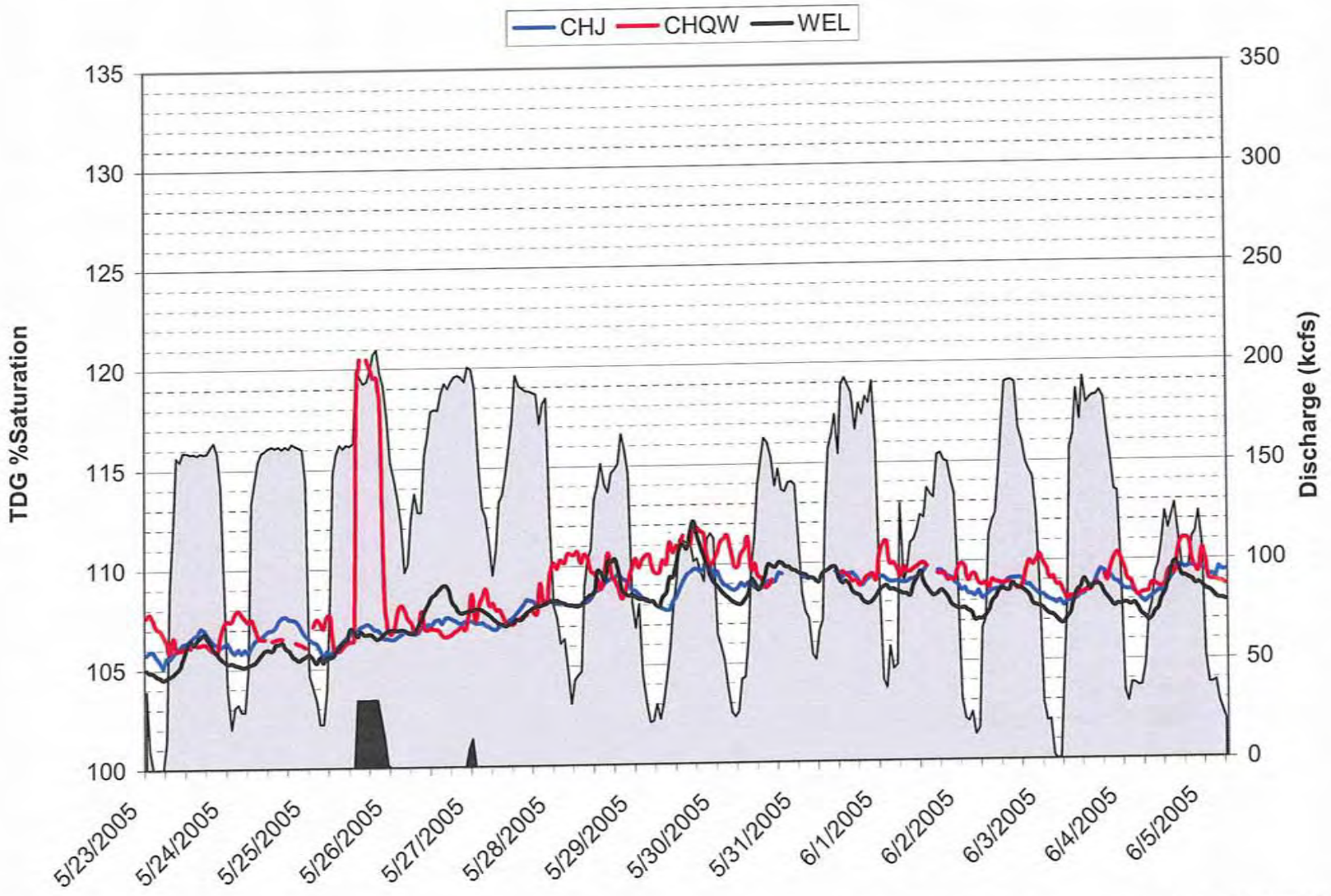

Figure 8. Total project and spill discharges for Chief Joseph Dam plotted with FMS TDG saturation data as reported by CROHMS.

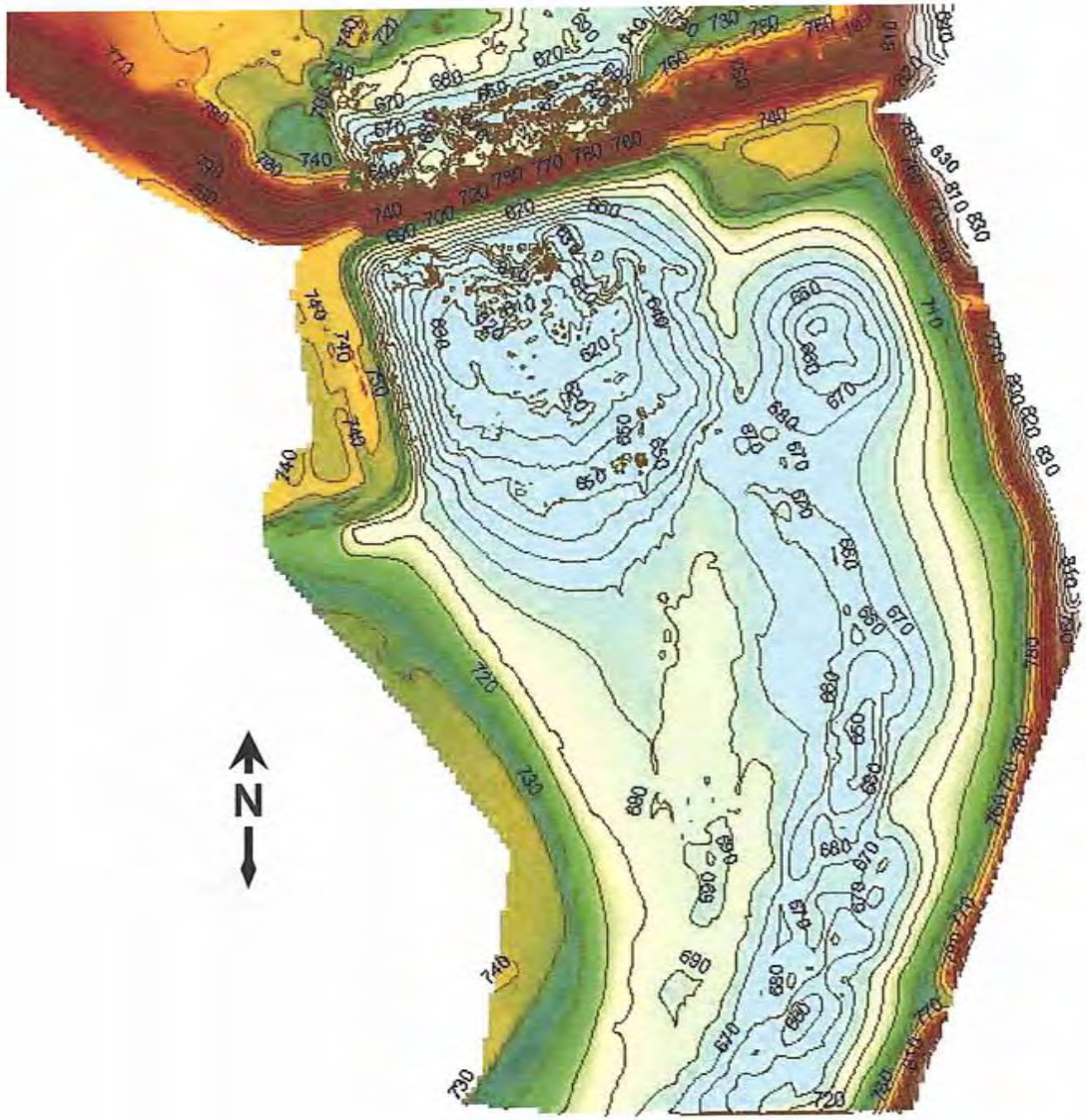

Figure 9. Wells Dam tailrace bathymetry. (Image provided by Jacobs Civil, Inc.)

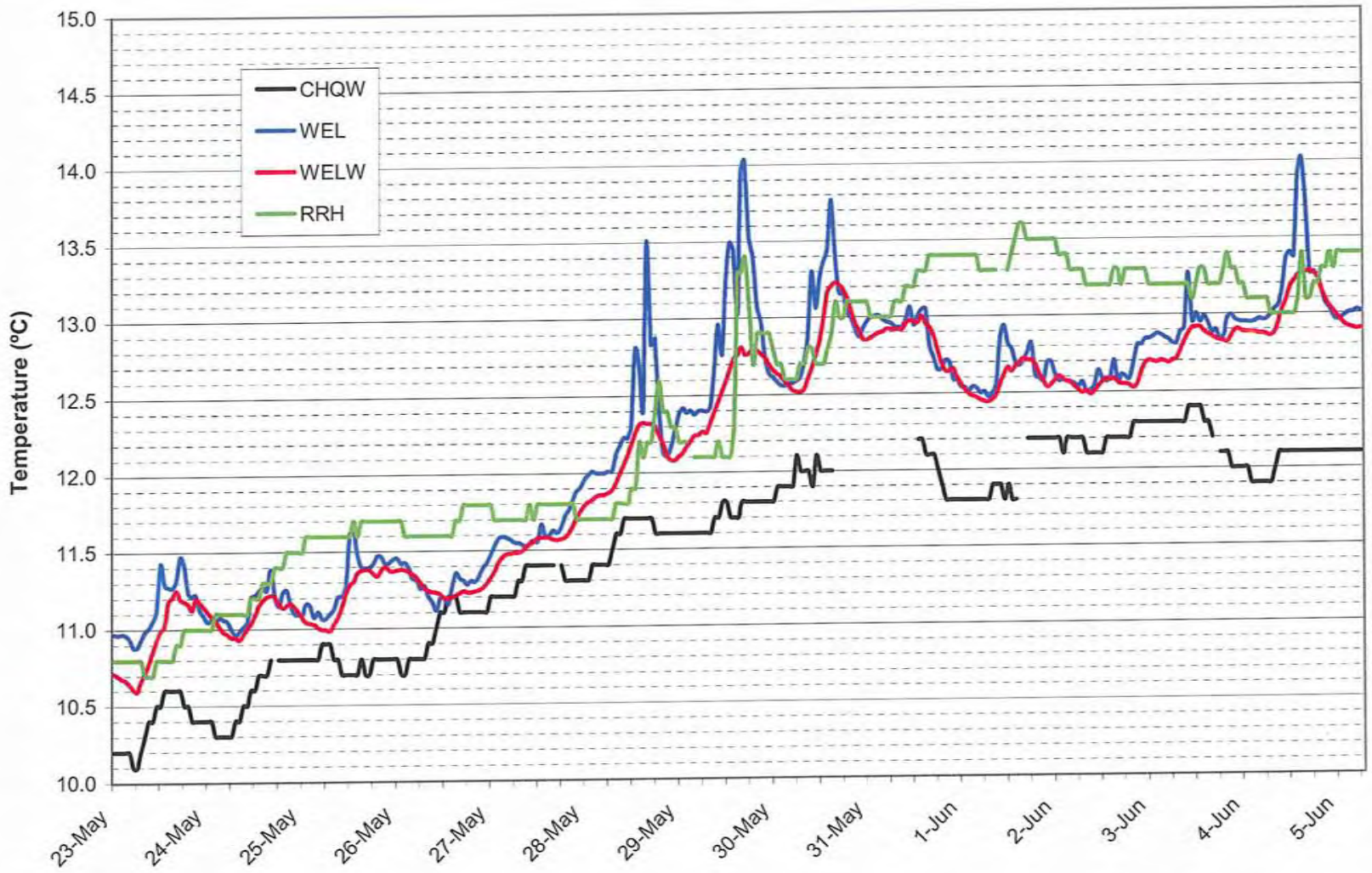

Figure 10. Hourly temperatures for the CHJ tailwater, Wells Dam, and the RRH forebay as reported the CROHMS.

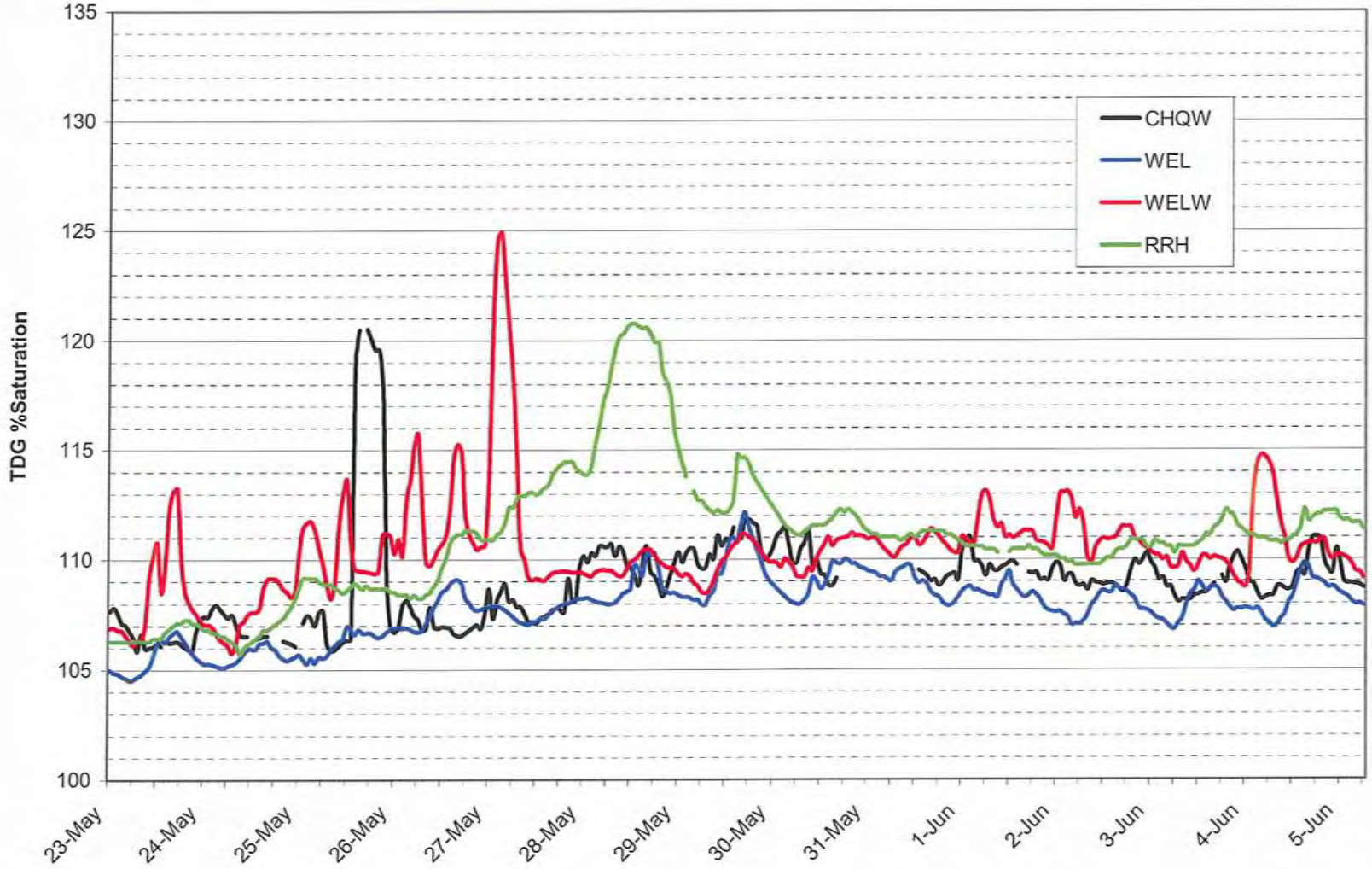

Figure 11. Hourly TDG saturations for the CHJ tailwater, Wells Dam, and the RRH forebay as reported the CROHMS.

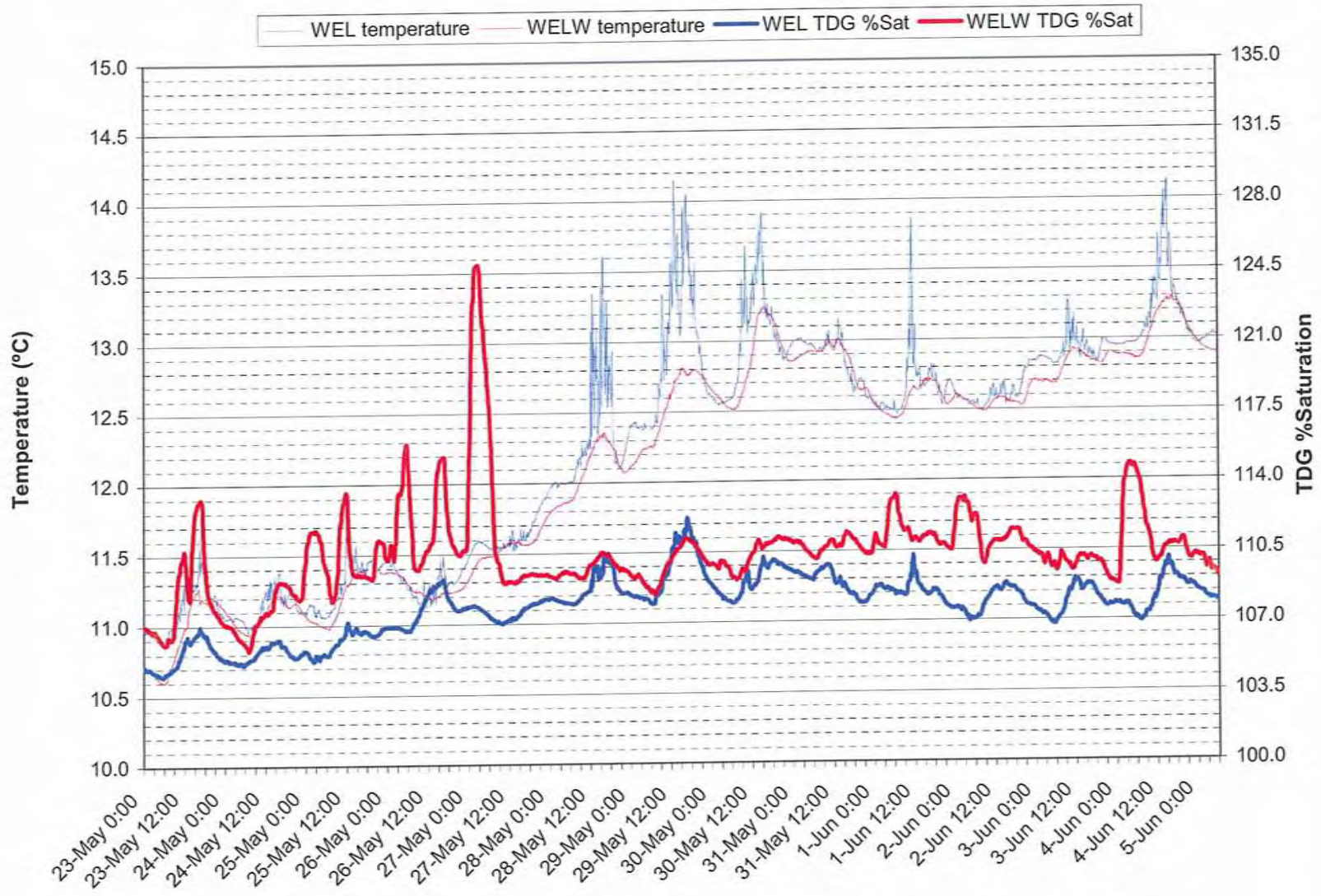

Figure 12. Water temperatures and TDG saturations reported for the Wells Dam permanent TDG monitors.

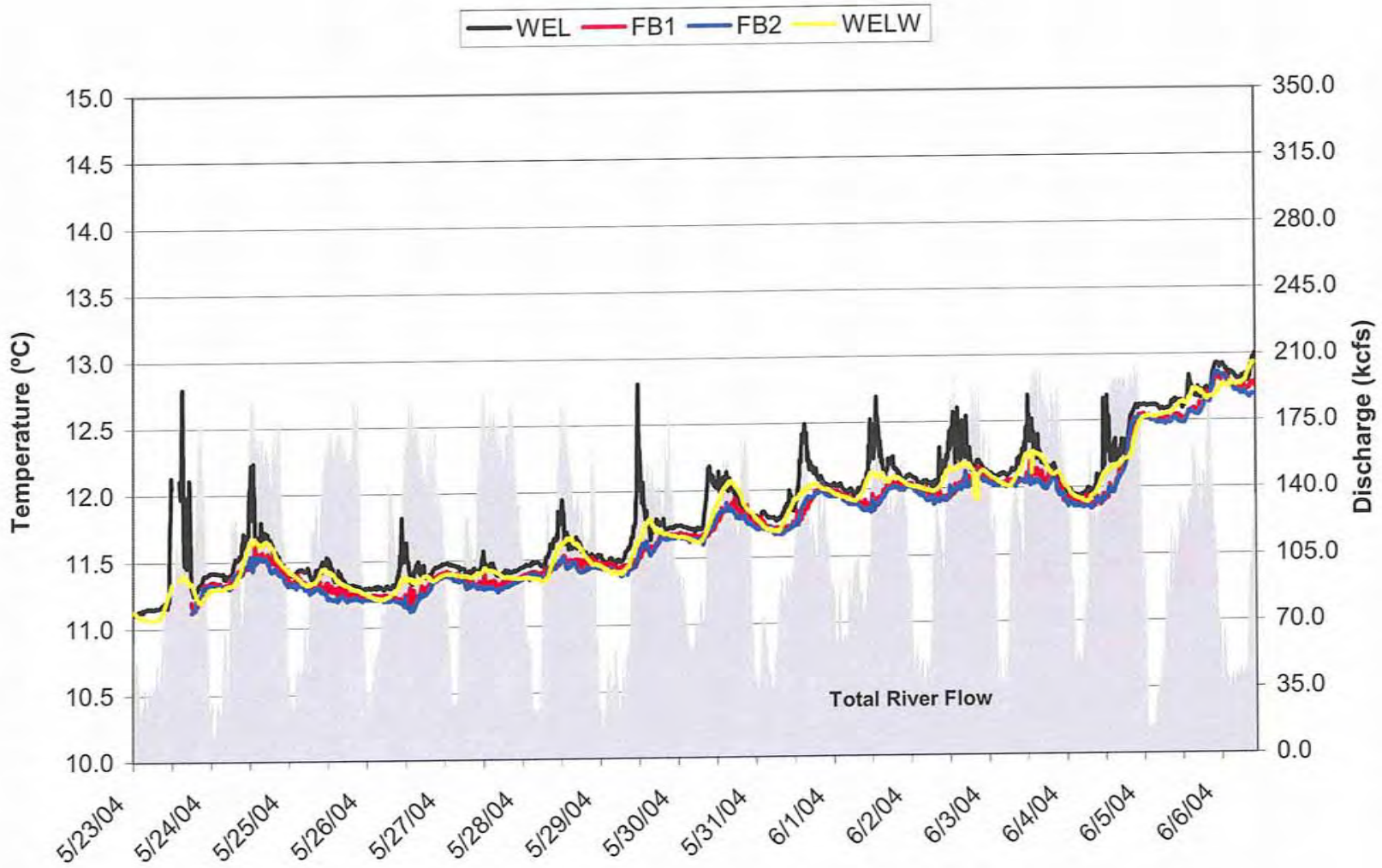

Figure 13. Water temperatures measured in the Wells Dam Forebay between 23 May and 6 June, 2004.

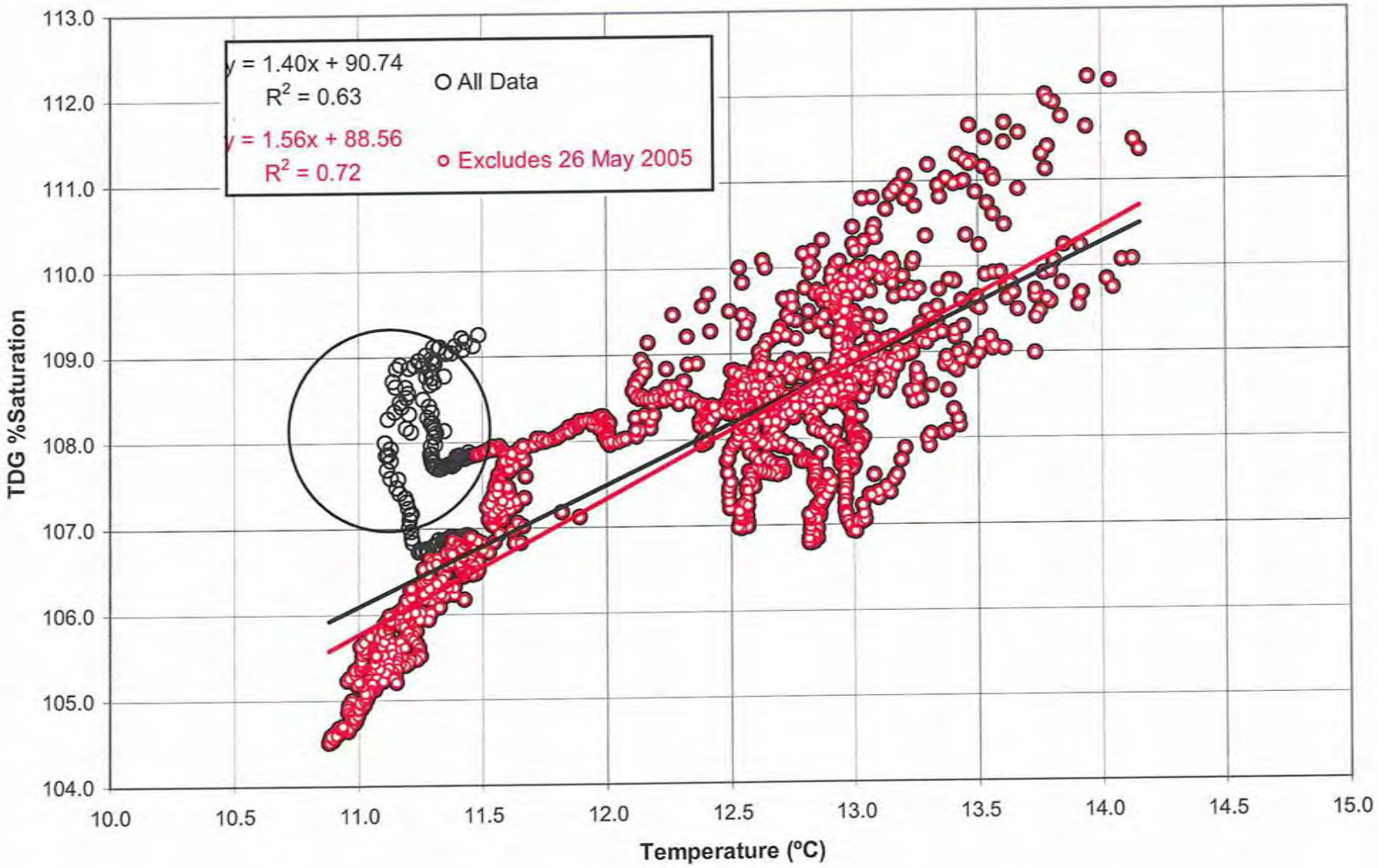

Figure 14. Wells Dam forebay (WEL) water temperatures plotted against TDG saturations.

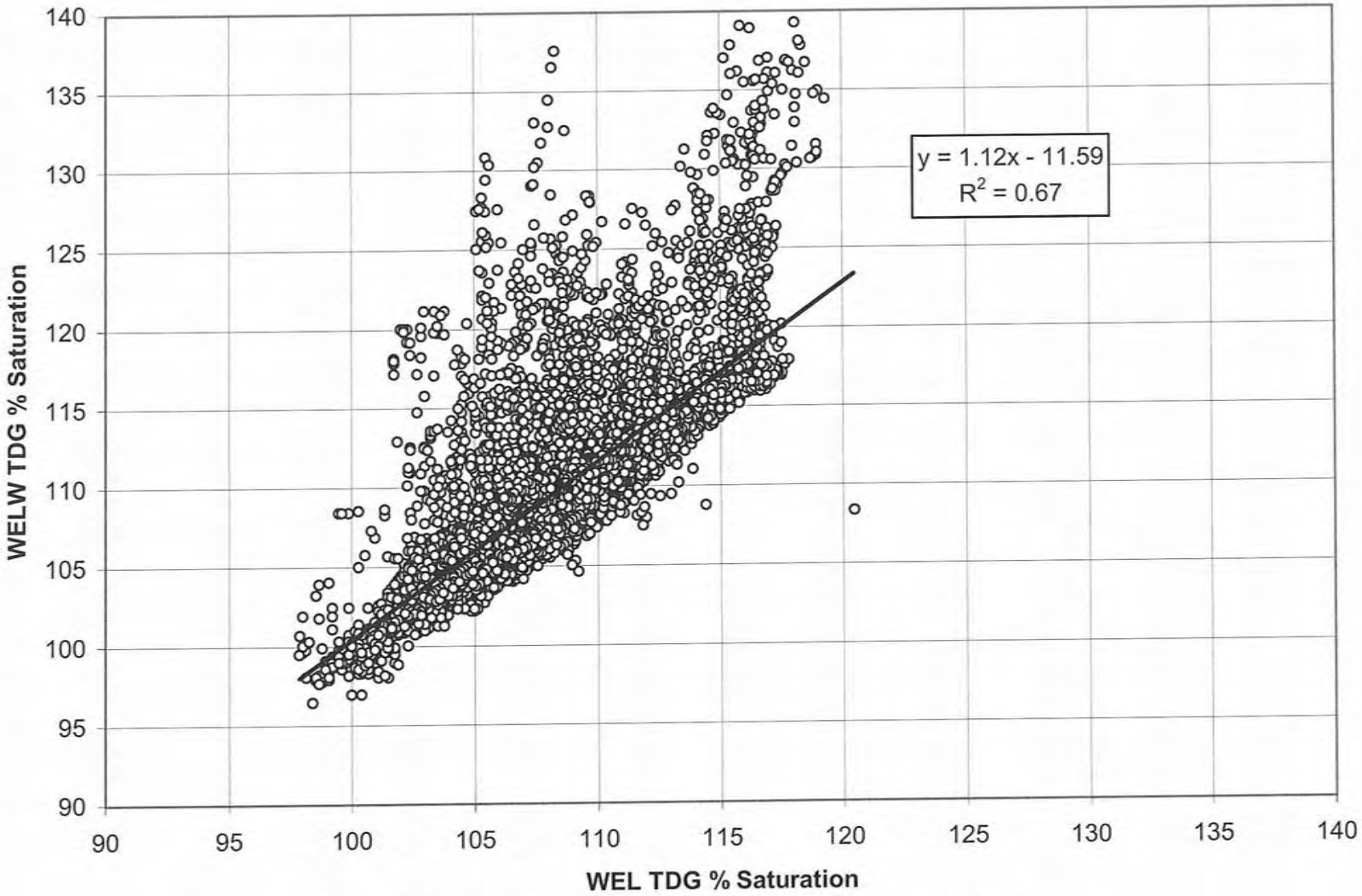

Figure 15. Relationship between WELW and WEL for 1998-2005.

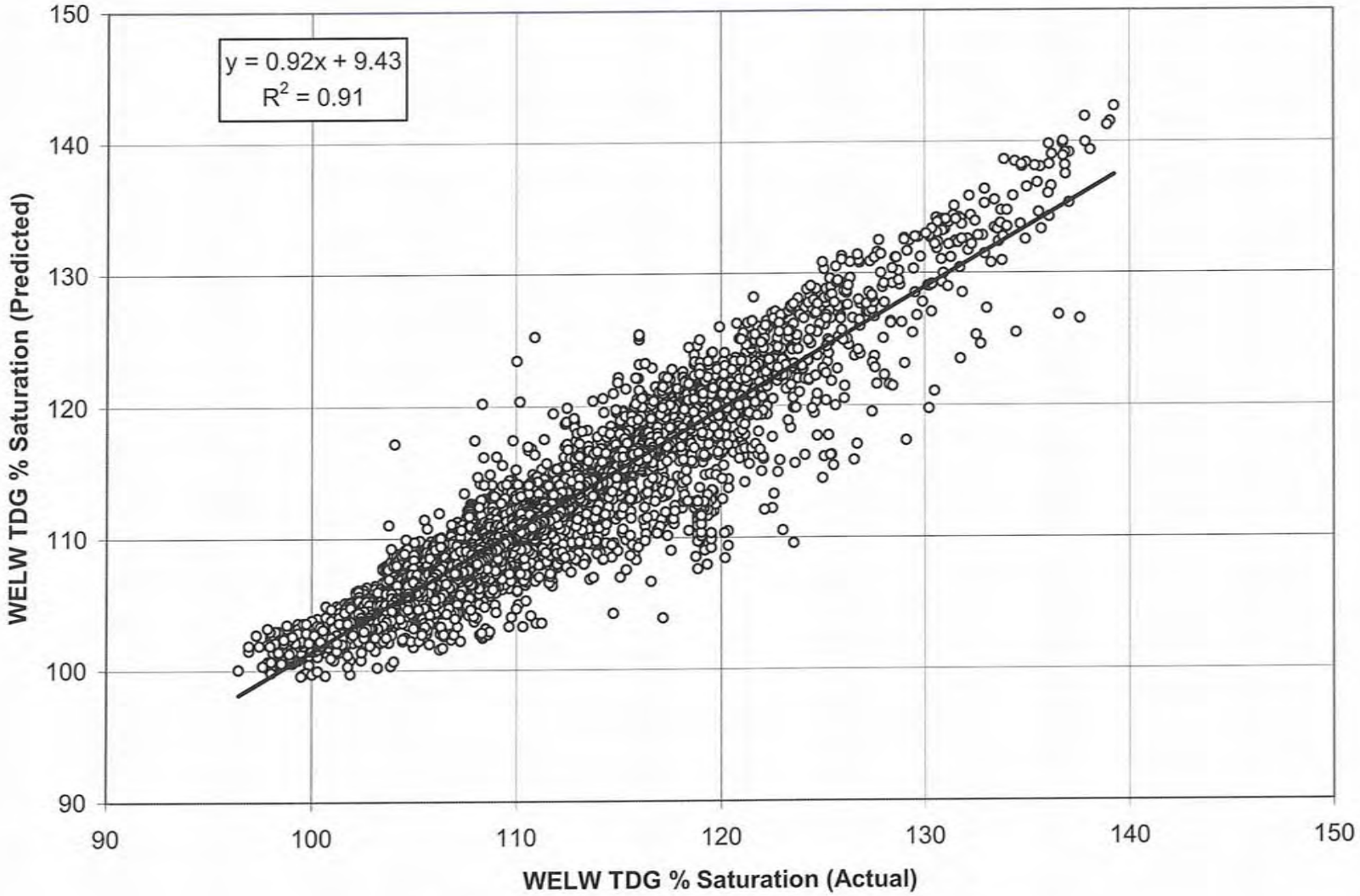

Figure 16. Predicted versus actual WELW TDG saturations.

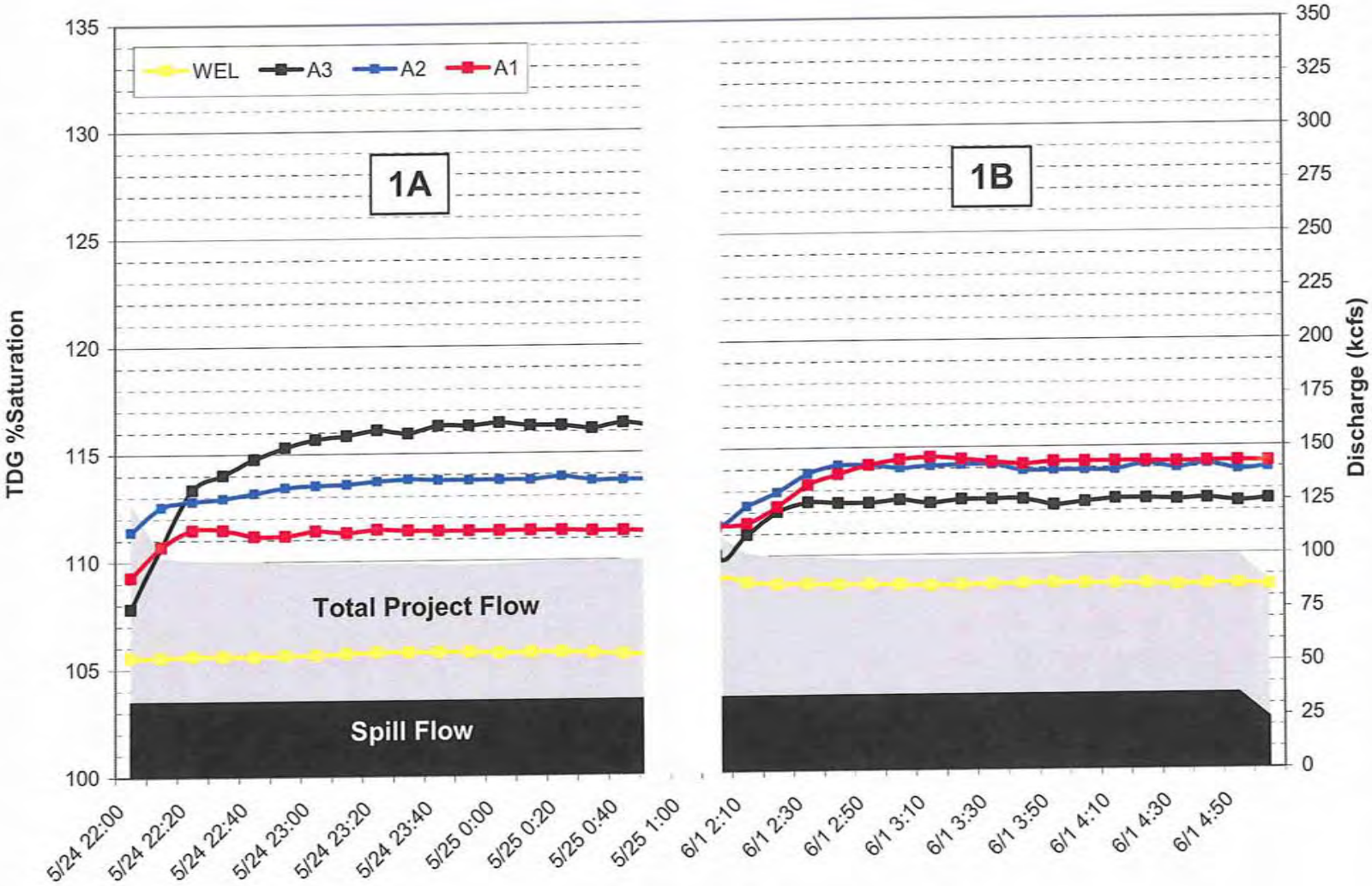

Figure 17. Project operation and Transect A values for tests 1A and 1B.

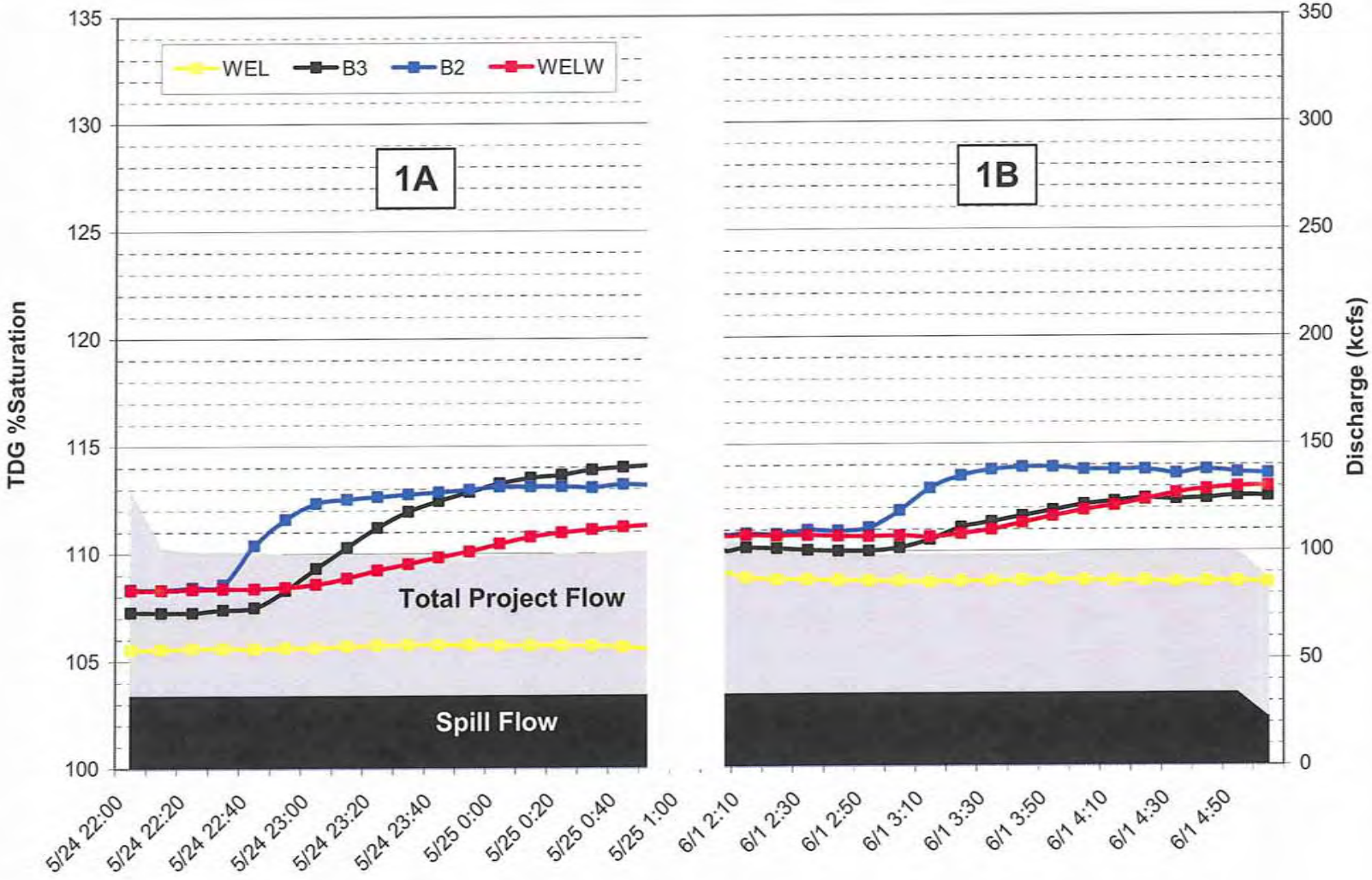

Figure 18. Project operation and Transect B values for tests 1A and 1B.

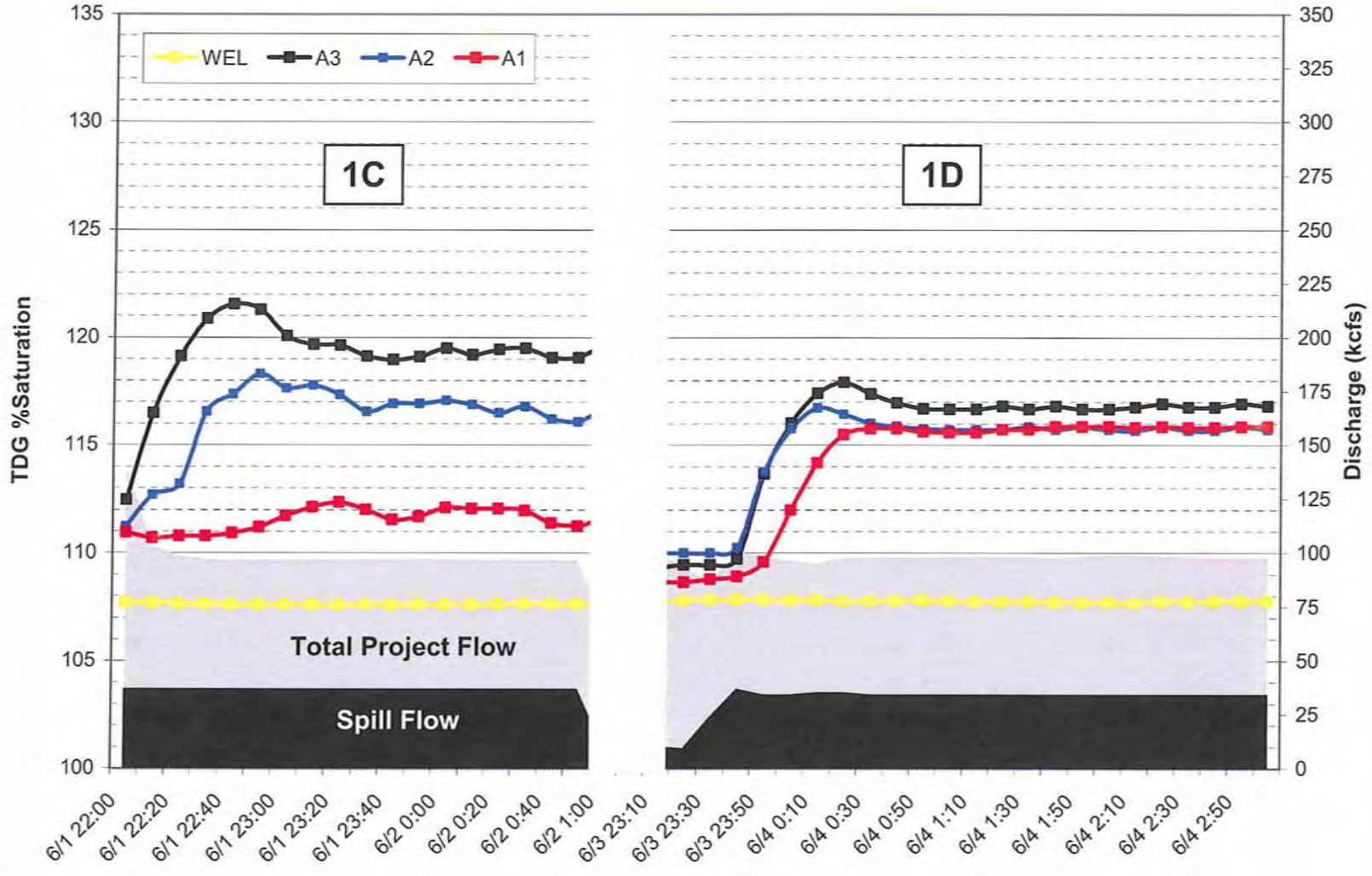

Figure 19. Project operation and Transect A values for tests 1C and 1D.

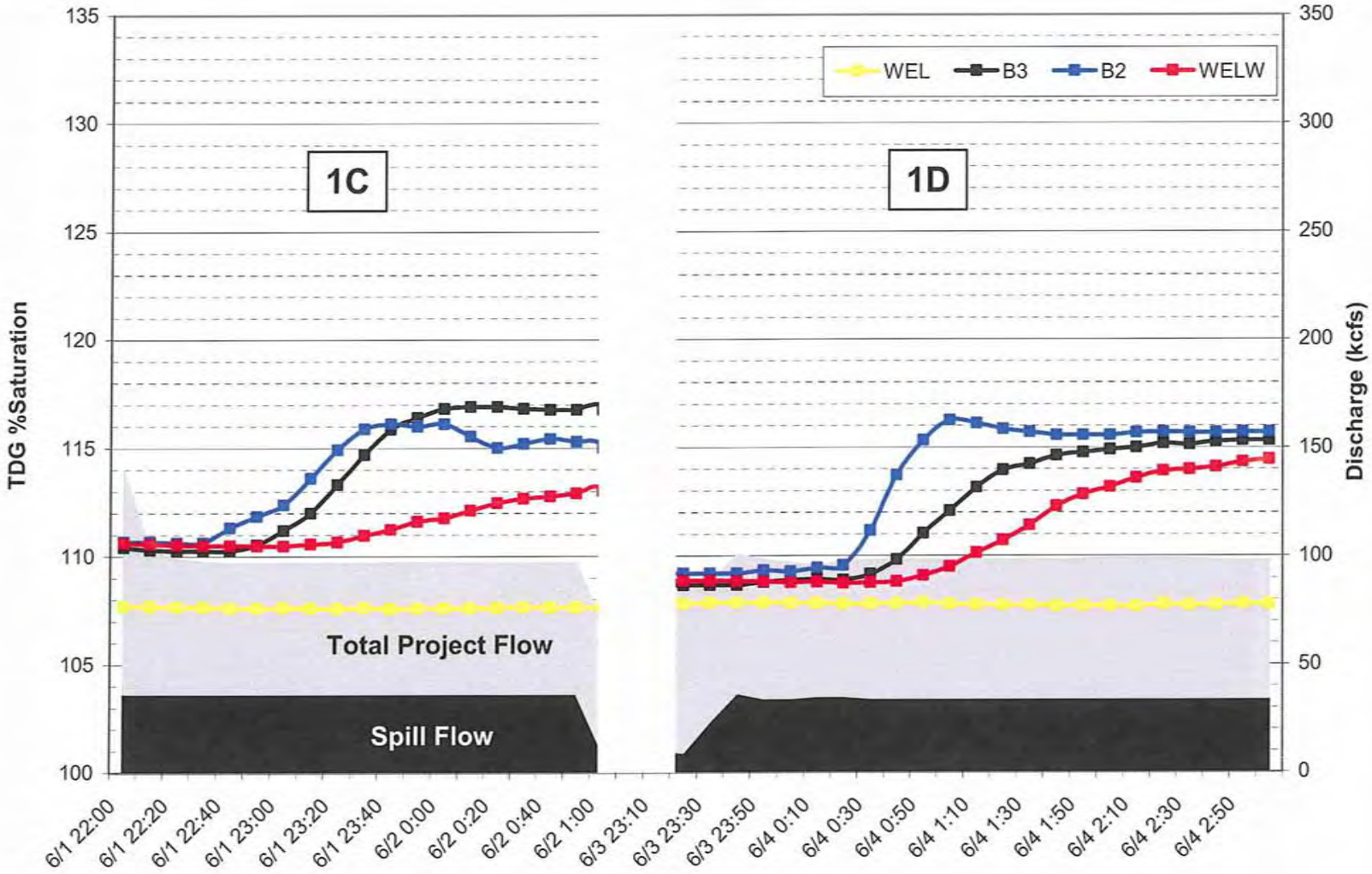

Figure 20. Project operation and Transect B values for tests 1C and 1D.

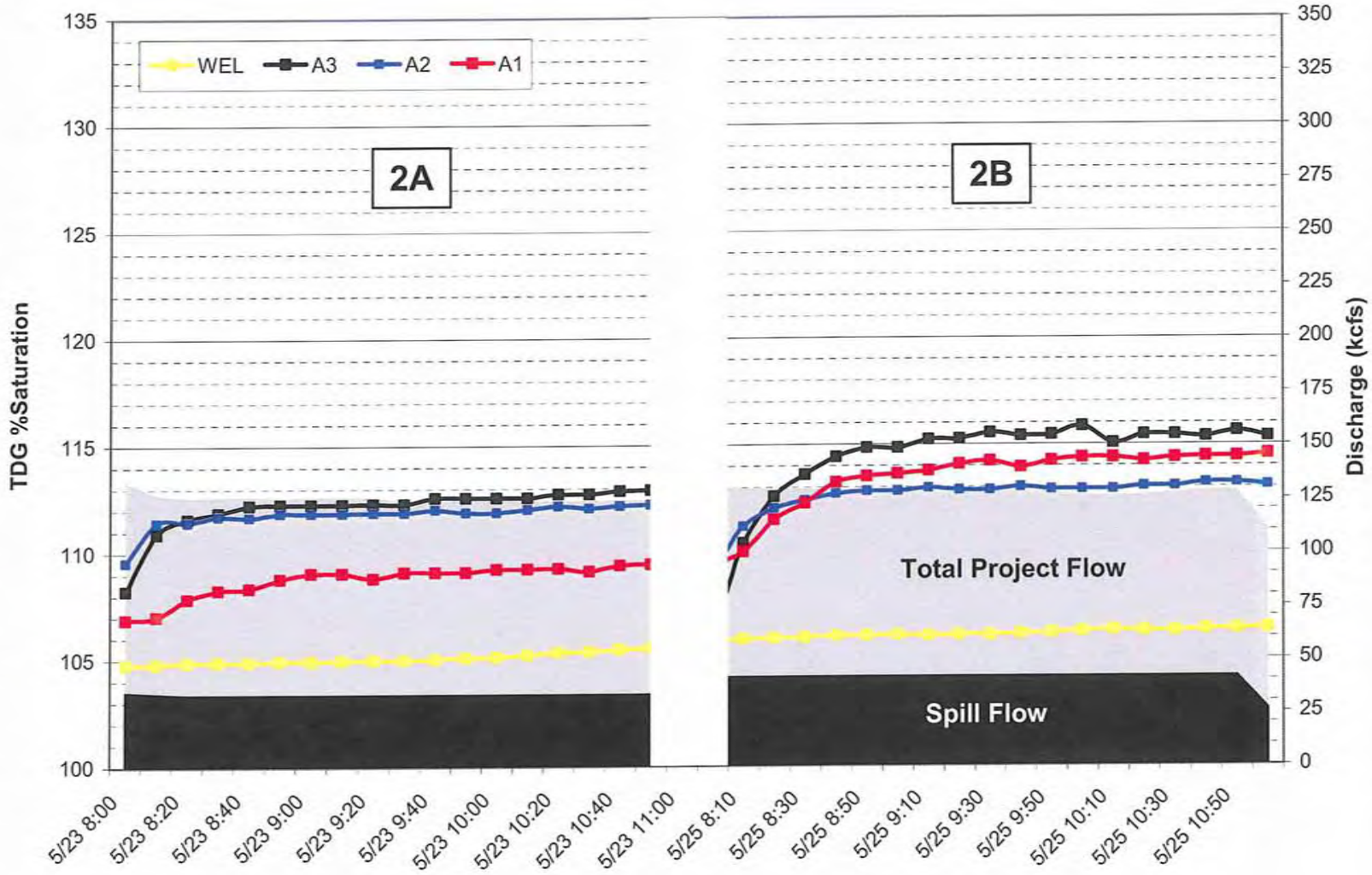

Figure 21. Project operation and Transect A values for tests 2A and 2B.

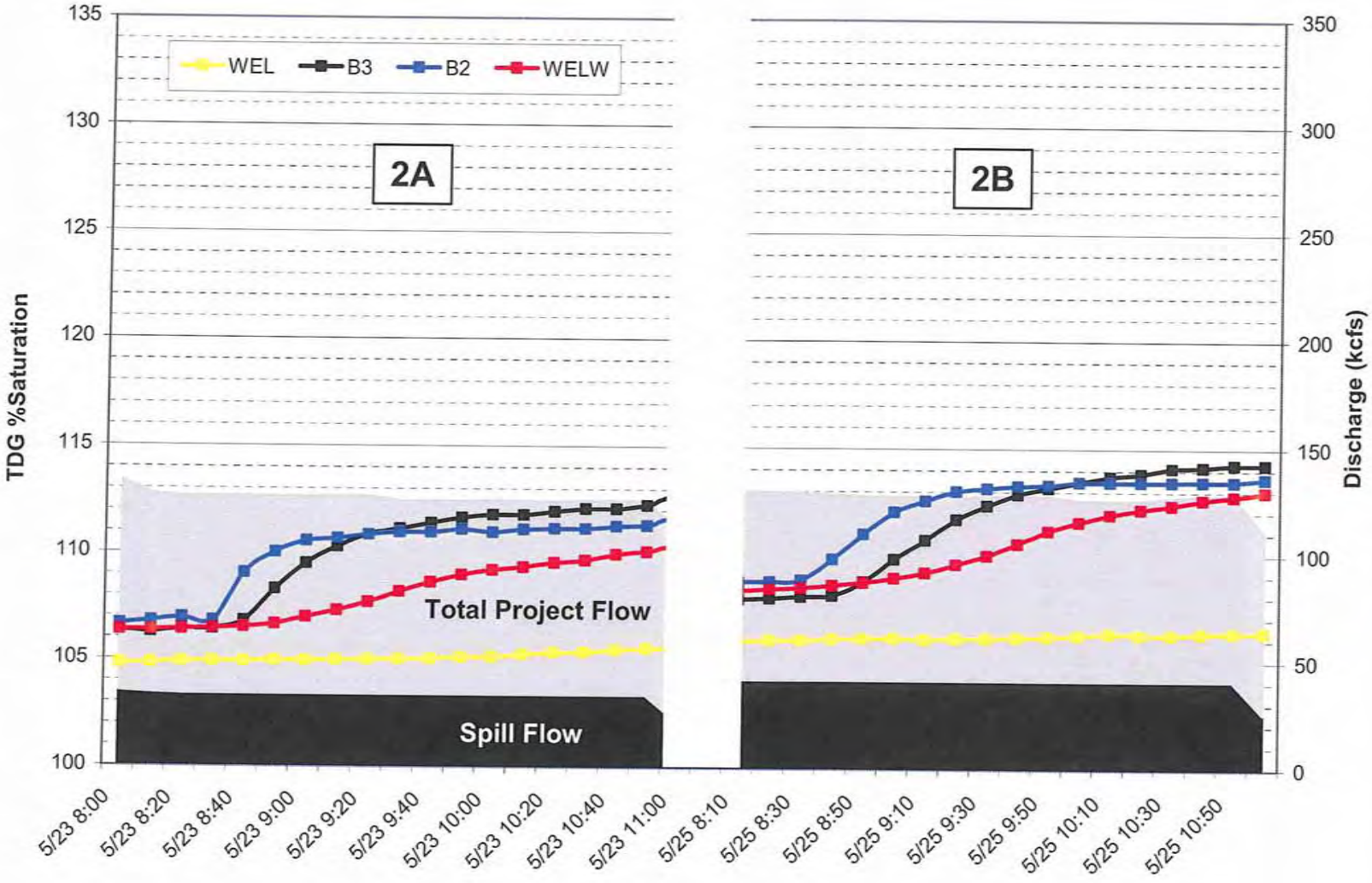

Figure 22. Project operation and Transect B values for tests 2A and 2B.

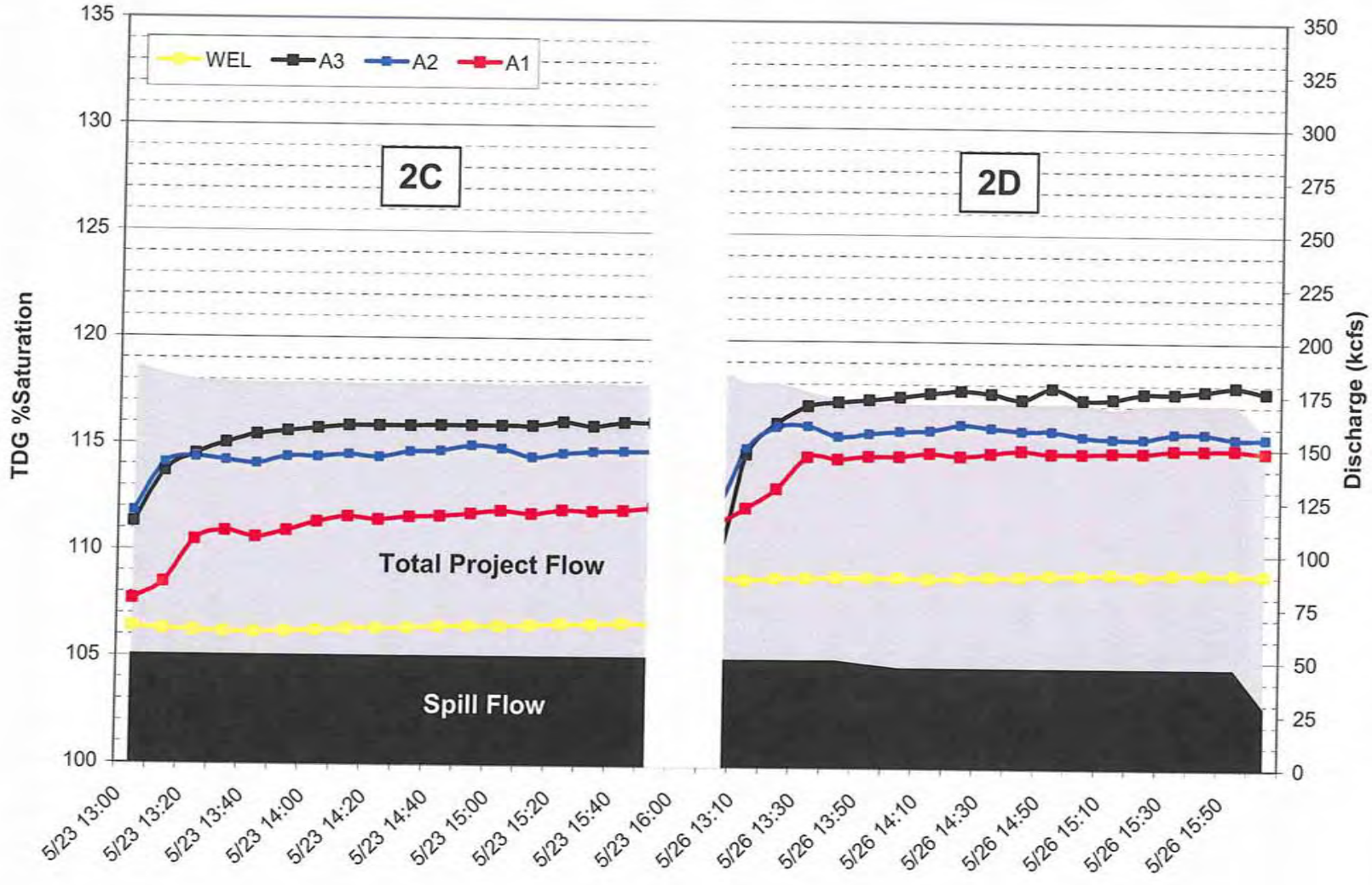

Figure 23. Project operation and Transect A values for tests 2C and 2D.

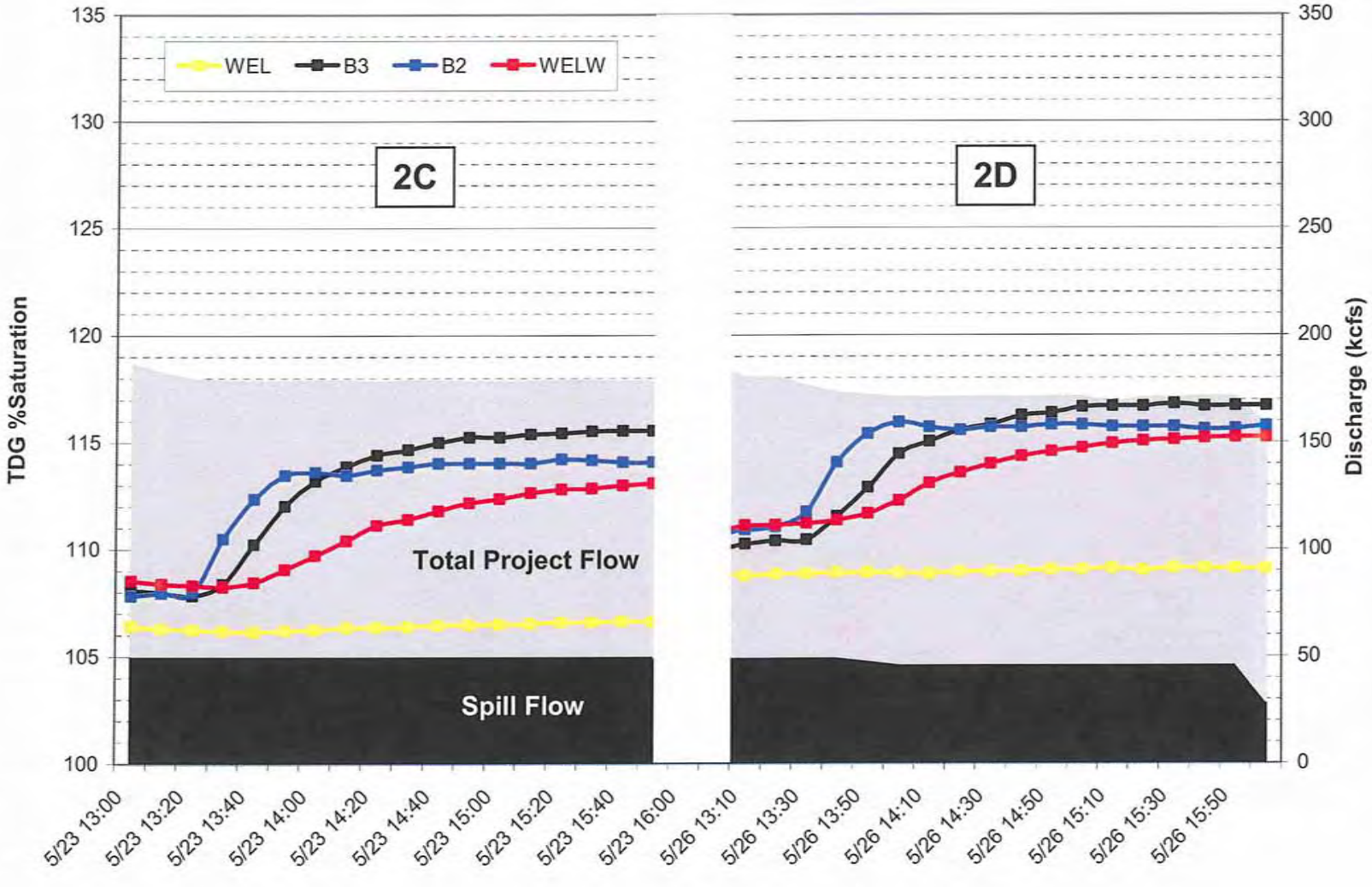

Figure 24. Project operation and Transect B values for tests 2C and 2D.

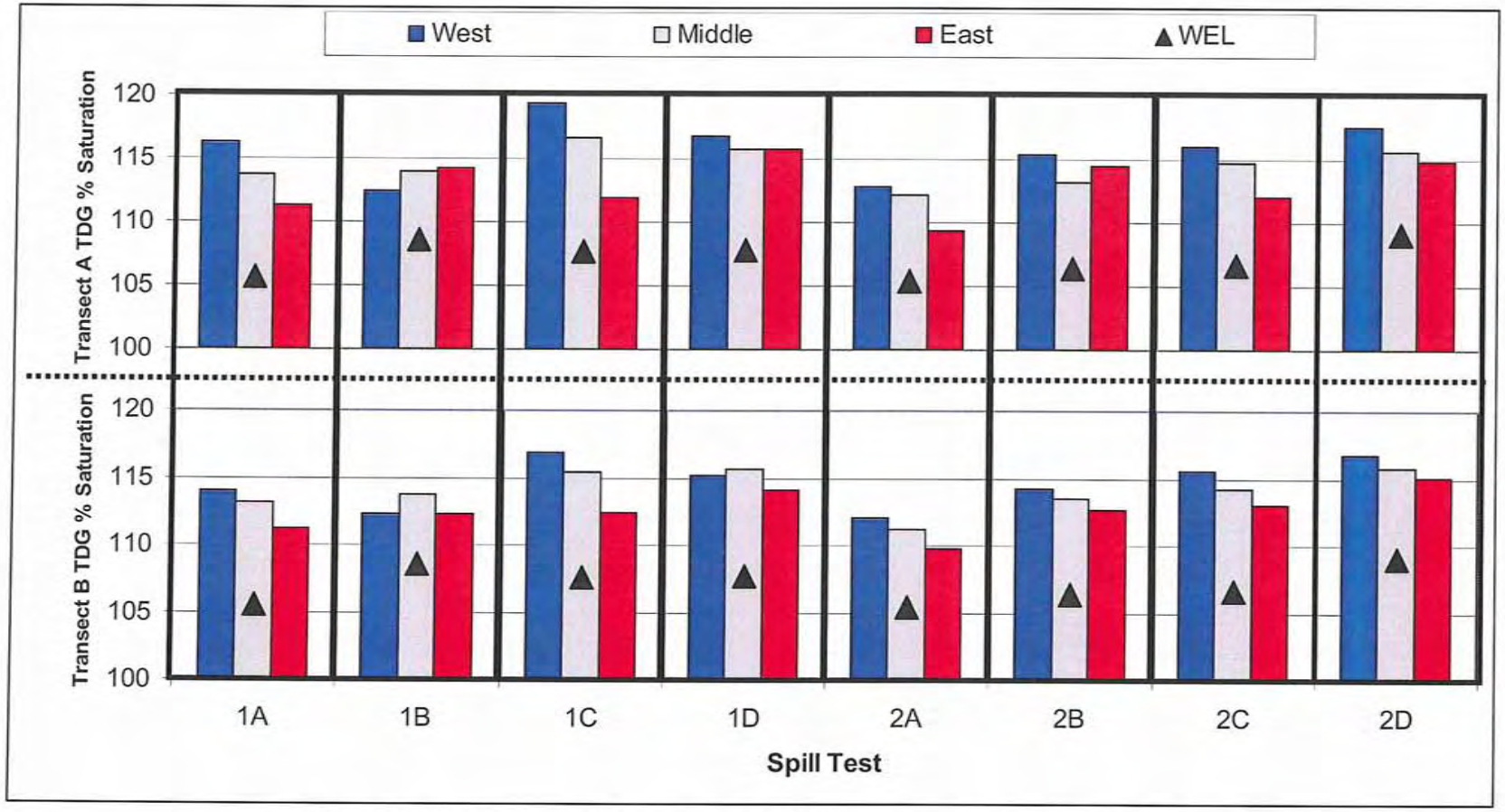

Figure 25. Upstream and downstream TDG saturations averaged by spill test.

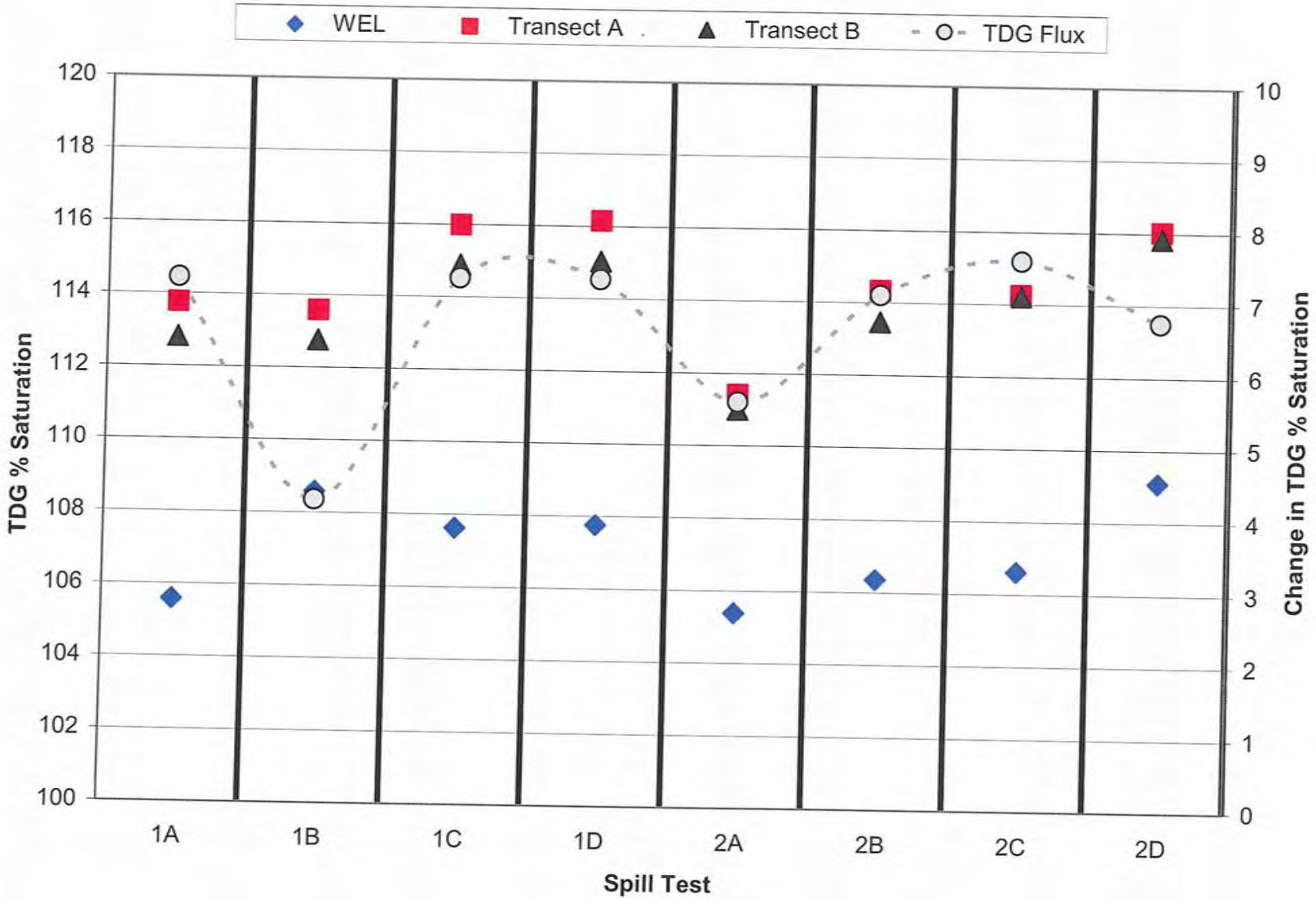

Figure 26. Mean TDG saturations by test for WEL, Transect A, and Transect B. TDG flux measures the difference in TDG saturations from WEL to Transect B.

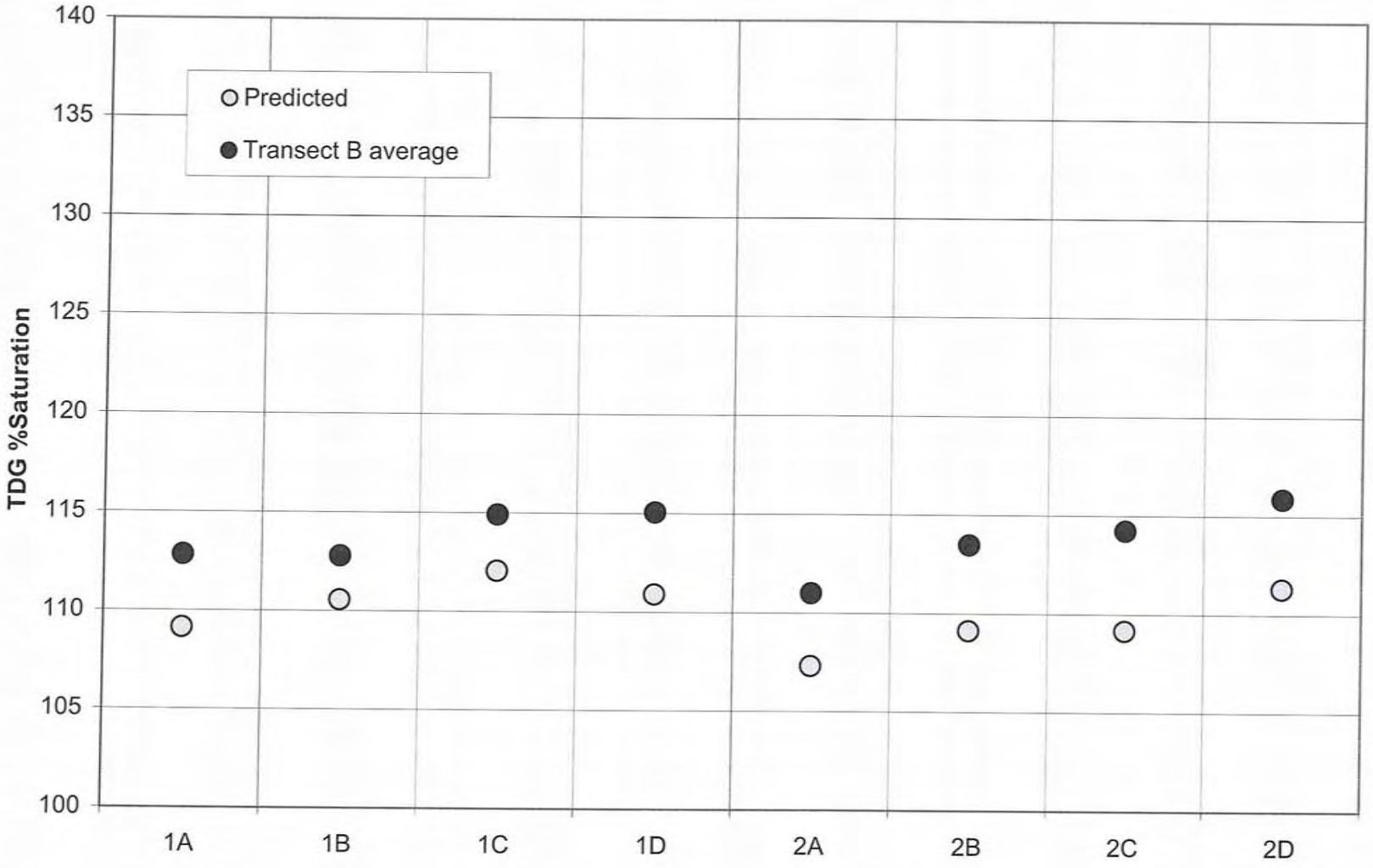

Figure 27. Empirical and predicted mean Transect B TDG saturations assuming no gassing of powerhouse release.

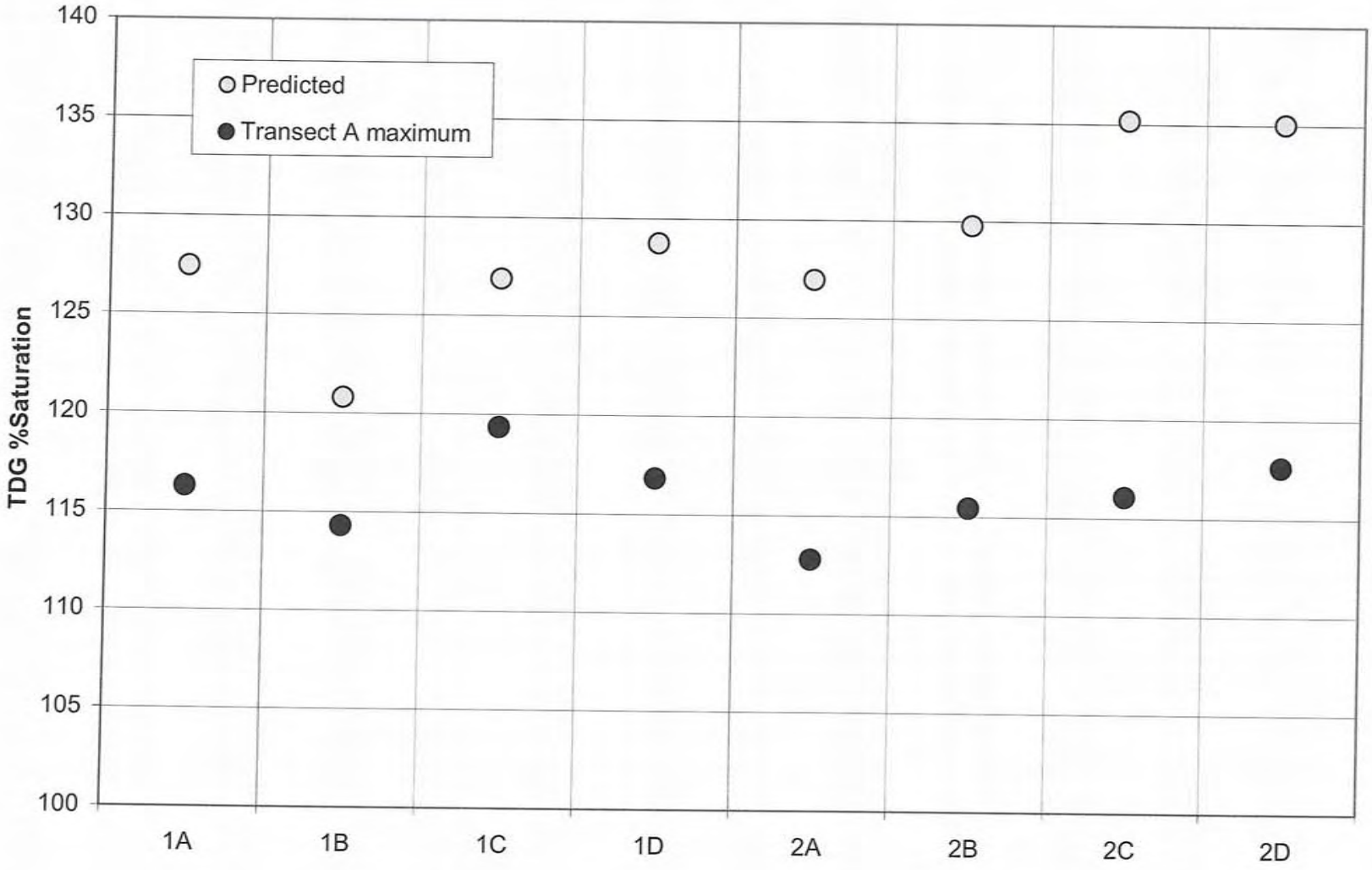

Figure 28. Empirical and predicted spillway TDG saturations assuming no gassing of powerhouse releases.

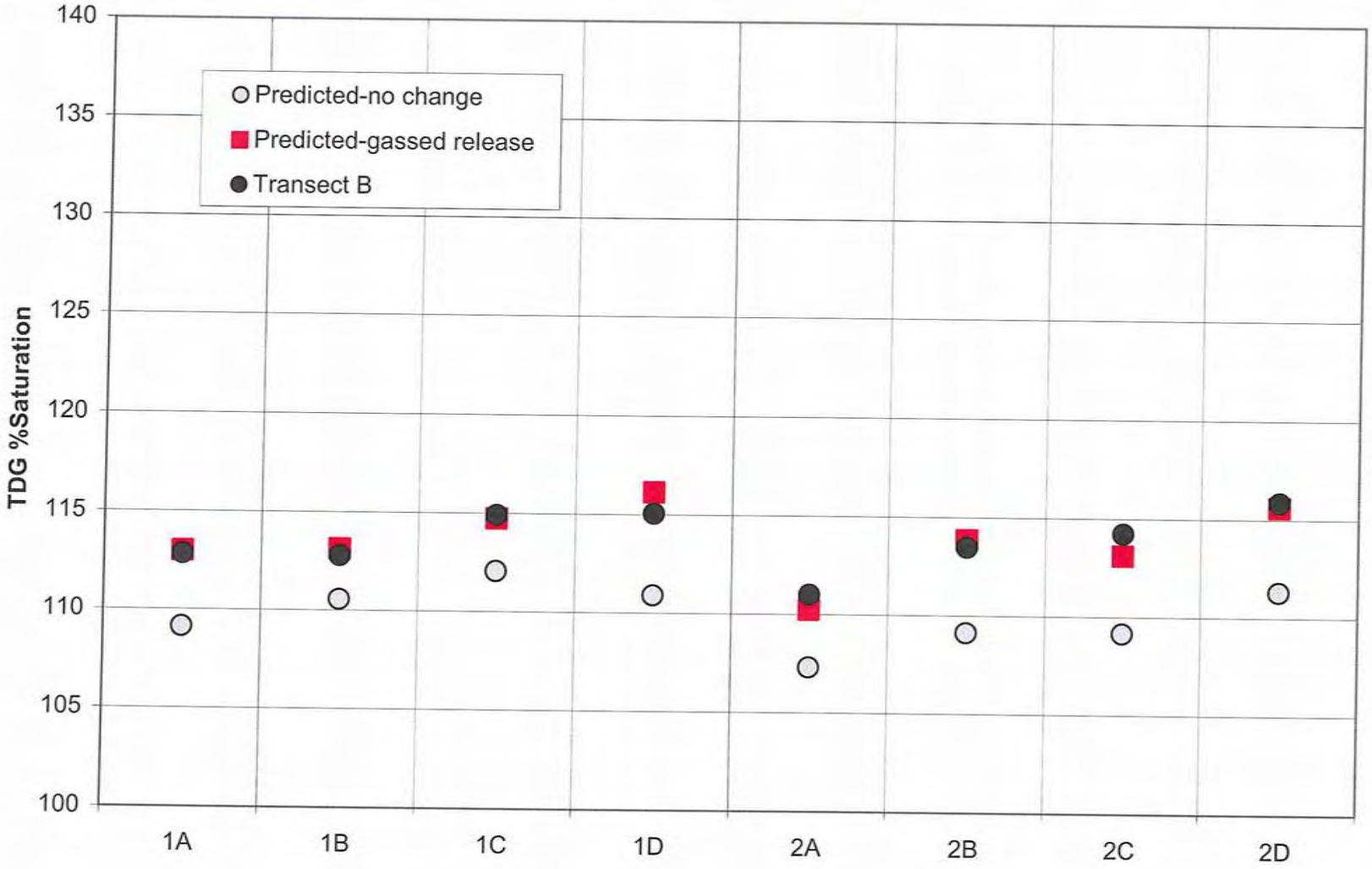

Figure 29. Predicted and actual Transect B weighted TDG saturations assuming some gassing of powerhouse releases.

Appendix A. Calibration procedures for Hydrolab® multiprobes

Following is an outline of the quality assurance/quality control (QA/QC) procedures utilized by Columbia Basin Environmental (CBE) in the handling of Hydrolab® multiprobes. All probes should be checked prior and subsequent to deployment. Individual sensors require different calibration methods, as described by the equipment manufacturer.

A. MiniSonde®/DataSonde® Temperature sensor

Temperatures reported by multiprobes are to be compared to an NIST traceable mercury thermometer. Sonde and standard values should agree within ± 0.2 °C. Temperature sensors are factory calibrated; therefore, probes failing temperature calibrations will be removed from service.

Manufacturer stated accuracy/precision: ± 0.1 °C/0.01 °C

B. MiniSonde®/DataSonde® depth sensor

Sensors are to be air-calibrated such that the depth equals 0 m (or feet, depending on depth units) in air (no storage cup) or they will be adjusted.

Manufacturer stated accuracy/precision: ± 0.1 m/0.01 m

C. MiniSonde®/DataSonde® Total Dissolved Gas sensor

1. Slowly loosen TDG membrane (if installed), being careful not to break the seal with the probe. Monitor the TDG pressure as the membrane is removed. Pressures should decrease by ~200 mmHg and slowly increase to ambient BP; otherwise, the membrane may be damaged. Visually inspect membrane and carefully clean tubing prior to storing.
2. Perform four-point TDG calibration:
   a. Attach NIST traceable pressure gage to TDG sensor and release pressure.
   b. Check TDG zero against primary standard (mercury barometer) pressure and document readings.
   c. Using the pressure gage, gradually add sufficient pressure to bracket the expected *in situ* values (typically, 300 mmHg). The TDG sensor should report pressures equivalent to the ambient BP (zero) plus the additional pressure, e.g. at BP=760 mmHg with 300 mmHg added pressure, the sensor should report 1060 mm Hg.
   d. Check the TDG sensor at BP, BP+100 mmHg, BP+200 mmHg, and BP+300 mmHg and document readings.
   e. If TDG sensor measurements differ from calibration values by more than ± 1 mmHg, the sensor's calibration should be adjusted. Set the TDG sensor at both ambient BP and BP+300 mmHg and recheck across the entire range.

3. Install a fresh TDG membrane. Monitor the TDG pressure as the membrane is attached. Pressure should increase as the seal is formed and then slowly return to ambient BP.
4. Replace sensor guard, if so equipped.
5. Perform final membrane check by immersing entire sensor in carbonated water, i.e. seltzer water. The TDG pressure should increase rapidly and exceed ~1000 mm Hg. Remove sensor from seltzer water and ensure that the pressure gradually returns to atmospheric levels. If pressures do not rise rapidly or if they spike and immediately return to atmospheric pressures, the membrane may be damaged. Repeat steps 7-9 with a new membrane. (*Note: It is important that the sensor guard be replaced BEFORE performing the membrane integrity check as it is possible to damage the membrane during this action.*)

Manufacturer stated accuracy/precision: ± 1.2 mmHg/ 0.1 mmHg

Appendix B. Spillway and Turbine Patterns for the 2005 Wells Dam Spillway Study

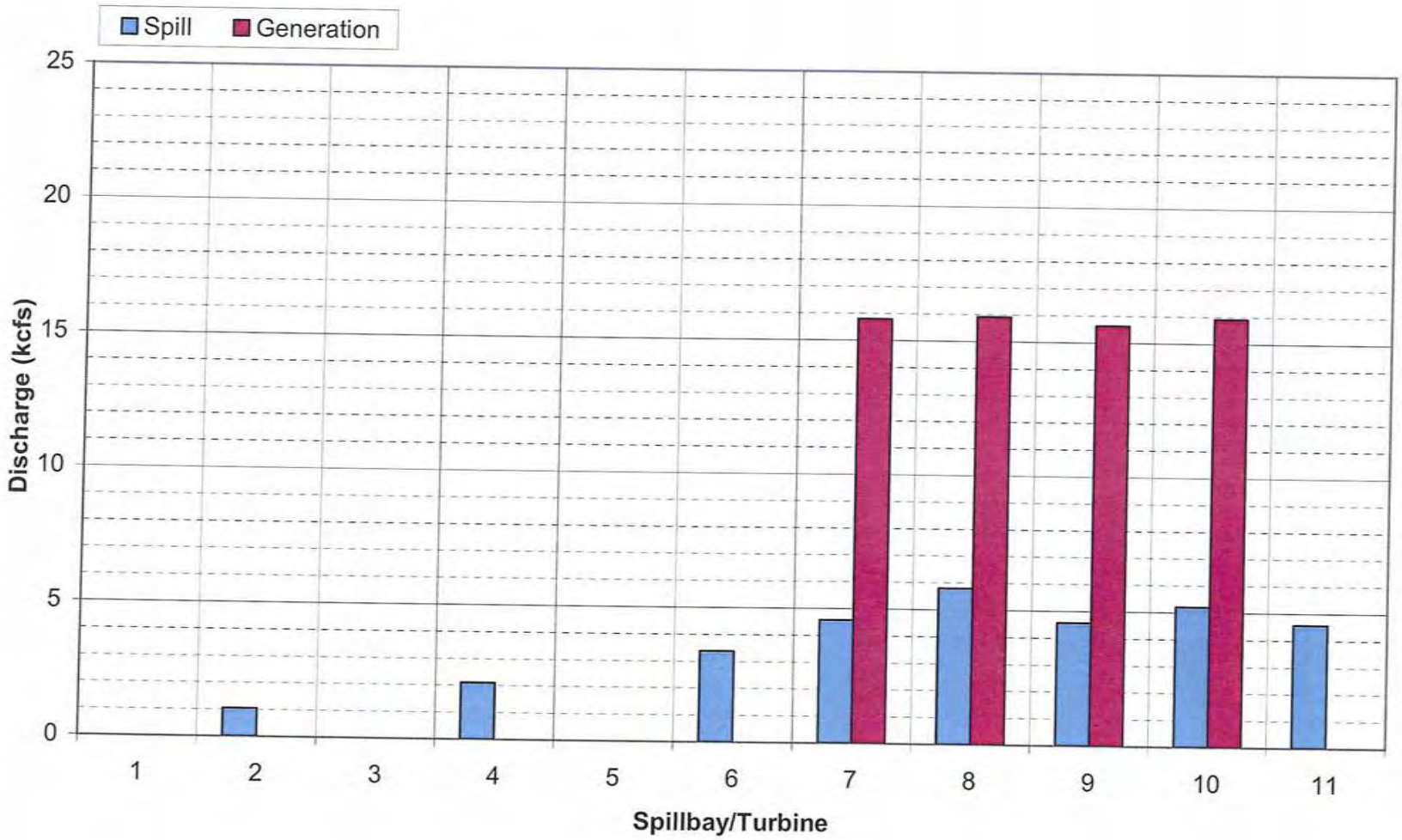

Figure B1. Spill and generator patterns for Spill Test 1A.

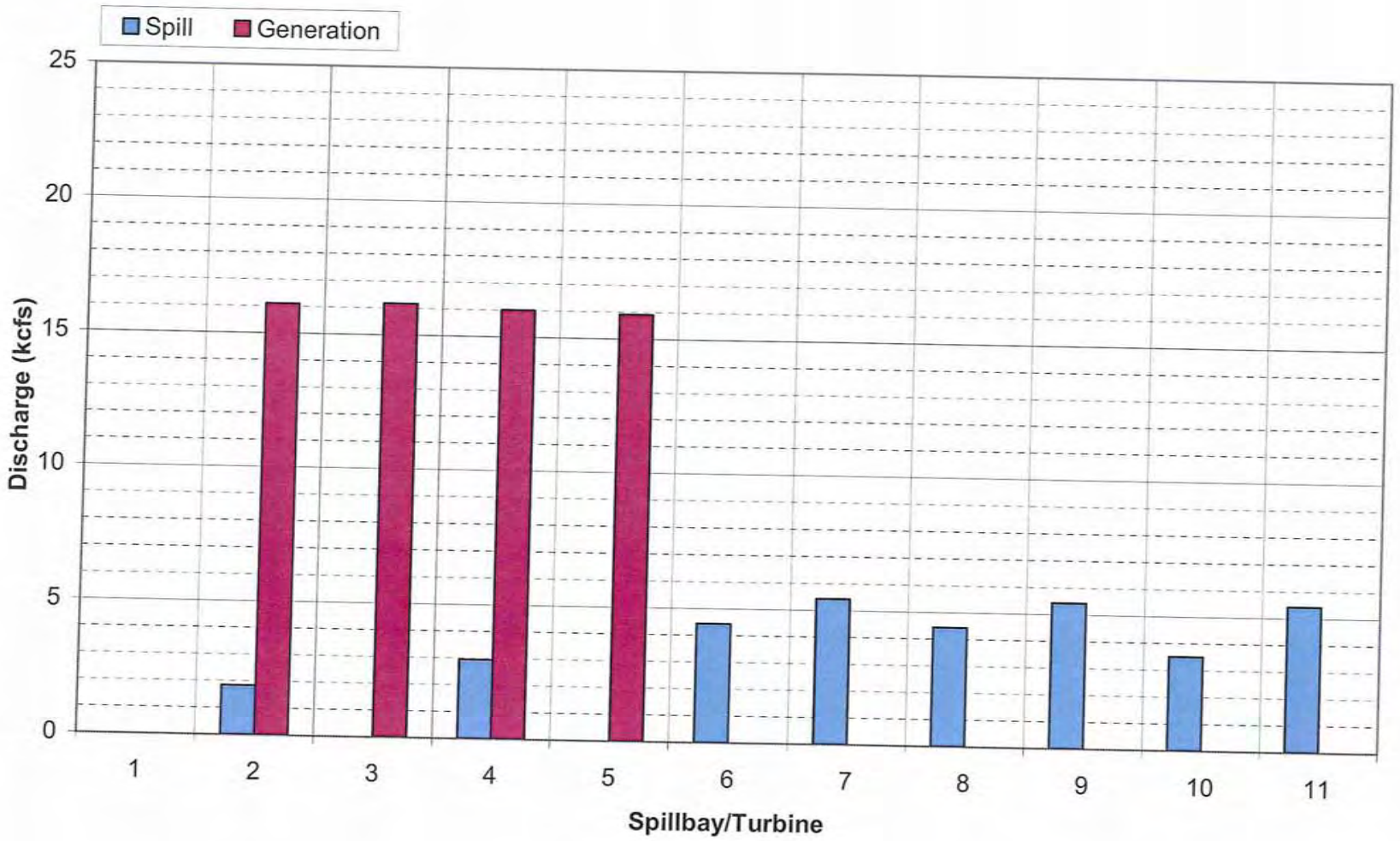

Figure B2. Spill and generator patterns for Spill Test 1B.

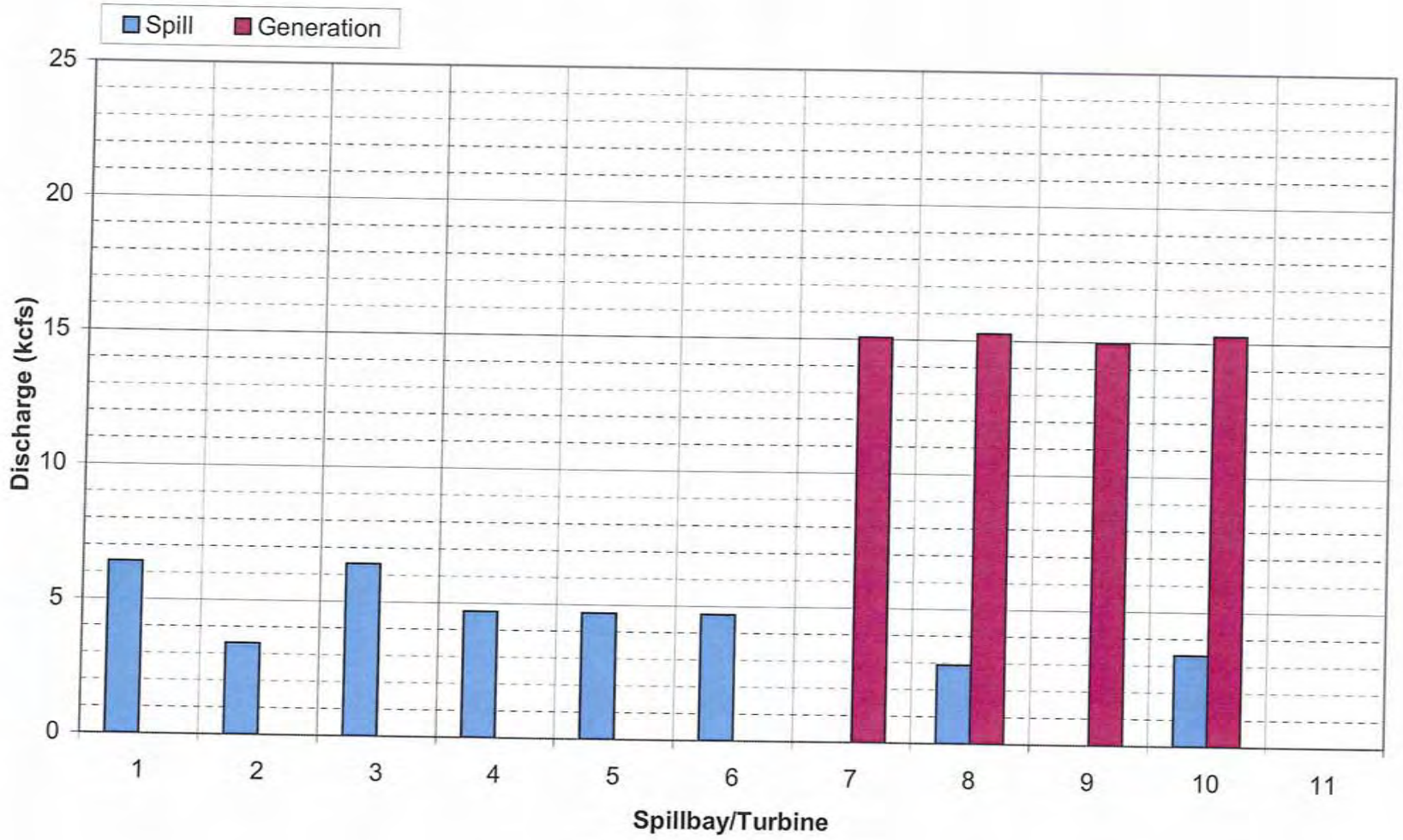

Figure B3. Spill and generator patterns for Spill Test 1C.

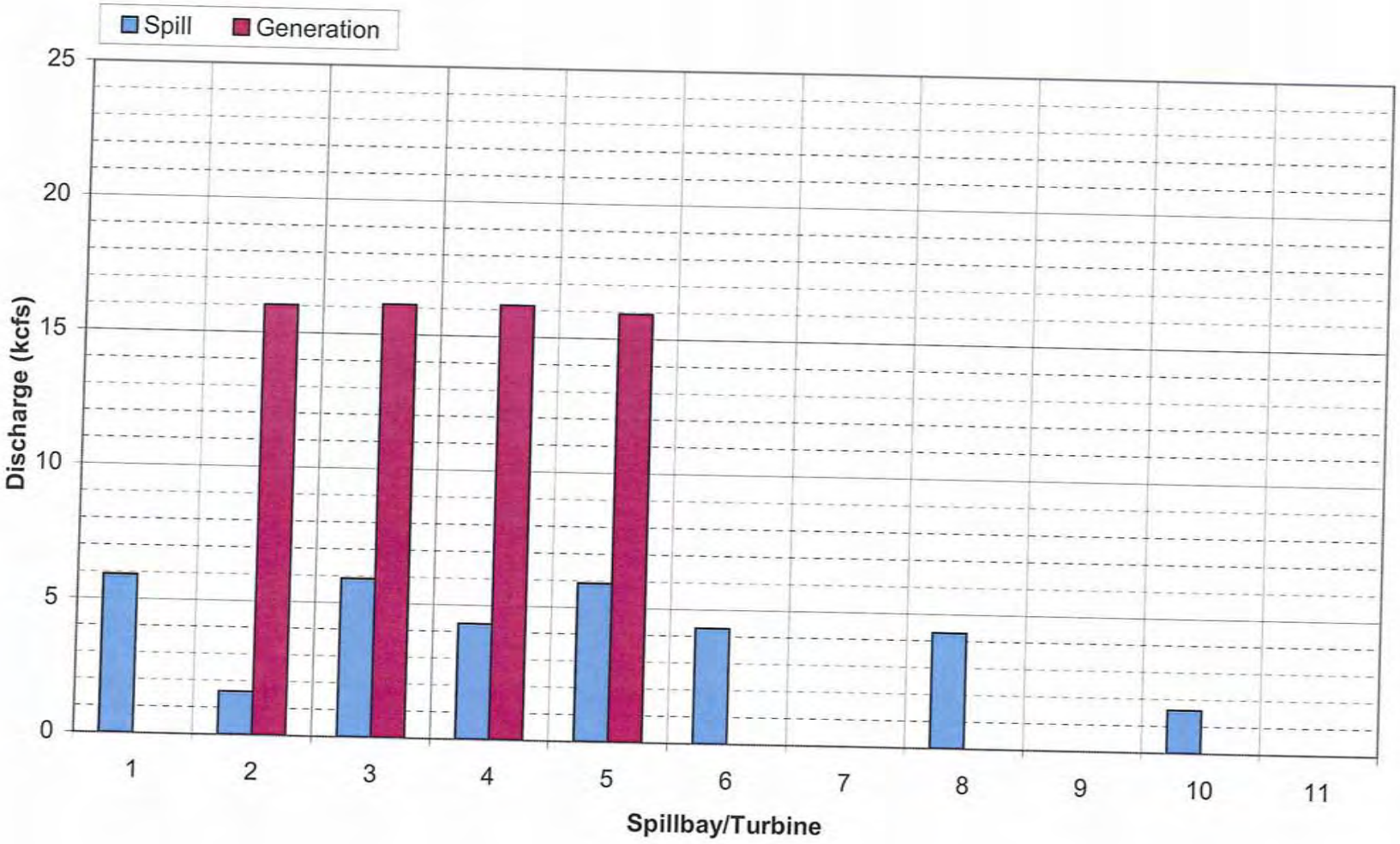

Figure B4. Spill and generator patterns for Spill Test 1D.

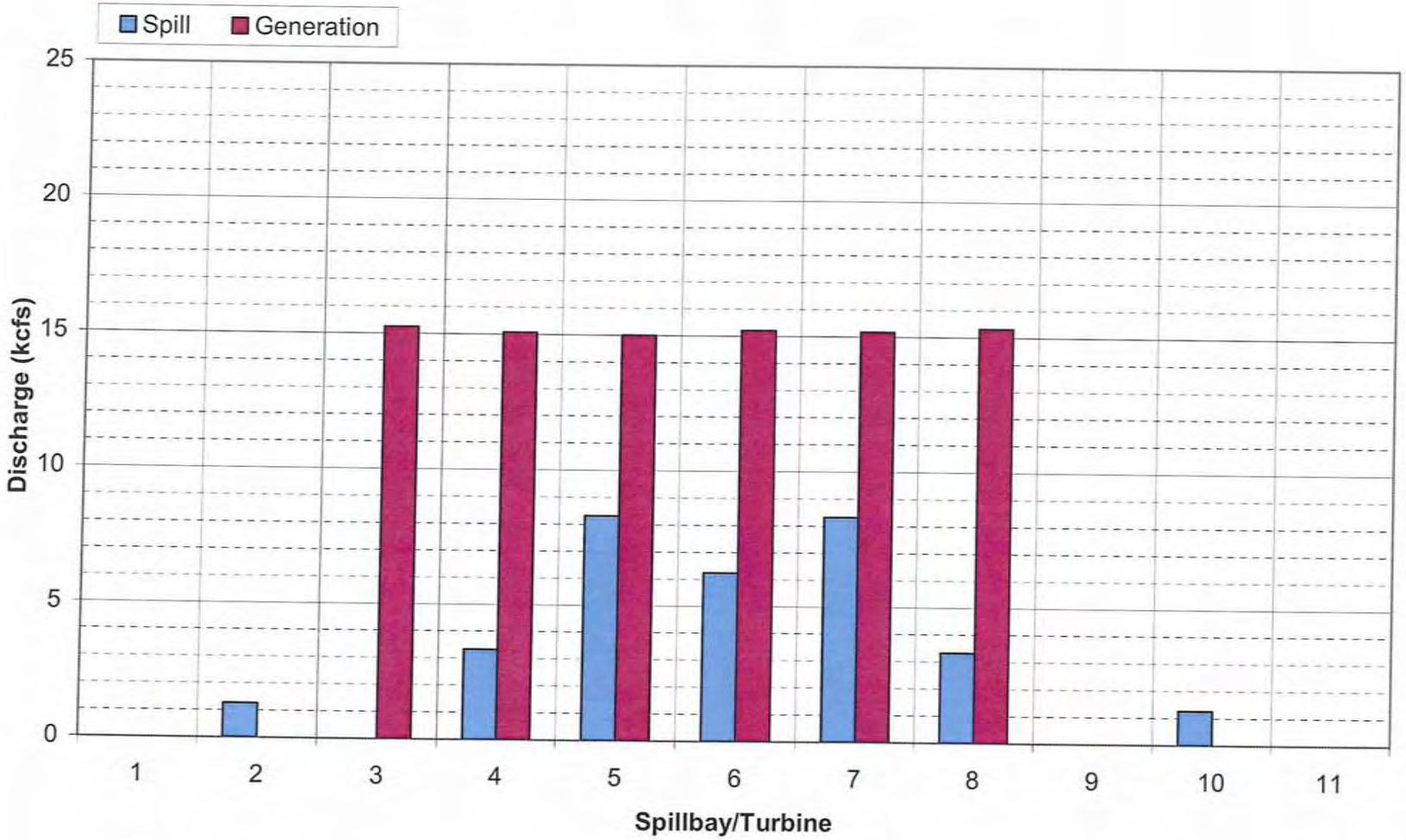

Figure B5. Spill and generator patterns for Spill Test 2A.

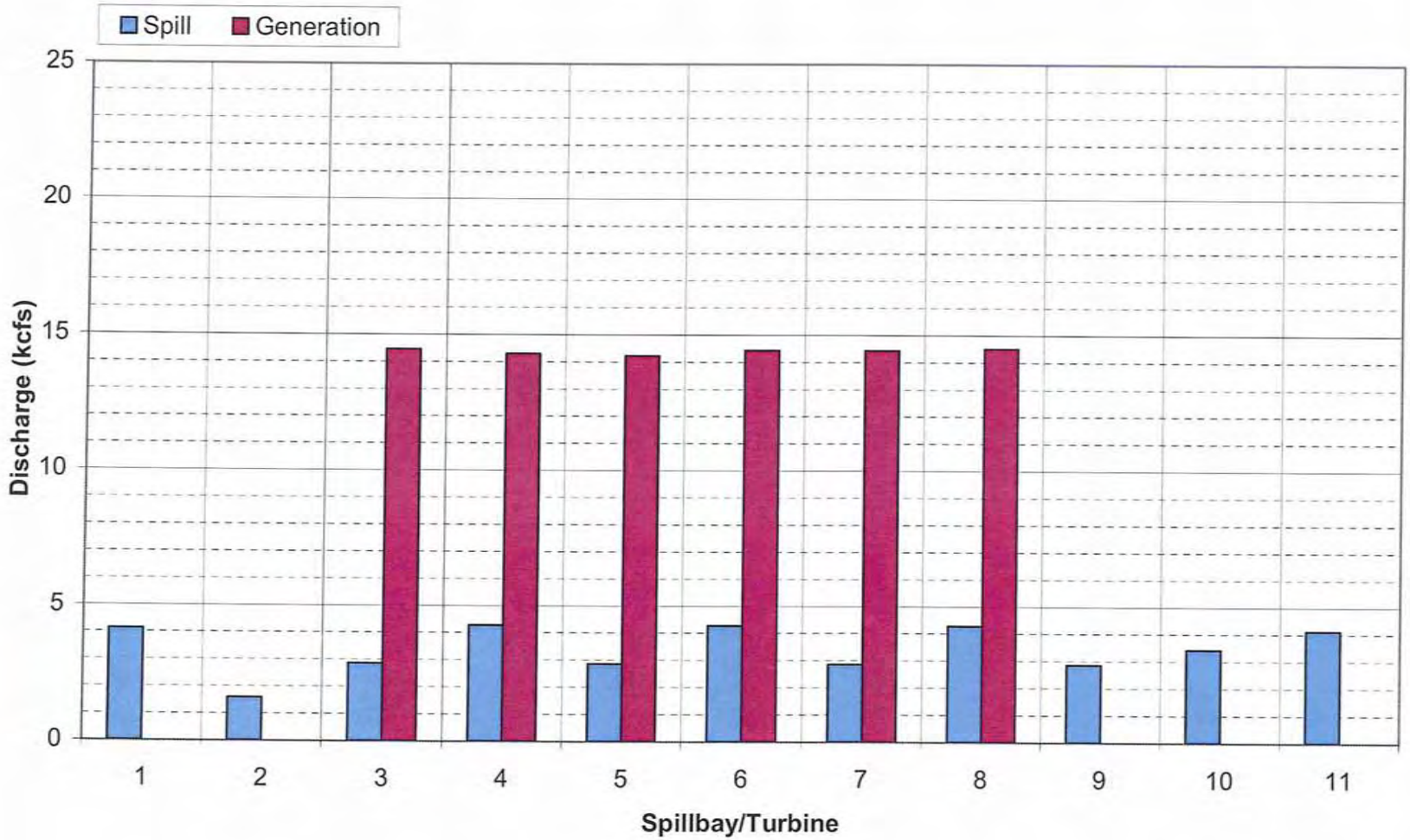

Figure B6. Spill and generator patterns for Spill Test 2B.

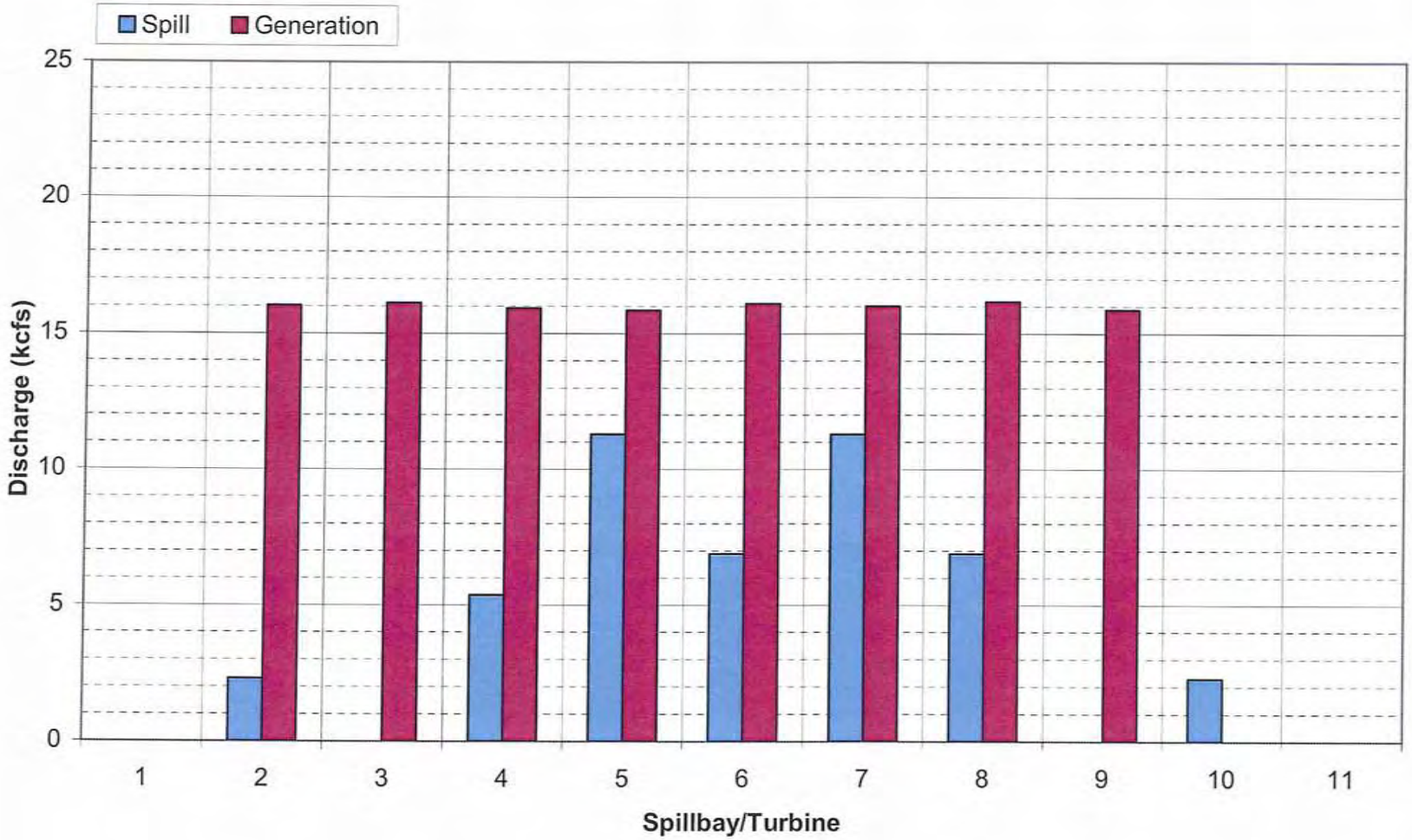

Figure B7. Spill and generator patterns for Spill Test 2C.

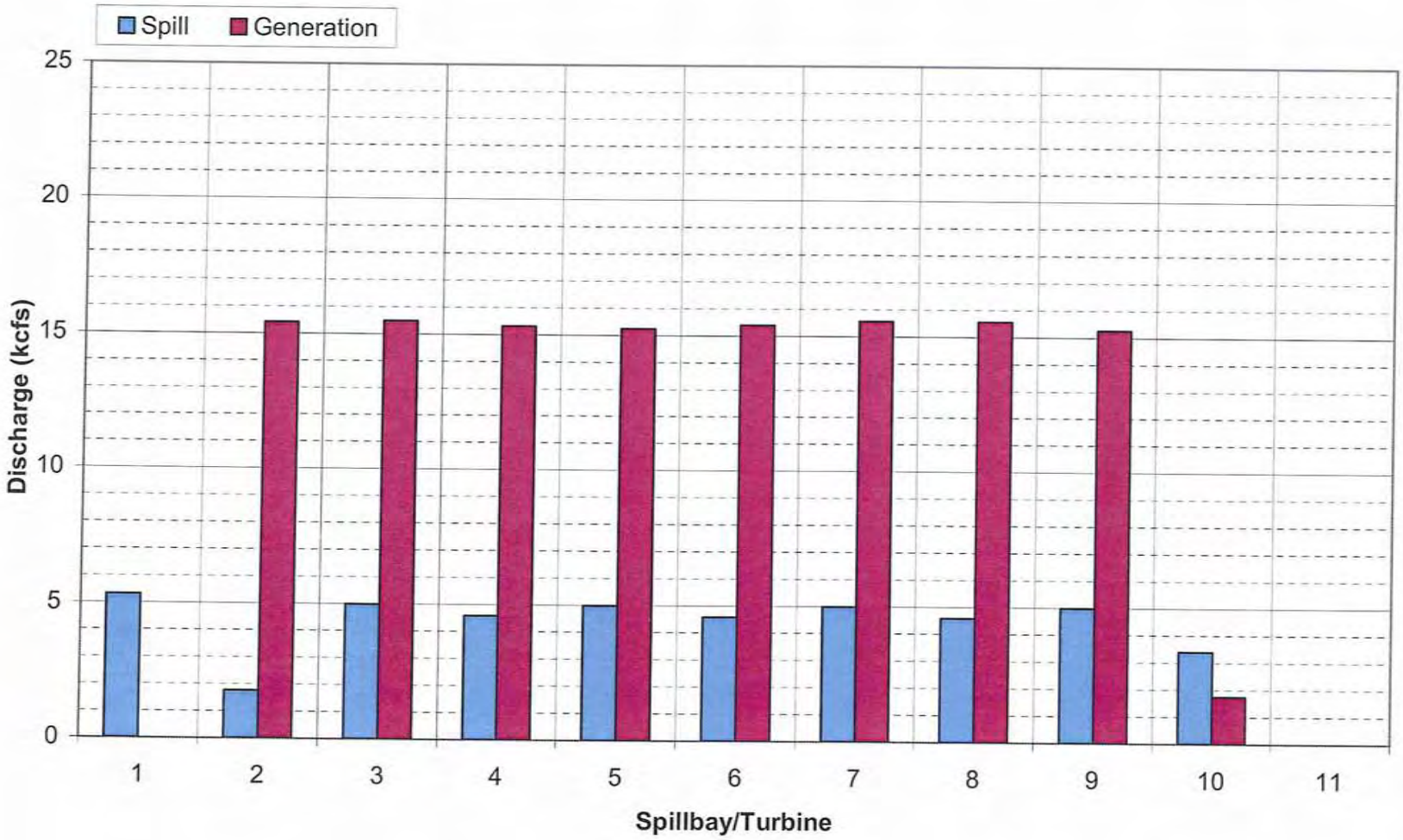

Figure B8. Spill and generator patterns for Spill Test 2D.

Douglas PUD. 2004. Wells Hydroelectric Project Bull Trout Monitoring and Management Plan, 2004-2008. Public Utility District No. 1 of Douglas County, East Wenatchee, WA.

WELLS HYDROELECTRIC PROJECT BULL TROUT MONITORING AND MANAGEMENT PLAN, 2004-2008

Wells Hydroelectric Project No. 2149

December 29, 2004
Final

Public Utility District No. 1 of Douglas County
East Wenatchee, Washington

SECTION 1: Introduction/Consultation History

In August 1993, Douglas, Chelan, and Grant PUDs (collectively, "Mid-Columbia PUDs") initiated discussions to develop a long-term, comprehensive program for managing fish and wildlife that inhabit the mid-Columbia River basin (the portion of the Columbia River from the tailrace of Chief Joseph Dam to the confluence of the Yakima and Columbia rivers).

These discussions first explored the possibility of developing an ecosystem-based plan for managing fish and wildlife resources inhabiting the mid-Columbia River basin, but because of the immense breadth of this type of plan the negotiating parties decided to focus on an agreement for aquatic species inhabiting the mid-Columbia River basin including fish, plants and animals. After extensive review, the negotiating parties further concluded, given the likelihood that certain species of salmon and steelhead would be listed in the near future under the Endangered Species Act (ESA) and given the lack of information regarding the other aquatic species, that the best basin-wide approach would be to develop an agreement for anadromous salmonids, specifically: spring, summer/fall Chinook salmon (*O. tshawytsha*); sockeye salmon (*O. nerka*); coho salmon (*O. kisutch*); and steelhead (*O. mykiss*) (collectively, "Plan Species") which are under the jurisdiction of the National Marine Fisheries Service (NMFS).

On July 30, 1998, following five years of negotiations, Douglas PUD, which operates the Wells Hydroelectric Project (Project), submitted an unexecuted form of an Application for Approval of the Wells Anadromous Fish Agreement and Habitat Conservation Plan (the "HCP Agreement") to the Federal Energy and Regulatory Commission (FERC) and to NMFS. Furthermore, to expedite the ability of FERC to complete formal consultation, biological evaluations of the effects of implementing the Habitat Conservation Plan (HCP) on listed species under the jurisdiction of the US Fish and Wildlife Service (Service) were prepared by Douglas PUD.

In a letter to the Federal Energy Regulatory Commission (FERC), the Service requested consultation under Section 7 of the ESA regarding the effects of hydroelectric project operations on bull trout in the Columbia River (letter from M. Miller, USFWS, to M. Robinson, FERC, dated January 10, 2000). The request for consultation was based on observations of bull trout in the study area. In its reply to the Service, FERC noted that there was virtually no information on bull trout in the mainstem Columbia River.

On December 10, 2003, the Service received a request from FERC for formal consultation to determine whether the proposed incorporation of the HCP Agreement into the FERC license for operation of the Wells Hydroelectric Project was likely to jeopardize the continued existence of the Columbia River distinct population segment (DPS) of ESA-listed bull trout (*Salvelinus confluentus*), or destroy or adversely modify proposed bull trout critical habitat. In response to the FERC request, the Service submitted a Biological Opinion (BO) and issued an Incidental Take Permit (ITP) to Douglas PUD. On June 21, 2004, FERC issued an order incorporating the HCP Agreement and the bull trout BO into the FERC license for the Wells Project.

This document outlines the goals, objectives and implementation strategy for the newly created Wells Bull Trout Management Plan (WBTMP). The proposed WBTMP is intended to monitor and evaluate bull trout presence in the Project area and quantify and address, to the extent feasible, potential project-related impacts on bull trout from Project operations and facilities.

SECTION 2: Biology and Life History

2.1 Biology

Bull trout are native to northwestern North America, historically occupying a large geographic range extending from California north into the Yukon and Northwest Territories of Canada, and east to western Montana and Alberta (Cavender 1978). They are generally found in interior drainages, but also occur on the Pacific Coast in Puget Sound and in the large drainages of British Columbia.

Bull trout currently occur in lakes, rivers and tributaries in Washington, Montana, Idaho, Oregon (including the Klamath River basin), Nevada, two Canadian Provinces (British Columbia and Alberta), and several cross-boundary drainages in extreme southeast Alaska. East of the Continental Divide, bull trout are found in the headwaters of the Saskatchewan River in Alberta, and the McKenzie River system in Alberta and British Columbia (Cavender 1978; McPhail and Baxter 1996; Brewin and Brewin 1997). The remaining distribution of bull trout is highly fragmented.

Bull trout are members of the char group within the family Salmonidae. Bull trout closely resemble Dolly Varden (*Salvelinus malma*), a related species. Genetic analyses indicate, however, that bull trout are more closely related to an Asian char (*Salvelinus leucomaenis*) than to Dolly Varden (Pleyte et al. 1992). Bull trout are sympatric with Dolly Varden over part of their range, most notably in British Columbia and the Coastal-Puget Sound region of Washington State.

Bull trout are believed to have more specific habitat requirements than other salmonids (Rieman and McIntyre 1993). Growth, survival, and long-term persistence are dependent upon habitat characteristics such as cold water, complex instream habitat, a stable substrate with a low percentage of fine sediments, high channel stability, and stream/population connectivity. Stream temperature and substrate type, in particular, are critical factors for the sustained long-term persistence of bull trout. Spawning is often associated with the coldest, cleanest, and most complex stream reaches within basins. However, bull trout may exhibit a patchy distribution, even in pristine habitats (Rieman and McIntyre 1995), and should not be expected to occupy all available habitats at the same time (Rieman et al. 1997).

2.2 Life History

Bull trout exhibit four distinct life history types: resident, fluvial, adfluvial, and anadromous. The fluvial, adfluvial, and resident forms exist throughout the range of the bull trout (Rieman and McIntyre 1993). These forms spend their entire life in freshwater. The anadromous life history form is currently known only to occur in the Coastal-Puget Sound region within the coterminous United States (Volk 2000; Kraemer 1994; Mongillo 1993). Multiple life history types may be expressed in the same population, and this diversity of life history types is considered important to the stability and viability of bull trout populations (Rieman and McIntyre 1993).

The majority of growth and maturation for anadromous bull trout occurs in estuarine and marine waters, adfluvial bull trout in lakes or reservoirs, and fluvial bull trout in large river systems. Resident bull trout populations are generally found in small headwater streams where fish remain their entire lives.

For migratory life history types, juveniles tend to rear in tributary streams for 1 to 4 years before migrating downstream into a larger river, lake, or estuary and/or nearshore marine area to mature (Rieman and McIntyre 1993). In some lake systems, age 0+ fish (less than 1 year old) may migrate directly to lakes (Riehle et al. 1997). Juvenile and adult bull trout in streams frequently inhabit side channels, stream margins and pools with suitable cover (Sexauer and James 1993) and areas with cold hyporheic zones or groundwater upwellings (Baxter and Hauer 2000).

2.3 Species Status

On June 10, 1998, the Service listed bull trout (Salvelinus confluentus) within the Columbia River basin as threatened under the Endangered Species Act (ESA) (50 CFR 63(111). Later (November 1, 1999), the Service listed bull trout within the coterminous United States as threatened under the ESA (50 CFR 64(21)). The Service identified habitat degradation, fragmentation and alterations associated with dewatering, road construction and maintenance, mining, and grazing; blockage of migratory corridors by dams or other diversion structures; poor water quality; incidental angler harvest; entrainment into diversion channels; and introduced non-native species as major factors affecting the distribution and abundance of bull trout. They noted that dams (and natural barriers) have isolated population segments resulting in a loss of genetic exchange among these segments (50 CFR 63(111):31657). The Service believes many populations are now isolated and disjunct.

In October 2002, the Service completed the first draft of a bull trout recovery plan intended to provide information and guidance that will lead to recovery of the species, including its habitat. Threatened bull trout population segments are widely distributed over a large area and because population segments were subject to listing at different times, the Service adopted a two-tiered approach to develop the draft recovery plan for bull trout (USFWS 2002).

The first tier addresses broad aspects of bull trout recovery that apply at the level of Distinct Population Segments. The Service identified the Columbia River, Coastal-Puget Sound, St. Mary-Belly River, Jarbidge River, and the Klamath River as Distinct Population Segments. The second tier addresses bull trout recovery in smaller areas, such as specific river basins or collections of river basins within population segments, termed "recovery units". There are 22 recovery units in the Columbia River, 1 in the Klamath River, 1 in the Jarbidge River, 1 in the St. Mary-Belly River, and 2 in the Coastal-Puget Distinct Population Segment (USFWS 2002).

The State of Washington contains the Coastal-Puget Sound Distinct Population Segment and is a part of the larger Columbia River Distinct Population Segment. In total, there are 9 recovery units within the state; the Olympic Peninsula, Puget Sound, Lower Columbia

River, Middle Columbia River, Upper Columbia River, Northeast Washington, and portions of the Snake River, Umatilla-Walla Walla River and Clark Fork River Recovery Unit.

The Wells Project Area is situated within the Upper Columbia River Recovery Unit and the Service has identified the Wenatchee, Entiat, and Methow Rivers as its core areas. A core area represents the closest approximation of a biologically functioning unit for bull trout. Within a core area, many local populations may exist. A local population is assumed to be the smallest group of fish that is known to represent an interacting reproductive unit). Sixteen local populations were identified in the Wenatchee (6), Entiat (2) and Methow (8) core areas (USFW 2002).

SECTION 3: Project Specific Studies

3.1 Project Description

The Wells Hydroelectric Project is located on the mainstem Columbia River at RM 515.8, approximately 12 miles north of the city of Chelan, Washington (Figure 1). The dam spans 4,460 feet, with the hydrocombine structure (spillway, turbine and fishways combined into one structure) comprising 1,130 feet. Wells Dam is a 185 foot high concrete gravity dam completed in 1967. The reservoir formed by the project extends upstream 29.5 miles, past the cities of Pateros, Brewster and Bridgeport and up to the Army Corps of Engineer's Chief Joseph Dam, totaling 331,200 acre feet of water, and having a surface area of 9,740 acres at the normal pool elevation of 781 feet above msl.

The project includes a spillway, powerhouse, an earthen embankment section, a juvenile bypass system and two adult fishways. The spillway consists of 11 spillway gates with a combined capacity of 1,180 kcfs. The powerhouse has 10 Kaplan turbine units, equipped with minimum gap turbine runners to increase protection for juvenile salmonids during turbine passage, with a combined hydraulic capacity of 205 kcfs and a peak generating capacity of 840 MW of electricity. The two adult fishways are mirror image left and right bank fishway facilities. Each of the two fishways contains a single main entrance, a collection gallery, a fish ladder, adult count station, trapping facilities and an exit in the forebay. The juvenile bypass system consists of five evenly spaced surface collector entrances that guide fish into and through the juvenile bypass system and into the tailrace of the dam.

3.2 Bull Trout Study at Wells

Columbia River bull trout are listed as threatened under the ESA (50 CFR 63(111):31651). Listed Columbia River bull trout have been observed and counted at Wells Dam since 1998. Because of the potential for operations at the to dam to affect the movement and survival of bull trout, in 2000 the Service requested that the mid-Columbia PUDs evaluate the movement and status of bull trout in the project area. At that time little was known about the life-history characteristics (e.g., movements, distribution, habitat use, etc.) of bull trout in the mid-Columbia River. Therefore, in order to assess the operational effects of hydroelectric projects on bull trout within the mid-Columbia, a three PUD (Grant, Chelan and Douglas PUDs) radio-telemtry study was implemented beginning in 2001. The goal of the study was to monitor the movements and migration patterns of adult bull trout in the mid-Columbia River (Figure 1). The number of trout to be collected and tagged at each dam (Rock Island, Rocky Reach, and Wells) was based on the proportion of fish that migrated past those dams in 2000.

Bull trout at Wells Dam were trapped at the brood-stock collection facility located within the left bank ladder. The brood-stock collection facility is located at pool 40 about half way up the fish ladder. The trap was operated by placing a barrier fence across the entire width of the pool. When the trap was in operation, all fish attempting to ascend the left bank ladder are blocked by the barrier fence and forced to ascend the off-ladder trap via a steep-pass denil that leads to an upwell enclosure. Once inside the upwell enclosure, fish moved down a sorting chute by jets of water introduced near the top of the chute. As

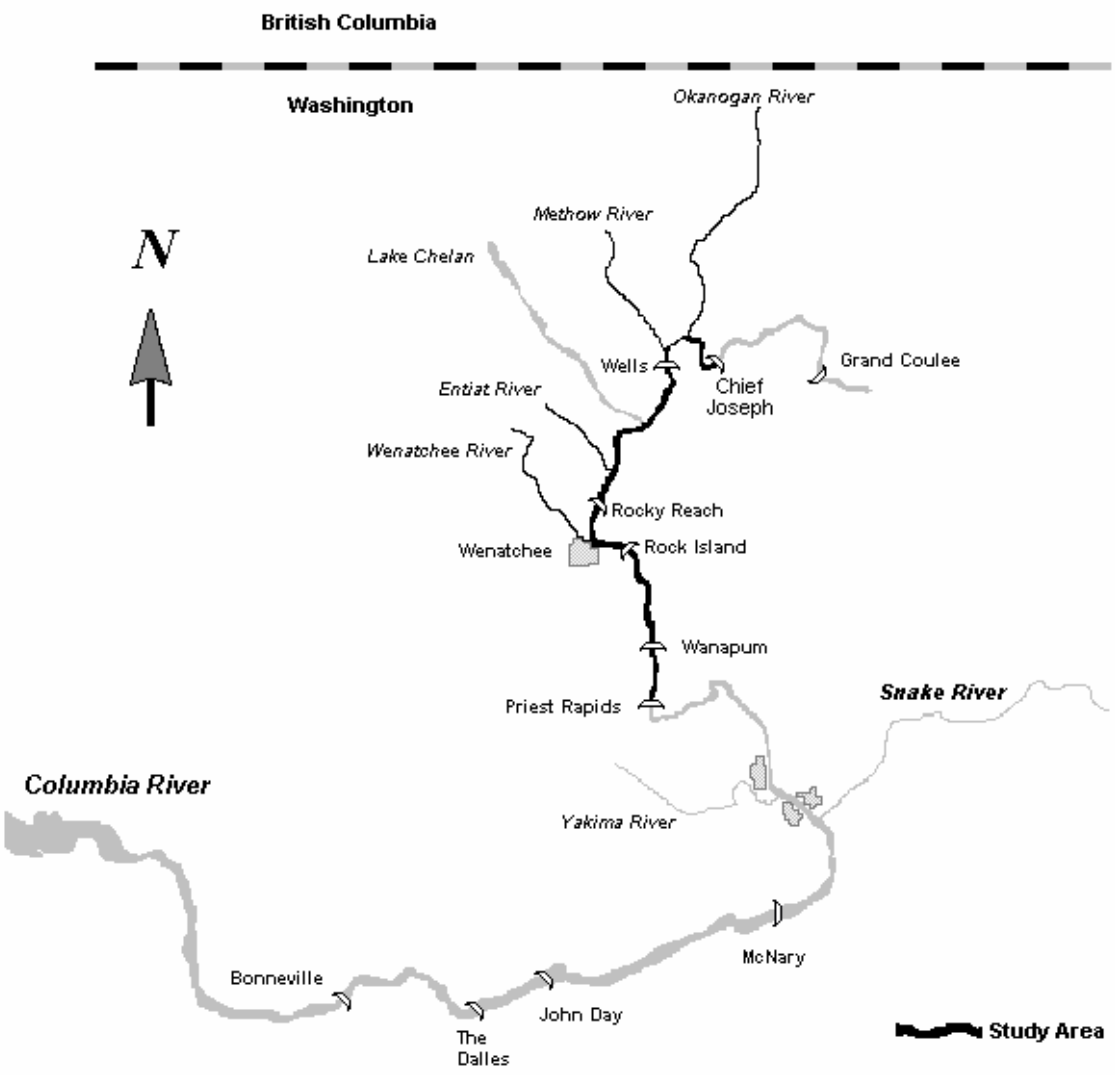

Figure 1: Study area for assessing migration patterns of bull trout in the mid-Columbia River. Fixed radio-telemetry sites monitored the movement of bull trout near Priest Rapids, Wanapum, Rock Island, Rocky Reach and Wells dams. Fixed sites placed in the Wenatchee, Entiat, Methow and Okanogan rivers monitored time of entry and exodus of bull trout in large tributaries of the mid-Columbia River.

the fish move down the chute, they were identified and either diverted into the holding tank or allowed to pass upstream of the trap. When a bull trout was observed in the chute, a technician activated a pneumatic gate diverting the fish into a 2,270-liter holding tank. Non-target species and small bull trout (<40 cm fork length) were shunted back to the ladder upstream of the trapping barrier. The fish ladder supplied the holding tank with freshwater at a rate of 114 to 151 L/hr to maintain adequate dissolved oxygen and temperature levels. At the time of tagging, bull trout were netted from the holding vessel and transferred to an anesthetic vessel containing an 80 mg/L solution of MS-222. Once anesthetized, fish were transferred to a mobile surgical station for further processing.

The surgical procedures employed were nearly identical to the methods described in Summerfelt and Smith (1990), with some modifications based on consultation with the Service. Bull trout were anesthetized in a pre-operative solution of MS 222 at a concentration of 80 mg/L. Service biologists found that 80 mg/L of MS 222 for initial induction, followed by a concentration of 40 mg/L during surgery was adequate to maintain anesthesia during implantation of transmitters in bull trout (J. De La Vergne, USFWS, personal communication). Before preparation of the pre-operative solution of MS-222, the water was sampled for pH. If the solution was acidic (pH<7.0), it was buffered with sodium bicarbonate to maintain a pH of 7, thereby reducing physiological stress associated with anesthesia (Wedemeyer 1970). After sedation, the fish was weighed, measured, and a genetic sample was taken from the upper lobe of the caudal fin. In addition, several scales were collected for age analysis from all bull trout collected. Scale analysis was performed by the Washington Department of Fish and Wildlife. Genetic samples were preserved and provided to the Service.

After the fish had recovered, the fish were loaded into the transport vessel. The transport vessel was simultaneously supplied with air delivered through an air stone. Once inside the transport vessel the fish were loaded into the truck and quickly transported to the release site. At the release site, the air stone was removed and the transport vessel was placed into the river. Upon release, the water temperature at the release site and inside the vessel was recorded. The vessel was then gently rolled onto its side and the lid was opened allowing the fish to swim free of the vessel. The swimming behavior of the fish was observed and any abnormalities were noted.

At the request of the Service, half of the radio-tagged fish were released downstream from the dam and the other half released upstream of the dam. The purpose of this release strategy was to increase the sample size of fish ascending the ladder systems at each of the projects where fish were collected and tagged. For fish released upstream from the dam, the fish were released as close to the dam as possible, while still ensuring that the fish were released well outside of the influence of the forebay hydraulics including spill and bypass entrainment flows.

Multiple-telemetry techniques were used to assess the movement of tagged bull trout within the study area. At Wells Dam, a combination of aerial and underwater antennas were deployed. The primary purpose for this system was to document the presence of bull trout at the project, identify passage times and determine their direction of travel

(upstream/downstream). In addition to these systems, a number of additional telemetry systems were deployed to address specific questions posed by the Service and Douglas PUD. At Wells Dam, several additional systems were installed to identify tagged bull trout that could enter, ascend, and exit specific gates and fish ladders. All possible access points to the adult fish ladders and the exits were monitored individually in 2001, 2002 and 2003, allowing the route of passage to be determined as well as the ability to establish the exact time of entrance and exit from the ladder system. English et al. (1998, 2001) provided a detailed description of the telemetry systems at each of the dams and within the tributaries.

To assess bull trout movements into and out of the Wells reservoirs, fixed-telemetry monitoring sites were established at the mouth of the Methow and Okanogan rivers and periodic aerial surveys were conducted on the reservoir and throughout both watersheds (see English et al. 1998, 2001).

Key Findings to Date

- Total upstream fishway counts (May 1st to November 15th) at Wells Dam from 2000 to 2003 were 90, 107, 76, and 53 bull trout, respectively.

- Adult bull trout make migrations upstream through Wells Dam from May through November. Peak movement occurs in May and June with 94, 95, 92, and 89 percent of adult bull trout being detected during these months at Wells Dam for years 2000-2003, respectively.

- Tagged migratory adult bull trout successfully move both upstream and downstream past the Project (radio-telemetry). From the 79 bull trout radio tagged in 2001 and 2002 at Rock Island, Rocky Reach, and Wells, five bull trout passed downstream through Wells Dam with no mortality. Twelve downstream passage events occurred at Rocky Reach (4) and Rock Island (8) through turbines from 2001 to 2003. None of the 17 observed downstream passage events resulted in injury or mortality to bull trout. A downstream passage event was assessed as the detection of a fish downstream from the dam after the fish had recently exited the ladder system.

- Between 2001-2003, a total of 10 (2 tagged at Rock Island, 4 Rocky Reach, 4 Wells), 11 (5 Rocky Reach, 4 Wells, 2 from 2001), and 1 (1 Wells) tagged bull trout were detected moving upstream of the Wells project, respectively.

- Median tailrace times (tailrace detection to ladder entrance detection) during the telemetry study at Wells in 2001-2003 were 1.53, 7.84, and 1.00 days, respectively. Median travel times (tailrace detection to ladder exit detection) during the telemetry study at Wells in 2001-2003 were 8.87, 7.60, and 1.16 days, respectively. Median ladder passage times (entrance detection to ladder exit detection) during the telemetry study at Wells in 2001-2003 were 5.70, 0.23, and 0.16 days, respectively.

- Adult bull trout migrating upstream of Wells Dam appear to be destined for the Methow River. Between 2001-2003, no bull trout selected the Okanogan system (one trout moved into the Okanogan, but left shortly thereafter and moved into the Methow system).

- Median travel time from Wells Dam (detection at ladder exit) to first detection in the Methow River in 2001-2003 was 0.40, 2.78, and 1.09 days, respectively.

- All tributary entrance events (fixed station detections) into the Methow River by bull trout (28 total events, 2001-2003) occurred before June 27. An additional two bull trout, not detected by the tributary fixed station systems, were detected in the Methow River via 2002 aerial surveys. Bull trout in the Methow system selected two primary areas, the mainstem Methow River and the Twisp River.

- To date, 30% (9/30) of bull trout that entered the Methow River have been detected leaving the system. Tributary exit dates were recorded for 78% (7/9) of these emigrating bull trout and 86% (6/7) of bull trout with a recorded exit date left the Methow River system between Oct-Dec.

- It appears that no radio tagged bull trout were injured at the dams or in the reservoirs due to project effects during telemetry monitoring in 2001, 2002, and 2003.

- Bull trout migrating upstream through Wells Dam in 2001 were 5 year old (n=2, mean fork length=55.6cm) and 6 year old (n=6, mean fork length= 54.6cm) fish as determined by scales.

- 92% (11/12) and 53% (8/15) of tagged bull trout detected in the vicinity of Wells Dam entered the Wells Hatchery Outfall in 2001 and 2002, respectively. It is possible that the bull trout frequented the outfall in search of prey. Typical operation at the hatchery is to volitionally release yearling chinook smolts between 15 and 30 April, and subyearling chinook smolts in early June. Given that bull trout feed opportunistically (Goetz 1989), it is likely that the tagged bull trout were taking advantage of the large concentration of juvenile salmonids within the hatchery outfall system.

SECTION 4. BULL TROUT MANAGEMENT PLAN

4.1 Plan Goal

The goal of the Wells Bull Trout Management Plan is to: identify, develop, and implement measures to monitor and address potential project-related impacts on bull trout from Wells Project operations and facilities. This Plan is intended to be an adaptive approach, where strategies for meeting the goals and objectives may be negotiated under a collaborative effort with stakeholders based on new information and ongoing monitoring results.

Through monitoring and implementation of WBTMP measures, this plan is designed specifically to (1) address ongoing project-related impacts through the life of the existing operating license; (2) provide consistency with recovery actions as outlined in the Service's draft bull trout recovery plan; and (3) monitor and minimize the extent of any incidental take of bull trout consistent with Section 7 of the Endangered Species Act.

4.2 Protection, Monitoring, and Evaluation Measures

Douglas PUD will utilize the management strategies outlined in this section to meet the protection, monitoring, and evaluation (PME) measures outlined in the 2004 BO for bull trout and will simultaneously address potential project-related impacts on bull trout for the duration of the existing license as required by license articles 61, 62 & 63. The PME measures will also be consistent with the overall USFWS bull trout recovery plan and with Section 7 of the Endangered Species Act.

Bull Trout Monitoring and Evaluation Program

Objective 1
Identify potential project-related impacts on upstream and downstream passage of adult bull trout through the Wells Dam and reservoir and implement appropriate measures to monitor any incidental take of bull trout.

Strategies for Objective 1
Strategy 1-1: *Implement an adult bull trout telemetry program to monitor adult upstream and downstream passage in the Project Area and implement appropriate measures to monitor any incidental take of bull trout.*

- For purposes of monitoring any incidental take, capture and insert active tags in 10 adult bull trout, each year for three years, (represents about 13% of the average annual ladder count May – July, 2000-2003) from May 2005 through July 2007 (three years of tagging). All tagged fish will be released upstream of Wells Dam,

- Install and maintain receiver arrays necessary to adequately monitor upstream and downstream passage through Wells Dam for 3 years from 2005 – 2008.

- Track and monitor monthly movements of tagged fish from May 2005 through July 2008 while in the Project area (dam and reservoir) until a tributary entrance is observed. Continue tracking all fish that re-enter the reservoir. Fixed receiver sites will be operated to detect any upstream and downstream movement at the dam and tributary entrances. Appropriate mobile tracking methods may include aircraft, boat, and/or vehicle surveys.

- Evaluate upstream and downstream tag detection data from May 2005 through July 2008 to determine status of tagged individuals.

- Compile tracking data to adequately determine fish locations, tag status, and the need to deploy tag recovery operations in the Wells Project area.

- Include upstream and downstream passage results to calculate a 6-year-average incidental take level for the Project in year 2008 by averaging the annual observed take levels for both the 2001 – 2003 3-year study and from the May 2005-July 2008 3-year study. Total Project effect will be calculated for each passage route where feasible, by dividing the number of tagged fish "taken" via that route, by the total number of radio tagged fish. EXAMPLE: If in the first year, 30 fish are tagged and one (1) bull trout is determined to be injured or killed during downstream passage through the dam in that monitoring year, then that year's contribution to the 6-year take average would be 1/52 (30+22), or 3.3%. Data from each of the three year studies will be evaluated in this manner, and then at the conclusion of the 2008 study, the results from all of the previous years of monitoring will be averaged to determine the Project's take level.

- The passage survival and level of incidental take of bull trout at the Wells Project will be assessed for each passage route where feasible. The number of fish detected using some routes may be very low. The incidental take for a passage route, if any and if feasible, will be estimated by the number of observed mortalities to tagged fish that are attributable to that passage route divided by the total number of tagged fish known to have passed through that route. If the route of passage cannot be separated into turbine, spill or bypass then the route determination will default to downstream passage through the dam. A statistical

analysis will be used to detect if the level of incidental take for each passage route and for the total project exceeds the anticipated incidental take level documented in the applicable USFWS biological opinion. The statistical analysis will be a one-tailed test of the hypothesis that the anticipated incidental take level is not exceeded.

- If project effects are shown to be negligible as measured by incidental take monitoring, then the monitoring program will be repeated on a ten year interval as follows. Every ten years for the term of the license (i.e. years 2015, 2025, 2035, etc.), implement the above monitoring program for a one-year period. If the take level is exceeded during that year, a second year of tagging will be implemented. If the take level is exceeded in the second year, Douglas PUD will work with stakeholders to develop a collaborative plan to address the identified problem.

- Douglas PUD will engage in cost share funding with the Service for analysis of genetic samples from fluvial bull trout sampled during the 2005 Mid-Columbia Bull Trout Radio-telemetry Study.

Strategy 1-2: *Analyze passage results and operational data to determine if correlations exist between passage times and passage events and project operations.*

- Compile and characterize Project (spill, turbines, reservoir elevations, TDG) and ladder operations data during times of downstream passage for active tagged fish.

Strategy 1-3: *Determine off-season adult bull trout passage through the adult fishway (numbers and times of year) at Wells for an experimental period 2004 - 2005.*

- Implement off-season video counts of fishway at Wells Dam during the entire winter of 2004 – 2005, to record dates and times of adult bull trout passage. Currently, Douglas PUD engages in video counts of at least 1 adult fishway for 28% (2 days a week) of the off-season period. During this period, no adult bull trout have been observed using the adult fishway.

- Evaluate results to determine if passage trends exist and when ladder maintenance should occur during the off-season.

- If trends exist, investigate ladder maintenance activities during low usage periods for bull trout (where reasonable and feasible) that do not conflict with adult anadromous fish passage.

Strategy 1-4: *Should upstream or downstream passage problems be identified, pursue the feasibility of options to modify upstream passage facilities or operations that reduce the impact to bull trout passage.*

- Douglas PUD will work with stakeholders to develop a collaborative plan should upstream or downstream passage problems be identified that impact adult bull trout passage.

Objective 2
Assess project-related impacts on upstream and downstream passage of sub-adult bull trout.

Strategies for Objective 2
Strategy 2-1: *The stakeholders agree at this time that because of the inability to collect a sufficient sample size of sub-adult bull trout, it is not feasible to assess sub-adult passage at Wells. However, when encountered at the project, or in tributary traps, sub-adult bull trout will be PIT tagged.*

- Douglas PUD will provide PIT tags, equipment and facilitate training to enable PIT tagging of sub-adult bull trout when these fish are incidentally encountered during certain fish sampling operations. Fish sampling operations that could have incidental captures of sub-adult bull trout include the Wells adult fishway, Methow broodstock traps, and juvenile salmonid trapping activities on the Methow, Twisp, and Chewuch rivers. Different entities conduct these fish sampling operations, thus the provision of tags, equipment and methodology should be standardized. Douglas PUD will provide the following for each site: 10 PIT tags (or more if appropriate) and tagging syringes, a list of standardized methods developed in consultation with the Service, and, in coordination with the Service, Douglas PUD will facilitate an annual pre-season coordination meeting with the fish sampling entities.

- Douglas PUD will participate in information exchanges and regional efforts to explore methods to monitor upstream and downstream movement of sub-adult bull trout in the mainstem Columbia River. If methodologies become available, Douglas PUD will, in conjunction with the Service, evaluate and implement those methods as appropriate, for monitoring bull trout at Wells.

- Douglas PUD will passively collect information from all PIT-tagged bull trout as they pass through the fishways at Wells Dam. The District will also remotely scan all bull trout incidentally captured at the screw traps and adult brood collection facilities. The information collected at the dam and in the tributaries will be posted on the PTAGIS website that is operated and maintained by the Pacific States Marine Fisheries Commission.

Strategy 2-2: *Determine off-season sub-adult bull trout passage through the adult fishway (numbers and times of year) at Wells for an experimental period 2004 - 2005.*

- Implement off-season video counts of fishway at Wells Dam during the entire winter of 2004 – 2005, to record dates and times of sub-adult bull trout passage. Currently, Douglas PUD engages in video counts of at least 1 adult fishway for

28% (2 days a week) of the off-season period. During this period, no sub-adult bull trout have been observed using the adult fishway.

- Evaluate results to determine if monthly passage trends exist.

- If trends exist, investigate feasibility to implement ladder maintenance activities during periods (where reasonable and feasible) that do not conflict with adult anadromous fish passage.

Objective 3
Investigate the potential for sub-adult entrapment or stranding in off-channel or backwater areas of Wells Reservoir.

Strategy 3-1: *Evaluate Wells inflow patterns, reservoir elevations, and backwater curves to determine if stranding or entrapment of bull trout may occur.*

- Review Wells forebay elevations, back-water curves, and historical discharges (daily, hourly) from Chief Joseph, to determine Wells Reservoir surface water elevations during low flow periods.

- Determine if backwater locations exist that could lose connectivity to the river during low flow hours. Determine elevations of backwater areas to identify flow scenarios that could result in de-watering or isolation that could result in take. If locations are identified, implement an appropriate fish sampling schedule and method to determine if bull trout are using the identified areas during low flow hours.

- If information shows that take of bull trout occurs due to stranding or de-watering, then Douglas PUD will work with stakeholders to develop a collaborative plan to address the identified problem.

Objective 4
Identify the Core Areas and Local Populations, as defined in the Service Draft Bull Trout Recovery Plan, of those bull trout that utilize the Project area.

Strategy 4-1
Gather genetic samples from radio tagged and pit tagged fish for comparison to baseline genetic samples from local populations and core areas.

- Douglas PUD will provide the equipment and facilitate training to enable genetic sampling of bull trout during bull trout radio-tagging operations and when bull trout are incidentally collected during certain fish sampling operations. Fish sampling operations that could have incidental captures of bull trout include the Wells adult fishway and juvenile and sub-adult salmonid trapping activities on the Methow, Twisp, and Chewuch rivers. Different entities conduct these fish sampling operations, thus the

provision of equipment and methodology should be standardized. Douglas PUD will provide the following for selected sites: 10 sampling kits (or more if appropriate) and a list of standardized methods developed in consultation and coordination with the Service. Douglas PUD will facilitate an annual pre-season coordination meeting with the fish sampling entities. After three years of genetic sampling, operations will be reviewed with the Service to evaluate whether or not to continue the program;

- Douglas PUD will provide funding for the analysis of the genetic samples and to assist in the comparison of genetic baseline samples when those baselines become available.

Strategy 4-2
Work cooperatively with other agencies to obtain locations of radio-tagged fish outside the Project area.

- Douglas PUD will participate in information exchanges and regional efforts to coordinate radio-tag frequencies for bull trout monitoring.

- If radio-tag frequencies deployed by Douglas PUD are not compatible with other monitoring efforts, the PUD will (when feasible) allow the use of their portable telemetry equipment for periodic aerial telemetry efforts.

IMPLEMENTATION
Douglas PUD will begin implementation of the WBTMP no later than May 1, 2005.

REPORTING
Douglas PUD will report any bull trout mortality in the Project area to the Service within 48 hours. During tagging and monitoring years, Douglas PUD will prepare an annual, interim summary report by March 31st for the prior year's activities to update the Service on tag status and take monitoring. Douglas PUD will prepare a final take monitoring report by December 31, 2008, to include a six year average annual take level for the Project.

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Douglas PUD. 2010. Land Use Policy for the Wells Hydroelectric Project

PUBLIC ULTILITY DISTRICT NO. 1 OF DOUGLAS COUNTY
LAND USE POLICY
JULY 15, 1993
(REVISED DECEMBER 17, 2007)
(UPDATED FEBRUARY 1, 2010)

Public Utility District No. 1 of Douglas County (Douglas PUD) owns and operates the Wells Hydroelectric Project (Wells Project) which is authorized under the Federal Power Act by the Federal Energy Regulatory Commission's (FERC) License #2149, as amended. All lands within the Wells Project Boundary are governed by the FERC License. Douglas PUD is organized and operates under Title 54 of the Revised Code of Washington. Douglas PUD also owns land and land rights for its electric, communication and water transmission and distribution systems.

The following are general land use policies which address all of Douglas PUD lands and land rights. The purpose of this policy is to provide guidance for land use management decisions and to:

1. Maintain compliance with FERC License obligations for the Wells Project;
2. Meet applicable federal and state requirements for non-Wells Project lands;
3. Provide for good stewardship of both project and non-Wells Project lands;
4. Provide for consideration of wildlife and/or riparian habitat;
5. Provide for the continued operation of the transmission and distribution system;
6. Provide for consideration of significant historical, cultural and natural features;
7. Evaluate all existing uses of Wells Project and non-Wells Project land and land rights;
8. Comply with existing agreements;
9. Develop a process by which a policy violation can be resolved.

GENERAL POLICIES

A. The use of Wells Project lands shall be governed by the Wells Project FERC License #2149. Douglas PUD shall use its best efforts to comply with all applicable State and federal laws and regulations.

B. A goal of Douglas PUD is to comply with federal and state laws for protection of cultural resources located on Wells Project or Douglas PUD lands in coordination with appropriate agencies.

C. A goal of Douglas PUD is to develop only those recreational facilities that will not interfere with the preservation of natural ecosystems associated with the Wells Project.

D. A goal of Douglas PUD is to sustain the existing natural systems associated with the Wells Project or other Douglas PUD lands.

E. The public shall be allowed access, where practicable, to the waters of Wells Reservoir and adjacent Wells Project lands owned by Douglas PUD. Access shall be without regard to race, color, sex, religion or national origin and shall be in accordance with Policy goals 3, 4 and 6. 5.

F. When making land use or related permit decisions on Wells Project lands that affect reservoir habitat for anadromous salmonids, Douglas PUD shall consider the cumulative impact effects in order to meet the conservation objectives of the Habitat Conservation Plan, the requirements of the FERC License and other applicable laws and regulations. Douglas PUD will notify and consider comments from the signatories to the Wells Project HCP regarding land use permit applications on Wells Project lands.

G. Douglas PUD shall notify all applicants for Douglas PUD permits to use or occupy Wells Project lands or water that such use or occupancy may result in an incidental take of species listed or proposed for listing as endangered or threatened under the Endangered Species Act, requiring advanced authorization from National Marine Fisheries Service or U.S. Fish and Wildlife Service.

Rules Governing Public Use

1. No refuse or litter shall be placed on Douglas PUD lands. The individual responsible for placing any refuse or litter on Douglas PUD lands shall be responsible for its removal. Douglas PUD, after requesting the responsible individual to remove the refuse or litter, shall have the option of removing same at the expense of the responsible individual.

2. Construction activities on Douglas PUD lands are prohibited, except by special permit issued by Douglas PUD. Construction activities include, but are not limited to, removal or destruction of vegetation or grading of the earth.

3. Destruction, defacement or removal of any vegetation or soil (includes sand, rock, minerals, etc.) on or from Douglas PUD property is prohibited.

4. Destruction, excavation, defacement, removal or disturbance of archaeological or historical sites, monuments, graves or boundary markers, material or artifacts is prohibited.

H. Use of Douglas PUD lands or waters within the Wells Project Boundary other than public use shall require a permit.

Rules Governing Permits

1. Application for permits shall be submitted to the Public Utility District No. 1 of Douglas County, 1151 Valley Mall Parkway, East Wenatchee, WA 98802-4497. Permit applications will be reviewed by Douglas PUD to ensure compliance with the FERC License provisions for the Wells Project or applicable federal or state statutes for the electrical or water distribution systems. Decisions may be appealed to Douglas PUD's Commission. All Permits will be in writing and must be approved by Douglas PUD's Commission.

2. Permits on Wells Project lands will be issued only if the proposed use and occupancy meets the requirements of the FERC license and considers protection of the environmental, scenic, historic, cultural or recreational values of the land. Permits are non-transferable and expire upon the sale or transfer of title or subdivision of subject or adjacent land. All permits will expire upon expiration of the Wells Project FERC License. Upon sale or transfer of adjacent lands or termination of a permit, Douglas PUD will re-evaluate the use of the associated Wells Project land to determine the best use of said lands for the future. A permit fee schedule, which may be amended from time to time, will be established by Douglas PUD's Commission.

3. The lands on which agricultural use and occupancy permits are issued must be maintained in accordance with good agricultural practices by Permittee and must comply with all applicable federal and state laws, including the Federal Power Act and specifically FERC License 2149. The use of the lands permitted shall not endanger health, create a public nuisance or otherwise be incompatible with overall Wells Project purpose.

4. Failure to adhere to conditions of the permit may result in cancellation of the permit and/or legal action. Non-permitted use of Douglas PUD lands or waters other than public use, as outlined in Section E hereof, may result in legal action or refusal of a request for permit.

5. Douglas PUD will monitor the uses and occupancies granted by the permit and shall take remedial action when non-compliance is discovered. Douglas PUD reserves the right to cancel the permit and to require removal of any structure, facility, landscaping or agricultural crop located on Wells Project lands, at Permittee expense, IF:

    a. Permittee fails to comply with the terms and conditions of the permit.
    b. Permittee interferes with Douglas PUD's operation of any hydroelectric or electric, communication or water distribution facility.
    c. Continued use or occupancy is incompatible with any new conditions or terms imposed by FERC.
    d. Continued use or occupancy is incompatible with changes in use of surrounding and/or adjacent lands.

6. Permits will be approved and issued by the Douglas PUD's Commission. Before granting a permit the Property Supervisor, after consulting the Chief Engineer for the Wells Project, or the Distribution Engineering Supervisor (depending upon the particular lands involved), must certify that the permit is in the best interest of Douglas PUD and will not adversely affect any current or future Douglas PUD operations. The Property Supervisor will maintain files containing documents and correspondence related to permits, leases, easements and sales of Douglas PUD lands.

7. Douglas PUD shall retain fee simple ownership and possession of all Douglas PUD lands that are subject to franchise, easements, water rights, permits and rights of occupancy and use.

8. If land conveyances occur, an annual report to FERC will be prepared by the Property Supervisor showing all easements, leases, sales and purchases of Wells Project land. Annually, the Property Supervisor will review Wells Project lands to determine if any lands are surplus to Douglas PUD. Following FERC guidelines for sales of surplus lands, these lands will be sold at public sale in order to return them to the tax rolls.

I. The Property Supervisor will be responsible for the acquisition of all Douglas PUD property. The Property Supervisor will provide a written recommendation for purchase, to the Douglas PUD General Manager for approval and submittal to the Douglas PUD Commission. The Property Supervisor's recommendation will require the approval of the Chief Engineer for the Wells Project or the Distribution Engineering Supervisor (dependent upon lands involved) and the Natural Resources Supervisor.

   A condemnation proceeding will only be initiated after an attempt at reasonable negotiations or in the event clear title cannot be secured.

J. Douglas PUD may choose to meet land management objectives through construction of fences or other approved barriers on Douglas PUD lands. Fencing or barriers may be used to assure protection of shoreline riparian and wetland habitat, control public access to sensitive wildlife, cultural or historic areas or to limit access to Douglas PUD facilities that may represent a danger to the public. Private individuals may NOT construct fences on Douglas PUD Property unless authorized by a Douglas PUD-issued permit.

<u>Permitting Process</u>

1. The use of Wells Project lands shall be consistent with and in accordance with the Wells Project FERC License No. 2149. Most Wells Project lands are open for public recreation. All permits for use of Wells Project lands, including fences and docks, will allow for public access. Private docks and fences will not be allowed on Douglas PUD lands without a Land Use Permit.

2. All applications for Land Use Permits will be subject to the General Policies and Rules of Douglas PUD's Land Use Policy as adopted or subsequently amended.

3. The proposed permit will be subject to review and comment as required by various agreements between Douglas PUD and other agencies.

4. Following the submittal of all necessary regulatory permits, Douglas PUD will review the application for compliance with the Land Use Policy, consider regulatory agency and tribal comments and develop a recommendation. The permit and a recommendation for action or denial will be submitted to the PUD Commission for action.

5. The required regulatory permits may include any of the following: Endangered Species Act permits, City/County – shoreline, flood plain, conditional use, substantial development, variance, Army Corps of Engineers – sections 10, 404 & 401, Washington Department of Fish and Wildlife – hydraulic project approval (HPA), Department of Ecology (DOE) –water quality certification, and Colville Confederated Tribes HPA.

6. Applications for permits requiring approval by the FERC will not be forwarded for FERC consideration until all the necessary documentation is submitted to Douglas PUD, Douglas PUD staff has reviewed the application for compliance with Douglas PUD policies and a recommendation has been presented to, and approved by the Douglas PUD Commission.

7. All Land Use Permits shall be approved by the Douglas PUD Commission prior to implementation of proposed activities.

PUBLIC UTILITY DISTRICT NO. 1 OF DOUGLAS COUNTY
LAND USE POLICY
SUPPLEMENT NO. 1, ADMINISTRATIVE RULES
GOVERNING DOCKS AND PIERS
REVISED DECEMBER 17, 2007
UPDATED FEBRUARY 1, 2010

1. ALLOWABLE DOCKS

A. Docks and piers are defined as:

Any structure, fixture, improvement, barge, substantial development, vessel or other platform, whether powered or not powered, whether licensed or not licensed; that is temporary, semi-permanent or permanently moored, affixed or attached to the shoreline; which is customarily or typically used for moorage of vessels, watercraft or floating craft, for recreational uses which include but are not limited to swimming, diving and jumping into the water and/or as a staging location for water associated activities such as waterskiing, fishing, personal watercraft or simple flotation devices; which may interfere or obstruct the use of surface waters or which may extend over surface waters within the Wells Project.

B. Single Party Docks.

1. A permit for a single party dock may be requested by the owner of land adjacent to Wells Project lands. Permits for single party docks are not transferable and must be renewed if the property is sold or transferred.

2. Single party docks may be allowed within the city limits of the Cities of Brewster, Bridgeport and Pateros, as those boundaries exist on or before October 15, 2007.

3. In accordance with FERC's standard land use license article, single party docks may be permitted by Douglas PUD for "noncommercial piers, landings, boat docks, or similar structures and facilities that can accommodate no more than 10 watercraft at a time where said facility is intended to serve a single-family dwelling."

4. Single party docks are prohibited outside the city limits of Brewster, Bridgeport and Pateros as those boundaries exist on or before October 15th, 2007.

C. Joint Use Docks (docks serving two properties)

1. A permit for a joint use dock may be requested if there is a recorded agreement between the parties applying for the permit. Permits for joint use docks are not transferable and must be renewed if either property changes ownership. Two single party docks may be converted to a joint use dock permit.

2. Joint use docks may be allowed within the city limits of the Cities of Brewster, Bridgeport and Pateros.

3. Joint use docks are prohibited outside the city limits of Brewster, Bridgeport and Pateros as those boundaries exist on or before October 15th, 2007.

D. Community Docks (docks serving three or more properties)

1. A permit for a community dock may be requested by a land developer platting or subdividing property or a home owner's association for land adjacent to Wells Project lands. All applicants for community docks must provide a common area within the plat or subdivision for access to the shoreline and the dock.

2. Permits for community docks will be issued to the developer in the name of the homeowner's association or directly to the homeowner's association. The developer or the homeowner's association will be responsible for obtaining the insurance required by the permit.

3. Community docks will be encouraged where necessary for protection of life, health or property or where Douglas PUD determines that it is necessary or desirable for the proper operation of the Wells Project.

4. Community docks are prohibited outside the city limits of Brewster, Bridgeport and Pateros as those boundaries exist on or before October 15th, 2007.

1. INSURANCE

A. Dock and pier permits being requested by the owner and/or homeowner's association of land adjacent to Wells Project lands, must furnish proof of liability insurance at the time of permit request. The proof of liability insurance shall be furnished in the following amounts:

1. Single party docks/piers: $1,000,000.00 (One Million Dollars).

2. Joint use docks/piers: $1,000,000.00 (One Million Dollars), for each adjacent land owner or; $2,000,000.00 (Two Million Dollars), for a joint policy.

3. Community docks/piers: $4,000,000.00 (Four Million Dollars).

B. The applicant also agrees that during the term of this permit a liability insurance policy will be provided covering all operations on the land in an amount not less than prescribed above for the specified permit request. The Permittee will provide Douglas PUD a certificate of insurance evidencing such coverage annually.

3. RESTRICTED AREAS

A. Wetlands, Woody Riparian and Native Vegetation

1. Private docks and piers will not be allowed in shoreline cattail/wetland areas unless the following conditions are met:

a. A mitigation plan is developed and approved by Douglas PUD that addresses the replacement of an area at least equal to the area to be disturbed.

b. The mitigation plan must address the conditions of Douglas PUD, and must consider the comments, if any, of the Washington State Department of Fish and Wildlife, signatories to the Wells Project Habitat Conservation Plan (HCP), Washington State Department of Ecology, the Corps of Engineers, and all local, state and federal agencies with shoreline jurisdiction

c. The approved mitigation plan must be implemented at the Permittee's expense prior to any construction activities related to the dock or pier installation.

C. Cultural Resources

1. No boat docks or piers will be allowed in areas of significant cultural resource value. Federal regulations mandate that these areas are not to be disclosed to the general public.

2. All applications, for dock and pier installations that will result in ground-disturbing activities, will be subject to a site review by a qualified archaeologist prior to construction. Construction activities are subject to the results of the site review. Costs for archaeological review shall be the responsibility of the Permittee.

D. Parks and Trail Areas

1. No additional private docks or piers will be permitted in areas designated as parks or in areas through which improved public access trails pass. Permits for existing facilities are not transferable upon a change of ownership. Areas considered as parks and trails are:

a. Memorial Park, Pateros;

b. Peninsula Park, Pateros;

c. Columbia Cove Park, Brewster;

d. Waterfront Trail, Brewster;

e. Marina Park, Bridgeport;

f. Any new recreation facilities constructed by Douglas PUD in association with the Wells Project.

4. DOCK AND PIER INSTALLATION AND CONSTRUCTION

A. Landscaping on Douglas PUD's Wells Project lands shall be requested by the applicant at the same time and on the same form as when requesting dock or pier approval.

B. The point of attachment to the shoreline shall adequately address erosion control.

C. Dock configuration and installation shall conform to the terms and conditions set forth in all regulatory permits as issued by the overseeing governmental agencies.

PUBLIC UTILITY DISTRICT NO. 1 OF DOUGLAS COUNTY
LAND USE POLICY
SUPPLEMENT NO. 2, ADMINISTRATIVE RULES
GOVERNING FENCES
UPDATED FEBRUARY 1, 2010

POLICY GOAL

The goal of this policy is to maintain open public access to Wells Project lands and compliance with the articles of FERC License No. 2149.

1. FENCES

A. Fences will be allowed only by permit issued by Douglas PUD. Fences will be permitted to the abutting upland owner by Douglas PUD in the following areas; within the cities of Pateros, Brewster, and Bridgeport.

B. Permits for fences are not transferable and new owners must submit an application requesting continuation of the use.

C. Outside the city limits of Brewster, Bridgeport, and Pateros, new fences will not be allowed after April 8, 2003.

D. Private fences installed outside of the city limits of Brewster, Bridgeport, or Pateros prior to April 8, 2003 will be allowed to remain until the ownership of the Permittee changes or Douglas PUD determines cancellation of the permit is in the best interest of Douglas PUD. At Douglas PUD's discretion, the property owner(s) or Douglas PUD shall remove fencing when either of the above actions occur.

E. Douglas PUD reserves the right to place, erect, and install fencing on any and all Douglas PUD owned property at any given time.

2. INSURANCE

A. Persons seeking a fence permit must furnish proof of liability insurance at the time of permit request. Each owner benefiting from a single party fence permit shall furnish proof of liability insurance, in the amount of $500,000.00. A homeowners' association shall furnish proof of liability insurance in the amount of $1,000,000.00, for a community fence permit.

B. The applicant must agree to maintain the liability insurance policy covering all operations on the land called for in 3A for the entire term of the Permit. The Permittee will annually provide Douglas PUD a certificate of insurance evidencing such coverage.

3. FENCE INSTALLATION AND CONSTRUCTION

A. Reasonable public access to Wells Project lands must be accommodated to the satisfaction of Douglas PUD.

B. All construction materials must be approved by Douglas PUD in advance.

C. Fence configuration and installation must be approved by Douglas PUD in advance.

D. All fences must allow for a minimum of 10 feet of width for access between the top of the bank or the ordinary high water mark (whichever is greatest) and the end of the fence. If the Wells Project Boundary is less than 10 feet from the top of the bank or the ordinary high water mark, then a fence will not be allowed on Douglas PUD lands.

Douglas PUD and CBE. 2009. 2009 Turbidity Monitoring on the Okanogan River. Data collected by Columbia Basin Environmental for Public Utility District No. 1 of Douglas County, East Wenatchee, Washington.

Memorandum

Aquatic Settlement Work Group

Date: August 3rd, 2009

To: Aquatic Settlement Work Group and USFWS

From: Douglas PUD and Columbia Basin Environmental

cc:

re: 2009 Turbidity Monitoring on the Okanogan River

Columbia Basin Environmental was contracted to monitor turbidity in the Okanogan River and the Wells Forebay during the spring of 2009. These data were collected to supplement results from the turbidity monitoring conducted in 2008, in which data gaps occurred on occasion due to log jams, battery failure, and location of instrumentation. Specifically, Douglas was requested to implement an additional season of data collection to demonstrate that turbidity did not increase in the Okanogan River as a result of Project effects. The Washington State water quality standard (WQS) is that turbidity shall not exceed 5 NTU over background when the background is 50 NTU or less; or a 10% increase in turbidity when the background turbidity is more than 50 NTU.

Hourly data were collected with a Hydrolab equipped with Hach's Self-Cleaning Turbidity Sensor[1] at Malott (RM 17.0, above Project boundary), Monse (RM 5.0), and the Highway 97 Bridge (RM 1.3; Figure 1). Instrument housing at Monse created a condition in which sediments were collecting in the Hydrolab and negating results for portions of the 2009 monitoring season (Figure 2; data not available between May 28th and June 10th, and between June 12th and 25th). Instrumentation was cleaned, calibrated, and re-deployed on June 25th. A 2100P IS Portable Turbidimeter[2] was subsequently used to conduct weekly grab samples beginning June 25th as an additional measure to compare turbidity between Malott and Monse.

Daily turbidity at Wells Dam Forebay was negligible, ranging from 0.00 to 2.42 NTUs (median 0.00 NTUs, average 0.29 NTUs, standard error ± 0.09 NTUs), and therefore not included in the attached graphs. There were no instances where turbidity at the Wells Dam Forebay exceeded measurements at Malott, Monse, or the Highway 97 Bridge (43, 17, and 42 comparable days between May 27th and July 8th, respectively). Compliance with the WQS numeric criteria for turbidity was demonstrated during all periods in the Wells Forebay.

[1] Accuracy: ± 1% up to 100 NTU, ± 3% from 100-400 NTU, ± 5% from 400-3000 NTU

[2] Accuracy: ± 2% of reading plus stray light from 0 to 1000 NTU (stray light: <0.02 NTU)

Turbidity in the Okanogan River decreased significantly from above the Project Boundary at Malott to Monse, and as waters reached the confluence with the Columbia River (Highway 97; Figure 3). There were no instances where turbidity at the Highway 97 Bridge exceeded measurements at Malott (background) out of 42 comparable days (May 28th – July 8th, 2009). Compliance with the WQS numeric criteria was demonstrated during all periods at the Highway 97 Bridge.

Turbidity was also examined between Monse and the background (Malott) since Columbia River water is known to influence the lowermost portions of the Okanagan River. Measurements collected at Monse (RM 5.0) supported the abovementioned trend of decreasing turbidity throughout the Okanogan and Columbia rivers. Average turbidity at Monse was typically lower than values collected at Malott. Despite the loss of data during periods of instrument blockage, 17 comparable days were collected at Monse. On only one of these days (June 11th) did turbidity at Monse exceed those observed at Malott, but only by 3.2 NTUs – well within the numeric criteria for turbidity (33.1 and 29.9 NTUs, respectively). Grab samples supported these findings that turbidity decreased between Malott and Monse (Table 1, Figure 4). On only one of the weekly grab samples (collected July 14th) did the turbidity at Monse exceed those observed at Malott, but only by 0.7 NTUs, also within the numeric criteria for turbidity (2.6 and 1.9 NTUs, respectively). Data collected in 2008 showed similar patterns between Malott and Monse, with turbidity generally lower at Monse and less deviation around the mean (Table 2, Figure 5).

Collectively, results from both the Hydrolab and grab samples indicate that the Wells Project is in compliance for turbidity at all locations, including Monse, Highway 97, and the Wells Dam Forebay. There were no instances where turbidity at Monse or Highway 97 exceeded turbidity at Malott by more than 5 NTU, and values were generally lesser at downstream locations. These results are consistent with limnological processes.

Figure 1. Location of CBE monitoring stations on the Okanogan River, 2009.

Figure 2. Hyrdolab and sediment blockage after retrieval from Monse on the Okanogan River, 2009.

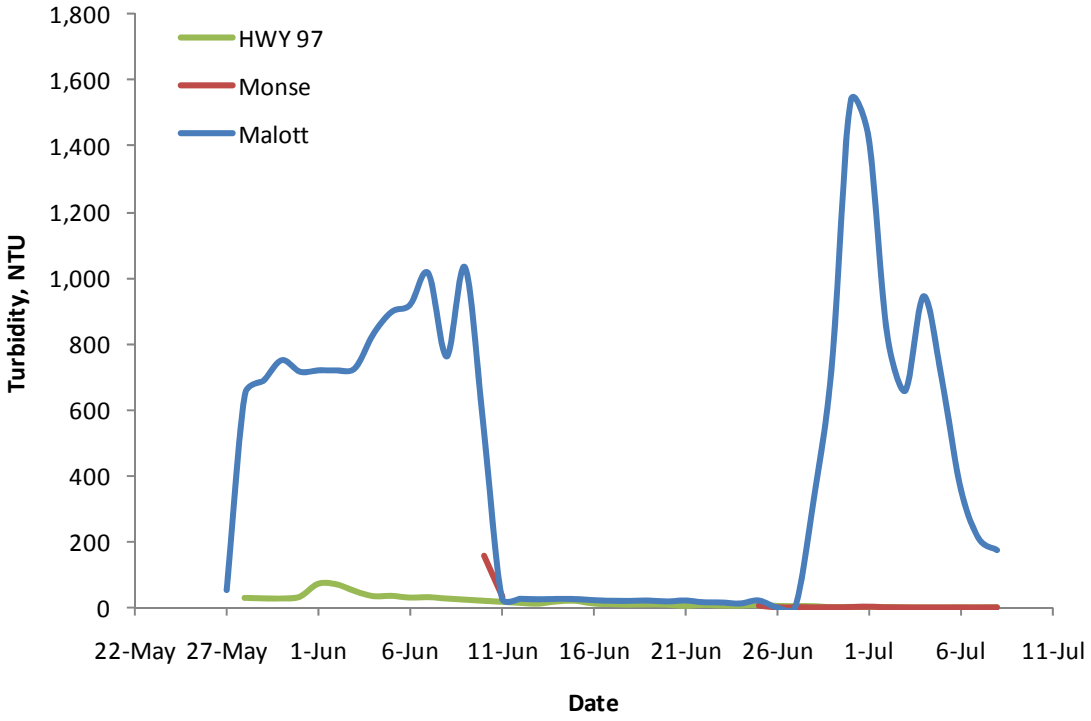

Figure 3. Turbidity (NTUs) collected by Hydrolabs in the Okanogan River at Malott, Monse, and Highway 97, 2009.

Table 1. Grab samples collected from the Okanogan River at Malott and Monse, 2009.

Site	Date	Sample	NTU	Site	Date	Sample	NTU
Malott	06/25/09	19:15	7.0	Monse	06/25/09	19:55	5.2
Malott	06/25/09	19:15	7.1	Monse	06/25/09	19:55	5.5
Malott	06/25/09	19:15	8.2	Monse	06/25/09	19:55	6.0
Malott	07/01/09	15:25	4.2	Monse	07/01/09	15:10	3.7
Malott	07/01/09	15:25	4.8	Monse	07/01/09	15:10	3.9
Malott	07/01/09	15:25	5.2	Monse	07/01/09	15:10	3.5
Malott	07/08/09	9:30	3.3	Monse	07/08/09	11:20	3.4
Malott	07/08/09	9:30	3.9	Monse	07/08/09	11:20	2.5
-	-	-	-	Monse	07/08/09	11:20	2.7
Malott	07/14/09	15:05	2.1	Monse	07/14/09	15:20	2.5
Malott	07/14/09	15:05	1.9	Monse	07/14/09	15:20	2.7
Malott	07/14/09	15:05	1.6	-	-	-	-

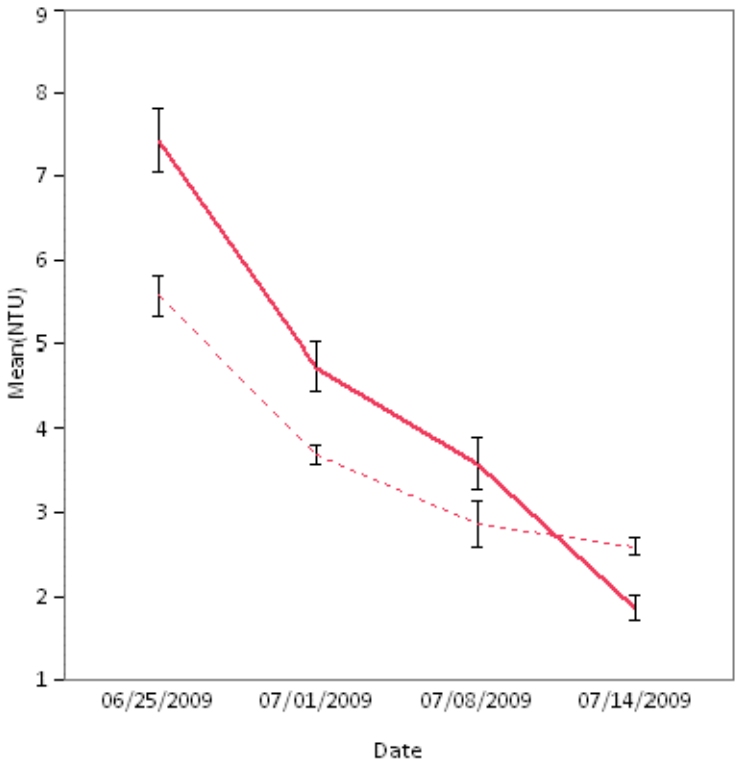

Figure 4. Mean turbidity values (NTUs, ± standard error) collected by a 2100P IS Portable Turbidimeter from the Okanogan River at Malott and Monse (dashed line), 2009.

Table 2. Quantiles and Moments of Hydrolab turbidity data collected at Malott and Monse on the Okanogan River, 2008.

Location	Malott	Monse
Quantiles		
Maximum	546.0	53.7
75% Quartile	15.7	8.5
Median	**5.6**	**4.9**
25% Quartile	2.8	1.2
Minimum	0.3	0.1
Moments		
Mean	**26.4**	**8.4**
Std Dev	81.8	11.6
Std Err Mean	7.8	1.2
upper 95% Mean	41.8	10.7
lower 95% Mean	11.0	6.0
N	111	97

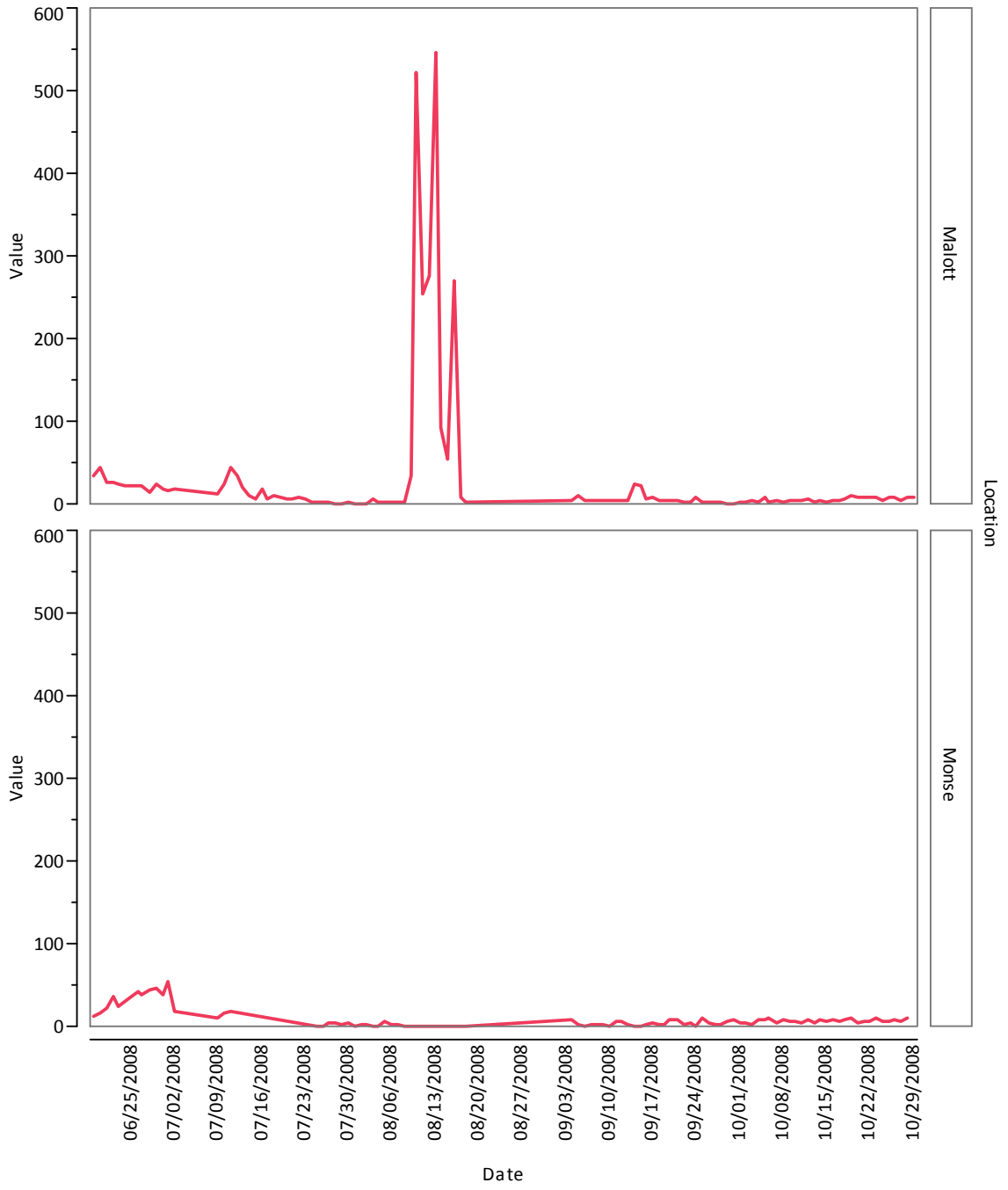

Figure 5. Overlapping Hydrolab turbidity data (NTUs) collected at Malott and Monse on the Okanogan River in 2008.

EES Consulting, J. Carroll, ENSR, and Parametrix. 2007. Total Dissolved Gas Production Dynamics Study. Wells Hydroelectric Project. FERC No. 2149. Prepared by EES Consulting, Joe Carroll, ENSR, and Parametrix. Prepared for Public Utility District No. 1 of Douglas County, East Wenatchee, WA.

TOTAL DISSOLVED GAS PRODUCTION DYNAMICS STUDY

WELLS HYDROELECTRIC PROJECT

FERC NO. 2149

March 2007

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ABSTRACT

This study of the dynamics of total dissolved gas (TDG) production at the Wells Hydroelectric Project (Wells Project) on the Columbia River at River Mile 515.6 included a retrospective analysis of historical TDG data as well as a field study conducted in 2006. The key goal of the study was to evaluate if the Wells Project can be operated to pass 7Q10 river flows (246 kcfs) while remaining in compliance with the TDG criteria allowed under a Gas Abatement Plan which has been approved by the Washington Department of Ecology (WDOE). The study also confirmed that the compliance TDG monitoring stations in the Wells Project forebay and tailrace are suitably located. During the 2006 field study, total river discharge ranged from 16 to 270 kcfs with the median occurrence of 190 kcfs. Four percent of the total discharges recorded during the test period exceeded the 7Q10 flow of 246 kcfs. Wells Dam spill discharges ranged from 5 kcfs to 168 kcfs during the test period.

As a general method of passing larger flows, spill evenly spread across spillways 2-10 resulted in the lowest TDG production, followed by full or single gate spills. Crown spills were intermediate and a dentate spill pattern produced the highest TDG levels.

The Wells hydrocombine spillways are equipped with draft tube deck extensions, which tend to act as deflectors for the spill. These structures tend to force the spill flow towards the surface at certain combinations of depth of submergence and flow rate, and this action impacts the gas exchange characteristics of the released water. Relationships were determined between the gas exchange at Wells Dam and both the depth of submergence of the deflector by tailwater and the spillway bay discharge or discharge per unit width of spillway (kcfs/ft). It was determined that operation at most tailwater levels and spill patterns with unit spillway discharges of less than 0.15 kcfs/ft, should produce TDG levels less than 120 percent, even if forebay TDG is up to 115 percent. For higher tailwater levels, unit spillway discharges of greater than 0.65 kcfs/ft should be employed to keep flow in a favorable regime to minimize TDG production.

A spread spill pattern may be used to pass spill flows up to 45 kcfs using the 0.15 kcfs/ft threshold. For spill flows between 45 kcfs and about 58 kcfs, if tailwater levels are greater than elevation 715 ft MSL, a full gate spill scenario is best at minimizing TDG production by creating a surface jet in the tailwater. For situations when the tailwater is 715 ft or less, expanding the flow through multiple adjacent spillbays is a possible means to maintain a surface jet and minimize TDG production.

The 7Q10 total river flow of 246 kcfs results in a project tailwater level of approximately elevation 720 ft and a flip lip submergence of 29 ft. For this submergence, a minimum unit spillway discharge of 0.65 kcfs/ft or 29.9 kcfs per spillway bay is required to maintain a flow regime favorable to minimizing TDG production. Providing 10 kcfs juvenile bypass flow and 1 kcfs fishway flow while nine turbines are passing 19.5 kcfs each, leaves 59.5 kcfs that must be passed through spillway bays. If two spillbays are used, the flow per bay will be less than the 29.9 kcfs required. The capacity of a single spillway bay is inadequate to handle the required 59.5 kcfs. Therefore the strategy could be to reduce turbine flow. However, this strategy would only be applicable when the 10th unit is not available; having 10 units operating would reduce the required spill.

1.0 INTRODUCTION

1.1 General Description of Wells Hydroelectric Project

The Wells Hydroelectric Project (Wells Project) is located at river mile (RM) 515.6 on the Columbia River in the State of Washington (Figure 1.1-1). Wells Dam is located approximately 30 river miles downstream from the Chief Joseph Hydroelectric Project, which is owned and operated by the United States Army Corps of Engineers, and 42 miles upstream from the Rocky Reach Hydroelectric Project, which is owned and operated by Public Utility District No. 1 of Chelan County (Chelan PUD). The nearest town is Pateros, Washington, which is located approximately 8 miles upstream from Wells Dam (Figure 1.1-1).

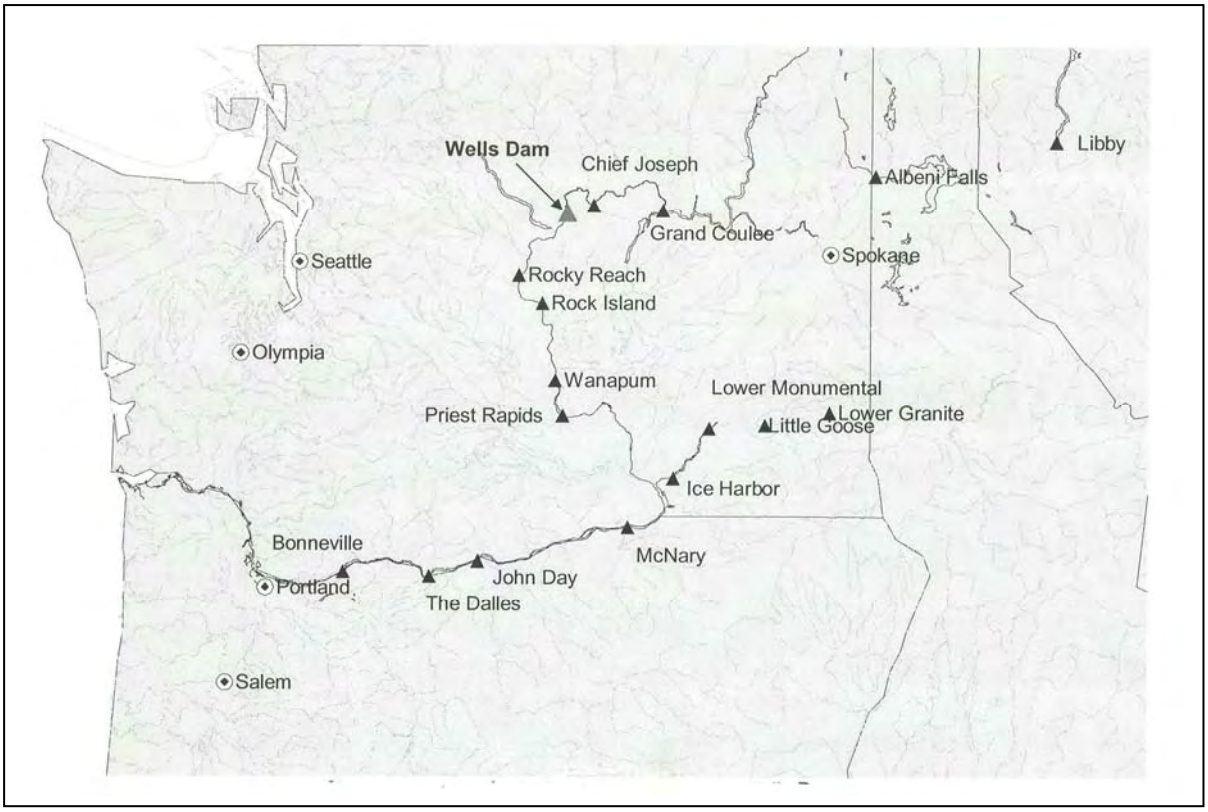


Figure 1.1-1 Regional Map with Project Location

The Wells Project is the chief generating resource for the Public Utility District No. 1 of Douglas County (Douglas PUD). It includes ten generating units with a nameplate rating of 774,300 kW and a peaking capacity of approximately 840,000 kW. The design of the Wells Project is unique in that the generating units, spillways, switchyard, and fish passage facilities were combined into a single structure referred to as a hydrocombine.

Figure 1.1-2 shows a cross section of a spillway unit. Fish passage facilities reside on both sides of the hydrocombine. The concrete structure of the dam is 1,130 feet long and 168 feet wide, with a top deck elevation of 795 feet. There are ten turbine generating units. The spillway is comprised of eleven spill gates that are capable of spilling a total of 1,180- kcfs. Turbines and spillways are numbered from west to east (Figure 1.1-3). The crest of the spillways is at elevation 716 ft which is approximately five and a half feet above normal tailwater elevation with a discharge of 86 kcfs and two feet below tailwater elevation when plant discharge is 200 kcfs.

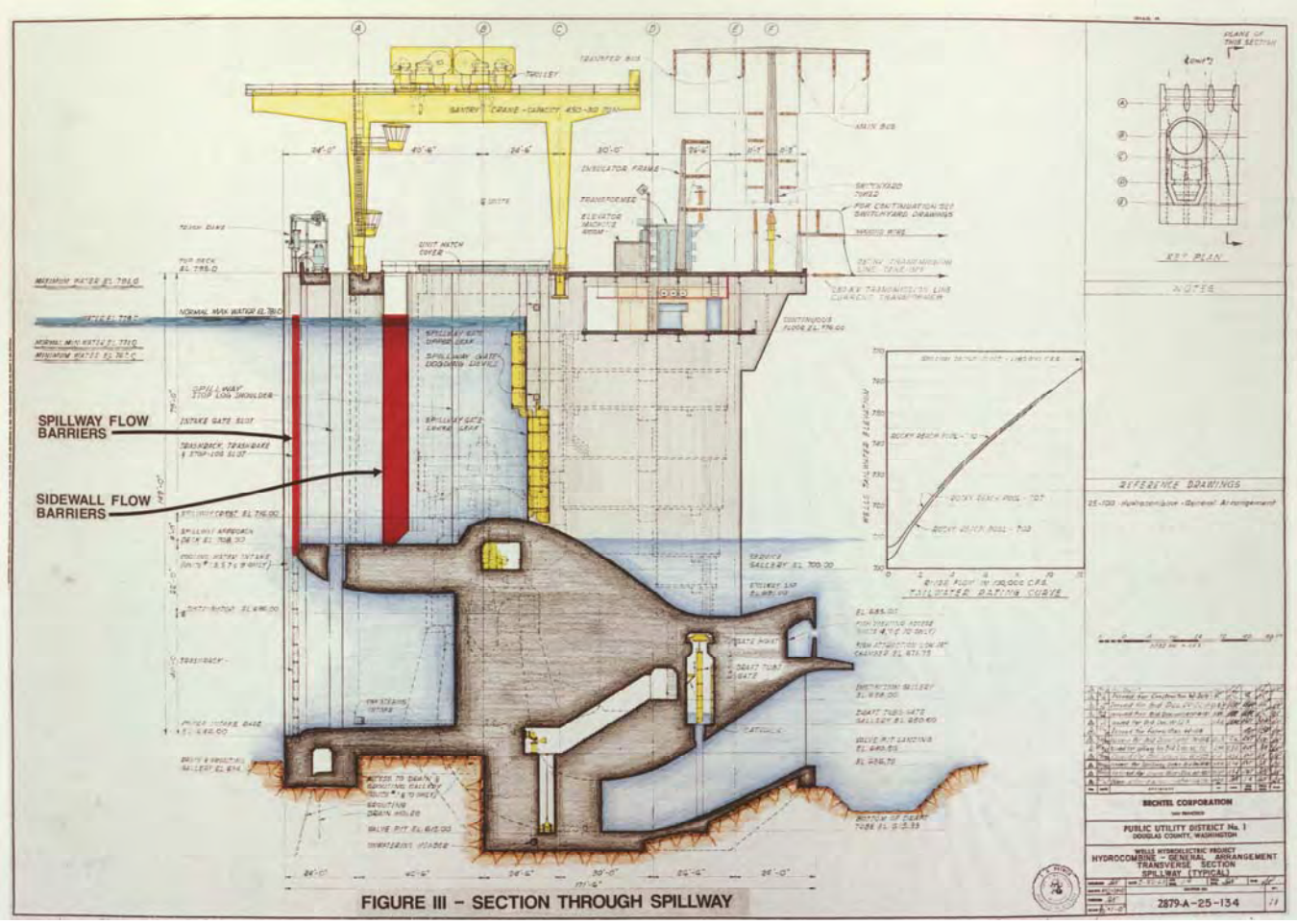


Figure 1.1-2 Cross Section of a Spillway Unit

Figure 1.1-3 Wells Project Turbine and Spillway Configuration

Wells Dam spillway operations consist of forced spill (inflow in excess of powerhouse capacity), fish bypass spill (spill released to assist the out migration of juvenile salmonids) and flood control spill (spill to prevent flooding along the mainstem Columbia River or in inundated sections of tributary streams). Forced spill occurs when the total flow is in excess of the Wells Project powerhouse hydraulic capacity (195 kcfs with 10 units operating). Spill may occur at flows less than the hydraulic capacity when the volume of water is greater than the amount required to meet electric power system loads. Hourly coordination among hydroelectric projects on the mid-Columbia River was established to minimize the latter situation for spill.

Wells Dam is a hydrocombine-designed dam with the spillway situated directly above the powerhouse. Research at Wells in the mid-1980's showed that a modest amount of spill would effectively guide between 92 percent and 96 percent of the downstream migrating juvenile salmonids through the Juvenile Bypass System (JBS) and away from the turbines. The operation of the Wells JBS utilizes five spillways that have been modified with constricting barriers to improve the attraction flow while using modest levels of water (Klinge, 2005). Typically, the JBS will use approximately 6-8 percent of the total river flow for fish guidance. The high level of fish protection at Wells Dam has met the approval of the fisheries agencies and tribes and was vital to the recently approved Habitat Conservation Plan (HCP) with the National Marine Fisheries Service (NMFS).

1.2 Water Quality Regulations

The Washington State Water Quality Standards, set forth in Chapter 173-201A of the Washington Administrative Code, include designated beneficial uses, water body classifications, and numeric and narrative water quality criteria for surface waters of the state. A revised version of the standards was adopted in 2003 and is currently awaiting approval by U.S. EPA.

The 2003 standards designated aquatic life use classification in the Wells Project as noncore salmon/trout (salmon and trout spawning, noncore rearing, and migration).

Under the 1997 standards, the section of the mid-Columbia River that encompasses the Wells Project has been designated a "Class A," or excellent quality water body (Chapter 173-201A WAC).

Total dissolved gas (TDG) is the amount of air dissolved in the water. Criteria in the standards are in terms of percent of saturation pressure relative to ambient atmospheric barometric pressure. The State standard for TDG states that TDG measurements shall not exceed 110 percent at any point of measurement.

NMFS has requested spill at selected hydroelectric projects within the Columbia River basin to assist with out migration of juvenile salmonids. Washington Department of Ecology (WDOE) approves a gas abatement plan which acts like a waiver to the TDG standard.

In addition to allowances for natural flood flows, dams in the Columbia and Snake rivers, have an exception to the 110 percent TDG standard to allow for passage of juvenile fish downstream over the dams rather than through the turbines. On the Columbia and Snake rivers there are three

separate standards. First, in the tailrace of a dam, TDG shall not exceed 125 percent as measured in any one-hour period. Further, TDG shall not exceed 120 percent in the tailrace of a dam and shall not exceed 115 percent in the forebay of the next dam downstream as measured as an average of the 12 highest consecutive hourly readings in any one-day (24-hour period). This exception is based on a risk analysis study conducted by NMFS (NOAA 2004). The study weighed the benefits of spilling water to assist juvenile salmon in avoiding turbine mortalities against the mortalities of fish exposed to harmful levels of dissolved gas.

WDOE recognizes that flood flows may result in elevated gas conditions that dam operators are not able to ameliorate. The TDG standard is waived when the river flow exceeds the seven-day, 10-year frequency flood (7Q10). The 7Q10 flow is the highest flow of a running seven consecutive day average using the daily average flows that may occur once in a 10-year period. The 7Q10 total river flow for the Wells Project was computed using the hydrologic record from 1974 through 1998 and a statistical analysis to estimate flows from 1930 through 1998. The USGS Bulletin 17B,"Guidelines to Determining Flood Flow Frequency" was followed. The resulting 7Q10 flow at Wells Dam is 246,000 cfs (WDOE 2004).

1.3 Project Hydrology Overview

The Columbia River system is primarily fed by snowmelt. Numerous dams and impoundments developed for hydropower and flood control alter the natural flow in the basin. The inflow to the Wells Project is primarily determined by operations of the Federal Columbia River Power System (FCRPS), which is managed for a number of objectives, the primary purpose being flood control, with irrigation, power production, protection of fish resources and recreation being a secondary purpose. In general, the FCRPS is operated to fill upstream storage reservoirs in June, provide augmented summer flows for fish passage and power production through the summer, draft storage reservoirs to meet power demand and salmon spawning requirements through the fall and winter, and, depending on snow accumulations and runoff forecasts, draft for flood control and fill to meet the June refill target through the spring. The FCRPS manages for these objectives using storage releases that pass through the Grand Coulee and Chief Joseph projects and adjusting for inflow from tributary streams above (the Okanogan, Methow rivers) and below (Entiat, Wenatchee, Yakima and Snake rivers) the Wells Project. This water management strategy is a product of the federal biological opinion (NMFS, 2004) and Mid-Columbia Hourly Coordination. The water released from the federal system is utilized by Wells Dam to cover the resource needs of Douglas PUD, Public Utility District No. 1 of Okanogan County (Okanogan PUD) and the four regional power purchasers (Puget Sound Energy, PacifiCorp, Portland General Electric and Avista).

The Wells Reservoir has a surface area of 9,740 acres at a maximum reservoir elevation of 781 feet and is between 1,300 feet and 8,000 feet wide, with an average width of 2,700 feet. Total Wells Reservoir storage volume is 331,200 acre-feet with 97,985 acre-feet of usable storage (based on 10 feet drawdown from 781 feet to 771 feet). The Wells Project is considered a run-of-river facility, meaning that on average, daily inflow to the Project equals daily outflow. The amount of useable storage and the ability to modify river flows is limited. River flows in excess of powerhouse capacity are spilled when reservoir elevations approach the FERC licensed maximum forebay elevation of 781 feet.

Douglas PUD records daily measurements of flow through each of the turbines and spillways passing the Project. The average monthly flow in the Columbia River at Wells Dam from 1976 to 2005 was 108.8 kcfs and ranged from 51.9 kcfs to 300.3 kcfs (Table 1.3-1). Recorded flows are measurements of Wells Project total discharge.

Table 1.3-1 Monthly Minimum, Mean, and Maximum Recorded Flows (kcfs) of the Columbia River at the Wells Project from 1976 to 2005.

Month	***Jan****	***Feb****	***Mar****	***Apr****	***May****	***Jun****	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***
Min	75.7	69.9	56.0	51.9	55.2	73.7	53.4	63.9	57.2	56.0	70.9	75.1
Mean	112.5	113.3	107.4	109.9	139.3	145.8	121.3	103.2	77.8	78.8	91.0	105.3
Max	159.2	180.7	193.9	177.4	251.9	300.3	182.8	181.3	123.0	108.9	110.0	149.0

This study took place during periods of spill up to 168 kcfs. The study specifically focused on project operations with spill at and above 69.5 kcfs, which is the spill rate associated with a 7Q10 total river flow of 246 kcfs with nine of ten Project turbines fully loaded at 19.5 kcfs for power production. The juvenile bypass system (JBS) at the Wells Project uses the even number spillway bays (2, 4, 6, 8 and 10). Normal operation of the JBS discharges 10 kcfs (1.7 kcfs for spillway bays 2 and 10, and 2.2 kcfs for spillway bays 4, 6, and 8) when river flows are greater than 140 kcfs with forebay elevations above 778.0 ft. During periods of extreme high flow (>200 kcfs), one or more of the JBS barriers that partially restrict the spillway opening may be removed to provide adequate spill capacity to respond to a plant load rejection. The odd numbered spillways are available for all other forms of spill.

WDOE requires that the evaluation of TDG level at the 7Q10 flow use the hydraulic capacity for generation at the Project less one unit. The amount of flow that the Wells Project can reliably pass through 9 of the 10 units is 175.5 kcfs (9 units * 19.5.kcfs/unit). Of the remaining 70.5 kcfs flow (246 kcfs – 175.5 kcfs), 1 kcfs is utilized by Wells Dam fishways (500 cfs * 2 fishways) leaving 69.5 kcfs or 28% of total flow distributed through the spillway during a 7Q10 spill event. The water spilled during this time includes the portion generally considered JBS spill through the even numbered bays (up to 8.5 kcfs per bay) plus the additional spill distributed through the odd numbered bays 3, 5, 7, and 9. Use of Bays 1 and 11 is generally avoided due to negative impact of the hydraulic turbulence on the pump efficiency for the fishways.

A key rationale for the design of this study was to evaluate if the Project can comply with the TDG criteria up to the 7Q10 flow and assuming a linear or asymptotic positive relationship between spill and percent TDG in the tailrace, then further assessment of abatement may not be necessary. Therefore, this study focused on evaluating downstream TDG production at a spill of 69.5 kcfs (10 kcfs through the JBS, 1 kcfs through the fishways plus 58.5 kcfs through the spillway), which is the equivalent of the spill occurring when the 9 out of 10 units are loaded and the total river flow is at 246 kcfs at Wells Dam. Flood events of total river flow of at least 246 kcfs occurred during the 2006 study period. TDG levels were also assessed for spills of 69.5 kcfs when the total river flow was less than 246 kcfs. Regression analysis and other relational models based on physical gas exchange processes were used to extrapolate TDG data for these spill conditions to expected TDG levels for higher total river flows.

1.4 Historical Data

The TDG retrospective data analysis was conducted to identify objectives for the 2006 TDG study. The individual objectives of the study included:

- Development of a database of historical water quality and operations data,
- Assess the reliability of the fixed forebay TDG monitoring station (WEL),
- Identification of TDG equilibration periods,
- Analysis of the impacts of project operations on tailrace TDG,
- Development of regression equations for predicting TDG in the tailrace,
- Analysis of expected tailrace TDG levels at the 7Q10 flow, and
- Developing recommendations for the 2006 field study program.

Two water quality and operations databases were developed based on long- and short-term monitoring data from 2000 to 2005. The long-term database includes powerhouse flow, spill flow, TDG saturation, temperature, barometric pressure, and water surface elevation data from fixed monitoring locations in the forebay (Station WEL) and tailrace (Station WELW) for the 2000 through 2005 spill seasons. The short-term database contained 10-minute interval data collected during spill events at the end of May and beginning of June during 2003, 2004, and 2005. These data were used in a statistical analysis to develop regression equations for predicting tailrace TDG at WELW as a function of relevant variables.

As part of this analysis, the reliability of the fixed forebay TDG station (WEL) data was assessed. The forebay TDG at WEL was compared to data measured at temporary TDG stations and found to have a higher daily variation in TDG than the temporary stations. Based on this study, additional data for creating a correction for the forebay station WEL data were obtained.

An analysis of short-term data was conducted to determine the TDG equilibration times in the tailrace. Based on the analysis of equilibrium times for TDG at the tailrace station WELW, the recommendation was made to hold operating conditions steady for a minimum of 3 hours during the 2006 field study program.

Data from the short-term database were analyzed in an attempt to determine the impacts of traditional (2000-2005) operating conditions such as loaded/unloaded spill, flat spill, and crowned spill on tailrace TDG. Short-term regression equations for TDG production as a function of spill flow and forebay TDG were developed to attempt to identify operating conditions that resulted in higher or lower TDG production. Because the data available were limited and the impacts of variation in spill flow during testing could not be isolated from the operational impacts, conclusions about operational impacts were not drawn, but recommendations for further testing during the 2006 field study were made.

As a result of the retrospective data analysis conducted for the long-term monitoring data at Wells Dam, a predictive equation for tailrace TDG at WELW as a function of 2000-2005 spillway configurations, flow and forebay TDG at WEL was developed. The equation was applied for a range of forebay TDG saturations for the spill flow (69.5 kcfs) required to pass the 7Q10 total river flow to predict tailrace TDG at WELW. The regression and historical data

indicated that changes are needed in the way water is spilled whenever forebay TDG ranges from 110.7% to 115.0% in order to meet the standard of 120% at tailrace station WELW. This study provided additional analyses of the effects of operations on TDG production for the purpose of determining if operational changes alone can be used to meet the standard.

2.0 STUDY GOAL AND OBJECTIVES

A key goal for this study was to evaluate if the Project can be operated to pass the 7Q10 river flow while remaining in compliance with the approved gas abatement plan's TDG criteria for the mid-Columbia River. Another goal of the study was to better define and quantify processes that contribute to dissolved gas transfer and downstream dynamics during spillway releases at Wells Dam. The study focused on spill events of 69.5 kcfs, which is the spill volume when the total river flow is at the 7Q10 flow with nine of ten turbine units fully loaded. The specific objectives of this study were to:

1) Characterize TDG percent saturation in the Wells tailrace as a function of project operational conditions including spill discharge, spill pattern, percent spill, tailwater elevation, total project discharge, forebay elevation and forebay TDG levels.

2) Describe dissolved gas levels and transport patterns in the Wells dam tailwater for several targeted operational scenarios during test spill events of up to 69.5 kcfs. Determine if the Project can be operated in compliance with the tailwater TDG criteria allowed under a WDOE approved gas abatement plan for the 7Q10 total river flow of 246 kcfs.

3) Quantify the extent of gassing of powerhouse flows due to interaction with spill.

4) Evaluate how representative the TDG compliance monitoring stations located in Wells forebay and tailrace are.

5) Collect geo-referenced velocity and depth data necessary to support a Computational Fluid Dynamics (CFD) model of the tailrace that may be later applied to evaluate operational means to mitigate dissolved gas production at the Project.

6) Identify operational spill scenarios that move towards Project compliance with the tailwater TDG criteria allowed under a WDOE approved gas abatement plan.

3.0 STUDY AREA

The study area (Figure 3.0-1) included the forebay and tailrace waters of the Wells Project. Total dissolved gas pressure and water temperature data were collected within 1 km upstream of Wells Dam. The study area extended approximately 5 km downstream of Wells Dam, which coincides with the TDG compliance monitoring station operated by Douglas PUD. TDG data for the Rocky Reach Hydroelectric Project forebay were collected and furnished by Chelan PUD and were also incorporated into the analysis.

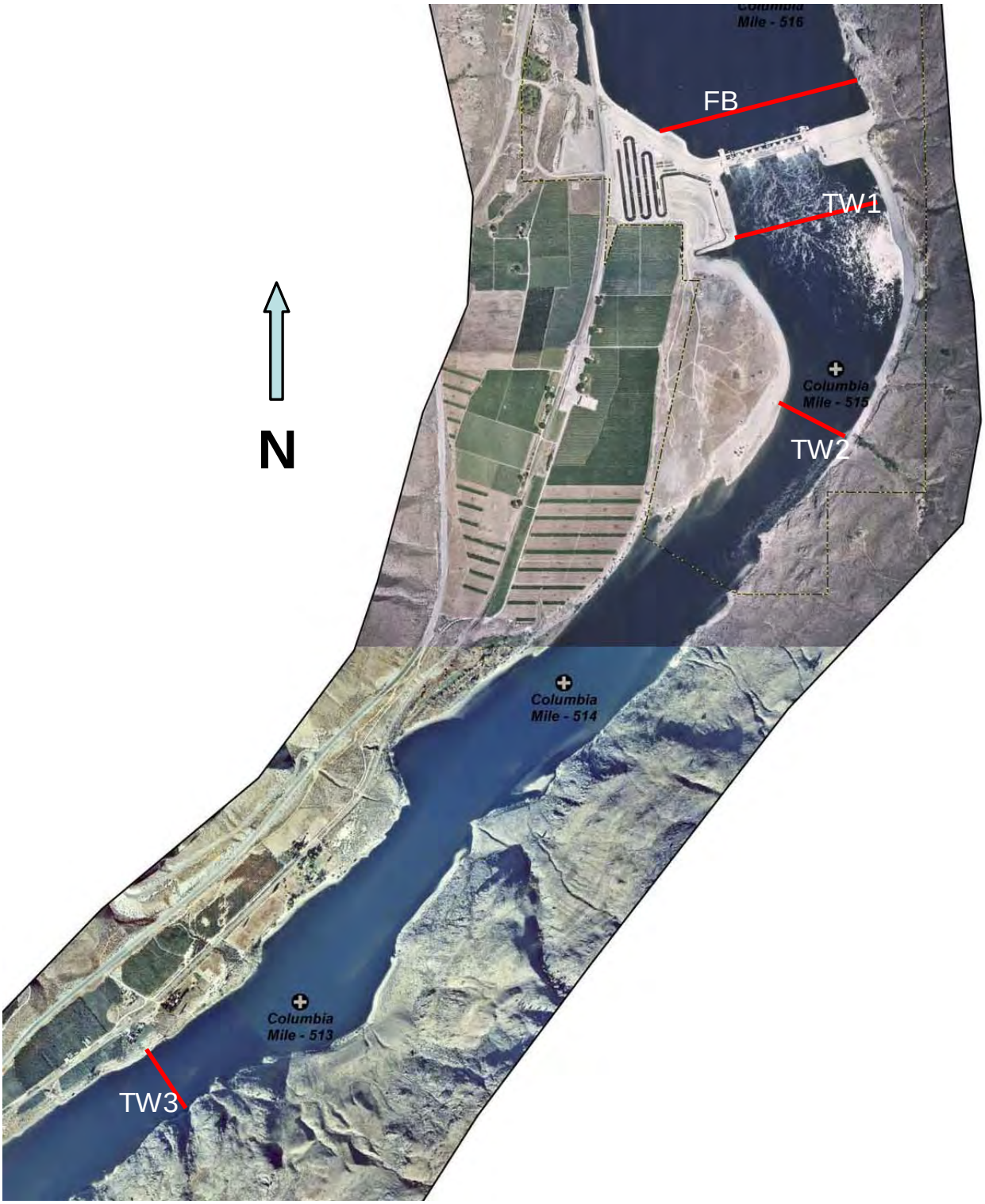


Figure 3.0-1 Study Area for 2006 Wells Hydroelectric Project TDG Study

4.0 METHODOLOGY

4.1 TDG Assessment

The 2006 Field Study was conducted over 46 days, from May 14 until June 29, 2006. Total dissolved gas pressure and other data relevant to characterizing TDG patterns in the tailrace were collected for a range of flows up to 254 kcfs (slightly higher than the 7Q10 discharge). Flow data for each test are reported as the average for the test period; however, instantaneous flows may be higher. The testing concentrated on dissolved gas dynamics in the near field to the dam (within the immediate forebay, tailrace/tailwater, and downstream to the tailwater fixed TDG monitor located approximately 5 km downstream of Wells Dam). An array of 15 automated remote instruments capable of logging time histories of TDG pressures were utilized at 13 instrument locations throughout the tailwater area of Wells Dam. Data from the instruments were complemented with velocity measurements suitable for estimating the TDG flux produced during test conditions. The change in TDG levels upstream and downstream of the Wells Dam were evaluated as an index of the amount of TDG added by project operations.

4.1.1 Monitoring Locations

Twelve temporary TDG monitoring stations were established downstream of Wells Dam in addition to the existing fixed tailwater monitor, WELW. There were four stations or locations distributed uniformly on each of 3 lateral transects. Ten of the 12 temporary stations consisted of 1 remote TDG logging instrument placed on river bottom. Two of the added stations had 2 instruments, one positioned near surface and the second placed on bottom. This came to a total of thirteen stations and 15 remote instruments deployed along 3 lateral transects located at various longitudinal distances downstream of the project to record the time history of TDG pressures as operational changes were implemented. Hence, lateral and longitudinal gradients in TDG pressures were investigated downstream of the spillway.

The tailwater-sampling station array was established to measure the TDG pressures during the study. Primary sampling transects were established at approximately 1,000 ft; 2,500 ft; and 15,000 ft downstream of Wells Dam (Figure 3.1-1). Station names consist of the transect label plus the order of position from the left bank. Transect TW1 with 4 stations distributed across the river was located nearest to Wells Dam and near the downstream edge of aerated flow resulting from spill. The two end stations had instruments at two depths, bottom and near surface. TW2 the mid-range transect, also with 4 instrument locations, was located near the area previously recommended by WDOE for a new downstream TDG compliance monitoring location. TW1 and TW2 with station positions are shown in Figure 4.1-1. The most downstream transect, TW3 with a total of 5 stations (including WELW), was located adjacent to the existing tailrace compliance monitoring station, WELW, and is depicted in Figure 4.1-2.

Forebay TDG monitoring was performed to establish background levels and evaluate how representative is the forebay compliance monitoring station, WEL. Two instruments were deployed in the forebay in addition to the compliance instrument WEL. These two instruments were deployed approximately 300 ft laterally to the WEL station. These instruments formed the TDG study forebay transect FB1 as shown in Figure 4.1-1.

The effort in both the forebay and tailwater resulted in a total of 14 temporary remote stations plus the two fixed monitors with a total of 18 logging TDG instruments.

Instantaneous grab sample measurements of TDG pressure were used to refine the selection of locations for deployment of the fixed station instruments. These manual grab sample TDG measurements taken from a boat or from the project deck were made by lowering a manual instrument and weight to a depth of approximately 5 m. The instrument was held in place for sufficient time to allow equilibration with ambient conditions.

A Trimble XRS Geographic Positioning System (GPS) was used to record instrument locations as well as the locations of grab sample measurements. This GPS provided sub-meter accuracy.

Figure 4.1-1 Station Deployment Locations for TDG Instruments in Forebay Transect FB1 and Tailwater Transects TW1 and TW2

Figure 4.1-2 Station Deployment Locations for TDG Instruments Downstream of Wells Dam at Transect TW3

4.1.2 Monitoring Instruments and Deployment Methods

Hydrolab® Datasonde® 4a instruments equipped with TDG, temperature, and depth sensors were used to automatically record data at 15 minute intervals (on the hour and quarter hour). The instruments recorded date, time, total dissolved gas pressure (mmHg), depth (ft), and water temperature (^{o}C). Instrument battery voltage (volts) was also recorded.

Upon retrieval, 17 of the 18 TDG instruments returned data. Station FBP1 failed to record TDG data. Two of the downstream instruments became silted in, which causes delayed or suppressed response to TDG; these data were excluded from future analysis. In addition, two instruments experienced intermittent power failures with subsequent data loss.

Instrument deployment methods for the tailwater stations was consistent, using 200 lb steel housings attached to a series of surface floats via 5/16 diameter steel cable that allowed deployment and retrieval of instruments by boat. (Figure 4.1-3). The forebay temporary instruments were weighted and suspended from the existing trash or boom line. All instruments were positioned at depths equal or greater than 5 m where possible.

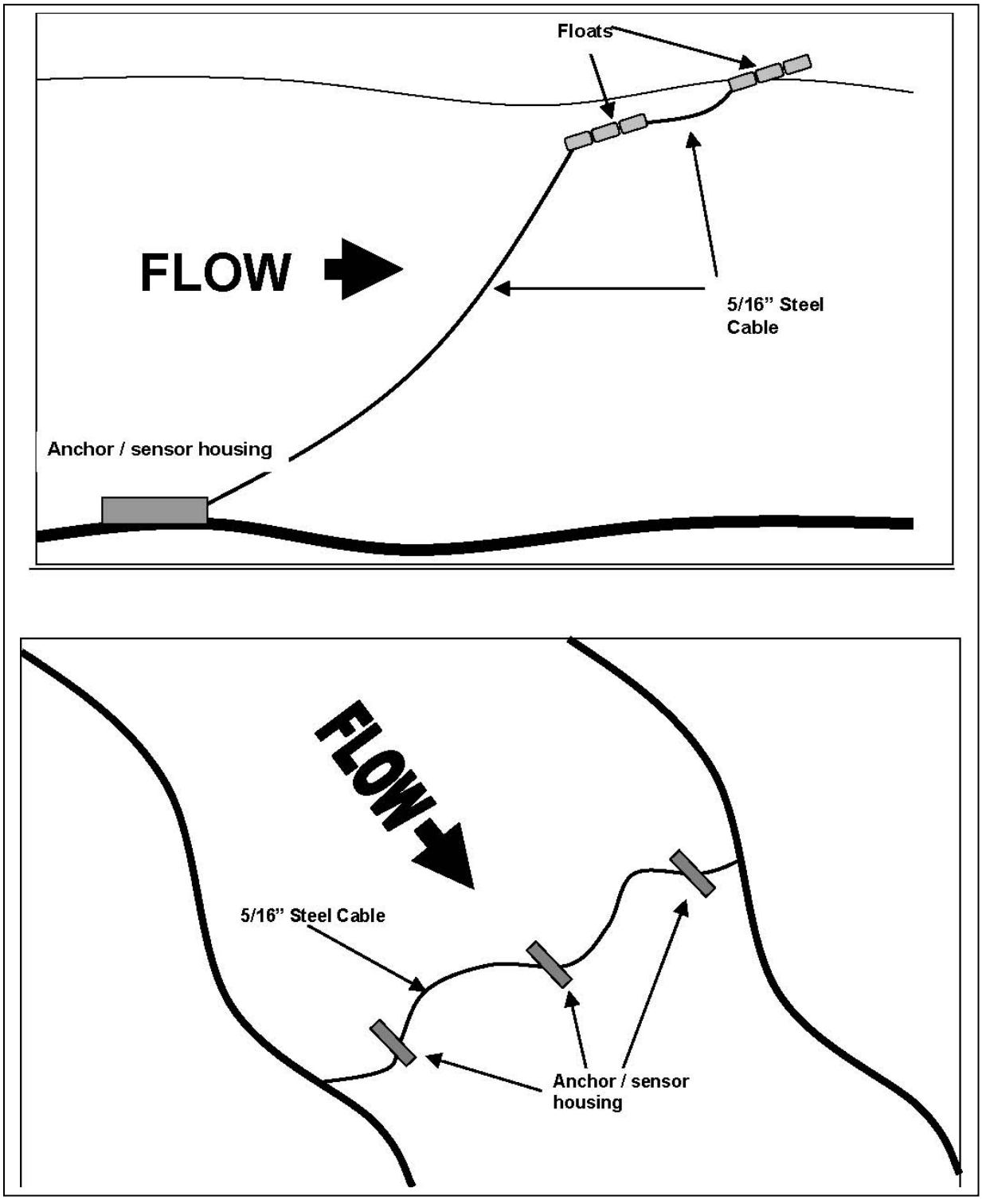


Figure 4.1-3 Typical TDG Sensor Deployment Scheme

4.1.3 Barometric Pressure

Barometric pressure is necessary to compute the percent saturation relative to total dissolved gas pressure. Douglas PUD operates a continuous recording climate station at Wells Dam, which includes the capability to record barometric pressure. A hand held digital barometer was used to verify the climate station barometric pressure. The handheld digital barometer (hydrosonde) was compared to a National Institute of Standards and Technology (NIST) traceable mercury barometer prior to and subsequent to field deployments. Forebay barometric pressure (BP) was taken from the Douglas PUD station located on top of the dam (≈790 ft msl). Tailwater BP used Douglas PUD station data corrected for -75 ft change in elevation (2 mmHg added to BP).

4.1.4 Calibration and Maintenance

Instruments were calibrated prior to deployment and checked again after retrieval according to the manufacturer's specifications. Instrument calibration procedures are summarized in Appendix D. At each servicing, competent personnel checked for and, if necessary, fixed site problems (probes clogging, leaking membranes, instruments out of calibration, etc.) and recalibrated the instrument(s) as needed. All instruments met Quality Assurance (QA) requirements following retrieval. No membrane failures occurred during the study.

4.2 Operational Data

Close coordination between the TDG assessment team and project operators during the field data collection period was essential for both safety and success of the study. Protocols for field teams to communicate with project operators when field personnel were working on the river downstream of the dam were detailed in the Health and Safety Plan. A representative of the TDG assessment team coordinated with the project operators to ensure the desired test conditions were provided during the monitoring period. This coordination was ongoing throughout the monitoring period in order to respond to changing flow conditions.

It was necessary to control operations at Wells Dam during test (spill) events as conditions allowed. Variations in total discharge, tailwater elevation, and spill discharge/pattern were minimized during testing periods. For the purposes of this study, a spill event was defined as at least three (3) hours of operation at targeted levels. This allowed flushing and steady state conditions of the entire tailwater region such that all probes had multiple equilibrated measurements, and thereby increased the sample size for a given spill event. The spill events were scheduled throughout the period when TDG matrix sensors were deployed. The schedule was coordinated between Douglas PUD and the assessment team operations coordinator.

Project operations data were queried from the Douglas PUD database on a 1-minute interval and then reduced to 15-minute intervals using the mid point value of a 15-minute running average. The resulting 15-minute operations data were used for analysis relative to the TDG data. Even numbered spill bay data were hand entered in the dataset from dam operator logs. Data were stored in the dataset on a 15-minute interval (on the hour and quarter hours) in an Excel format for the duration of the study. Table 4.2-1 summarizes the project information requirements logged for this study.

Table 4.2-1 Wells Project Operation Data Logged for Spillway Evaluation

Parameter	Units of Measure
Total river discharge	(kcfs)
Total spill discharge by gate	(kcfs)
Total generation discharge by unit	(cfs or kcfs)
Juvenile Bypass System by gate	(cfs or kcfs)
Total fishway discharge (constant)	1 kcfs
Forebay elevation	(ft above mean sea level)
Tailwater elevation	(ft above mean sea level)

4.2.1 Project Operating Conditions

A complete summary of specific project operations during the TDG field data collection period is shown in Appendix B and was developed as the results of the retrospective data analysis and on input from other team members and Douglas PUD. The spill rate identified for a 7Q10 flow when 9 of the 10 turbines are loaded to the sustainable capacity of 19.5 kcfs is 69.5 kcfs.

The tests were devised to evaluate various operational modes for trends in TDG production and are listed in Table 4.2-2.

Table 4.2-2 Spill Categories for TDG Tests

Symbol	Name	Description
JBS	Juvenile Bypass spill	Standard fish spill through bays 2, 4, 6, 8, and 10 at approx 2 kcfs per bay, flap gates are used in bays 2 and 10 with underflow at others
MJBS	Modified Juvenile Bypass spill	Reduced JBS spill as total project release is minimal
S	Spread spill	Spill is spread across bays 2 through 10 in a near uniform pattern
FG	Full Gate spill	In addition to normal JBS discharge, spill was concentrated through one gate, generally gate 7 but gate 5 was used for 2 of these treatments
C	Crowned spill	Spill is concentrated across 3 adjacent bays, either 5-7 or 7-9, normal JBS from other even numbered bays
BC	Biased Crowned spill	Specific to concentrated spill across 3 adjacent bays 7-9
D	Dentate	Normal JBS with the added spill distributed uniformly across the odd numbered bays (this is the operators choice under normal conditions)

A test was defined as operating the Project for the stated test condition for at least a 3-hour time block. Numerous operational constraints were considered when devising the spill configuration for test conditions. These constraints included:

1. Avoid spilling in gates 1 and 11 due to negative impact of hydraulic turbulence on the pump efficiency for the fishways.
2. Turbine unit 1 is out of service until late in the testing period.
3. Turbine capacity is 20.5 kcfs; however 19.5 kcfs provides for continuous steady operation near capacity. Maximum turbine capacity is 21.5 kcfs but this rate can only be sustained for a very short time.
4. To pass the 7Q10 river flow, need to be operating no more than 9 turbines.
5. Gates 2 and 10 require the gantry crane to set, which increases the time and effort to set up. These two gates have the ability to utilize both top spill and bottom spill (all other gates utilize bottom spill) as they also function as ice trash sluiceways. When the forebay elevation is between 781 (full pool) and 778, the top spill is operating but when it drops below that, they can use the gantry crane to open the bottom spill to maintain fish passage flows as required by the HCP. In short, these are the most difficult spillbays to manipulate and scheduling test scenarios had to take this into consideration.
6. Minimum turbine operation load is 12-15 kcfs.
7. JBS minimum spill is 2.2 kcfs for even numbered gates4, 6, and 8.
8. JBS minimum spill is 1.7kcfs for flap gates 2 and 10.
9. JBS maximum spill is 8.5 kcfs without affecting baffles.
10. Maximum spill for a gate adjacent to a JBS spillbay is 44 kcfs at a 26 foot opening.
11. Total River Flow includes 1 kcfs for fishways.

The study produced data resulting from 80 tests, 30 scheduled (District 2006) and 50 unscheduled or incidental.

4.3 Hydrodynamics

4.3.1 Sample Design

4.3.1.1 Sampling Locations and Strategy

Three-dimensional velocity data were acquired at the approximate locations and transects shown in Figure 4.3-1 and tabulated in Table 4.3-1. The target locations and transects were prioritized, as also indicated in Table 4.3-1, because it may not have been possible to occupy all stations and transects due to field conditions and/or time constraints. The prioritization ensured that the most important data were indeed collected.

Acoustic Doppler Current Profiler (ADCP) data were collected on stations along the transects, as indicated in Figure 4.3-1. These locations were selected based on the locations of the TDG sampling locations (also shown in Figure 4.3-1), consideration for the use of the data for calibration and verification of a CFD model, and consideration for characterizing the hydrodynamic conditions responsible for TDG flux. Moving transect discharge measurements were collected along the same transects.

Water level measurements were collected at several approximate locations, as indicated in Figure 4.3-1. These locations were selected based on considerations for the use of the data for calibration and verification of a CFD model, and consideration for characterizing the hydrodynamic conditions responsible for TDG flux.

4.3.1.2 Instrumentation

A 1200 kHz RD Instruments Workhorse Rio Grande ADCP was used to collect current profiles on all measurement lines. This meter was capable of collecting velocity data in a profile extending from approximately 7 feet below the surface to a depth of approximately 65 feet, assuming data collection at 2 meter depth intervals (bins) and using the low resolution/long range mode of the instrument. ADCPs determine current velocity by measuring the frequency shift of reflected acoustic energy. The flow velocity components along the paths of three beams are used to resolve the vector and the fourth beam provides a consistency check. Each acoustic beam is a cone 3.0 degrees wide originating from the unit. The centerline of each beam projects 20 degrees from the instrument centerline resulting in a total beam spread of 43 degrees. The ADCP is capable of determining vessel motion relative to the riverbed to within ±0.02 feet per second (fps). This feature is used to provide absolute current velocity and direction with respect to the bottom by subtracting vessel motion from the resultant flow vector. An internal flux gate compass with tilt sensor corrected all velocity data automatically to magnetic north.

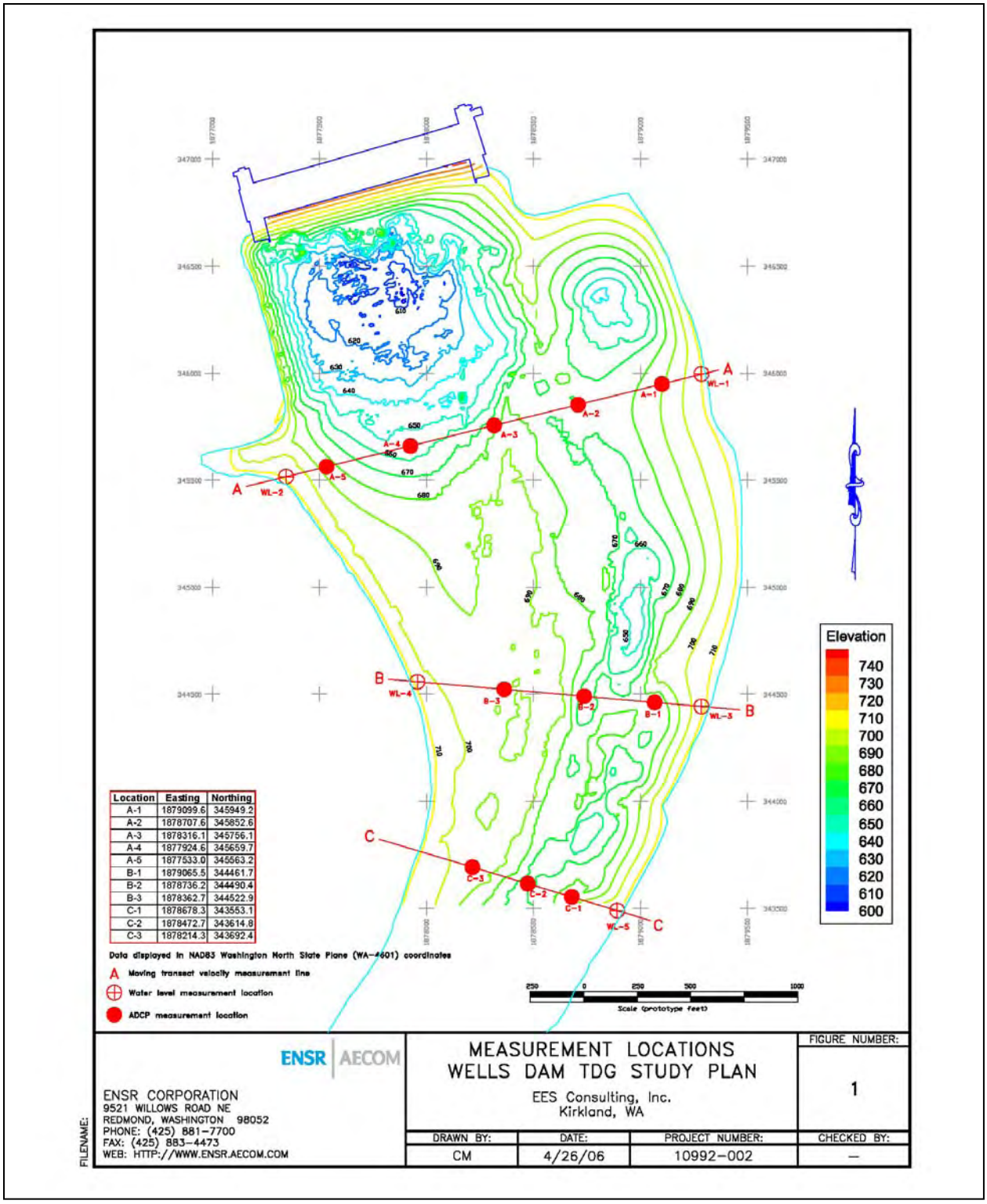


Figure 4.3-1 Bathymetry and Station Deployment Locations for Hydrodynamic Data Collection

Table 4.3-1 Prioritized Stationary Velocity Profile and Moving Transect Discharge Target Measurement Locations				
Priority	**Station/Line**	**Easting (ft)**	**Northing (ft)**	**Stationary (S) or Moving Transect (MT) Measurement**
1	A (West to East) – Begin	1877344.1	345516.7	MT
	A (West to East) – End	1879284.0	345996.6	
2	A (East to West) - Begin	1879284.0	345996.6	MT
	A (East to West) - End	1877344.1	345516.7	
3	A5	1877533.0	345563.2	S
4	A4	1877924.6	345659.7	S
5	A3	1878316.1	345756.1	S
6	A2	1878707.6	345852.6	S
7	A1	1879099.6	345949.2	S
8	B (East to West) - Begin	1879284.2	344442.7	MT
	B (East to West) - End	1877957.0	344558.1	
9	B (West to East) - Begin	1877957.0	344558.1	MT
	B (West to East) - End	1879284.2	344442.7	
10	B1	1879065.5	344461.7	S
11	B2	1878736.2	344490.4	S
12	B3	1878362.7	344522.9	S
13	C (West to East) - Begin	1878890.5	343489.4	MT
	C (West to East) - End	1877988.1	343756.8	
14	C (East to West) - Begin	1877988.1	343756.8	MT
	C (East to West) - End	1878890.5	343489.4	
15	C3	1878214.3	343692.4	S
16	C2	1878472.7	343614.8	S
17	C1	1878678.3	343553.1	S

The ADCP was mounted directly to the hull of the survey boat with its beams aligned with the long axis of the boat. This facilitated the use of a gyroscopic compass to correct the ADCP compass data to a true north orientation.

The ADCP has a manufacturer specified procedure for checking the electronic circuitry and transducer transmitting frequency that was performed prior to deployment. In addition, the fourth ADCP acoustic beam was used to measure differential error to establish whether the bin measurements were affected by spatial variations in the field and interference from flow boundaries. A significant differential error indicates that the bin is not adequately homogenous, which may indicate that the meter's ability to resolve all three velocity vectors was compromised.

The proprietary software WinRiver version 1.06, available from the manufacturer of the ADCP, was used to record data to a computer on-board each boat. The software was set up to accept additional data input from both an external heading device (gyroscopic compass) and a GPS.

The survey boat was equipped with a Seatronics gyroscopic compass to correct internal ADCP flux gate compass headings to true north. This instrument can report headings within ±1.5 degrees of true north and was interfaced to the ADCP data collection software (WinRiver) to correct measured velocity components to a true north orientation. The gyroscopic compass has no factory-specified checks, other than turning the equipment on and making sure it works and transmits data properly. The gyroscopic compass required significant start-up time to stabilize, up to three hours. The gyroscopic compass was started and checked for operation prior to the start of data collection. No field calibration can be performed, but its output was checked against a known bearing. The only user input to the gyroscopic compass was the latitude of the measurement site (48°).

The survey boat was equipped with a Trimble Ag132s Differential Global Positioning System (DGPS) receiver capable of receiving real-time differential corrections from either the Coast Guard beacons in Appleton, WA or Fort Stevens, OR, or from a commercial OmniSTAR satellite. The DGPS antenna was mounted directly above the ADCP, so no position offset correction was required in the ADCP data. The DGPS was also interfaced with the ADCP data collection software (WinRiver) computer to obtain the position for each velocity data point. Positions were recorded in NAD 83, Washington State Plane, North Zone, coordinates. The DGPS had no factory-specified checks, other than turning the equipment on and making sure it works and transmits data properly.

Hypack MAX v. 4.3 Gold navigational software provided real-time positioning guidance to the boat operator by providing on-screen boat position versus target location. This helped in locating measurement stations and in station-keeping once current measurement started.

The vertical position of the ADCP was determined by measured water surface elevations for each flow condition and a measurement of its submergence below the water.

An Impulse 200 laser rangefinder mounted on a tripod was used to measure the water surface elevation along the river banks relative to a reference benchmark. The manufacturer's reported accuracy of the instrument is + 0.1 ft vertical at an approximate distance of 1800 ft. Distance accuracy at maximum measuring distance is 0.1 to 0.2 ft. Instrument resolution is 0.01 ft.

4.3.2 Data Collection Methods

4.3.2.1 Velocity Measurements

The data collection software WinRiver was set up such that ensembles of data were collected at approximately 1 Hz with 1 ping per ensemble. Data were collected at depth increments (bin size) of approximately 6.6 feet for the majority of the data. Based on an average sampling time of 10 minutes at each station, this resulted in approximately 600 data points per station, from which average and standard deviations of the velocity components can be calculated.

No velocity data were recorded at depths shallower than 5 feet or deeper than 75 feet, due to the limitations of the 1200 kHz Workhorse Rio Grande ADCP. The ADCP was attached to a staff that could be lowered and tilted to ensure the instrument was vertical. It was anticipated that 15 minutes were required to position the boat at a station, collect ADCP data, and move to the next station or transect.

4.3.2.2 Discharge Measurements

Approximately 30 minutes were required to complete each moving transect and position the boat at the next measurement station or transect.

The survey boat moved along the transect line at 1-2 knots, during which time ADCP data were collected at approximately a 1 Hz sampling rate at depth increments (bin size) of approximately 6.6 feet for the majority of the data. The distance from shore to the instrument at the beginning and end of the transect were estimated and noted to allow an estimate of the near-shore discharges to be computed by the WinRiver software.

4.3.2.3 Water Level Measurements

A crew surveyed the water elevation along the right and left bank. A local semi-permanent benchmark was established nearby each location where water surface elevations were being measured. One surveyor positioned a stadia rod with attached rangefinder target so that the foot of the rod was just touching the water surface forming a meniscus. The crew was instructed to select a location with minimal wave action to ensure accurate water level measurements.

The field person operating the rangefinder (lead surveyor) recorded the elevation of the local benchmark and radioed that information to the rod holder. The local benchmark elevation was noted on flagging attached to the benchmark. The lead surveyor next measured and recorded the water surface elevation. The measurement of the water surface elevation was repeated at least twice at each site with duplicate measurements having a difference no greater than 0.01 ft. The survey was closed out by rechecking the elevation of the local benchmark. The rod holder then moved to the next location and the process was repeated. At the end of the survey, the reference benchmark was again surveyed.

The coordinates for the reference benchmark, position of the rangefinder, and location of measurement of water surface elevations were recorded with a Trimble global positioning system (GPS). The rangefinder also recorded the compass bearing and distance to each measurement location so that the points could later be plotted if necessary.

4.3.2.4 Data Storage and Backup

The primary storage of collected velocity data was on the internal hard drive of the data acquisition computers. The data were also backed up onto a removable USB flash drive at the end of each day.

4.3.3 Analytical Approach

The DGPS and velocity data were reviewed upon return to the office and obvious data outliers were excluded from further analysis. The data were then transformed into consistent engineering units and combined into single time series for each measurement location. Finally, the results were reviewed for accuracy and stored for later use. However, some additional analysis will be necessary prior to use for calibrating or verifying a CFD model. See Section 5.4.4 for more details.

5.0 RESULTS

5.1 Hydrology and Project Operations

5.1.1 Overview of Conditions

River discharge at Wells Dam during April through June 2006 was above average, as compared for the last eight years but quite similar for the months of July through September (Figure 5.1-1). The averages for the month of June ranged from 85 kcfs to 205 kcfs with the 2006 June average at 195 kcfs.

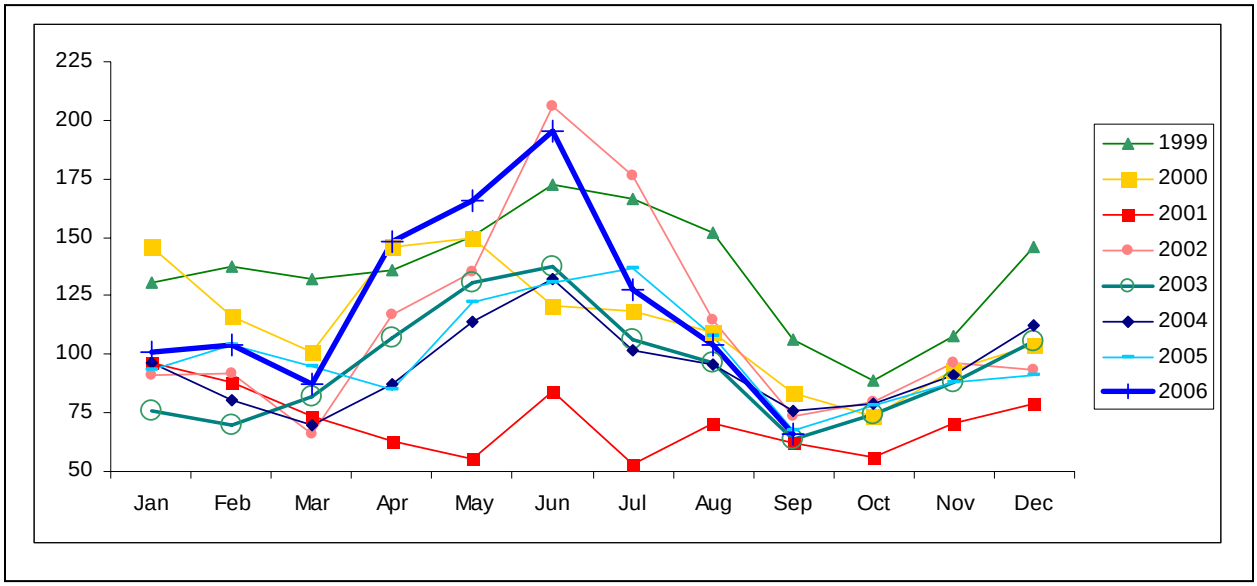


Figure 5.1-1 Wells Dam average discharge by month since 1999

Figure 5.1-2 depicts river discharge percentiles from 10% to 90% for the years of record at Wells Dam from 1968 to 2006. This shows the 2006 average monthly discharges for April, May, and June to be remarkably close to the 75th percentile.

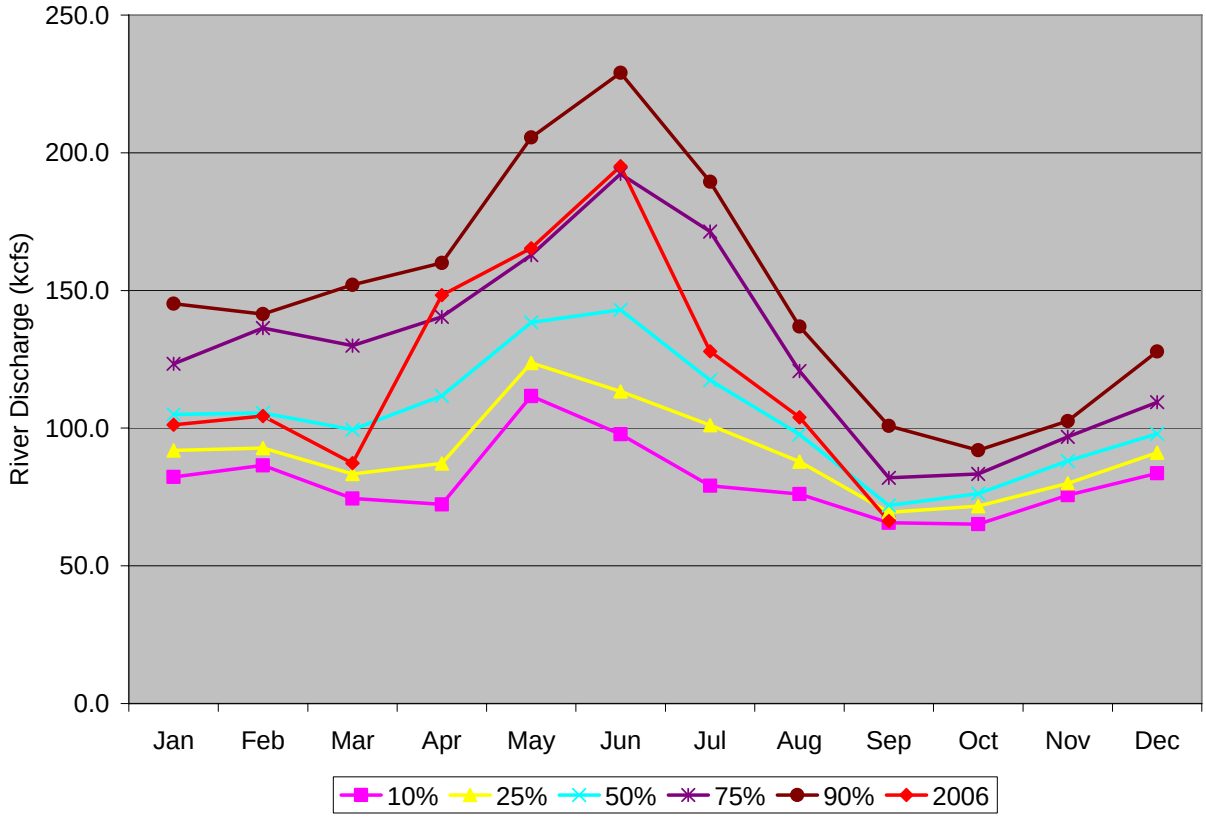


Figure 5.1-2 Wells Dam average discharge by month, percentile distribution for years 1968-2006

Figure 5.1-3 shows detailed 15-minute interval time histories of the project operations/releases at Wells Dam during the 46 day test period, May 14 through June 29, 2006. Total river discharge ranged from 16 to 270 kcfs with the median occurrence of 190 kcfs. Four percent of the total discharges recorded during the test period exceeded the 7Q10 flow of 246 kcfs. Wells Dam spill discharges ranged from 5 kcfs to 168 kcfs during the test period. The median spill discharge for this period was 49 kcfs with 32 percent of the recorded spills exceeding 69.5 kcfs, which is the equivalent spill rate during a 7Q10 total river flow. In order to capture operations with the 69.5 kcfs flow, spill as a percentage of total river flow averaged 42.8 percent and varied from 29.9 to 97.9 percent as compared to 28 percent for passage of the 7Q10 total river flow.

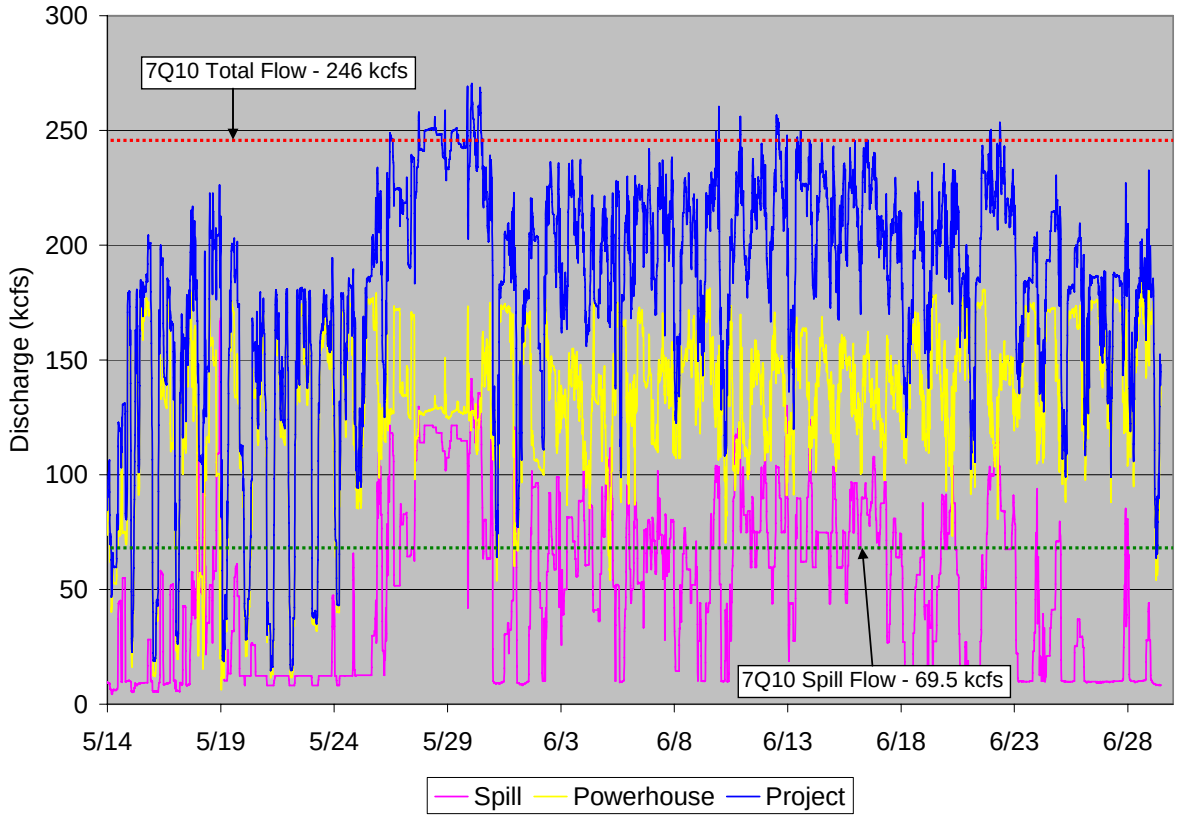


Figure 5.1-3 Wells Dam project operations (15 minute interval) for the test period of May 14 through June 29, 2006

Forebay and tailwater water surface elevations (ft msl) are presented in Figure 5.1-4. The tailwater elevations during the study ranged from 705 ft msl during mid-May to 722 ft msl by late May. The forebay levels were generally in the 778 ft to 780 ft msl range with the exception of the period from May 18 until May 26. Upstream flows during the last half of May were heavily impacted by high flood level discharges from the upstream tributaries. In order to minimize upstream flood damage, the forebay elevation was reduced and held at approximately 772 ft msl using increased project releases (both spill and generation). These lower elevations were accompanied by low water releases from spill bays 1 and 10 versus the normal surface or flap gate operation.

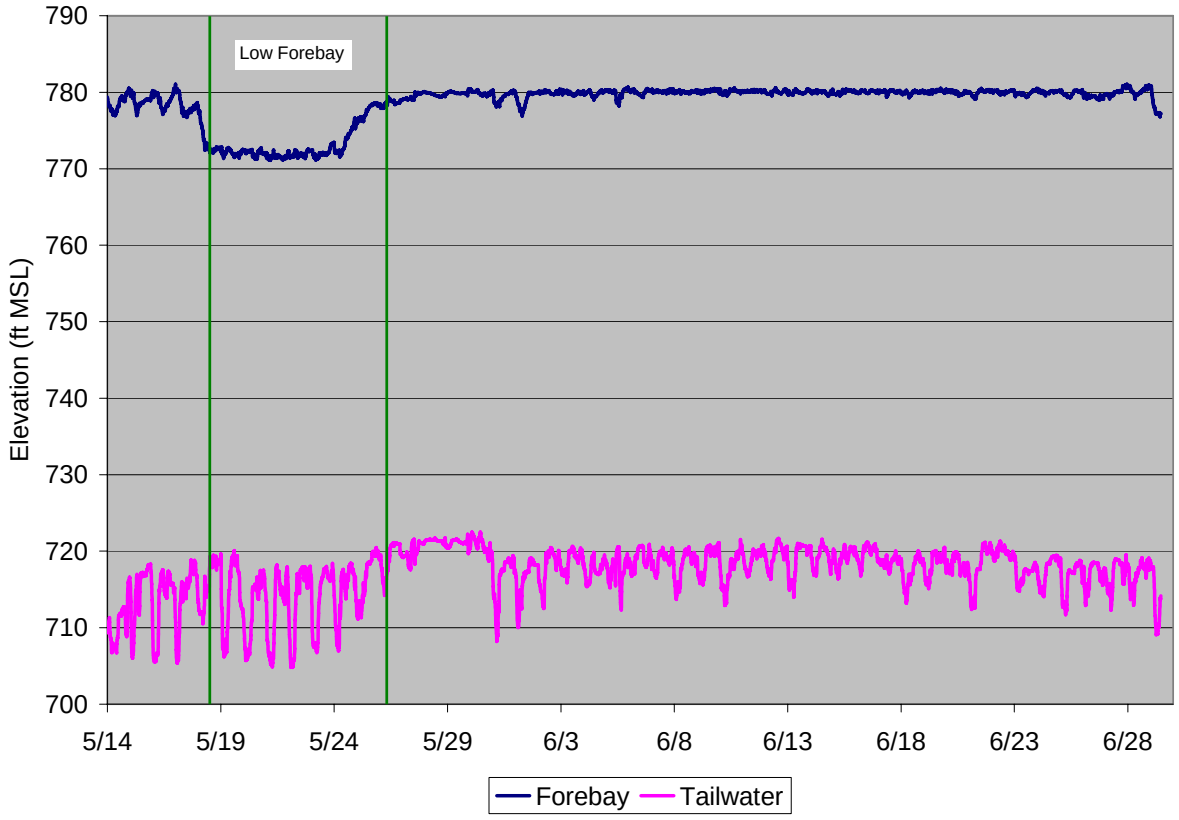


Figure 5.1-4 Wells Dam forebay and tailwater elevations (ft msl) during the test period

5.1.2 Targeted Test Spills

As mentioned the major objectives of the test were focused on relating project operation both spill quantity and spill pattern to downstream TDG concentration. In order to accomplish this, it was necessary to coordinate all testing around the incidental river discharges and required power production as described in the preceding section. There were 80 test events completed during the field study. The effort included 30 targeted as well as 50 incidental spill pattern and discharge scenarios.

The targeted tests were those tests requested prior to the initiation of field testing to address certain questions. For instance the first pattern called for was a spread (S) or uniform pattern

which was to be spread uniformly across as many bays as possible. This would tend to minimize spill volume per length of overflow section and possibly influence TDG production. An example of the spread pattern test is presented for test S46 Figure 5.1-5. In this example, Test S46 was run for a period of 4 hours and 45 minutes with an average spill and total discharge of 40.6 kcfs and 173.4 kcfs, respectively. A total of 5 targeted spread spill tests were completed during the field study with total spill ranging from 26 kcfs to 76 kcfs. The total project releases varied from 164 kcfs up to 217 kcfs for the spread spill tests.

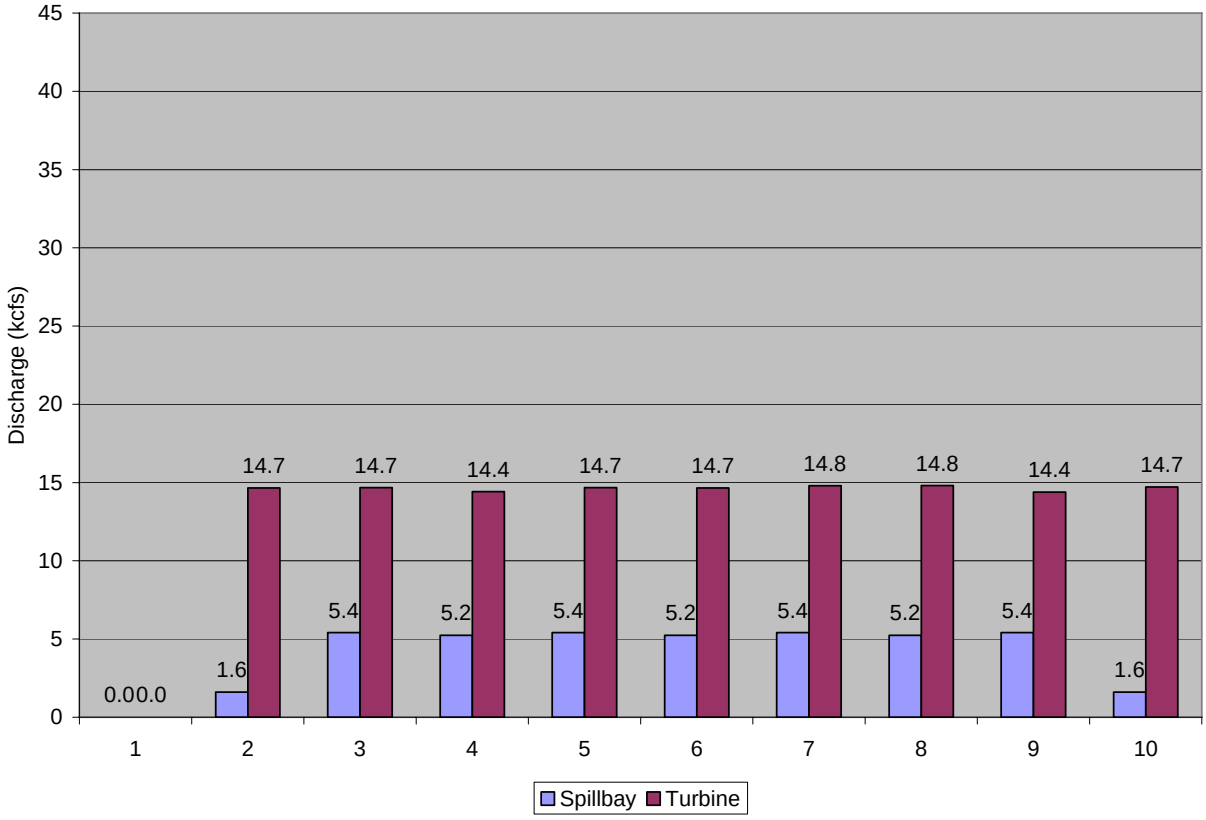


Figure 5.1-5 Wells Dam project operations for test number S46

The second targeted pattern was a full gate (FG) operation where in addition to normal JBS discharge, spill was concentrated through one gate generally bay 7 but bay 5 was used for 2 of these treatments. Test FG50, shown as an example in Figure 5.1-6, averaged 53 kcfs spill and 220 kcfs total discharge for a period of 3 hours. Eighty-one percent of the spill or 43 kcfs was released from bay 5 during the test. Twelve similarly shaped full gate tests were completed during the study. Total spill ranged from 28 kcfs up to 55 kcfs while total project discharge ranged from a low of 106 kcfs to a high of 229 kcfs for the 12 full gate spill tests.

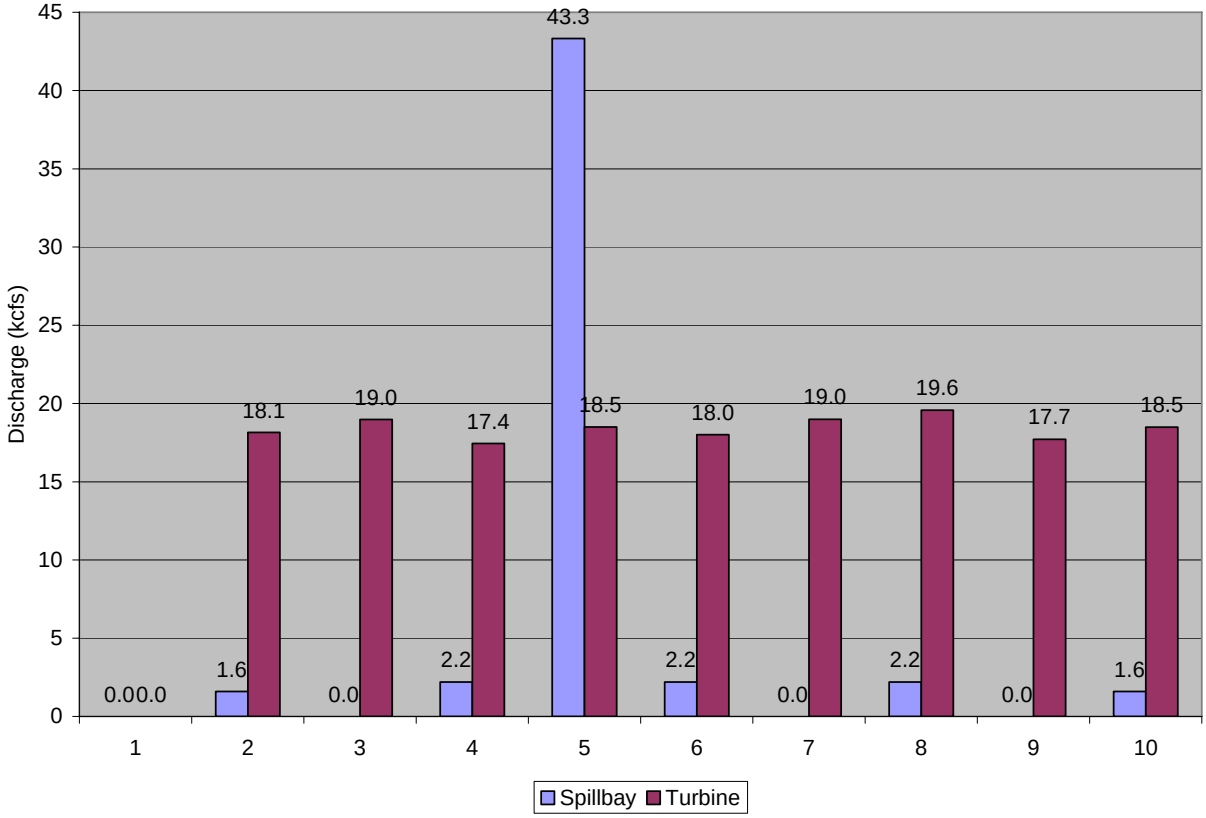


Figure 5.1-6 Wells Dam project operations for test number FG50

The third targeted test pattern, crowned spill (C), was similar to the full gate tests but concentrated spill across 3 adjacent bays rather than one single bay plus normal JBS from the other even numbered bays. The highest releases were generally from bays 5-7 or 7-9. There were a total of 13 crowned pattern spill tests conducted with spills ranging from 21 kcfs to 87.4 kcfs and total releases ranging from 130.9 kcfs up to 241.9 kcfs. An example of the crowned pattern test operations is shown in Figure 5.1-7 for test C63 which had an average spill of 87.4 kcfs and an average total project release of 205.5 kcfs for the 3 hour and 45 minute test.

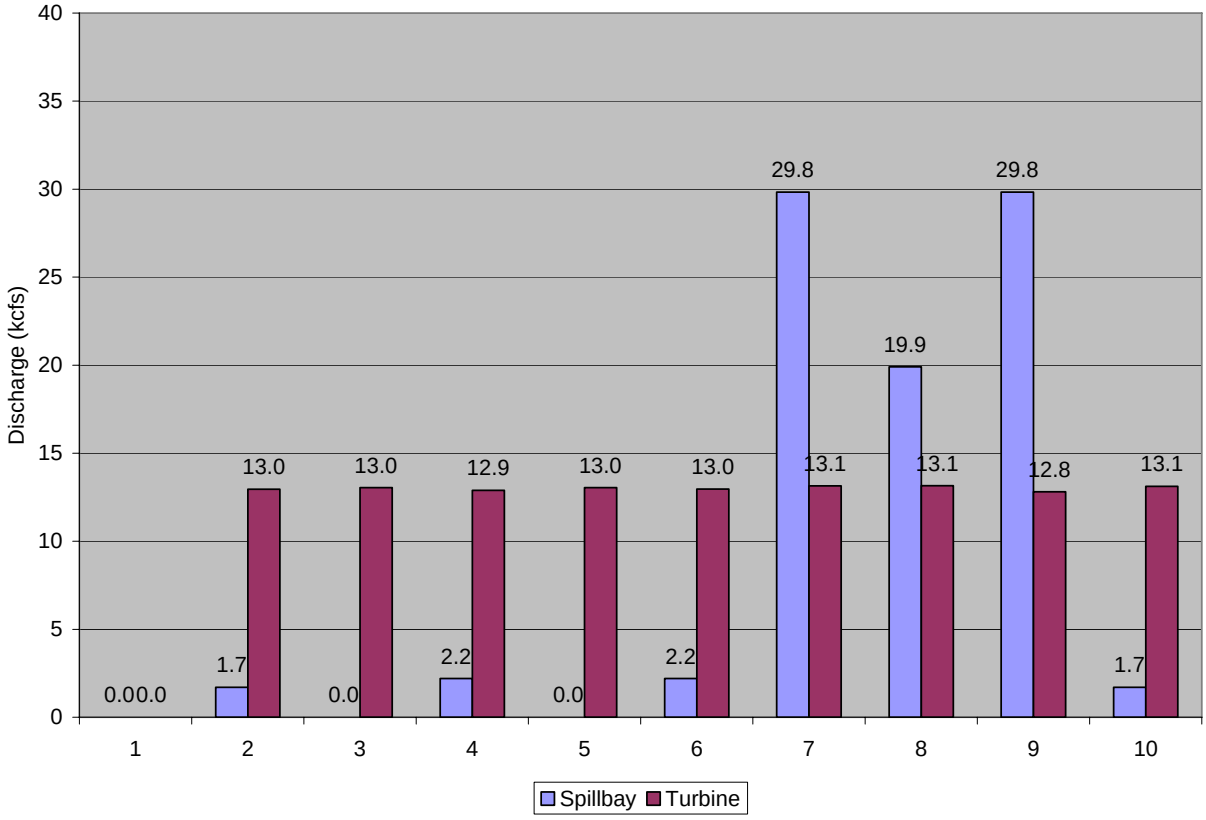


Figure 5.1-7 Wells Dam project operations for test C63

5.1.3 Incidental Test Spills

There were 50 incidental tests that occurred over the 46 day field study due to normal operations and which met the basic criteria of the study (duration greater than 3 hours at near constant operation both spill and generation). These incidental tests were further categorized as juvenile bypass spill only (JBS), modified juvenile bypass spill (MJBS), or dentate (D) patterns. The JBS pattern and MJBS were similar in that they were both limited to standard fish spill but the MJBS was indicative of minimal project release coupled with reduced JBS with only a subset of the fish spill bays operating. The normal JBS pattern spills through bays 2, 4, 6, 8, and 10 at approximately 2 kcfs per bay. Surface "flap gates" are used in bays 2 and 10 while underflow gates are used at the other JBS bays.

An example of the JBS test pattern is shown in Figure 5.1-8 for test JBS19 with an average spill of 12.5 kcfs and average total project release of 114.2 kcfs. There were a total of 23 JBS tests conducted with spills ranging from 8.8 kcfs to 13.1 kcfs and total releases ranging from 128.2 kcfs up to 189.6 kcfs.

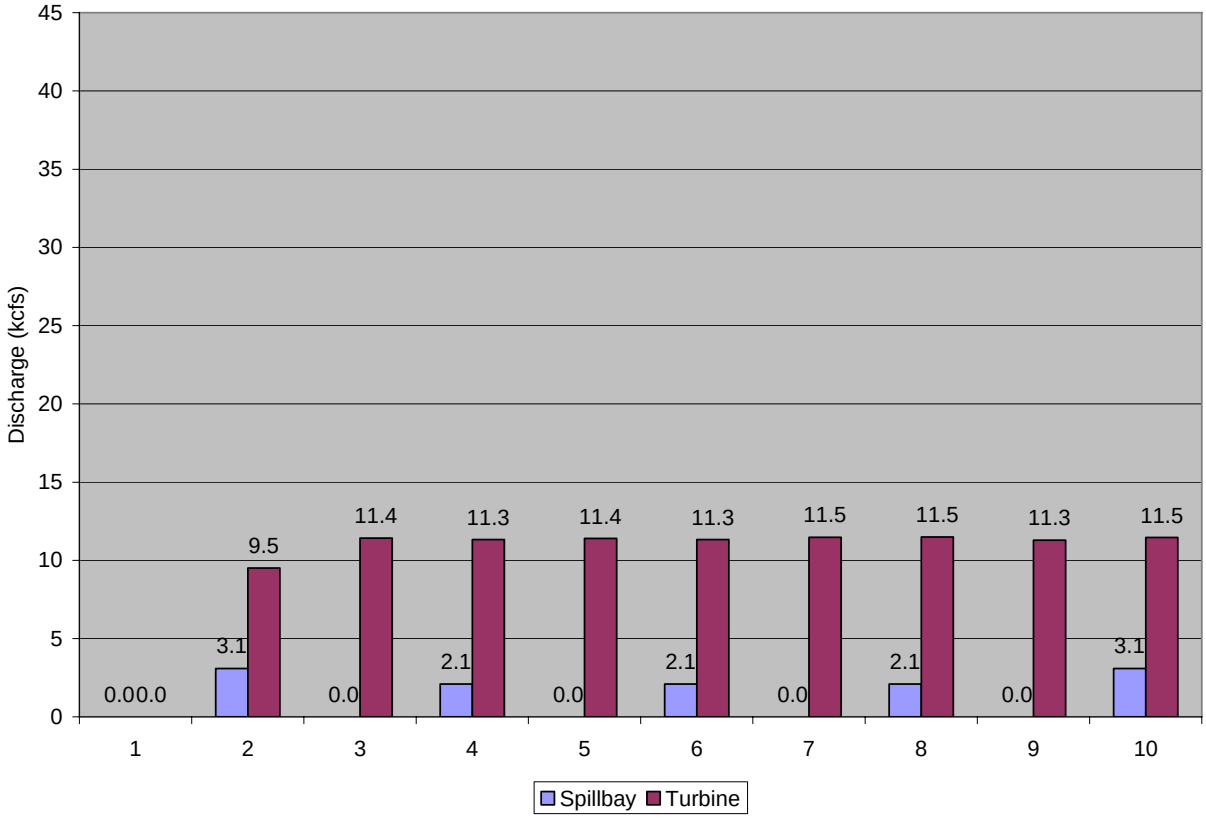


Figure 5.1-8 Wells Dam project operations for test JBS19

Figure 5.1-9 depicts test MJBS10, which averaged only 2.3 kcfs spill and 27 kcfs total project release. Average spill for the 7 MJBS tests ranged from 2.2 kcfs up to 8.7 kcfs. Project releases for these same tests ranged from 16.4 up to 50.3 kcfs. The turbine flow shown for unit 9 is a result of averaging flows for the test period.

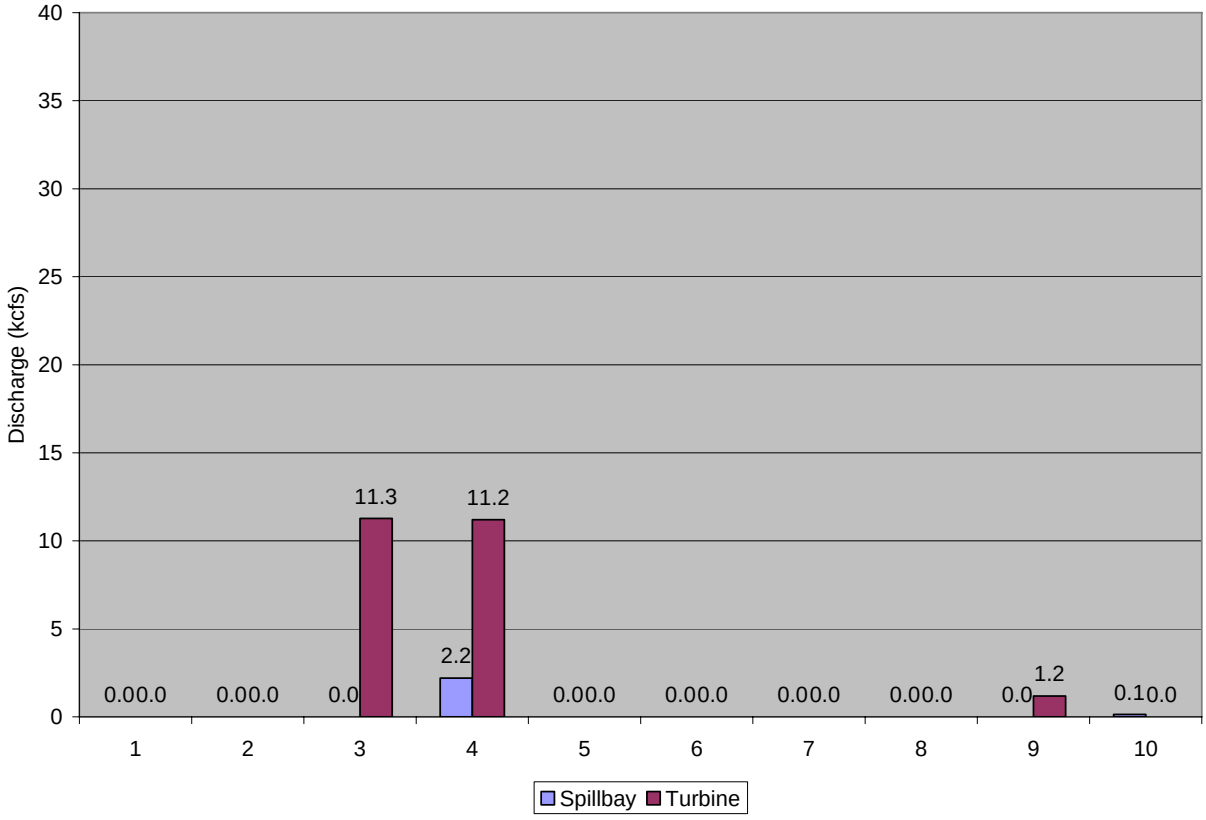


Figure 5.1-9 Wells Dam project operations for test MJBS10

The third pattern documented for the incidental spill tests was named dentate (D). This pattern had uniform JBS releases from the even number gates and the balance of the spill was released uniformly through the odd numbered gates which normally appeared as a staggered or dentate pattern. This pattern was generally the dam operator's choice when spill was required beyond the normal fish spill or JBS resulting in a total of 20 dentate tests during the field study. Average spill for the 20 dentate tests ranged from 42.3 kcfs up to 162.9 kcfs. An example of the dentate pattern operation is shown in Figure 5.1-10 for test D34. The average spill and total project releases for this test were 68.2 kcfs and 194.4 kcfs respectively over a 3 hour period.

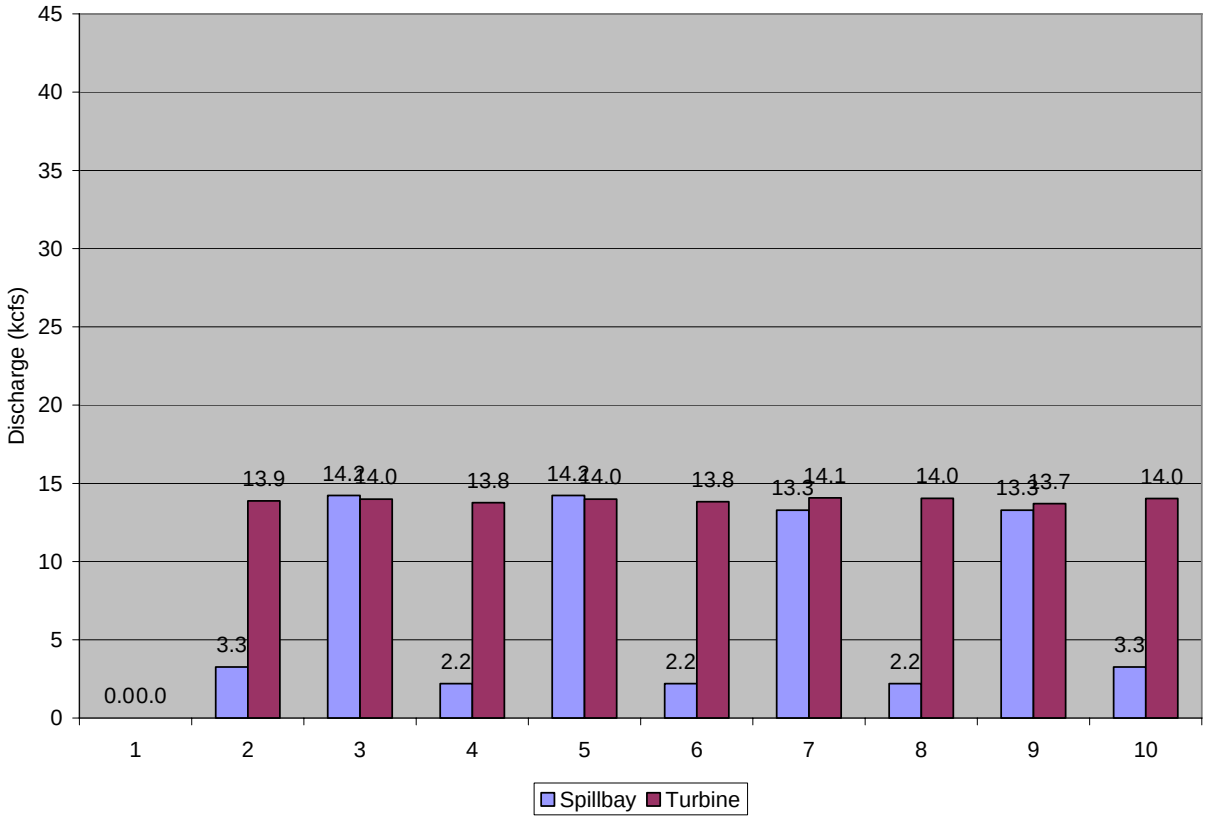


Figure 5.1-10 Wells Dam project operations for test D34

Appendix C fully describes the operations for each of the 80 events including spill per bay and generation per unit. Summaries for each test in Appendix C include time and duration of each test in addition to the unit and bay specific operation, total project operations, project surface elevations, and resulting average TDG saturation at the downstream transects.

5.2 Data Quality

5.2.1 Hydrologic and Operational Data

Operational data were provided by Douglas PUD from the computer stored operations database. The data are reduced from 1-minute incrementally recorded data. The data quality is considered excellent.

5.2.2 TDG Data

5.2.2.1 Data Completeness

Total dissolved gas pressure, related physical and hydrological parameters were monitored for 46 days from May 14, 2006 though June 29, 2006. Instruments for compliance monitoring were deployed for a longer period. A total of 16 Hydrolab instruments were deployed. Three instruments were placed in the forebay and 13 instruments in the tailwater reach along three transects.

Table 5.2-1 lists the period of record for each hydrolab. One of the forebay instruments failed to properly record dissolved gas pressure data due to a probe malfunction. Two of the tailrace instruments became silted in, which causes delayed or suppressed TDG response. Data affected by instrument siltation were eliminated from the analyses. Two instruments experienced intermittent power failures, which resulted in data gaps.

Table 5.2-1 Period of record and data quality for hydrolab instruments

Station	Start Date	End Date	Data Quality	Comment
RRH	5/14/06 11:00	7/1/06 0:00	good	hourly data
FBP1			bad TDG data	
FBP2	5/14/06 11:00	6/29/06 10:30	good	DPUD forebay fms
FBP3	5/14/06 11:00	6/29/06 10:30	good	Right side forebay instrument, deployed/suspended from boom line
TW1P1Z1	5/14/06 11:00	6/29/06 7:30	good/silted in	transect 1 (TW1), bottom instrument, P1, this instrument became silted in on 5/24 at 1530 and became progressively worse throughout the study until total bias by 6/16. Disregard data after 5/24
TW1P1Z2	5/14/06 11:00	6/29/06 7:45	good/power failure	transect 1, shallow instrument, P1, with power failures from 5/21 at 1615 to 5/24 at 1130 then again at 5/31 0645 to 6/5 1500
TW1P2	5/14/06 11:00	6/29/06 7:30	good	transect 1 P2
TW1P3	5/14/06 11:00	6/29/06 7:00	good	transect 1 P3
TW1P4Z1	5/14/06 11:00	6/29/06 8:00	good	transect 1 P4, bottom instrument
TW1P4Z2	5/14/06 11:00	6/29/06 8:00	good	transect 1 P4, shallow instrument
TW2P1	5/14/06 11:00	5/25/06 9:00	good up to power failure on 5/25	transect 2 (TW2) P1, turbulent
TW2P2	5/14/06 11:00	6/29/06 6:00	good	transect 2 P2
TW2P3	5/14/06 11:00	6/29/06 6:30	good	transect 2 P3
TW2P4	5/14/06 11:00	6/29/06 6:30	good	transect 2 P4
TW3P1	5/13/06 18:00	6/29/06 10:30	good	transect 3 (TW3) P1, tailwater fms WELW
TW3P2	5/13/06 18:00	6/29/06 5:30	good	transect 3 P2
TW3P3	5/13/06 18:00	6/29/06 5:00	good until silted	transect 3 P3, effects from silting

Table 5.2-1 Period of record and data quality for hydrolab instruments				
Station	Start Date	End Date	Data Quality	Comment
			in also experienced some power failures	was noticeable after 5/28 1200 until end of study
TW3P4	5/13/06 18:00	6/29/06 4:45	good	transect 3 P4
TW3P5	5/13/06 18:00	6/29/06 4:30	good	transect 3 P5

Operations data were electronically logged at 1-minute intervals. The data were then subsequently queried to develop 15-minute interval data using the mid-point of a 15-minute running average. Even numbered spillbay data had to be hand entered into the database from operator logs. Barometric pressure data were available from the logging barometer located at elevation 790 ft msl on the deck of Wells Dam.

A total of 26 test scenarios were initially identified and prioritized. A total of 30 scheduled tests and 50 unscheduled or incidental tests were completed. A completed test required at least three continuous hours of near-steady operation (near constant spill, generation flows and gate settings). Total river discharge at Wells Dam ranged from 16 kcfs to 270 kcfs during the test periods. The range for spill during the study was 5 kcfs to 168 kcfs.

5.2.2.2 Data Quality

Each hydrolab was calibrated according to protocols described in Appendix D at the time of deployment and at retrieval. Eight of the 16 instruments were pulled and calibrations verified mid-way through the study. Other instruments could not be retrieved at that time due to high flow volumes. At the time of deployment, an instrument was recalibrated if the total dissolved gas pressure reading differed by more than 2 mmHg from the standardized barometer. With the exception of instrument siltation or electronic failures as noted in Table 5.2-1, all the instruments met the calibration criteria of being within 2mmHg total gas pressure both before and after each deployment. The instrument reported water depth was within 0.1 m of the field verified depth. Instrument temperatures were within 0.2^{o}C of the temperature reported for a NIST mercury thermometer used for verification. The reference Hydrolab instrument used for calibration for other instruments was checked for ambient gas pressure before and after each servicing trip relative to the reported local NIST barometric pressure.

5.2.3 Hydrodynamic Data Collection

All planned stationary and moving transect ADCP data were collected for the flat spill condition (Spill Test 14) and all units operating. All moving transect data and all but one set of stationary data were collected for the single gate spill condition, although Transect A had to be adjusted downstream due to a combination of flow conditions and debris in the tailrace.

A review of the stationary raw velocity data revealed no significant quality concerns. There were occasional ensembles lost during data collection, but these losses did not exceed levels that are typical of ADCP measurements. These ensembles were filtered out during post-processing

of the data. There were also occasional erroneous velocity data at various depths, but these bad data were also normal and expected and were filtered out during post-processing of the data. The intent of the stationary data collection was to obtain and archive data for possible future use in physical or computational fluid dynamics model calibration if such modeling is required. Prior to future use of these data, they should be fully processed to develop average velocity component profiles normal to the measurement cross sections and the velocity components should be integrated to calculate flows passing through the cross sections to determine if the data indicate continuity of flow between cross sections. Complete data processing was not in the scope of the effort described in this report.

Discharges through cross sections were provided by the real-time ADCP data processing software for the moving transects and are presented in Table 5.2-2. The variation in transect discharge from that reported by the powerhouse control room increased with transect distance downstream from the powerhouse. The width of the river cross section decreased with distance downstream from the powerhouse. As a result of the decreasing width, the cross section near each shoreline where ADCP data could not be acquired had a greater effect in reducing the measured flow. Integration of moving transect data, which represent neither long-term averages nor synoptic data, to within ± 10 percent of the value reported by the powerhouse for the same time period, is considered acceptable.

Table 5.2-2 Flow Continuity Check on ADCP Moving Transect Data

Date	Transect	Boat Direction	Total Discharge (kcfs)	Variation from Reported Discharge (%)
4-Jun-06	Reported by control room	n.a.	180.9	0.0%
	A	East to West	166.9	-7.7%
	A	West to East	181.0	0.1%
	B	East to West	165.3	-8.6%
	B	West to East	169.5	-6.3%
	C	West to East	162.3	-10.3%
	C	East to West	162.1	-10.4%
5-Jun-06	Reported by control room	n.a.	244.0	0.0%
	A	West to East	242.5	-0.6%
	A	East to West	260.2	6.6%
	B	West to East	222.8	-8.7%
	B	East to West	223.3	-8.5%
	C	East to West	232.7	-4.6%
	C	West to East	219.6	-10.0%

5.3 TDG Assessment

5.3.1 Forebay TDG

5.3.1.1 Variation Between Stations

As mentioned in the previous study by Columbia Basin Environmental (CBE) (CBE, 2006), the reliability of the long-term TDG measured at forebay station WEL has been questioned due to high variability of temperature and TDG measured at WEL near the face of the dam. One design objective of the 2006 study was to examine spatial and temporal variability of temperature and total dissolved gas pressure within the forebay with respect to the long-term compliance TDG monitoring station location, WEL. Although three instruments were deployed, only two instruments provided reliable TDG data throughout the 2006 study. The third instrument (FB1P1) was only successful at monitoring water temperature. All three instruments were deployed at a depth of approximately 3m below the surface. Figure 5.3-1 shows the recorded TDG pressure and water temperature data for the Wells forebay instruments. Figure 5.3-2 shows the corresponding %TDG for forebay instruments.

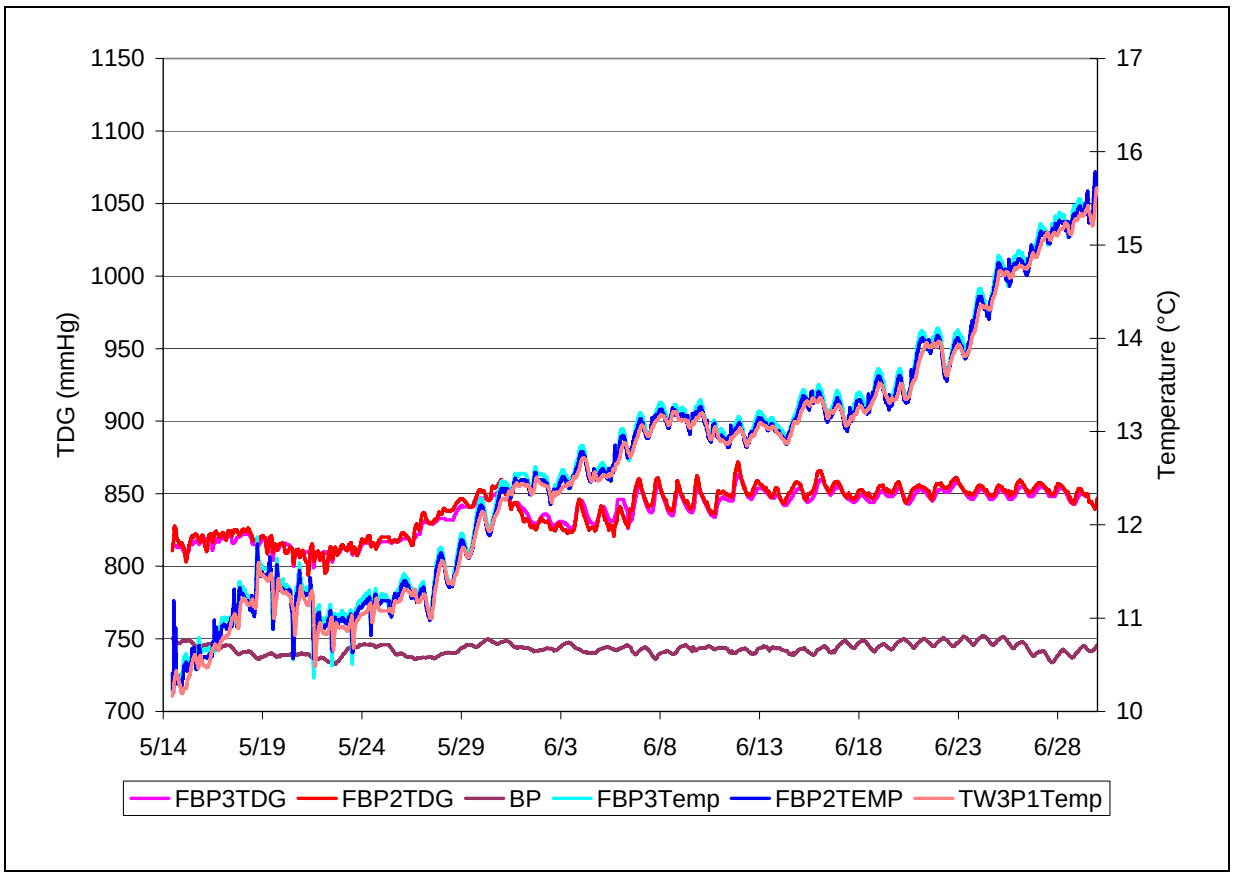


Figure 5.3-1 **Forebay total dissolved gas pressure and water temperature**
(FB2 is synonymous with WEL).
(Downstream water temperature at TW3P1 (WELW) is shown for comparison.)

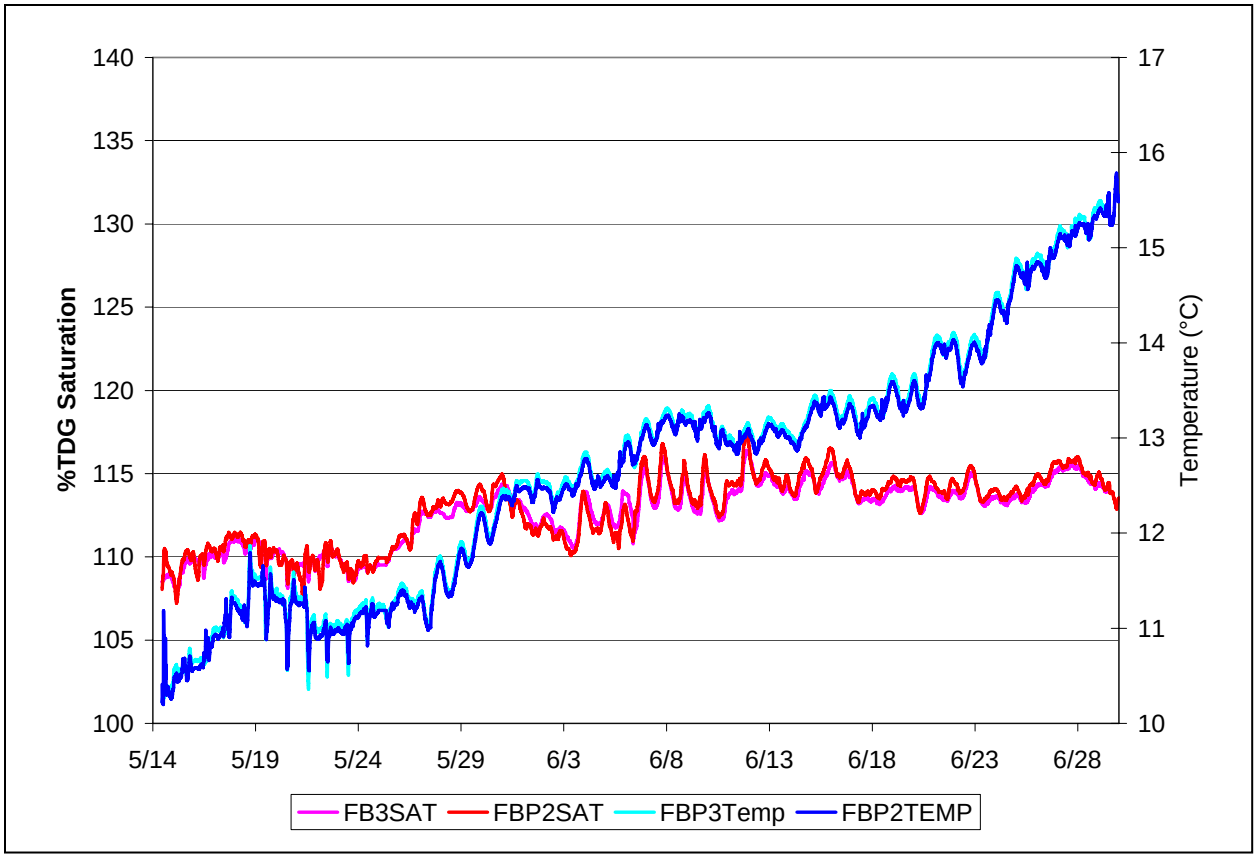


Figure 5.3-2 Forebay %TDG and water temperature

Table 5.3-1 lists the range of percent gas saturation recorded for the forebay. The %TDG data for the two forebay instruments that provided reliable data were not significantly different based on a 2-tailed Levene's test ($\rho < 0.001$, $\alpha = 0.05$). The instrument FB2 was located at the same location as the instrument WEL reported in previous studies. No correlation correction to the historical data was calculated since there was no significant difference between data from the two forebay instruments in 2006. Table 5.3-2 shows the range in differences in water temperature recorded by the forebay hydrolabs.

Table 5.3-1 Forebay %TDG and water temperature data 2006

		%TDG			
Station	**Period of Record**	**Min**	**Max**	**Mean**	**St. Dev**
FB1	Failed				
FB2 (WEL)	5/14/06 11:00 – 6/30/06 0:00	107.22	117.55	112.85	2.09
FB3	5/14/06 11:00 – 6/30/06 0:00	108.04	116.39	112.62	1.93
		Water Temperature (^{o}C)			
		Min	Max	Mean	St. Dev
FB1	5/14/06 11:00 – 6/6/06 0:00[1]	10.07	12.91	11.50	0.70
FB2 (WEL)	5/14/06 11:00 – 6/30/06 0:00	10.20	15.78	12.66	1.32
FB3	5/14/06 11:00 – 6/30/06 0:00	10.23	15.49	12.67	1.29

[1] *Note difference in period of record*.

Table 5.3-2 Difference in water temperature (^{o}C) between forebay monitoring stations

	FB3TEMP-FB2TEMP	FB3TEMP-FB1 TEMP	FB2 TEMP -FB1 TEMP
Max	0.15	0.28	0.75
Mean	0.05	0.11	0.06
Min	-0.57	-0.03	-0.04

Figure 5.3-3 plots the 15-minute interval water temperature data for each of the forebay instruments. With the exception of two data points, the differences in reported temperature between forebay stations are within instrument resolution (+0.2°C for each instrument or 0.4 °C cumulative). Data for the hydrolab FB2SAT were used for all subsequent analyses. It was concluded from this analysis that the WEL location is representative and appropriate for the long-term monitoring station. However, the variation in readings between the two instruments might have been greater during a low flow year, when the reservoir is less well-mixed.

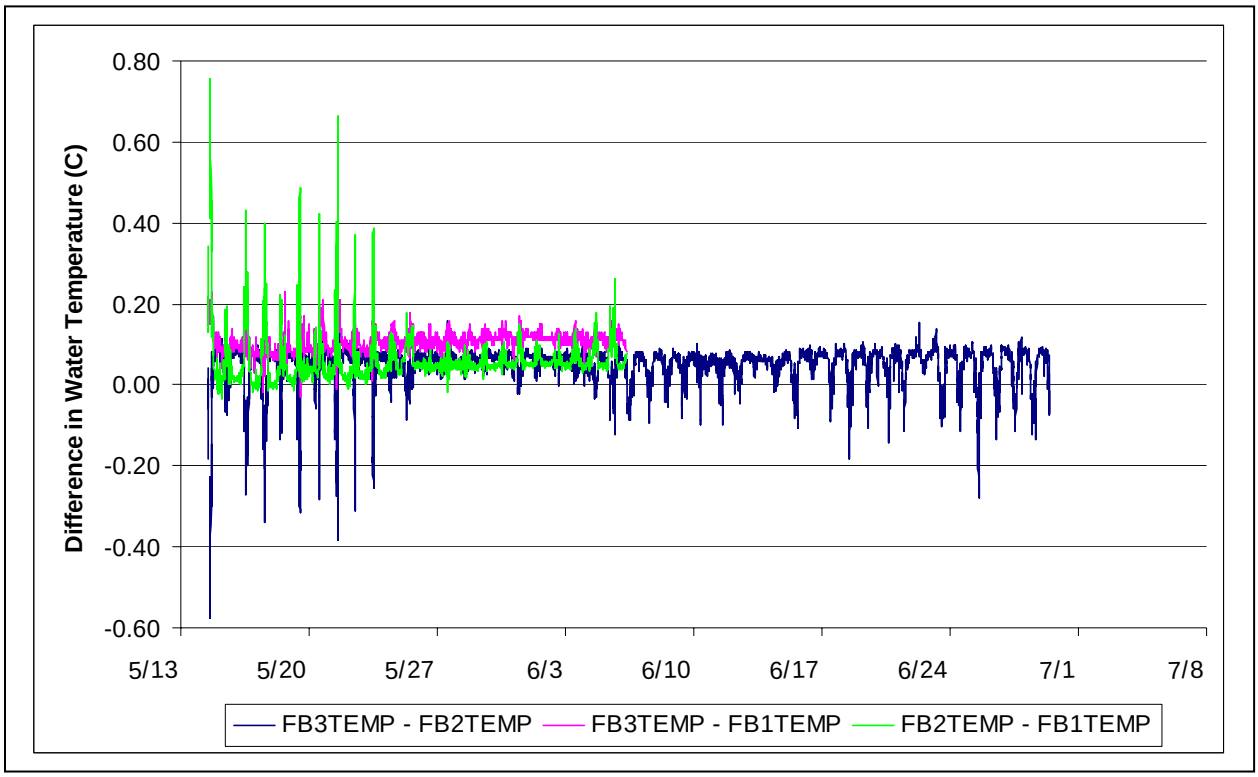


Figure 5.3-3 Water temperature for forebay instruments

5.3.2 TDG Equilibrium Time

Representative measurements for total dissolved gas saturation at each monitoring station during equilibrated conditions were important in describing the TDG production relationships with project operation at Wells Dam. The distances downstream of the project for each transect of stations resulted in varying time lags in the TDG measures corresponding with identifiable project operations such as a change in total discharge or spill. Previous evaluations had determined that it would require approximately 1 hour of constant operation from Wells Dam to achieve near equilibrated TDG conditions in the downstream study reach. This was based on the river discharge, water velocities and the time required for discharge to mix both laterally and longitudinally down to the tailwater TDG fixed monitor, WELW, located 4.6 km downstream from the dam. Two hours of equilibrated time were necessary to produce a sample size of eight recorded measurements at 15-minute intervals. The minimum time requirement for each test was

then set at 3 hours. Eighty tests that met the requirements of a minimum of 3 hours of near constant project operating conditions were identified during the field study.

The actual time until initial and ending equilibration was different for each downstream transect of stations. A review of responses by transect was useful in establishing these approximate times and subsequent selection of TDG measures characteristic of a particular project operation. Examples of this can be seen in the following figures. Time history plots of Tests 6 and 7, occurring on May 16, 2006, are depicted in Figures 5.3-4, 5.3-5, and 5.3-6 for stations on transects TW1, TW2, and TW3, respectively. Test 6 began at 6:00 AM when total spill was increased from 9 kcfs to 58 kcfs, generation operation was held constant to maintain a total project release of approximately 193 kcfs. Test 7 was initiated at 12:00 AM by setting operations to about 8 kcfs spill and 140 kcfs total release. Test 7 continued until after 2:45 PM. Based on the TDG response curves for the TW1 stations the equilibrated readings occurred starting at 45 minutes following onset of the tests and continued for 15 minutes following the end of the tests.

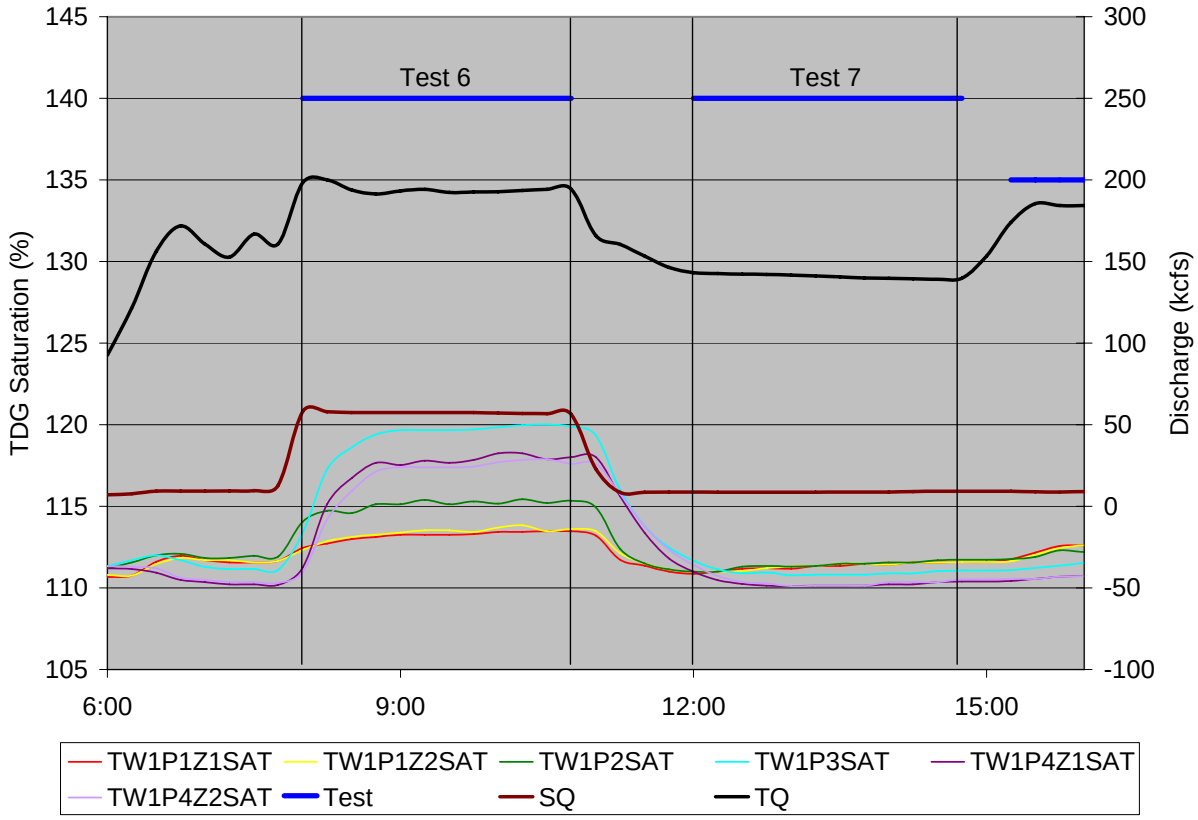


Figure 5.3-4 Transect TW1 TDG Saturation Responses to Test 6 and Test 7 for May 16, 2006

The TW2 station response curves for TDG (Figure 5.3-5) indicate the equilibrated readings start at 1 hour following onset of the tests and continue until 15 minutes following the end of the tests.

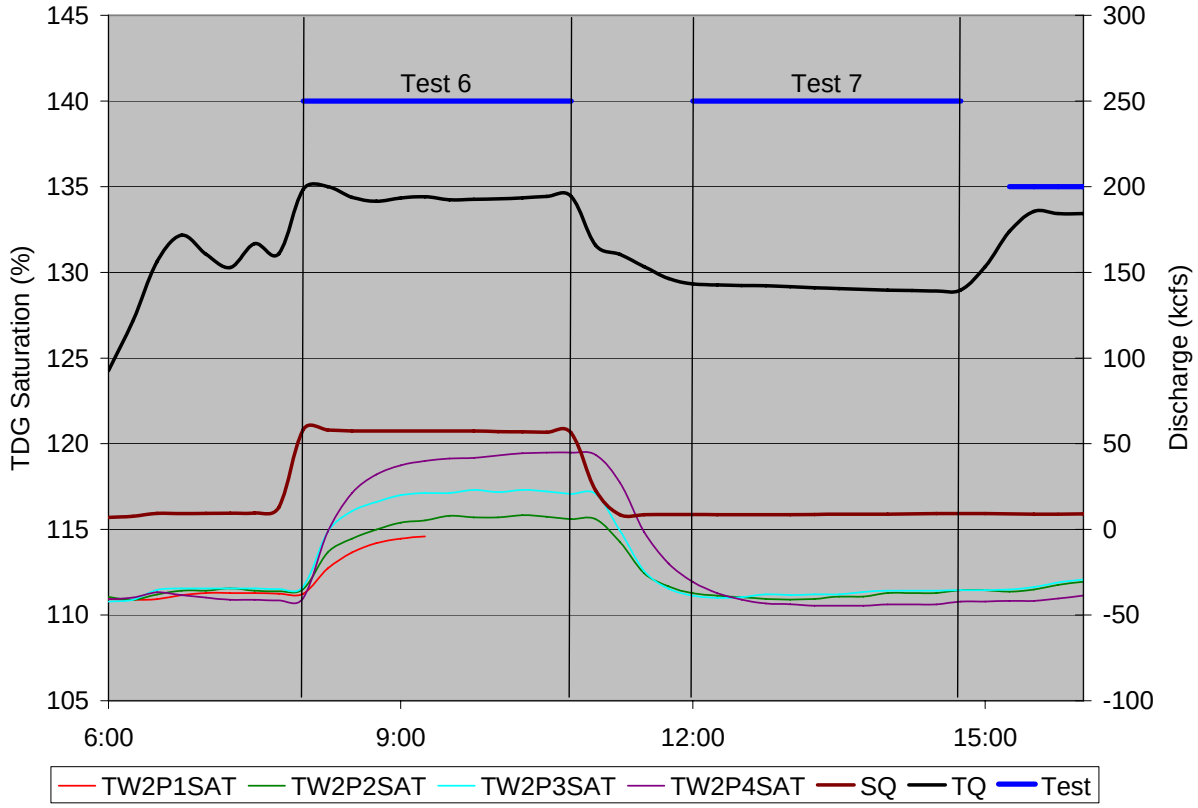


Figure 5.3-5 Transect TW2 TDG Saturation Responses to Test 6 and Test 7 for May 16, 2006

In Figure 5.3-6, the TW3 stations indicate equilibrated conditions to be established across the entire transect at 2 hours and 15 minutes following onset of each test. This continued until approximately 45 minutes following the end of the tests.

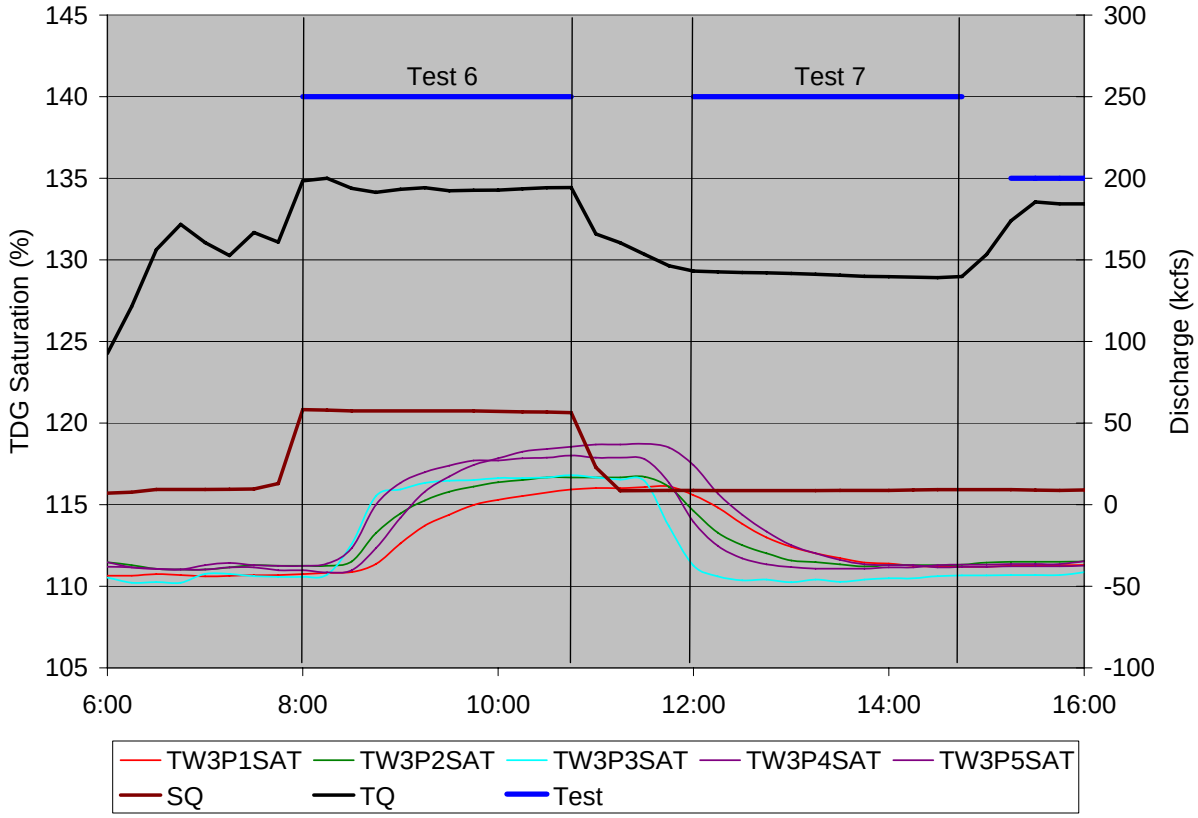


Figure 5.3-6 Transect TW3 TDG Saturation Responses to Test 6 and Test 7 for May 16, 2006

Many of the test data sets were further refined by deleting readings from the start and/or end of a test time series for all stations on a transect. This was generally based on review of the variance associated with individual station measures within a test. For example, a change of more than 1% saturation for a particular station was used as a flag to eliminate leading and trailing edge measures. This effort was directed at selecting measures which were most representative of a particular operation in time and would still allow for an adequate number of observations for each test. Mean test values for the forebay stations were calculated using all measures collected from start to finish of each individual test.

5.3.3 Spatial Variation in TDG Levels

Fifteen Hydrolab sensors were deployed at thirteen stations in the tailwater downstream of Wells Dam along three transects. The transects and stations are identified in Table 5.3-3 below, with a summary of the measured %TDG saturation. Transect TW1 provided near-field data and was located 0.3 km downstream of the dam. Transect TW2 was located 0.76 km downstream of the dam. Transect TW3, located 4.6 km downstream, coincided with the location for the compliance

monitoring station WELW1. All instruments were coded by transect and station number with station numbering running east to west. Instruments were positioned at both shallow (8 m) and on bottom for TW1P1 and TW1P4. All other instruments were deployed on the channel bed.

Figure 5.3-7 through 5.3-9 show the total dissolved gas pressure (TDGP) reported for transect TW1, TW2 and TW3, respectively. For TW1, a lateral gradient of 15 – 85 mmHg occurred during spills with the higher TDGP occurring in the central portion of the channel (TW1P2 and TW1P3). Lateral TDGP differences for periods when spill was limited to juvenile bypass flow (JBS) were minor with differences typically less than 10 mmHg. Two instruments were placed vertically at TW1P1 and TW4P4; however, the bottom instrument at TW1P1 was affected by siltation. Vertical differences in TDGP at TW1P4 were not significant.

The lateral gradient at TW2 was much reduced from TW1 (Figure 5.3-8); the equilibrated data for each of the stations were not significantly different ($\rho = 0.798$, $\alpha = 0.05$). Dissolved gas pressure at TW2P4 (west side) was similar to other stations most of the time but was less during some spills, especially spills occurring after June 16 20:00. The temporal difference suggests that TW2P4 may have experienced minor siltation effects during the last two weeks of the study period.

The lateral gradient at TW3 was minor to non-existent. %TDG data for the equilibrium test periods were not significantly different ($\rho = 0.825$, $\alpha = 0.05$) between the monitoring stations along this transect. The instrument at station TW3P3 did not provide reliable data for the entire study period due to siltation.

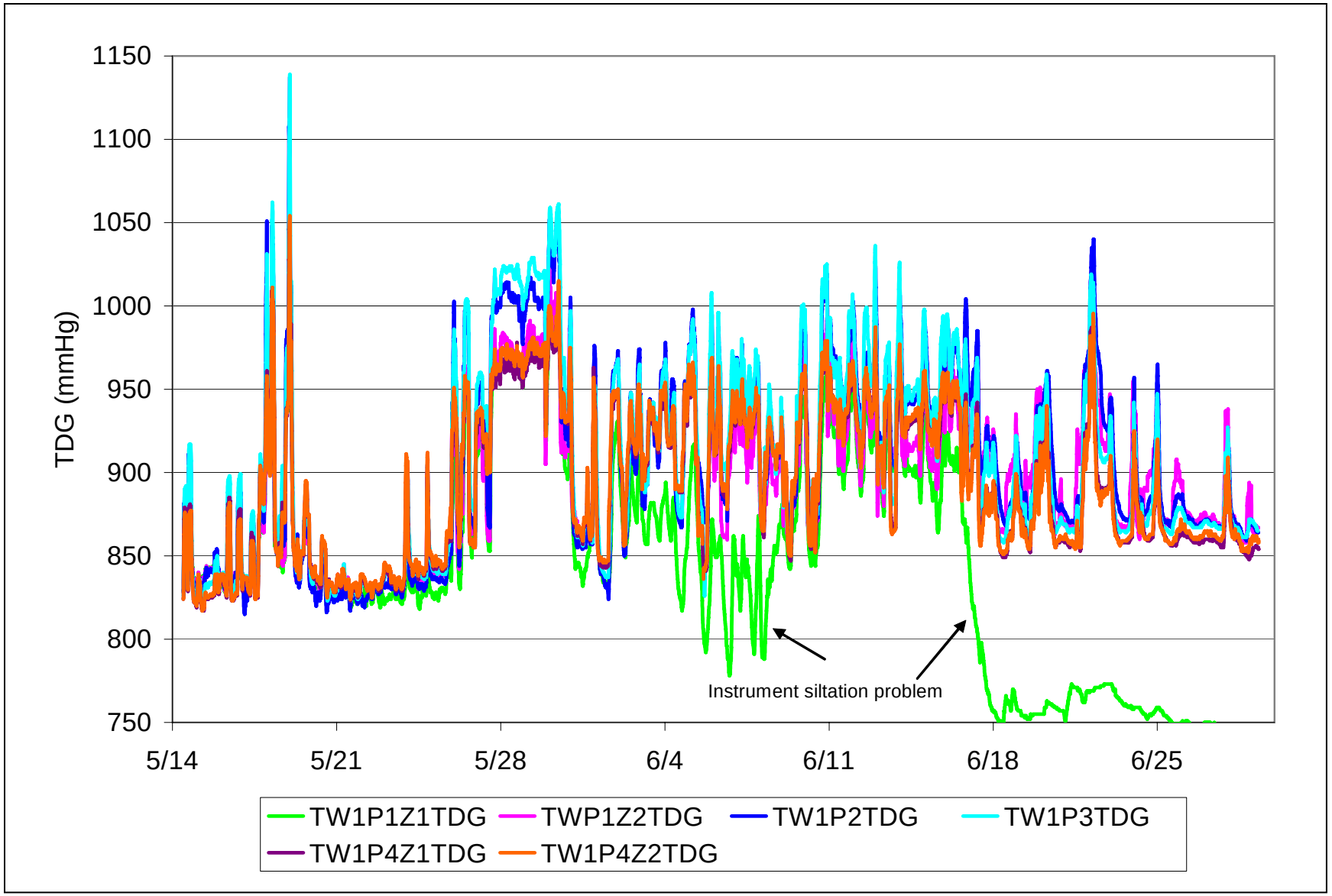


Figure 5.3-7 Total dissolved gas pressure (TDGP) for TW1

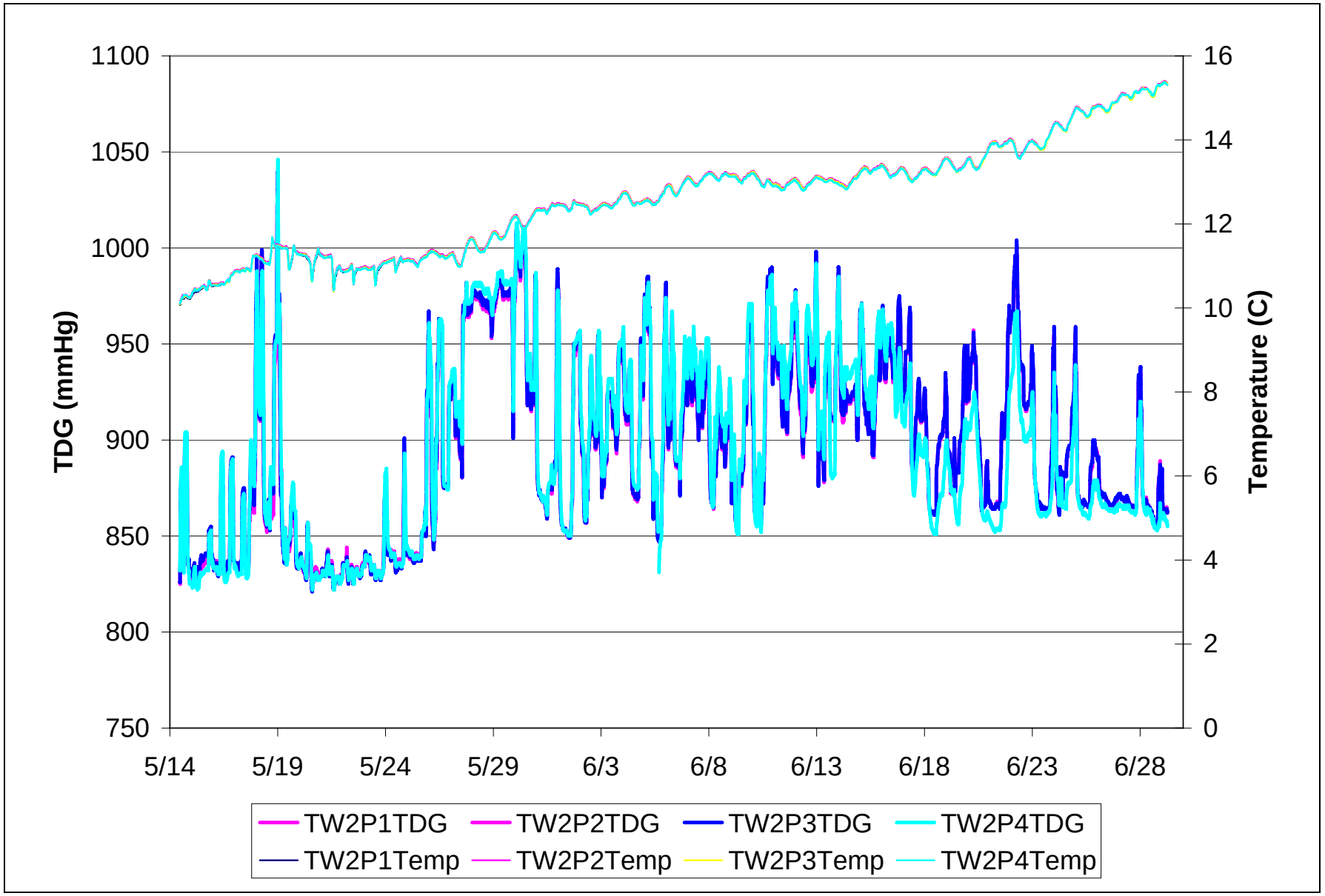


Figure 5.3-8 Total dissolved gas pressure (TDGP) for TW2

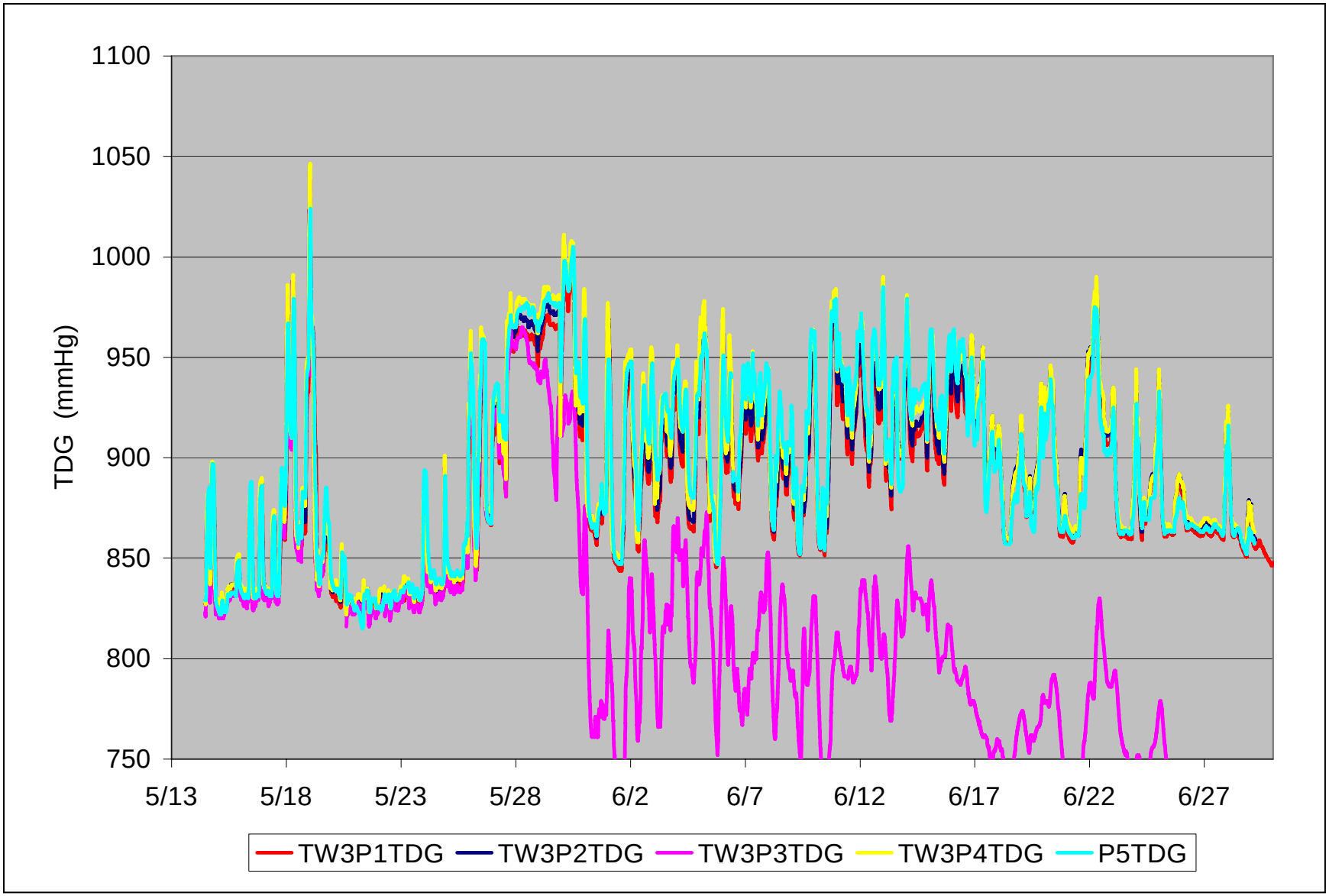


Figure 5.3-9 Total dissolved gas pressure (TDGP) for TW3

Periods of equilibrium conditions for each test were identified by transect. For each equilibrium test period, average values for hydrologic and TDG parameters were calculated for each instrument. The longitudinal gradient for dissolved gas is portrayed in Figure 5.3-10. Gas saturation during JBS spills is very similar among all three transects. For test conditions generating higher gas levels, the difference, on average, between TW1 and TW2 was about 3%. There was essentially no longitudinal %TDG gradient, on average, between TW2 and TW3 for the tests.

Table 5.3-3 %TDG saturation at tailrace monitoring sites for 2006 test periods

	Number	% TDG Saturation			
Station	**Tests**	**Min**	**Max**	**Mean**	**St. Dev.**
TW1P1Z1	0				
TW1P1Z2	67	111.44	131.85	119.16	5.87
TW1P2	80	71.60	136.06	119.18	9.03
TW1P3	80	110.89	137.72	120.09	7.51
TW1P4Z1	80	110.20	129.98	118.19	5.65
TW1P4Z2	80	110.26	130.92	118.33	5.82
TW2P1	80	111.16	131.18	118.81	5.72
TW2P2	80	111.33	131.47	119.00	5.82
TW2P3	80	110.61	132.16	118.86	6.15
TW2P4	80	111.16	131.18	118.81	5.72
WELW	80	110.88	129.66	117.99	5.40
TW3P2	80	111.36	130.61	118.51	5.50
TW3P3	34	110.60	129.529	116.35	5.89
TW3P4	80	111.27	131.74	119.02	5.84
TW3P5	80	110.00	131.28	118.80	5.91

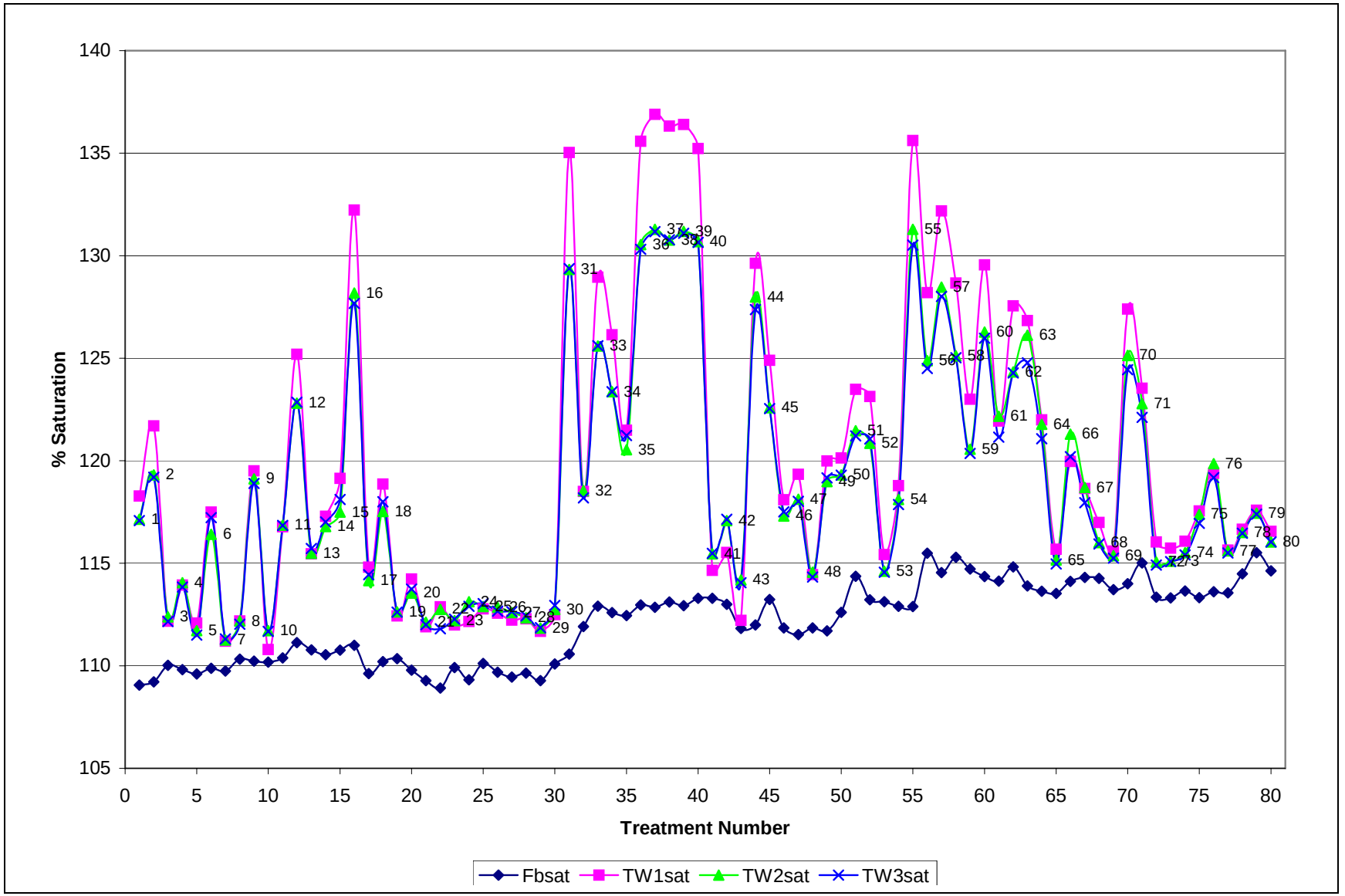


Figure 5.3-10 Longitudinal comparison of %TDG for the 80 test spills

5.3.4 Meta-Analysis of Spill Test Results

The 2006 spill tests greatly expand the TDG data collected during periods when equilibrium conditions existed, which allow correlation between downstream gas saturation data and Project operations. A meta-analysis of all the test data is first presented to provide insight as to independent variables important to predicting downstream gas saturation. Results of the meta-analysis were also used to confirm the suitability of the tailwater compliance monitoring station. The meta-analysis also provides comparable analyses to results for gas saturation studies for previous years. Initially analyzing the 2006 test data by conventions previously applied to historical data demonstrates that spill dynamics during the 2006 test period behaved in a consistent manner with historical patterns. The distinction of the 2006 tests are that specific operations were targeted to evaluate Project operational practices that best move towards compliance with the water quality TDG criteria. Following the meta-analysis results, the next section analyzes specific operational scenarios (spill type such as crowned, full gate, spread, etc.). Regression tools developed in the meta-analysis are applied to test data for individual spill scenarios. Finally, the test results are analyzed as to causative hydrodynamic factors that may be governing the gas production relative to Project operations.

A total of 80 test scenarios were completed that comprise the database used in the TDG correlation analyses. TDG and operations data were screened to identify periods when equilibrium conditions existed for each of the downstream TDG monitoring transects. The mean values for each of the parameters were calculated for the equilibrium period for the data from each Hydrolab®. Total river discharge during these tests ranged from 15.3 kcfs to 270 kcfs with spill during tests ranging from 5.5 kcfs to 121.5kcfs based on the average spill value for each test. The instantaneous spill range during the tests ranged from 5.2 kcfs to 168 kcfs. Forebay TDG percent saturation ranged from 108% to 116% during the test periods. This range is slightly greater than that reported for the historical analysis (summarized in Appendix A). The percent saturation at the most downstream transect ranged from 111% to 129.7% as recorded at WELW.

Factors influencing downstream TDG levels included forebay TDG, barometric pressure, water surface elevation for both forebay and tailwater, water temperature, spill flow, generation flow through turbines and total discharge. A stepwise multiple regression was performed to determine the non-operational parameters that provide the best capability for predicting downstream %TDG saturation at WELW. All of the independent variables were initially used with %TDG being the dependent variable. The resulting correlation is:

$$WELW_{TDG} = 12.865 + 0.819\ FB2_{TDG} - 0.075_{BP} - 0.035Q_{spill} - 0.182FB2_{elev} + 1.018FB2_{temp}$$

$$R^2 = 0.983 \quad (5.3\text{-}1)$$

Independent variables were sequentially removed from the regression to evaluate the relative contribution of each variable. The spill discharge (Q_{spill}) was the primary determinant of downstream %TDG. A regression that relies on both Q_{spill} and $FB2_{TDG}$ as the independent variables provided a slightly better correlation than just Q_{spill}. The other variables were not significantly correlated with downstream %TDG. The correlation equations for each instrument at transect TW3 are:

$WELW_{TDG}$ = 42.244 + 0.622 $FB2_{TDG}$ + 0.129Q_{spill} R^2 = 0.953 (5.3-2)

$TW3P2_{TDG}$ = 47.962 + 0.574* $FB2_{TDG}$ + 0.133* Q_{spill} R^2 = 0.957 (5.3-3)

$TW3P4_{TDG}$ = 41.287 + 0.635* $FB2_{TDG}$ + 0.144* Q_{spill} R^2 = 0.967 (5.3-4)

$TW3P5_{TDG}$ = 43.742 + 0.610$FB2_{TDG}$ + 0.145* Q_{spill} R^2 = 0.947 (5.3-5)

Figure 5.3-11 compares the predicted % TDG at $WELW_{TDG}$ relative to measured %TDG as well as the 95% confidence intervals. The dashed line is the slope for unity (perfect correlation between predicted and measured values).

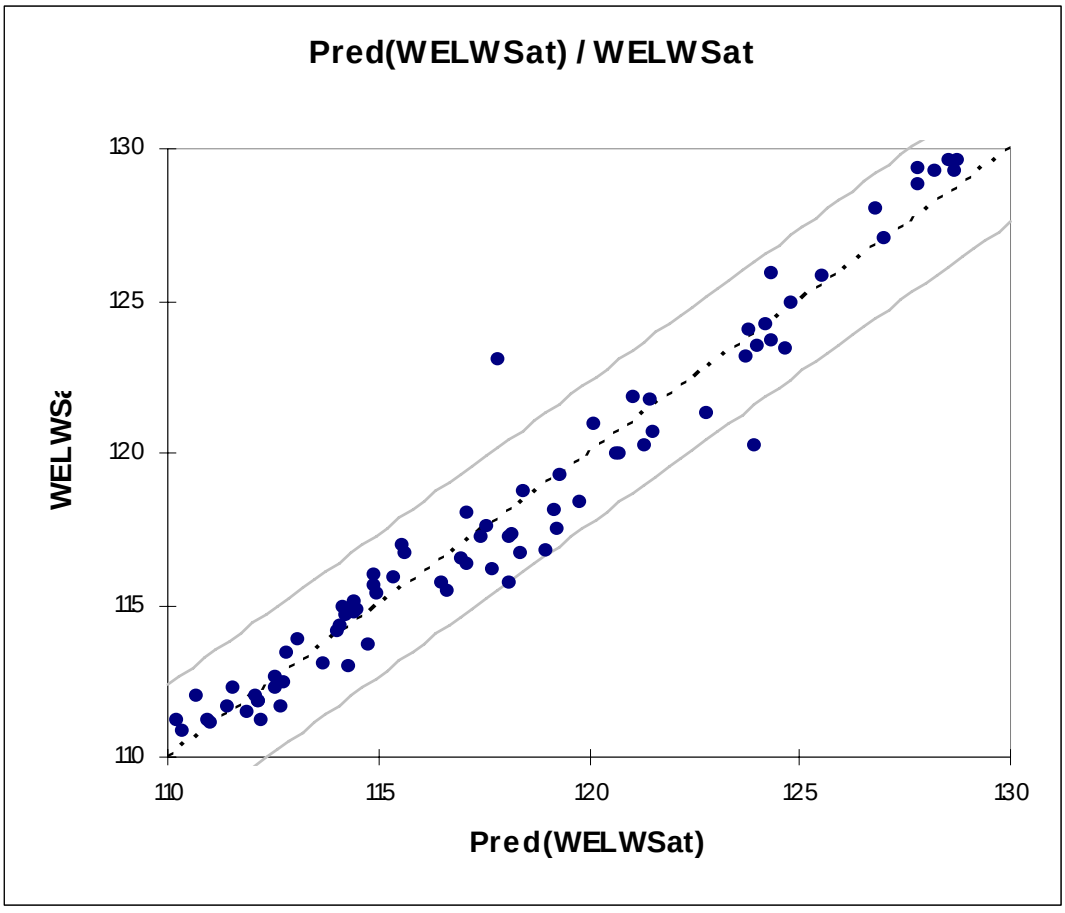


Figure 5.3-11 Predicted and measured percent TDG saturation at WELW for 80 test scenarios based on spill discharge and forebay %TDG

The correlations for spill discharge and %TDG saturation are only slightly weaker than when forebay %TDG is not incorporated.

$WELW_{TDG} = 111.539+0.141Q_{spill}$ $R^2 = 0.901$ (5.3-6)
$TW3P2_{TDG} = 111.889+0.145Q_{spill}$ $R^2 = 0.913$ (5.3-7)
$TW3P4_{TDG} = 111.942+ 0.154Q_{spill}$ $R^2 = 0.927$ (5.3-8)
$TW3P5_{TDG} = 111.704+ 0.156Q_{spill}$ $R^2 = 0.910$ (5.3-9)

The Hydrolab® instrument at TW3P3 became fouled by silt part way through the study. Reliable data were collected at this station for only 46 of the 80 tests with data not being used after May 28, 2006 at 12:00. Trends in TDG data at TW3P3 were similar to data from other monitoring stations on this transect. The correlation equation for %TDG saturation and spill is:

$TW3P3_{TDG} = 111.539 + 0.141Q_{spill}$ $R^2 = 0.901$ (5.3-10)

The relationships between %TDG saturation and spill are linear (Figure 5.3-12); transformation of non-linear polynomial relationships were evaluated and determined to provide no additional benefit. Figure 5.3-13 shows the 95% confidence limits for the regression for $WELW_{TDG}$ and spill discharge.

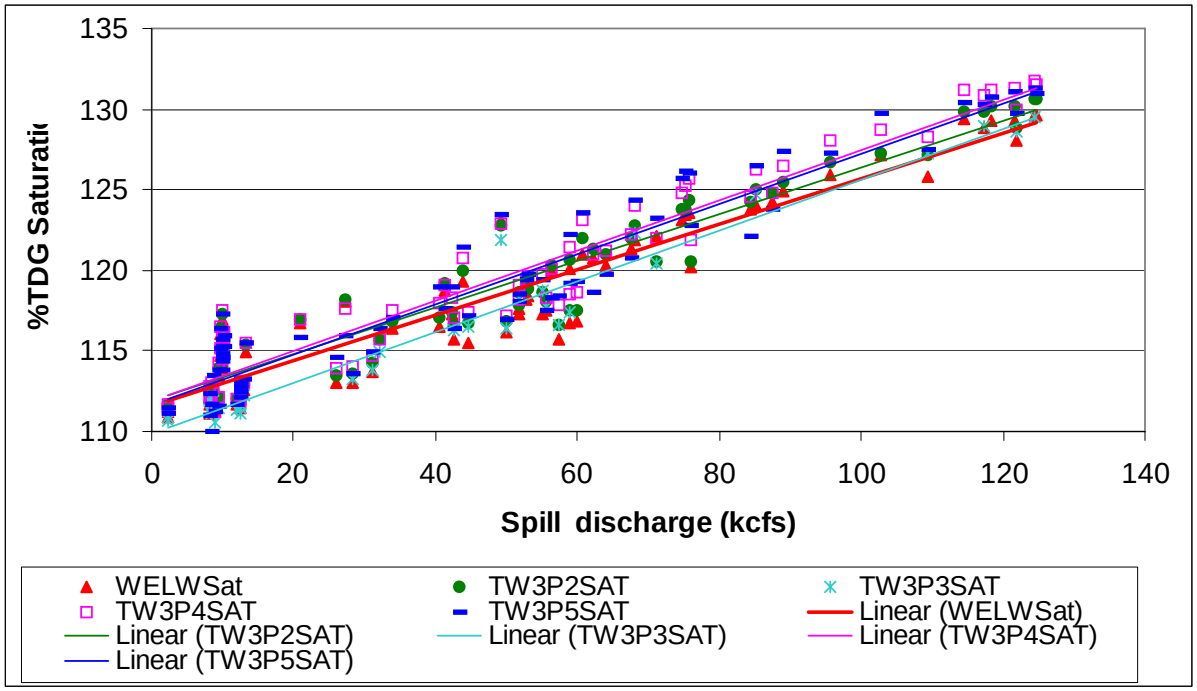


Figure 5.3-12 Regression relations for test conditions for spill discharge and percent TDG saturation at WELW

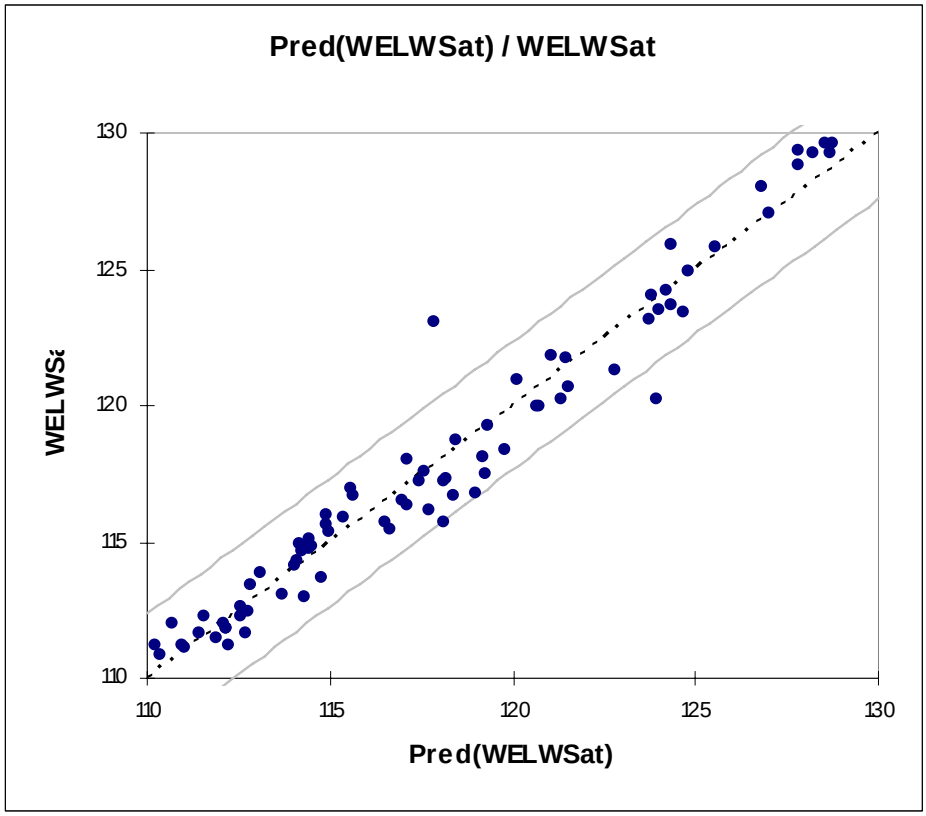


Figure 5.3-13 Predicted and measured percent TDG saturation at WELW for 80 test scenarios based on spill discharge

The production of TDG at Wells Dam was also investigated by incorporating both the forebay TDG and downstream TDG into the regression analysis. The concentration of dissolved gas in the water arriving at the forebay influences the gas saturation levels downstream of the Project. The change in % saturation (deltasat) was evaluated. A stepwise multiple regression was performed with %TDG production (calculated as $WELW_{TDG} - FB2_{TDG}$) as the dependent variable. The resulting correlation is:

$WELW_{TDG} - FB2_{TDG} = 1.89 + 0.125Q_{spill} - 0.013Q_{gen}$ $R^2 = 0.949$ (5.3-11)

The spill discharge once again was the primary determinant of downstream %TDG production at WELW. The resulting correlation is:

$WELW_{TDG} - FB2_{TDG} = 0.197 + 0.125Q_{spill}$ $R^2 = 0.935$ (5.3-12)
$WT3P2_{TDG} - FB2_{TDG} = 0.547 + 0.128Q_{spill}$ $R^2 = 0.934$ (5.3-13)
$WT3P4_{TDG} - FB2_{TDG} = 0.6 + 0.138Q_{spill}$ $R^2 = 0.94$ (5.3-14)
$WT3P5_{TDG} - FB2_{TDG} = 0.362 + 0.139Q_{spill}$ $R^2 = 0.914$ (5.3-15)

Figure 5.3-14 shows the correlations for TDG production for transect TW3.

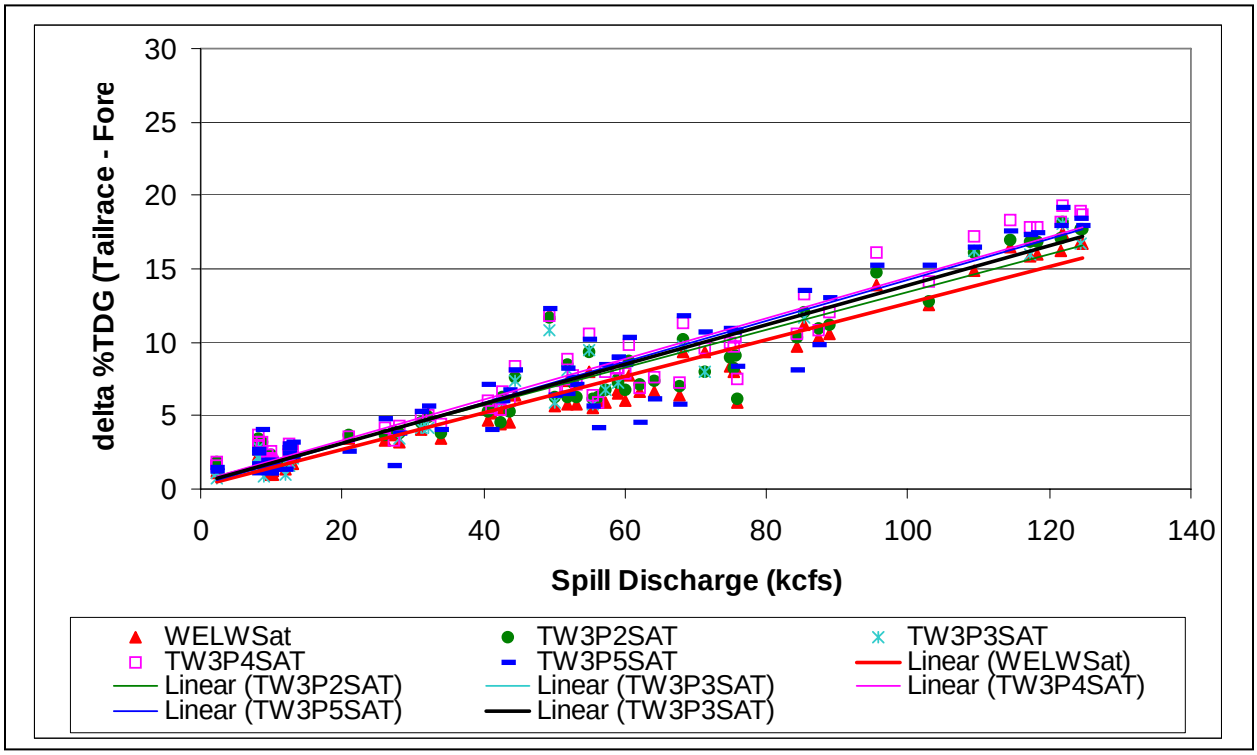


Figure 5.3-14 Regression relation for TDG production at transect TW3

The effect of spill as a percentage of total flow was also investigated (Figure 5.3-15). The correlation equations are:

$WELW_{TDG} - FB2_{TDG} = -0.896 + 28.5\ Q_{spill}/Q_{tot}$ $R^2 = 0.822$ (5.3-16)
$TW3P2_{TDG} - FB2_{TDG} = -0.635 + 29.594\ Q_{spill}/Q_{tot}$ $R^2 = 0.838$ (5.3-17)
$TW3P4_{TDG} - FB2_{TDG} = -0.678 + 31.884\ Q_{spill}/Q_{tot}$ $R^2 = 0.845$ (5.3-18)
$TW3P5_{TDG} - FB2_{TDG} = -0.838 + 31.653\ Q_{spill}/Q_{tot}$ $R^2 = 0.804$ (5.3-19)

The percent spill correlation showed a higher standard error (Figure 5.3-16) and the correlation to TDG production was slightly weaker than for just the spill, which suggests that the spill flow may be gassing the turbine flow.

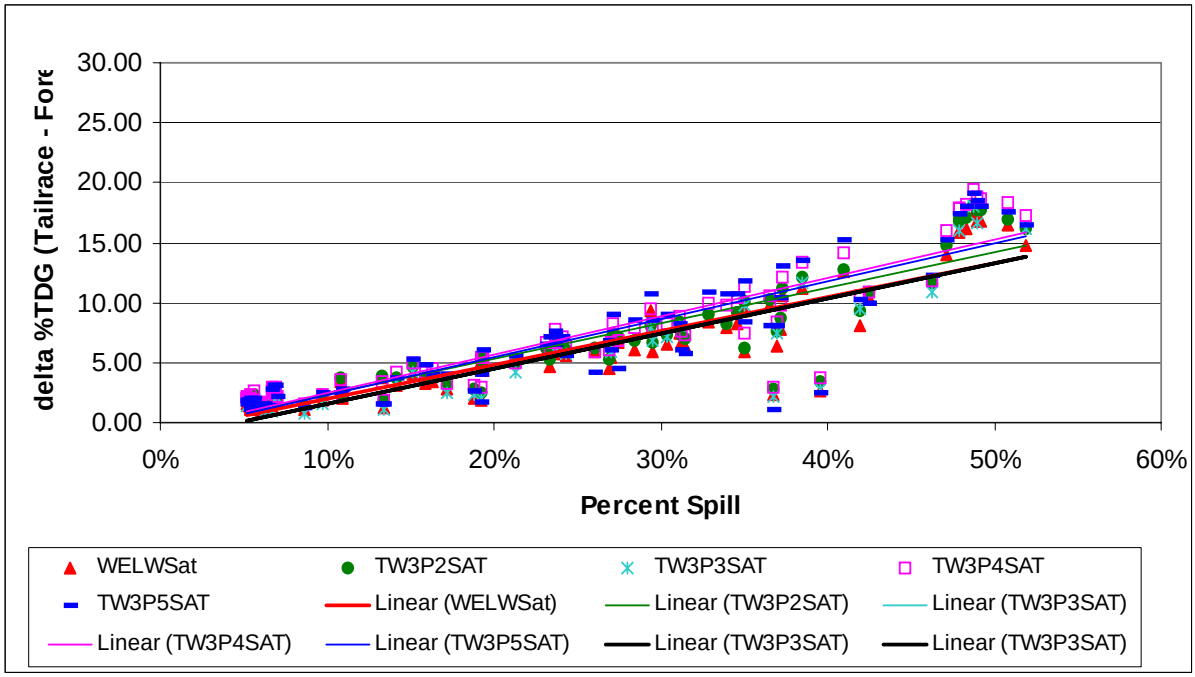


Figure 5.3-15 Regression relation for TDG production and percent spill for downstream transect TW3

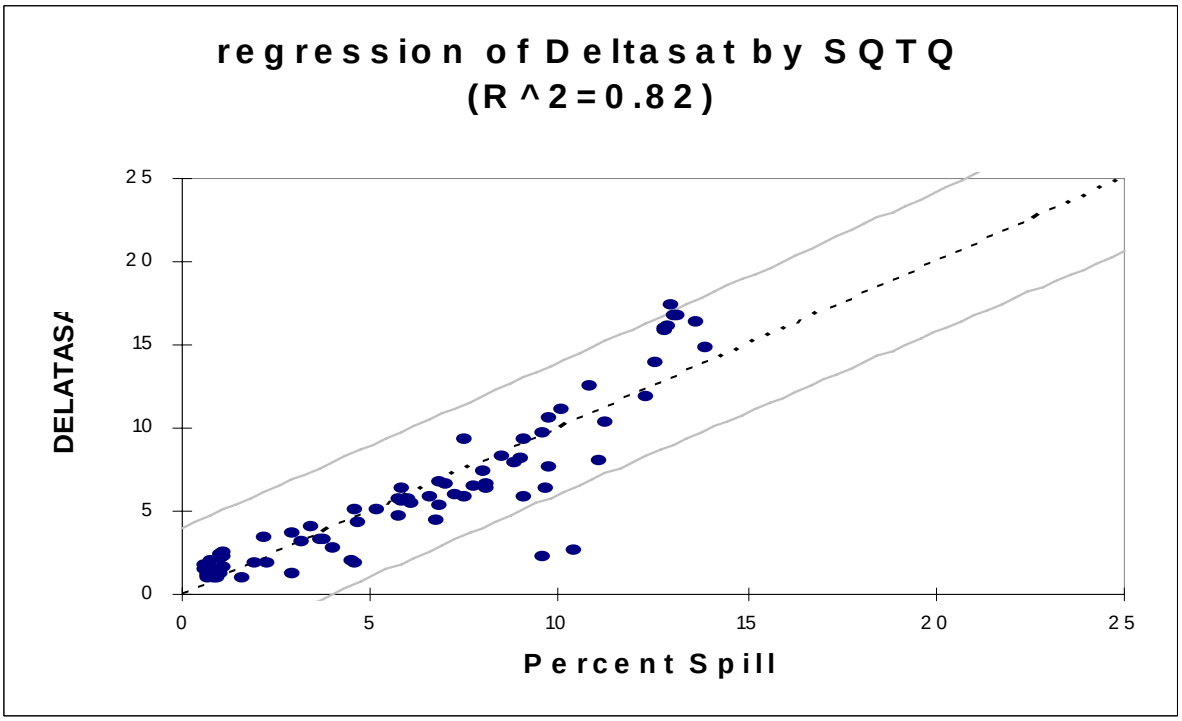


Figure 5.3-16 Regression relationship for test conditions for TDG Production and Percent Spill

The predicted values resulting from Equation 5.3-2 were compared to the predicted results based on the long term regression relationship reported in the Retrospective Data Analysis (ENSR 2006, equation 5-7). This comparison was initially applied to the data from all of the 80 tests conducted in 2006. The predicted percent saturation at WELW for two regressions are not significantly different based on a t-test ($\rho = 0.552$; $\alpha = 0.05$). The predicted values for the two correlations are presented in Figure 5.3-17.

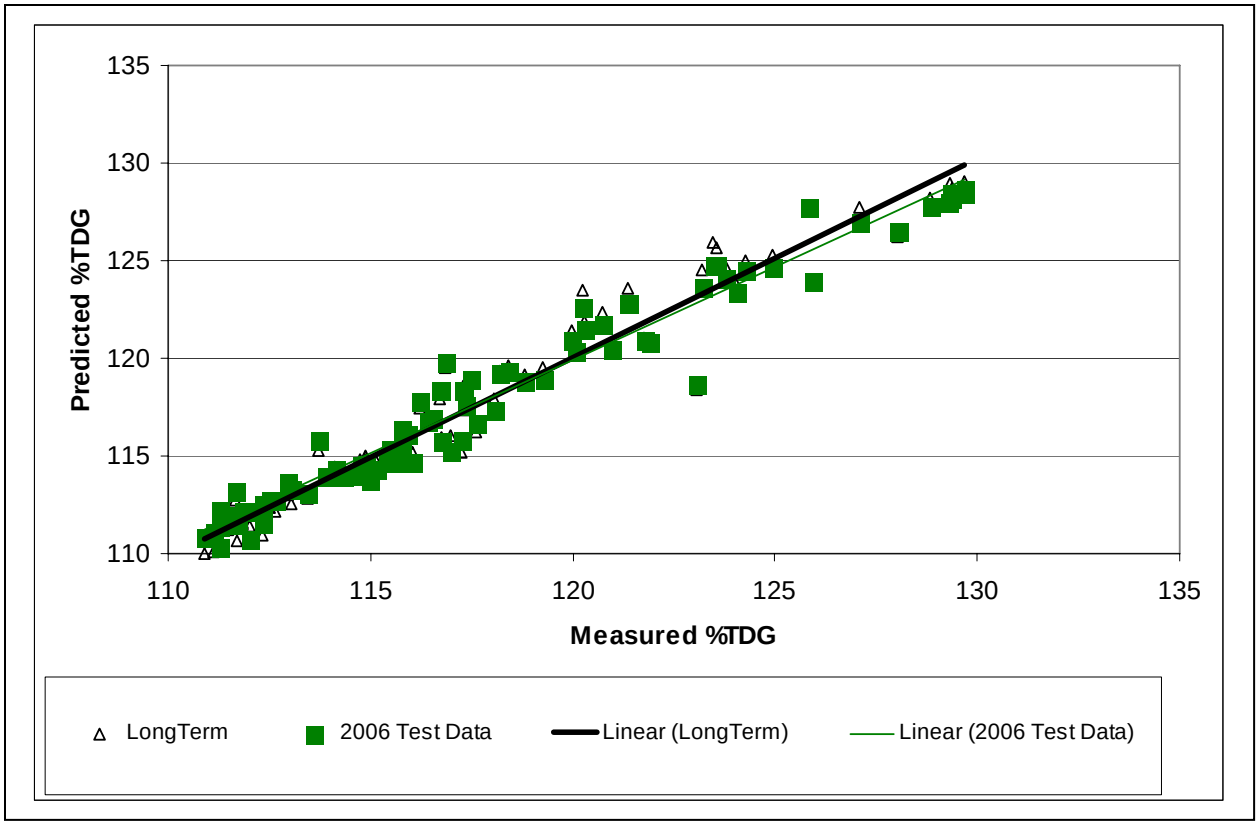


Figure 5.3-17 Comparison of regression relationships 2006 and long term (2000 – 2005) for percent saturation at WELW as a function of forebay percent saturation and spill

As a verification of their predictive capability, the two regression equations were next applied to the data for non-test periods in 2006. The time to reach equilibrium at WELW had to be accounted for when applying the regression equations. The historical data used to develop the long term regression were hourly values with the reported value being the average value for the preceding hour. The 2006 data were summarized into 15-minute increments for analysis. The time to reach equilibrium at WELW is approximately one hour. Therefore, the forebay TDG saturation and spill data were offset by the preceding 60 minute period; i.e., the predicted %TDG saturation for 9:15 relies upon the forebay %TDG saturation and spill flow occurring at 8:15. Predicted %TDG data are compared to measured %TDG in Figure 5.3-18. Both predictive equations showed a generalized trend of good predictive capability over a wide range of TDG levels with an uncertainty of + 2%TDG.

The two regression equations were also applied to the long term data set (2000 – 2005). In this case no correction for equilibrium time was necessary since the data are hourly and the equilibrium time was already accounted for by the manner that the historical data were archived. The results for this analysis are presented in Figure 5.3-19.

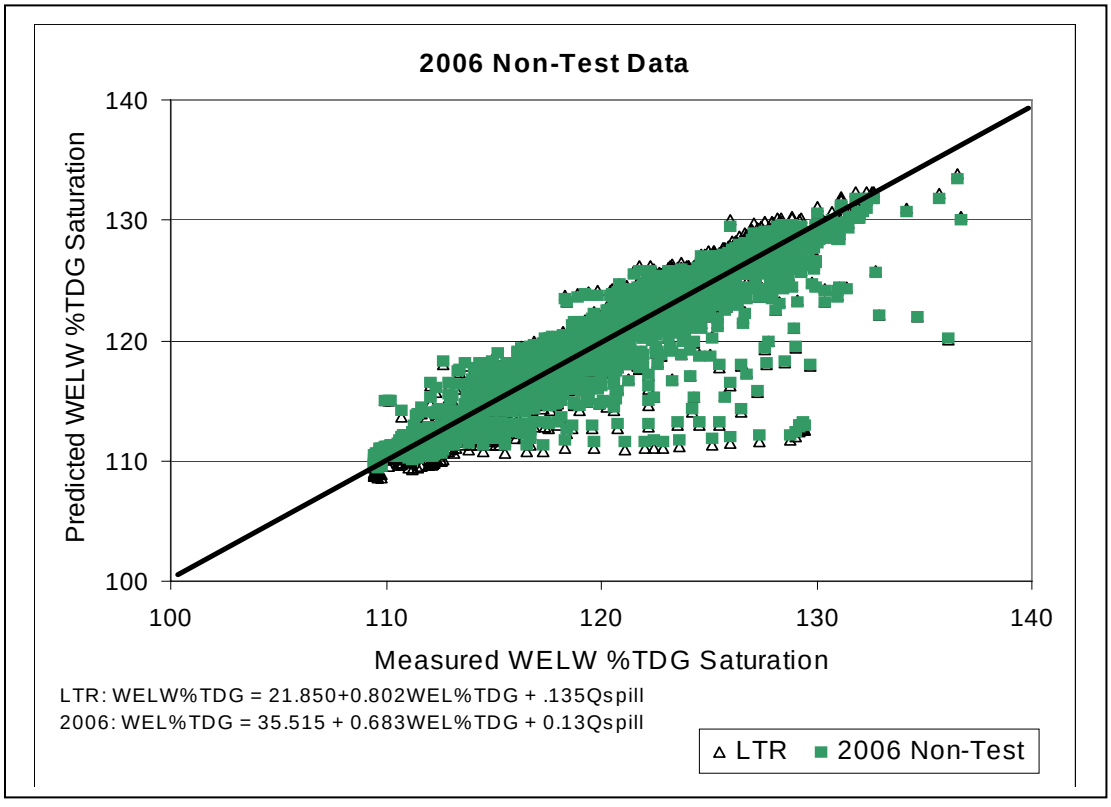


Figure 5.3-18 Comparison of regression relationships applied to 2006 Non-Test Data

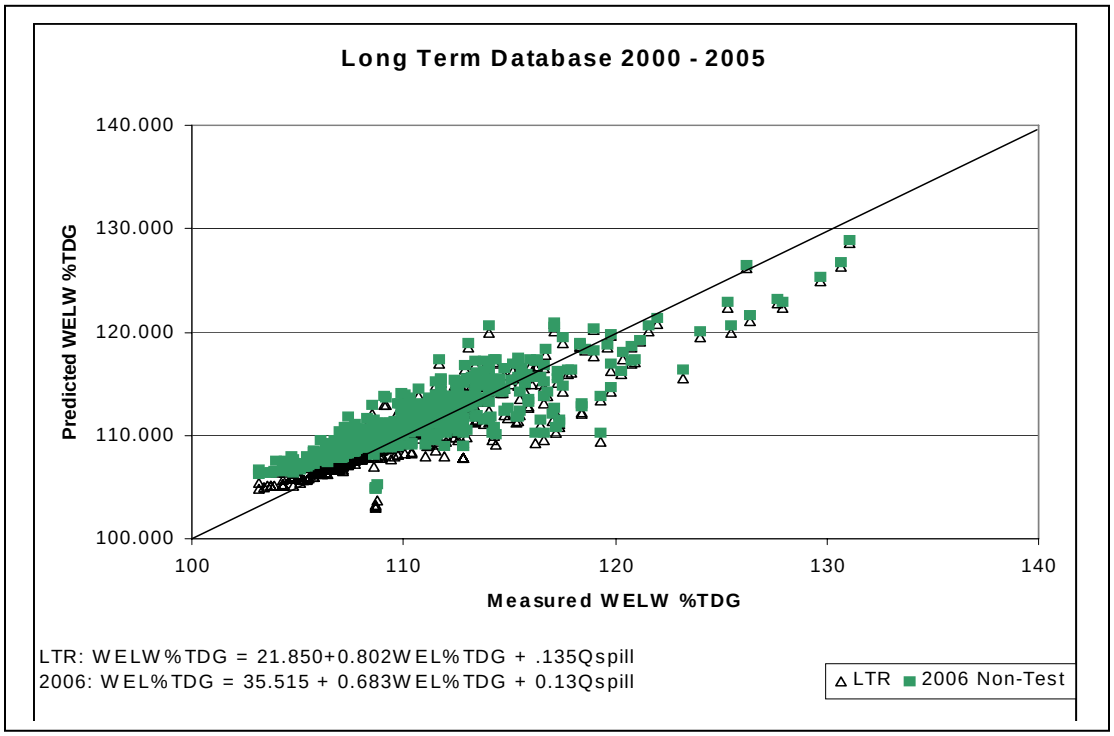


Figure 5.3-19 Comparison of regression relationships applied to 2000 – 2005 Long-term database

5.3.5 Spill Shaping

Determining the effect of project operations on downstream TDG as a means of identifying specific project operations that may reduce TDG production was a primary objective for the 2006 study. Each test was assigned to one of six operational categories listed in Table 4.2-2. Figure 5.3-20 shows the test results by operational category. The tests for crowned and dentate spill patterns were performed over a relatively wide range of spill flows. The JBS spills, by definition, occurred within a narrow range of spill flows.

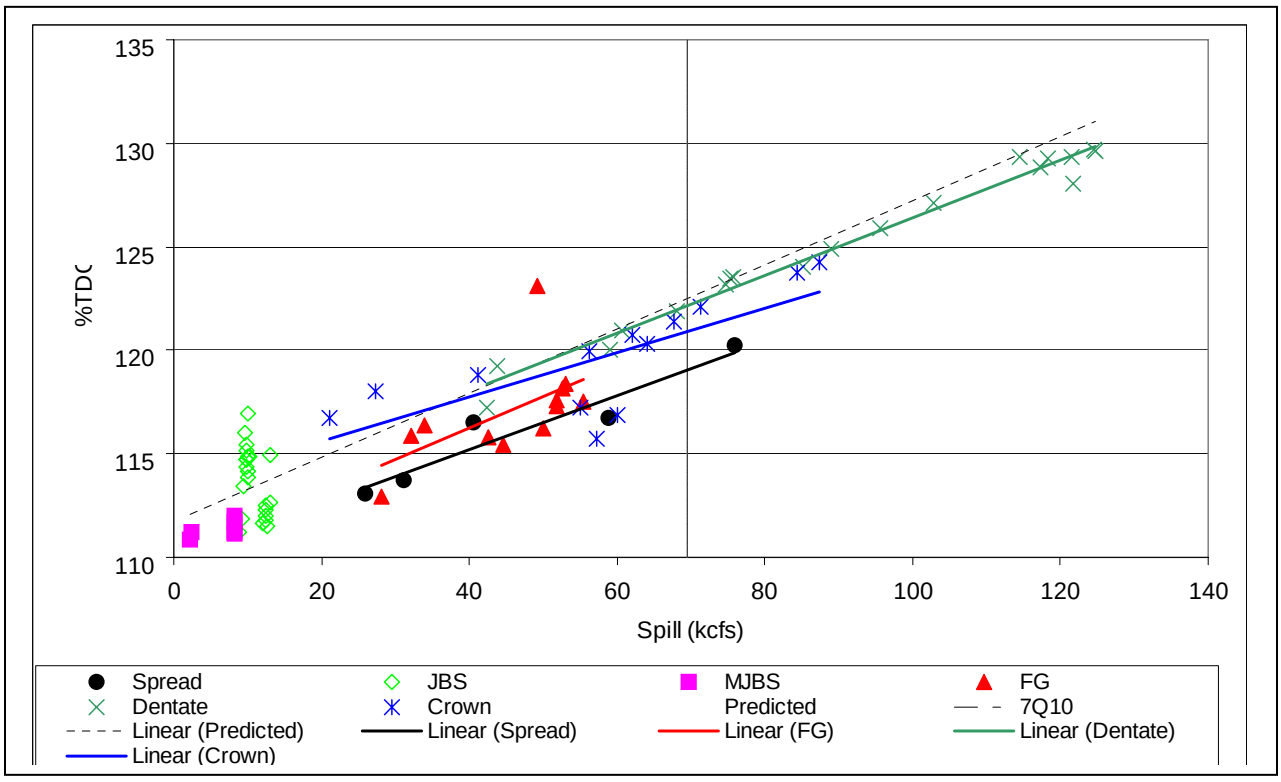


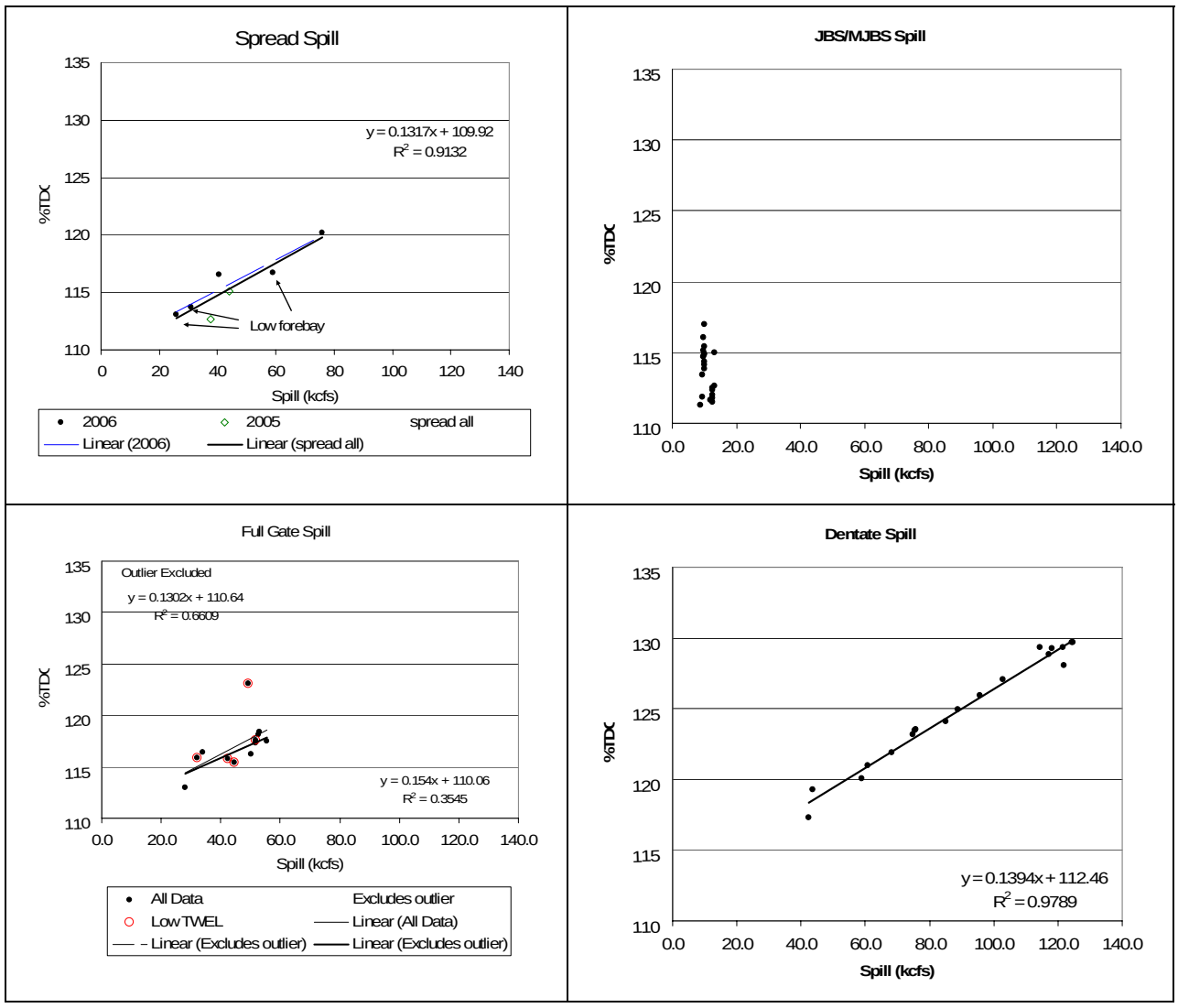
Figure 5.3-20 %TDG saturation at WELW for categories of spill gate configurations

The small sample size for spread and full gate spills resulted in some cases having a large leverage on the resulting correlation. All operational categories except the dentate spill had at least one data point that was an outlier. The full gate spill test 12 with 41.3 kcfs through gate 7, resulting in 50% spill with a total spill of 49.2 kcfs was the most pronounced outlier. The regression was calculated with and without this outlier; the trendlines shown for full gate spills in Figures 5.3-21 through 5.3-24 are based on the regression that excluded the outlier test 12. Figure 5.3-21 shows the correlations for %TDG saturation at WELW as a function of spill for each operational category. Figure 5.3-22 shows the results for TDG production and Figure 5.3-23 whose correlations for specific operational categories.

Three of the five spread spills had a low forebay elevation (below 772 ft). The forebay was lowered during part of the test period to alleviate upstream flooding on the Methow River. Data from the 2005 study were added to the spread spill analysis to increase the total sample size. Several of the full gate tests were also conducted when the forebay was lowered; data for these tests are indicated on Figures 5.3-21 and 5.3-23. There were three outliers for the crowned spill regression analysis for %TDG vs. spill. Minor drift during the equilibrium period for the %TDG at WELW was noted for one of these outliers. The forebay elevation was lower for the other two crowned spill outliers.

Tailwater elevation also varied during the tests. Although tailwater elevation did not prove to be a significant factor in the regression analysis for %TDG and spill, it did prove an important

determinant when spill flow regimes were analyzed. Section 5.3.7 further elaborates on flow regimes and explains some of the outliers observed in Figure 5.3-23.



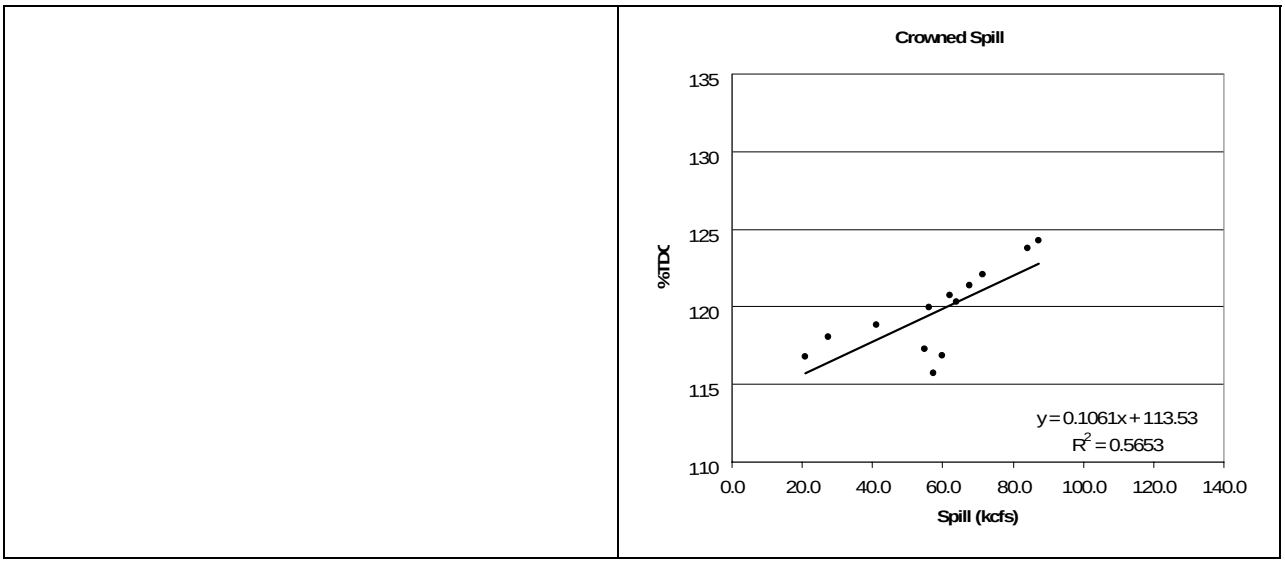


Figure 5.3-21 %TDG saturation at WELW as a function of spill for operation categories

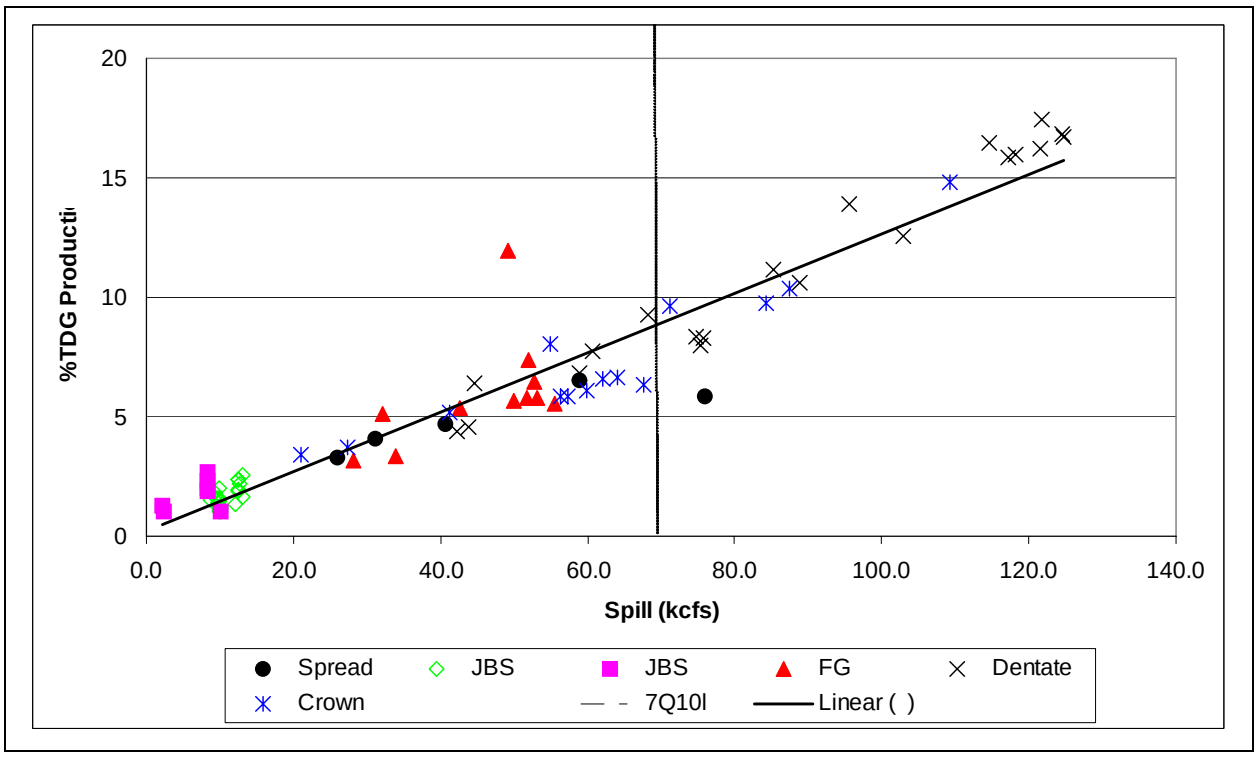
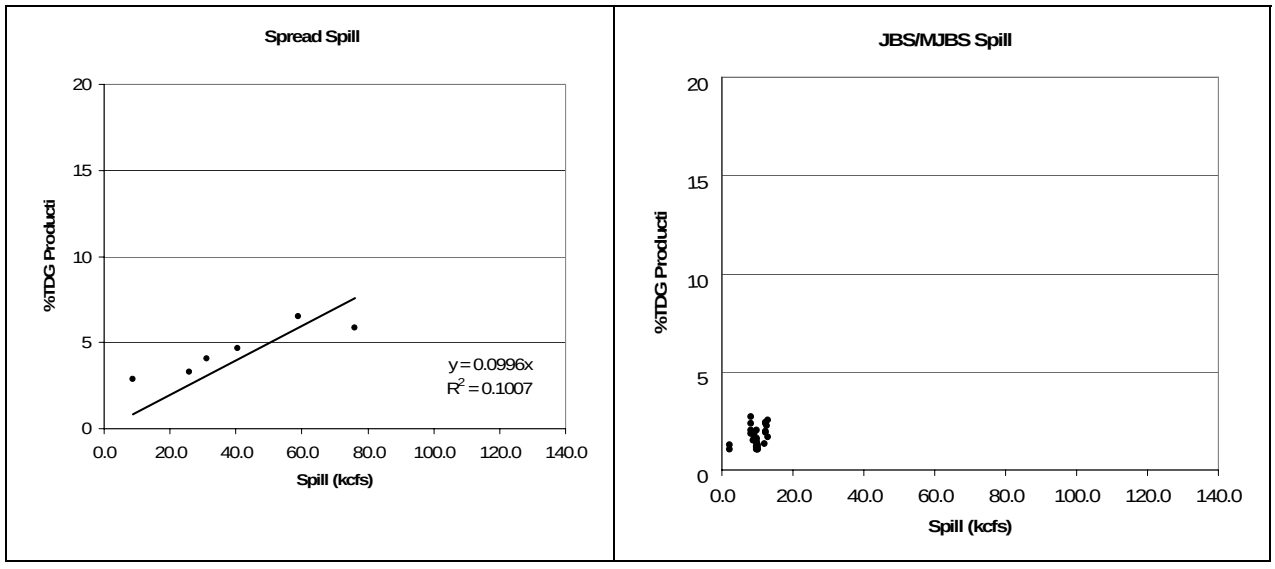


Figure 5.3-22 %TDG production (WELWTDG – FB2TDG) for categories of spill gate configurations



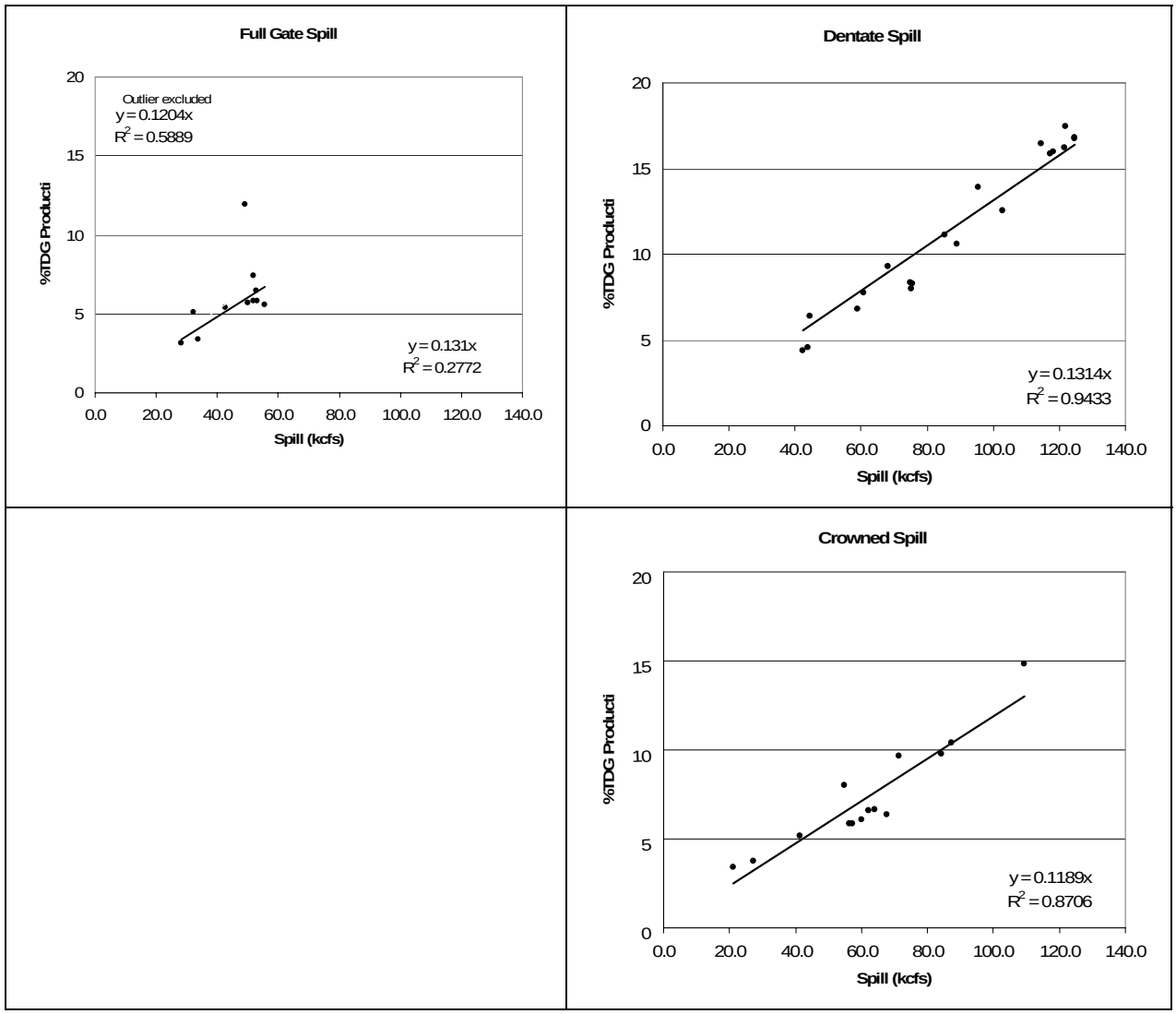


Figure 5.3-23 %TDG production (WELWTDG – FB2TDG) for operation categories

The best correlation for downstream %TDG saturation for the 80 test conditions was based on both spill and forebay %TDG saturation (Equation 5.3-2). A similar regression analysis was performed using test data for each spill category; the resulting equations are:

Spread	$WELW_{TDG} = 44.344 + 0.086Q_{spill} + 0.609\ FB2_{TDG}$	N = 6	R^2=0.963	(5.3-20)
JBS/MJBS	$WELW_{TDG} = 32.155 - 0.045Q_{spill} + 0.723\ FB2_{TDG}$	N = 29	R^2=0.909	(5.3-21)
Full Gate	$WELW_{TDG} = 61.832 + 0.108Q_{spill} + 0.448\ FB2_{TDG}$	N = 11	R^2=0.835	(5.3-22)
Dentate	$WELW_{TDG} = 79.554 + 0.144Q_{spill} + 0.286FB2_{TDG}$	N = 20	R^2=0.988	(5.3-23)
Crowned	$WELW_{TDG} = 15.561 + 0.102Q_{spill} + 0.861FB2_{TDG}$	N = 13	R^2=0.884	(5.3-24)

The average forebay TDG saturation for 2000 – 2005 was 108.4% (ENSR, 2006). Figure 5.3-24 shows the predicted %TDG at WELW based on equations 5.3-20 through 5.3-24 assuming forebay %TDG is 108.4%. The correlation for JBS is not shown since it only applies to a very limited and low range of spill. The 95% confidence intervals for the regression based on all test data combined are also shown. The results for individual spill scenarios fall within these confidence intervals. The Y-intercept was not forced for the lines shown in Figure 5.3-24; therefore, the lines for each spill are best viewed relative to one another.

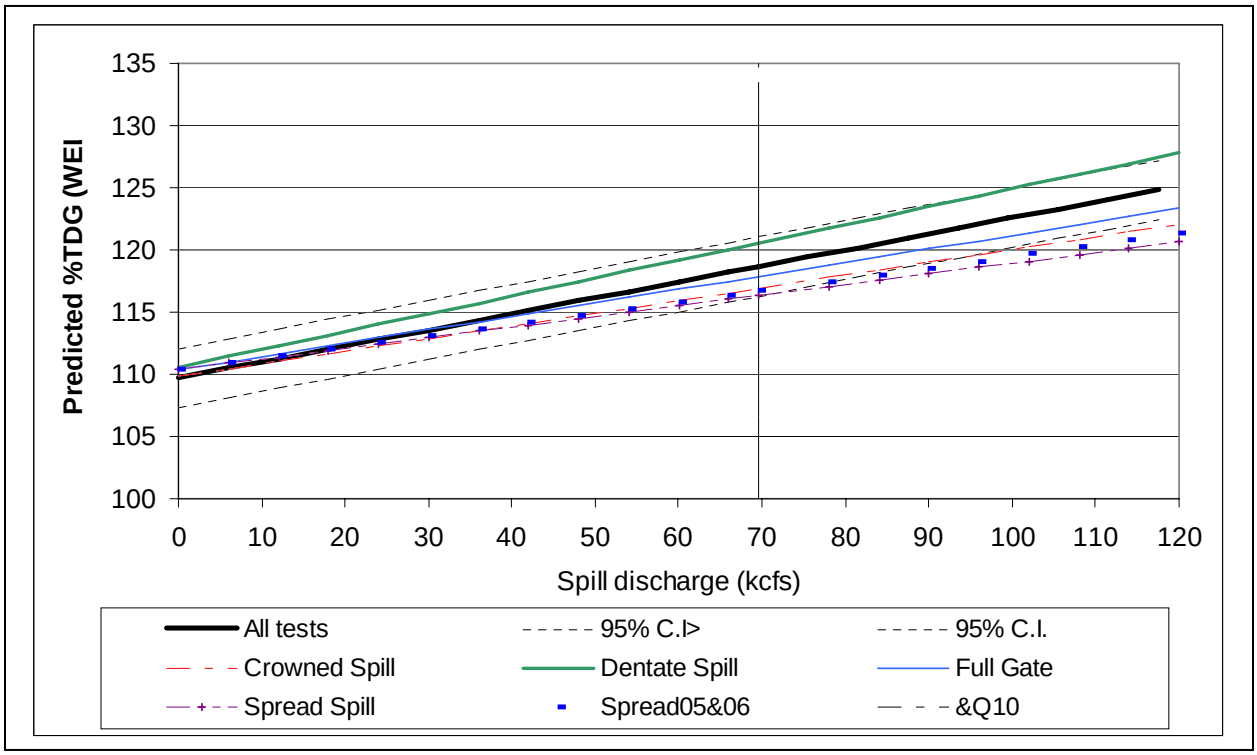


Figure 5.3-24 Predicted %TDG saturation at WELW when forebay %TDG = 108.4%

The spread spill correlation predicted the lowest downstream %TDG saturation; however, the correlation was strongly leveraged by two data points within the small sample size. The data from spread spill tests conducted in 2005 were added to reduce the leverage of individual data points. Spread spills and crowned spills result in the lowest gas saturation. Dentate spills result in higher gas saturation for all spill rates. Spread spills and crowned spills produced similar results for downstream %TDG when the forebay %TDG was at 108.4%. Increasing the forebay

%TDG to 113% resulted in spread spills producing lower %TDG than crown spills when the spill exceeds about 25 kcfs.

Transforming the predicted %TDG data for the various spill types so that the forebay %TDG equaled the downstream %TDG when there was zero spill (forcing the Y intercept in Figure 5.3-24) resulted in the spread spill outperforming the dentate spill by 1.7% and 4%, respectively, for spills of 30 kcfs and the spill flow of 69.5 kcfs required to pass the 7Q10 total flow. The transformed data for full gate and crowned spills were intermediate to spread and dentate spills. The transformed predicted values for crowned and full gate tests were essentially the same.

The downstream %TDG at WELW was predicted to be at or below 120% for all spill patterns except dentate spills when the forebay %TDG equaled 108.4%. The %TDG for the dentate spill was predicted to be 120.5%. The %TDG at WELW predicted for a spread spill pattern for the 7Q10 equivalent spill of 69.5 kcfs was 120.3%.when the forebay %TDG was set at 115%. All other spill patterns resulted in higher downstream %TDG at the 7Q10 spill equivalent.

5.3.6 Laterally Biased Spill

Previous studies (CBE, 2006) reported that spill from the west spillbays resulted in higher dissolved gas saturation than similar spill volumes from the east spillbays. The 2005 study results indicated that TDG gradients of up to 5% persisted downstream for at least three miles to Transect TW3. The western side of the tailrace channel is uniformly 3m – 6m deeper than the eastern side. The eastern side of the channel gradually shallows toward the eastern shore. The deeper channel on the western side (spillbays 1-6) promotes a greater plunge depth for the spilled water and subsequently could lead to higher dissolved gas saturation.

The crowned spill tests were visually stratified for those where the majority of the spill occurred through spillbays 7-10 on the eastern side of the spillway (see Appendix B). The spill for four crowned spill tests (C2, C6, C15 and C35) was not biased towards the eastern spillbays. The spill for nine tests (C61, C63, C64, C66, C67, C70, C71, C75, and C76) was distinctly biased for spillbays 7-10. The biased crowned spills resulted in higher dissolved gas saturation across the near-field transect TW1 (Figure 5.3-25) up to spills approximately equivalent with the spill of 69.5 kcfs that is associated with a 7Q10 flow. There were no crowned non-biased spills in excess of 71.3 kcfs but the trendline suggests that spills biased toward the eastern side would produce less gas than non-biased spills when the spill is in excess of 71 kcfs.

The lateral gradient at TW1 was about 4% favoring higher %TDG along the western side for crowned spills when the spill was unbiased and primarily concentrated in spillbays 5 and 7. For spills in excess of 80 kcfs, %TDG levels at TW1P2 were 6.5% - 10% higher than recorded at other stations along transect 1; the other stations showed little variation in %TDG for these high spill events.

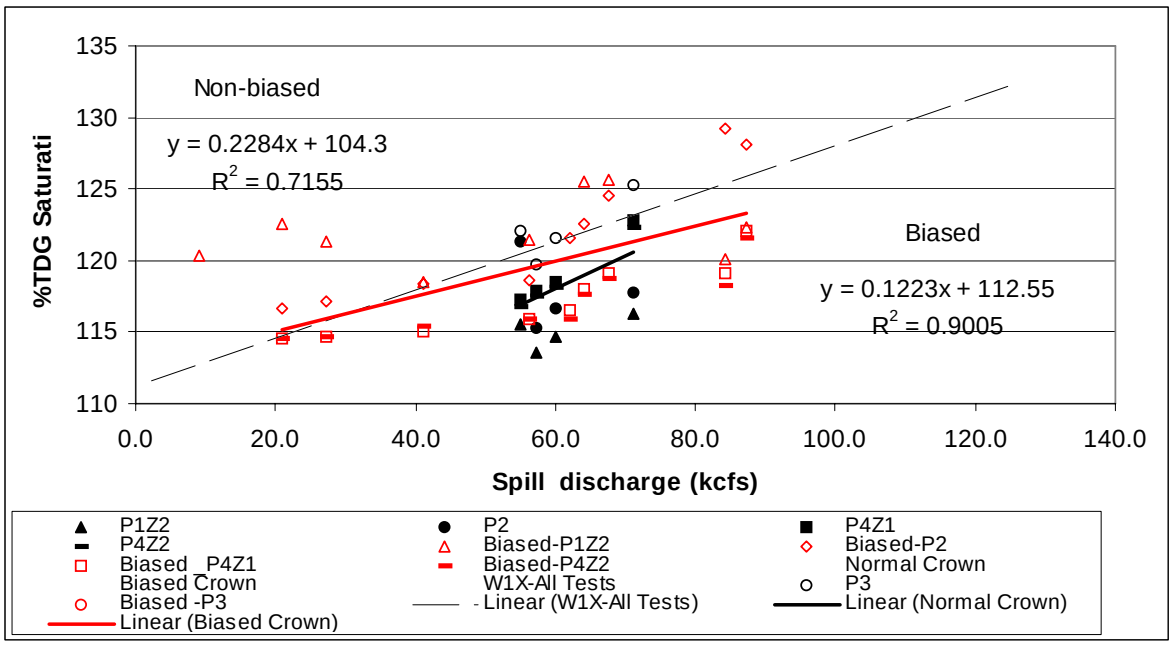


Figure 5.3-25 Near-field (TW1) %TDG for biased and un-biased crowned spills

Biased crowned spills resulted in higher %TDG saturation at the downstream TW3 transect relative to unbiased spills when the spill was less than the 7Q10 equivalent spill (Figure 5.3-26). There was little or no lateral gradient at TW3 for biased crowned spills and about a 2-3% lateral gradient for un-biased crowned spills. For the un-biased crowned spills, the %TDG was slightly higher for TW3P4 (western side) than for WELW1 (TW3P1) and TW3P2. Biased crowned spills resulted in about 2.5% higher TDG at TW3. The slope of the trendline for non-biased crowned spills (Figure 5.3-26) is primarily a function of tailwater depth relative to the elevation of the submerged spillway flip lips, which is discussed in section 5.3.7 of this report.

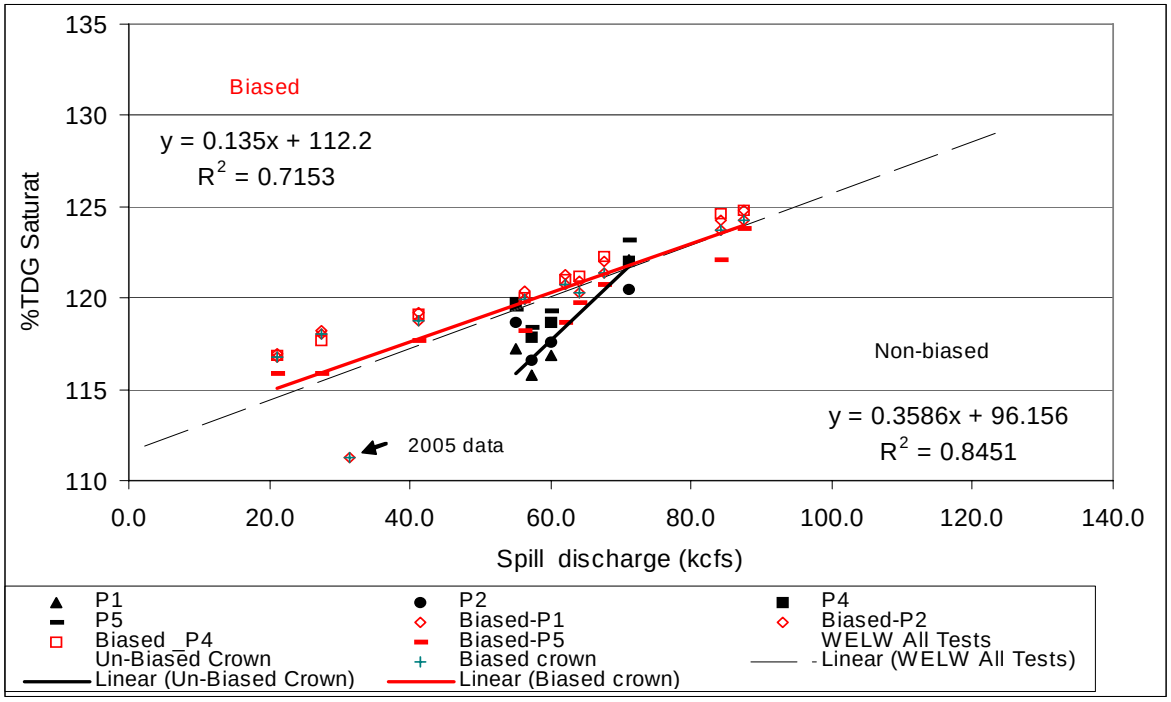


Figure 5.3-26 Downstream (TW3) %TDG for biased and un-biased crowned spills

5.3.6.1 Loaded and Unloaded Spill

Previous studies have investigated the effects on gas saturation of loaded and unloaded spill. Loaded spill occurs when the spill is located through gates above generating turbines. Unloaded spill occurs when the generating turbines are laterally segregated from the active spill gates. Total flow volumes during the 2006 study period provided little opportunity to compare loaded and unloaded spill. The flows were too high to laterally segregate turbine generation from spill except for full gate spills. Crowned spill C2 was the only test other than full gate spills that had an unloaded spill configuration.

Regression analysis was applied to evaluate the effect of spill loading. Unloaded spill tests include the full gate spill tests 1, 9, 11 and crowned spill test 2. The full gate spill test 12 was not included in the analysis as the downstream %TDG measurement was anomalous and had an unacceptably high leverage on the regression result. The full gate loaded spill tests 14, 32, 42, 47, 49, and 50 were used for comparison. The spill range for the unloaded full gate tests was 33.85 kcfs to 43.39 kcfs. The spill range for loaded full gate tests was 31.75 kcfs to 52.7 kcfs. Although the correlation for the loaded full gate tests was poor, there was little difference between the downstream %TDG levels for the loaded and unloaded tests. The results are inconclusive regarding the benefit of loaded and unloaded spill.

The application of a mass balance analysis provides an additional method to assess the effect of spill over turbine generation. A simple mass balance approach was used to compare the

unloaded and loaded tests. If no gassing of the turbine flow occurred, then the following equation can be used to calculate the expected downstream %TDG:

$$WELW_{TDG}=(SP_{TDG}Q_{sp}+PH_{TDG}Q_{ph})/(Q_{sp}+Q_{ph})$$

Equation 5.3-25

where

$WELW_{TDG}$= %TDG at WELW

$\mathbf{SP_{TDG}}$= %TDG of spill

$\mathbf{Q_{sp}}$= Spill discharge

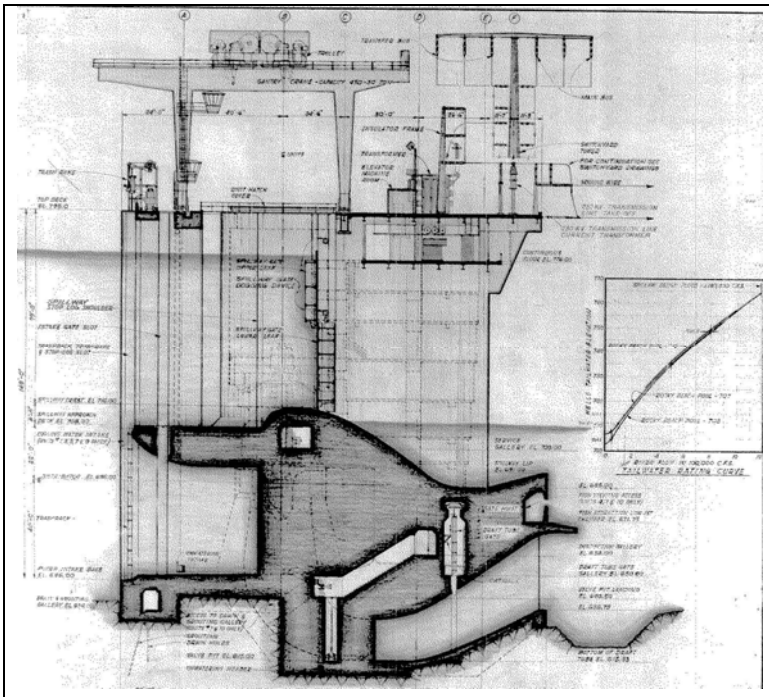
$\mathbf{PH_{TDG}}$= TDG pressure of powerhouse releases

$\mathbf{Q_{ph}}$= Powerhouse discharge

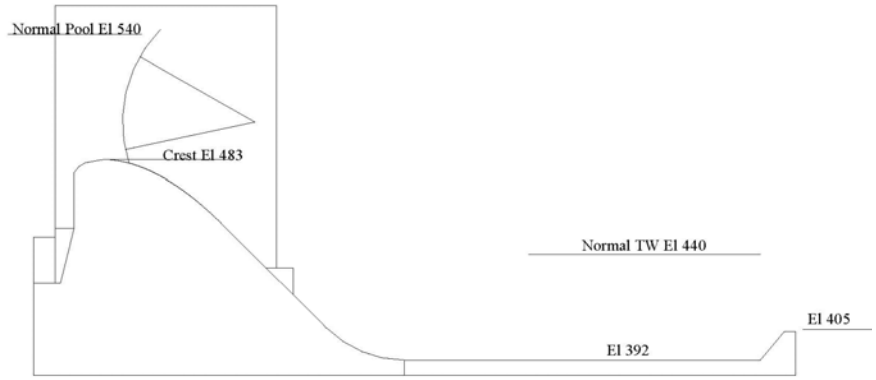
Assuming that the gas saturation is unaltered for water passing through the turbines, the forebay TDG data can be used in equation 5.3-25 as an equivalent to PH_{TDG}. Equation 5.3-25 can be reformatted to solve for $\mathbf{SP_{TDG}}$. The calculated $\mathbf{SP_{TDG}}$ was compared to the high range of measured gas saturation at the uppermost tailrace transect (TW1). A significant difference between the calculated $\mathbf{SP_{TDG}}$ (equation 5.3-25) and the measured $\mathbf{SP_{TDG}}$ is indicative that the powerhouse is adding dissolved gas to the downstream. The average for the calculated $\mathbf{SP_{TDG}}$ for the unloaded tests was 14.7% higher than the maximum %TDG measured at TW1 for those tests. The average calculated $\mathbf{SP_{TDG}}$ for the loaded test was 16.5% higher than the maximum measured %TDG for those tests. This suggests that the turbine flow is being gassed in both situations.

5.3.7 Test Spill Comparison to Spillway Deflector Flow Regimes

The Wells hydrocombine spillways are equipped with a flip lip that forces the spill flow back up towards the surface under certain spill and tailwater elevations. This action is similar to the action of deflectors installed on spillway ogees to mitigate TDG production. Deep plunging, combined with the air entrainment in the hydraulic jump at the spillway can produce high levels of TDG. The purpose of deflectors is to redirect flow on the spillway ogee under the smaller gate openings typical for normal flow releases so that it does not plunge deep in the stilling basin in a classic hydraulic jump formation. The action of flow leaving the deflector will vary with the depth of submergence of the deflector by tailwater and the spillway bay discharge or discharge per unit width of spillway. A comparison of the Wells spillway profile to the deflector equipped spillway at Lower Monumental Dam is shown in Figure 5.3-27. Variation in flow patterns affected by a deflector can be fit into one of several distinct flow regimes as illustrated in Figure 5.3-28.

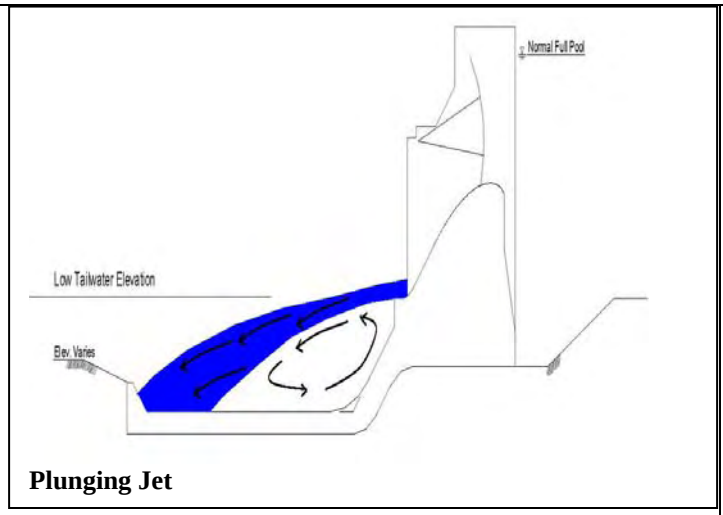


a) Wells Dam

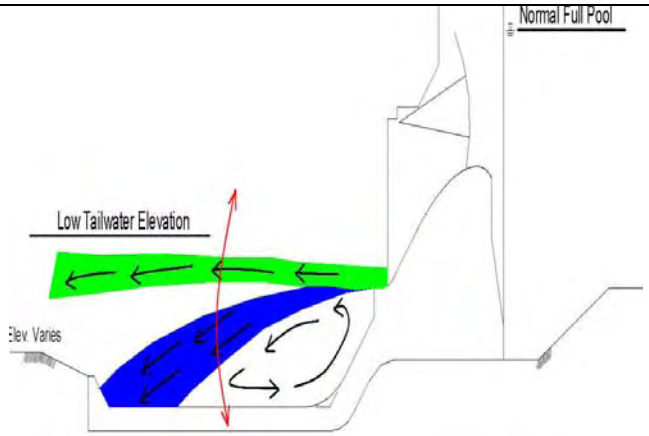


B) Lower Monumental Dam (Wilhelms et al., 2003)

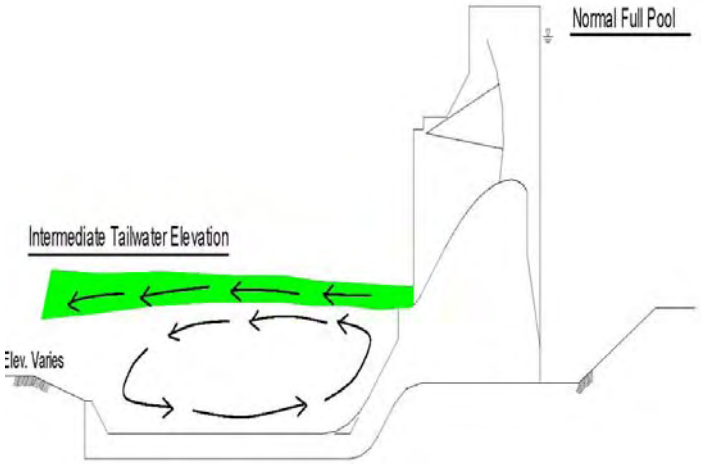
Figure 5.3-27 Comparison of Wells hydrocombine to a deflector equipped spillway



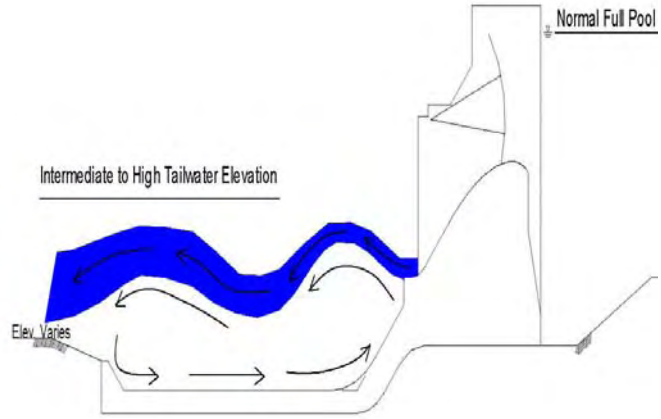
Plunging Jet



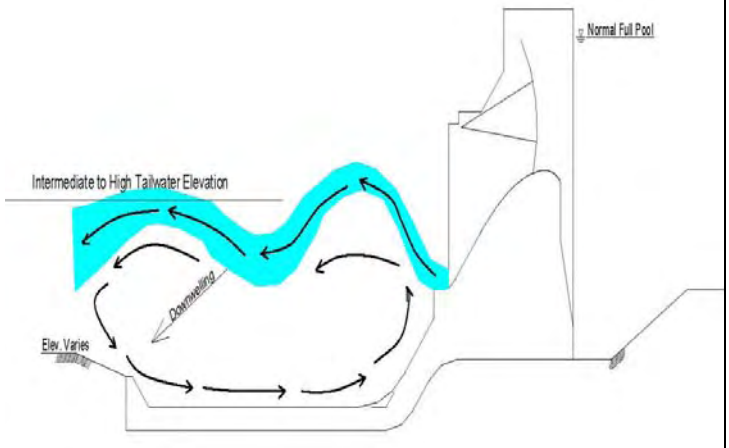
Unstable Plunging Jet



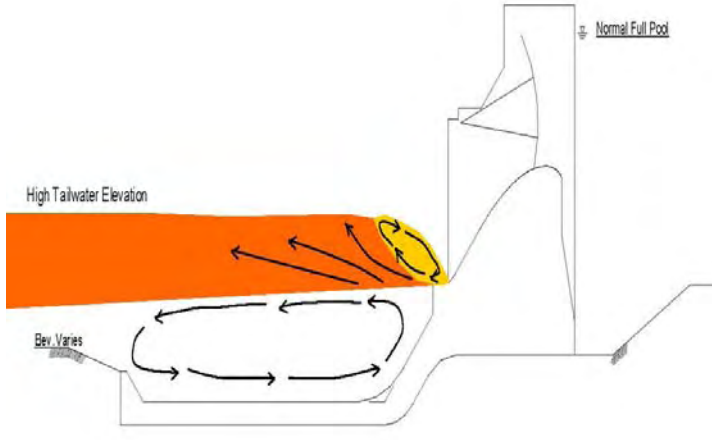
Skimming Surface Jet



Undulating Surface Jet



Ramped Surface Jet



Surface Jump

Figure 5.3-28 Spillway deflector flow regimes

The best TDG performance can be achieved by maintaining flow in the skimming, undulating, and ramped surface jet regimes, where air entrainment is less and the flow pattern is less likely to carry entrained air to depth. Surface flows also provide greater opportunity for degassing through exchange with the ambient atmosphere particularly if the surface flow is turbulent. Either end of the spectrum will tend to increase TDG production through either plunging flow carrying air deep or the surface jump increasing air entrainment. These regimes of performance can be easily determined in a physical scale sectional hydraulic model of the spillway in which flow can be observed through a clear viewing wall and the flow patterns and tendency for entrained air to be driven to depth identified. Figure 5.3-29 shows a plot of spillway deflector regimes at Lower Monumental Dam (Wilhelms et. al, 2003). Such plots can be used to guide spillway operation to maintain a favorable flow regime.

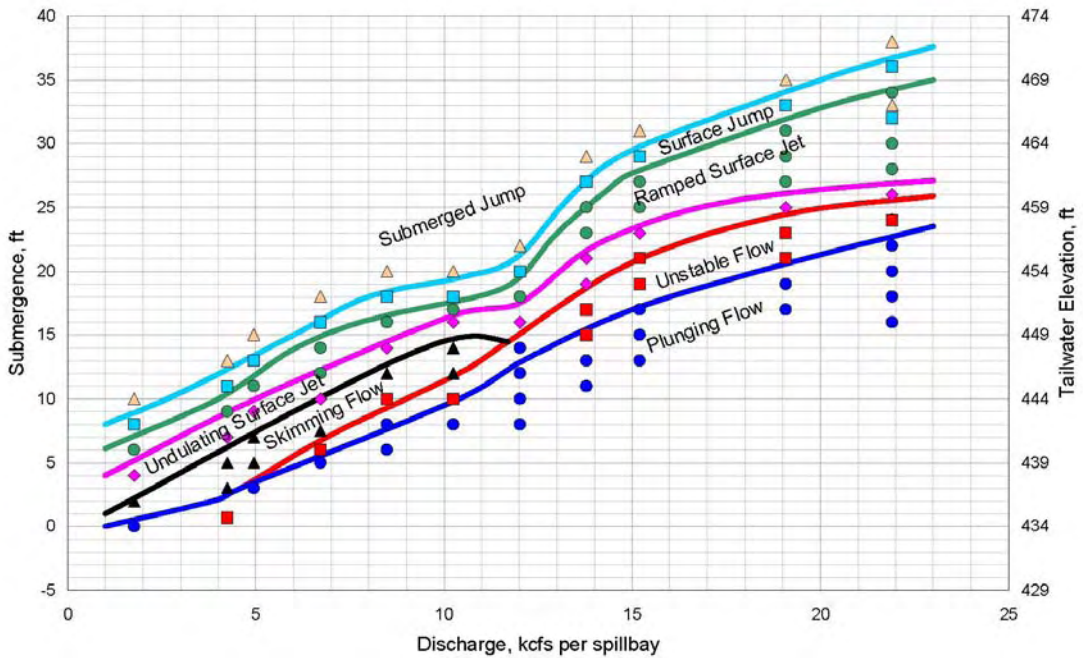


Figure 5.3-29 Lower Monumental Dam Spillway Deflector Regime Plot (from Wilhelms et. al. 2003)

While a similar regime relationship has not been developed for the Wells Project through physical hydraulic modeling, the 2006 test data were analyzed in an effort to discern similar regime patterns.

The spill data were transformed to create a spill momentum index that was assigned the name unit spill (spill cfs/width ft). A single weighted average value for each spill test was computed with the weighing proportionate to the flow through individual spillbays. The equation for the weighted average unit spill is:

$$\frac{SQ_1}{SQ_T} * \frac{SQ_1}{W_1} + \frac{SQ_2}{SQ_T} * \frac{SQ_2}{W_2} + \frac{SQ_n}{SQ_T} * \frac{SQ_n}{W_n} = WeightedSpill / Width \qquad \text{(Eq 5.3-26)}$$

Where: SQ_1 = Spill for spillbay 1
SQ_T = Total Spill
W_1 = Width of spillbay 1

The above equation weights the momentum index (spill/width) by the proportion of flow passing through each spillbay. All of the spillbays are 46 ft wide. The weighted discharge per unit (unit spill) was plotted relative to the submergence depth of the flip lip at Wells Dam; the latter was calculated as the average tailwater elevation during a test minus the elevation of the top of the flip lip (691 ft). Figure 5.3-30 shows the unit spill relative to submergence depth with the data points annotated with the $WELW_{TDG}$ values. Figure 5.3-31 shows the same plot with data annotated for the delta %TDG ($WELW_{TDG}$ – $Forebay_{TDG}$). Data in both plots were stratified by spill type.

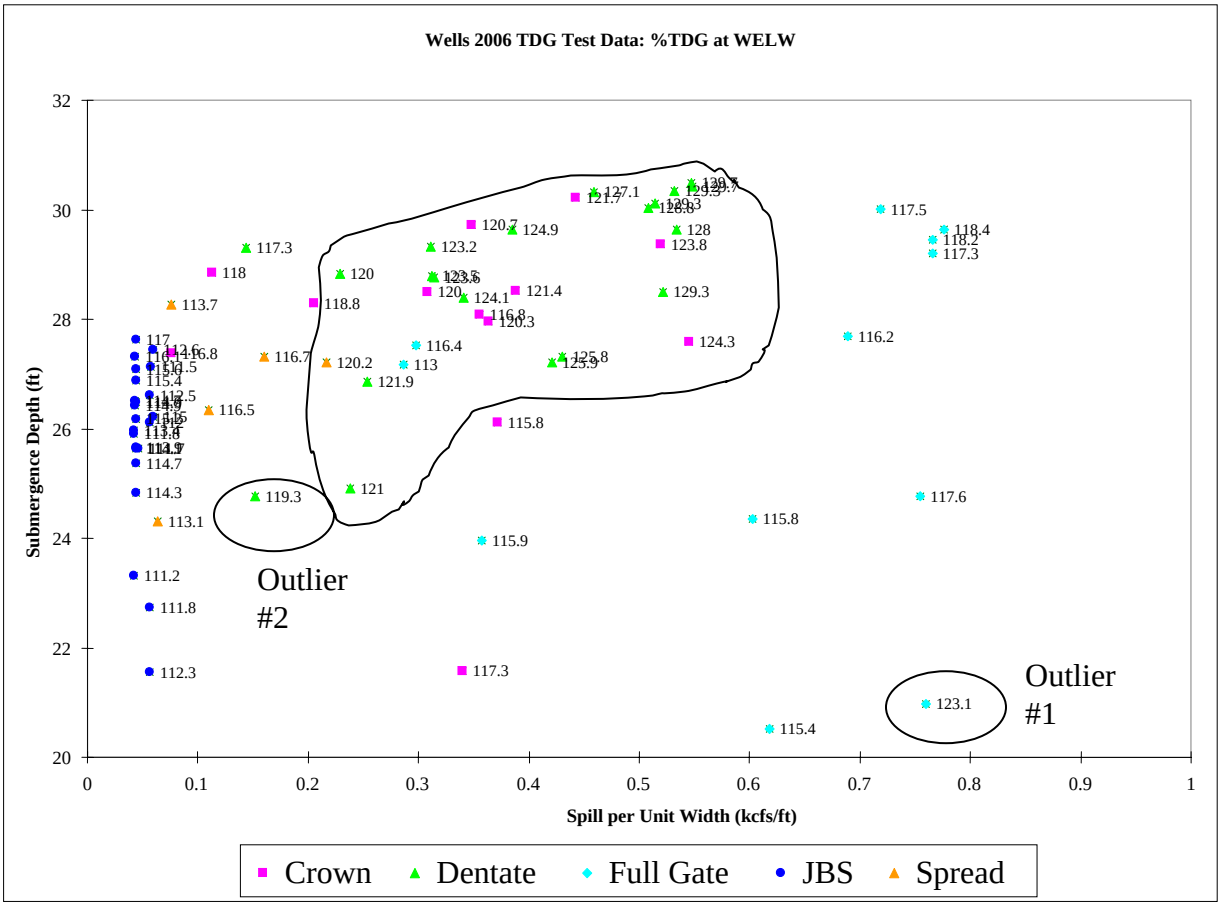


Figure 5.3-30 Variation of TDG with Test Treatment Type, Flip Lip Submergence, and Weighted Unit Spill

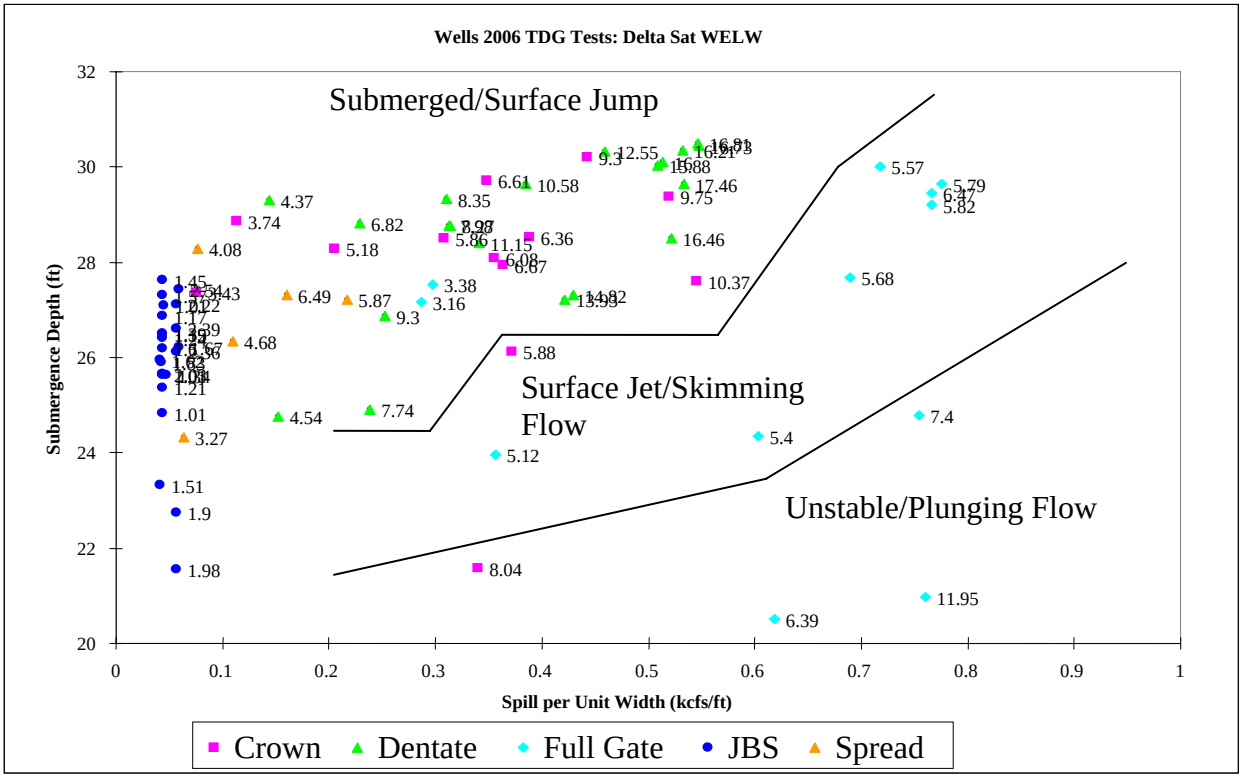


Figure 5.3-31 Variation of ΔTDG with Test Treatment Type, Flip Lip Submergence, and Weighted Unit Spill

In Figure 5.3-30, the region of data with WELWTDG in excess of the 120 % criteria is identified, along with some data points that appear to be outliers. The region of high TDG appears to encompass a wide range of submergence, unit flow rate, and operations. Outlier number 1 represents test treatment 12, a case where high unit discharge spilled through a single gate with a low tailwater submergence. Outlier number 2 was a test with a high forebay TDG (114.7 %), which biased the tailrace TDG. Forebay TDG also may be biasing interpretation of other test results.

Figure 5.3-31 is a similar plot but the data points are annotated with the TDG production (ΔTDG) values. Data at very low unit spill discharges (spill per unit width) are mostly associated with JBS and MJBS spill patterns. For low unit spill, the TDG production is not dependent upon submergence depth and the TDG production is relatively low. Three of the spread spill tests also had very low unit spill rates and low TDG production; the forebay elevation was lower for these three spread spills as well and therefore there was less energy available to entrain air in the tailrace and increase TDG. Lines were drawn that separate TDG production above and below approximately 6 %. The emerging pattern is similar to the deflector regime plot in Figure 5.3-29. The central region, with relatively good TDG performance (ΔTDG < 6 %) is analogous to the surface jet and skimming regimes of the deflector performance plot.

The region above this is analogous to the submerged and surface jump regimes and the region below to the unstable and plunging flow regimes of the deflector performance plot.

There is good repeatability for a spill scenario for the relationship of unit spill and submergence depth and the associated TDG production. The full gate tests in the upper right corner of the plot in Figure 5.3-31 produced similar results; these full gate spills likely produced a surface jet or skimming flow, which reduced the TDG production.

Two outliers are notable within the area demarcated for high %TDG shown in Figure 5.3-30. The two full gate spills within this region of the chart were both distinguished from other full gate spills in that the spill and turbine discharge for hydrocombine unit 7 were similar (19-20 kcfs). This suggests that when spill and turbine discharge were about the same for a given unit, greater gassing of the turbine water occurred. In other full gate tests, the spill was much greater than the turbine flow for unit 7. Full gate test 12 was noted as an outlier in many of the regressions. This test had a very high unit spill and the tailwater elevation was low. These conditions likely resulted in an unstable plunging flow and high TDG production, which is consistent with its plotted position in Figure 5.3-31.

The crowned spills that were not biased toward the eastern shore had the spill in excess of the JBS spill directed through spillbays 5-7. Differences in TDG production for these un-biased crowned spills were a function of submergence depth of the flip lip. The crowned spills biased towards the east bank where the tailwater basin depth is less varied for unit spill but all had submergence depths in excess of 27.5 ft and most resulted in %TDG greater than 120%.

5.4 Hydrodynamic Flow Data Collection

5.4.1 Test Conditions

Table 5.4-1 below summarizes the test conditions during the hydrodynamic flow data collection on June 4 and 5, 2006.

The flow condition on June 5, single gate spill, resulted in a large amount of forebay debris flushed into the tailrace. The single gate spill also generated significant tailrace waves, which forced the adjustment of Transect A downstream for boat safety reasons.

5.4.2 Water Levels

The right and left shoreline water level measurements as surveyed by the EES Consulting survey team are presented in Table 5.4-2 below.

5.4.3 ADCP Data

Table 5.4-3 below presents the stationary and moving transect velocity data points that were collected for the test conditions in Table 5.4-1. The results are not presented herein as it was not the intent of this task to fully analyze the data at this time, but rather to prepare and store the data for possible future use in a CFD model. Section 5.4.4 describes the status of the data and the necessary steps to complete the analysis. However, the results from the moving transects are

presented in Figures 5.4-1 and 5.4-2 and indicate the hydrodynamic conditions responsible for TDG flux in the tailrace for Tests 14 (June 4) and Test 1 (June 5), respectively.

Flow patterns for both conditions followed the same pattern, with a large counterclockwise eddy present near the east bank, downstream from the earthen embankment dam, as shown by the velocity directions on Transect A. The effects of the eddy were not present in the two downstream transects (B and C). The velocity was uniformly distributed across the cross section by the time flow reached Transect C.

5.4.4 Data Storage and Future Analysis

The raw velocity data have been minimally processed and analyzed. The data from each target (stationary or moving transect) are stored in separate files and have been filtered based on the physical limitations of the ADCP (bottom 6% of data have been removed) and based on data quality indicators (percent good). All data are stored on ENSR's server, which is backed up daily.

Each data file contains a tabulation of data points (ensemble) number in rows and the following data in columns: latitude and longitude (WGS84; degrees), easting and northing (NAD83, state plane coordinates; feet), and east, north, and vertical velocity components (mm/s) at each depth increment.

Table 5.4-1 Summary of Wells Dam project flow setup during ADCP data collection June 4-5, 2006

Date		June 4	June 5	Comments
Flow Test No.		46	47	
Forebay Level (ft)		779.6	778.6	
Tailwater Level (ft)		717.3	720.2	
Powerhouse Unit Discharge (kcfs)	Unit 1	0	0.0	Unit 1 was out of operation
	Unit 2	14.7	18.9	
	Unit 3	14.7	18.0	
	Unit 4	14.4	18.5	
	Unit 5	14.7	18.3	
	Unit 6	14.7	19.0	
	Unit 7	14.8	20.2	
	Unit 8	14.8	19.6	
	Unit 9	14.4	19.9	
	Unit 10	14.7	18.2	
	Powerhouse Total	131.8*	170.6**	
Spillbay Discharge (kcfs)	Bay 1	0.0	0.0	
	Bay 2	1.6	1.3	Top spill for juvenile bypass system flow
	Bay 3	5.4	0.0	
	Bay 4	5.2	2.2	
	Bay 5	5.4	0.0	
	Bay 6	5.2	2.2	
	Bay 7	5.4	42.5	As reported by operator and based on gate rating curve; bay partially blocked (estimated 40%) by installed barriers, which would not significantly affect the bay discharge; bottom elevation of barriers = 750.46 ft.
	Bay 8	5.2	2.2	
	Bay 9	5.4	0.0	
	Bay 10	1.6	1.3	Top spill for juvenile bypass system flow
	Spill Total	40.6	51.7	
TOTAL RIVER FLOW		172.4	222.3	

* It is not explicitly known whether the powerhouse was operated for constant generation or constant discharge. However, based on communication with the operator, the project flows did not vary much during the course of data collection indicating the project was operated for constant discharge.

** After switching to constant discharge project operation from constant generation project operation.

Table 5.4-2 Right and Left Bank Water Surface Level Measurements

Flow Test	Station	Survey Coordinates (NAD 83 State Plane)		Water Surface Elevation [1] (feet)	Date / Time
		Easting (feet)	Northing (feet)		
14	RB1	1877312.39	345945.42	83.37	June 4 / 11:30
14	RB2	1877426.53	345314.53	82.17	June 4
14	RB3	1877746.63	344874.71	81.55	June 4
14	RB4	1877978.63	344293.95	80.77	June 4
14	RB5	1877944.14	343788.87	80.41	June 4
14	LB1	1878499.15	346750.77	81.87	June 4
14	LB2	1879282.08	346213.47	81.07	June 4
14	LB3	1879477.67	345607.94	78.27	June 4
14	LB4	1879454.46	344215.31	77.07	June 4
14	LB5	1879076.03	343772.76	77.36	June 4
14	LB6	1878920.26	343491.11	76.96	June 4 / 15:30
1	RB1	1877307.93	345975.76	84.97	June 5 / 10:45
1	RB2	1877421.00	345429.98	83.32	June 5
1	RB3	1877428.41	344840.31	83.07	June 5
1	RB4	1877973.25	344397.24	82.6	June 5
1	RB5	1877915.39	343800.67	82.19	June 5
1	LB1	1879320.77	346384.20	82.84	June 5
1	LB2	1879409.70	345813.80	82.18	June 5
1	LB3	1879577.70	345128.88	81.35	June 5
1	LB4	1879370.61	344384.49	80.57	June 5
1	LB5	1879116.65	343791.51	79.10	June 5 / 13:30

[1] *Water surface elevations reported are relative to a temporary benchmark established along the lower end of the west shore fish ladder and assigned an arbitrary elevation of 100.00 ft.*

Table 5.4-3 Collected Stationary and Moving Transect Velocity Data

Flow Test	Station / Line	Date / Start Time	Stationary (S) or Moving Transect (MT) Measurement
14	A (East to West)	June 4 / 11:42	MT
14	A (West to East)	June 4 / 12:00	MT
14	A5	June 4 / 12:34	S
14	A4	June 4 / 12:51	S
14	A3	June 4 / 13:06	S
14	A2	June 4 / 13:25	S
14	A1	June 4 / 13:44	S
14	B (East to West)	June 4 / 13:57	MT
14	B (West to East)	June 4 / 14:05	MT
14	B1	June 4 / 14:19	S
14	B2	June 4 / 14:36	S
14	B3	June 4 / 14:46	S
14	C (West to East)	June 4 / 14:58	MT
14	C (East to West)	June 4 / 15:03	MT
14	C3	June 4 / 15:08	S
14	C2	June 4 / 15:23	S
14	C1	June 4 / 15:34	S
1	A (West to East)	June 5 / 10:45	MT
1	A (East to West)	June 5 / 10:50	MT
1	A5	June 5 / 11:00	S
1	A4	June 5 / 11:11	S
1	A3	June 5 / 11:22	S
1	A2	June 5 / 11:37	S
1	A1	No data collected due to adverse flow conditions	
1	B (West to East)	June 5 / 11:54	MT
1	B (East to West)	June 5 / 11:59	MT
1	B3	June 5 / 12:05	S
1	B2	June 5 / 12:15	S
1	B1	June 5 / 12:27	S
1	C (East to West)	June 5 / 12:36	MT
1	C (West to East)	June 5 / 12:46	MT
1	C1	June 5 / 12:51	S
1	C2	June 5 / 13:03	S
1	C3	June 5 / 13:15	S

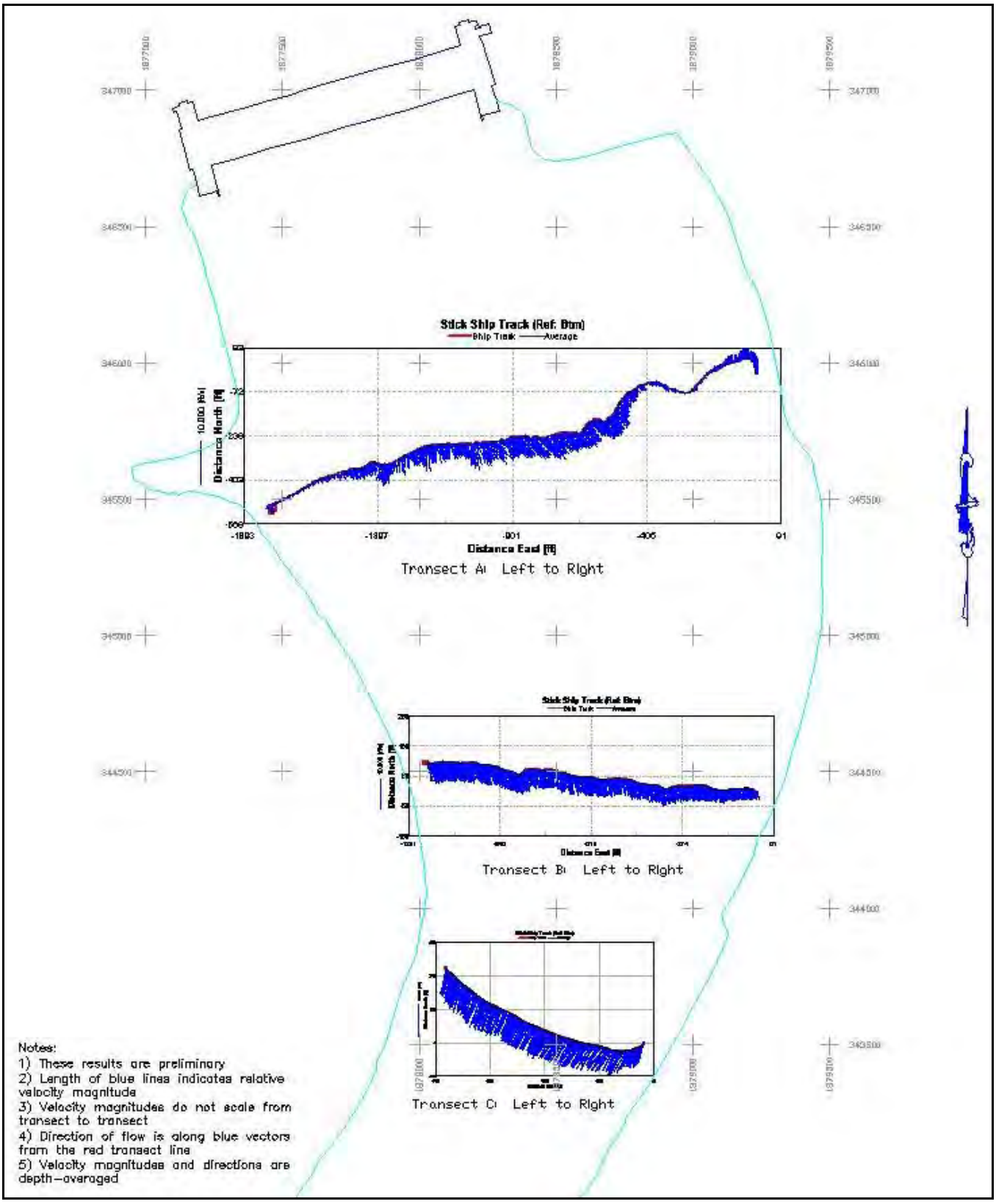


Figure 5.4-1 Moving Transects from June 4, Flow Test 14

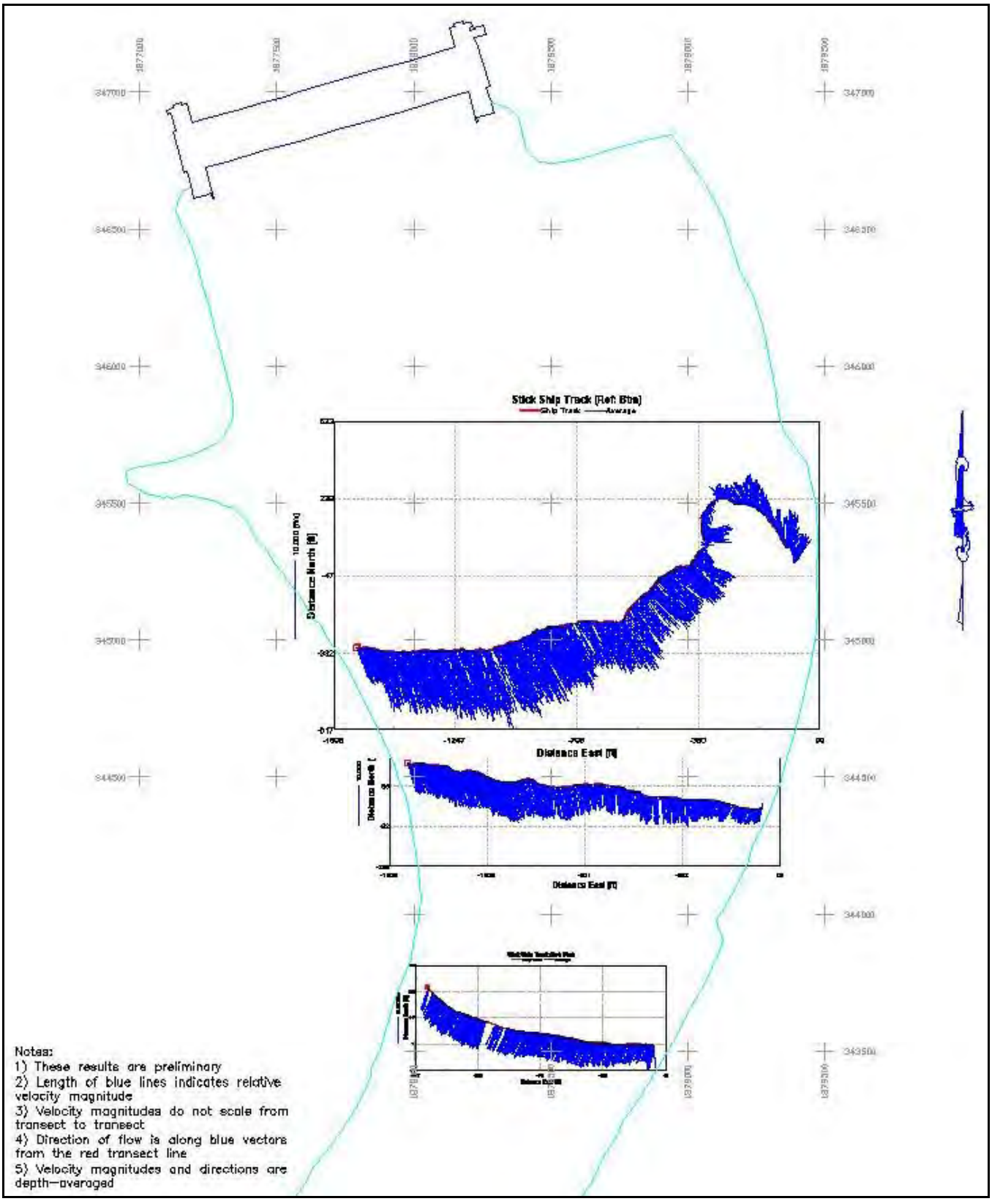


Figure 5.4-2 Moving Transects from June 5, Flow Test 1

Additional analysis of the stationary data will be necessary prior to use for verifying or calibrating a CFD model. Only approximately 100 data points are necessary to calculate an average target position and velocity vector. These 100 points should preferably be located very close to each other to minimize errors due to spatial variation in the flow field. The following steps outline the necessary procedure to complete analysis of the stationary points.

1. For each data point, calculate the distance to all other points.
2. For each data point, calculate the average distance to all other data points. To give more weight to points nearby, use for example the square of the distance between the points to calculate the average distance.
3. Select the data point with the smallest average distance to the other points. Then sort the data in ascending order based on the calculated distances from this point to the other points.
4. Calculate the average and standard deviation of the coordinates (northing and easting) for the top 100 data surrounding the point selected in step 3.
5. For each depth, calculate the average and standard deviations of the velocity components (east, north, and vertical) for the top 100 data surrounding the point in step 3.

6.0 DISCUSSION

Total river flows in spring 2006 were at approximately the 75% exceedance level for April through June. Total river discharge ranged from 16 to 270 kcfs with a median occurrence of 190 kcfs and monthly mean of 195 kcfs. Four percent of the total discharges recorded at 15-minute intervals during the test period exceeded the 7Q10 flow of 246 kcfs. Wells Dam spill discharges ranged from 5 kcfs to 168 kcfs during the test period. The median spill discharge for this period was 49 kcfs. Spill exceeded 69.5 kcfs 32 percent of the time during the 2006 study period. The spill rates were higher in spring 2006 than normally associated with the concurrent total river flow due to a need to hold the forebay elevation at a lower level for upstream flood control operations in the latter part of May. Implementation of the spill tests, while generally consistent with operations, did require some deviation from normal operations.

Coordination of operational considerations for meeting required power production while still providing for the desired range of test spills led to the successful completion of 80 test scenarios that investigated dissolved gas production relative to spill rates and gate configurations. Operations were held near constant for at least three hours during each of these tests, which allowed equilibrium conditions to extend downstream 4.6 km encompassing the grid of TDG monitoring stations. The travel time between Wells Dam and the compliance monitoring station WELW was approximately 1 hour.

The best predictive relationship for tailrace TDG at WELW from the metadata analysis ($R^2 = 0.953$) was based on spill and forebay %TDG at WEL as the independent variables. This correlation closely coincides with a similar correlation (ENSR, 2006) developed from the long-term (2000 – 2005) data set summarized in Appendix A. The 2006 study confirms that the long-term regression is applicable to a range of spill flows extending well above 69.5 kcfs. Both models slightly under predict percent saturation at WELW for levels in excess of about 122%.

The study results are consistent with the conclusions of previous studies that spill flow is gassing the turbine flow. The mass balance analysis supports this conclusion as well as the finding that loaded and unloaded full gate tests were very similar for the relationship between spill and gas production. The lower correlation for spill expressed as a percent of the total discharge also supports the conclusion that turbine discharge is being gassed by spill flow.

The locations for the long-term compliance stations in the forebay (WEL) and tailrace (WELW) are appropriate based on the 2006 study results. There was no significant difference in total dissolved gas pressure readings or temperature for the forebay instruments. Previous concerns that temperature variation in the forebay or other factors may have resulted in TDG spatial gradients within the forebay were not observed in the 2006 study. Based on the results of the 2006 study, it does not appear necessary to develop a corrective adjustment to historical forebay TDG data. However, 2006 was a wet year with flows during the study period running between the 50^{th} and 75^{th} percentile for the years of record from 1968 to 2006. Spatial temperature and TDG gradients in the forebay may be more prominent during low flow years when there is less reservoir mixing.

WDOE had indicated that the effectiveness of moving the tailrace compliance monitoring station further upstream to the vicinity of TW2 should be evaluated. The rationale was that monitoring should be as close as feasible to the source of gas saturation (spillway) while also providing safe access. Accurate measurements of gas saturation in the tailrace should be outside of the zone where high turbulence and air bubbles within the water column could result in unreliable data. The instruments at TW1 were located just at the edge of the aeration plume for most spill conditions with visible turbulence and aeration at least for the surface water. Lateral gradients were evident for the most upstream transect (TW1), where instrument readings were affected by differences in spill across the spillway and the eddying flow pattern downstream from the east earthen embankment dam. Gas saturation during JBS spills is very similar among all three transects. For test conditions generating higher gas levels, the difference, on average, between TW1 and TW2 was about 3%. There was essentially no longitudinal %TDG gradient, on average, between TW2 and TW3 for the tests. The lateral gradient at TW3 was minor to non-existent. %TDG data for the equilibrium test periods were not significantly different ($\rho = 0.825$, $\alpha = 0.05$) between the monitoring stations along this transect. The compliance monitoring station at WELW is well positioned. The regression line for %TDG as a function of spill and forebay %TDG for TW3P4 and TW3P5 (west side of channel) were within the 95% confidence limits of the regression line for WELW. In addition, the location at WELW provides access to this site that is easier and safer for both equipment and personnel than instruments located mid-channel.

The 2006 test spills were classified according to the configuration of spill across the spillway. Spill types included dentate, spread, full gate and crowned. The crowned tests were further categorized as laterally biased towards the east side of the channel or un-biased when most of the flow in excess of the JBS spill passed through spillbays 5-7. Predictive correlation equations were developed for the various spill configurations. The spread spill correlation predicted the lowest downstream %TDG saturation; however, the correlation was strongly leveraged by two data points within the small sample size. The data from spread spill tests conducted in 2005 showed a similar response. Spread spills and crowned spills resulted in the lowest gas saturation.

Dentate spills resulted in higher gas saturation for all spill rates. Spread spills and crowned spills produced similar results for downstream %TDG when the forebay %TDG was at 108.4%. Increasing the forebay %TDG to 115% resulted in spread spills producing lower %TDG than crown spills when the spill exceeds about 25 kcfs. Spread spills consistently outperformed the dentate spills by about 2.5 to 4% dependent on the spill rate. Crowned spills and full gate spills performed similarly when all tests within each category were aggregated for regression analyses.

For a spill of 69.5 kcfs (the equivalent spill for a 7Q10 flow), the downstream %TDG at WELW was predicted to be at or below 120% for all spill patterns except dentate spills when the forebay %TDG equaled 108.4%. The %TDG for the dentate spill of 69.5kcfs was predicted to be 120.4%. The %TDG at WELW predicted for the 7Q10 equivalent spill of 69.5 kcfs when the forebay %TDG was set at 115% was 120.3% (spread), 120.8% (full gate), 122.4% (dentate) and 122.6% (crown) spill. As discussed later, the regression analyses do not account for differences in spill momentum and submergence depth for spill tests within a type of spill.

Crowned spills laterally biased towards the eastern side of the channel resulted in higher %TDG saturation relative to unbiased crowned spills based on %TDG data for the downstream TW3 transect. There was little or no lateral gradient at TW3 for biased crowned spills and about a 2-3% lateral gradient for un-biased crowned spills.

Dentate and crowned spills biased towards the eastern shore produced the highest TDG production for a wide range of flow conditions. Differences among spill types are attributable to how they affect the hydraulic regime for the tailrace.

While tailwater elevation was not significant as an independent variable for multiple regression analysis, its importance on affecting TDG production was demonstrated through an evaluation of spill regime in a manner similar to analyses performed for TDG mitigating spillway deflectors. This approach considers the influence of spill momentum and tailwater submergence on tailrace hydraulics and the associated TDG production. The spill momentum was characterized by calculating the weighted unit spill discharge. The unit discharge from individual spill bays was calculated by dividing spill by the width that the spill is spread across. The values for individual spillbays were weighted by the proportion of the total spill passing through a given spillbay.

The 2006 test data showed a pattern that indicates that TDG production in the Wells tailrace are at least partially a function of the flow regime, which is in turn driven by the combination of unit discharge and submergence depth of the spillway flip lip, the latter of which is analogous to a spillway deflector. For a deflector, spill flow regimes go from a submerged hydraulic jump to a surface jump through a ramped surface jet, to a skimming surface jet and finally to a plunging jet as the tailwater elevation, or submergence, depth decreases. The corresponding TDG production is initially high and then reduced for the skimming surface jet regime range before once again producing high TDG levels with a plunging jet.

The total spill for JBS flow is relatively small and spread out over all of the even numbered spillbays. Subsequently, the unit spill discharge values are relatively small. This results in reduced energy to entrain air and low TDG production. The TDG production is not responsive to submergence depth for these low spills.

The spread spill tests ranged in total spill from 26 to 76 kcfs; however, since the spill was spread over more spillbays, the spill/width values were low. With the exception of the spread spill of 75.9 kcfs, the spread spills resulted in %TDG at WELW less than 120%. Even this large spill (35% of total 216.7 kcfs flow) only resulted in 120.2% TDG at WELW. Although three of the five spread spill tests in 2006 occurred during periods of low forebay elevation, the spill momentum (spill pr unit width) would not be substantially affected. The forebay elevation was at typical levels for the spread spill of 75.9 kcfs and the submergence depth was also fairly high; the results indicate that spread spills up to 69.5 kcfs comply with the water quality standard. Shallower submergence depths for this type of spill with a low unit spill discharge would only tend to reduce TDG production. Both the spill regime analysis and the multiple regression analysis support the conclusion that spread spills comply with the tailwater TDG fish migration criteria allowed by an approved gas abatement plan; however, it is not always feasible or amenable to JBS requirements to spread the spill out over a maximum number of spillbays.

The results of previous studies have suggested that TDG production may be less for crowned spills when the spill is biased toward the eastern shoreline. The depth of the tailwater basin immediately downstream of the dam is shallower on the eastern side, which might reduce the plunging depth. The 2006 test results found that crowned spills laterally biased toward the eastern shoreline produced higher %TDG relative to un-biased spills. The effect of submergence depth of the flip lip was a primary factor for the 2006 un-biased crown spill tests producing lower %TDG than biased crown spills. The range of submergence depths was broad for un-biased crowned spills; however, they had unit spill discharges within a small range of 0.34 – 0.44 kcfs/ft (Figure 6.0-1). The unbiased crowned spill with a submergence depth of 21.6 ft (test 2) probably produced a plunging jet, which resulted in a relatively high TDG production (ΔTDG = 8.04%). The unbiased crowned spill test 6 had a submergence depth of 26.1 ft and was plotted as a surface jet with lower %TDG production (Figure 5.3-31). The other two un-biased crowned spills had relatively deep submergence depths and likely resulted in a submerged surface jump regime. The 2006 crowned spill tests that were biased towards the east bank varied for unit spill discharge, but all had submergence depths in excess of 27.5 ft and most of the latter tests resulted in %TDG greater than 120%. The biased crown spills were associated with a submerged surface jump tailwater flow regime that produces high TDG. The spill test in 2005 (CBE, 2006) that was laterally biased toward the east shore had a spill energy (spill discharge of 0.1) so it resulted in low TDG production.

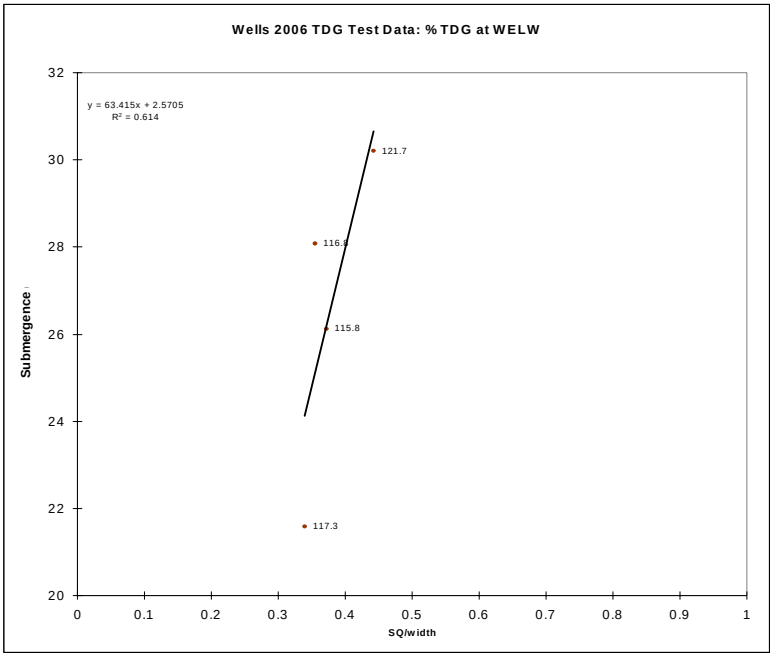


Figure 6.0-1 Submergence depth and unit spill for un-biased crowned spill tests

Full gate tests that occurred when the tailwater elevation and submergence depth of the flip lip were low (less than approximately 24 ft) had high spill rates and high unit spill discharges. This high momentum resulted in these spills probably producing a plunging flow that resulted in high %TDG. Full gate test 12, which was considered anomalous, had a high unit spill flow and high spill ratio as a percent of total river flow (46%) as well as a low tailwater elevation. The low submergence depth along with the high spill that was concentrated in a single bay other than JBS spill led to the high %TDG.

The evaluation of the effectiveness of spill type in reducing TDG production is best viewed relative to the tailwater flow regime. Operation of the project spillway within the parameters defined by the surface/skimming jet region of Figure 5.3-31, should minimize TDG production during spill. An operational playbook could be prepared that would indicate the number of spillway bays to be utilized for increments of total river flow, tailwater elevation, JBS flow, and available powerhouse capacity. The 2006 study results suggest that the downstream TDG for these operations could be maintained within 6 % of forebay TDG and should be in compliance at WELW as long as forebay TDG is less than 114 %.

All spill types and associated gate configurations only result in low TDG production when the unit spill discharge is less than approximately 0.15 kcfs/ft or 6.9 kcfs per spillbay. A unit spill discharge within an individual spillbay may be slightly higher provided that the weighted average unit spill discharge of all spillbays is 0.15 kcfs/ft or less. A spread spill with the total spill of 62.1 kcfs over spillbays 2-10 meets the requirement of a low unit spill discharge value.

Adding additional spill at spillbays 1 and 11provides up to the 69.5 kcfs spill flow required to pass the 7Q10 total flow; however, these spillbays are typically not preferred as the spill is detrimental to the attraction flow in the nearby fishways.

Spread spills up to a total spill of approximately 45 kcfs provide for a low unit spill discharge that is effective over a wide range of tailwater elevations. Spread spills for higher flows may still result in a sufficiently low unit spill discharge and low gas production; however, shifting from spread spill to full gate spill at about 45 kcfs provides for a margin of uncertainty. For spill flows between 45 kcfs and about 58 kcfs, a full gate spill scenario is suggested as best minimizing TDG production by creating a surface jet in the tailwater. Fully opening the bottom leaf for full gate spills within this spill range is suggested for minimizing TDG production. It is noted that full gate spill over a turbine with the spill and turbine flows being approximately equal resulted in high TDG production and exceedance of the 120% criteria for two tests. For situations when the tailwater is 715 ft or less, expanding the flow through multiple adjacent spillbays is a possible means to maintain a surface jet. Data within the skimming/surface jet flow regime portion of the plot, with the exception of one test, were generated for full gate scenarios. While only one test was completed for a crowned spill within the surface jet/skimming region of the plot, it is likely that operation of a pair, or even three adjacent spillway gates at equal unit discharges defined by the surface jet/skimming region of the plot will give similar TDG performance to the full gate tests. Operation of adjacent bays in this manner is incompatible with the present JBS bulkhead arrangement and may require changing the pattern of spillway bays where JBS bulkheads are installed.

The 7Q10 total river flow of 246 kcfs results in a project tailwater level of approximately elevation 720 ft and a flip lip submergence of 29 ft. For this submergence, Figure 5.3-31 requires a minimum unit spillway discharge of 0.65 kcfs/ft to prevent moving into the submerged/surface jump regime. This requires individual spillway bay flows of greater than 29.9 kcfs. If JBS flow is maintained at 10 kcfs, nine turbines are available to pass 19.5 kcfs each for a total powerhouse flow of 175.5 kcfs, and 1 kcfs is passed through the adult fishways, the remaining 59.5 kcfs must be passed through spillway bays. If two spillbays are used, the flow per bay will be less than the 29.9 kcfs required. However, the capacity of a single spillway bay is inadequate to handle the required 59.5 kcfs. Therefore, the strategy could be to shut down one additional turbine and pass the resulting 79 kcfs through two spillway bays at 39.5 kcfs per bay and a unit discharge of 0.86 kcfs per ft, well within the desired regime. This strategy would only be applicable when the 10^{th} unit is not available; having 10 units operating would reduce the required spill.

The borders of the surface jet/skimming regime region of Figure 5.3-31 are not clearly delineated due to the lack of data density at the required tailwater submergences and unit spill discharges. Temperature effects on TDG pressure (Charles Ideal Gas Law) have been documented in many of the DGAS studies (USACE, 2002) and in routine water quality monitoring conducted by the Corps of Engineers. Typical daily cycles during the warm sunny periods of the year range from 1-2 °C for much of the Columbia River. The diel cycles in water temperature during the current study was in the order of 0.3 to 0.5 °C. With constant TDG mass (no change in concentration of air) the thermal cycles would result in approximately 1% fluctuation in TDG saturation.

Photosynthesis and aquatic community respiration can bring about diel change in dissolved oxygen (DO) concentrations. This biological phenomenon affecting DO and carbon dioxide concentrations are well documented in the scientific literature. The DO change represents a change in mass of dissolved gas that will result in a direct change in TDG pressure. For a known or standard temperature, this pressure change attributable to a change in DO concentration can be calculated (Colt, 1984). For the water temperatures (10-15 °C) occurring during testing, a change of 1.0 mg/l DO would account for a 16 mm Hg or 2% saturation change in TDG. Since the daily cycles in water temperature and DO concentration are related to solar cycles and generally occur together then associated downstream cycles in TDG saturation may be +/- 3% saturation on many days regardless of operation at the upstream project.

Since barometric pressure (BP) is applied in the calculation of TDG % saturation, then independent of changes in TDG pressures, the saturation values will vary by 1% for each shift of 7.6 mm Hg atmospheric pressure. The study documented daily changes in BP to be up to +/- 2 to 5 mm Hg. This would account for variation in TDG saturation of approximately 0.5 %. The BP fluctuation generally cycle with daily thermal shifts, hence the effect is often additive to the thermal and DO effects.

An additional natural process affecting TDG pressure is wind. This effect may be highly variable especially with high winds which produce breaking waves. This type of wave action may reduce TDG pressures by 30-70 mm Hg or 4-10 % saturation (USACE, 2002, USACE, 2003).

7.0 ACKNOWLEDGMENTS

The technical team for this study would like to acknowledge the exceptional cooperation and contribution to this study by the operators at Wells Hydroelectric Project. Their input on the design and commitment to implementing the tests in a well documented manner would not have been possible without their full participation. Duncan Hay of Oakwood Consulting, Inc (Belcarra, British Columbia, Canada) is also acknowledged for his contributions to study design and technical review.

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Summary
of

TOTAL DISSOLVED GAS (TDG) RETROSPECTIVE DATA ANALYSIS

WELLS HYDROELECTRIC PROJECT

FERC NO. 2149

May 2006

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This document summarizes pertinent information from a report on a retrospective analysis of total dissolved gas data for the Wells Hydroelectric Project prepared for Douglas County Public Utility District (DCPUD) by Sweeney et. al. (2006)[1].

The TDG retrospective data analysis was conducted to develop tools to aid DCPUD in meeting the TDG water quality standards at Wells Dam. The individual objectives of the study included:

- Development of a database of historical water quality and operations data,
- Assessment of the reliability of the fixed forebay TDG monitoring station (WEL)
- Identification of TDG equilibration periods,
- Analysis of the impacts of project operations on tailrace TDG,
- Development of regression equations for predicting TDG in the tailrace,
- Analysis of expected tailrace TDG levels at the 7Q10 flow, and
- Developing recommendations for the 2006 field study program.

Two water quality and operations databases were developed based on long- and short-term monitoring data from 2000 to 2005. The long-term database includes powerhouse flow, spill flow, TDG saturation, temperature, barometric pressure, and water surface elevation data from fixed monitoring locations in the forebay (Station WEL) and tailrace (Station WELW) for the 2000 through 2005 spill seasons. The short-term database contained 10-minute interval data collected during spill events at the end of May and beginning of June during 2003, 2004, and 2005. These data were used in a statistical analysis to develop regression equations for predicting tailrace TDG at WELW as a function of relevant variables.

As part of this analysis, the reliability of the fixed forebay TDG station (WEL) data was assessed. The forebay TDG at WEL was compared to data measured at temporary TDG stations and found to have a higher daily variation than at the temporary stations. Based on this study we recommended obtaining additional data for creating a correction for the forebay station WEL data.

An analysis of short-term data was conducted to determine the TDG equilibration times in the tailrace. Based on the analysis of equilibrium times for TDG at the tailrace station WELW, we recommended holding operating conditions steady for a minimum of 3 hours during the 2006 field study program.

Data from the short-term database were analyzed in an attempt to determine the impacts of operating conditions such as loaded/unloaded spill, flat spill, and crowned spill on tailrace TDG. Short-term regression equations for TDG production as a function of spill flow and forebay TDG were developed to attempt to identify operating conditions that resulted in higher or lower TDG production. Because the data available were limited and the impacts of variation in spill flow during testing could not be isolated from the operational impacts, conclusions about operational impacts were not drawn, but recommendations for further testing during the 2006 field study were made.

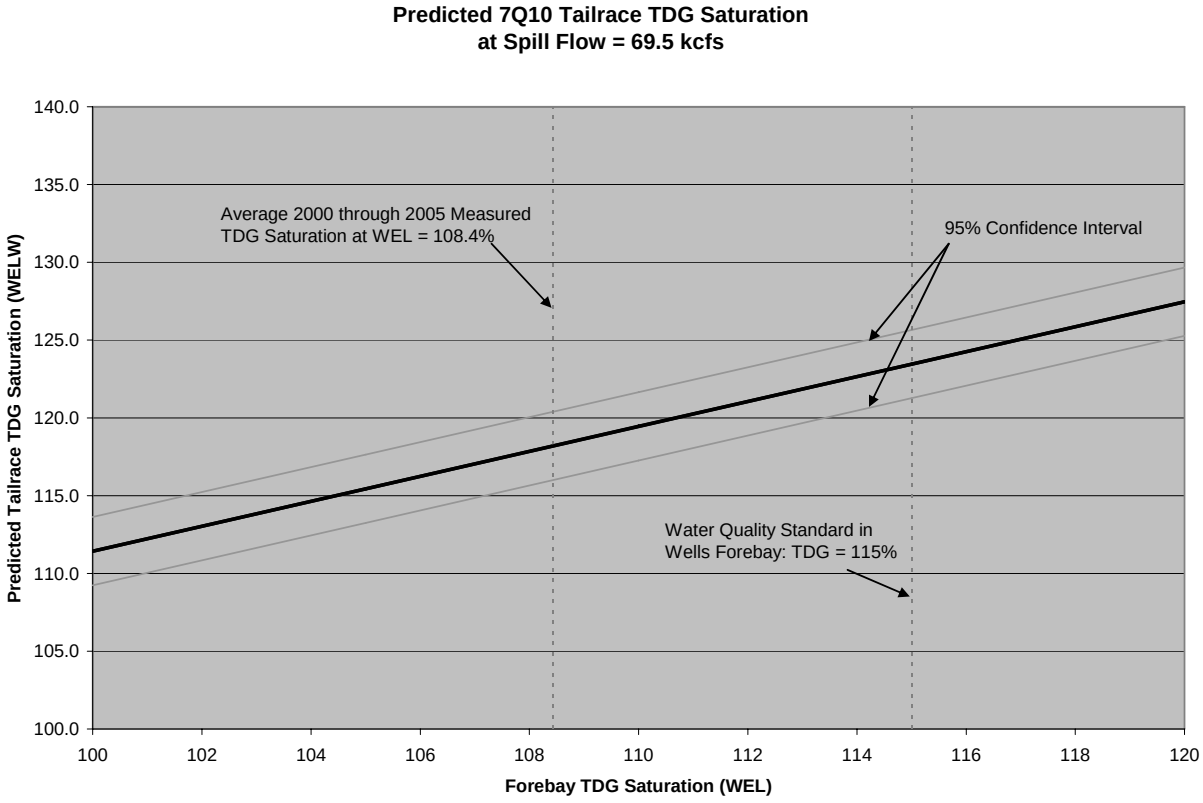
[1] Sweeney, Charles; Liza Roy; and Becca Pease. Total Dissolved Gas (TDG) Retrospective Data Analysis, Wells Hydroelectric Project, FERC No. 2149. Prepared by ENSR for Public Utility District No. 1 of Douglas County, East Wenatchee, Washington. May 2006

Through the retrospective data analysis conducted for the long-term monitoring data at Wells Dam, a predictive equation for tailrace TDG at WELW as a function of spill flow and forebay TDG at WEL was developed for data collected during the years 2000-2005.

$$TDG_{WELW} = 0.802 \cdot TDG_{WEL} + 0.135 \cdot Q_{spill} + 21.850 \qquad R^2 = 0.910$$

Regression analyses were also conducted using percent spill as an independent variable instead of spill flow and resulted in R^2 values of less than 0.6. This finding is consistent with the previous studies conducted by Columbia Basin Environmental and may indicate that the powerhouse flow is becoming gassed by the spill flow rather than diluting the spill.

The equation developed for operations experienced during 2000-2005 was applied to a range of forebay TDG saturations for the 7Q10 spill flow (69.5 kcfs) to predict tailrace TDG at WELW and develop the following figure. These operations, the basis for the equation, were not aimed at mitigating for gas production. [Note: the 2006 study report updated the relationship described in the figure.]



The regression and historical data indicate that mitigation of TDG production by operational changes will likely be required for forebay TDG ranging from 110.7% to 115.0% in order to meet the standard of 120% at tailrace station WELW. If forebay standards for TDG equals 115 % are met by flow coming downstream from Chief Joseph Dam, then according to the regression equation developed for operations experienced during 2000-2005, the tailrace TDG at WELW

would be approximately 3.5% (+/- 2.2%) higher than the 120% required by the standard. The 2006 study should focus on testing whether operational changes alone can bring the Wells Project into compliance with the tailrace TDG criterion of 120%.

Based on the conclusions of the retrospective analysis of 2000-2005 data and the prediction of TDG levels in the tailrace for the 7Q10 flow, several recommendations were suggested for the 2006 field study as follows.

We recommended obtaining additional data for creating a correction for the forebay station WEL data. One method would be installation of a new fixed monitoring location in the forebay and simultaneously recording at station WEL to provide a longer record with a wider range of forebay TDG values. These data could be used to develop a correction for long-term data obtained from the WEL station and adjusting the regression equations developed from WEL TDG data. This adjustment would likely improve the regression equations developed from the long-term WEL data and provide more confidence in the TDG predictions in the tailrace at WELW.

Based on the analysis of equilibrium times for TDG at the tailrace station WELW, we recommended holding operating conditions steady for a minimum of 3 hours during the 2006 field study program. This time frame will provide a minimum equilibration time for TDG levels at the WELW station for each operating condition. Equilibration following a decrease in spill may take even longer, up to 6 hours.

A more comprehensive data set with a well-conceived and implemented gate operation plan was recommended for the 2006 study to better understand the impact of project operation on TDG production. This plan included the following elements:

- Consistent conditions of forebay TDG, total river and spill flow, and gate operations for pairs of tests being run for comparison, i.e. contrasting loaded versus unloaded or flat versus crowned spill;
- Tests at higher spill flows approaching the 60 to 70 kcfs that will be required to pass the 7Q10 flow;
- Testing further comparing the effects of loaded and unloaded spill and testing the possible thesis that unloaded spill over the shallower eastern side of the tailrace affords the greatest mitigation in TDG production; and
- Testing further comparing the effects of flat versus crowned spill with gate operations that produce a more exaggerated crown effect, possibly even concentrating spill through a single gate with the exception of the required JBS flow.

We recommended the spill event data for the 2006 field measurements should be incorporated into a revised regression for long-term data based on the hourly capture of those events at the fixed stations WEL and WELW. The hourly capture should be compared to the short-term data measured in 15-minute increments to compare the equilibration times and peaks for spill flows and TDG saturation. The data for higher spill events (~30 kcfs and greater) will likely have a high leverage in the statistical regression analysis and may change the regression equation for

predicting TDG at WELW. Therefore, the statistical analysis of the 2006 field data should be performed in a manner consistent with the analysis performed for the 2000 through 2005 data.

Appendix B

Test Treatment Summary

Information
Summary Table Variables

Treatment	The treatment number (from 1 to 80) in chronological order
Type	The type of treatment (see description of types)
Start Time	starting time for treatment
End Time	ending time for treatment
Duration	duration of treatment (hours)
FBEL	forebay elevation (ft msl)
TWEL	tailwater elevation (ft msl)
Total MW	total power generated in Mega Watts
SQ	total spill discharge (kcfs)
GQ	total powerhouse discharge (kcfs)
TQ	total project discharge (kcfs) (SQ+GQ+1 kcfs fishway)
FBsat	average saturation of forebay stations FBP2 and FBP3 as %
sd	standard deviation of FBsat
N	number of observations for Fbsat
TW1sat	average saturation as % of tailwater transect 1 stations significantly exposed to majority of spill (TW1P2, TW1P3, and TW1P1-for crowned spill biased to the left bank)
sd	standard deviation of TW1sat
N	number of observations for TW1sat
TW2sat	average saturation as % of tailwater transect 2 center stations (TW2P2 and TW2P3)
sd	standard deviation of TW2sat
N	number of observations for TW2sat
TW3sat	average saturation as % of tailwater transect 3 center stations (TW3P2 and TW4P3)
sd	standard deviation of TW3sat
N	number of observations for TW3sat
S1	discharge for spillbay 1 as kcfs (not used during study)
S2	discharge for spillbay 2 as kcfs
S3	discharge for spillbay 3 as kcfs
S4	discharge for spillbay 4 as kcfs
S5	discharge for spillbay 5 as kcfs
S6	discharge for spillbay 6 as kcfs
S7	discharge for spillbay 7 as kcfs
S8	discharge for spillbay 8 as kcfs
S9	discharge for spillbay 9 as kcfs
S10	discharge for spillbay 10 as kcfs
S11	discharge for spillbay 11 as kcfs (not used during study)
U1	generation unit 1 discharge as kcfs
U2	generation unit 2 discharge as kcfs
U3	generation unit 3 discharge as kcfs
U4	generation unit 4 discharge as kcfs
U5	generation unit 5 discharge as kcfs
U6	generation unit 6 discharge as kcfs
U7	generation unit 7 discharge as kcfs
U8	generation unit 8 discharge as kcfs
U9	generation unit 9 discharge as kcfs
U10	generation unit 10 discharge as kcfs

Summary plots
Chart Xsat depicts the mean TDG saturation data by treatment for each transect
Plots FG42 etc depict the operation discharge distribution across the project for each treatment, the plot names start with the type symbol plus the treatment number

Description of Treatment Types

Symbol	Name	Description
JBS	Juvenile Bypass spill	Standard fish spill through bays 2, 4, 6, 8, and 10 at approx 2 kcfs per bay, flap gates are used in bays 2 and 10 with underflow at others
MJBS	Modified Juvenile Bypass spill	Reduced JBS spill as total project release is minimal
S	Spread spill	Spill is spread across bays 2 through 10 in a near uniform pattern
FG	Full Gate spill	In addition to normal JBS discharge spill was concentrated through one gate, generally gate 7 but gate 5 was used for 2 of these treatments
C	Crowned spill	Spill is concentrated across 3 adjacent bays, either 5-7 or 7-9, normal JBS from other even numbered bays
D	Dentate	Normal JBS with the added spill distributed uniformly across the odd numbered bays (this is the operators choice under normal conditions)

Treatment	Type	Start Time	End Time	Duration	FBEL	TWEL	Total MW
1	FG	5/14/2006 11:15	5/14/2006 14:15	3:00	778.7	711.5	380.9
2	C	5/14/2006 15:45	5/14/2006 18:45	3:00	778.9	712.6	375.1
3	JBS	5/15/2006 13:45	5/15/2006 16:45	3:00	778.8	716.9	746.0
4	FG	5/15/2006 19:00	5/15/2006 21:45	2:45	779.0	718.2	732.3
5	MJBS	5/16/2006 0:30	5/16/2006 3:15	2:45	779.8	705.9	73.8
6	C	5/16/06 8:00	5/16/06 10:45	2:45	777.9	717.1	619.6
7	JBS	5/16/06 12:00	5/16/06 14:45	2:45	777.9	714.3	630.3
8	JBS	5/16/06 15:00	5/16/06 18:30	3:30	778.6	716.7	731.2
9	FG	5/16/06 18:45	5/16/06 21:45	3:00	779.4	715.8	515.3
10	MJBS	5/17/06 0:30	5/17/06 3:15	2:45	780.2	706.1	128.8
11	FG	5/17/06 8:00	5/17/06 10:45	2:45	777.3	715.4	499.4
12	FG	5/18/06 1:15	5/18/06 4:15	3:00	776.3	712.0	259.9
13	FG	5/18/06 8:30	5/18/06 11:45	3:15	772.9	715.0	476.6
14	FG	5/18/06 12:00	5/18/06 15:00	3:00	772.3	718.7	613.5
15	C	5/18/06 15:30	5/18/06 19:00	3:30	772.4	719.1	583.9
16	D	5/18/06 19:30	5/18/06 22:30	3:00	772.7	718.3	402.7
17	S	5/19/06 11:15	5/19/06 14:00	2:45	771.9	719.3	628.9
18	S	5/19/06 14:30	5/19/06 17:15	2:45	771.9	718.3	534.5
19	JBS	5/19/06 20:00	5/20/06 0:15	4:15	772.2	712.7	449.1
20	S	5/20/06 9:30	5/20/06 12:30	3:00	771.6	715.3	571.8
21	MJBS	5/21/06 1:15	5/21/06 4:30	3:15	771.5	706.9	161.1
22	MJBS	5/21/06 4:45	5/21/06 7:00	2:15	771.5	705.2	70.8
23	JBS	5/21/06 17:45	5/21/06 20:00	2:15	771.4	713.6	503.2
24	MJBS	5/22/06 1:30	5/22/06 3:45	2:15	771.6	705.3	58.7
25	JBS	5/22/06 11:45	5/22/06 15:15	3:30	771.8	717.6	644.0
26	MJBS	5/23/06 1:00	5/23/06 6:15	5:15	771.6	707.6	168.8
27	MJBS	5/24/06 2:30	5/24/06 5:15	2:45	772.2	707.6	183.2
28	JBS	5/24/06 7:15	5/24/06 10:15	3:00	772.3	717.1	654.1
29	JBS	5/24/06 15:15	5/24/06 18:45	3:30	774.8	718.1	682.5
30	JBS	5/25/06 10:15	5/25/06 15:45	5:30	778.0	718.4	728.9
31	D	5/26/06 10:45	5/26/06 14:00	3:15	778.9	720.6	557.3
32	FG	5/26/06 15:30	5/26/06 21:30	6:00	778.6	721.0	688.8
33	D	5/26/06 22:00	5/27/06 4:45	6:45	779.1	719.4	603.8
34	D	5/27/06 6:15	5/27/06 9:15	3:00	779.2	717.8	583.1
35	C	5/27/06 9:45	5/27/06 12:45	3:00	779.1	721.2	685.9
36	D	5/27/06 18:15	5/27/06 23:30	5:15	779.9	721.0	562.6
37	D	5/28/06 0:00	5/28/06 12:00	12:00	779.8	721.5	562.7
38	D	5/28/06 12:15	5/28/06 17:45	5:30	779.5	721.3	563.0
39	D	5/29/06 4:00	5/29/06 9:45	5:45	780.0	721.5	562.4
40	D	5/29/06 11:30	5/29/06 20:30	9:00	779.9	721.1	564.0
41	JBS	5/31/06 6:45	5/31/06 12:00	5:15	779.0	717.2	750.0
42	FG	5/31/06 12:15	5/31/06 15:30	3:15	779.7	718.5	742.6
43	JBS	6/1/06 7:30	6/1/06 14:00	6:30	778.6	717.0	727.1
44	D	6/1/06 19:30	6/2/06 0:00	4:30	779.9	718.2	503.2
45	D	6/4/06 1:45	6/4/06 5:45	4:00	780.0	715.9	498.8
46	S	6/4/06 11:00	6/4/06 15:45	4:45	779.6	717.3	618.7
47	FG	6/5/06 10:30	6/5/06 13:30	3:00	778.6	720.2	700.5
48	JBS	6/5/06 16:15	6/5/06 18:45	2:30	779.9	716.7	751.6
49	FG	6/6/06 9:15	6/6/06 12:15	3:00	779.7	720.5	713.8
50	FG	6/6/06 12:15	6/6/06 15:15	3:00	779.4	720.6	707.4
51	S	6/6/06 16:00	6/6/06 18:00	2:00	780.0	718.2	646.3

Treatment	Type	SQ	GQ	TQ	FBsat	sd	N
1	FG	44.6	74.8	120.4	109.1	0.73	26
2	C	55.0	74.9	130.9	109.2	0.40	26
3	JBS	9.3	169.4	179.8	110.0	0.33	26
4	FG	28.2	170.7	199.9	109.8	0.11	24
5	MJBS	2.2	13.2	16.4	109.6	0.35	24
6	C	57.3	136.0	194.3	109.9	0.24	24
7	JBS	8.8	131.0	140.8	109.7	0.49	24
8	JBS	12.0	166.0	179.1	110.3	0.38	30
9	FG	51.9	113.5	166.3	110.2	0.18	26
10	MJBS	2.3	23.7	27.0	110.2	0.15	24
11	FG	42.6	113.7	157.2	110.4	0.24	24
12	FG	49.2	56.2	106.4	111.1	0.13	24
13	FG	32.2	117.6	150.8	110.8	0.24	26
14	FG	50.1	160.4	211.5	110.5	0.22	26
15	C	60.0	150.4	211.3	110.8	0.16	30
16	D	109.4	100.2	210.5	111.0	0.23	26
17	S	31.1	172.5	204.6	109.6	0.58	24
18	S	58.9	134.4	194.3	110.2	0.19	24
19	JBS	12.5	100.7	114.2	110.3	0.08	34
20	S	26.0	136.9	163.9	109.8	0.25	26
21	MJBS	8.3	33.8	43.1	109.3	0.33	28
22	MJBS	8.3	13.3	22.5	108.9	0.72	20
23	JBS	12.5	114.7	128.2	109.9	0.12	24
24	MJBS	8.3	11.7	21.0	109.3	0.77	20
25	JBS	12.5	172.9	186.4	110.1	0.43	30
26	MJBS	8.3	34.8	44.1	109.7	0.23	44
27	MJBS	8.7	40.6	50.3	109.5	0.11	24
28	JBS	12.5	169.7	183.2	109.6	0.33	26
29	JBS	12.6	174.3	187.9	109.3	0.10	30
30	JBS	13.1	175.5	189.6	110.1	0.24	46
31	D	121.8	127.2	250.0	110.6	0.10	26
32	FG	55.5	172.0	228.6	111.9	0.42	46
33	D	85.2	135.1	221.3	112.9	0.48	50
34	D	68.2	125.3	194.4	112.6	0.09	26
35	C	71.3	169.7	241.9	112.4	0.06	24
36	D	117.2	126.5	244.7	113.0	0.23	44
37	D	124.5	128.5	254.0	112.9	0.42	98
38	D	121.6	129.1	251.7	113.1	0.51	46
39	D	124.7	127.7	253.4	112.9	0.22	48
40	D	118.3	127.4	246.6	113.3	0.45	74
41	JBS	13.1	172.0	186.1	113.3	0.50	44
42	FG	33.9	172.4	207.3	113.0	0.22	28
43	JBS	9.4	164.4	174.8	111.8	0.32	54
44	D	95.6	106.4	203.0	112.0	0.20	38
45	D	60.7	101.6	163.2	113.2	0.49	30
46	S	40.6	131.8	173.4	111.8	0.23	36
47	FG	51.7	170.6	223.3	111.5	0.31	26
48	JBS	10.0	164.8	175.8	111.8	0.63	22
49	FG	52.7	169.5	223.2	111.7	0.54	24
50	FG	53.1	165.9	220.0	112.6	0.58	26
51	S	75.9	139.8	216.7	114.4	0.61	18

Treatment	Type	TW1sat	sd	N	TW2sat	sd	N	TW3sat	sd	N
1	FG	118.3	0.37	18	117.1	0.31	16	117.1	0.50	14
2	C	121.7	0.62	20	119.3	0.91	18	119.2	0.63	14
3	JBS	112.2	0.51	20	112.4	0.17	18	112.2	0.03	14
4	FG	113.9	0.34	18	114.1	0.43	16	113.8	0.26	12
5	MJBS	112.1	0.14	18	111.7	0.21	16	111.5	0.13	12
6	C	117.5	2.33	18	116.4	0.79	16	117.2	0.67	12
7	JBS	111.2	0.34	18	111.2	0.18	16	111.3	0.10	12
8	JBS	112.2	0.37	20	112.2	0.14	18	112.0	0.07	12
9	FG	119.5	0.87	18	119.1	0.26	16	118.9	0.26	12
10	MJBS	110.8	1.33	18	111.7	0.08	16	111.7	0.06	12
11	FG	116.8	0.51	18	116.9	0.32	16	116.8	0.28	12
12	FG	125.2	0.52	18	122.8	0.17	16	122.8	0.33	14
13	FG	115.5	0.51	20	115.5	0.17	18	115.7	0.17	14
14	FG	117.3	0.65	20	116.8	0.37	18	117.0	0.24	14
15	C	119.1	2.57	24	117.5	0.89	22	118.1	0.57	18
16	D	132.2	0.80	20	128.2	0.88	18	127.7	0.62	14
17	S	114.8	0.40	18	114.1	0.24	16	114.4	0.32	12
18	S	118.9	0.56	18	117.5	0.32	16	118.0	0.53	12
19	JBS	112.4	0.48	28	112.6	0.18	26	112.6	0.10	22
20	S	114.2	0.79	20	113.5	0.12	18	113.7	0.27	14
21	MJBS	111.9	0.39	22	112.1	0.10	20	112.0	0.19	16
22	MJBS	112.9	0.67	12	112.7	0.29	10	111.8	0.11	6
23	JBS	112.0	0.27	18	112.2	0.09	16	112.3	0.08	12
24	MJBS	112.2	0.84	14	113.1	0.06	12	112.9	0.17	8
25	JBS	112.8	0.41	24	112.9	0.39	22	113.0	0.30	18
26	MJBS	112.6	0.45	36	112.9	0.26	34	112.7	0.31	30
27	MJBS	112.2	0.72	18	112.6	0.09	16	112.6	0.07	12
28	JBS	112.3	0.34	20	112.3	0.13	18	112.4	0.10	14
29	JBS	111.7	0.43	24	111.8	0.15	22	111.9	0.11	18
30	JBS	112.5	0.33	38	112.7	0.16	36	112.9	0.15	32
31	D	135.0	0.70	20	129.3	0.21	18	129.4	0.58	16
32	FG	118.5	0.81	38	118.5	0.11	36	118.2	0.19	32
33	D	128.9	0.75	42	125.6	0.49	40	125.6	0.76	38
34	D	126.1	0.37	20	123.4	0.16	18	123.4	0.63	14
35	C	121.5	3.90	18	120.5	0.22	16	121.2	0.78	12
36	D	135.6	0.64	36	130.5	0.18	34	130.3	0.54	30
37	D	136.9	0.90	90	131.3	0.24	88	131.2	0.59	84
38	D	136.3	1.18	38	130.8	0.19	36	130.8	0.56	32
39	D	136.4	0.94	42	131.2	0.19	40	131.1	0.51	36
40	D	135.2	1.14	68	130.7	0.20	66	130.6	0.50	62
41	JBS	114.7	0.36	36	115.5	0.33	34	115.5	0.27	30
42	FG	115.5	0.82	22	117.1	0.16	20	117.1	0.35	16
43	JBS	112.2	0.45	48	114.2	0.13	46	114.1	0.19	42
44	D	129.6	0.39	32	128.0	0.32	30	127.4	0.71	26
45	D	124.9	0.56	24	122.6	0.22	22	122.5	0.59	18
46	S	118.1	0.76	30	117.3	0.11	28	117.5	0.43	24
47	FG	119.3	1.18	20	118.1	0.09	18	118.0	0.22	14
48	JBS	114.4	0.85	16	114.6	0.25	14	114.3	0.20	10
49	FG	120.0	1.27	18	119.0	0.22	16	119.2	0.34	12
50	FG	120.1	1.47	20	119.3	0.27	16	119.3	0.42	14
51	S	123.5	0.68	12	121.5	0.23	10	121.2	0.71	6

Treatment	Type	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
1	FG	0.0	1.3	0.0	2.2	0.0	2.2	35.4	2.2	0.0	1.3	0.0
2	C	0.0	1.4	0.0	2.2	19.7	8.4	19.7	2.2	0.0	1.4	0.0
3	JBS	0.0	1.4	0.0	2.2	0.0	2.2	0.0	2.2	0.0	1.4	0.0
4	FG	0.0	1.4	0.0	2.2	0.0	2.2	18.8	2.2	0.0	1.4	0.0
5	MJBS	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	C	0.0	1.1	0.0	2.2	21.2	8.4	21.2	2.2	0.0	1.1	0.0
7	JBS	0.0	1.1	0.0	2.2	0.0	2.2	0.0	2.2	0.0	1.1	0.0
8	JBS	0.0	1.3	0.0	2.2	0.0	2.2	2.8	2.2	0.0	1.3	0.0
9	FG	0.0	1.5	0.0	2.2	0.0	2.2	42.2	2.2	0.0	1.5	0.0
10	MJBS	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0
11	FG	0.0	0.9	0.0	2.2	0.0	2.2	34.1	2.2	0.0	0.9	0.0
12	FG	0.0	0.7	0.0	2.2	0.0	2.2	41.3	2.2	0.0	0.7	0.0
13	FG	0.0	1.5	0.0	2.1	0.0	2.1	22.6	2.1	0.0	1.8	0.0
14	FG	0.0	2.1	0.0	2.1	0.0	2.1	39.6	2.1	0.0	2.1	0.0
15	C	0.0	2.8	0.0	2.1	21.2	7.9	21.1	2.1	0.0	2.8	0.0
16	D	0.0	3.1	23.1	2.1	22.4	7.9	22.4	2.1	23.1	3.1	0.0
17	S	0.0	3.1	2.9	3.9	3.9	3.9	3.1	3.9	3.1	3.1	0.0
18	S	0.0	3.1	9.9	6.0	8.2	6.0	7.0	6.0	9.7	3.1	0.0
19	JBS	0.0	3.1	0.0	2.1	0.0	2.1	0.0	2.1	0.0	3.1	0.0
20	S	0.0	3.1	3.1	3.1	2.2	3.1	2.1	3.1	3.1	3.1	0.0
21	MJBS	0.0	3.1	0.0	2.1	0.0	0.0	0.0	0.0	0.0	3.1	0.0
22	MJBS	0.0	3.1	0.0	2.1	0.0	0.0	0.0	0.0	0.0	3.1	0.0
23	JBS	0.0	3.1	0.0	2.1	0.0	2.1	0.0	2.1	0.0	3.1	0.0
24	MJBS	0.0	3.1	0.0	2.1	0.0	0.0	0.0	0.0	0.0	3.1	0.0
25	JBS	0.0	3.1	0.0	2.1	0.0	2.1	0.0	2.1	0.0	3.1	0.0
26	MJBS	0.0	3.1	0.0	2.1	0.0	0.0	0.0	0.0	0.0	3.1	0.0
27	MJBS	0.0	3.1	0.0	2.1	0.0	0.4	0.0	0.0	0.0	3.1	0.0
28	JBS	0.0	3.1	0.0	2.1	0.0	2.1	0.0	2.1	0.0	3.1	0.0
29	JBS	0.0	3.2	0.0	2.1	0.0	2.1	0.0	2.1	0.0	3.2	0.0
30	JBS	0.0	3.3	0.0	2.2	0.0	2.2	0.0	2.2	0.0	3.3	0.0
31	D	0.0	3.3	26.3	2.2	28.1	2.2	28.1	2.2	26.2	3.3	0.0
32	FG	0.0	3.3	0.0	2.2	0.0	2.2	42.4	2.2	0.0	3.3	0.0
33	D	0.0	3.3	18.1	2.2	17.7	2.2	18.2	2.2	18.2	3.3	0.0
34	D	0.0	3.3	14.2	2.2	14.2	2.2	13.3	2.2	13.3	3.3	0.0
35	C	0.0	3.3	0.0	2.2	26.4	8.4	25.6	2.2	0.0	3.3	0.0
36	D	0.0	3.3	26.6	2.2	25.8	2.2	25.8	2.2	25.8	3.3	0.0
37	D	0.0	3.3	27.4	2.2	27.4	2.2	28.2	2.2	28.2	3.3	0.0
38	D	0.0	3.3	26.5	2.2	27.3	2.2	28.1	2.2	26.5	3.3	0.0
39	D	0.0	3.3	28.3	2.2	27.5	2.2	27.5	2.2	28.3	3.3	0.0
40	D	0.0	3.3	25.8	2.2	26.9	2.2	26.6	2.2	25.8	3.3	0.0
41	JBS	0.0	3.3	0.0	2.2	0.0	2.2	0.0	2.2	0.0	3.3	0.0
42	FG	0.0	3.3	0.0	2.2	0.0	2.2	20.7	2.2	0.0	3.3	0.0
43	JBS	0.0	1.3	0.0	2.2	0.0	2.2	0.0	2.2	0.0	1.3	0.0
44	D	0.0	1.7	21.2	2.2	21.6	2.2	21.2	2.2	21.6	1.7	0.0
45	D	0.0	1.7	12.4	2.2	13.4	2.2	13.4	2.2	11.4	1.7	0.0
46	S	0.0	1.6	5.4	5.2	5.4	5.2	5.4	5.2	5.4	1.6	0.0
47	FG	0.0	1.3	0.0	2.2	0.0	2.2	42.5	2.2	0.0	1.3	0.0
48	JBS	0.0	1.7	0.0	2.2	0.0	2.2	0.0	2.2	0.0	1.7	0.0
49	FG	0.0	1.6	0.0	2.2	42.9	2.2	0.0	2.2	0.0	1.6	0.0
50	FG	0.0	1.6	0.0	2.2	43.3	2.2	0.0	2.2	0.0	1.6	0.0
51	S	0.0	1.7	10.5	10.5	10.5	10.5	9.5	10.5	10.5	1.7	0.0

Treatment	Type	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
1	FG	0.0	15.0	15.0	14.8	0.0	0.0	0.0	0.0	14.8	15.2
2	C	0.0	14.9	0.0	14.9	0.0	14.9	0.0	15.1	0.0	15.1
3	JBS	0.0	18.7	18.8	18.6	18.8	18.7	19.1	19.2	18.4	19.0
4	FG	0.0	18.9	18.9	18.7	19.1	18.8	19.3	19.3	18.5	19.1
5	MJBS	0.0	0.0	0.0	12.5	0.0	0.0	0.0	0.0	0.8	0.0
6	C	0.0	15.1	15.1	14.9	15.2	15.0	15.3	15.3	14.9	15.2
7	JBS	0.0	14.5	14.5	14.4	14.5	14.5	14.7	14.7	14.4	14.7
8	JBS	0.0	18.7	18.8	18.3	18.8	17.4	17.7	19.0	18.5	18.8
9	FG	0.0	18.8	19.0	18.8	19.0	0.0	0.0	0.0	18.6	19.2
10	MJBS	0.0	0.0	11.3	11.2	0.0	0.0	0.0	0.0	1.2	0.0
11	FG	0.0	18.9	19.1	18.7	19.2	0.0	0.0	0.0	18.7	19.2
12	FG	0.0	18.8	0.0	18.5	0.0	0.0	0.0	0.0	0.0	19.0
13	FG	0.0	18.7	19.1	18.2	18.9	1.0	3.8	0.0	19.4	18.5
14	FG	0.0	17.7	18.0	17.6	17.9	17.8	17.9	18.1	17.5	17.9
15	C	0.0	16.5	16.9	16.5	16.9	16.5	17.0	16.9	16.4	16.9
16	D	0.0	11.1	11.2	11.1	11.2	11.1	11.2	11.2	11.1	11.2
17	S	0.0	19.0	19.5	17.6	19.6	19.6	19.2	19.8	19.5	18.7
18	S	0.0	14.8	15.0	15.0	14.9	14.8	15.1	15.1	14.7	15.1
19	JBS	0.0	9.5	11.4	11.3	11.4	11.3	11.5	11.5	11.3	11.5
20	S	0.0	15.2	15.3	15.0	15.3	15.1	15.3	15.3	15.0	15.4
21	MJBS	0.0	11.3	11.3	11.2	0.0	0.0	0.0	0.0	0.0	0.0
22	MJBS	0.0	8.8	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0
23	JBS	0.0	12.7	12.8	12.6	12.8	12.8	12.9	12.8	12.5	12.8
24	MJBS	0.0	0.0	0.0	11.7	0.0	0.0	0.0	0.0	0.0	0.0
25	JBS	0.0	19.3	19.8	17.9	19.7	19.6	19.5	19.8	19.2	18.1
26	MJBS	0.0	0.0	11.7	11.6	0.0	0.0	0.0	0.0	11.6	0.0
27	MJBS	0.0	10.2	10.0	10.2	0.0	0.0	0.0	0.0	10.2	0.0
28	JBS	0.0	19.0	19.0	18.1	19.1	19.0	19.1	19.1	18.9	18.5
29	JBS	0.0	19.5	19.9	18.5	18.4	19.8	19.9	20.0	19.6	18.8
30	JBS	0.0	19.8	20.1	18.6	18.0	20.1	20.1	20.2	20.2	18.6
31	D	0.0	14.0	14.2	14.0	14.2	14.0	14.3	14.3	13.9	14.3
32	FG	0.0	19.8	18.0	18.8	17.6	18.1	20.2	20.3	20.3	18.9
33	D	0.0	15.0	15.0	14.9	15.0	15.0	15.2	15.2	14.7	15.1
34	D	0.0	13.9	14.0	13.8	14.0	13.8	14.1	14.0	13.7	14.0
35	C	0.0	19.9	16.0	19.1	18.8	18.2	19.9	18.6	20.4	18.8
36	D	0.0	14.0	14.1	13.9	14.2	13.9	14.2	14.2	13.9	14.1
37	D	0.0	14.2	14.3	14.1	14.4	14.2	14.4	14.4	14.1	14.4
38	D	0.0	14.3	14.4	14.2	14.5	14.2	14.5	14.5	14.1	14.4
39	D	0.0	14.1	14.3	14.1	14.3	14.1	14.4	14.3	14.0	14.3
40	D	0.0	14.0	14.2	14.0	14.3	14.0	14.3	14.3	13.9	14.3
41	JBS	0.0	19.1	19.2	18.9	18.9	19.1	19.8	19.7	18.8	18.6
42	FG	0.0	19.2	19.4	19.1	19.1	19.3	19.4	19.4	18.8	18.8
43	JBS	0.0	18.2	18.3	18.0	18.4	18.2	18.6	18.6	17.9	18.3
44	D	0.0	11.8	11.9	11.7	11.9	11.8	11.9	11.9	11.7	11.9
45	D	0.0	12.7	12.7	12.6	0.0	12.7	12.8	12.8	12.5	12.8
46	S	0.0	14.7	14.7	14.4	14.7	14.7	14.8	14.8	14.4	14.7
47	FG	0.0	18.9	18.0	18.5	18.3	19.0	20.2	19.6	19.9	18.2
48	JBS	0.0	18.2	18.3	18.2	18.4	18.2	18.6	18.5	18.0	18.4
49	FG	0.0	18.9	19.1	18.0	19.1	18.7	19.5	19.4	17.5	19.3
50	FG	0.0	18.1	19.0	17.4	18.5	18.0	19.0	19.6	17.7	18.5
51	S	0.0	15.5	15.6	15.3	15.6	15.5	15.7	15.7	15.3	15.6

Treatment	Type	Start Time	End Time	Duration	FBEL	TWEL	Total MW
52	D	6/8/06 13:00	6/8/06 16:45	3:45	779.9	719.8	687.0
53	JBS	6/9/06 4:45	6/9/06 8:45	4:00	780.0	716.6	717.7
54	D	6/9/06 9:30	6/9/06 14:00	4:30	780.2	720.3	730.9
55	D	6/10/06 16:15	6/10/06 22:00	5:45	780.1	719.5	502.9
56	D	6/11/06 15:30	6/11/06 19:30	4:00	780.2	719.8	651.4
57	D	6/12/06 11:30	6/12/06 14:45	3:15	780.1	721.3	638.3
58	D	6/12/06 17:15	6/12/06 21:30	4:15	780.1	719.8	636.0
59	D	6/13/06 2:00	6/13/06 5:45	3:45	779.8	715.8	576.3
60	D	6/13/06 9:30	6/13/06 13:30	4:00	780.0	720.6	648.4
61	C	6/13/06 14:00	6/13/06 20:00	6:00	779.9	720.7	706.9
62	D	6/14/06 8:30	6/14/06 19:00	10:30	780.0	720.3	664.6
63	C	6/17/06 2:15	6/17/06 6:00	3:45	780.1	718.6	549.5
64	C	6/17/06 18:30	6/17/06 22:30	4:00	780.1	719.0	636.7
65	JBS	6/18/06 7:00	6/18/06 12:30	5:30	779.7	716.4	711.7
66	C	6/18/06 16:15	6/18/06 20:00	3:45	780.0	719.5	694.7
67	C	6/19/06 10:15	6/19/06 13:30	3:15	780.1	719.9	741.6
68	JBS	6/20/06 15:30	6/20/06 19:00	3:30	779.8	717.9	754.2
69	JBS	6/21/06 7:15	6/21/06 11:30	4:15	779.9	717.5	761.4
70	C	6/22/06 9:30	6/22/06 13:45	4:15	779.9	720.4	639.3
71	C	6/22/06 14:15	6/22/06 21:15	7:00	780.1	719.5	655.3
72	JBS	6/23/06 5:30	6/23/06 9:30	4:00	779.8	715.8	691.9
73	JBS	6/23/06 10:00	6/23/06 14:30	4:30	779.5	717.5	752.8
74	JBS	6/23/06 15:30	6/23/06 19:30	4:00	779.9	717.4	762.8
75	C	6/24/06 10:00	6/24/06 13:30	3:30	779.9	718.4	745.0
76	C	6/24/06 15:15	6/24/06 19:15	4:00	780.1	719.3	734.4
77	JBS	6/25/06 8:15	6/25/06 15:30	7:15	779.6	717.2	753.0
78	JBS	6/26/06 8:00	6/26/06 16:15	8:15	779.4	718.3	754.2
79	JBS	6/27/06 8:45	6/27/06 17:45	9:00	780.0	718.6	758.0
80	JBS	6/28/06 11:00	6/28/06 18:00	7:00	780.1	718.1	780.4

Treatment	Type	SQ	GQ	TQ	FBsat	sd	N
52	D	59.0	157.2	217.2	113.2	0.32	32
53	JBS	10.0	155.0	166.1	113.1	0.22	34
54	D	42.3	175.5	218.8	112.9	0.22	36
55	D	114.6	109.9	225.4	112.9	0.58	40
56	D	75.3	145.6	221.9	115.5	0.91	32
57	D	102.8	147.4	251.2	114.5	0.20	24
58	D	75.7	141.8	218.5	115.3	0.41	36
59	D	43.8	118.1	162.9	114.7	0.20	30
60	D	88.9	148.1	238.0	114.3	0.18	34
61	C	62.2	162.8	226.0	114.1	0.31	50
62	D	74.8	151.8	227.6	114.8	0.63	86
63	C	87.4	117.1	205.5	113.9	0.28	32
64	C	64.0	139.7	204.7	113.6	0.21	34
65	JBS	9.9	153.0	163.9	113.5	0.30	46
66	C	56.3	158.5	215.7	114.1	0.26	32
67	C	27.3	176.4	204.8	114.3	0.28	28
68	JBS	9.9	173.2	184.1	114.3	0.44	30
69	JBS	10.0	173.7	184.7	113.7	0.19	36
70	C	84.3	145.3	230.6	114.0	0.30	36
71	C	67.6	146.4	215.1	115.0	0.35	58
72	JBS	9.9	145.2	156.1	113.3	0.11	34
73	JBS	9.8	172.4	183.2	113.3	0.20	38
74	JBS	10.2	173.7	184.9	113.6	0.26	34
75	C	21.0	171.4	193.4	113.3	0.16	30
76	C	41.2	171.9	214.1	113.6	0.20	34
77	JBS	9.8	169.7	180.6	113.6	0.25	60
78	JBS	9.7	175.2	185.9	114.5	0.23	68
79	JBS	10.0	174.9	185.9	115.5	0.18	74
80	JBS	10.1	175.5	186.6	114.6	0.21	58

Treatment	Type	TW1sat	sd	N	TW2sat	sd	N	TW3sat	sd	N
52	D	123.1	0.35	26	120.9	0.12	24	121.1	0.40	20
53	JBS	115.4	1.01	28	114.6	0.11	26	114.6	0.20	22
54	D	118.8	0.74	30	118.1	0.50	28	117.9	0.60	24
55	D	135.6	0.73	32	131.3	0.66	30	130.5	0.75	26
56	D	128.2	0.73	26	124.9	0.44	24	124.5	0.82	20
57	D	132.2	2.33	18	128.5	0.20	16	128.0	0.78	14
58	D	128.7	0.26	30	125.1	0.27	28	125.0	0.67	24
59	D	123.0	0.52	24	120.6	0.12	22	120.4	0.41	18
60	D	129.6	1.21	28	126.3	0.24	26	126.0	0.52	22
61	C	121.938	0.51	42	122.2	0.12	40	121.2	0.17	36
62	D	127.5	0.53	78	124.3	0.34	76	124.3	0.52	70
63	C	126.837	1.35	26	126.1	0.09	24	124.8	0.09	20
64	C	121.992	0.65	28	121.8	0.13	26	121.1	0.21	22
65	JBS	115.7	0.95	40	115.2	0.12	38	115.0	0.14	34
66	C	119.965	1.37	26	121.3	0.12	24	120.2	0.16	20
67	C	118.643	1.54	22	118.7	0.12	20	117.9	0.29	16
68	JBS	117.0	0.90	24	116.0	0.12	22	115.9	0.10	18
69	JBS	115.6	0.37	30	115.4	0.06	28	115.2	0.06	24
70	C	127.391	1.86	30	125.1	0.15	28	124.4	0.19	24
71	C	123.535	1.11	52	122.8	0.14	50	122.1	0.19	46
72	JBS	116.0	1.05	28	115.1	0.09	26	114.9	0.13	22
73	JBS	115.7	0.57	32	115.1	0.07	30	115.1	0.11	26
74	JBS	116.1	0.40	28	115.5	0.12	26	115.4	0.13	22
75	C	117.553	0.97	24	117.4	0.06	22	116.9	0.10	18
76	C	119.388	1.04	28	119.9	0.12	26	119.2	0.10	22
77	JBS	115.6	0.35	52	115.6	0.16	50	115.5	0.16	46
78	JBS	116.7	0.23	60	116.5	0.13	58	116.5	0.18	54
79	JBS	117.6	0.18	66	117.4	0.12	64	117.4	0.14	60
80	JBS	116.6	0.16	50	116.0	0.21	48	116.0	0.22	44

Treatment	Type	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
52	D	0.0	1.7	11.5	2.2	12.5	2.2	12.5	2.2	12.4	1.7	0.0
53	JBS	0.0	1.7	0.0	2.2	0.0	2.2	0.0	2.2	0.0	1.7	0.0
54	D	0.0	1.8	7.6	2.2	8.5	2.2	8.5	2.2	7.6	1.8	0.0
55	D	0.0	1.7	25.8	2.2	26.4	2.2	26.4	2.2	25.8	1.7	0.0
56	D	0.0	1.8	16.3	2.2	16.3	2.2	16.3	2.2	16.3	1.8	0.0
57	D	0.0	1.7	23.2	2.2	23.2	2.2	23.2	2.2	23.2	1.7	0.0
58	D	0.0	1.8	16.4	2.2	16.4	2.2	16.4	2.2	16.4	1.8	0.0
59	D	0.0	1.7	8.5	2.2	8.5	2.2	8.5	2.2	8.5	1.7	0.0
60	D	0.0	1.7	19.7	2.2	19.7	2.2	19.7	2.2	19.7	1.7	0.0
61	C	0.0	1.7	0.1	2.2	0.1	2.2	18.1	18.0	18.1	1.7	0.0
62	D	0.0	1.7	16.2	2.2	16.2	2.2	16.2	2.2	16.2	1.7	0.0
63	C	0.0	1.7	0.0	2.2	0.0	2.2	29.8	19.9	29.8	1.7	0.0
64	C	0.0	1.7	0.0	2.2	0.0	2.2	18.2	19.9	18.2	1.7	0.0
65	JBS	0.0	1.6	0.0	2.2	0.0	2.2	0.0	2.2	0.0	1.6	0.0
66	C	0.0	1.7	0.0	2.2	0.0	2.2	16.2	16.2	16.2	1.7	0.0
67	C	0.0	1.7	0.0	2.2	0.0	2.2	6.5	6.5	6.5	1.7	0.0
68	JBS	0.0	1.7	0.0	2.2	0.0	2.2	0.0	2.2	0.0	1.7	0.0
69	JBS	0.0	1.7	0.0	2.2	0.0	2.2	0.0	2.2	0.0	1.7	0.0
70	C	0.0	1.7	0.0	2.2	0.0	2.2	28.3	19.9	28.3	1.7	0.0
71	C	0.0	1.7	0.0	2.2	0.0	2.2	19.9	19.9	19.9	1.7	0.0
72	JBS	0.0	1.7	0.0	2.2	0.0	2.2	0.0	2.2	0.0	1.7	0.0
73	JBS	0.0	1.6	0.0	2.2	0.0	2.2	0.0	2.2	0.0	1.6	0.0
74	JBS	0.0	1.7	0.0	2.2	0.0	2.2	0.1	2.2	0.1	1.7	0.0
75	C	0.0	1.7	0.0	2.2	0.0	2.2	4.4	4.4	4.4	1.7	0.0
76	C	0.0	1.7	0.0	2.2	0.0	2.2	10.5	12.4	10.5	1.7	0.0
77	JBS	0.0	1.6	0.0	2.2	0.0	2.2	0.0	2.2	0.0	1.6	0.0
78	JBS	0.0	1.6	0.0	2.2	0.0	2.2	0.0	2.2	0.0	1.6	0.0
79	JBS	0.0	1.7	0.0	2.2	0.0	2.2	0.0	2.2	0.0	1.7	0.0
80	JBS	0.0	1.8	0.0	2.2	0.0	2.2	0.0	2.2	0.0	1.8	0.0

Treatment	Type	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
52	D	0.0	17.4	17.5	17.3	17.5	17.4	17.7	17.7	17.1	17.6
53	JBS	0.0	17.1	17.3	17.0	17.3	17.1	17.5	17.5	16.9	17.4
54	D	0.0	19.5	19.7	19.3	18.6	19.6	19.8	19.8	19.5	19.5
55	D	0.0	12.2	12.2	12.1	12.2	12.2	12.3	12.3	12.0	12.3
56	D	0.0	16.1	16.2	16.0	16.2	16.1	16.3	16.4	15.9	16.3
57	D	0.0	16.3	16.4	16.2	16.4	16.3	16.6	16.6	16.1	16.5
58	D	0.0	15.7	15.8	15.6	15.8	15.7	15.9	15.9	15.5	15.9
59	D	0.0	13.1	13.2	13.0	13.2	13.1	13.2	13.2	12.9	13.2
60	D	0.0	16.4	16.5	16.3	16.5	16.4	16.6	16.6	16.2	16.6
61	C	0.0	17.1	18.7	16.9	18.7	17.1	18.9	19.0	17.5	18.9
62	D	0.0	16.8	16.9	16.7	16.9	16.8	17.1	17.1	16.6	17.0
63	C	0.0	13.0	13.0	12.9	13.0	13.0	13.1	13.1	12.8	13.1
64	C	0.0	15.5	15.6	15.4	15.6	15.4	15.7	15.7	15.3	15.7
65	JBS	0.0	16.9	17.1	16.8	17.1	16.8	17.2	17.2	16.7	17.2
66	C	0.0	17.5	17.7	17.4	17.7	17.4	17.9	17.9	17.2	17.8
67	C	0.0	18.8	19.8	19.7	19.5	19.7	19.8	19.8	19.7	19.6
68	JBS	0.0	19.1	19.2	18.9	19.1	19.0	19.7	19.8	18.9	19.5
69	JBS	0.0	19.2	19.5	18.9	19.3	18.9	19.7	19.8	18.7	19.7
70	C	0.0	16.1	16.2	16.0	16.2	15.9	16.3	16.4	15.9	16.3
71	C	0.0	15.8	16.4	16.1	16.4	16.1	16.5	16.5	16.1	16.5
72	JBS	0.0	15.8	16.2	16.0	16.2	16.0	16.3	16.4	15.9	16.3
73	JBS	0.0	18.9	19.2	18.8	19.2	18.8	19.6	19.7	18.7	19.6
74	JBS	0.0	19.3	19.6	18.9	19.2	18.9	19.7	19.7	18.8	19.6
75	C	0.0	19.0	19.1	18.8	19.2	18.8	19.3	19.3	18.7	19.3
76	C	0.0	19.0	19.3	18.8	19.3	18.7	19.4	19.4	18.6	19.4
77	JBS	0.0	18.7	18.9	18.6	19.0	18.6	19.2	19.2	18.4	19.2
78	JBS	0.0	19.3	19.6	19.5	19.3	19.5	19.6	19.6	19.4	19.4
79	JBS	0.0	19.2	19.6	19.3	19.0	19.1	19.8	19.8	19.8	19.5
80	JBS	12.8	17.9	18.1	17.9	18.2	17.8	18.4	18.4	17.7	18.3

Test Sum Plot Data

Number	Test	Label	Start Time	End Time	Start Time	End Time
1	T17	250	38851.46875	38851.59375	5/14/2006 11:15	5/14/2006 14:15
2	T19	250	38851.65625	38851.78125	5/14/2006 15:45	5/14/2006 18:45
3	T10	250	38852.57292	38852.69792	5/15/2006 13:45	5/15/2006 16:45
4	T4	250	38852.79167	38852.90625	5/15/2006 19:00	5/15/2006 21:45
5	TJ1	200	38853.02083	38853.13542	5/16/2006 0:30	5/16/2006 3:15
6	T9	250	38853.33333	38853.44792	5/16/06 8:00	5/16/06 10:45
7	T21	250	38853.5	38853.61458	5/16/06 12:00	5/16/06 14:45
8	TJ2	200	38853.625	38853.77083	5/16/06 15:00	5/16/06 18:30
9	T11	250	38853.78125	38853.90625	5/16/06 18:45	5/16/06 21:45
10	TJ3	200	38854.02083	38854.13542	5/17/06 0:30	5/17/06 3:15
11	T12	250	38854.33333	38854.44792	5/17/06 8:00	5/17/06 10:45
12	T23	250	38855.05208	38855.17708	5/18/06 1:15	5/18/06 4:15
13	T18	250	38855.35417	38855.48958	5/18/06 8:30	5/18/06 11:45
14	T5	250	38855.5	38855.625	5/18/06 12:00	5/18/06 15:00
15	T3A	200	38855.64583	38855.79167	5/18/06 15:30	5/18/06 19:00
16	T9	250	38855.8125	38855.9375	5/18/06 19:30	5/18/06 22:30
17	T6	250	38856.46875	38856.58333	5/19/06 11:15	5/19/06 14:00
18	T8	250	38856.60417	38856.71875	5/19/06 14:30	5/19/06 17:15
19	TJ4	200	38856.83333	38857.01042	5/19/06 20:00	5/20/06 0:15
20	T13	250	38857.39583	38857.52083	5/20/06 9:30	5/20/06 12:30
21	TJ5	200	38858.05208	38858.1875	5/21/06 1:15	5/21/06 4:30
22	TJ6	200	38858.19792	38858.29167	5/21/06 4:45	5/21/06 7:00
23	TJ7	200	38858.73958	38858.83333	5/21/06 17:45	5/21/06 20:00
24	TJ8	200	38859.0625	38859.15625	5/22/06 1:30	5/22/06 3:45
25	TJ9	200	38859.48958	38859.63542	5/22/06 11:45	5/22/06 15:15
26	TJ10	200	38860.04167	38860.26042	5/23/06 1:00	5/23/06 6:15

Number	Test	Label	Start Time	End Time	Start Time	End Time
27	TJ11	200	38861.10417	38861.21875	5/24/06 2:30	5/24/06 5:15
28	TJ12	200	38861.30208	38861.42708	5/24/06 7:15	5/24/06 10:15
29	TJ13	200	38861.63542	38861.78125	5/24/06 15:15	5/24/06 18:45
30	TJ14	200	38862.42708	38862.65625	5/25/06 10:15	5/25/06 15:45
31	TJ15	200	38863.44792	38863.58333	5/26/06 10:45	5/26/06 14:00
32	T1	200	38863.64583	38863.89583	5/26/06 15:30	5/26/06 21:30
33	TJ16	200	38863.91667	38864.19792	5/26/06 22:00	5/27/06 4:45
34	TJ17	200	38864.26042	38864.38542	5/27/06 6:15	5/27/06 9:15
35	T3	200	38864.40625	38864.53125	5/27/06 9:45	5/27/06 12:45
36	TJ18	200	38864.76042	38864.97917	5/27/06 18:15	5/27/06 23:30
37	TJ19	200	38865	38865.5	5/28/06 0:00	5/28/06 12:00
38	TJ20	200	38865.51042	38865.73958	5/28/06 12:15	5/28/06 17:45
39	TJ21	200	38866.16667	38866.40625	5/29/06 4:00	5/29/06 9:45
40	TJ22	200	38866.47917	38866.85417	5/29/06 11:30	5/29/06 20:30
41	TJ23	200	38868.28125	38868.5	5/31/06 6:45	5/31/06 12:00
42	T4	250	38868.51042	38868.64583	5/31/06 12:15	5/31/06 15:30
43	TJ24	200.0	38869.8125	38870	6/1/06 7:30	6/1/06 14:00
44	TJ25	200.0	38869.8125	38870	6/1/06 19:30	6/2/06 0:00
45	TJ26	200.0	38872.07292	38872.23958	6/4/06 1:45	6/4/06 5:45
46	T14	250.0	38872.45833	38872.65625	6/4/06 11:00	6/4/06 15:45
47	T1	250.0	38873.4375	38873.5625	6/5/06 10:30	6/5/06 13:30
48	TJ27	200.0	38873.67708	38873.78125	6/5/06 16:15	6/5/06 18:45
49	T1	250.0	38874.38542	38874.51042	6/6/06 9:15	6/6/06 12:15
50	T1	250.0	38874.51042	38874.63542	6/6/06 12:15	6/6/06 15:15
51	T14	250.0	38874.66667	38874.75	6/6/06 16:00	6/6/06 18:00

Number	Test	Label	Start Time	End Time	Start Time	End Time
52	TJ28	200.0	38876.54167	38876.69792	6/8/06 13:00	6/8/06 16:45
53	TJ29	200.0	38877.19792	38877.36458	6/9/06 4:45	6/9/06 8:45
54	TJ30	200.0	38877.39583	38877.58333	6/9/06 9:30	6/9/06 14:00
55	TJ31	200.0	38878.67708	38878.91667	6/10/06 16:15	6/10/06 22:00
56	TJ32	200.0	38879.64583	38879.8125	6/11/06 15:30	6/11/06 19:30
57	TJ33	200.0	38880.47917	38880.61458	6/12/06 11:30	6/12/06 14:45
58	TJ34	200.0	38880.71875	38880.89583	6/12/06 17:15	6/12/06 21:30
59	TJ35	200.0	38881.08333	38881.23958	6/13/06 2:00	6/13/06 5:45
60	TJ36	200.0	38881.39583	38881.5625	6/13/06 9:30	6/13/06 13:30
61	TJ37	200.0	38881.58333	38881.83333	6/13/06 14:00	6/13/06 20:00
62	TJ38	200.0	38882.35417	38882.79167	6/14/06 8:30	6/14/06 19:00
63	TJ39	200.0	38885.09375	38885.25	6/17/06 2:15	6/17/06 6:00
64	TJ40	200.0	38885.77083	38885.9375	6/17/06 18:30	6/17/06 22:30
65	TJ41	200.0	38886.29167	38886.52083	6/18/06 7:00	6/18/06 12:30
66	TJ42	200.0	38886.67708	38886.83333	6/18/06 16:15	6/18/06 20:00
67	TJ43	200.0	38887.42708	38887.5625	6/19/06 10:15	6/19/06 13:30
68	TJ44	200.0	38888.64583	38888.79167	6/20/06 15:30	6/20/06 19:00
69	TJ45	200.0	38889.30208	38889.47917	6/21/06 7:15	6/21/06 11:30
70	TJ46	200.0	38890.39583	38890.57292	6/22/06 9:30	6/22/06 13:45
71	TJ47	200.0	38890.59375	38890.88542	6/22/06 14:15	6/22/06 21:15
72	TJ48	200.0	38891.22917	38891.39583	6/23/06 5:30	6/23/06 9:30
73	TJ49	200.0	38891.41667	38891.60417	6/23/06 10:00	6/23/06 14:30
74	TJ50	200.0	38891.64583	38891.8125	6/23/06 15:30	6/23/06 19:30
75	TJ51	200.0	38892.41667	38892.5625	6/24/06 10:00	6/24/06 13:30
76	TJ52	200.0	38892.63542	38892.80208	6/24/06 15:15	6/24/06 19:15
77	TJ53	200.0	38893.34375	38893.64583	6/25/06 8:15	6/25/06 15:30

Number	Test	Label	Start Time	End Time	Start Time	End Time
78	TJ54	200.0	38894.33333	38894.67708	6/26/06 8:00	6/26/06 16:15
79	TJ55	200.0	38895.36458	38895.73958	6/27/06 8:45	6/27/06 17:45
80	TJ56	200.0	38896.45833	38896.75	6/28/06 11:00	6/28/06 18:00

Duration	FBEL	FB	TWEL	Head	Total MW	SQ	GQ	TQ
3:00	778.7	778.6	711.5	67.2	380.9	44.6	74.8	120.4
3:00	778.9	779.0	712.6	66.3	375.1	55.0	74.9	130.9
3:00	778.8	778.8	716.9	61.9	746.0	9.3	169.4	179.8
2:45	779.0	779.0	718.2	60.8	732.3	28.2	170.7	199.9
2:45	779.8	779.8	705.9	73.8	73.8	2.2	13.2	16.4
2:45	777.9	777.9	717.1	60.8	619.6	57.3	136.0	194.3
2:45	777.9	777.9	714.3	63.6	630.3	8.8	131.0	140.8
3:30	778.6	778.6	716.7	61.9	731.2	12.0	166.0	179.1
3:00	779.4	779.3	715.8	63.6	515.3	51.9	113.5	166.3
2:45	780.2	780.2	706.1	74.0	128.8	2.3	23.7	27.0
2:45	777.3	777.3	715.4	61.9	499.4	42.6	113.7	157.2
3:00	776.3	776.3	712.0	64.4	259.9	49.2	56.2	106.4
3:15	772.9	772.9	715.0	57.9	476.6	32.2	117.6	150.8
3:00	772.3	772.3	718.7	53.7	613.5	50.1	160.4	211.5
3:30	772.4	772.4	719.1	53.3	583.9	60.0	150.4	211.3
3:00	772.7	772.7	718.3	54.4	402.7	109.4	100.2	210.5
2:45	771.9	771.9	719.3	52.7	628.9	31.1	172.5	204.6
2:45	771.9	772.0	718.3	53.6	534.5	58.9	134.4	194.3
4:15	772.2	772.3	712.7	59.6	449.1	12.5	100.7	114.2
3:00	771.6	771.7	715.3	56.3	571.8	26.0	136.9	163.9
3:15	771.5	771.5	706.9	64.6	161.1	8.3	33.8	43.1
2:15	771.5	771.5	705.2	66.3	70.8	8.3	13.3	22.5
2:15	771.4	771.4	713.6	57.8	503.2	12.5	114.7	128.2
2:15	771.6	771.6	705.3	66.3	58.7	8.3	11.7	21.0
3:30	771.8	771.7	717.6	54.1	644.0	12.5	172.9	186.4
5:15	771.6	771.6	707.6	64.0	168.8	8.3	34.8	44.1

Duration	FBEL	FB	TWEL	Head	Total MW	SQ	GQ	TQ
2:45	772.2	772.3	707.6	64.7	183.2	8.7	40.6	50.3
3:00	772.3	772.3	717.1	55.2	654.1	12.5	169.7	183.2
3:30	774.8	774.8	718.1	56.6	682.5	12.6	174.3	187.9
5:30	778.0	778.0	718.4	59.6	728.9	13.1	175.5	189.6
3:15	778.9	779.0	720.6	58.3	557.3	121.8	127.2	250.0
6:00	778.6	778.5	721.0	57.6	688.8	55.5	172.0	228.6
6:45	779.1	779.0	719.4	59.7	603.8	85.2	135.1	221.3
3:00	779.2	779.2	717.8	61.4	583.1	68.2	125.3	194.4
3:00	779.1	779.0	721.2	57.8	685.9	71.3	169.7	241.9
5:15	779.9	780.0	721.0	58.9	562.6	117.2	126.5	244.7
12:00	779.8	779.9	721.5	58.3	562.7	124.5	128.5	254.0
5:30	779.5	779.5	721.3	58.1	563.0	121.6	129.1	251.7
5:45	780.0	780.0	721.5	58.5	562.4	124.7	127.7	253.4
9:00	779.9	780.0	721.1	58.8	564.0	118.3	127.4	246.6
5:15	779.0	779.0	717.2	61.8	750.0	13.1	172.0	186.1
3:15	779.7	779.6	718.5	61.1	742.6	33.9	172.4	207.3
6:30	778.6	778.7	717.0	61.7	727.1	9.4	164.4	174.8
4:30	779.9	780.0	718.2	61.7	503.2	95.6	106.4	203.0
4:00	780.0	780.0	715.9	64.1	498.8	60.7	101.6	163.2
4:45	779.6	779.6	717.3	62.2	618.7	40.6	131.8	173.4
3:00	778.6	778.7	720.2	58.4	700.5	51.7	170.6	223.3
2:30	779.9	779.9	716.7	63.2	751.6	10.0	164.8	175.8
3:00	779.7	779.6	720.5	59.2	713.8	52.7	169.5	223.2
3:00	779.4	779.5	720.6	58.8	707.4	53.1	165.9	220.0
2:00	780.0	780.1	718.2	61.8	646.3	75.9	139.8	216.7

Duration	FBEL	FB	TWEL	Head	Total MW	SQ	GQ	TQ
3:45	779.9	780.0	719.8	60.1	687.0	59.0	157.2	217.2
4:00	780.0	780.0	716.6	63.4	717.7	10.0	155.0	166.1
4:30	780.2	780.1	720.3	59.9	730.9	42.3	175.5	218.8
5:45	780.1	780.1	719.5	60.6	502.9	114.6	109.9	225.4
4:00	780.2	780.2	719.8	60.4	651.4	75.3	145.6	221.9
3:15	780.1	780.1	721.3	58.8	638.3	102.8	147.4	251.2
4:15	780.1	780.2	719.8	60.4	636.0	75.7	141.8	218.5
3:45	779.8	779.8	715.8	64.0	576.3	43.8	118.1	162.9
4:00	780.0	780.0	720.6	59.4	648.4	88.9	148.1	238.0
6:00	779.9	780.0	720.7	59.2	706.9	62.2	162.8	226.0
10:30	780.0	779.9	720.3	59.7	664.6	74.8	151.8	227.6
3:45	780.1	780.0	718.6	61.5	549.5	87.4	117.1	205.5
4:00	780.1	780.0	719.0	61.1	636.7	64.0	139.7	204.7
5:30	779.7	779.7	716.4	63.3	711.7	9.9	153.0	163.9
3:45	780.0	780.0	719.5	60.5	694.7	56.3	158.5	215.7
3:15	780.1	780.0	719.9	60.2	741.6	27.3	176.4	204.8
3:30	779.8	779.8	717.9	61.9	754.2	9.9	173.2	184.1
4:15	779.9	780.0	717.5	62.4	761.4	10.0	173.7	184.7
4:15	779.9	779.9	720.4	59.5	639.3	84.3	145.3	230.6
7:00	780.1	780.0	719.5	60.6	655.3	67.6	146.4	215.1
4:00	779.8	779.9	715.8	64.0	691.9	9.9	145.2	156.1
4:30	779.5	779.5	717.5	62.0	752.8	9.8	172.4	183.2
4:00	779.9	780.0	717.4	62.5	762.8	10.2	173.7	184.9
3:30	779.9	780.0	718.4	61.5	745.0	21.0	171.4	193.4
4:00	780.1	780.0	719.3	60.8	734.4	41.2	171.9	214.1
7:15	779.6	779.6	717.2	62.4	753.0	9.8	169.7	180.6

Duration	FBEL	FB	TWEL	Head	Total MW	SQ	GQ	TQ
8:15	779.4	779.4	718.3	61.1	754.2	9.7	175.2	185.9
9:00	780.0	780.0	718.6	61.4	758.0	10.0	174.9	185.9
7:00	780.1	780.1	718.1	62.0	780.4	10.1	175.5	186.6

	S1	S2	S3	S4	S5	S6	S7	S8
Spillbay	0.0	1.3	0.0	2.2	0.0	2.2	35.4	2.2
Turbine	0.0	15.0	15.0	14.8	0.0	0.0	0.0	0.0
Spillbay	0.0	1.4	0.0	2.2	19.7	8.4	19.7	2.2
Turbine	0.0	14.9	0.0	14.9	0.0	14.9	0.0	15.1
Spillbay	0.0	1.4	0.0	2.2	0.0	2.2	0.0	2.2
Turbine	0.0	18.7	18.8	18.6	18.8	18.7	19.1	19.2
Spillbay	0.0	1.4	0.0	2.2	0.0	2.2	18.8	2.2
Turbine	0.0	18.9	18.9	18.7	19.1	18.8	19.3	19.3
Spillbay	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0
Turbine	0.0	0.0	0.0	12.5	0.0	0.0	0.0	0.0
Spillbay	0.0	1.1	0.0	2.2	21.2	8.4	21.2	2.2
Turbine	0.0	15.1	15.1	14.9	15.2	15.0	15.3	15.3
Spillbay	0.0	1.1	0.0	2.2	0.0	2.2	0.0	2.2
Turbine	0.0	14.5	14.5	14.4	14.5	14.5	14.7	14.7
Spillbay	0.0	1.3	0.0	2.2	0.0	2.2	2.8	2.2
Turbine	0.0	18.7	18.8	18.3	18.8	17.4	17.7	19.0
Spillbay	0.0	1.5	0.0	2.2	0.0	2.2	42.2	2.2
Turbine	0.0	18.8	19.0	18.8	19.0	0.0	0.0	0.0
Spillbay	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0
Turbine	0.0	0.0	11.3	11.2	0.0	0.0	0.0	0.0
Spillbay	0.0	0.9	0.0	2.2	0.0	2.2	34.1	2.2
Turbine	0.0	18.9	19.1	18.7	19.2	0.0	0.0	0.0
Spillbay	0.0	0.7	0.0	2.2	0.0	2.2	41.3	2.2
Turbine	0.0	18.8	0.0	18.5	0.0	0.0	0.0	0.0
Spillbay	0.0	1.5	0.0	2.1	0.0	2.1	22.6	2.1
Turbine	0.0	18.7	19.1	18.2	18.9	1.0	3.8	0.0
Spillbay	0.0	2.1	0.0	2.1	0.0	2.1	39.6	2.1
Turbine	0.0	17.7	18.0	17.6	17.9	17.8	17.9	18.1
Spillbay	0.0	2.8	0.0	2.1	21.2	7.9	21.1	2.1
Turbine	0.0	16.5	16.9	16.5	16.9	16.5	17.0	16.9
Spillbay	0.0	3.1	23.1	2.1	22.4	7.9	22.4	2.1
Turbine	0.0	11.1	11.2	11.1	11.2	11.1	11.2	11.2
Spillbay	0.0	3.1	2.9	3.9	3.9	3.9	3.1	3.9
Turbine	0.0	19.0	19.5	17.6	19.6	19.6	19.2	19.8
Spillbay	0.0	3.1	9.9	6.0	8.2	6.0	7.0	6.0
Turbine	0.0	14.8	15.0	15.0	14.9	14.8	15.1	15.1
Spillbay	0.0	3.1	0.0	2.1	0.0	2.1	0.0	2.1
Turbine	0.0	9.5	11.4	11.3	11.4	11.3	11.5	11.5
Spillbay	0.0	3.1	3.1	3.1	2.2	3.1	2.1	3.1
Turbine	0.0	15.2	15.3	15.0	15.3	15.1	15.3	15.3
Spillbay	0.0	3.1	0.0	2.1	0.0	0.0	0.0	0.0
Turbine	0.0	11.3	11.3	11.2	0.0	0.0	0.0	0.0
Spillbay	0.0	3.1	0.0	2.1	0.0	0.0	0.0	0.0
Turbine	0.0	8.8	0.0	4.5	0.0	0.0	0.0	0.0
Spillbay	0.0	3.1	0.0	2.1	0.0	2.1	0.0	2.1
Turbine	0.0	12.7	12.8	12.6	12.8	12.8	12.9	12.8
Spillbay	0.0	3.1	0.0	2.1	0.0	0.0	0.0	0.0
Turbine	0.0	0.0	0.0	11.7	0.0	0.0	0.0	0.0
Spillbay	0.0	3.1	0.0	2.1	0.0	2.1	0.0	2.1
Spillbay	0.0	3.1	0.0	2.1	0.0	0.0	0.0	0.0

	S1	S2	S3	S4	S5	S6	S7	S8
Turbine	0.0	0.0	11.7	11.6	0.0	0.0	0.0	0.0
Spillbay	0.0	3.1	0.0	2.1	0.0	0.4	0.0	0.0
Turbine	0.0	10.2	10.0	10.2	0.0	0.0	0.0	0.0
Spillbay	0.0	3.1	0.0	2.1	0.0	2.1	0.0	2.1
Turbine	0.0	19.0	19.0	18.1	19.1	19.0	19.1	19.1
Spillbay	0.0	3.2	0.0	2.1	0.0	2.1	0.0	2.1
Turbine	0.0	19.5	19.9	18.5	18.4	19.8	19.9	20.0
Spillbay	0.0	3.3	0.0	2.2	0.0	2.2	0.0	2.2
Turbine	0.0	19.8	20.1	18.6	18.0	20.1	20.1	20.2
Spillbay	0.0	3.3	26.3	2.2	28.1	2.2	28.1	2.2
Turbine	0.0	14.0	14.2	14.0	14.2	14.0	14.3	14.3
Spillbay	0.0	3.3	0.0	2.2	0.0	2.2	42.4	2.2
Turbine	0.0	19.8	18.0	18.8	17.6	18.1	20.2	20.3
Spillbay	0.0	3.3	18.1	2.2	17.7	2.2	18.2	2.2
Turbine	0.0	15.0	15.0	14.9	15.0	15.0	15.2	15.2
Spillbay	0.0	3.3	14.2	2.2	14.2	2.2	13.3	2.2
Turbine	0.0	13.9	14.0	13.8	14.0	13.8	14.1	14.0
Spillbay	0.0	3.3	0.0	2.2	26.4	8.4	25.6	2.2
Turbine	0.0	19.9	16.0	19.1	18.8	18.2	19.9	18.6
Spillbay	0.0	3.3	26.6	2.2	25.8	2.2	25.8	2.2
Turbine	0.0	14.0	14.1	13.9	14.2	13.9	14.2	14.2
Spillbay	0.0	3.3	27.4	2.2	27.4	2.2	28.2	2.2
Turbine	0.0	14.2	14.3	14.1	14.4	14.2	14.4	14.4
Spillbay	0.0	3.3	26.5	2.2	27.3	2.2	28.1	2.2
Turbine	0.0	14.3	14.4	14.2	14.5	14.2	14.5	14.5
Spillbay	0.0	3.3	28.3	2.2	27.5	2.2	27.5	2.2
Turbine	0.0	14.1	14.3	14.1	14.3	14.1	14.4	14.3
Spillbay	0.0	3.3	25.8	2.2	26.9	2.2	26.6	2.2
Turbine	0.0	14.0	14.2	14.0	14.3	14.0	14.3	14.3
Spillbay	0.0	3.3	0.0	2.2	0.0	2.2	0.0	2.2
Turbine	0.0	19.1	19.2	18.9	18.9	19.1	19.8	19.7
Spillbay	0.0	3.3	0.0	2.2	0.0	2.2	20.7	2.2
Turbine	0.0	19.2	19.4	19.1	19.1	19.3	19.4	19.4
Spillbay	0.0	1.3	0.0	2.2	0.0	2.2	0.0	2.2
Turbine	0.0	18.2	18.3	18.0	18.4	18.2	18.6	18.6
Spillbay	0.0	1.7	21.2	2.2	21.6	2.2	21.2	2.2
Turbine	0.0	11.8	11.9	11.7	11.9	11.8	11.9	11.9
Spillbay	0.0	1.7	12.4	2.2	13.4	2.2	13.4	2.2
Turbine	0.0	12.7	12.7	12.6	0.0	12.7	12.8	12.8
Spillbay	0.0	1.6	5.4	5.2	5.4	5.2	5.4	5.2
Turbine	0.0	14.7	14.7	14.4	14.7	14.7	14.8	14.8
Spillbay	0.0	1.3	0.0	2.2	0.0	2.2	42.5	2.2
Turbine	0.0	18.9	18.0	18.5	18.3	19.0	20.2	19.6
Spillbay	0.0	1.7	0.0	2.2	0.0	2.2	0.0	2.2
Turbine	0.0	18.2	18.3	18.2	18.4	18.2	18.6	18.5
Spillbay	0.0	1.6	0.0	2.2	42.9	2.2	0.0	2.2
Turbine	0.0	18.9	19.1	18.0	19.1	18.7	19.5	19.4
Spillbay	0.0	1.6	0.0	2.2	43.3	2.2	0.0	2.2
Turbine	0.0	18.1	19.0	17.4	18.5	18.0	19.0	19.6
Spillbay	0.0	1.7	10.5	10.5	10.5	10.5	9.5	10.5
Turbine	0.0	15.5	15.6	15.3	15.6	15.5	15.7	15.7

	S1		S2		S3		S4		S5		S6		S7		S8	
Spillbay	0.0	1.7	11.5	2.2	12.5	2.2	12.5	2.2
Turbine	0.0	17.4	17.5	17.3	17.5	17.4	17.7	17.7
Spillbay	0.0	1.7	0.0	2.2	0.0	2.2	0.0	2.2
Turbine	0.0	17.1	17.3	17.0	17.3	17.1	17.5	17.5
Spillbay	0.0	1.8	7.6	2.2	8.5	2.2	8.5	2.2
Turbine	0.0	19.5	19.7	19.3	18.6	19.6	19.8	19.8
Spillbay	0.0	1.7	25.8	2.2	26.4	2.2	26.4	2.2
Turbine	0.0	12.2	12.2	12.1	12.2	12.2	12.3	12.3
Spillbay	0.0	1.8	16.3	2.2	16.3	2.2	16.3	2.2
Turbine	0.0	16.1	16.2	16.0	16.2	16.1	16.3	16.4
Spillbay	0.0	1.7	23.2	2.2	23.2	2.2	23.2	2.2
Turbine	0.0	16.3	16.4	16.2	16.4	16.3	16.6	16.6
Spillbay	0.0	1.8	16.4	2.2	16.4	2.2	16.4	2.2
Turbine	0.0	15.7	15.8	15.6	15.8	15.7	15.9	15.9
Spillbay	0.0	1.7	8.5	2.2	8.5	2.2	8.5	2.2
Turbine	0.0	13.1	13.2	13.0	13.2	13.1	13.2	13.2
Spillbay	0.0	1.7	19.7	2.2	19.7	2.2	19.7	2.2
Turbine	0.0	16.4	16.5	16.3	16.5	16.4	16.6	16.6
Spillbay	0.0	1.7	0.1	2.2	0.1	2.2	18.1	18.0
Turbine	0.0	17.1	18.7	16.9	18.7	17.1	18.9	19.0
Spillbay	0.0	1.7	16.2	2.2	16.2	2.2	16.2	2.2
Turbine	0.0	16.8	16.9	16.7	16.9	16.8	17.1	17.1
Spillbay	0.0	1.7	0.0	2.2	0.0	2.2	29.8	19.9
Turbine	0.0	13.0	13.0	12.9	13.0	13.0	13.1	13.1
Spillbay	0.0	1.7	0.0	2.2	0.0	2.2	18.2	19.9
Turbine	0.0	15.5	15.6	15.4	15.6	15.4	15.7	15.7
Spillbay	0.0	1.6	0.0	2.2	0.0	2.2	0.0	2.2
Turbine	0.0	16.9	17.1	16.8	17.1	16.8	17.2	17.2
Spillbay	0.0	1.7	0.0	2.2	0.0	2.2	16.2	16.2
Turbine	0.0	17.5	17.7	17.4	17.7	17.4	17.9	17.9
Spillbay	0.0	1.7	0.0	2.2	0.0	2.2	6.5	6.5
Turbine	0.0	18.8	19.8	19.7	19.5	19.7	19.8	19.8
Spillbay	0.0	1.7	0.0	2.2	0.0	2.2	0.0	2.2
Turbine	0.0	19.1	19.2	18.9	19.1	19.0	19.7	19.8
Spillbay	0.0	1.7	0.0	2.2	0.0	2.2	0.0	2.2
Turbine	0.0	19.2	19.5	18.9	19.3	18.9	19.7	19.8
Spillbay	0.0	1.7	0.0	2.2	0.0	2.2	28.3	19.9
Turbine	0.0	16.1	16.2	16.0	16.2	15.9	16.3	16.4
Spillbay	0.0	1.7	0.0	2.2	0.0	2.2	19.9	19.9
Turbine	0.0	15.8	16.4	16.1	16.4	16.1	16.5	16.5
Spillbay	0.0	1.7	0.0	2.2	0.0	2.2	0.0	2.2
Turbine	0.0	15.8	16.2	16.0	16.2	16.0	16.3	16.4
Spillbay	0.0	1.6	0.0	2.2	0.0	2.2	0.0	2.2
Turbine	0.0	18.9	19.2	18.8	19.2	18.8	19.6	19.7
Spillbay	0.0	1.7	0.0	2.2	0.0	2.2	0.1	2.2
Turbine	0.0	19.3	19.6	18.9	19.2	18.9	19.7	19.7
Spillbay	0.0	1.7	0.0	2.2	0.0	2.2	4.4	4.4
Turbine	0.0	19.0	19.1	18.8	19.2	18.8	19.3	19.3
Spillbay	0.0	1.7	0.0	2.2	0.0	2.2	10.5	12.4
Turbine	0.0	19.0	19.3	18.8	19.3	18.7	19.4	19.4
Spillbay	0.0	1.6	0.0	2.2	0.0	2.2	0.0	2.2

	S1		S2		S3		S4		S5		S6		S7		S8	
Spillbay		0.0		1.6		0.0		2.2		0.0		2.2		0.0		2.2
Turbine		0.0		19.3		19.6		19.5		19.3		19.5		19.6		19.6
Spillbay		0.0		1.7		0.0		2.2		0.0		2.2		0.0		2.2
Turbine		0.0		19.2		19.6		19.3		19.0		19.1		19.8		19.8
Spillbay		0.0		1.8		0.0		2.2		0.0		2.2		0.0		2.2
Turbine		12.8		17.9		18.1		17.9		18.2		17.8		18.4		18.4

S9	S10
0.0	1.3
14.8	15.2
0.0	1.4
0.0	15.1
0.0	1.4
18.4	19.0
0.0	1.4
18.5	19.1
0.0	0.0
0.8	0.0
0.0	1.1
14.9	15.2
0.0	1.1
14.4	14.7
0.0	1.3
18.5	18.8
0.0	1.5
18.6	19.2
0.0	0.1
1.2	0.0
0.0	0.9
18.7	19.2
0.0	0.7
0.0	19.0
0.0	1.8
19.4	18.5
0.0	2.1
17.5	17.9
0.0	2.8
16.4	16.9
23.1	3.1
11.1	11.2
3.1	3.1
19.5	18.7
9.7	3.1
14.7	15.1
0.0	3.1
11.3	11.5
3.1	3.1
15.0	15.4
0.0	3.1
0.0	0.0
0.0	3.1
0.0	0.0
0.0	3.1
12.5	12.8
0.0	3.1
0.0	0.0
0.0	3.1
0.0	3.1

S9	S10
11.6	0.0
0.0	3.1
10.2	0.0
0.0	3.1
18.9	18.5
0.0	3.2
19.6	18.8
0.0	3.3
20.2	18.6
26.2	3.3
13.9	14.3
0.0	3.3
20.3	18.9
18.2	3.3
14.7	15.1
13.3	3.3
13.7	14.0
0.0	3.3
20.4	18.8
25.8	3.3
13.9	14.1
28.2	3.3
14.1	14.4
26.5	3.3
14.1	14.4
28.3	3.3
14.0	14.3
25.8	3.3
13.9	14.3
0.0	3.3
18.8	18.6
0.0	3.3
18.8	18.8
0.0	1.3
17.9	18.3
21.6	1.7
11.7	11.9
11.4	1.7
12.5	12.8
5.4	1.6
14.4	14.7
0.0	1.3
19.9	18.2
0.0	1.7
18.0	18.4
0.0	1.6
17.5	19.3
0.0	1.6
17.7	18.5
10.5	1.7
15.3	15.6

S9	S10
12.4	1.7
17.1	17.6
0.0	1.7
16.9	17.4
7.6	1.8
19.5	19.5
25.8	1.7
12.0	12.3
16.3	1.8
15.9	16.3
23.2	1.7
16.1	16.5
16.4	1.8
15.5	15.9
8.5	1.7
12.9	13.2
19.7	1.7
16.2	16.6
18.1	1.7
17.5	18.9
16.2	1.7
16.6	17.0
29.8	1.7
12.8	13.1
18.2	1.7
15.3	15.7
0.0	1.6
16.7	17.2
16.2	1.7
17.2	17.8
6.5	1.7
19.7	19.6
0.0	1.7
18.9	19.5
0.0	1.7
18.7	19.7
28.3	1.7
15.9	16.3
19.9	1.7
16.1	16.5
0.0	1.7
15.9	16.3
0.0	1.6
18.7	19.6
0.1	1.7
18.8	19.6
4.4	1.7
18.7	19.3
10.5	1.7
18.6	19.4
0.0	1.6

S9	S10
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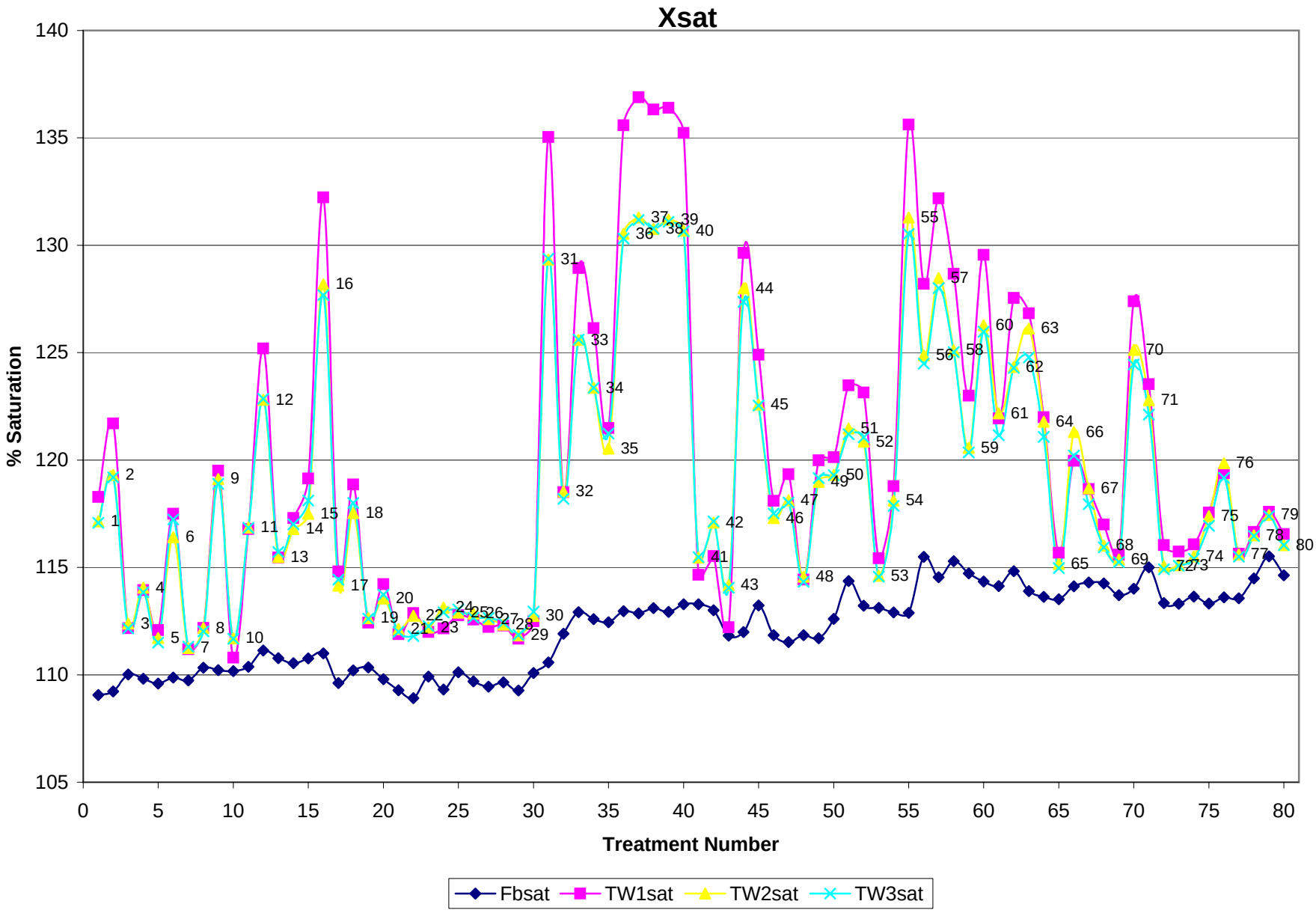
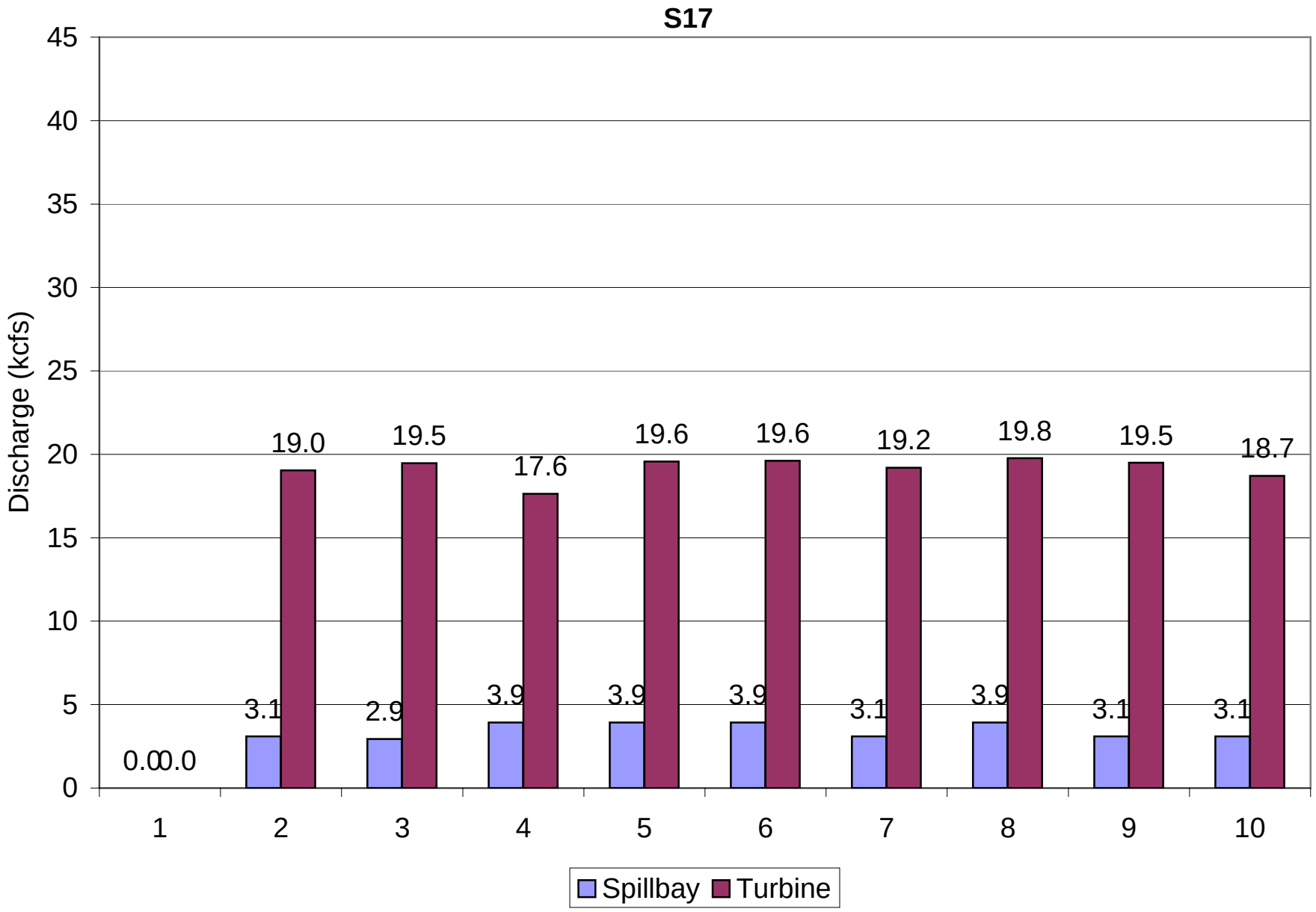
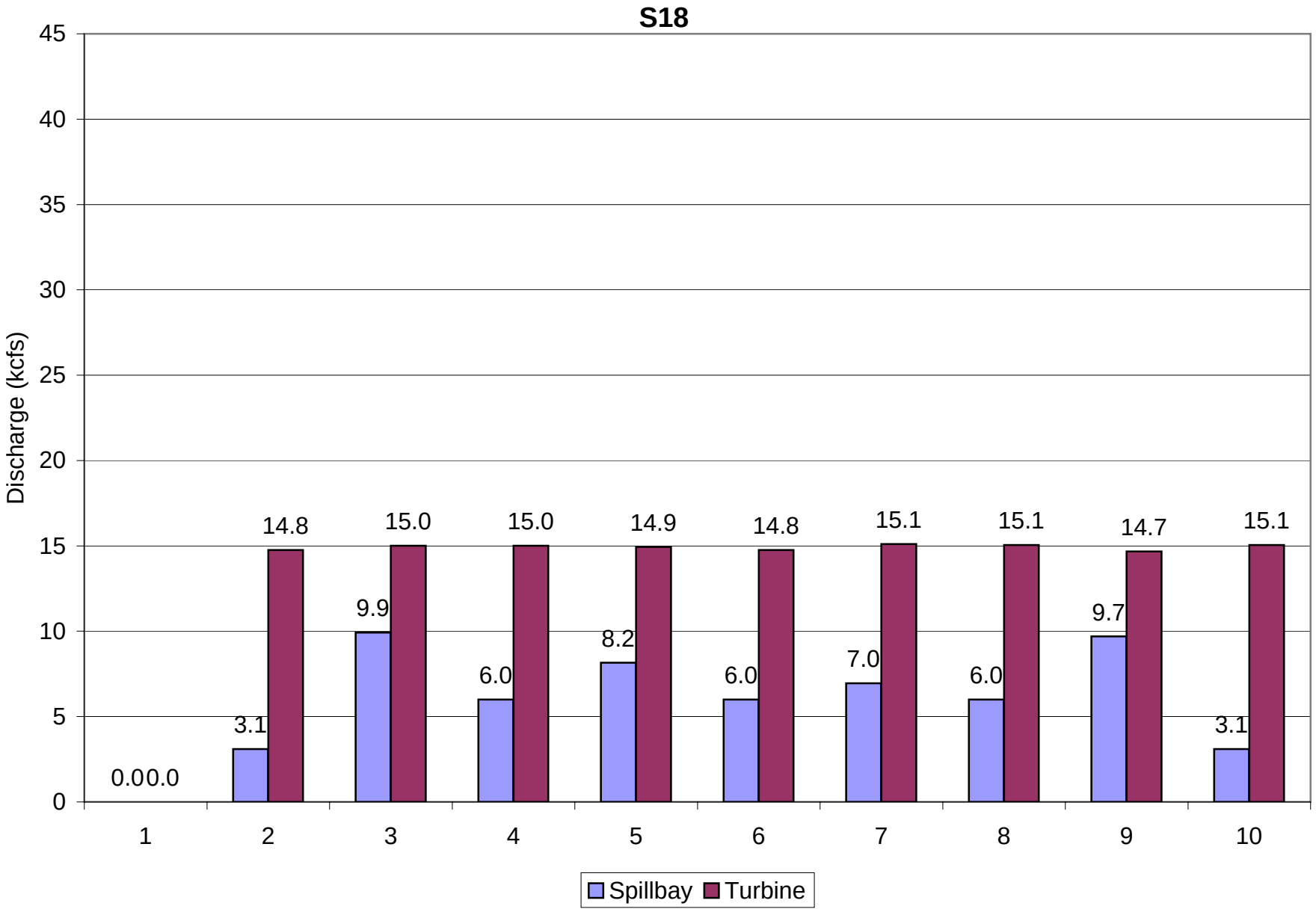
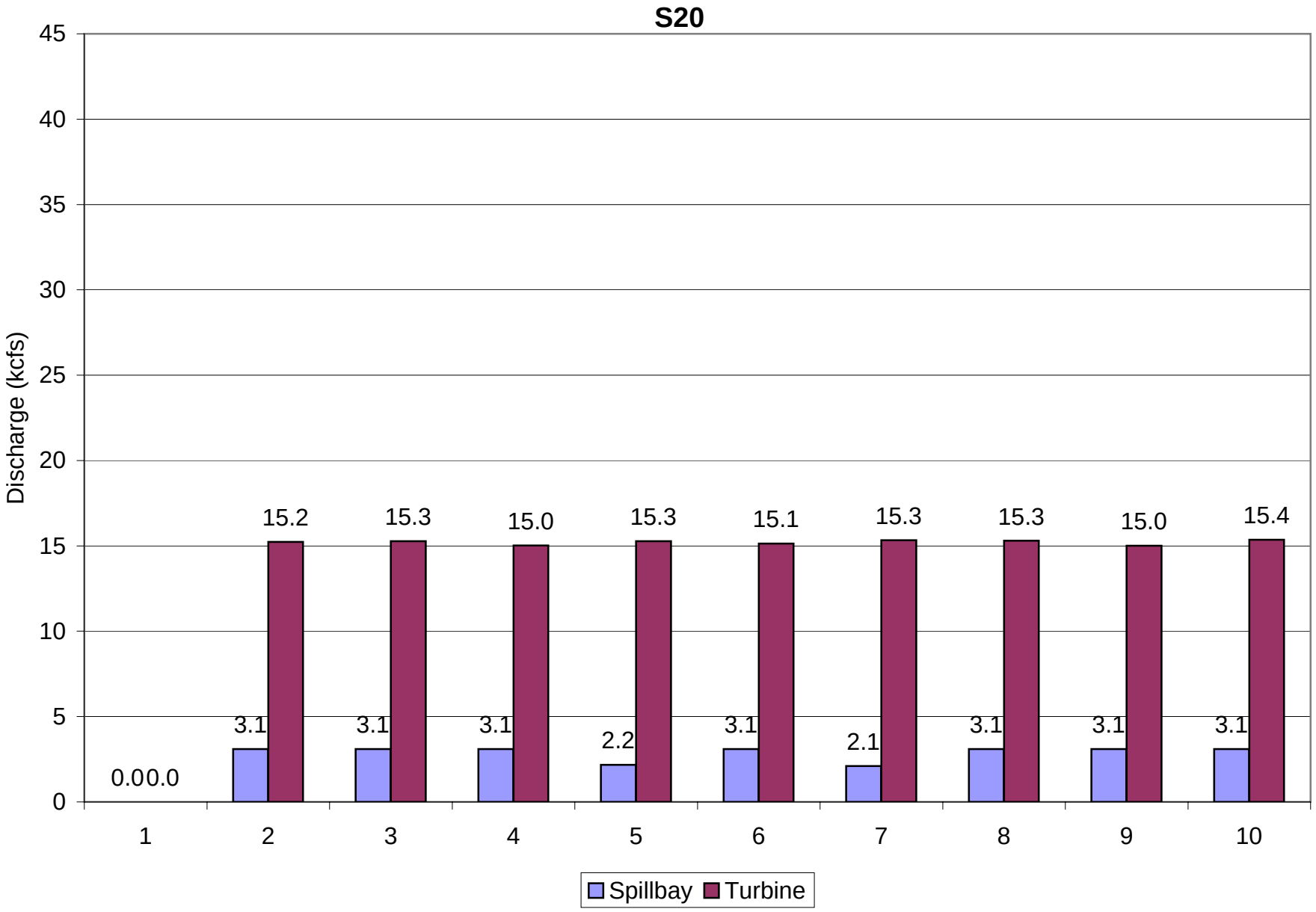
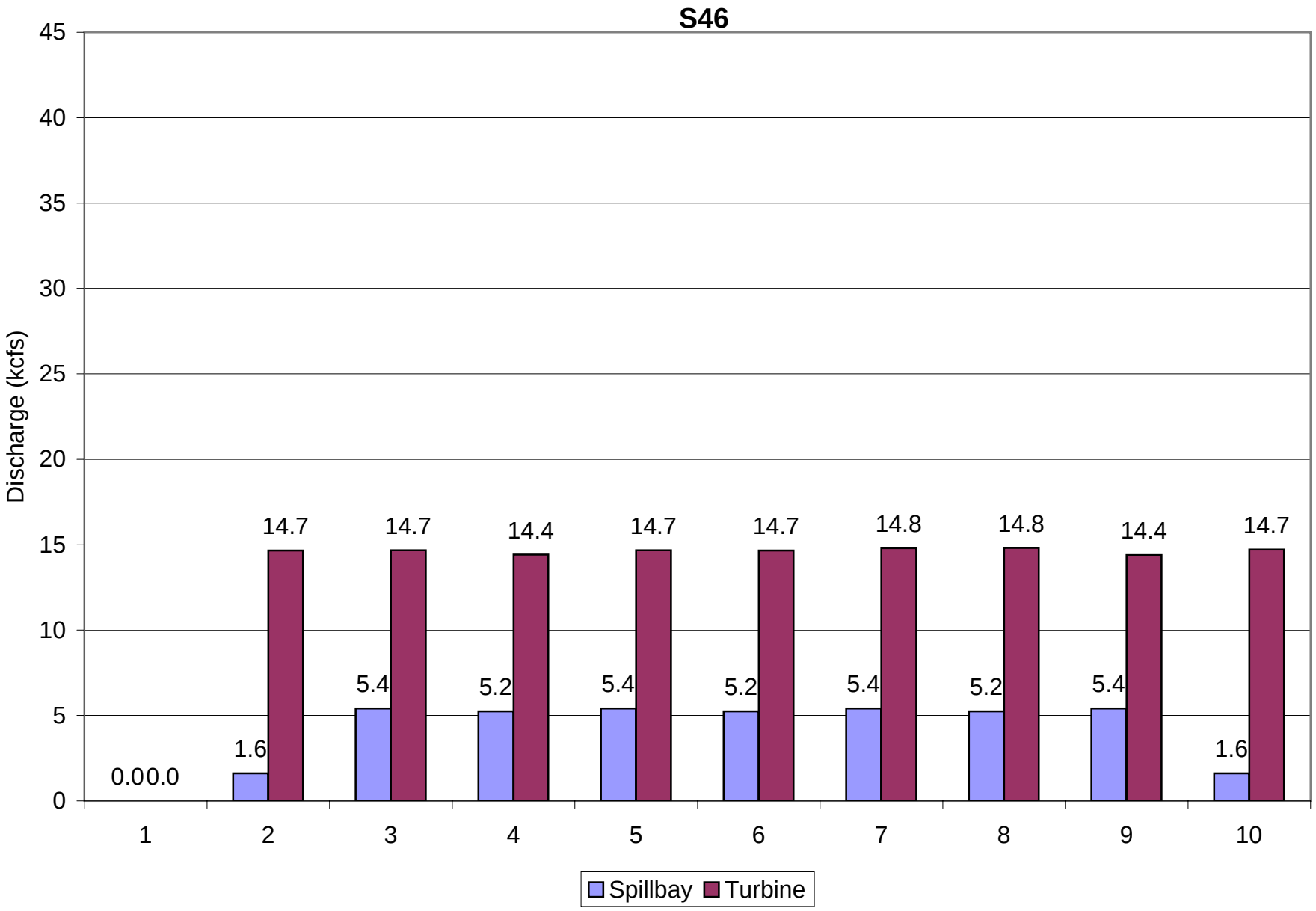
19.4	19.4
0.0	1.7
19.8	19.5
0.0	1.8
17.7	18.3

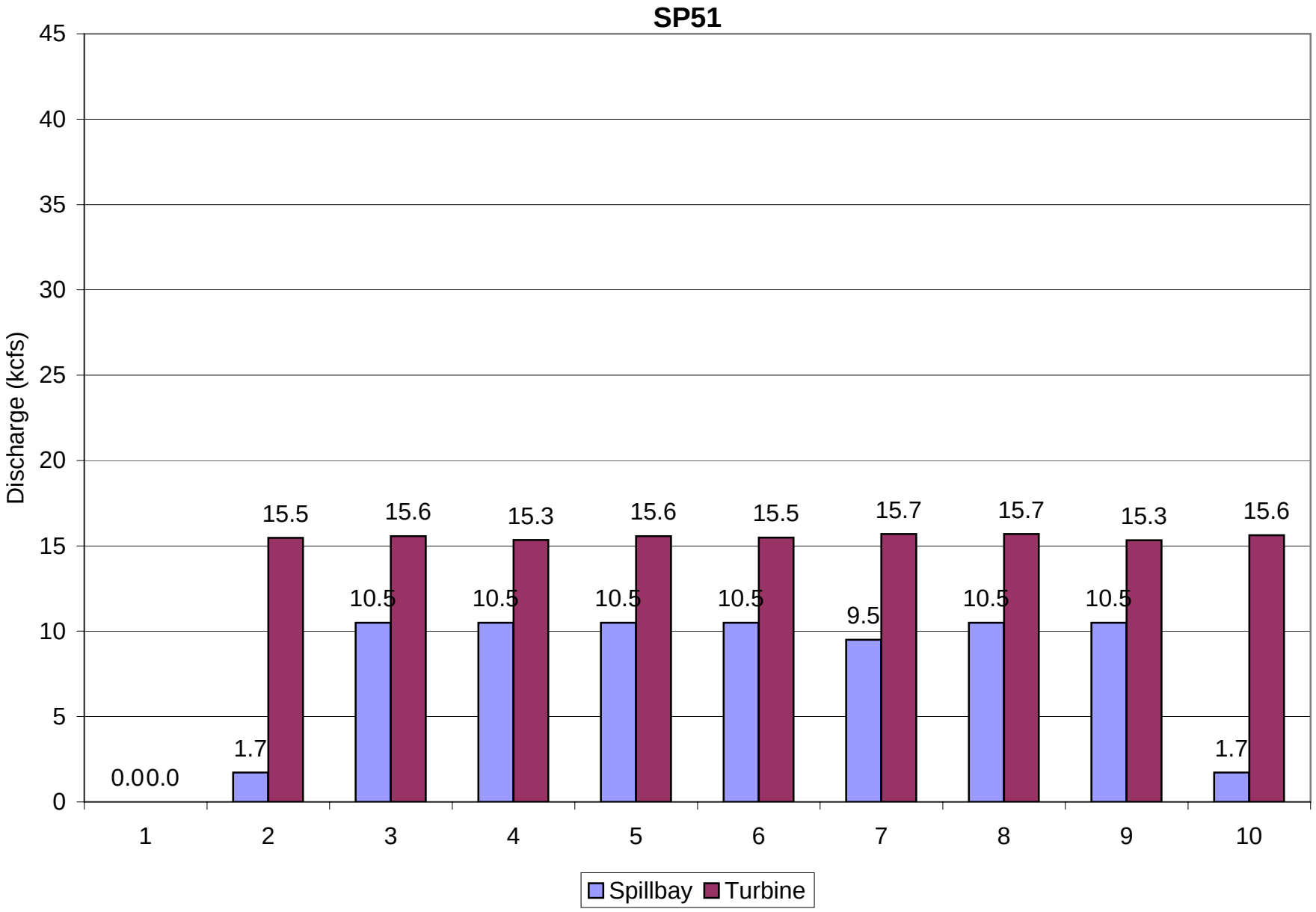

Xsat
% Saturation
Treatment Number
Fbsat
TW1sat
TW2sat
TW3sat

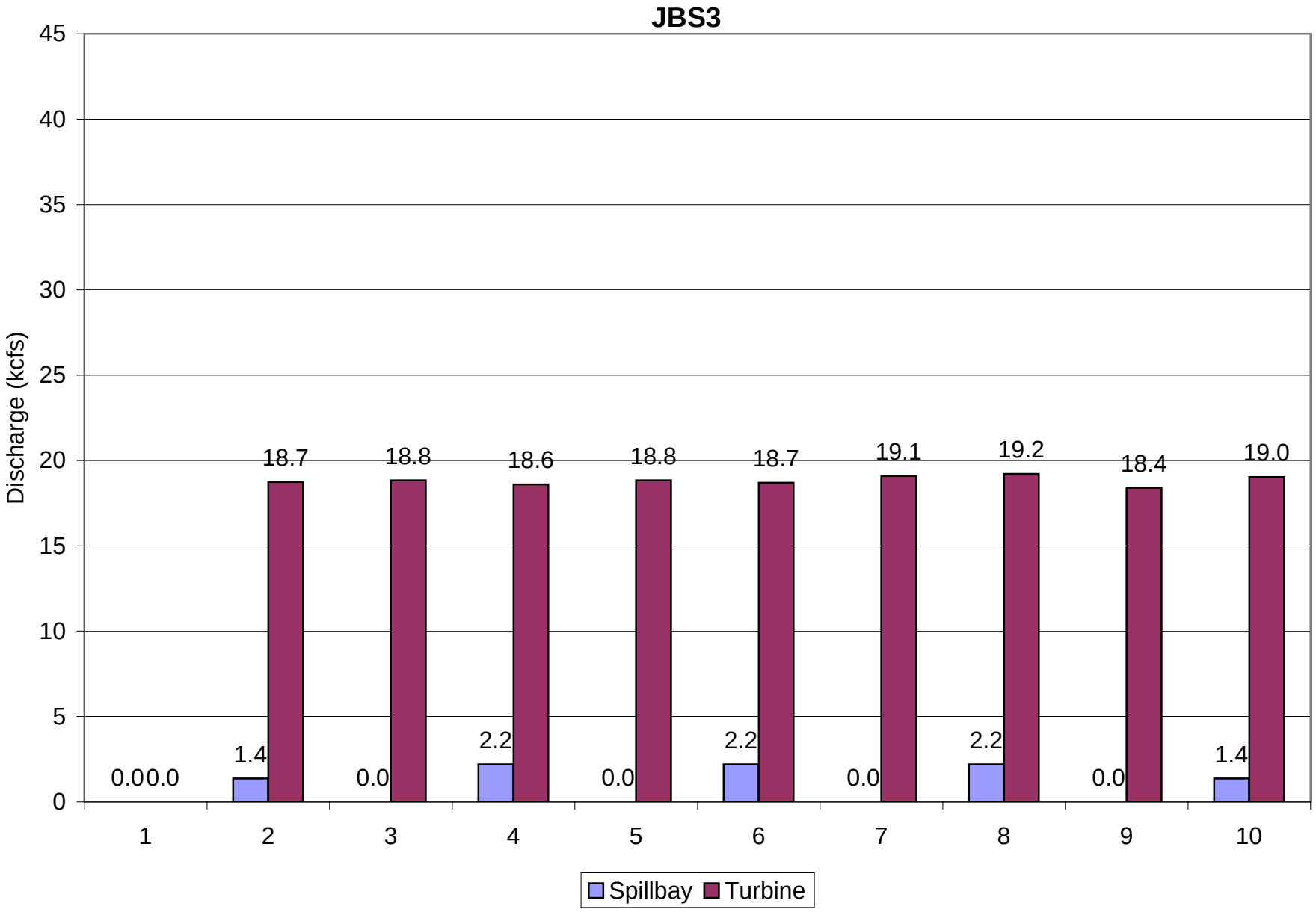

S17
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
3.1
19.0
2.9
19.5
3.9
17.6
3.9
19.6
3.9
19.6
3.1
19.2
3.9
19.8
3.1
19.5
3.1
18.7
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

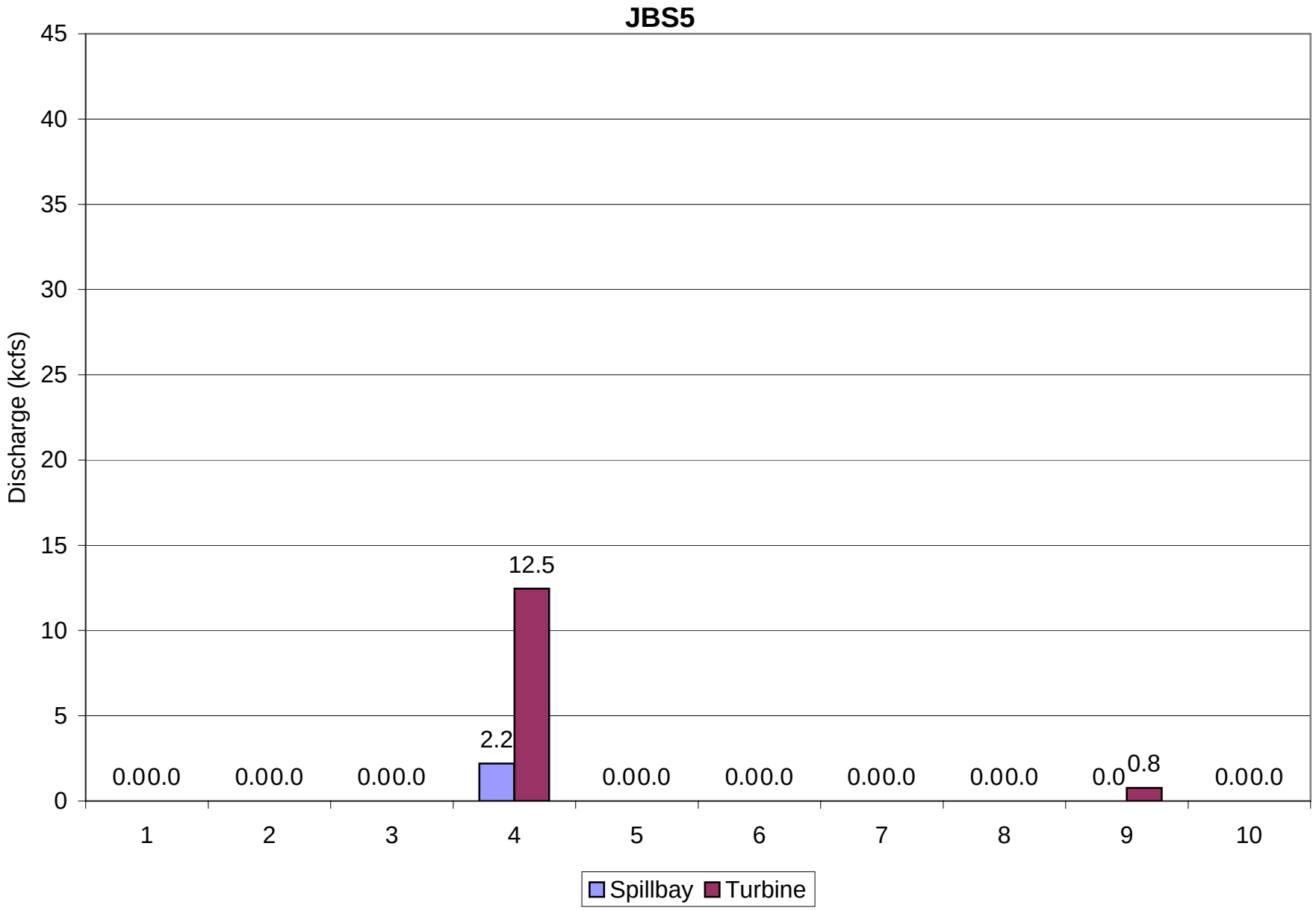

S18
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
3.1
14.8
9.9
15.0
6.0
15.0
8.2
14.9
6.0
14.8
7.0
15.1
6.0
15.1
9.7
14.7
3.1
15.1
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

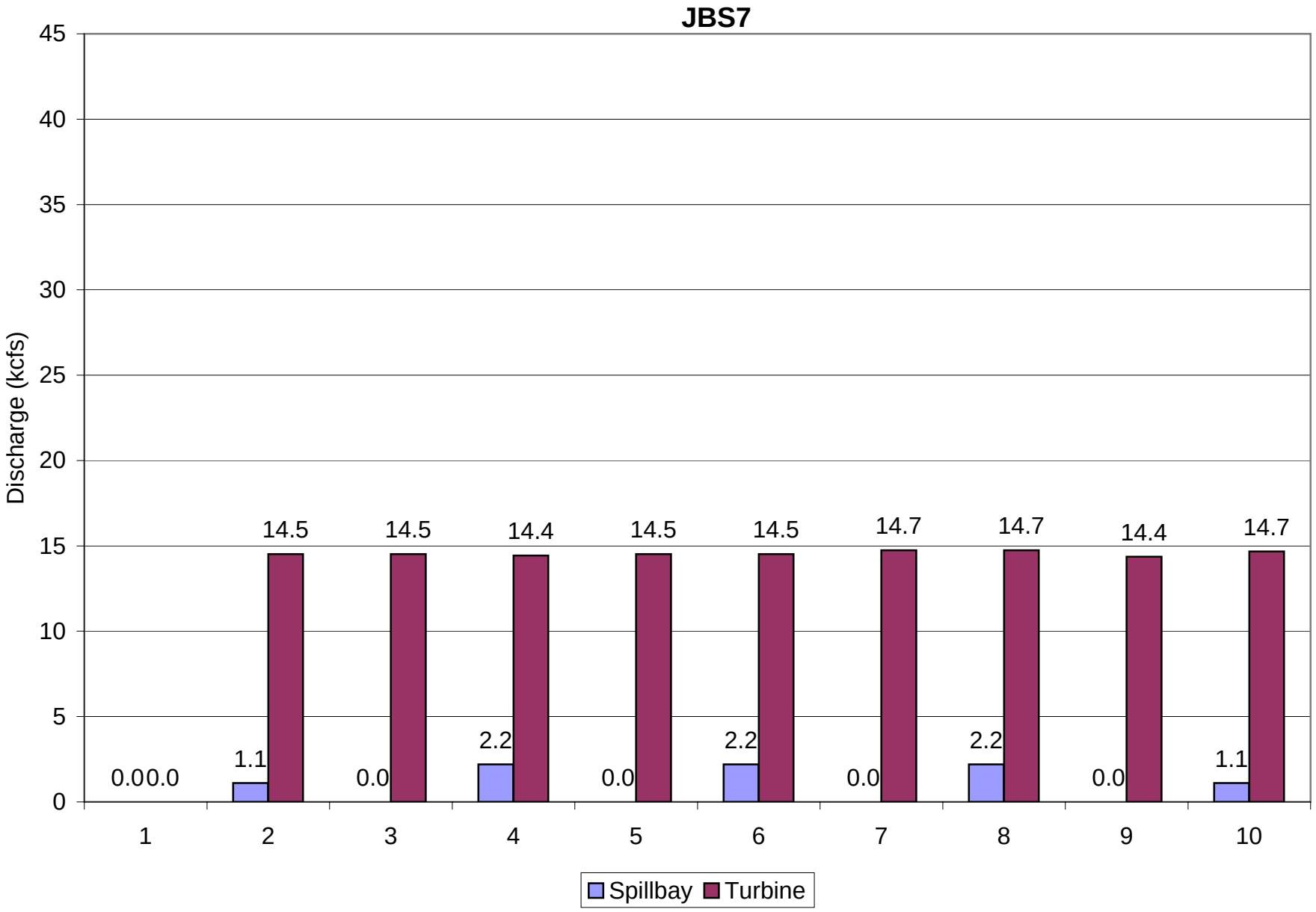

S20
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.00.0
3.1
15.2
3.1
15.3
3.1
15.0
2.2
15.3
3.1
15.1
2.1
15.3
3.1
15.3
3.1
15.0
3.1
15.4
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

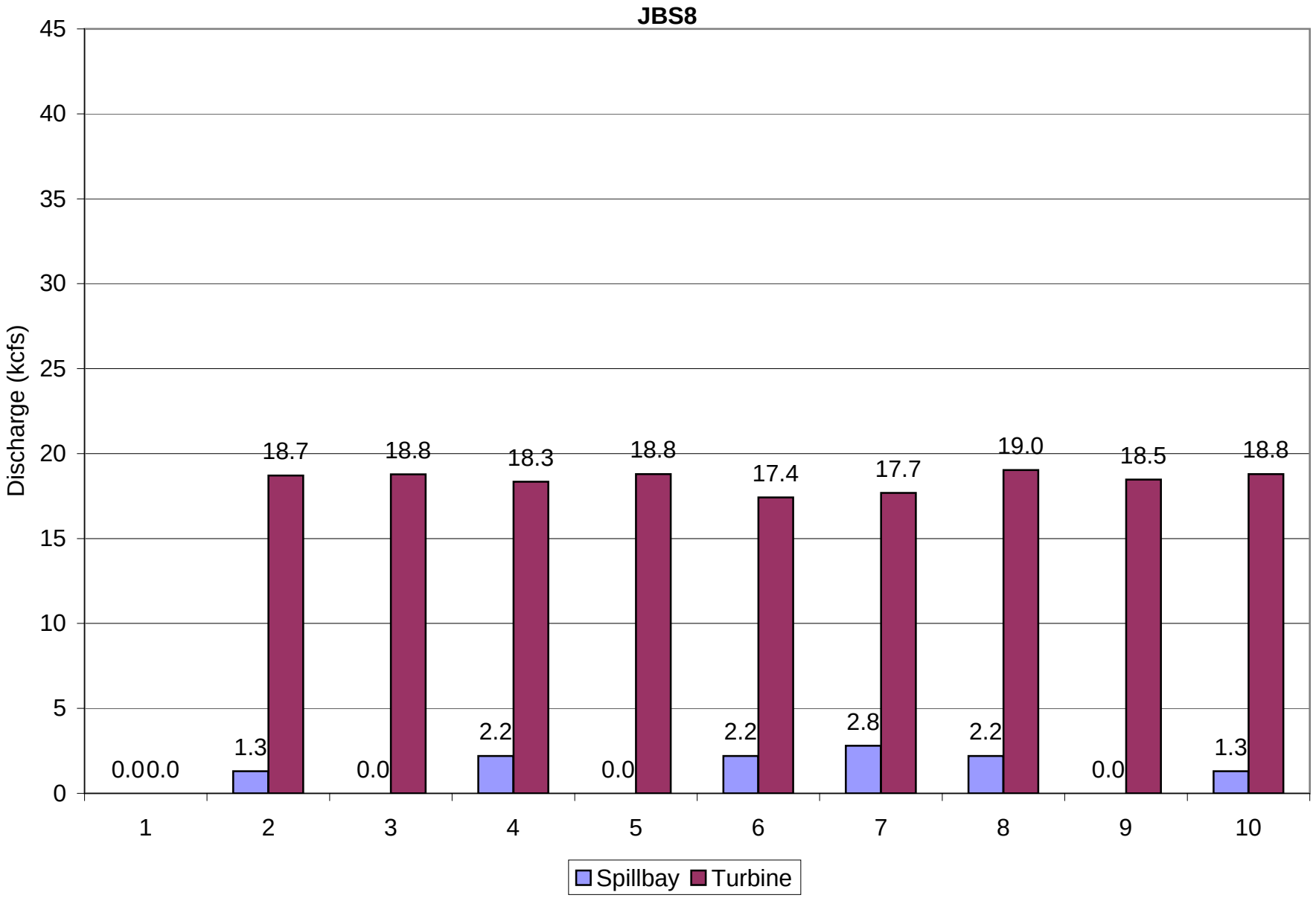

S46
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.6
14.7
5.4
14.7
5.2
14.4
5.4
14.7
5.2
14.7
5.4
14.8
5.2
14.8
5.4
14.4
1.6
14.7
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

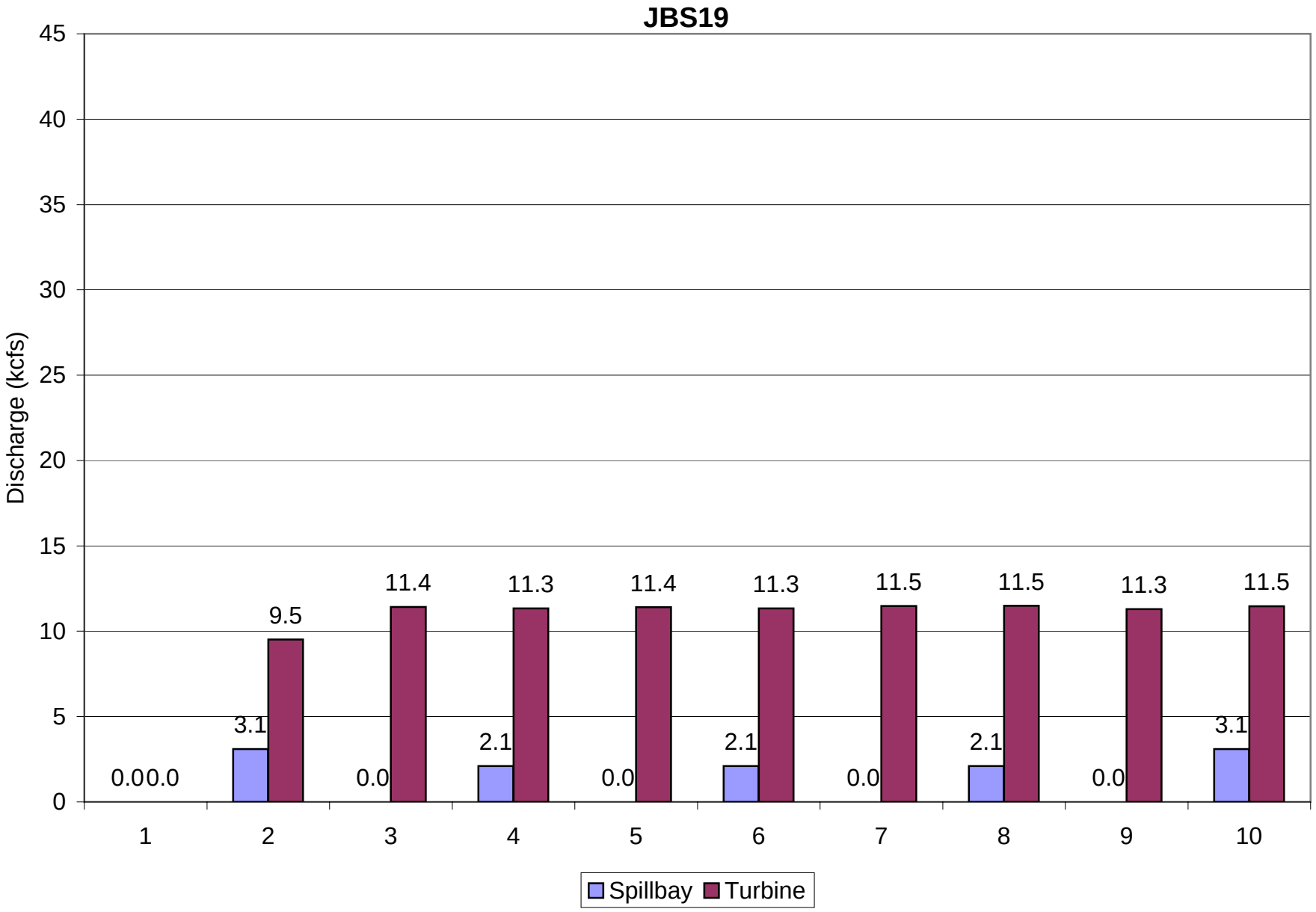

SP51
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.7
15.5
10.5
15.6
10.5
15.3
10.5
15.6
10.5
15.5
9.5
15.7
10.5
15.7
10.5
15.3
1.7
15.6
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

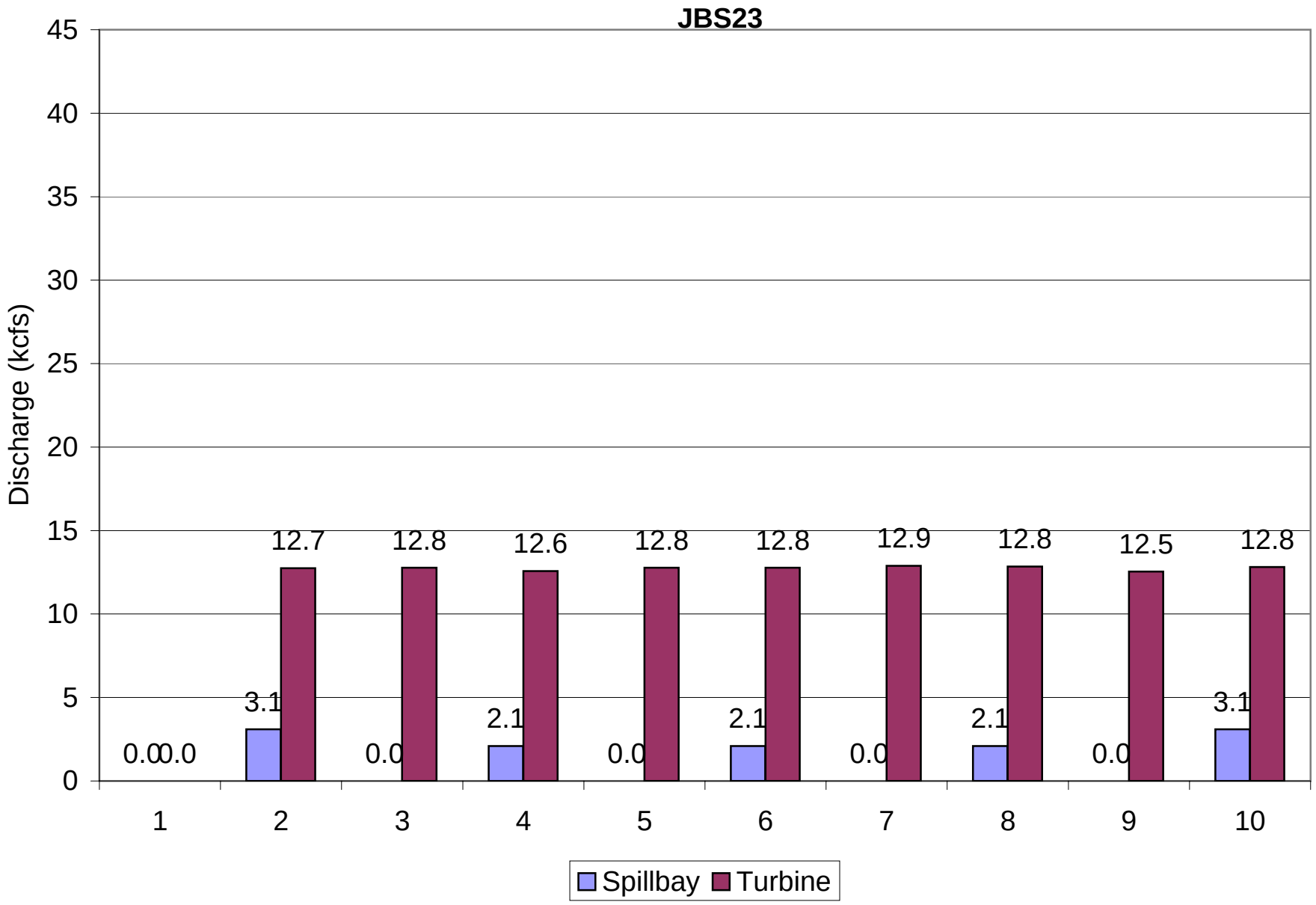

JBS3
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.4
18.7
0.0
18.8
2.2
18.6
0.0
18.8
2.2
18.7
0.0
19.1
2.2
19.2
0.0
18.4
1.4
19.0
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

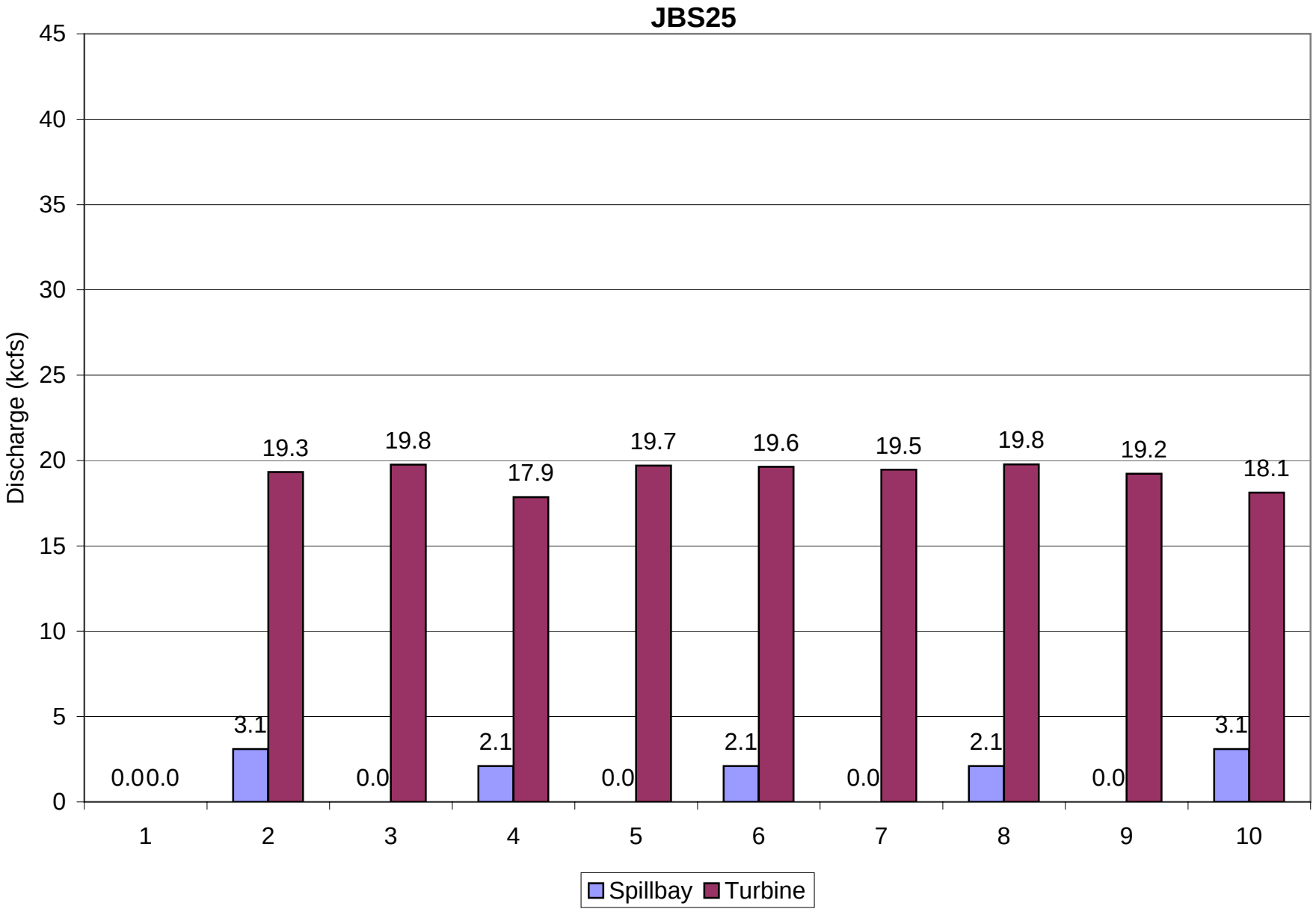

JBS5
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.00.0
0.00.0
0.00.0
2.2
12.5
0.00.0
0.00.0
0.00.0
0.00.0
0.0
0.8
0.00.0
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

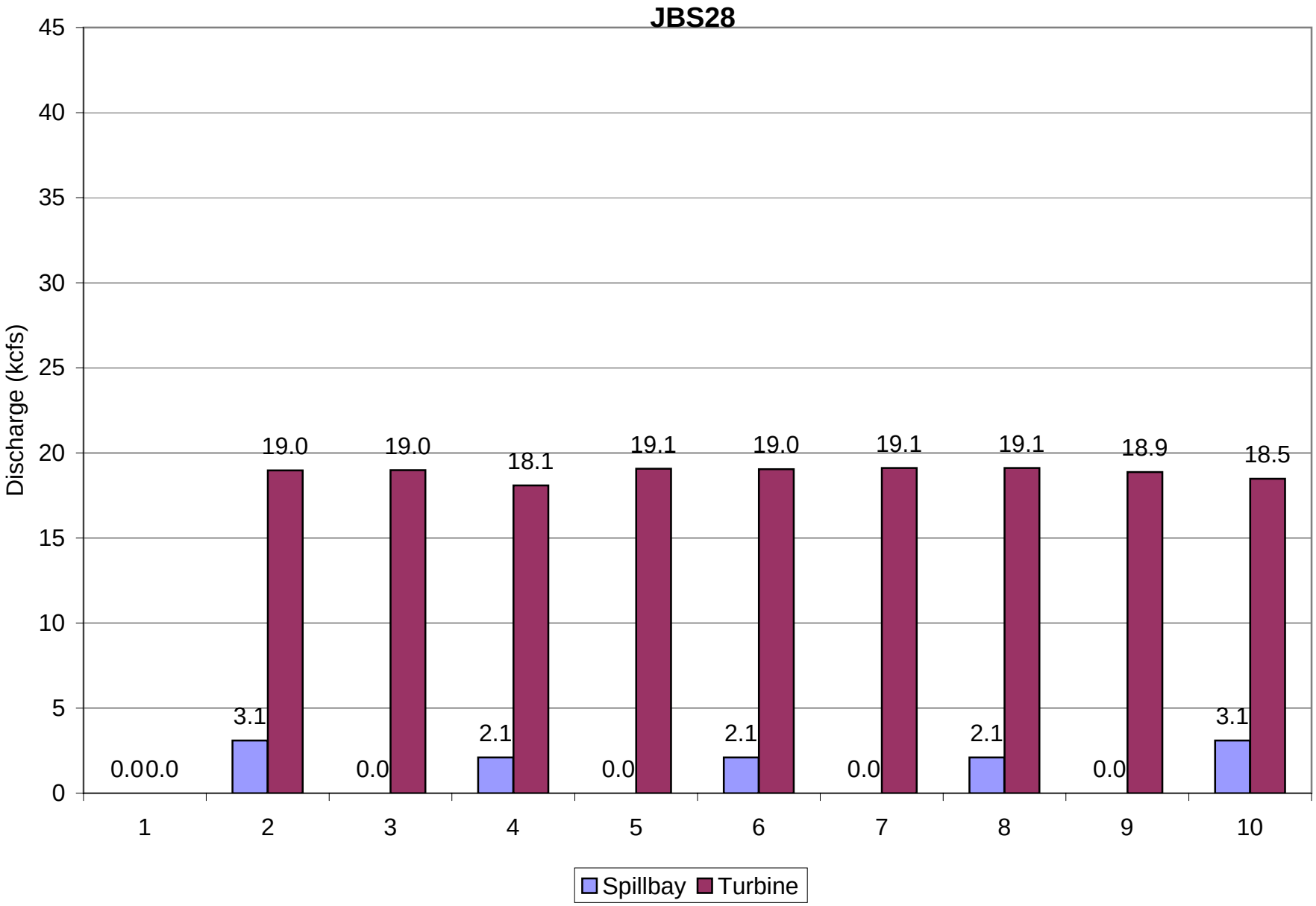

JBS7
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.00.0
1.1
14.5
0.0
14.5
2.2
14.4
0.0
14.5
2.2
14.5
0.0
14.7
2.2
14.7
0.0
14.4
1.1
14.7
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

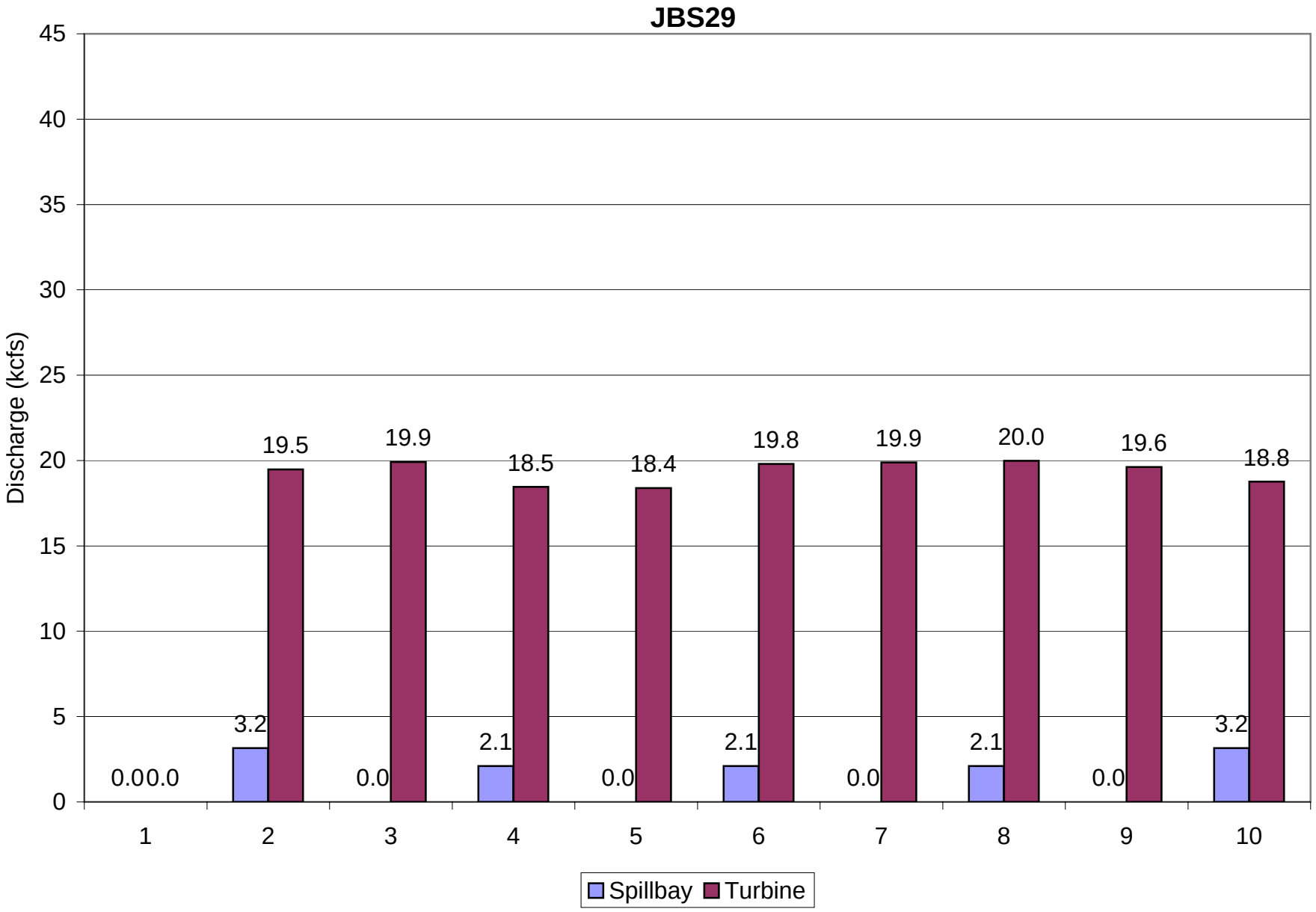

JBS8
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.3
18.7
0.0
18.8
2.2
18.3
0.0
18.8
2.2
17.4
2.8
17.7
2.2
19.0
0.0
18.5
1.3
18.8
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

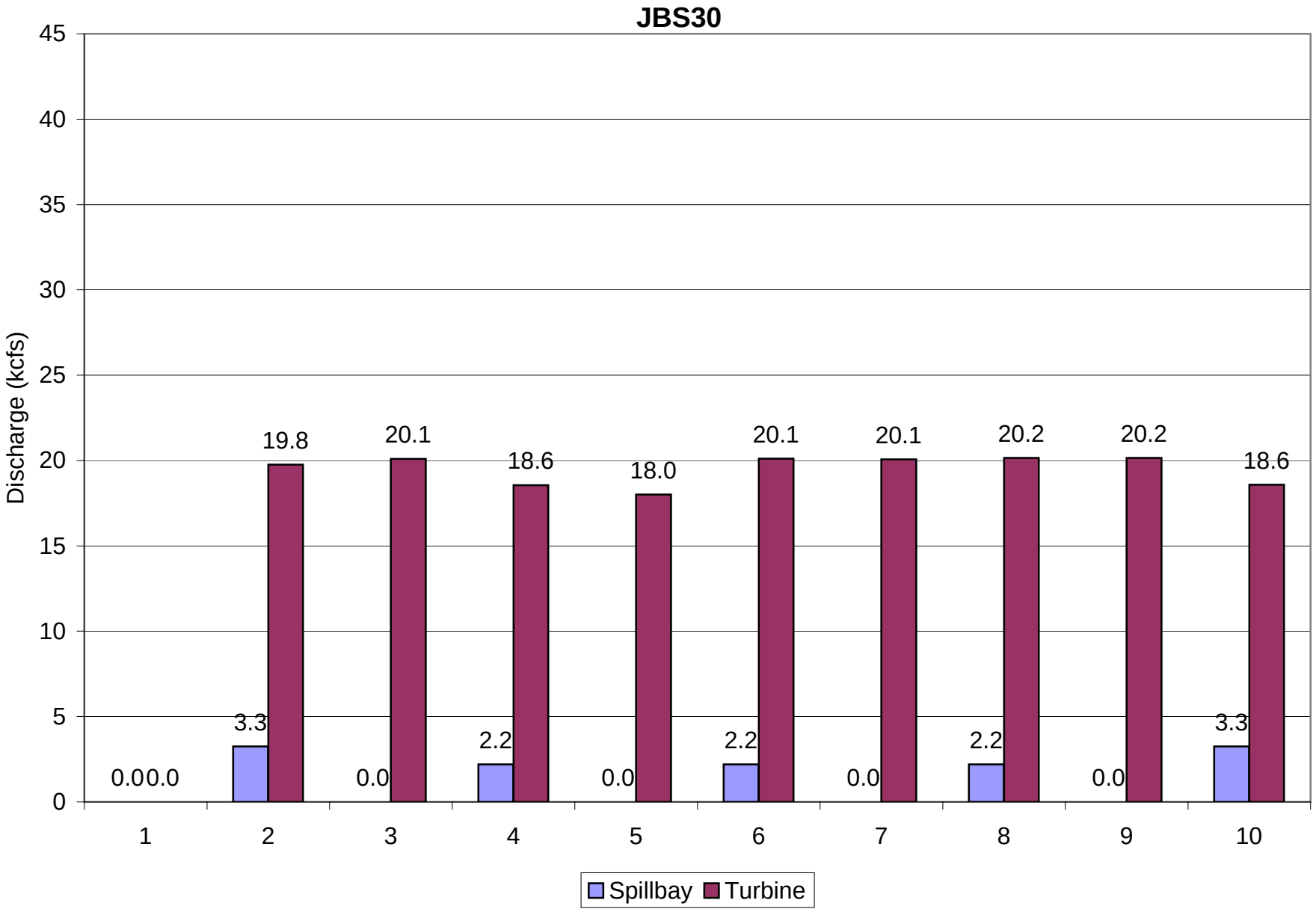

JBS19
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
3.1
9.5
0.0
11.4
2.1
11.3
0.0
11.4
2.1
11.3
0.0
11.5
2.1
11.5
0.0
11.3
3.1
11.5
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

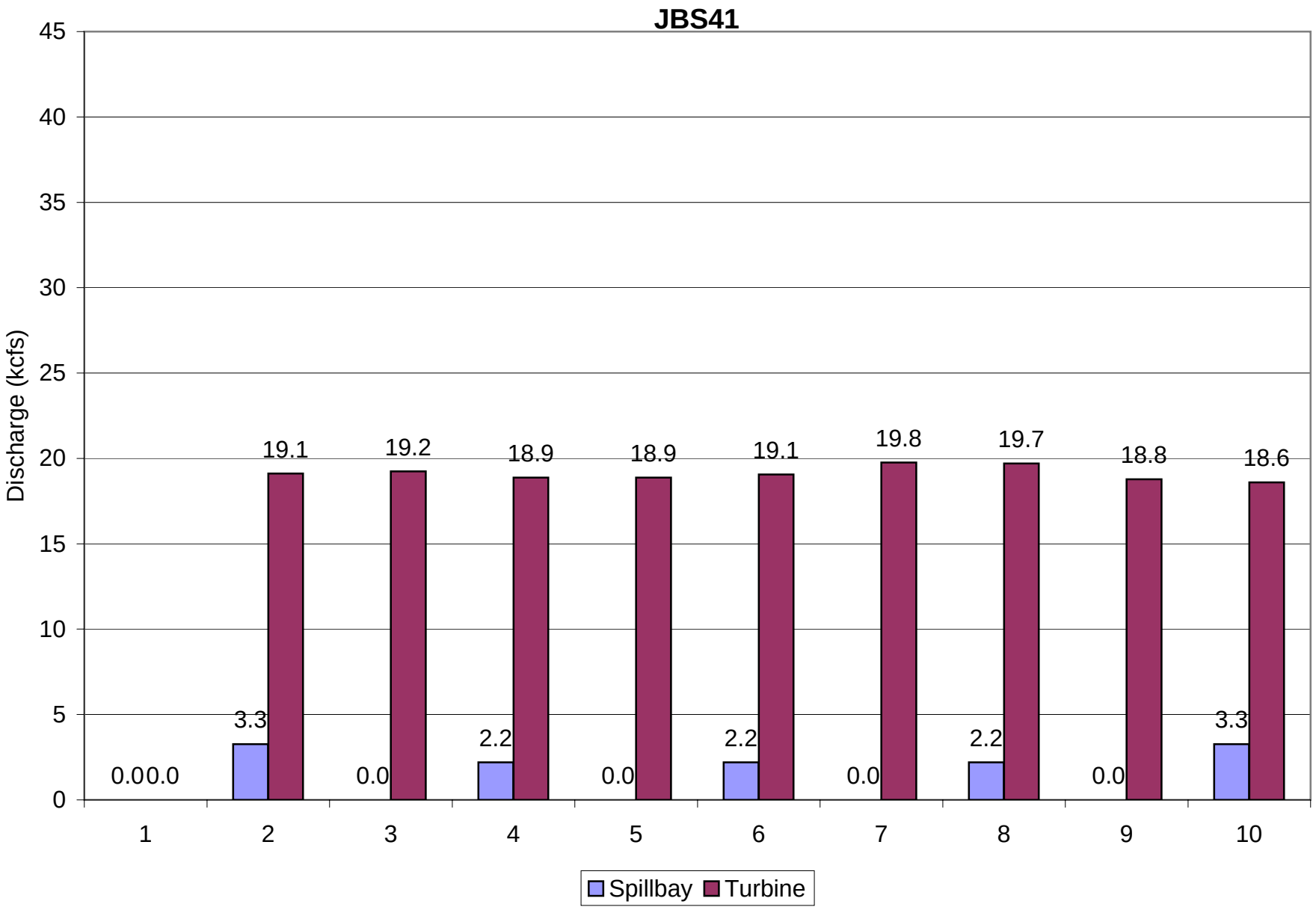

JBS23
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
0.0
0.0
3.1
12.7
0.0
12.8
2.1
12.6
0.0
12.8
2.1
12.8
0.0
12.9
2.1
12.8
0.0
12.5
3.1
12.8
Spillbay
Turbine

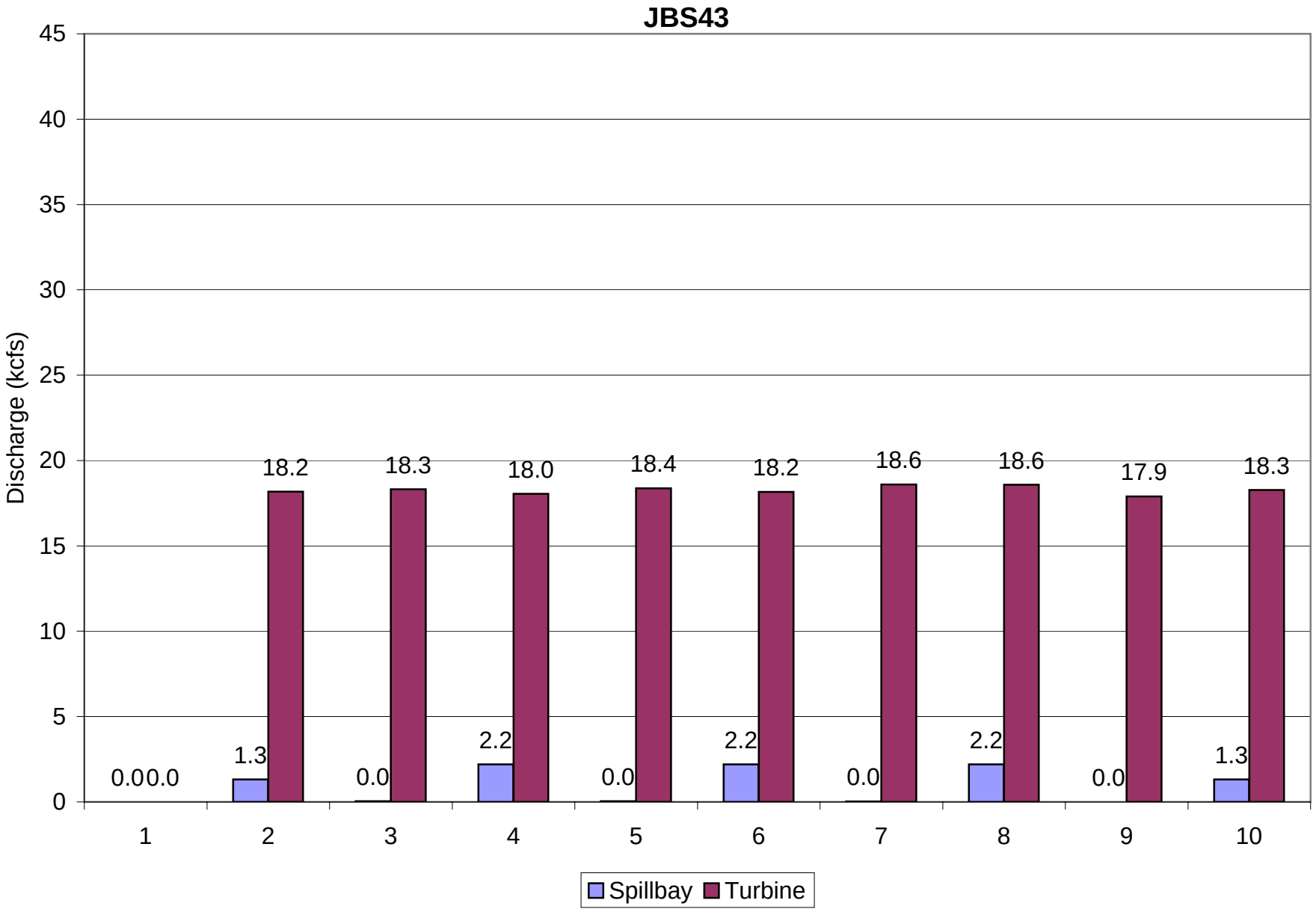

JBS25
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.00.0
3.1
19.3
0.0
19.8
2.1
17.9
0.0
19.7
2.1
19.6
0.0
19.5
2.1
19.8
0.0
19.2
3.1
18.1
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

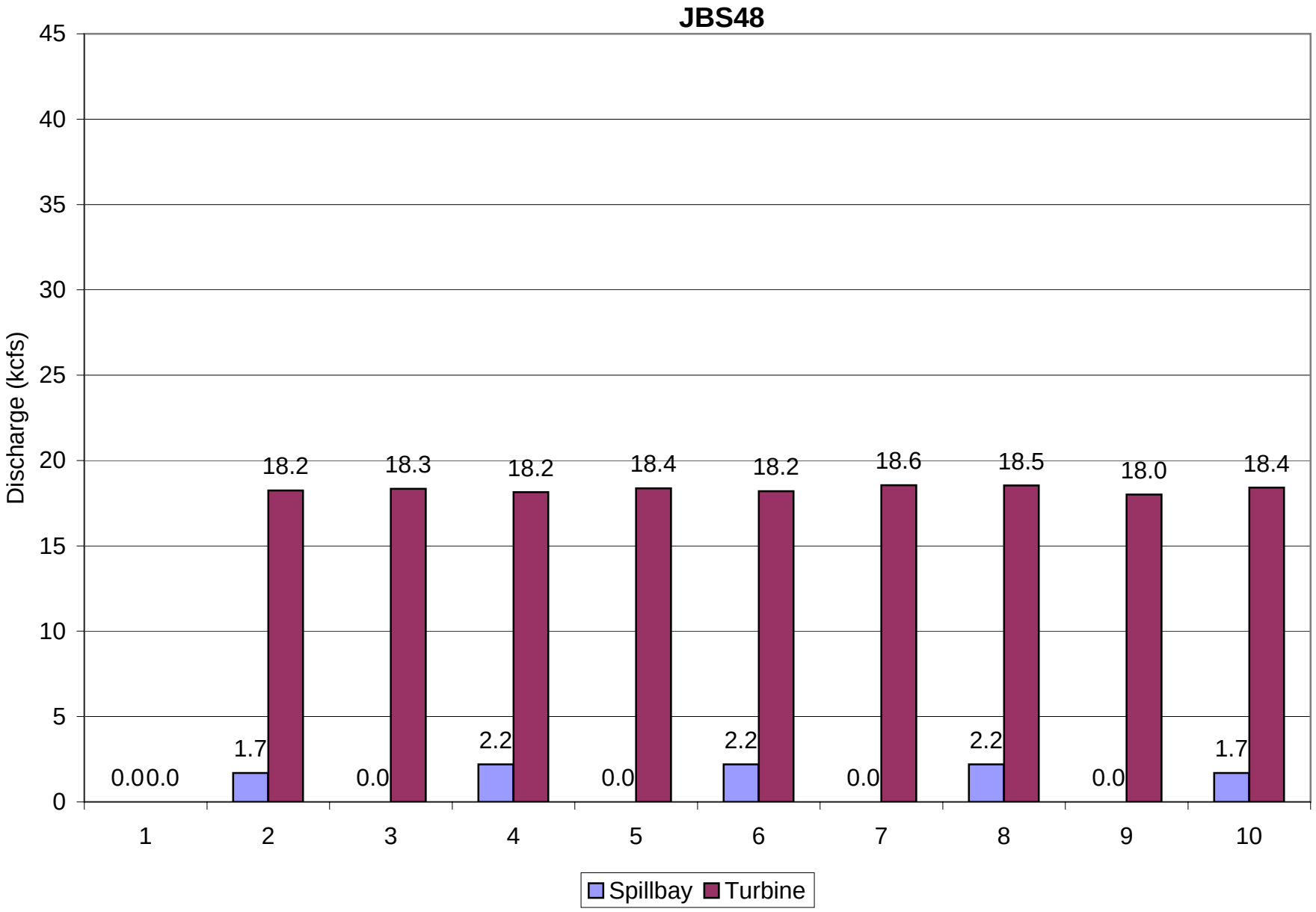

JBS28
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.00.0
3.1
19.0
0.0
19.0
2.1
18.1
0.0
19.1
2.1
19.0
0.0
19.1
2.1
19.1
0.0
18.9
3.1
18.5
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

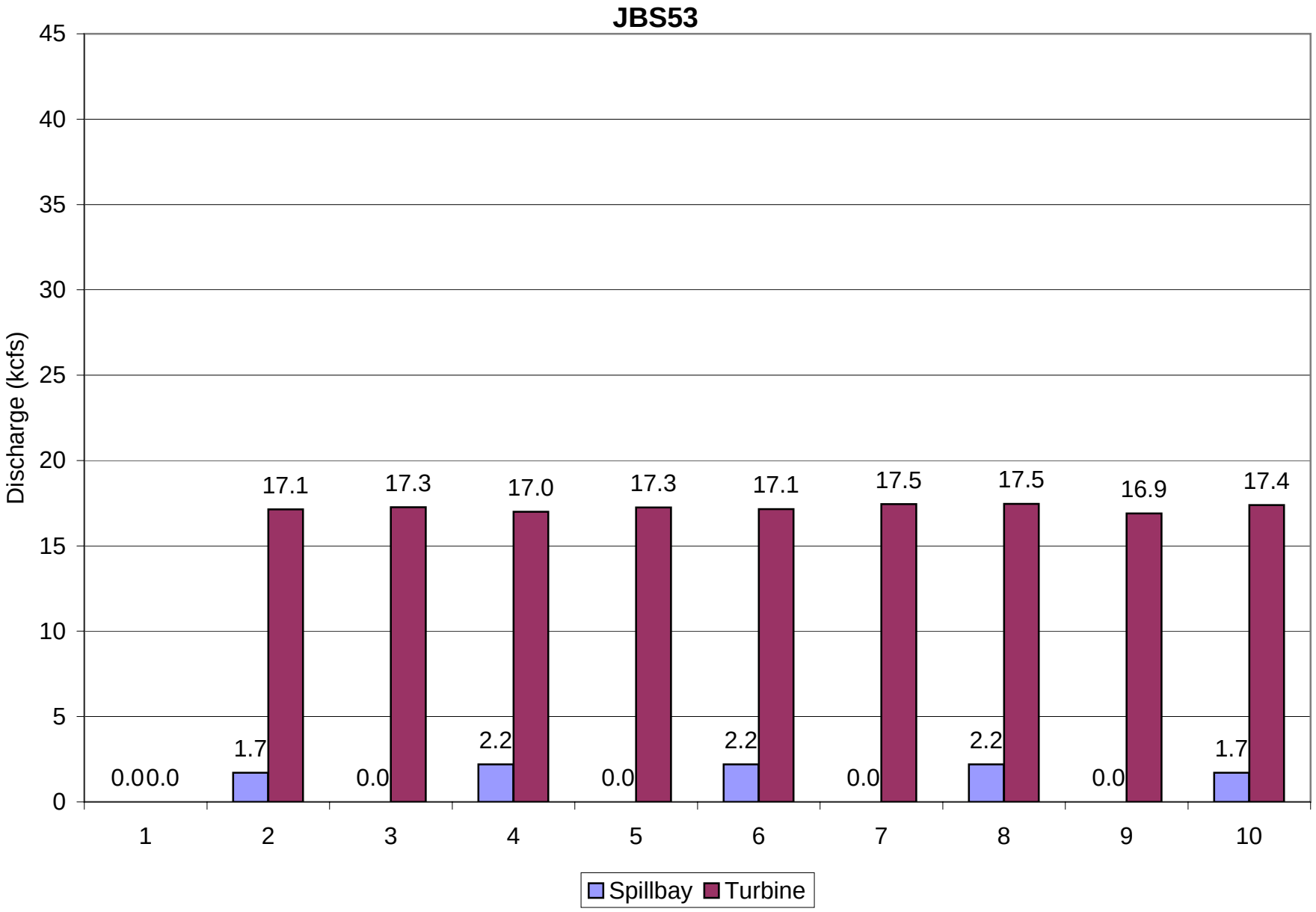

JBS29
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
3.2
19.5
0.0
19.9
2.1
18.5
0.0
18.4
2.1
19.8
0.0
19.9
2.1
20.0
0.0
19.6
3.2
18.8
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

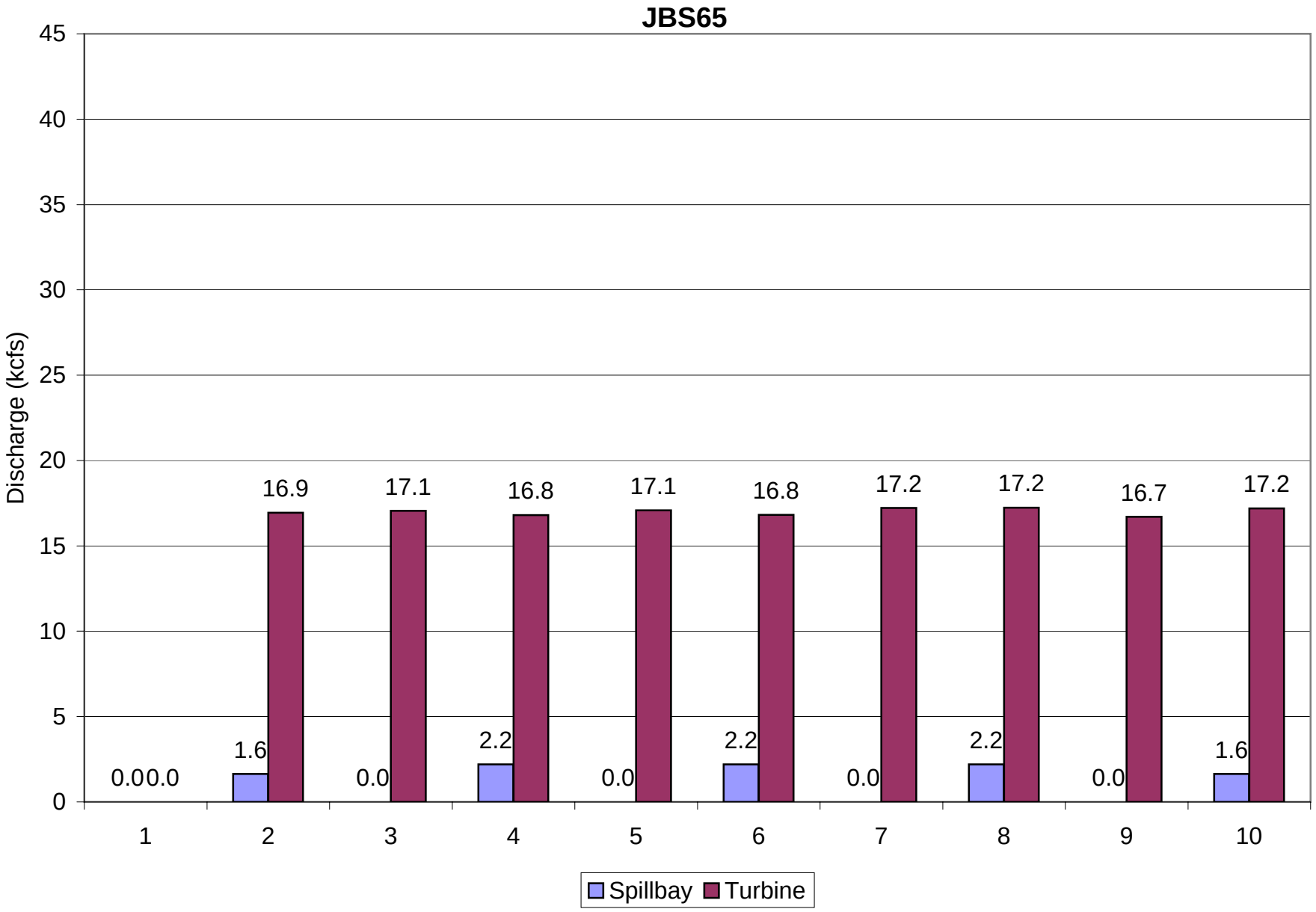

JBS30
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.00.0
3.3
19.8
0.0
20.1
2.2
18.6
0.0
18.0
2.2
20.1
0.0
20.1
2.2
20.2
0.0
20.2
3.3
18.6
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

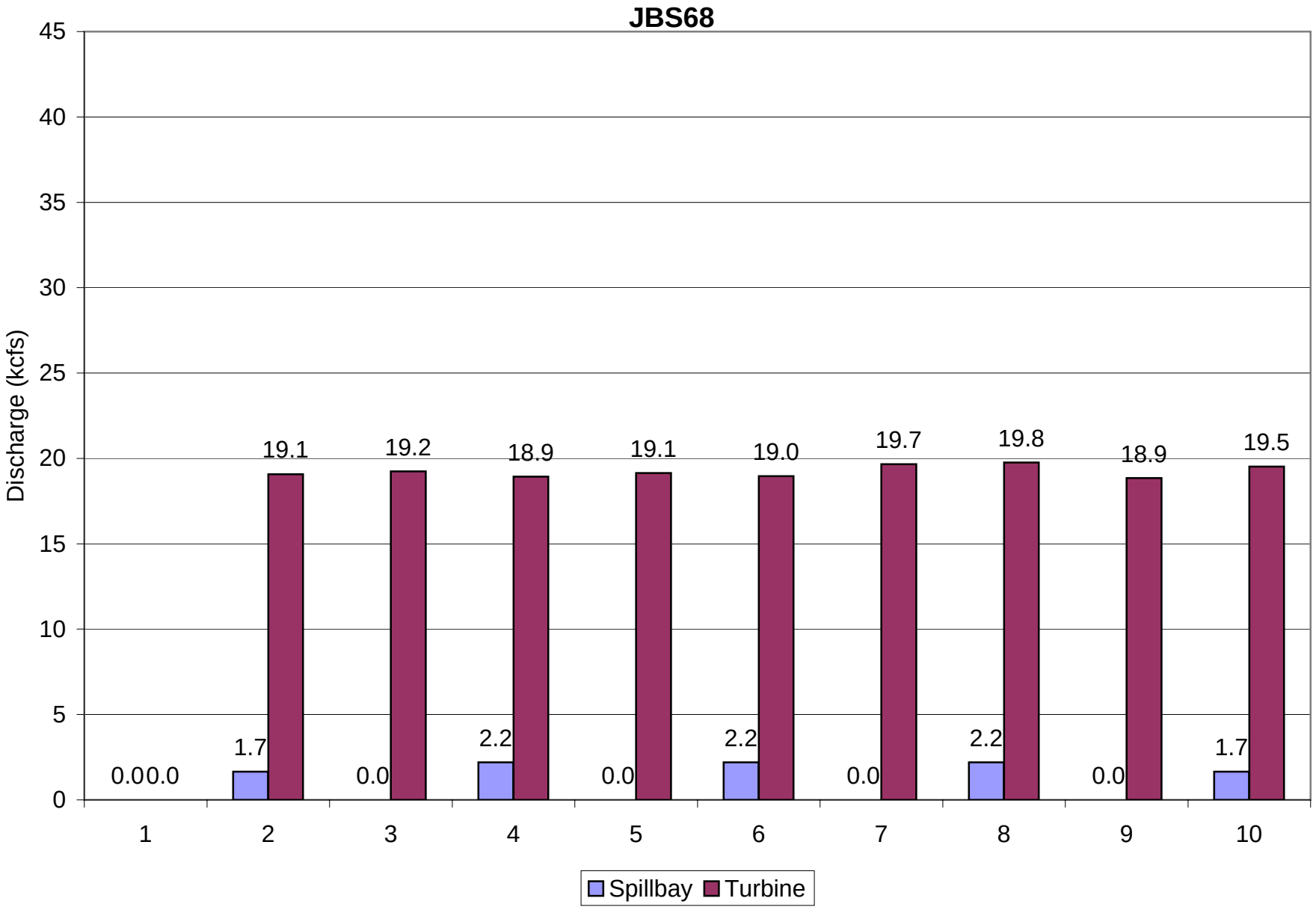

JBS41
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
3.3
19.1
0.0
19.2
2.2
18.9
0.0
18.9
2.2
19.1
0.0
19.8
2.2
19.7
0.0
18.8
3.3
18.6
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

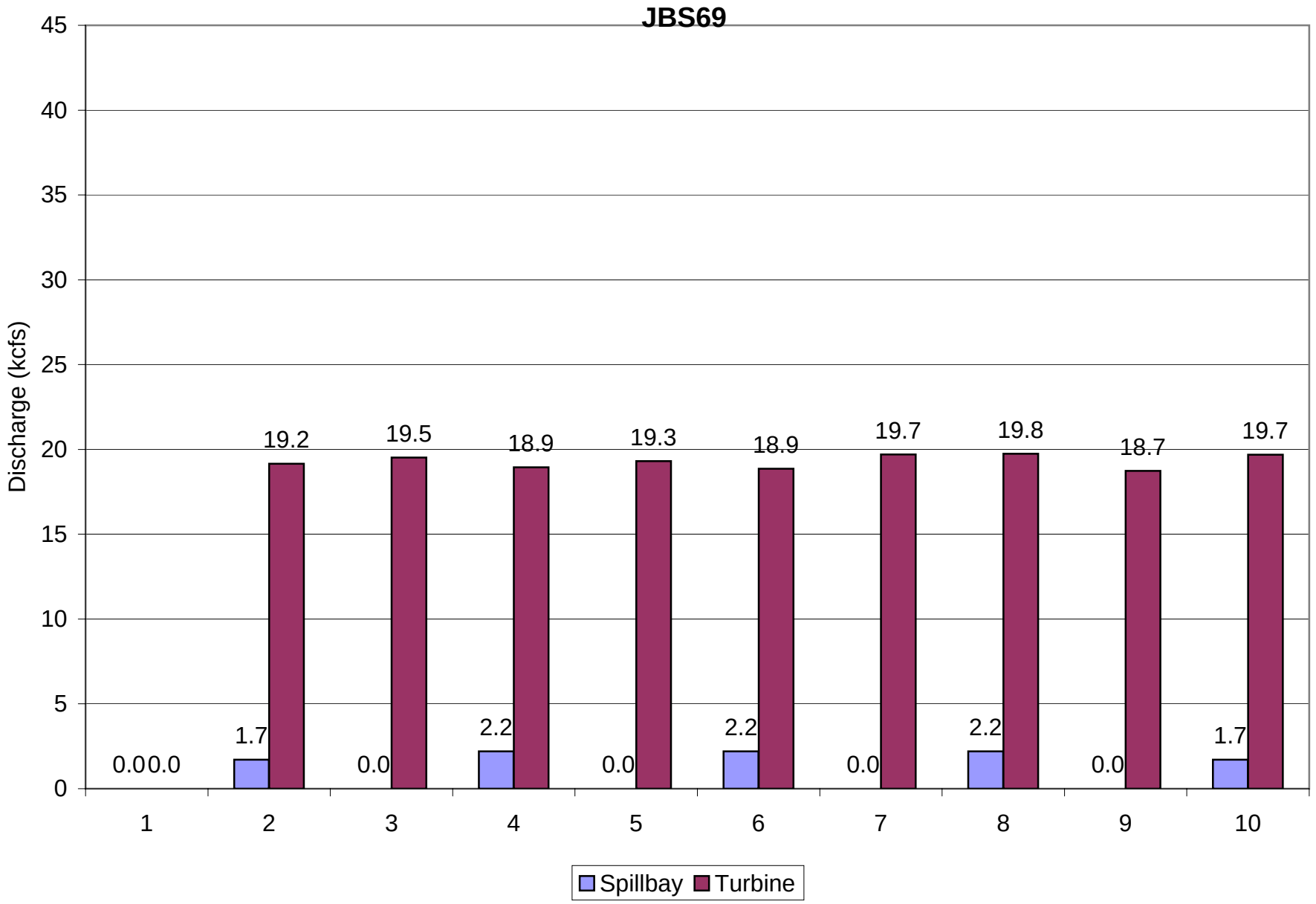

JBS43
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.00.0
1.3
18.2
0.0
18.3
2.2
18.0
0.0
18.4
2.2
18.2
0.0
18.6
2.2
18.6
0.0
17.9
1.3
18.3
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

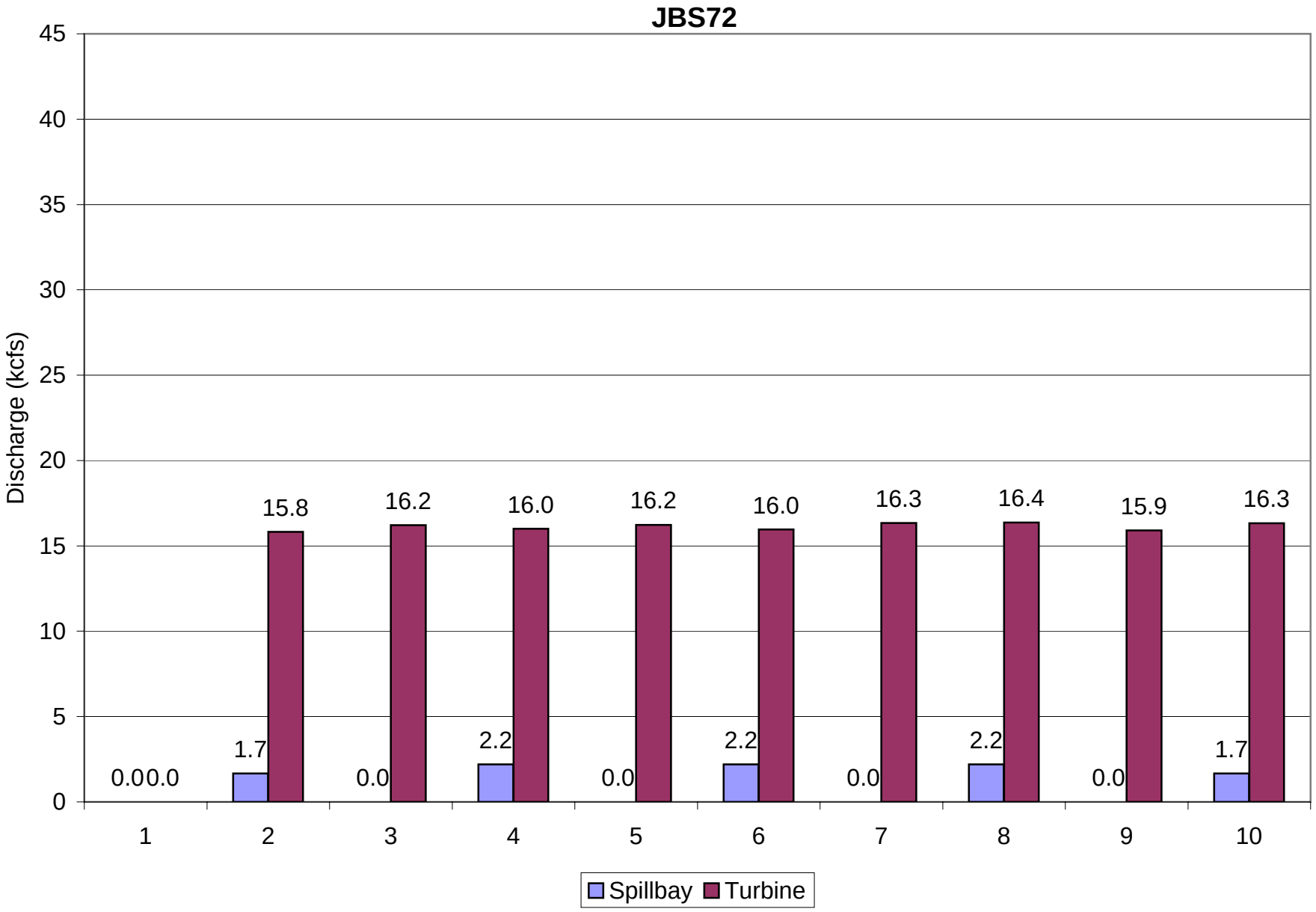

JBS48
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.00.0
1.7
18.2
0.0
18.3
2.2
18.2
0.0
18.4
2.2
18.2
0.0
18.6
2.2
18.5
0.0
18.0
1.7
18.4
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

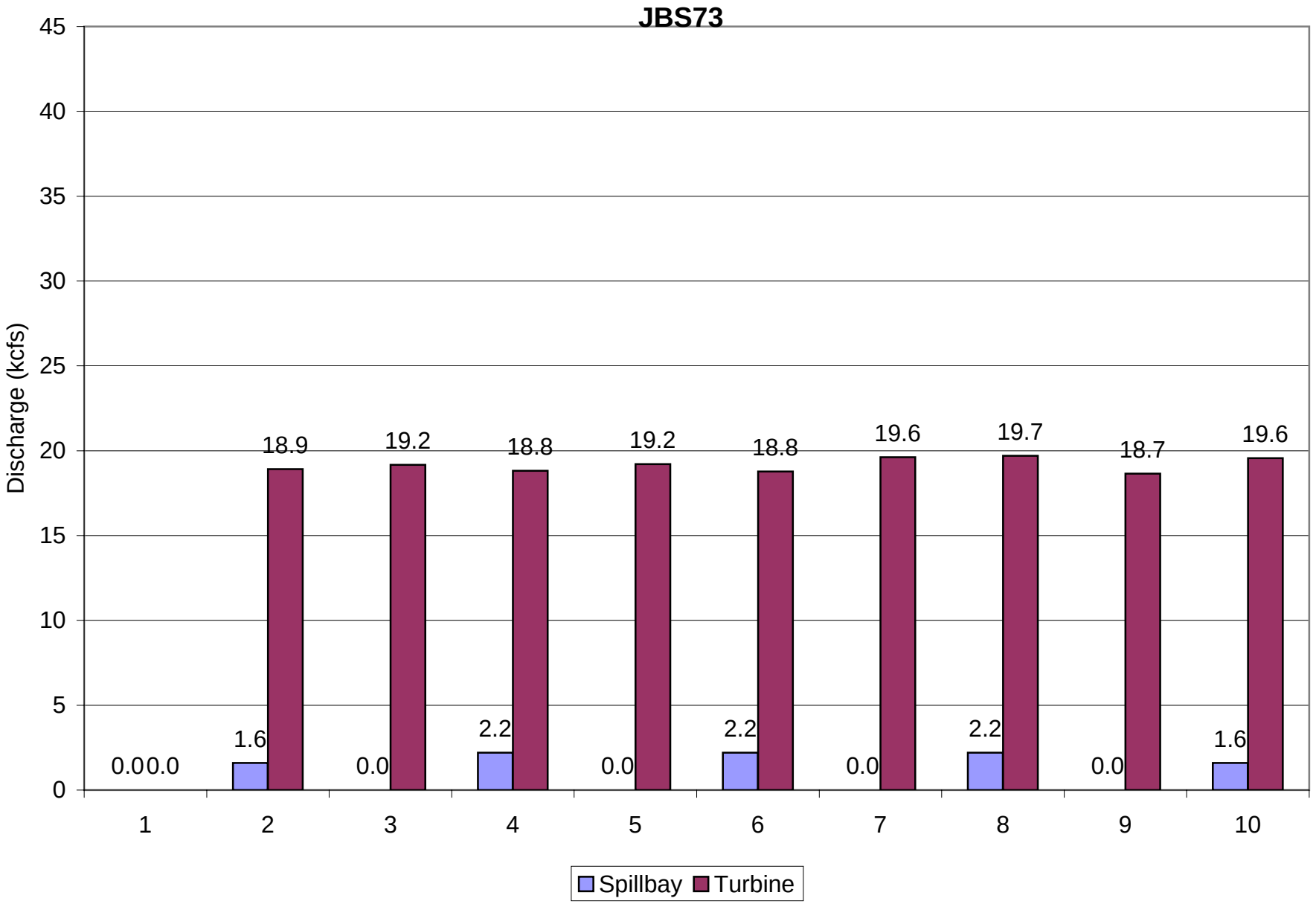

JBS53
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.7
17.1
0.0
17.3
2.2
17.0
0.0
17.3
2.2
17.1
0.0
17.5
2.2
17.5
0.0
16.9
1.7
17.4
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

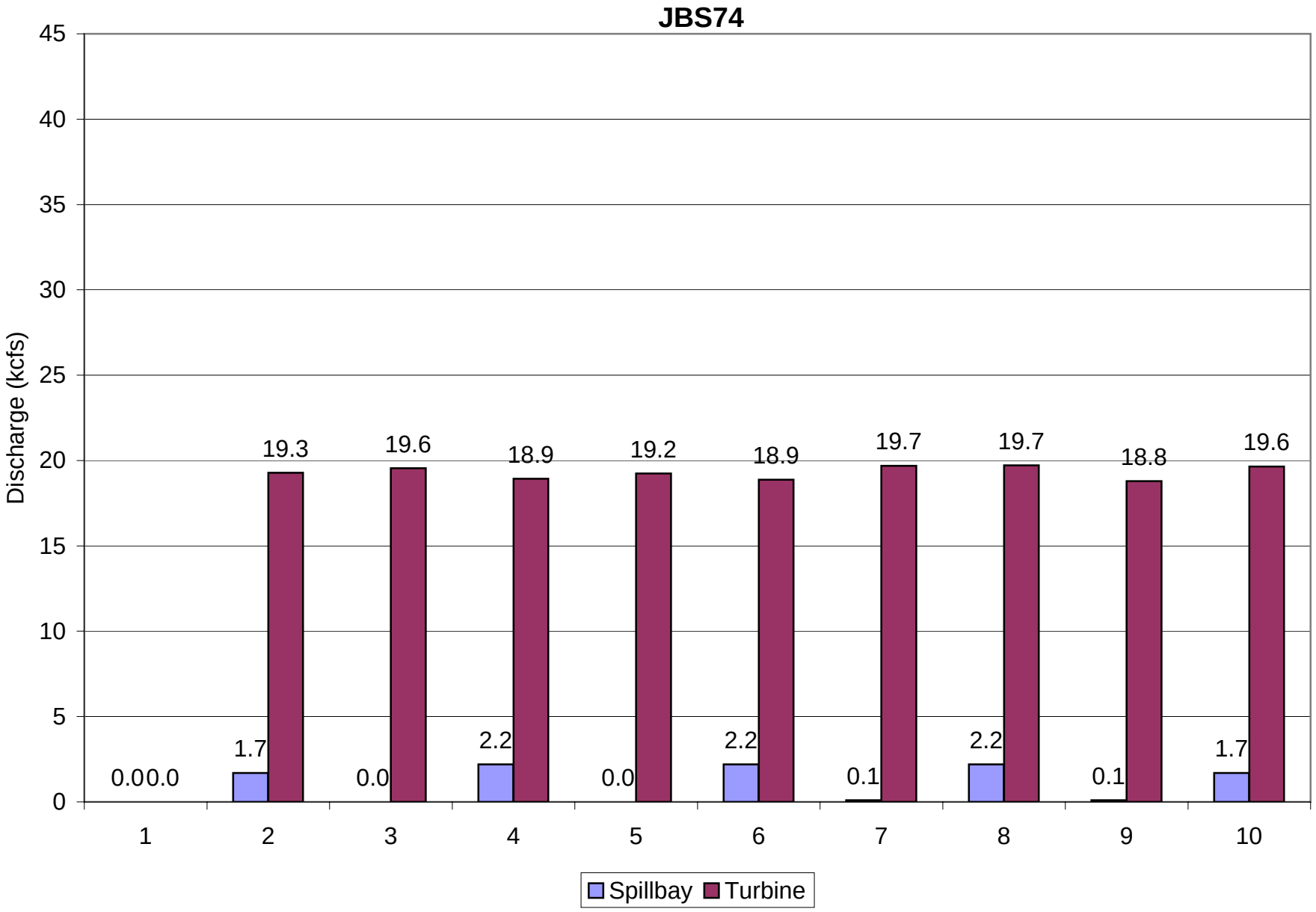

JBS65
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.6
16.9
0.0
17.1
2.2
16.8
0.0
17.1
2.2
16.8
0.0
17.2
2.2
17.2
0.0
16.7
1.6
17.2
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

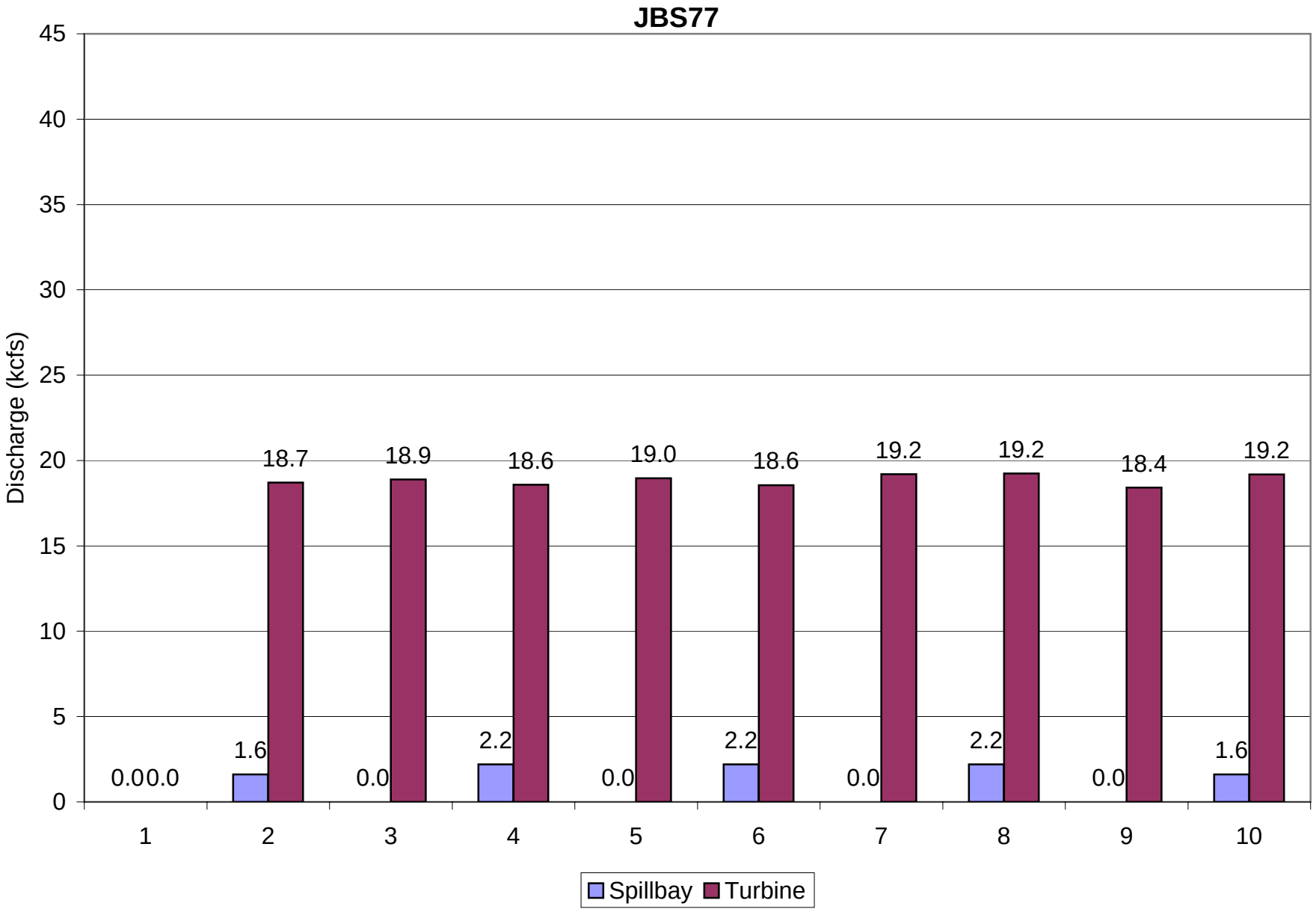

JBS68
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.00.0
1.7
19.1
0.0
19.2
2.2
18.9
0.0
19.1
2.2
19.0
0.0
19.7
2.2
19.8
0.0
18.9
1.7
19.5
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

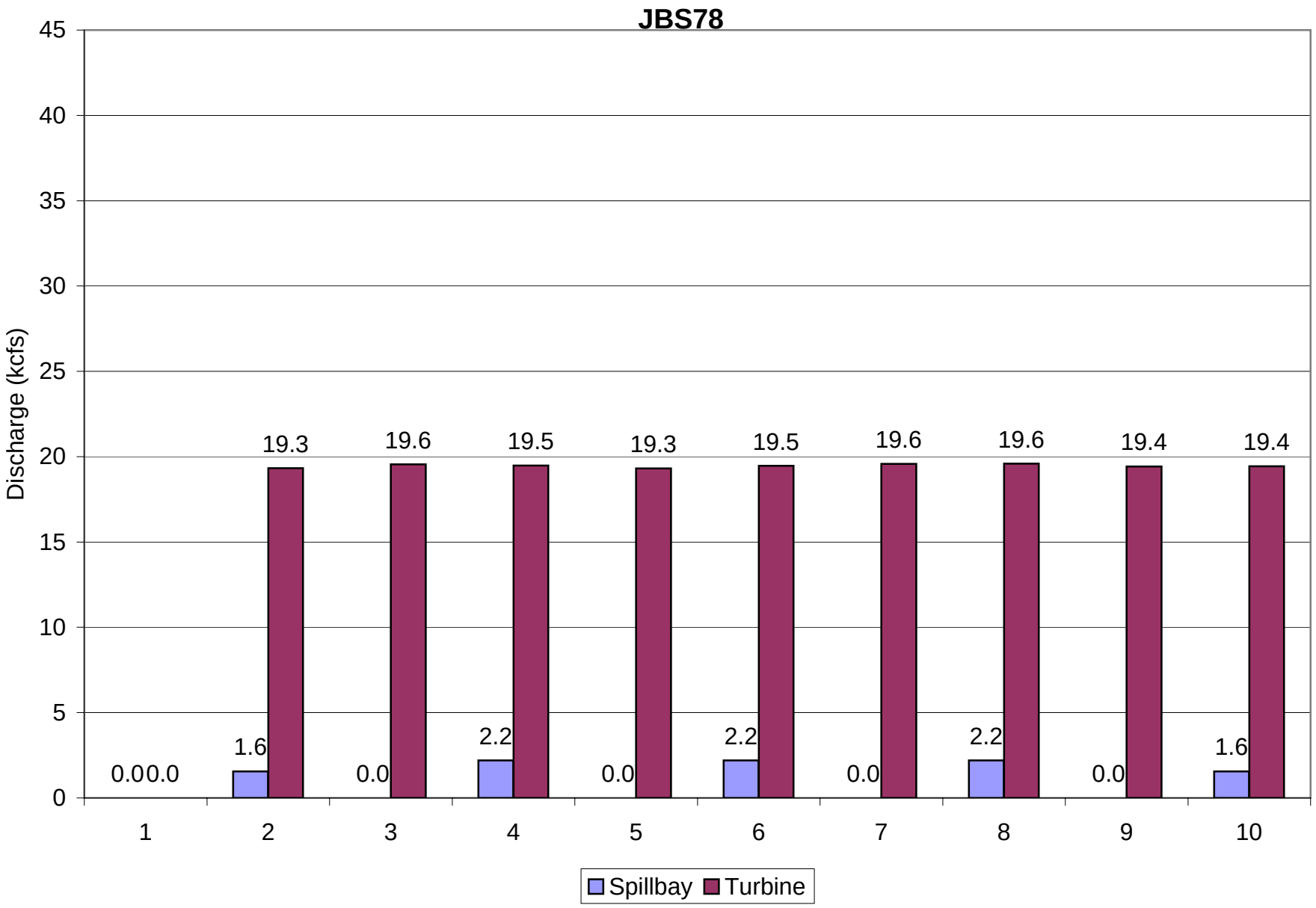

JBS69
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.7
19.2
0.0
19.5
2.2
18.9
0.0
19.3
2.2
18.9
0.0
19.7
2.2
19.8
0.0
18.7
1.7
19.7
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

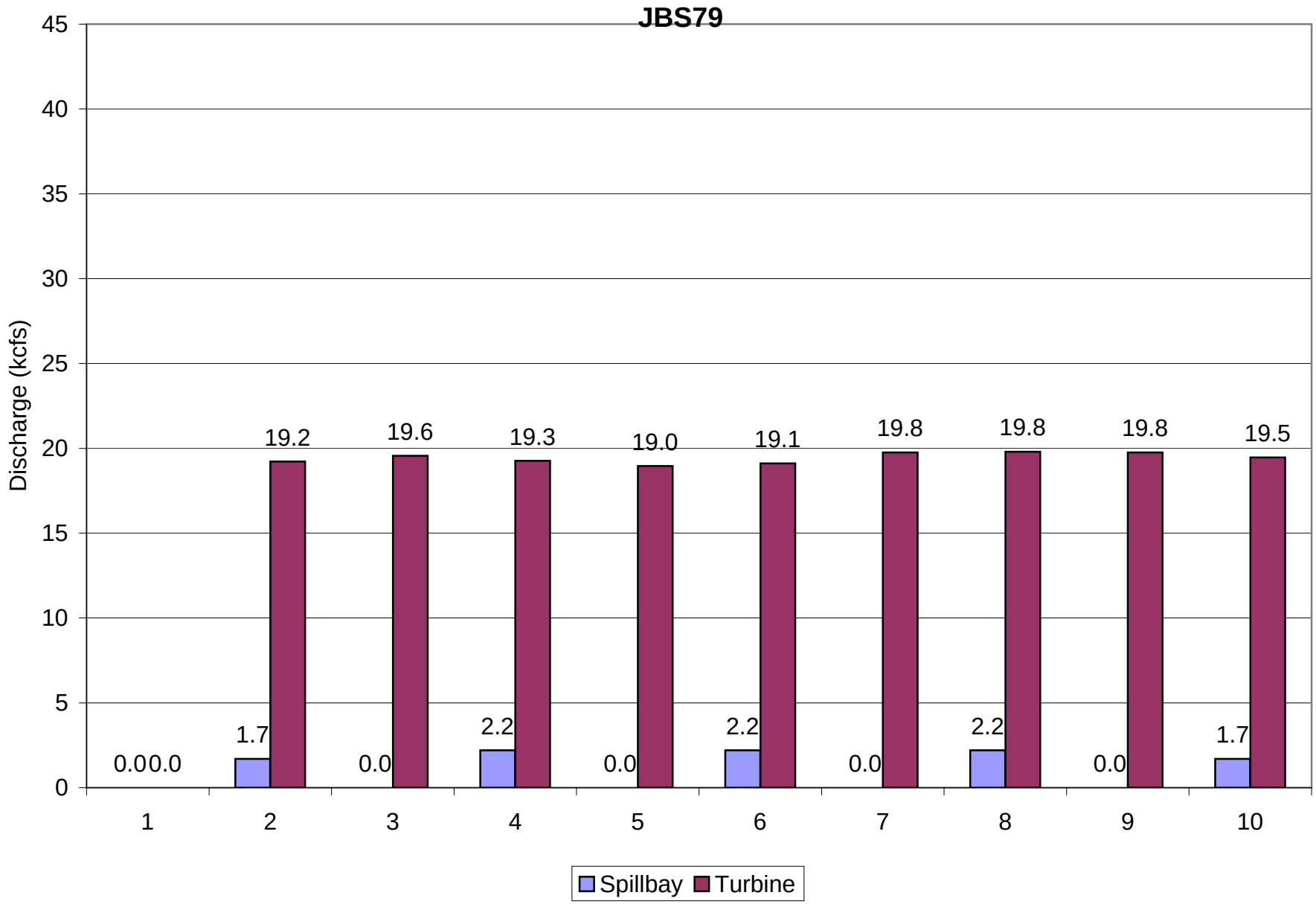

JBS72
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.00.0
1.7
15.8
0.0
16.2
2.2
16.0
0.0
16.2
2.2
16.0
0.0
16.3
2.2
16.4
0.0
15.9
1.7
16.3
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

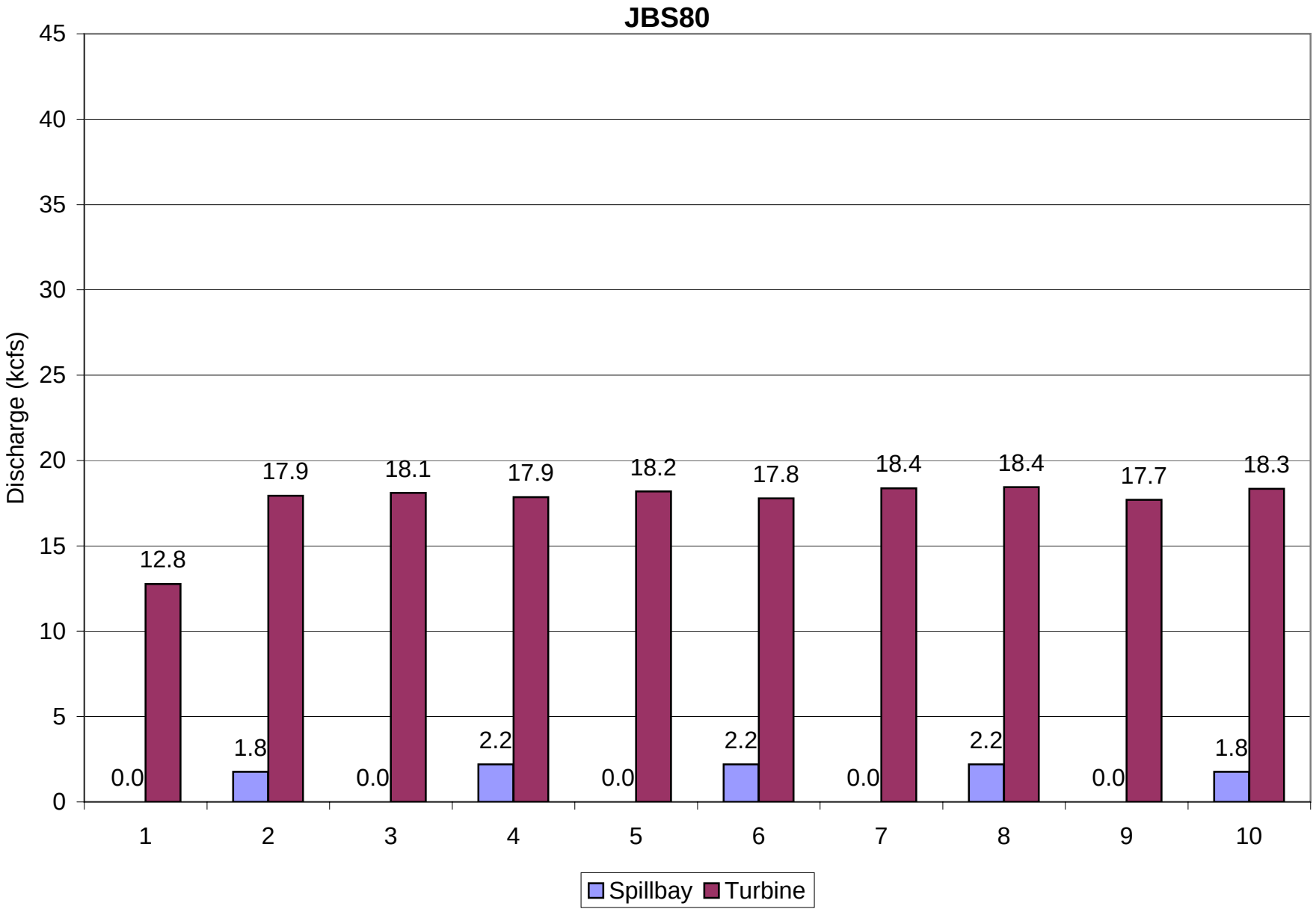

JBS73
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.6
18.9
0.0
19.2
2.2
18.8
0.0
19.2
2.2
18.8
0.0
19.6
2.2
19.7
0.0
18.7
1.6
19.6
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

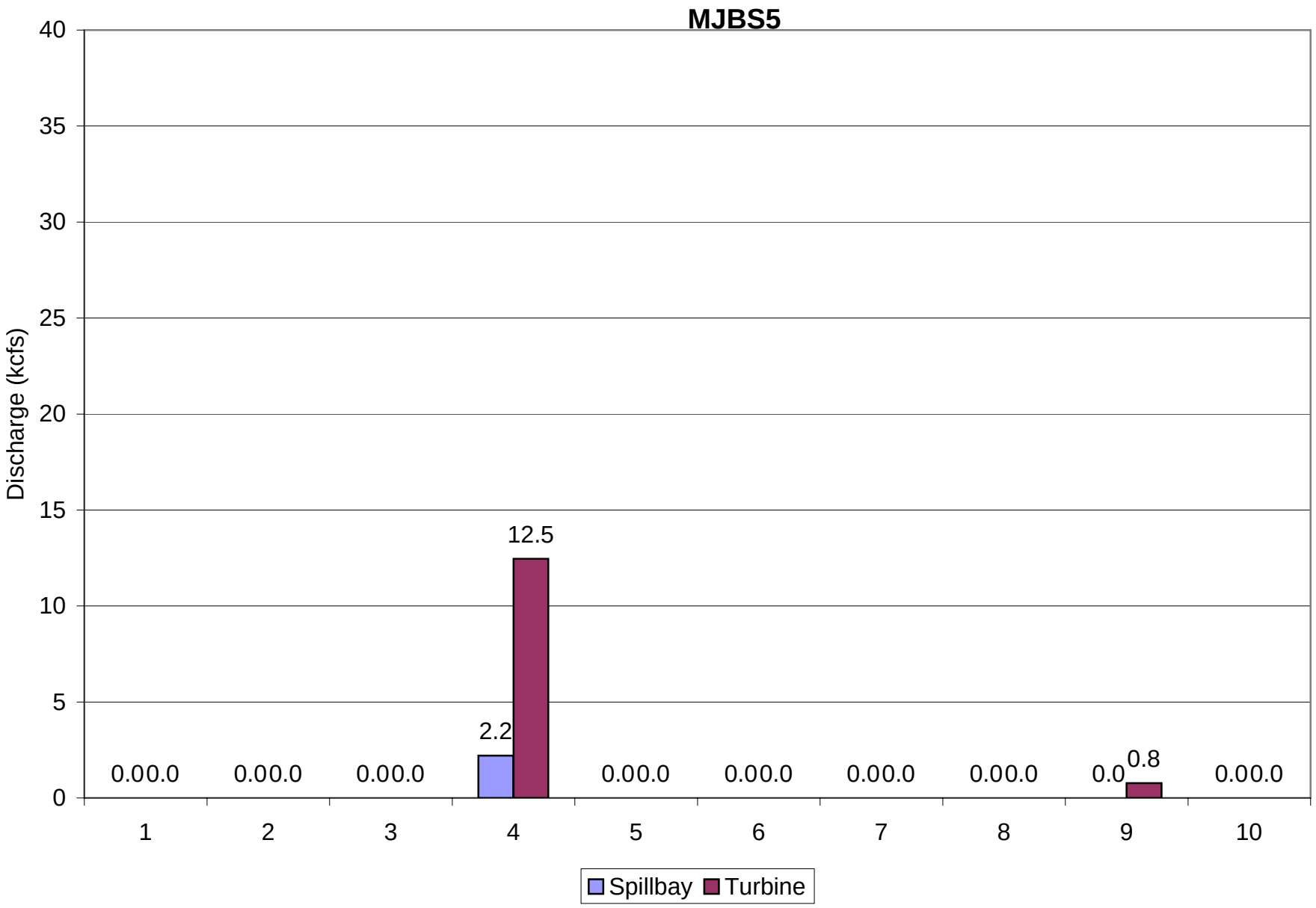

JBS74
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.00.0
1.7
19.3
0.0
19.6
2.2
18.9
0.0
19.2
2.2
18.9
0.1
19.7
2.2
19.7
0.1
18.8
1.7
19.6
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

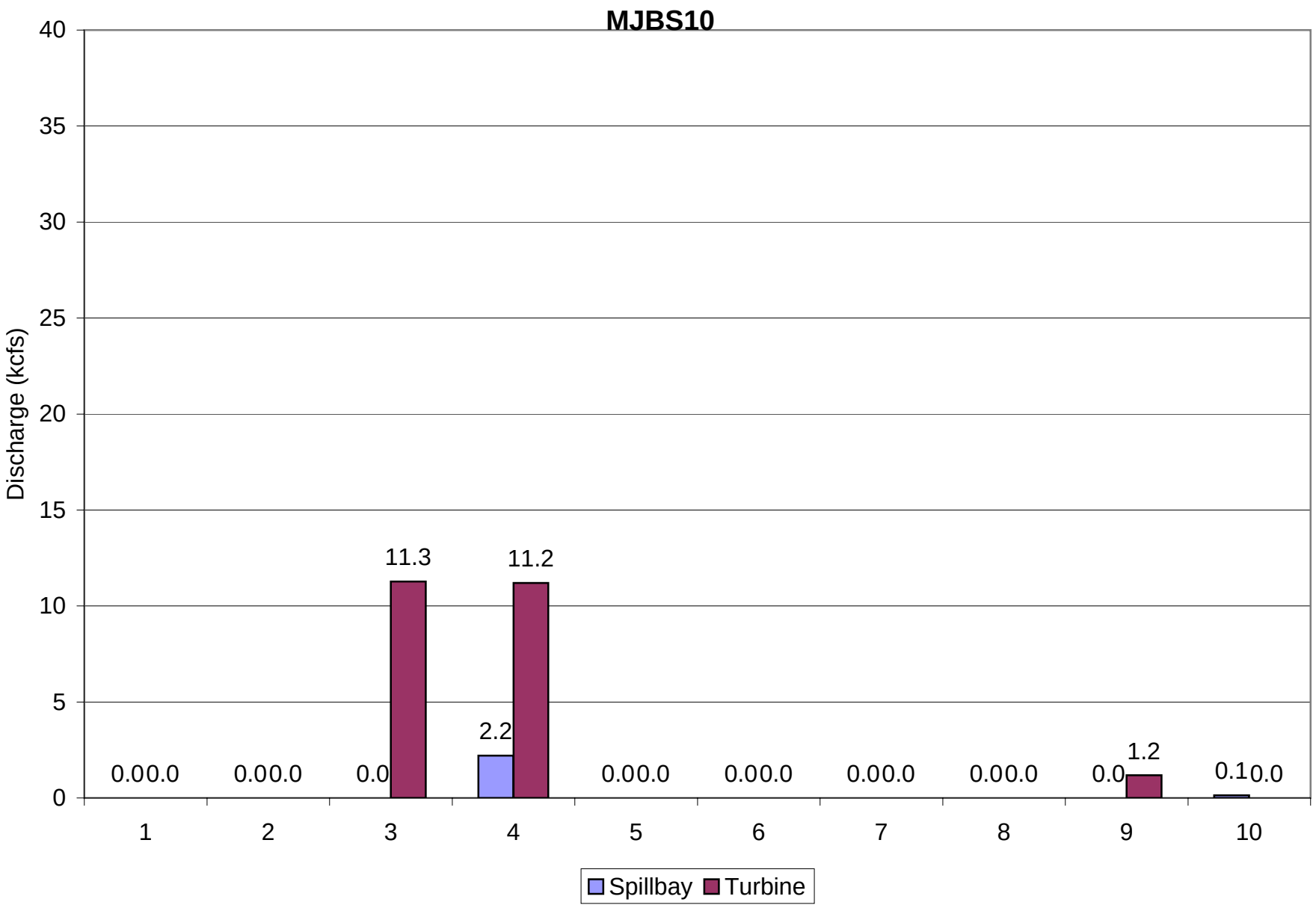

JBS77
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.00.0
1.6
18.7
0.0
18.9
2.2
18.6
0.0
19.0
2.2
18.6
0.0
19.2
2.2
19.2
0.0
18.4
1.6
19.2
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

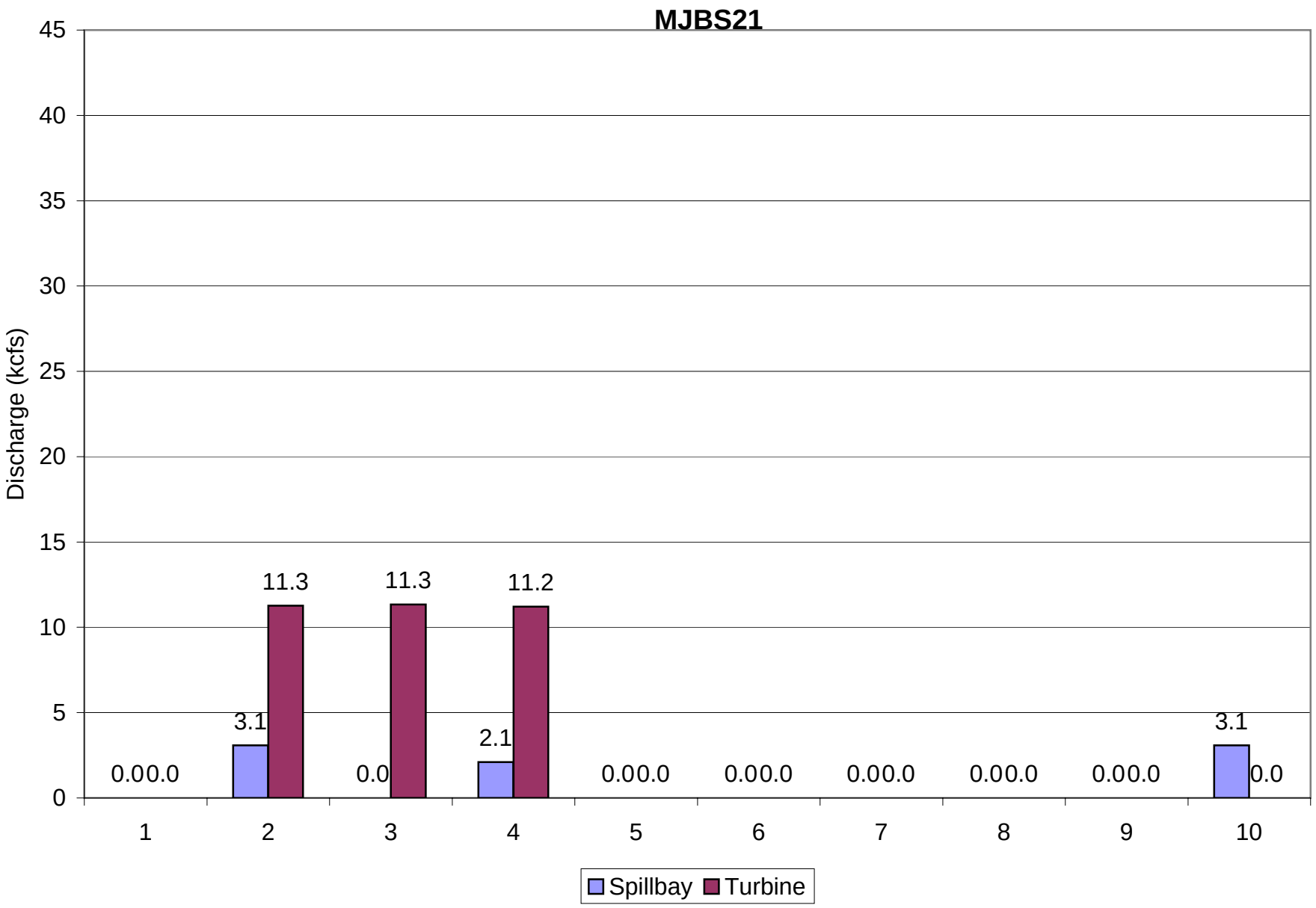

JBS78
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.6
19.3
0.0
19.6
2.2
19.5
0.0
19.3
2.2
19.5
0.0
19.6
2.2
19.6
0.0
19.4
1.6
19.4
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

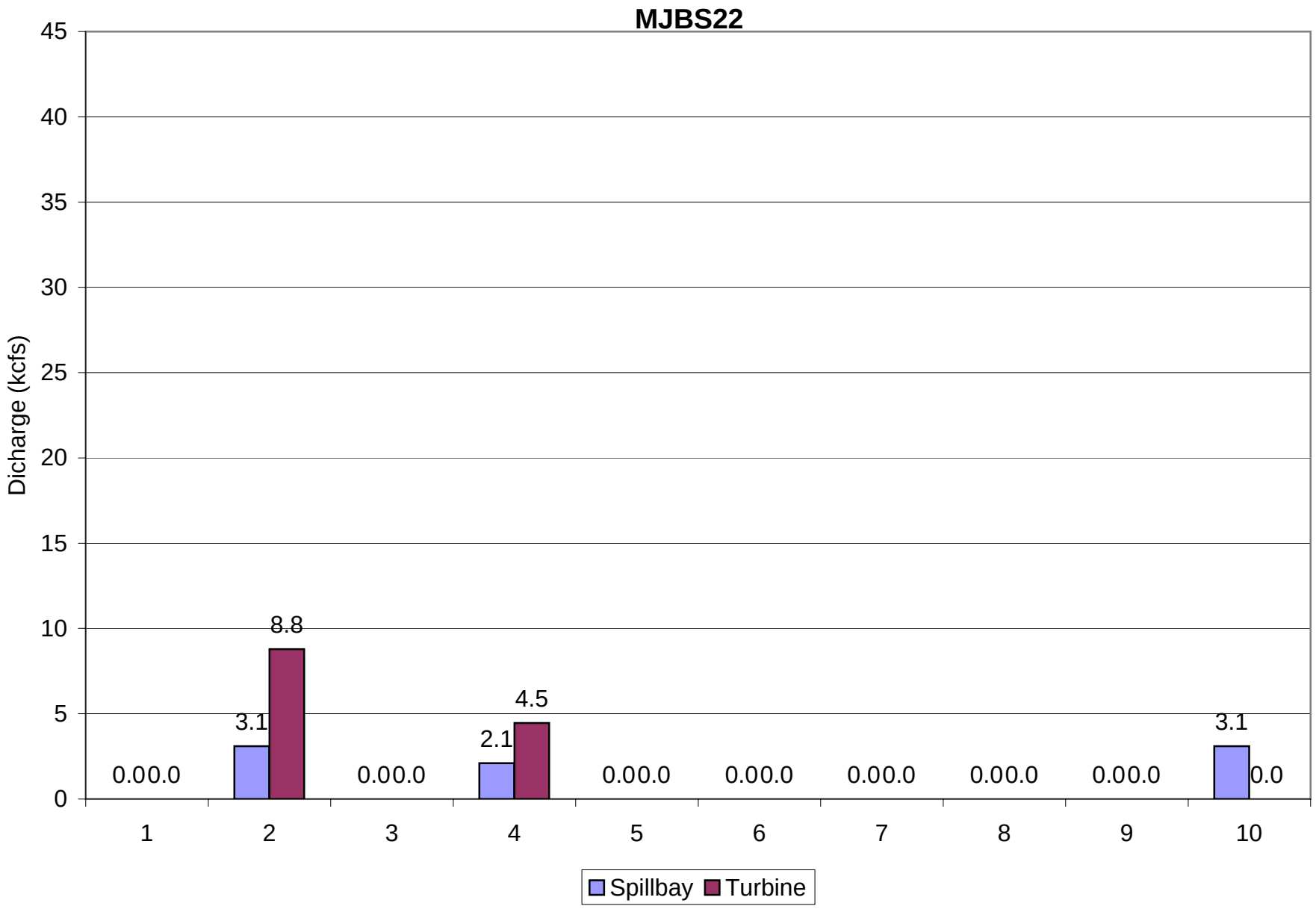

JBS79
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.7
19.2
0.0
19.6
2.2
19.3
0.0
19.0
2.2
19.1
0.0
19.8
2.2
19.8
0.0
19.8
1.7
19.5
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

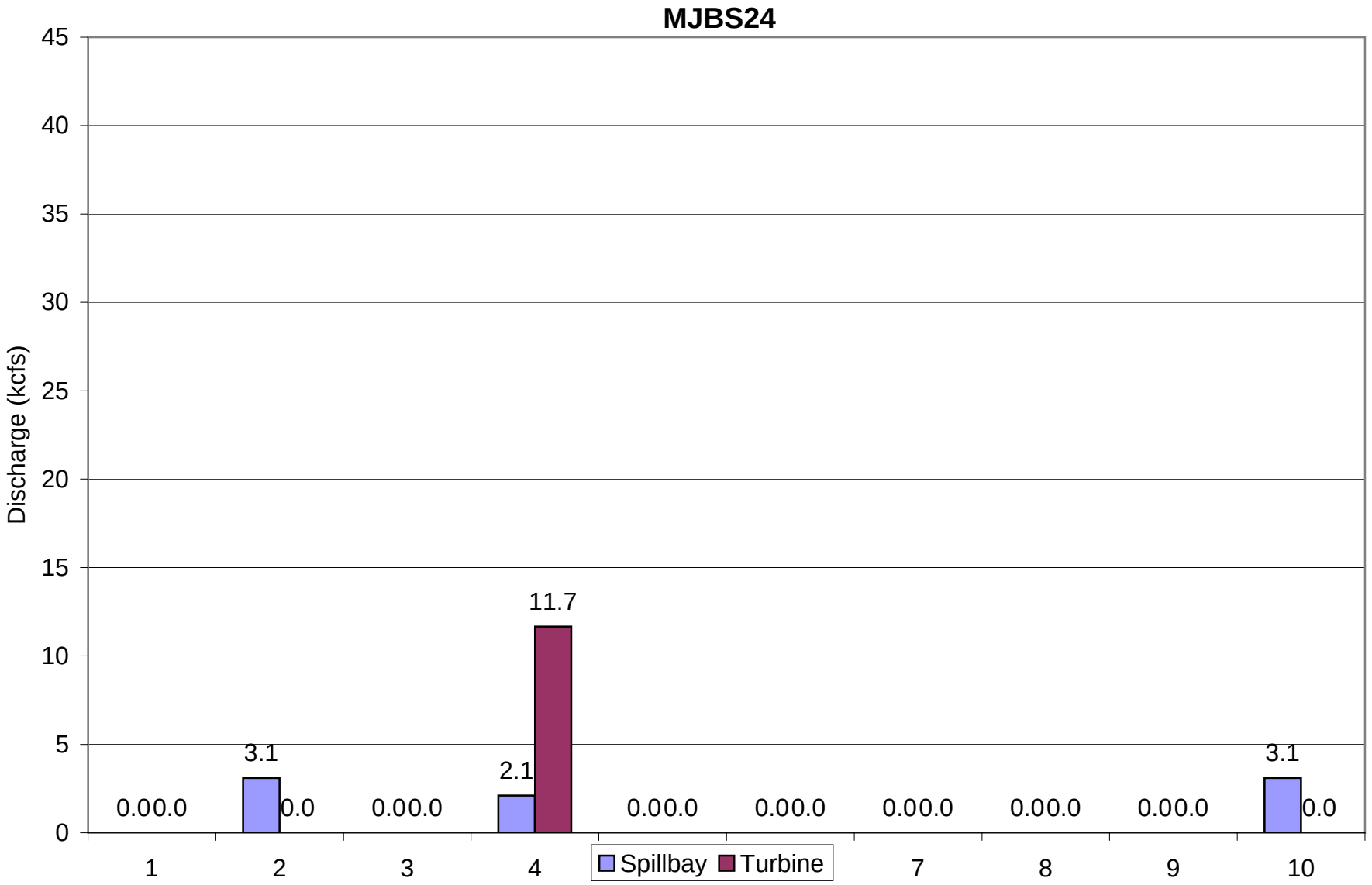

JBS80
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
12.8
17.9
18.1
17.9
18.2
17.8
18.4
18.4
17.7
18.3
0.0
1.8
0.0
2.2
0.0
2.2
0.0
2.2
0.0
1.8
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

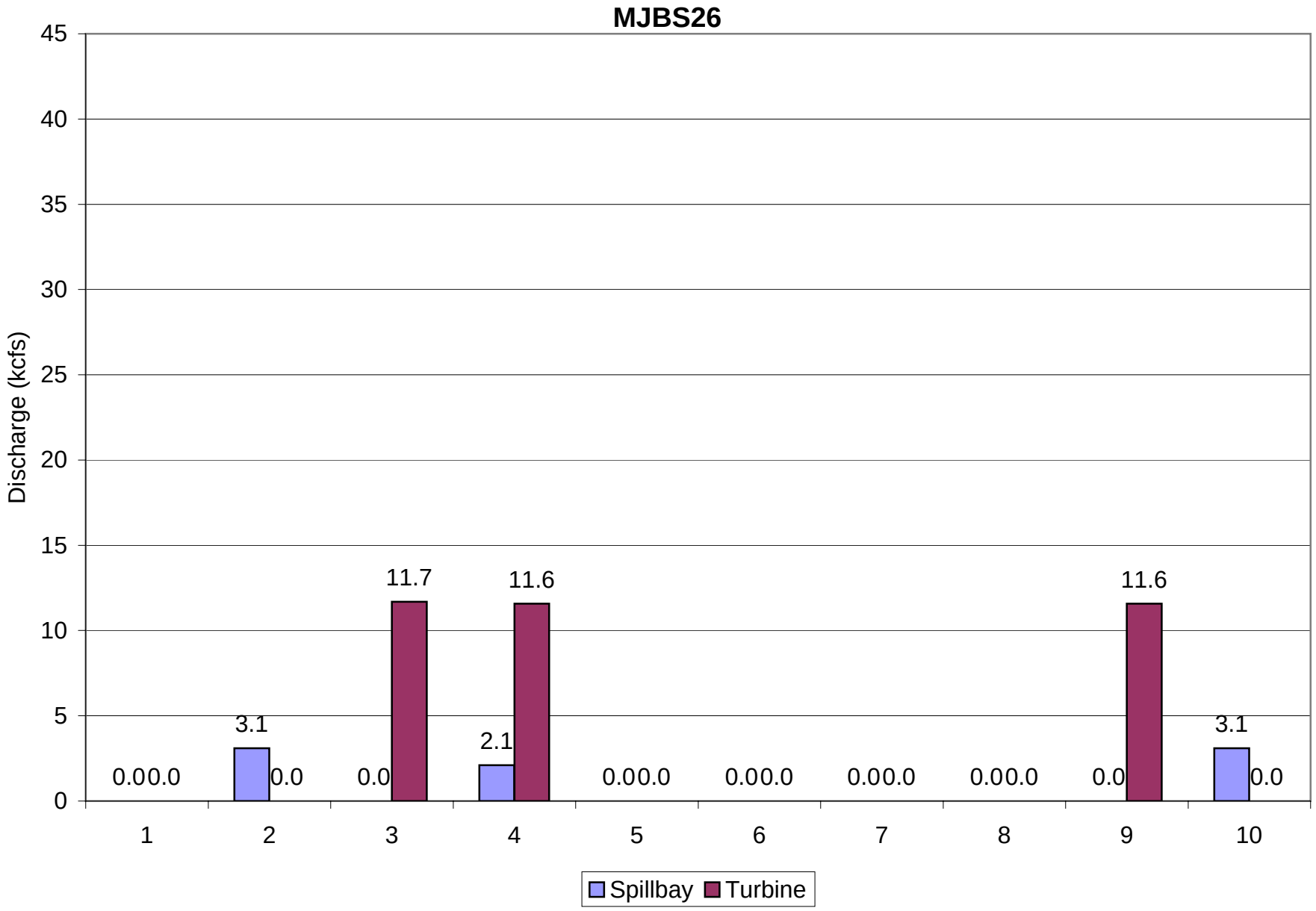

MJBS5
Discharge (kcfs)
40
35
30
25
20
15
10
5
0
0.00.0
0.00.0
0.00.0
2.2
12.5
0.00.0
0.00.0
0.00.0
0.00.0
0.0
0.8
0.00.0
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

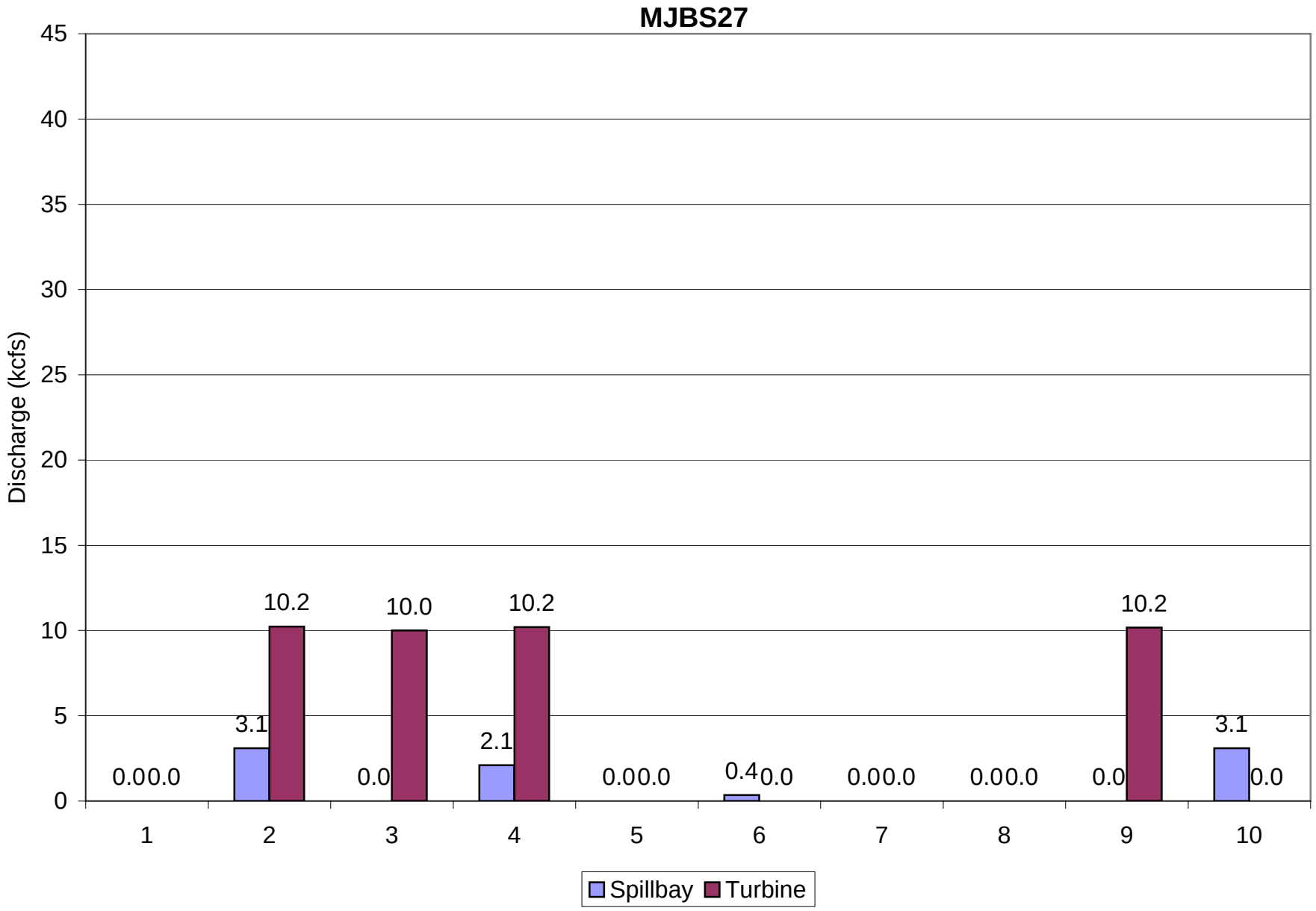

MJBS10
Discharge (kcfs)
40
35
30
25
20
15
10
5
0
0.0
0.0
0.0
11.3
2.2
11.2
0.0
0.0
0.0
0.0
0.0
1.2
0.1
0.0
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

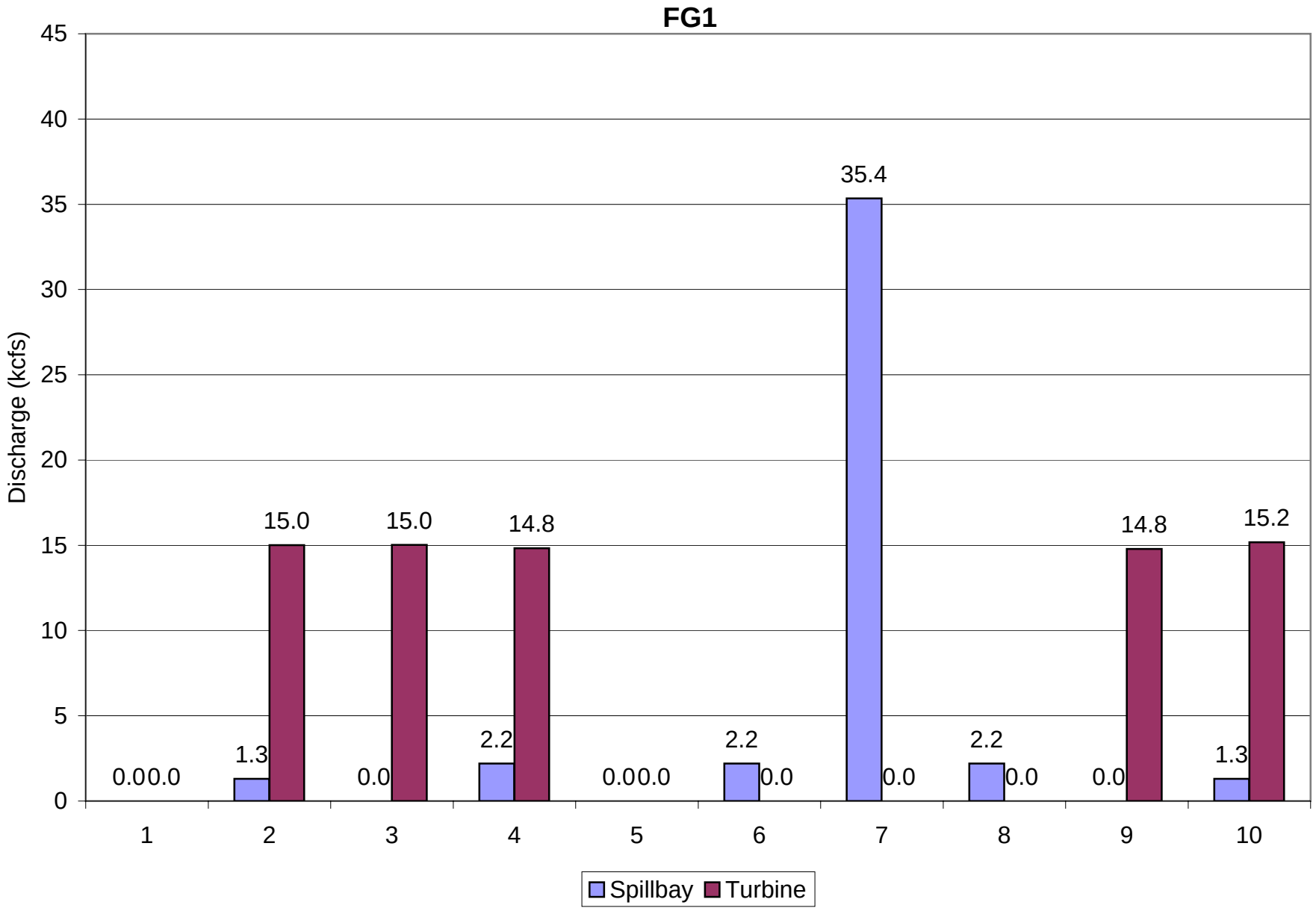

MJBS21
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
3.1
11.3
0.0
11.3
2.1
11.2
0.0
0.0
0.0
0.0
0.0
3.1
0.0
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

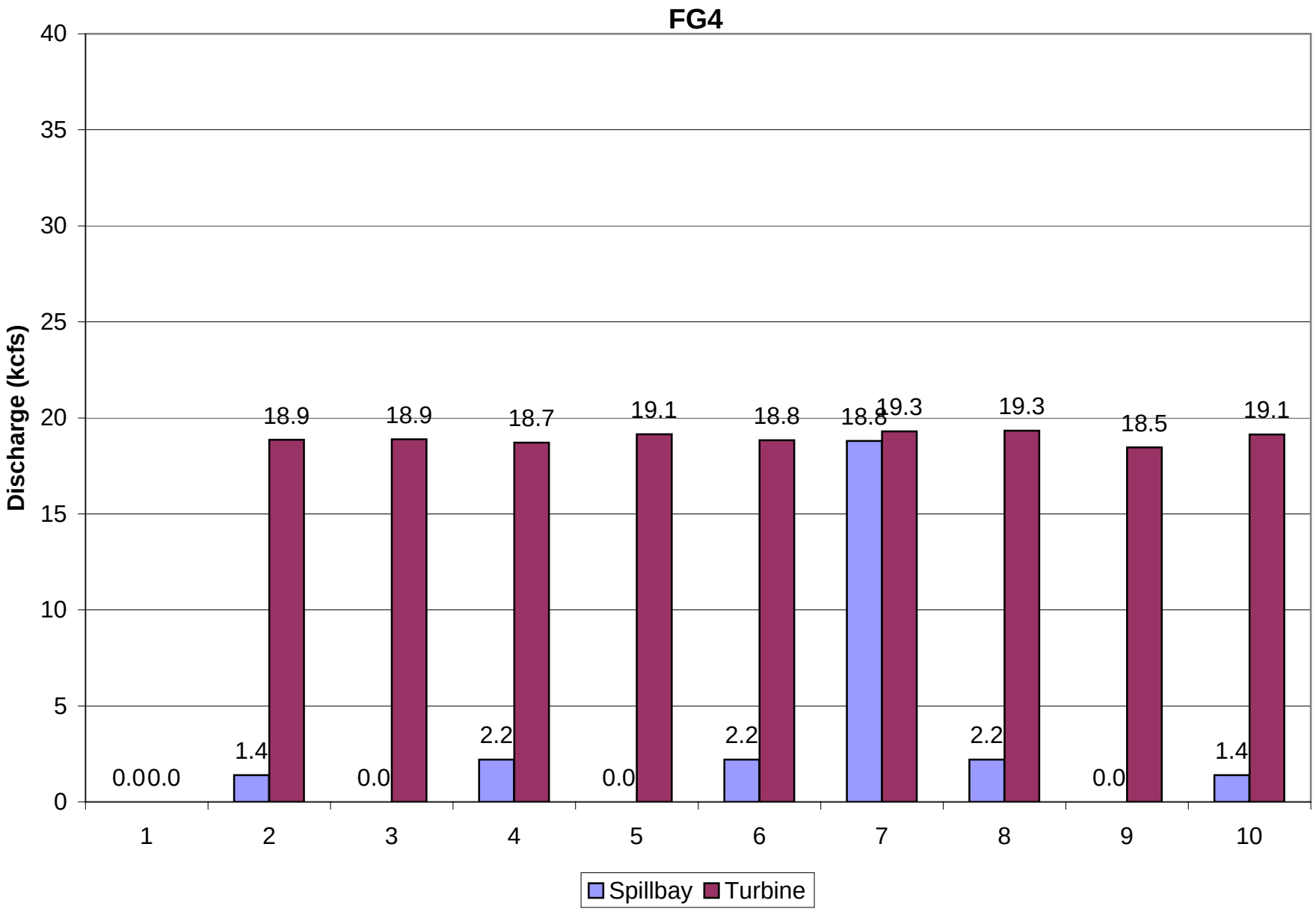

MJBS22
Dicharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.00.0
3.1
8.8
0.00.0
2.1
4.5
0.00.0
0.00.0
0.00.0
0.00.0
0.00.0
3.1
0.0
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

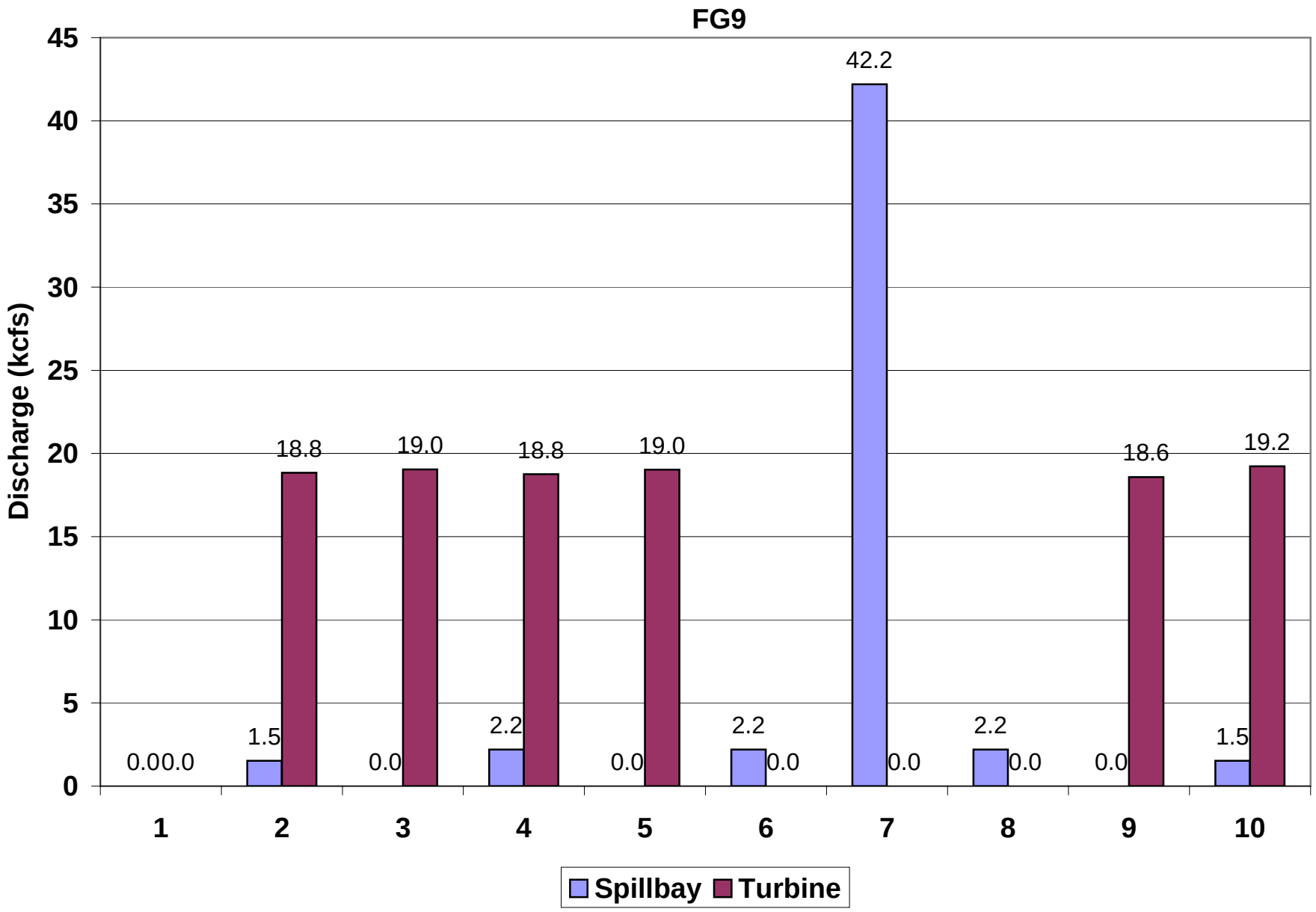

MJBS24
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.00.0
3.1
0.0
0.00.0
2.1
11.7
0.00.0
0.00.0
0.00.0
0.00.0
0.00.0
3.1
0.0
1
2
3
4
Spillbay
Turbine
7
8
9
10

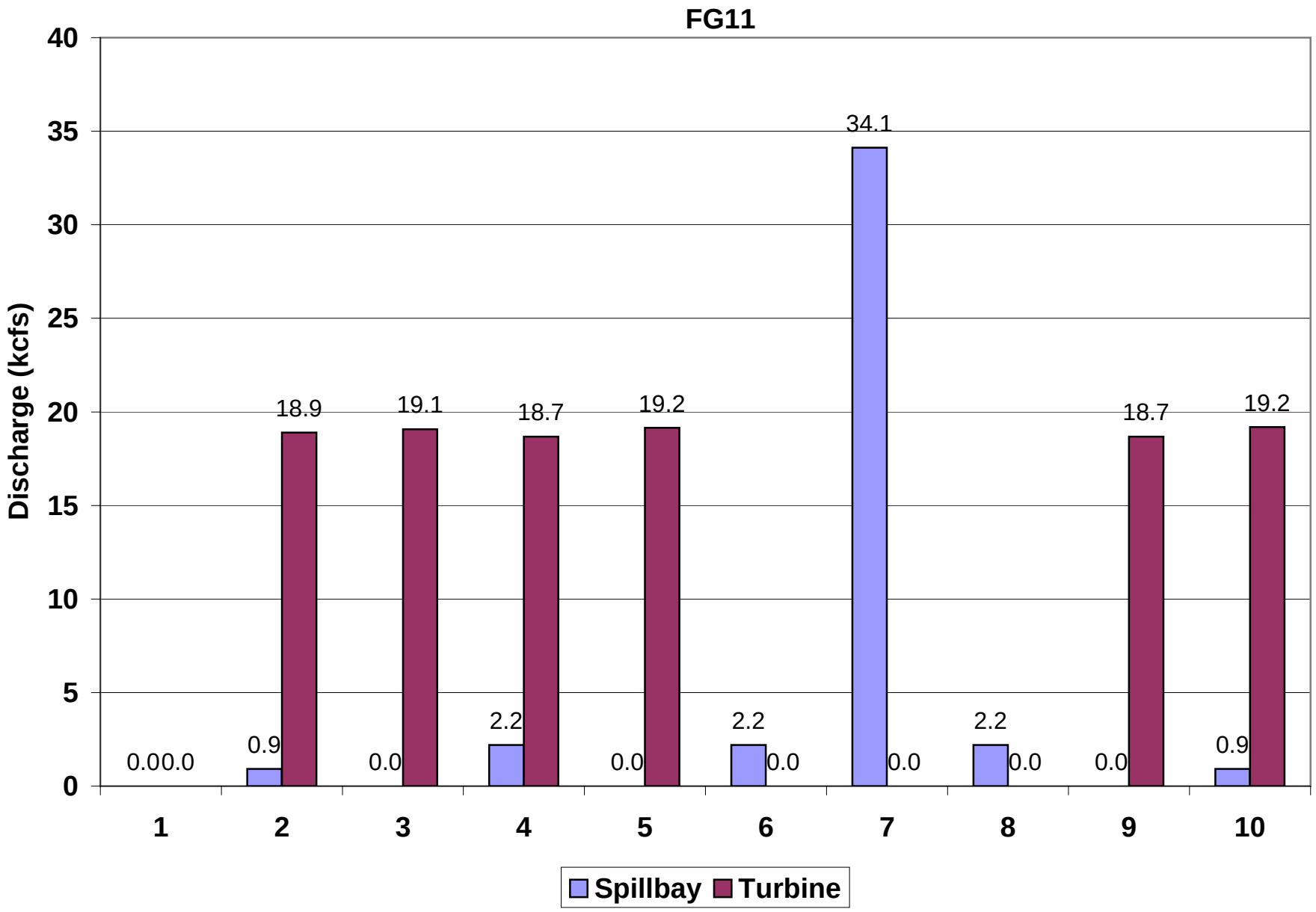

MJBS26
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
3.1
0.0
0.0
11.7
2.1
11.6
0.0
0.0
0.0
0.0
0.0
0.0
11.6
3.1
0.0
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

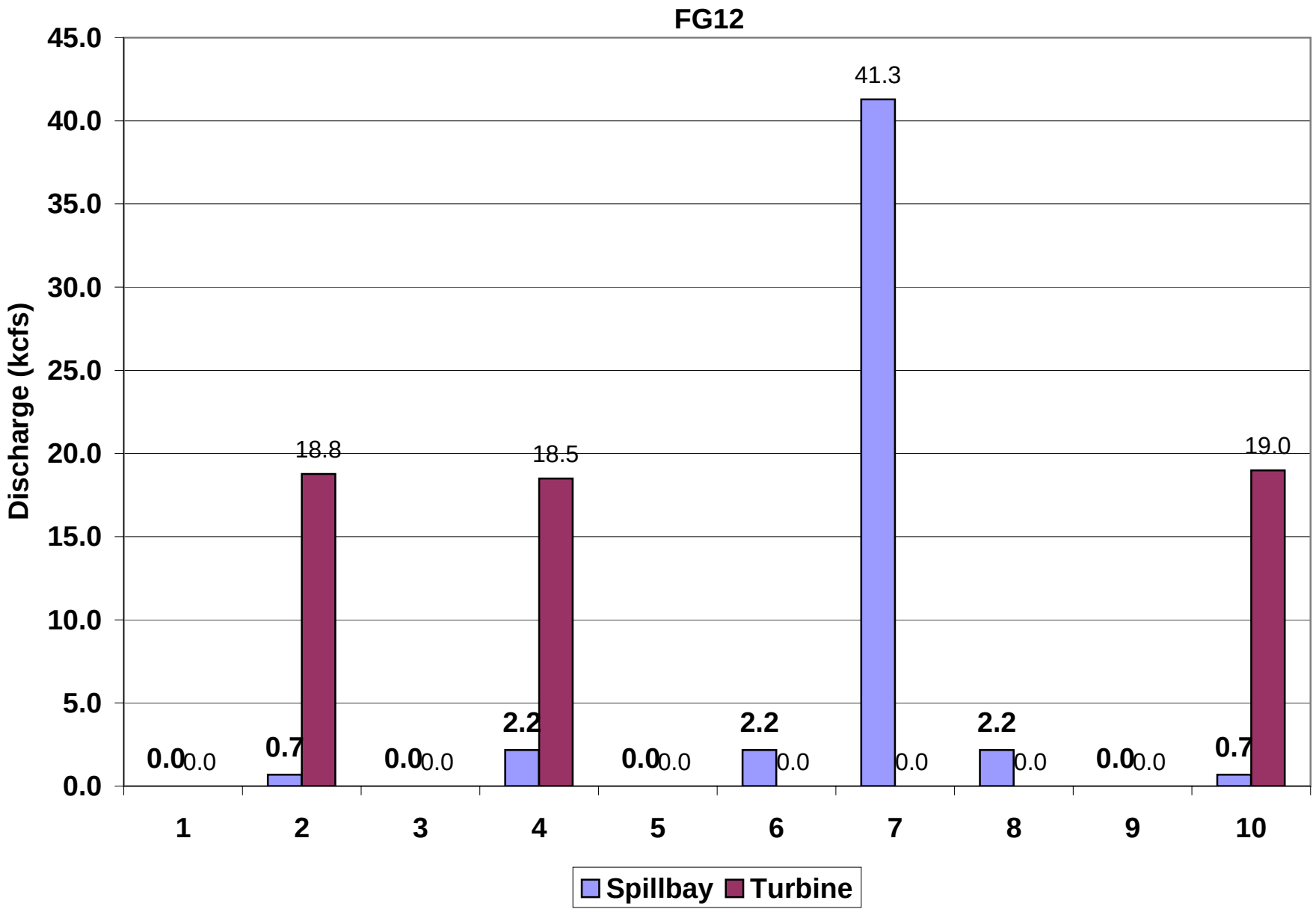

MJBS27
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
3.1
10.2
0.0
10.0
2.1
10.2
0.0
0.0
0.4
0.0
0.0
0.0
0.0
0.0
0.0
10.2
3.1
0.0
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

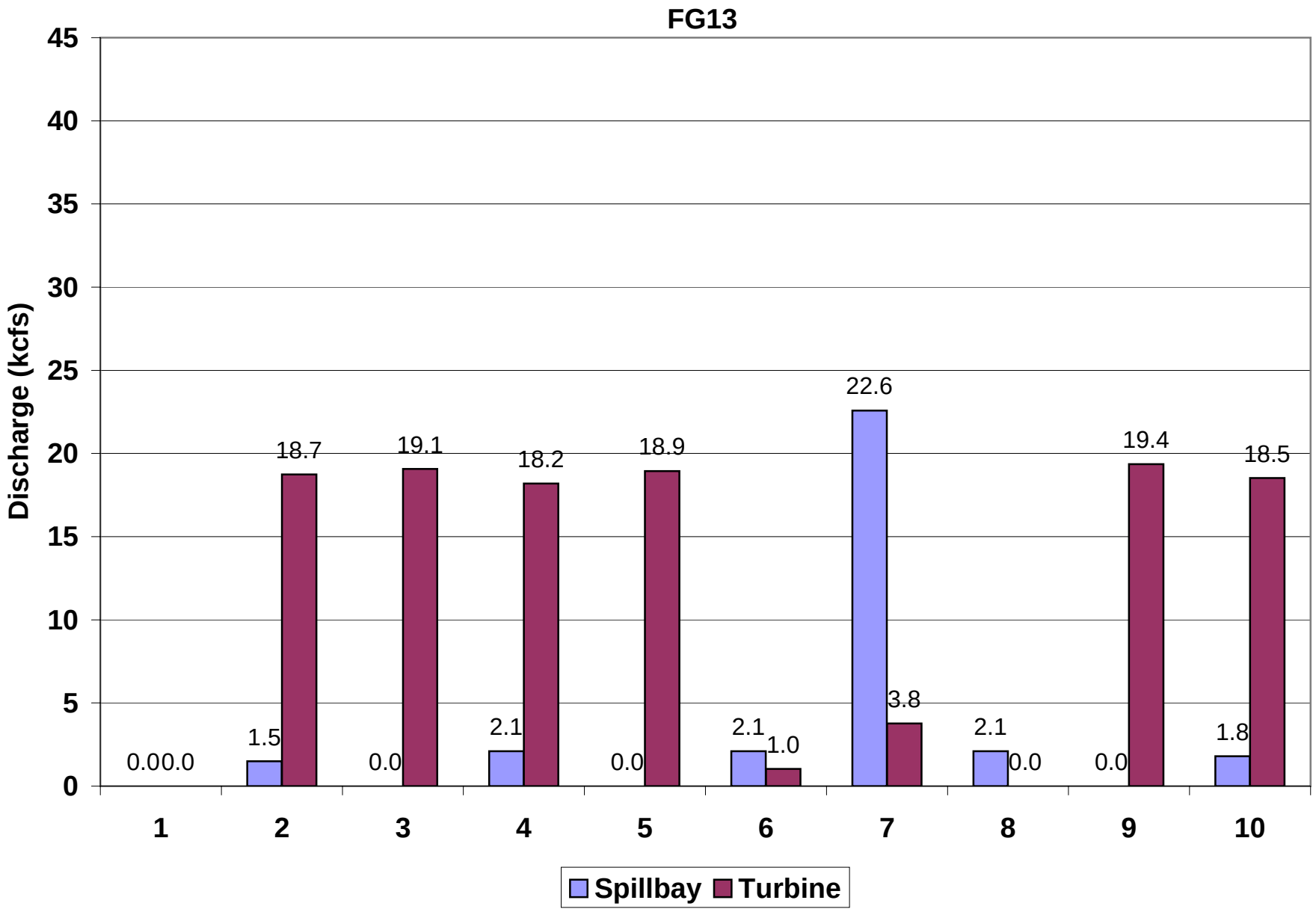

FG1
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.3
15.0
0.0
15.0
2.2
14.8
0.0
0.0
2.2
0.0
35.4
0.0
2.2
0.0
0.0
14.8
1.3
15.2
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

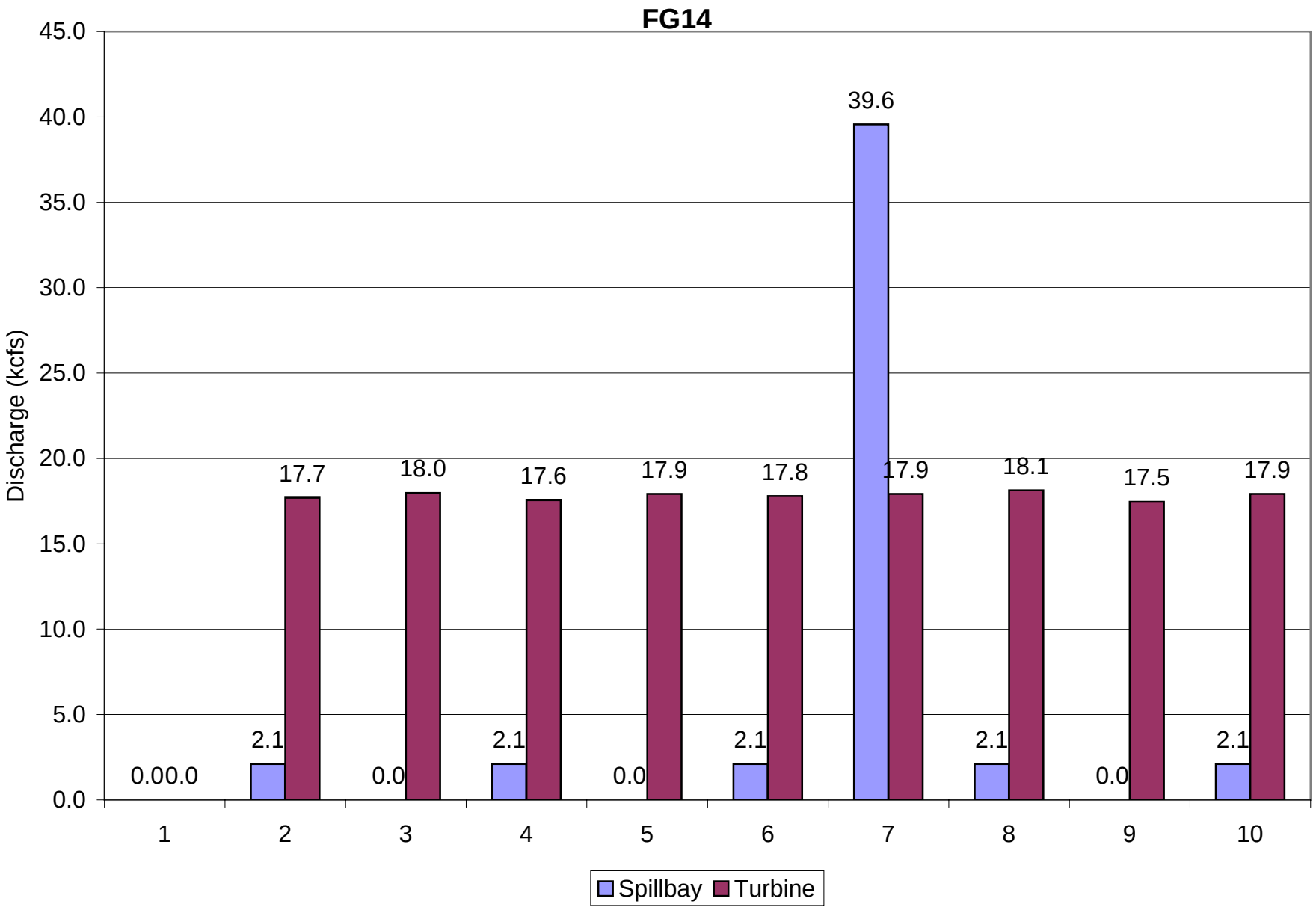

FG4
Discharge (kcfs)
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
0.0
0.0
1.4
18.9
0.0
18.9
2.2
18.7
0.0
19.1
2.2
18.8
18.8
19.3
2.2
19.3
0.0
18.5
1.4
19.1
Spillbay
Turbine

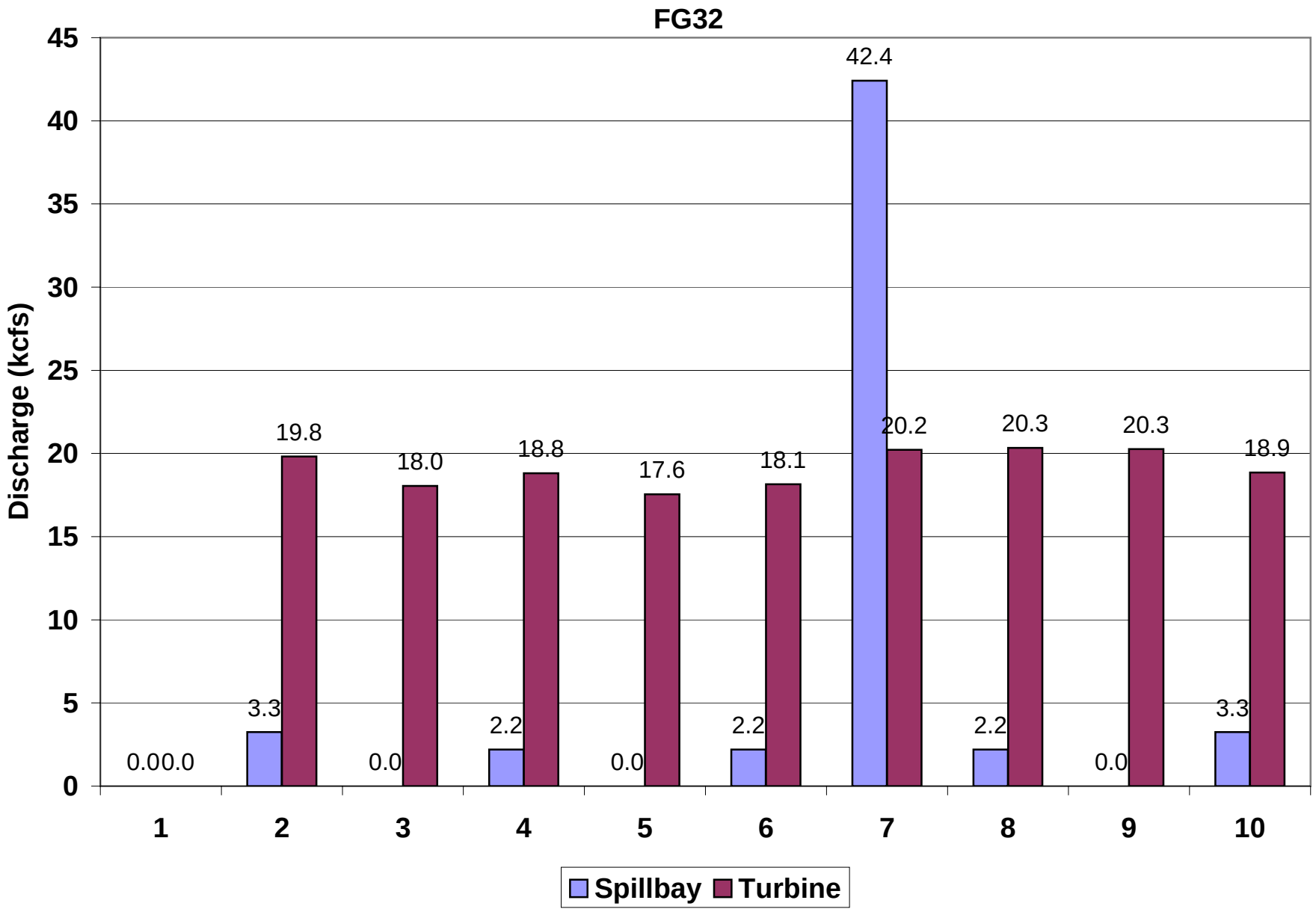

FG9
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
1.5
18.8
0.0
19.0
2.2
18.8
0.0
19.0
2.2
0.0
42.2
0.0
2.2
0.0
0.0
18.6
1.5
19.2
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

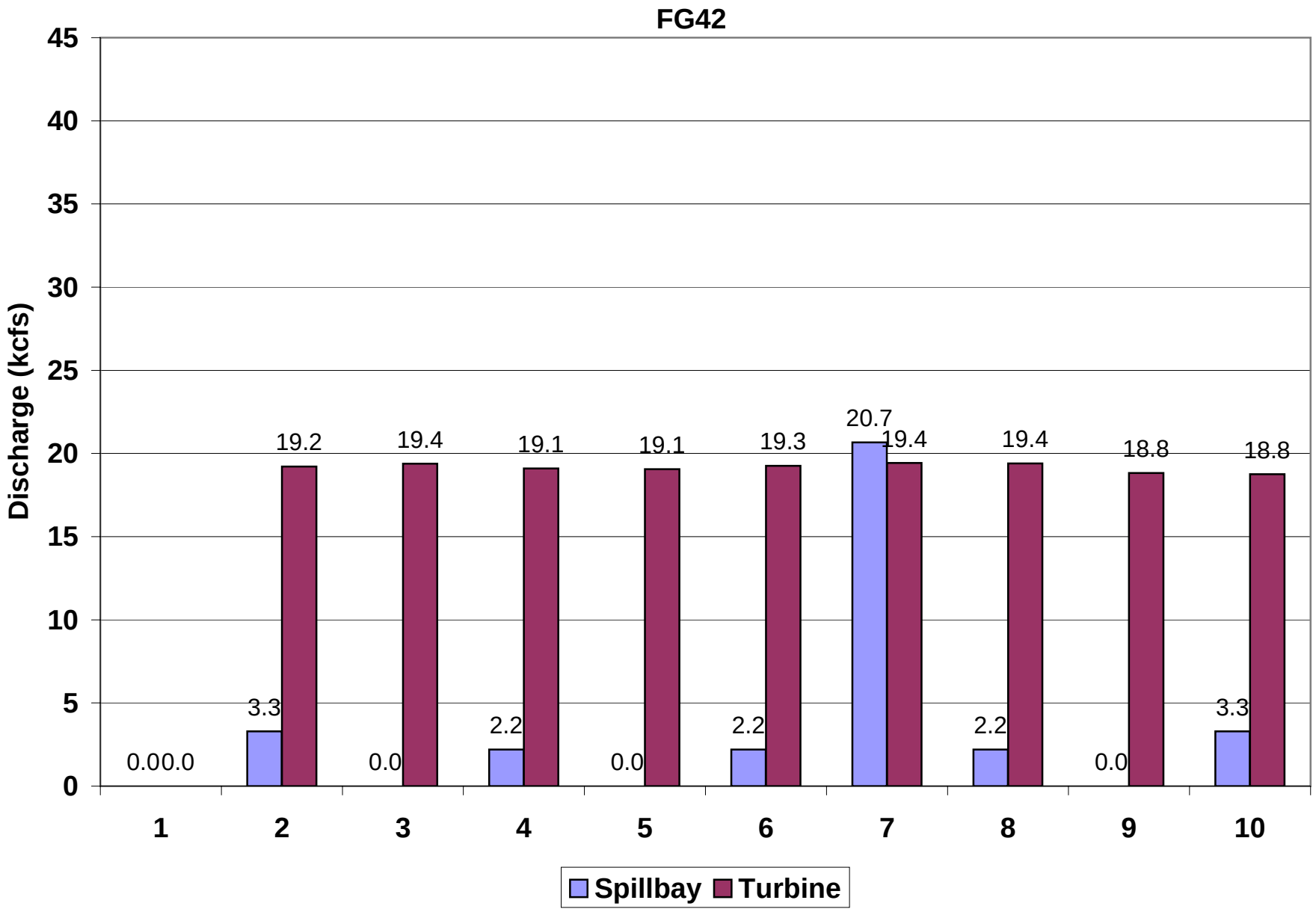

FG11
Discharge (kcfs)
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
0.0
0.9
18.9
0.0
19.1
2.2
18.7
0.0
19.2
2.2
0.0
34.1
0.0
2.2
0.0
0.0
18.7
0.9
19.2
Spillbay
Turbine

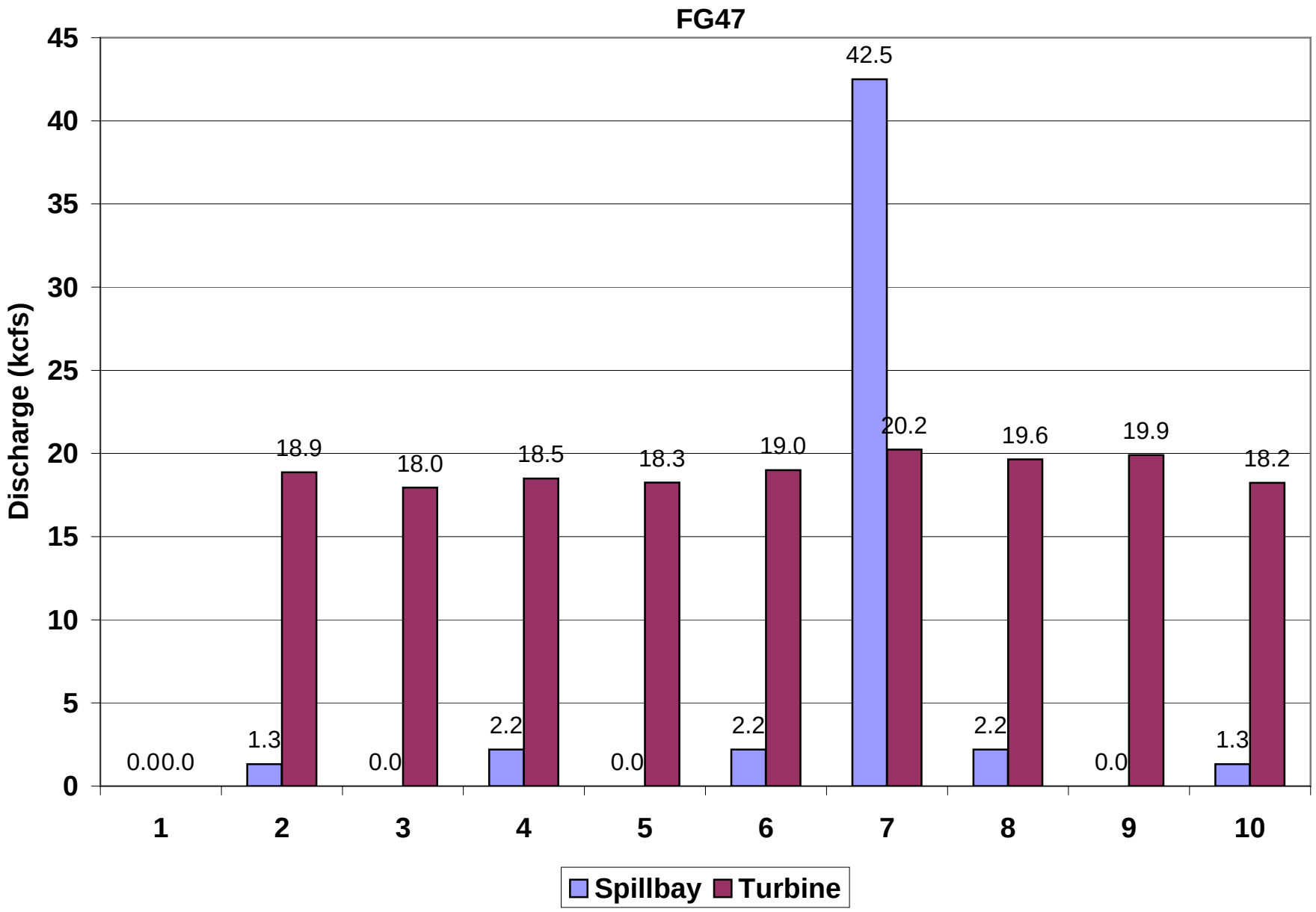

FG12
Discharge (kcfs)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0.0 0.0
0.7 18.8
0.0 0.0
2.2 18.5
0.0 0.0
2.2 0.0
41.3 0.0
2.2 0.0
0.0 0.0
0.7 19.0
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

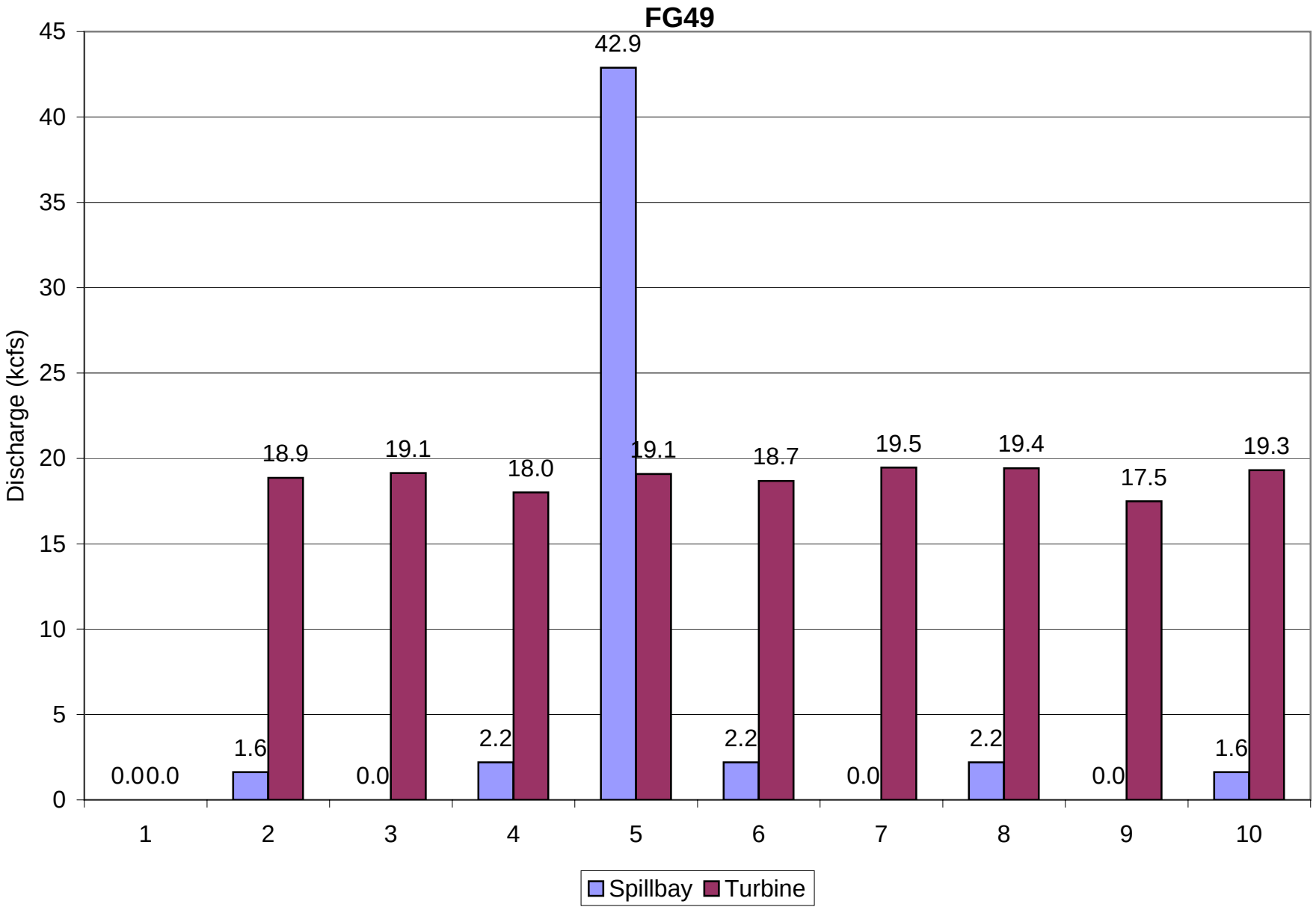

FG13
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.5
18.7
0.0
19.1
2.1
18.2
0.0
18.9
2.1
1.0
22.6
3.8
2.1
0.0
0.0
19.4
1.8
18.5
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

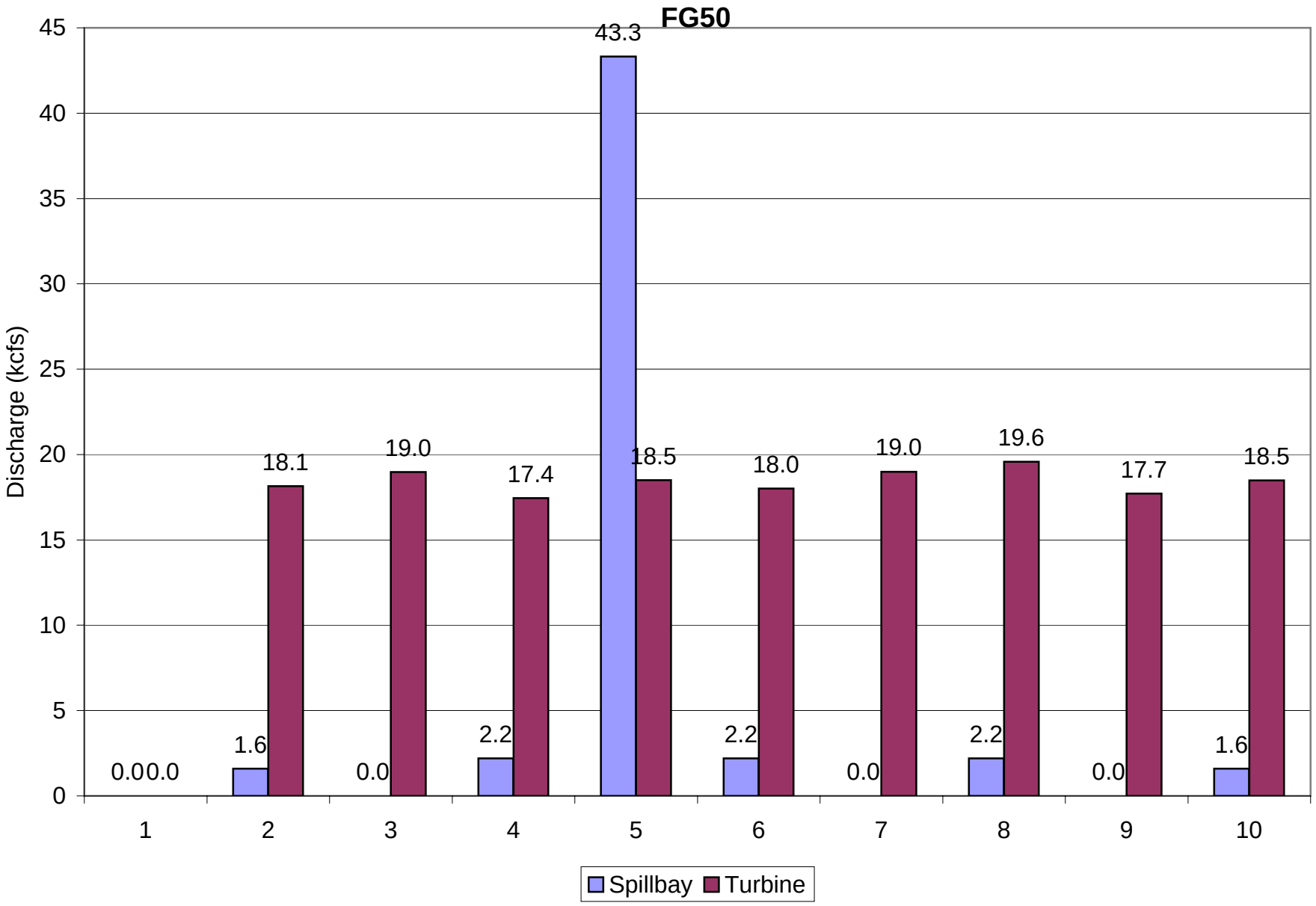

FG14
Discharge (kcfs)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0.00.0
2.1
17.7
0.0
18.0
2.1
17.6
0.0
17.9
2.1
17.8
39.6
17.9
2.1
18.1
0.0
17.5
2.1
17.9
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

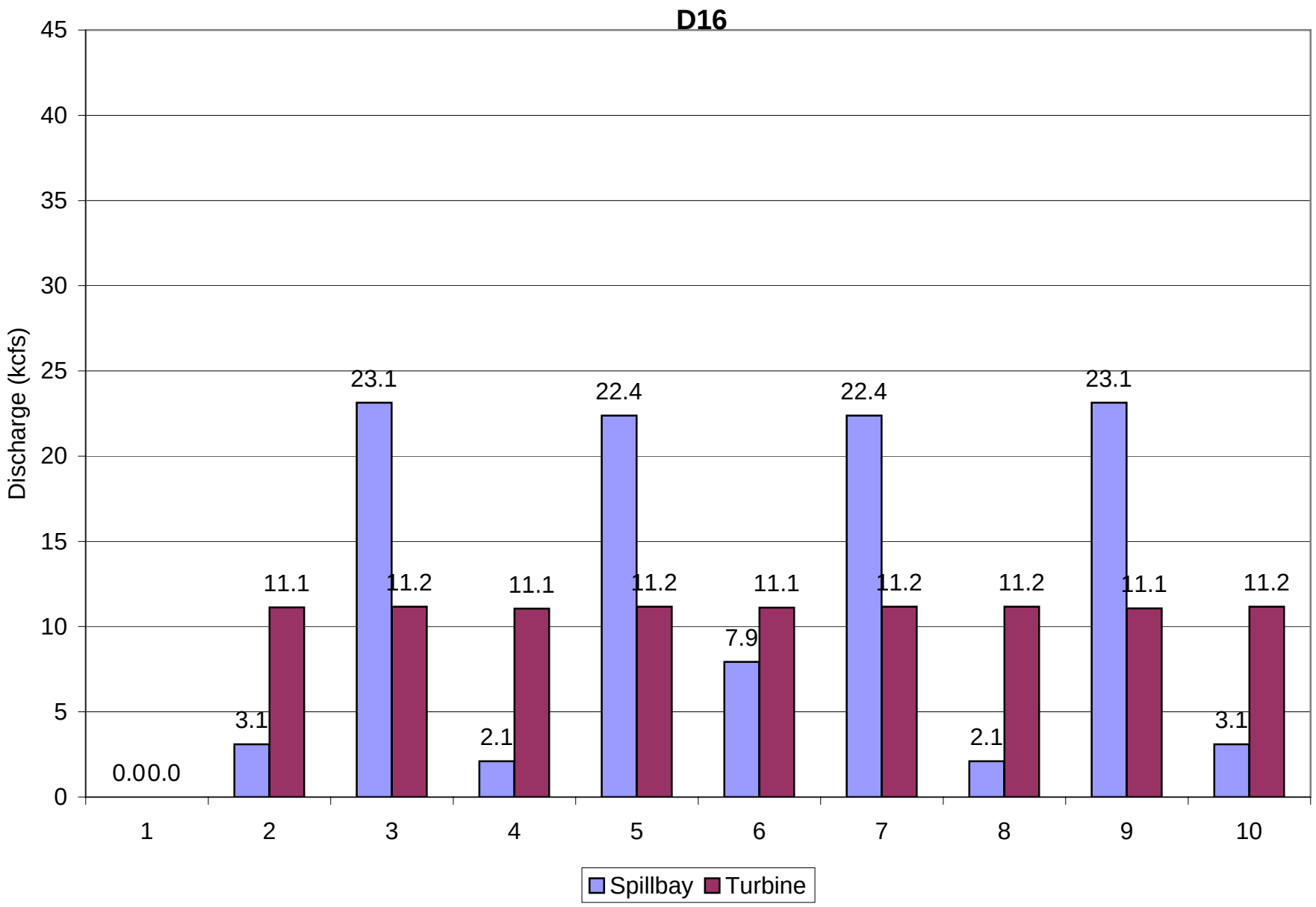

FG32
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
3.3
19.8
0.0
18.0
2.2
18.8
0.0
17.6
2.2
18.1
42.4
20.2
2.2
20.3
0.0
20.3
3.3
18.9
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

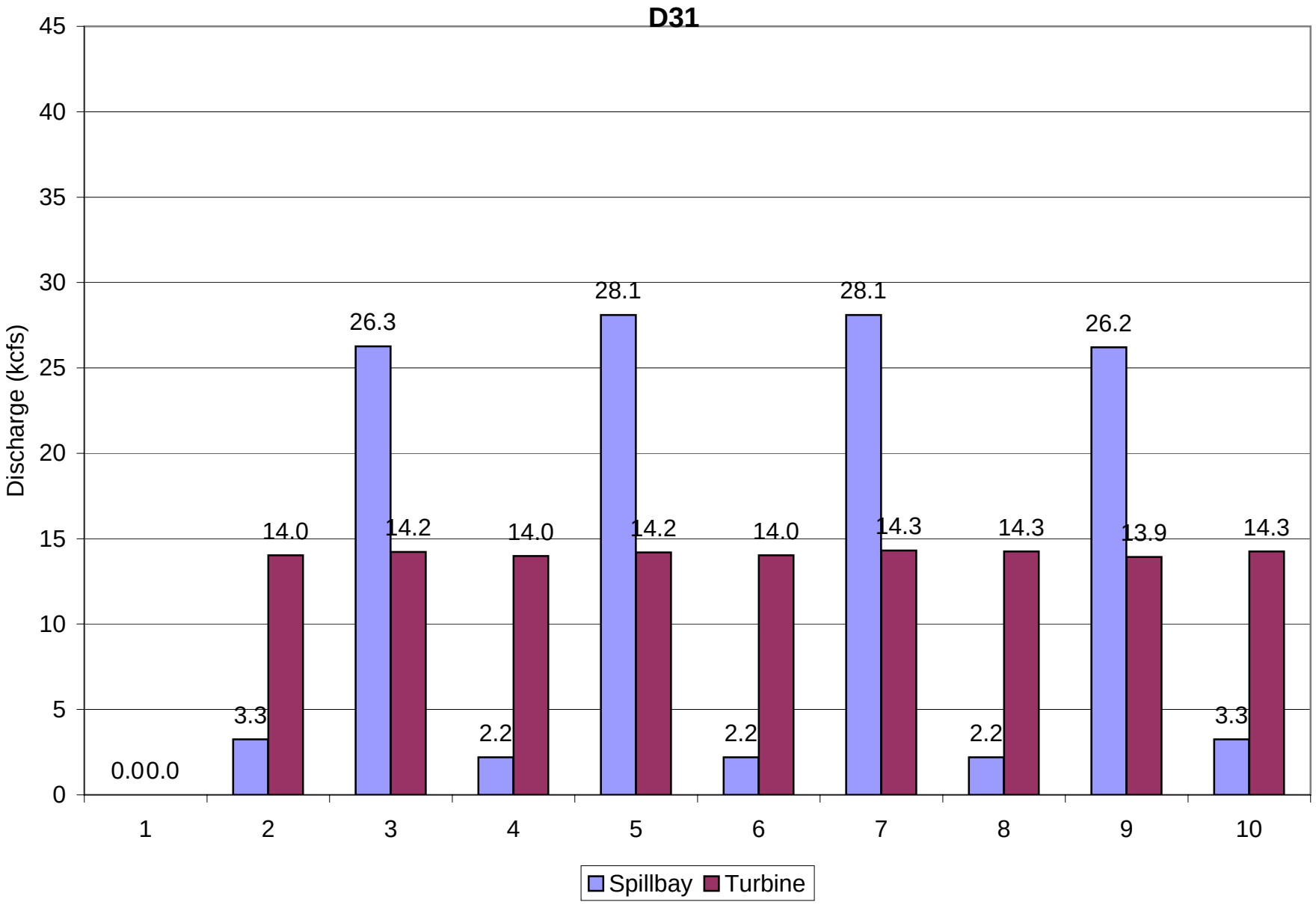

FG42
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
3.3
19.2
0.0
2.2
19.4
0.0
2.2
19.1
0.0
2.2
19.1
20.7
19.3
19.4
2.2
19.4
0.0
18.8
3.3
18.8
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

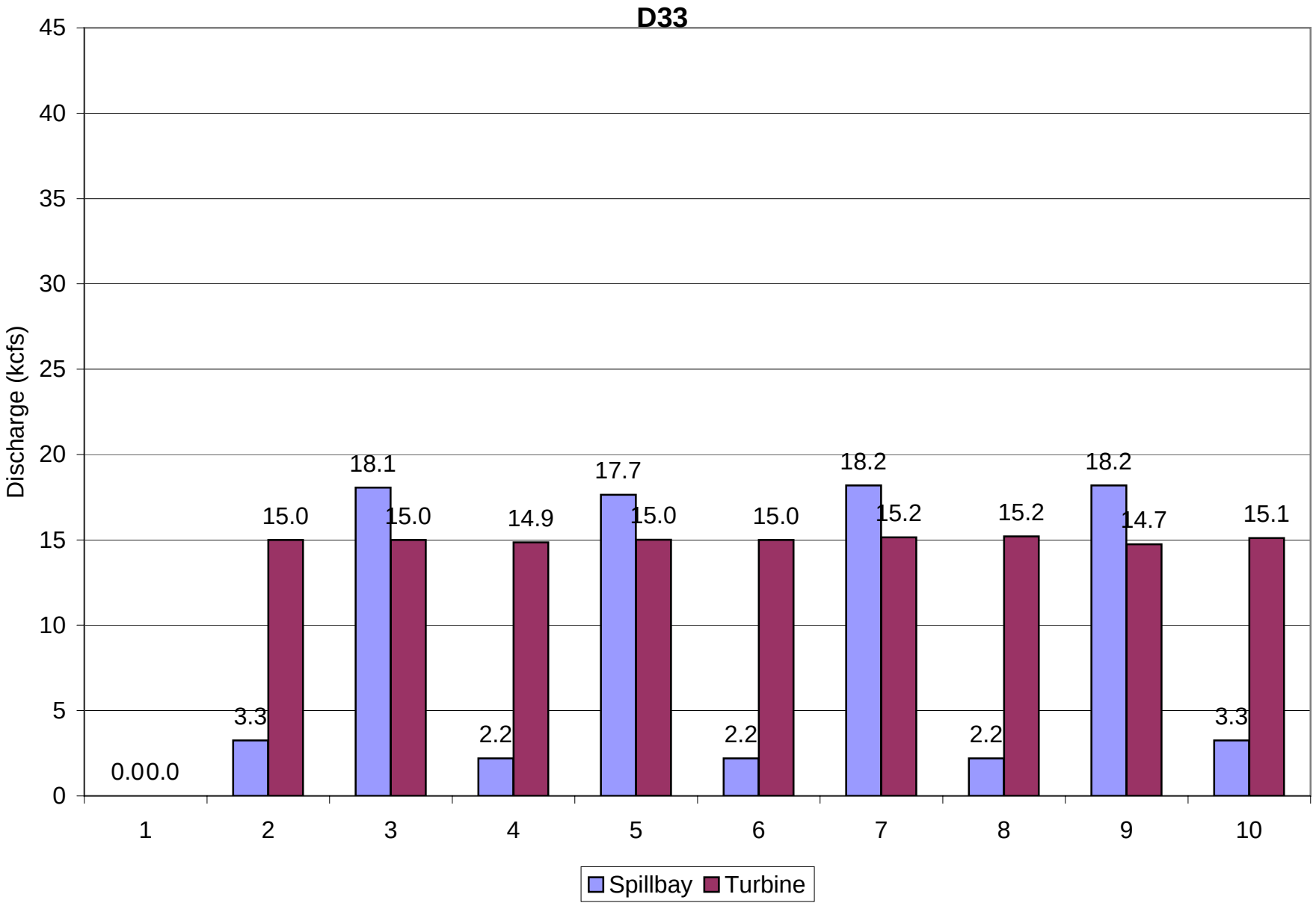

FG47
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.3
18.9
0.0
18.0
2.2
18.5
0.0
18.3
2.2
19.0
42.5
20.2
2.2
19.6
0.0
19.9
1.3
18.2
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

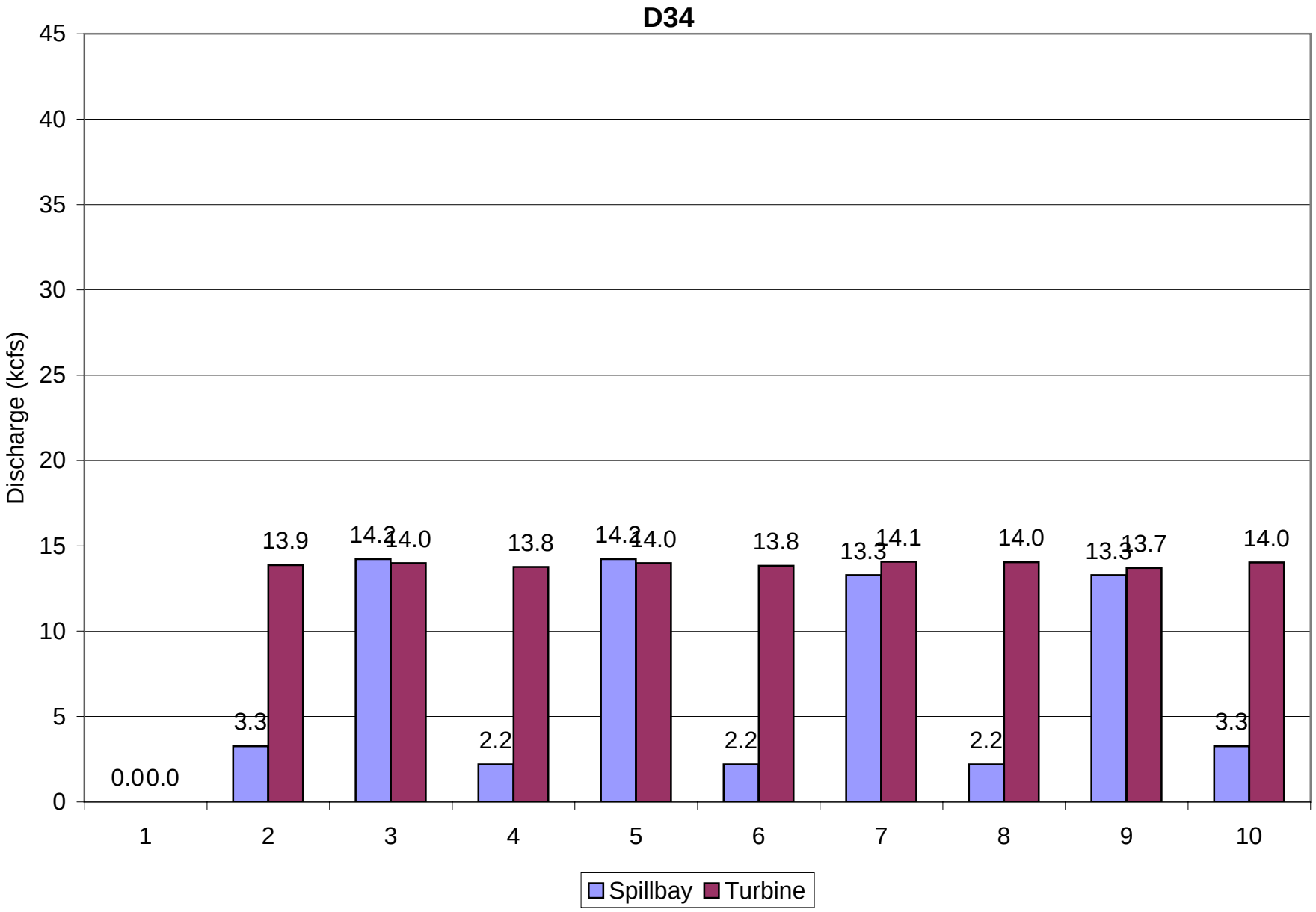

FG49
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.6
18.9
0.0
19.1
2.2
18.0
42.9
19.1
2.2
18.7
0.0
19.5
2.2
19.4
0.0
17.5
1.6
19.3
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

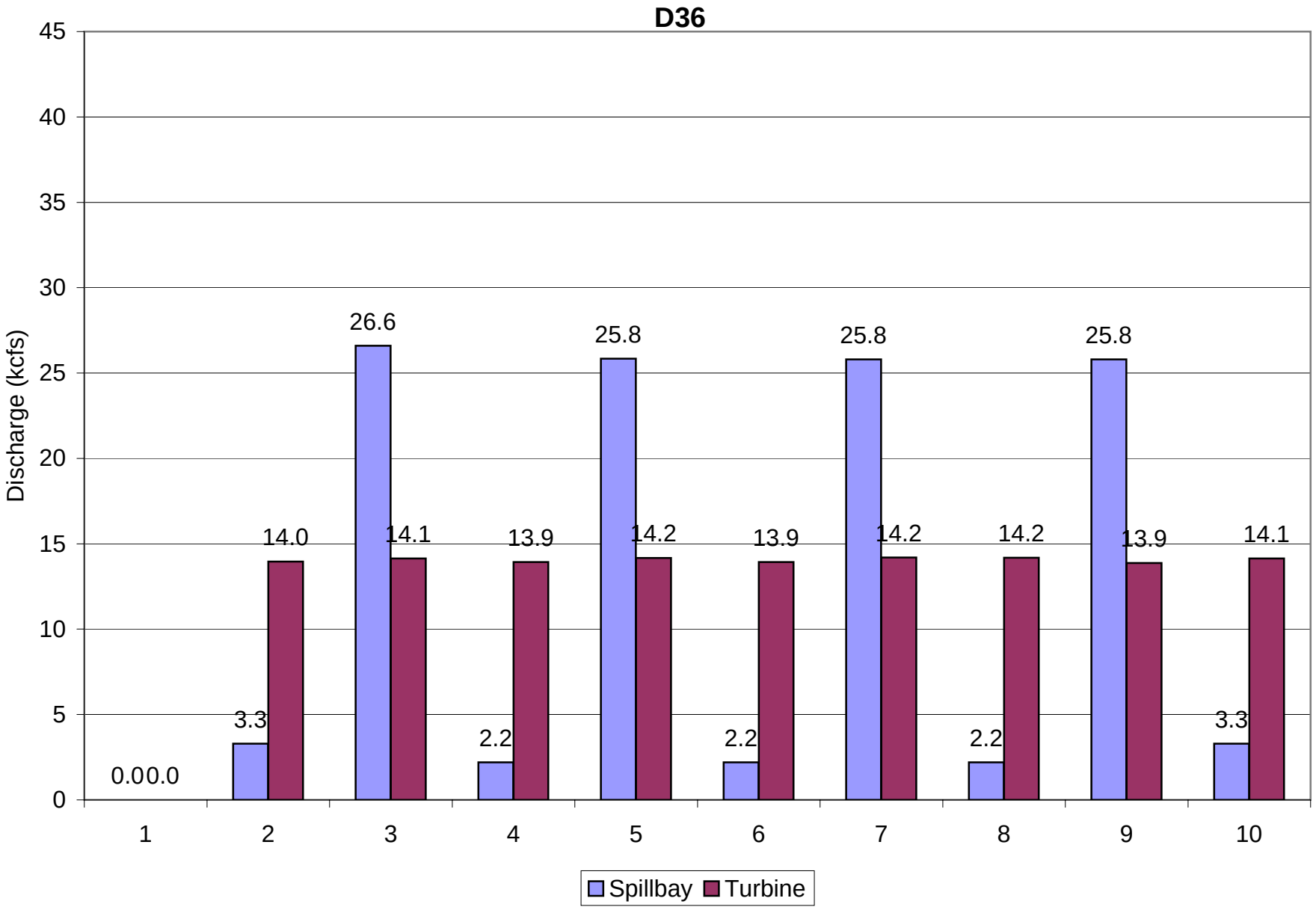

FG50
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.6
18.1
0.0
19.0
2.2
17.4
43.3
18.5
2.2
18.0
0.0
19.0
2.2
19.6
0.0
17.7
1.6
18.5
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

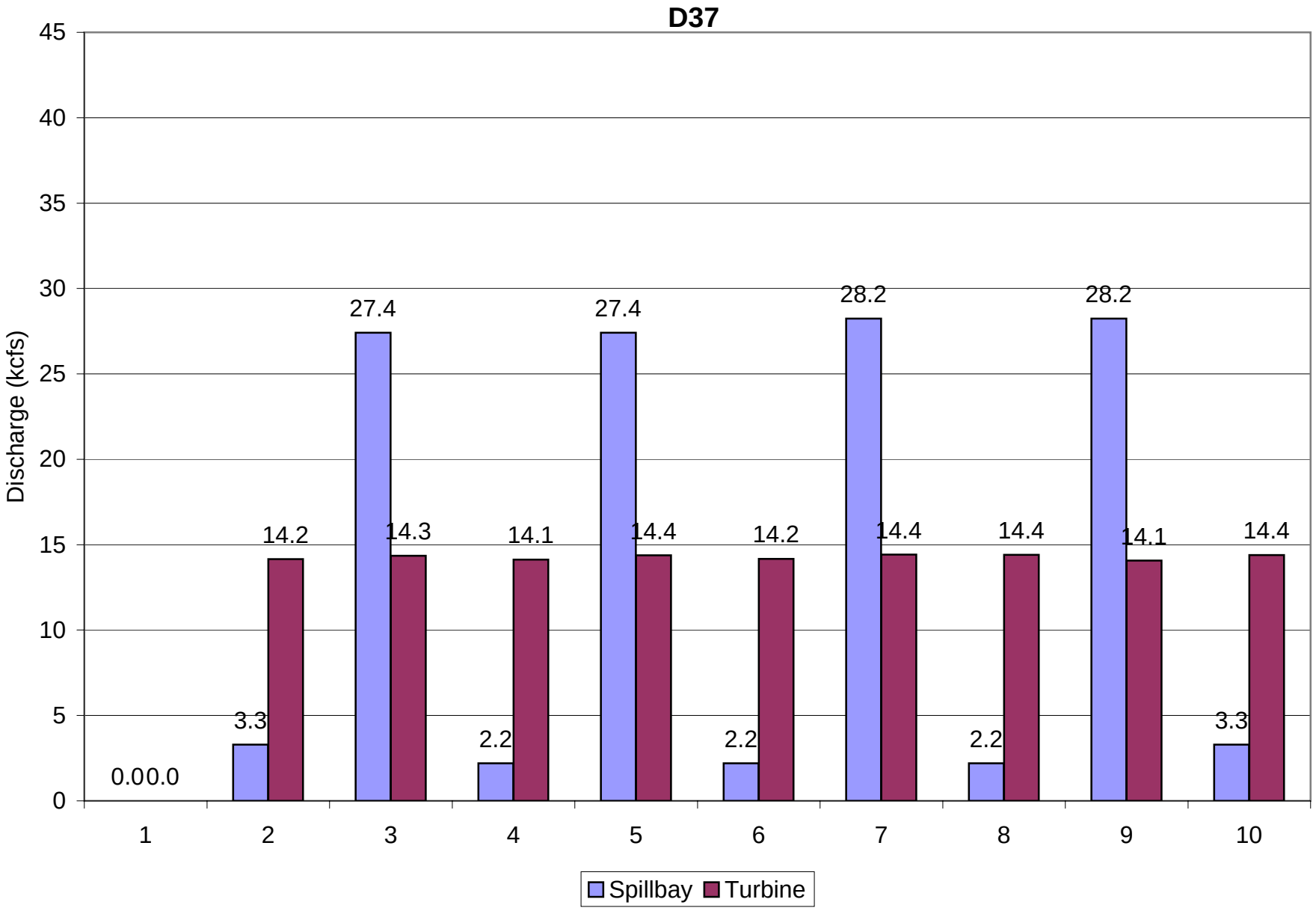

D16
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.00.0
3.1
11.1
23.1
11.2
2.1
11.1
22.4
11.2
7.9
11.1
22.4
11.2
2.1
11.2
23.1
11.1
3.1
11.2
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

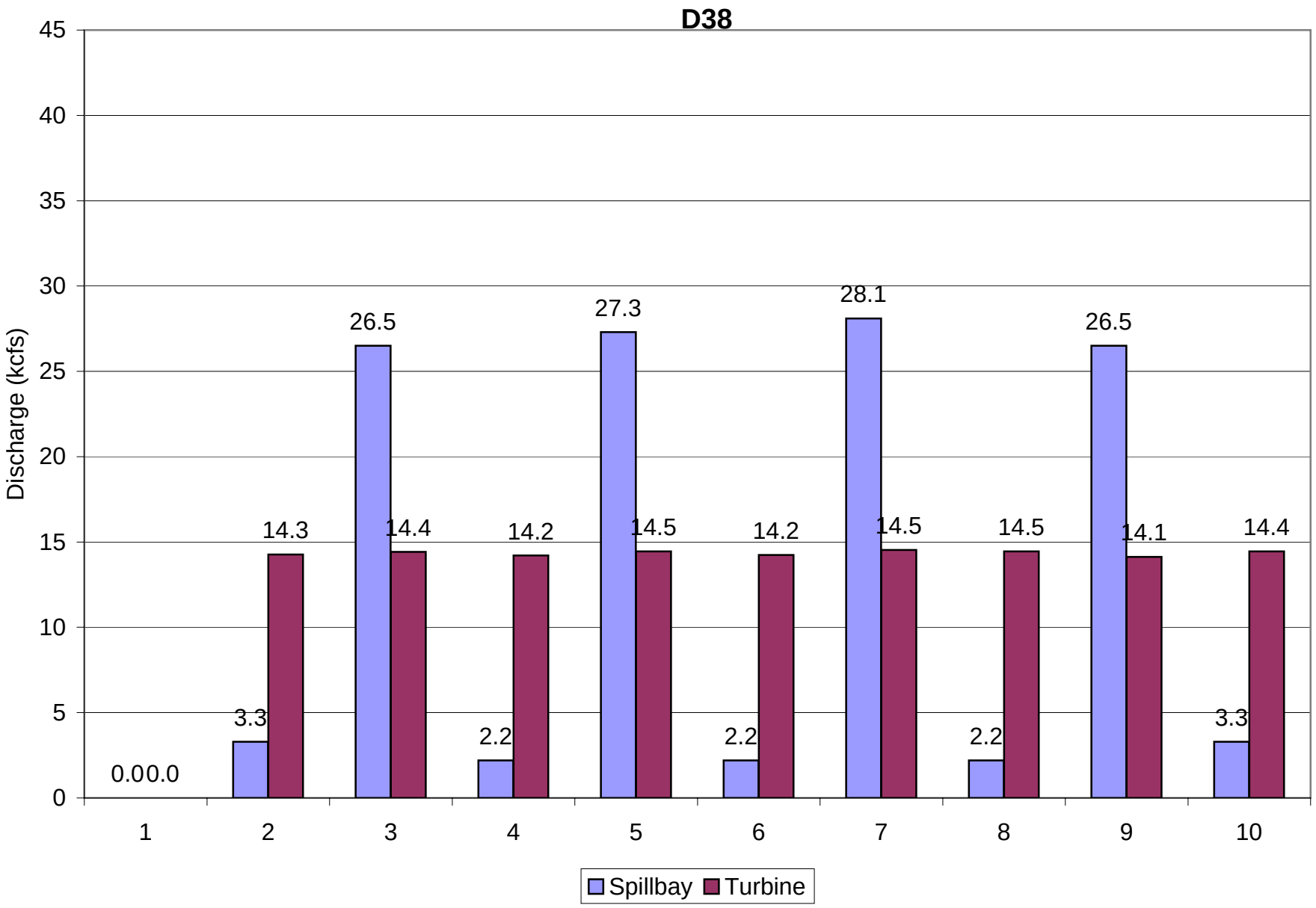

D31
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
3.3
14.0
26.3
14.2
2.2
14.0
28.1
14.2
2.2
14.0
28.1
14.3
2.2
14.3
26.2
13.9
3.3
14.3
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

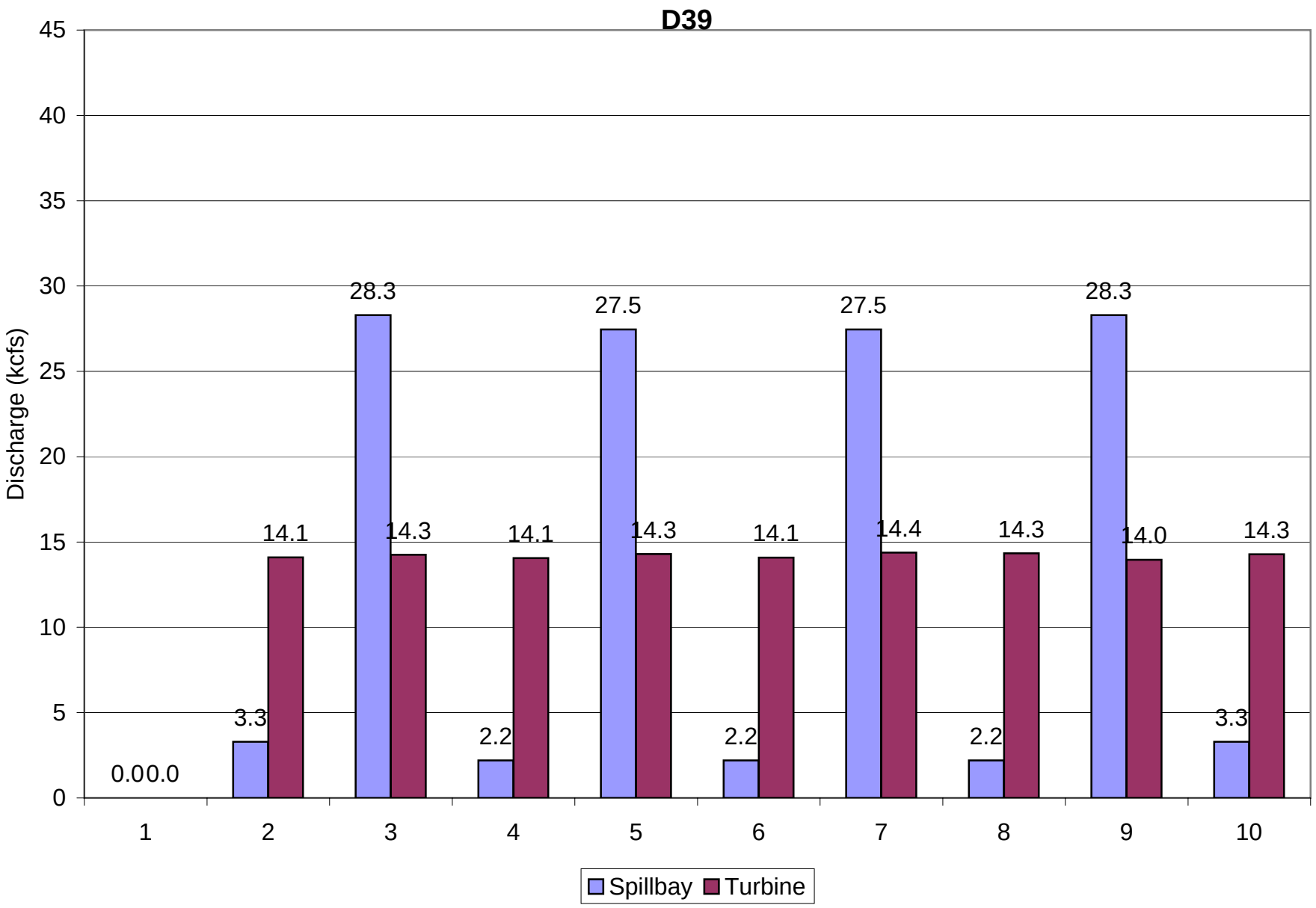

D33
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
3.3
15.0
18.1
15.0
2.2
14.9
17.7
15.0
2.2
15.0
18.2
15.2
2.2
15.2
18.2
14.7
3.3
15.1
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

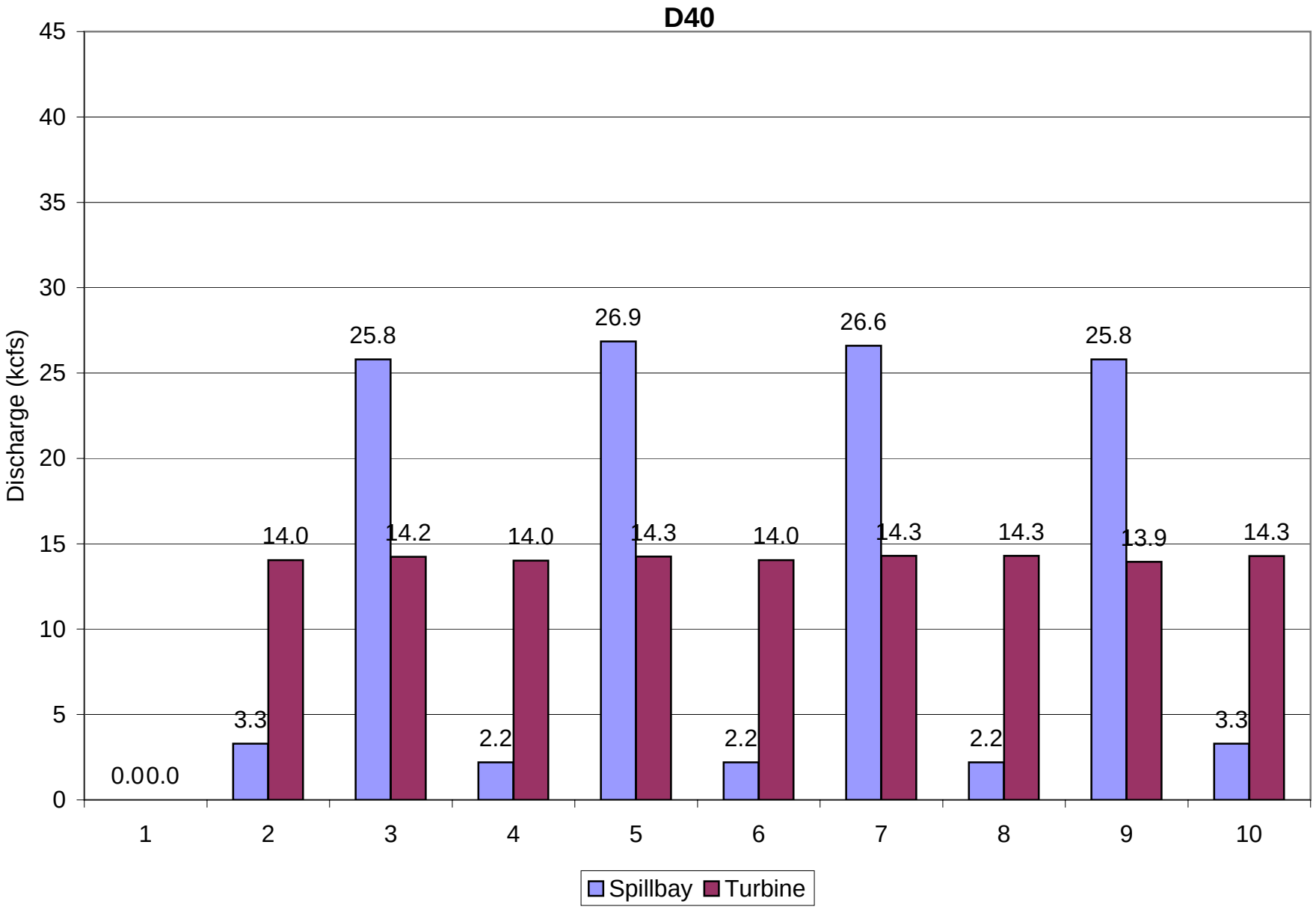

D34
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
3.3
13.9
14.2
14.0
2.2
13.8
14.2
14.0
2.2
13.8
13.3
14.1
2.2
14.0
13.3
13.7
3.3
14.0
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

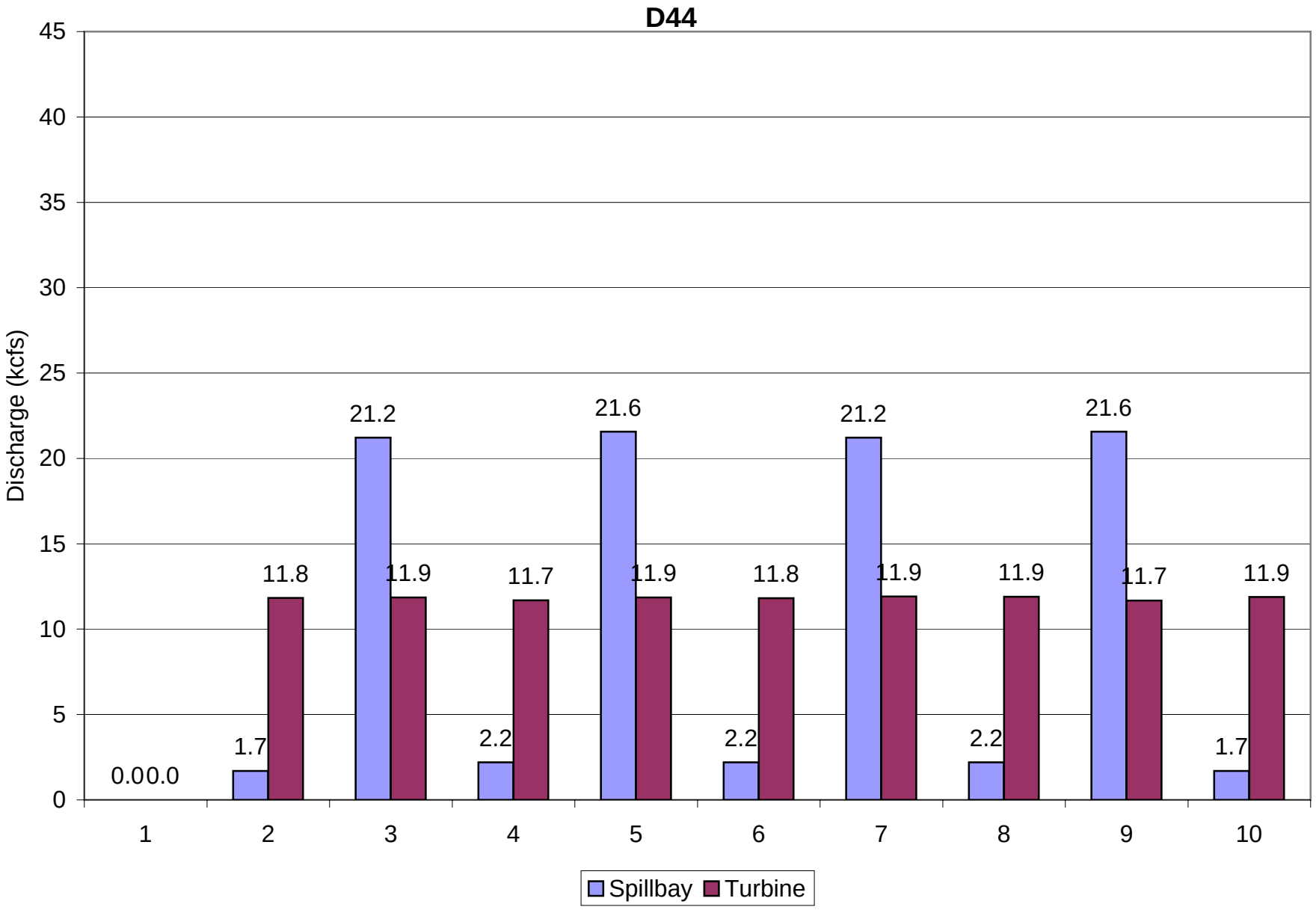

D36
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
3.3
14.0
26.6
14.1
2.2
13.9
25.8
14.2
2.2
13.9
25.8
14.2
2.2
14.2
25.8
13.9
3.3
14.1
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

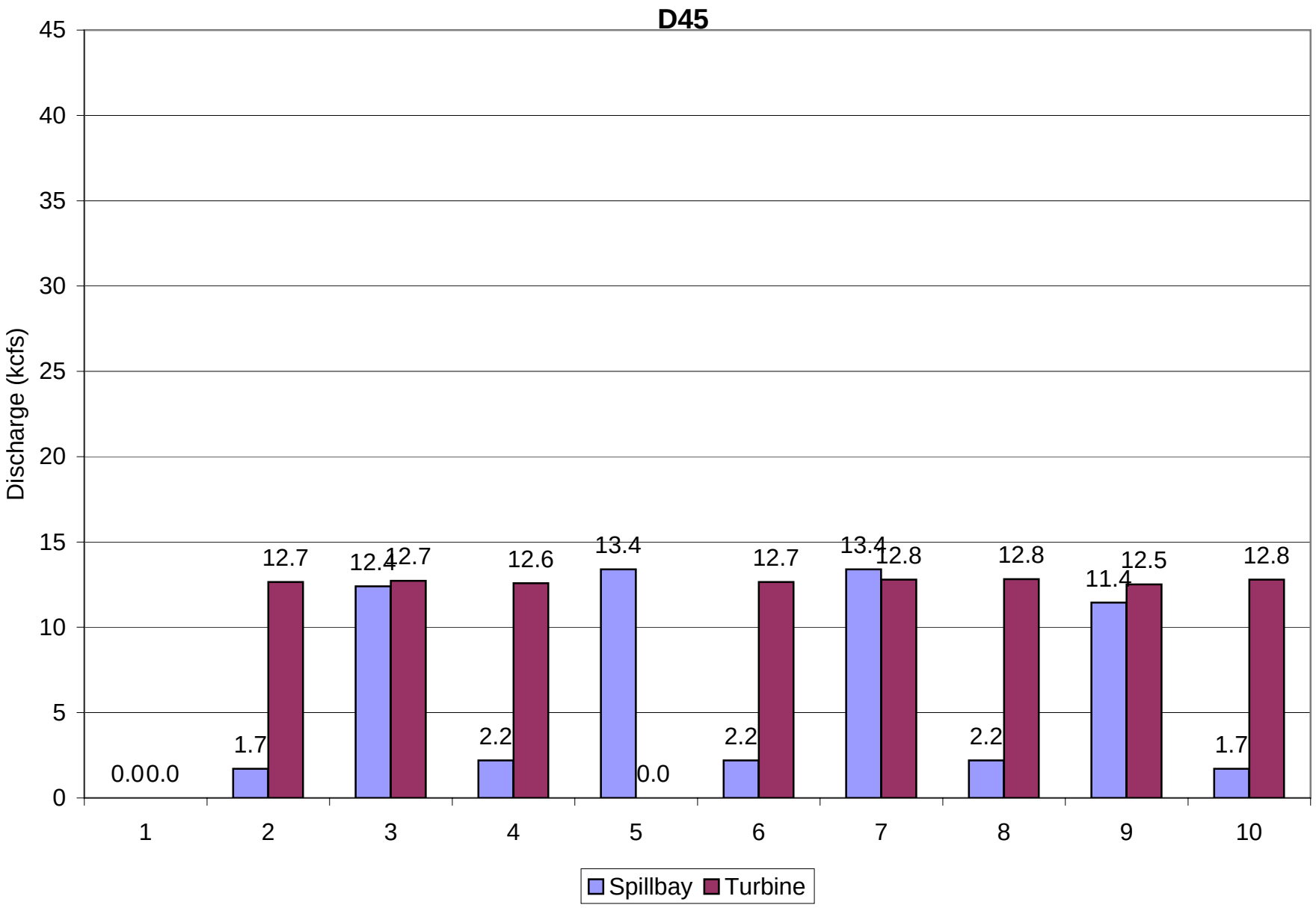

D37
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
3.3
14.2
27.4
14.3
2.2
14.1
27.4
14.4
2.2
14.2
28.2
14.4
2.2
14.4
28.2
14.1
3.3
14.4
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

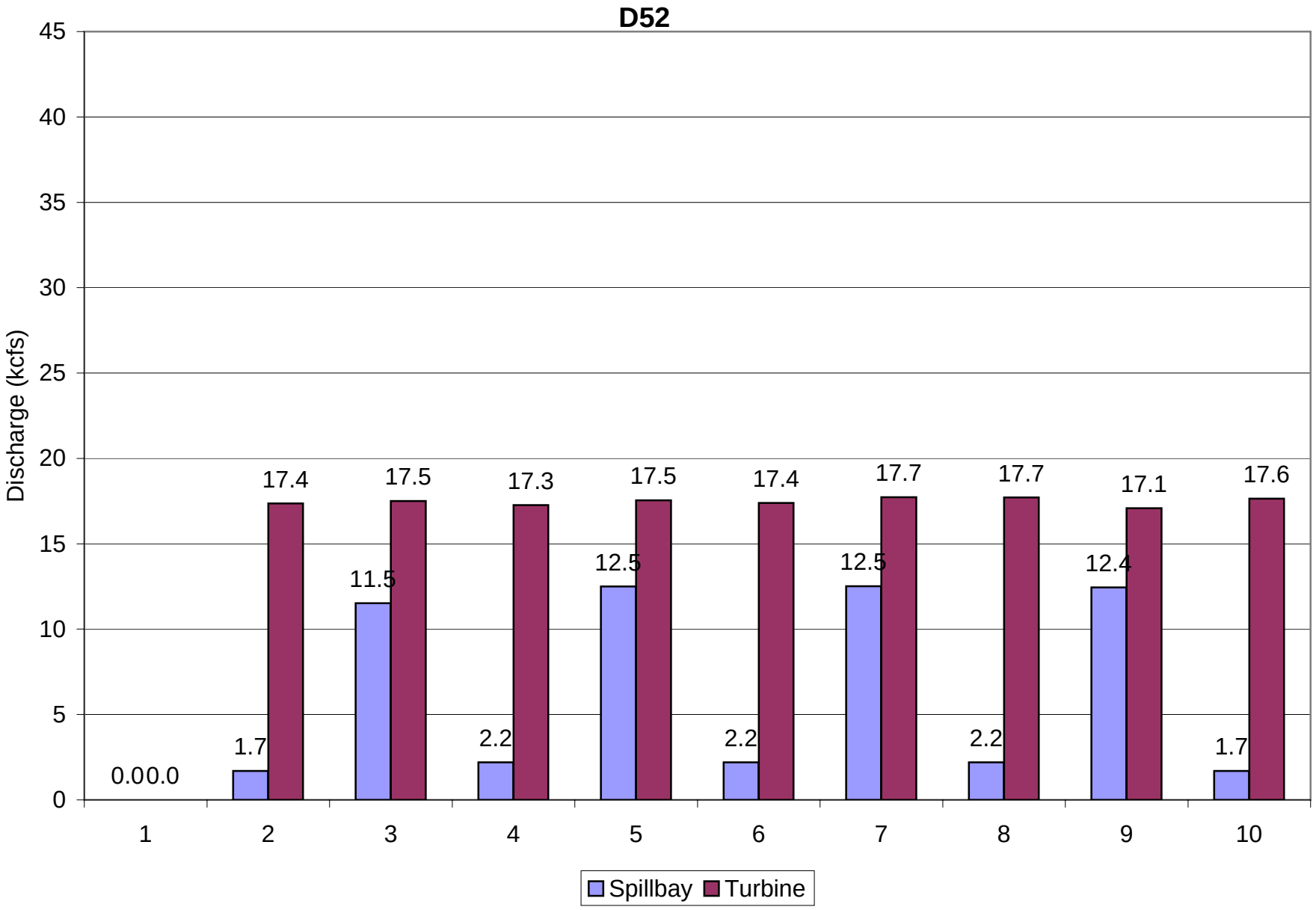

D38
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
3.3
14.3
26.5
14.4
2.2
14.2
27.3
14.5
2.2
14.2
28.1
14.5
2.2
14.5
26.5
14.1
3.3
14.4
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

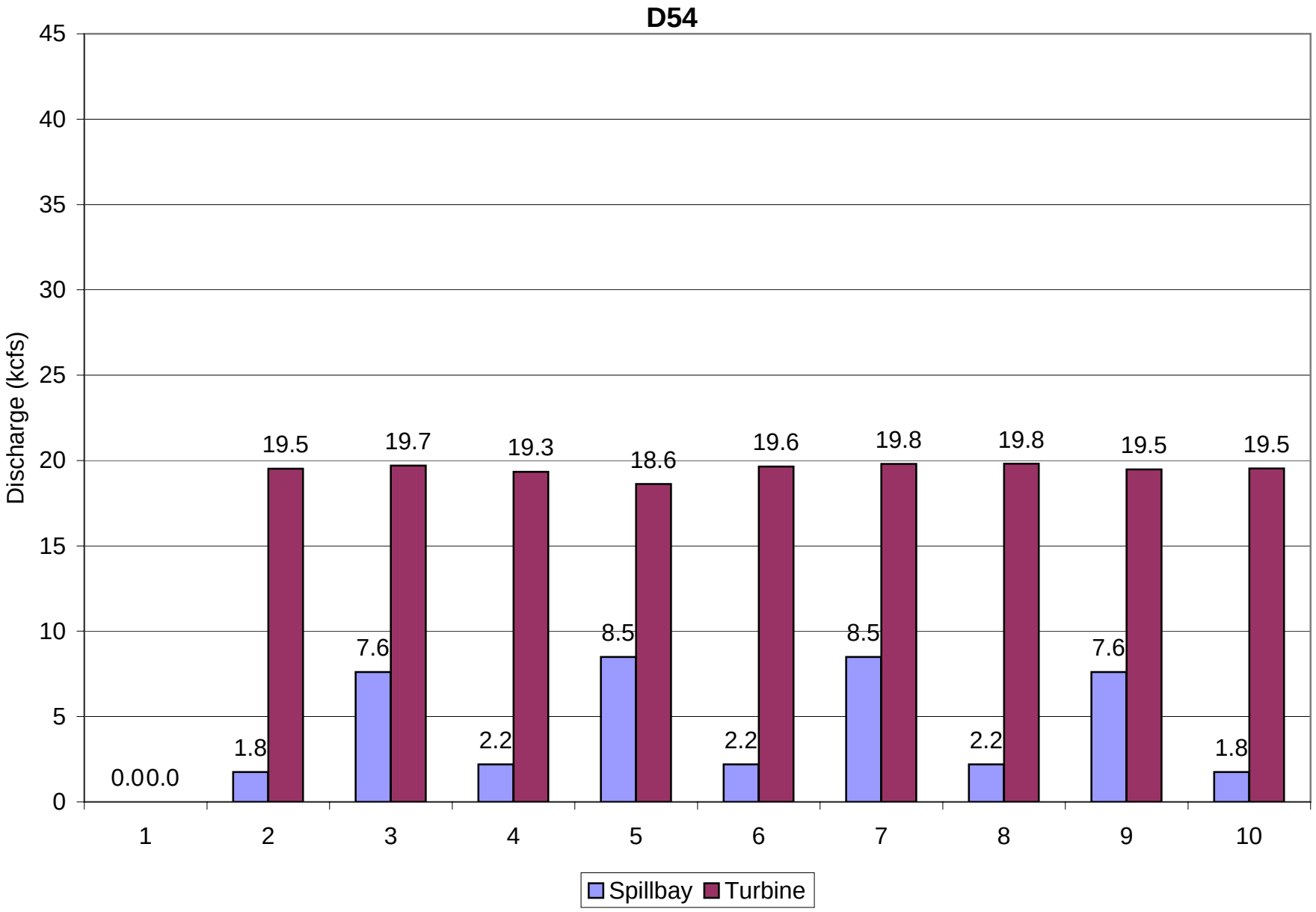

D39
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
3.3
14.1
28.3
14.3
2.2
14.1
27.5
14.3
2.2
14.1
27.5
14.4
2.2
14.3
28.3
14.0
3.3
14.3
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

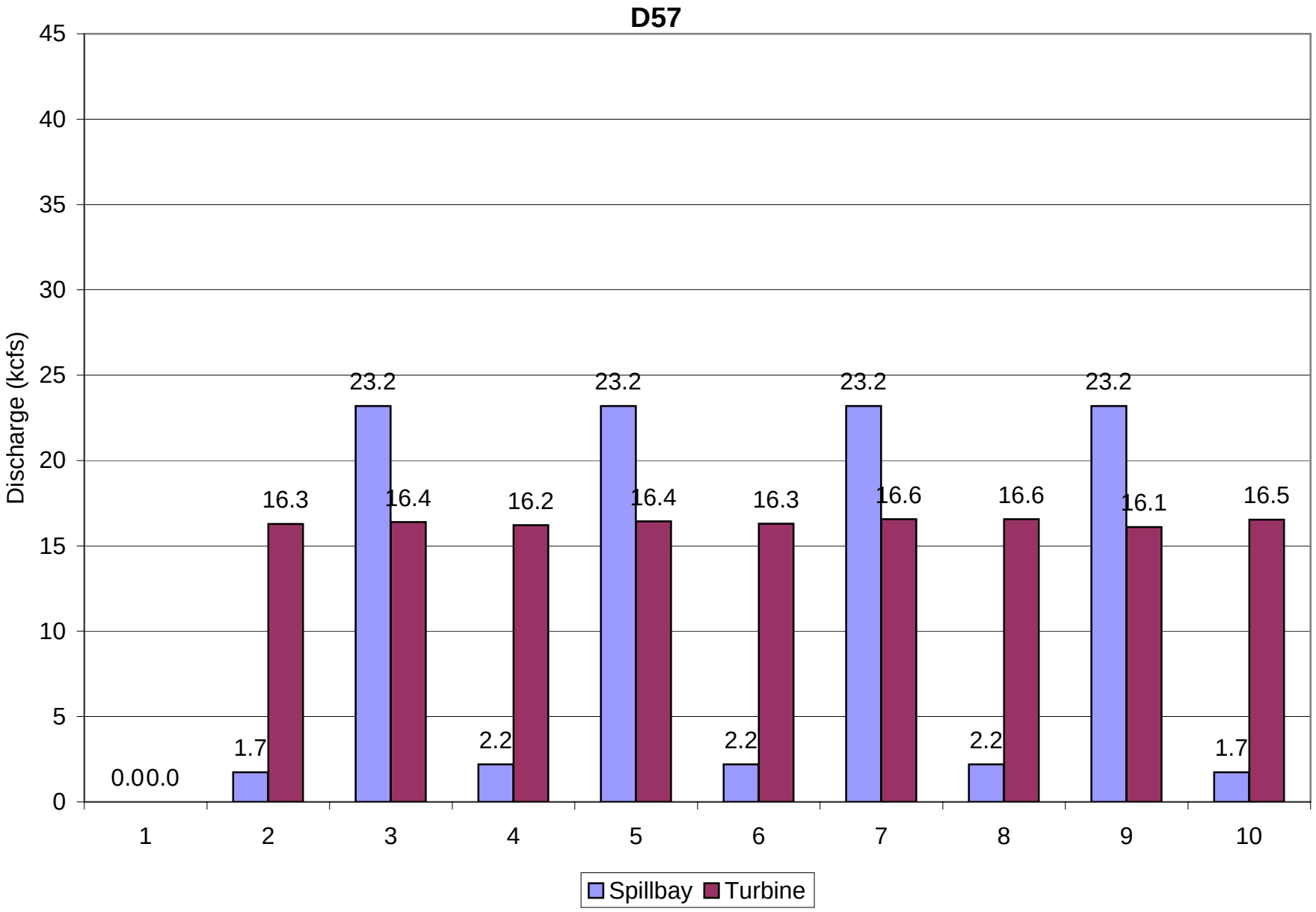

D40
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
3.3
14.0
25.8
14.2
2.2
14.0
26.9
14.3
2.2
14.0
26.6
14.3
2.2
14.3
25.8
13.9
3.3
14.3
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

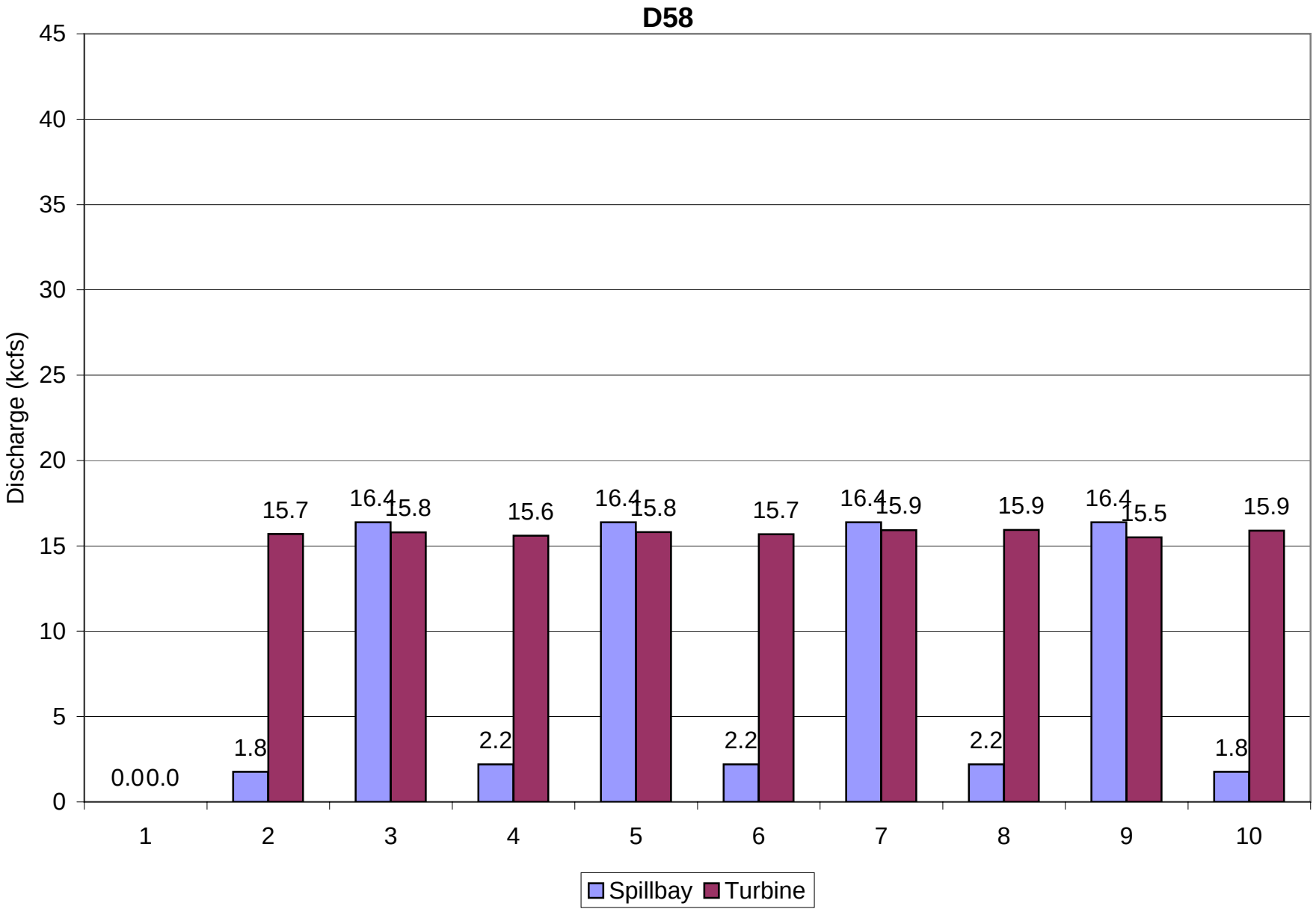

D44
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.7
11.8
21.2
11.9
2.2
11.7
21.6
11.9
2.2
11.8
21.2
11.9
2.2
11.9
21.6
11.7
1.7
11.9
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

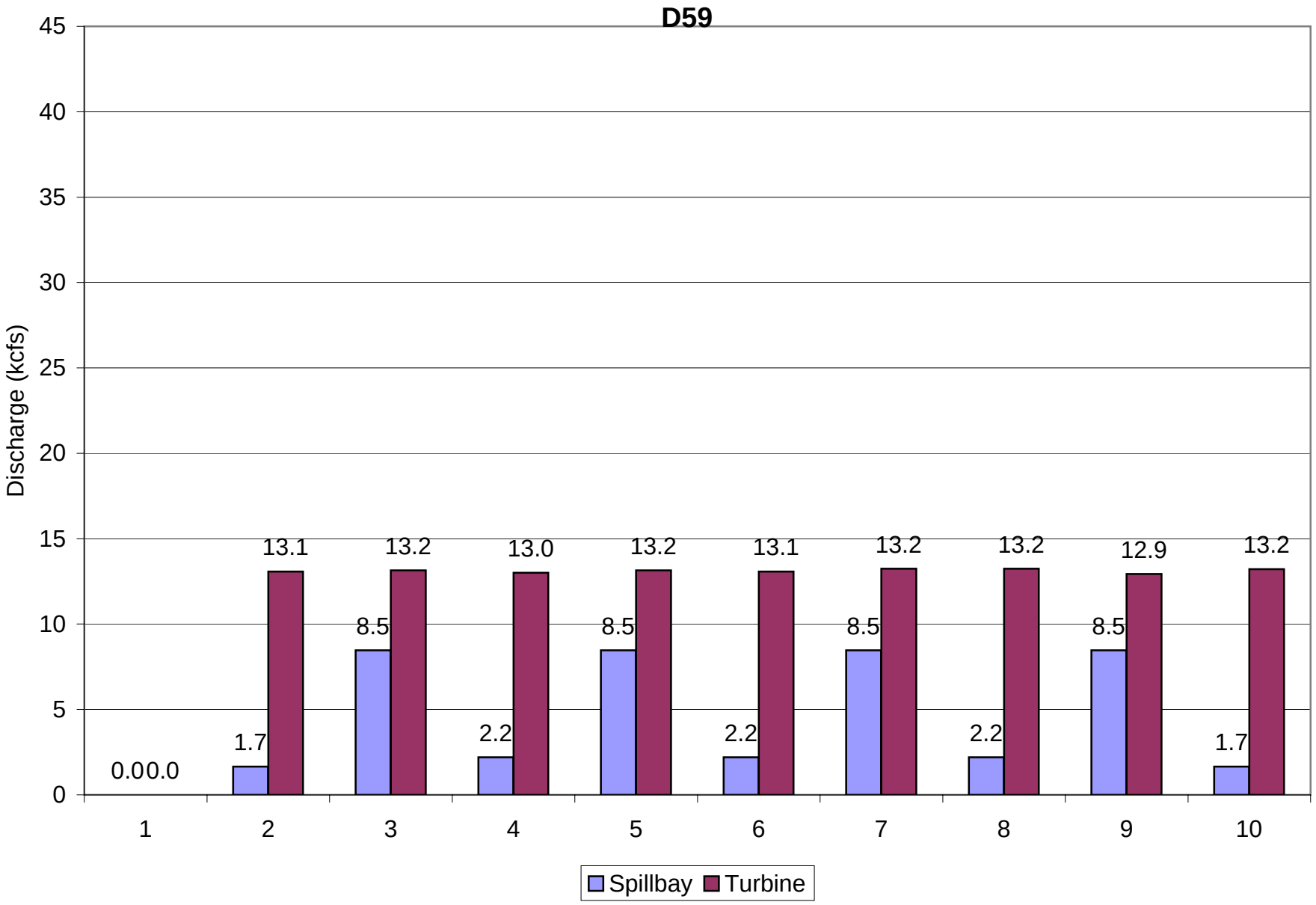

D45
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.7
12.7
12.4
12.7
2.2
12.6
13.4
0.0
2.2
12.7
13.4
12.8
2.2
12.8
11.4
12.5
1.7
12.8
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

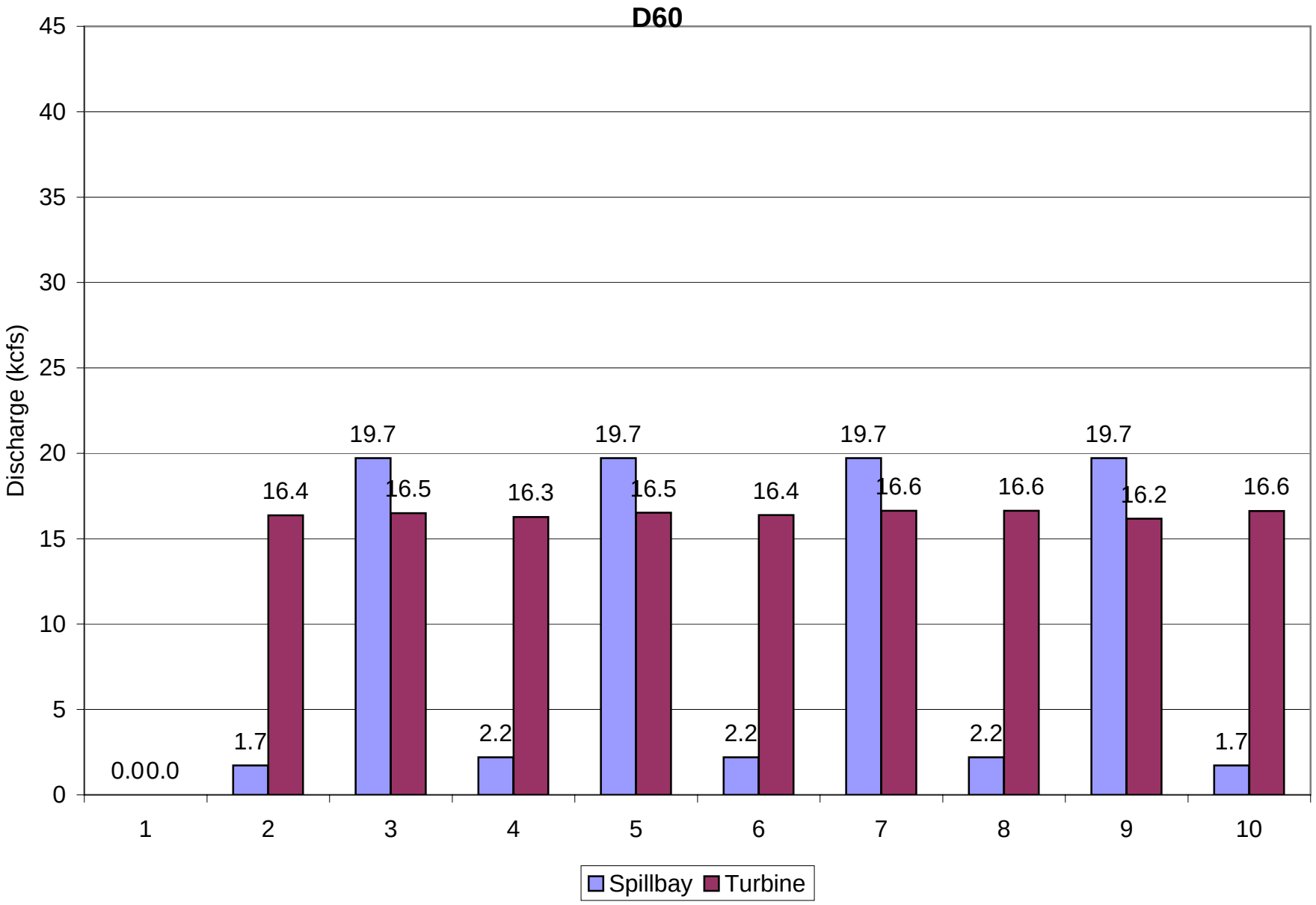

D52
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.7
17.4
11.5
17.5
2.2
17.3
12.5
17.5
2.2
17.4
12.5
17.7
2.2
17.7
12.4
17.1
1.7
17.6
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

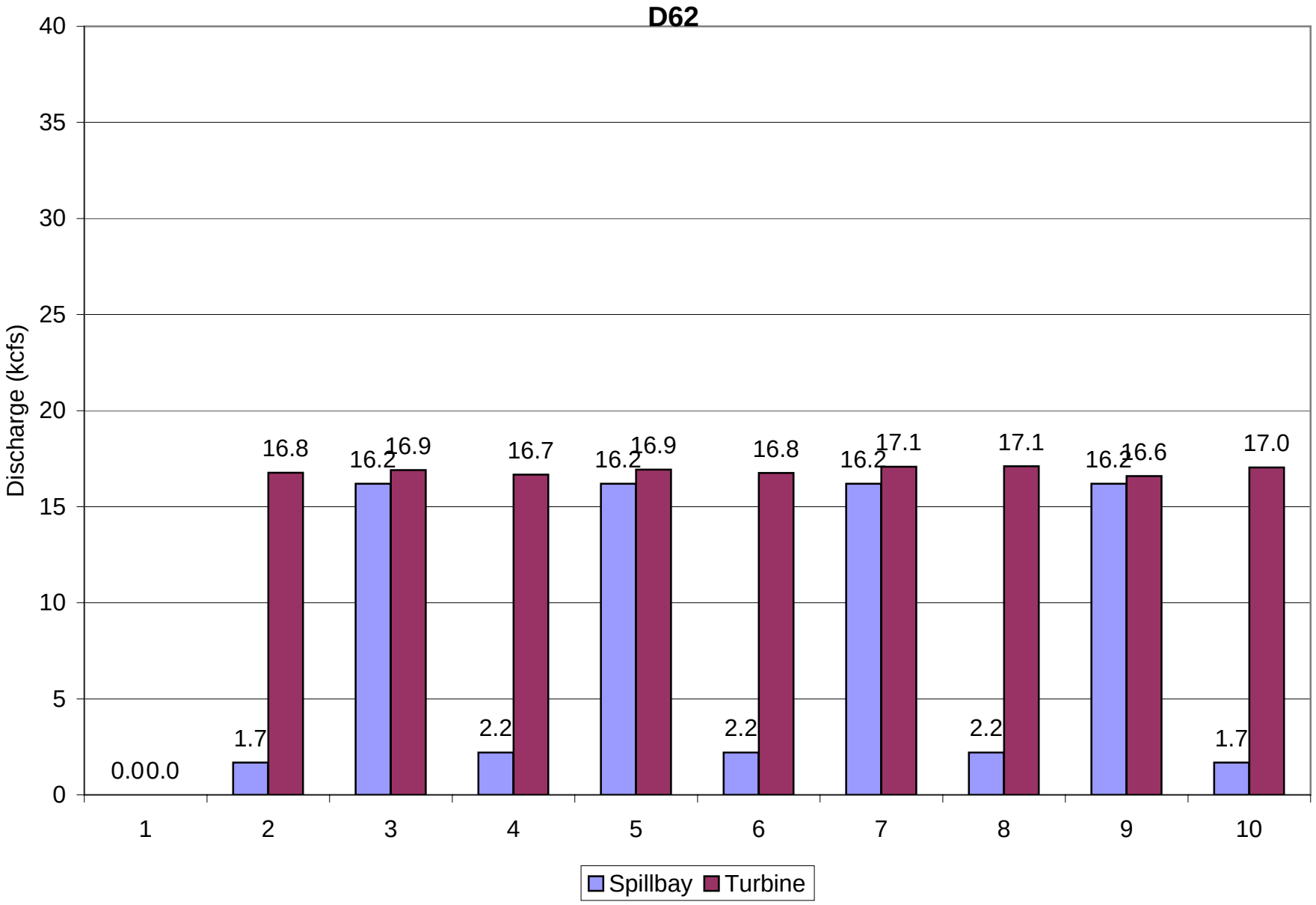

D54
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
1.8
19.5
7.6
19.7
2.2
19.3
8.5
18.6
2.2
19.6
8.5
19.8
2.2
19.8
7.6
19.5
1.8
19.5
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

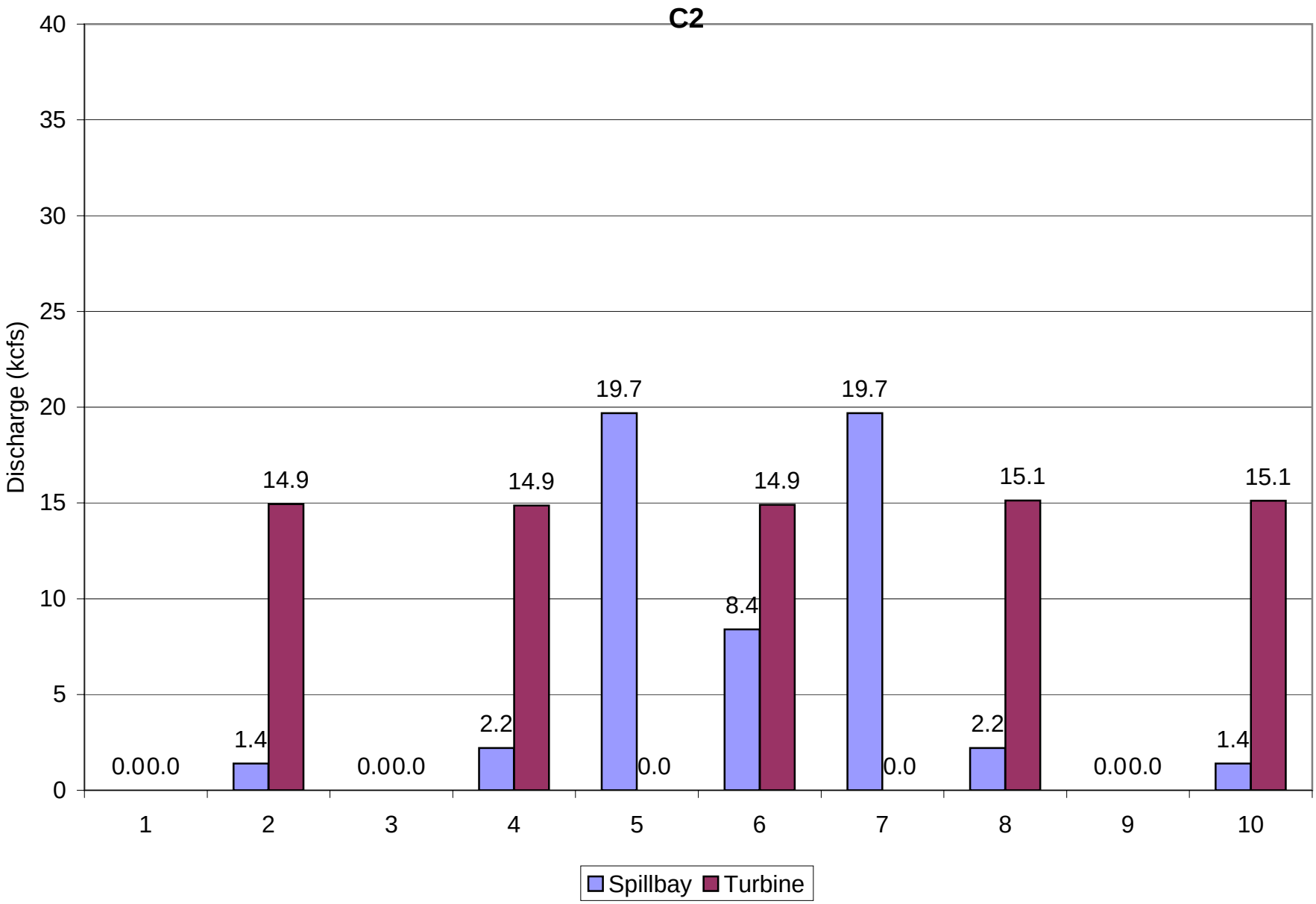

D57
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.7
16.3
23.2
16.4
2.2
16.2
23.2
16.4
2.2
16.3
23.2
16.6
2.2
16.6
23.2
16.1
1.7
16.5
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

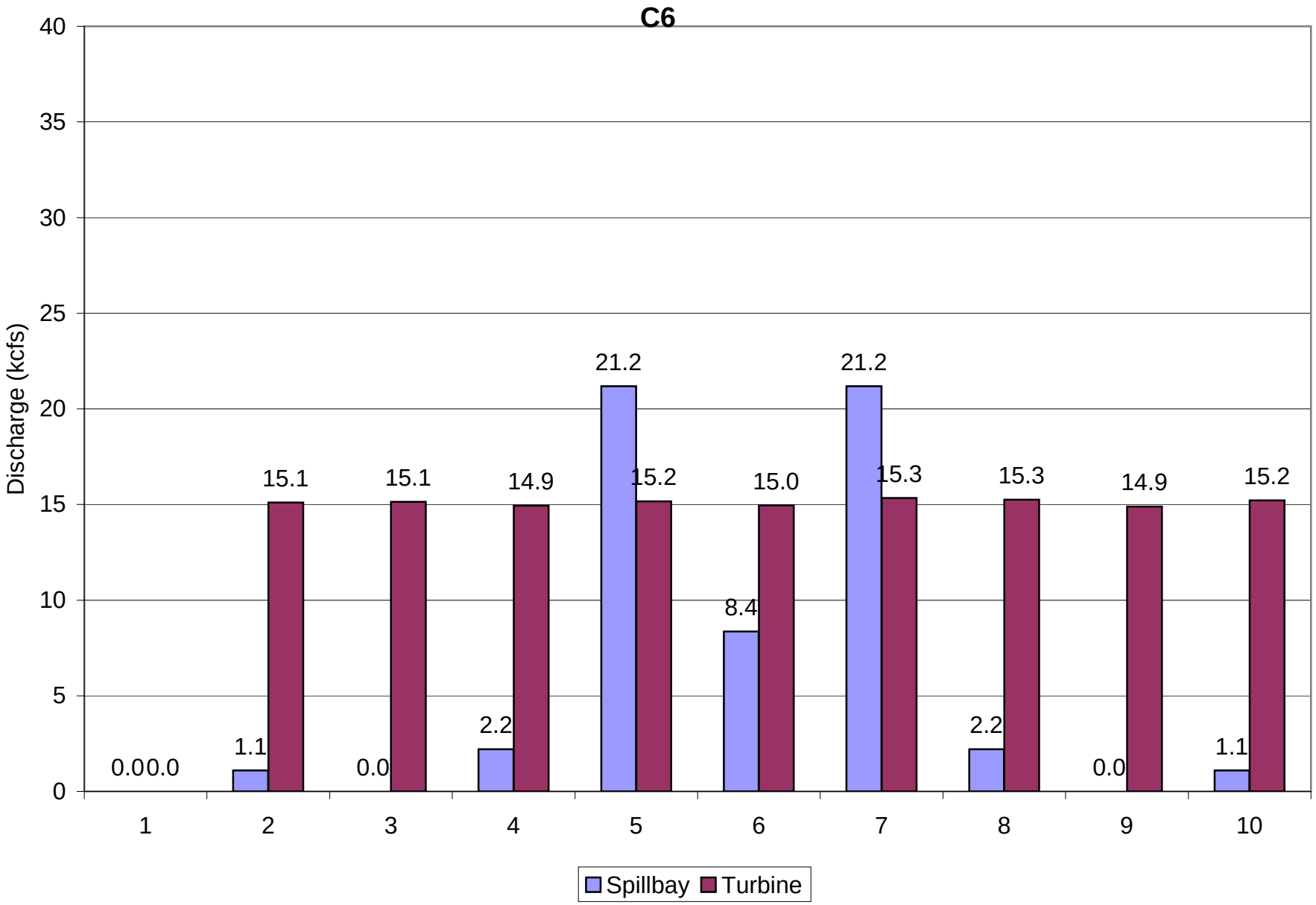

D58
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.8
15.7
16.4
15.8
2.2
15.6
16.4
15.8
2.2
15.7
16.4
15.9
2.2
15.9
16.4
15.5
1.8
15.9
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

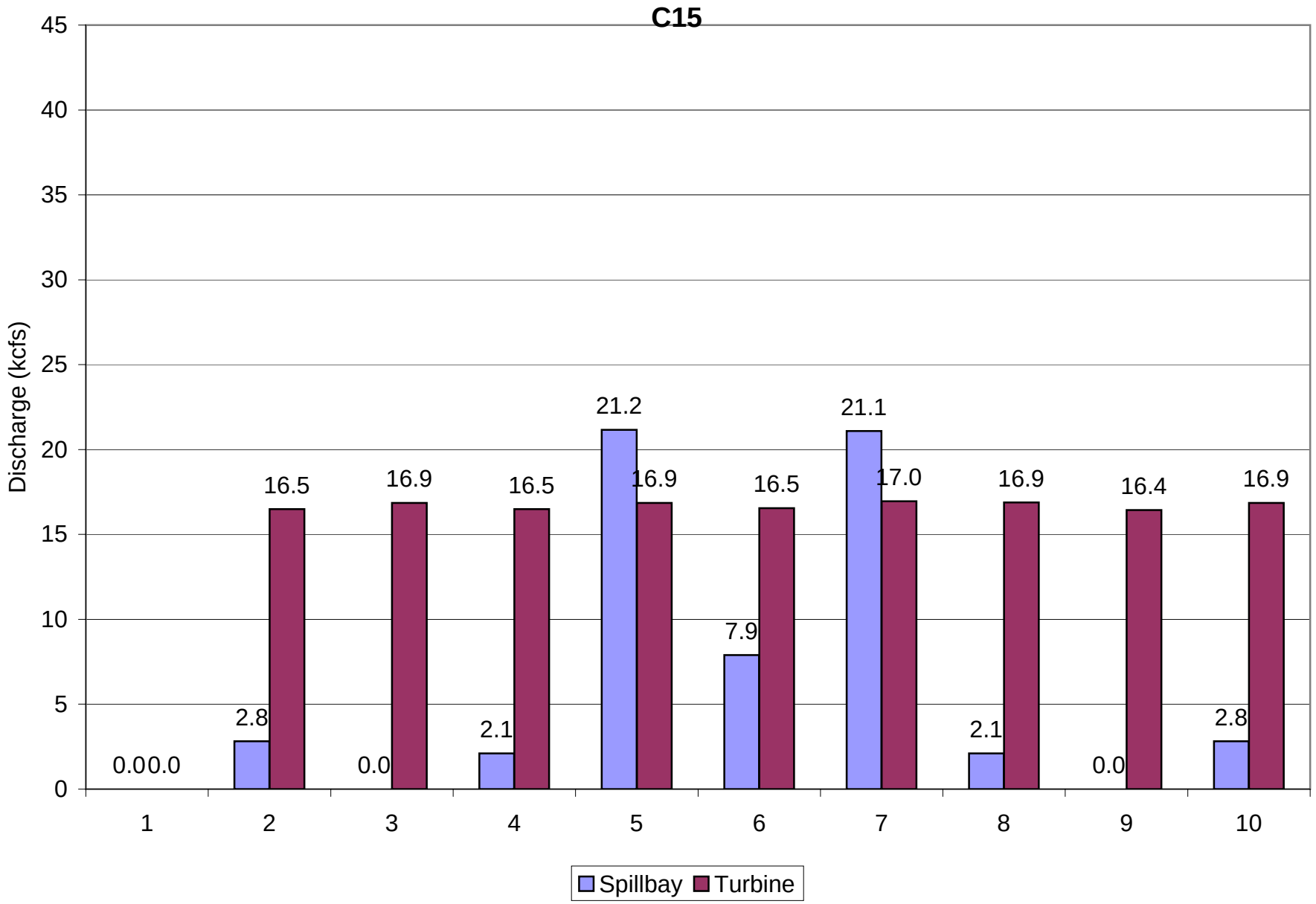

D59
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.7
13.1
8.5
13.2
2.2
13.0
8.5
13.2
2.2
13.1
8.5
13.2
2.2
13.2
8.5
12.9
1.7
13.2
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

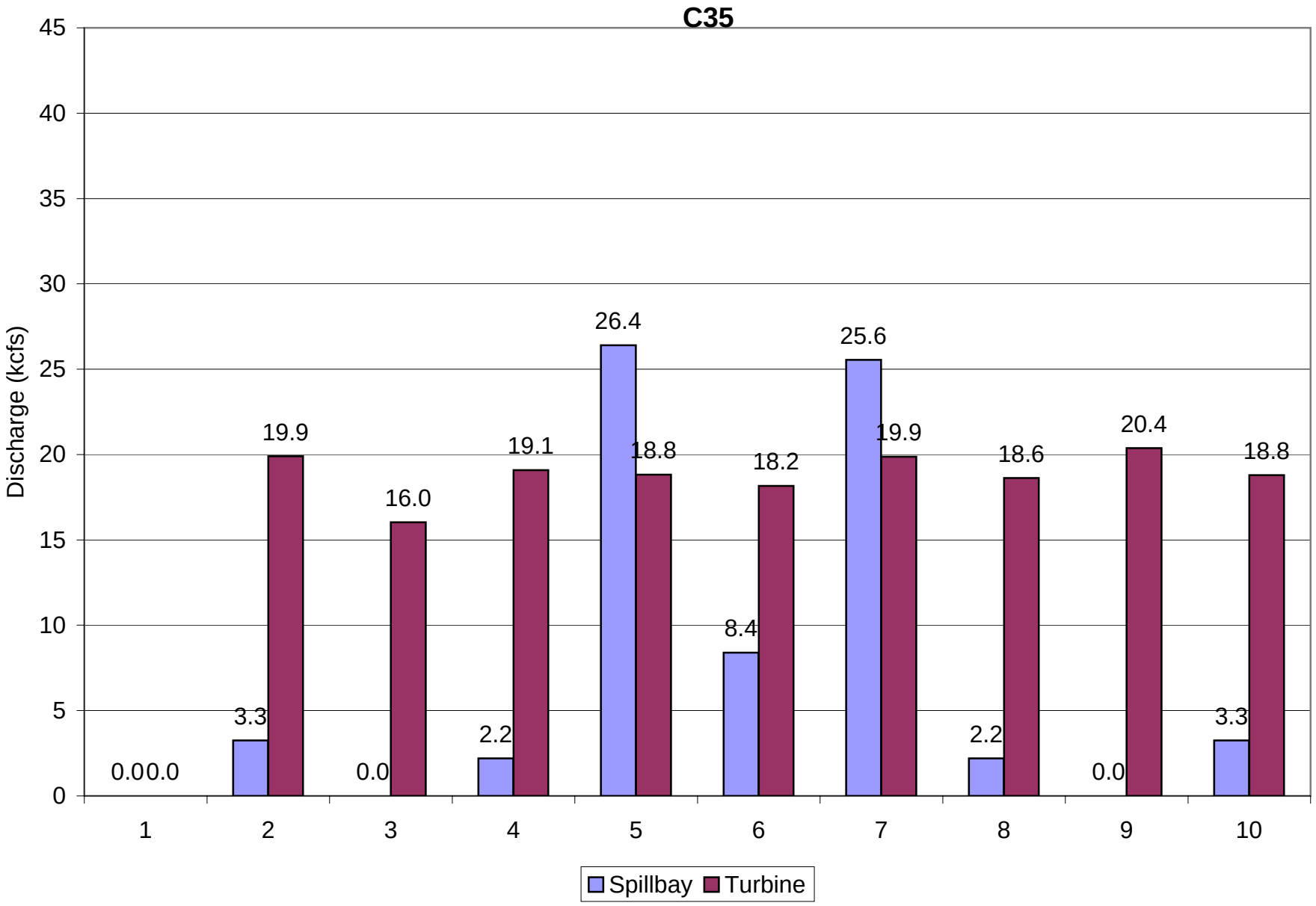

D60
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.7
16.4
19.7
16.5
2.2
16.3
19.7
16.5
2.2
16.4
19.7
16.6
2.2
16.6
19.7
16.2
1.7
16.6
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

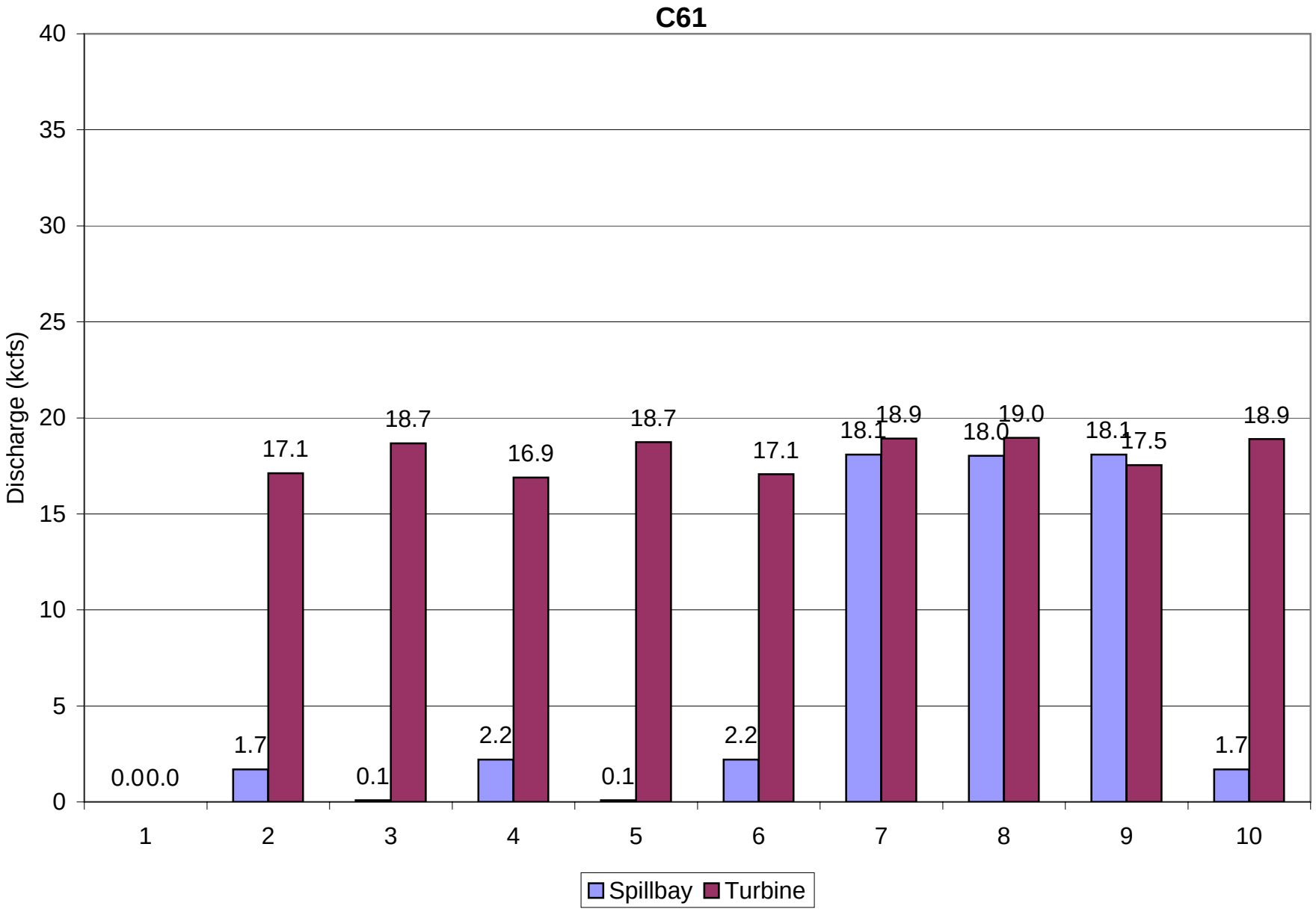

D62
Discharge (kcfs)
40
35
30
25
20
15
10
5
0
0.0
0.0
1.7
16.8
16.2
16.9
2.2
16.7
16.2
16.9
2.2
16.8
16.2
17.1
2.2
17.1
16.2
16.6
1.7
17.0
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

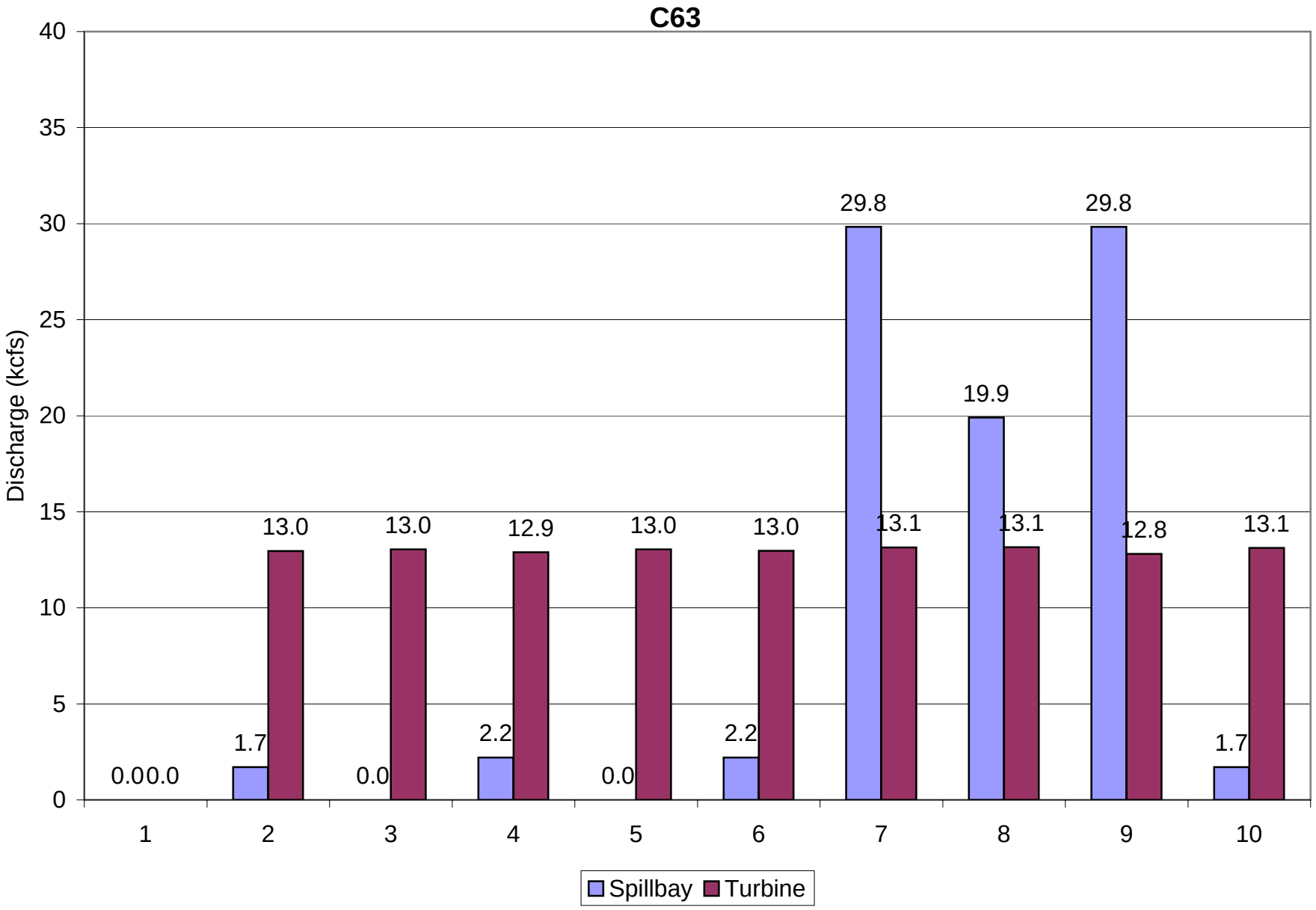

C2
Discharge (kcfs)
40
35
30
25
20
15
10
5
0
0.0
0.0
1.4
14.9
0.0
0.0
2.2
14.9
19.7
0.0
8.4
14.9
19.7
0.0
2.2
15.1
0.0
0.0
1.4
15.1
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

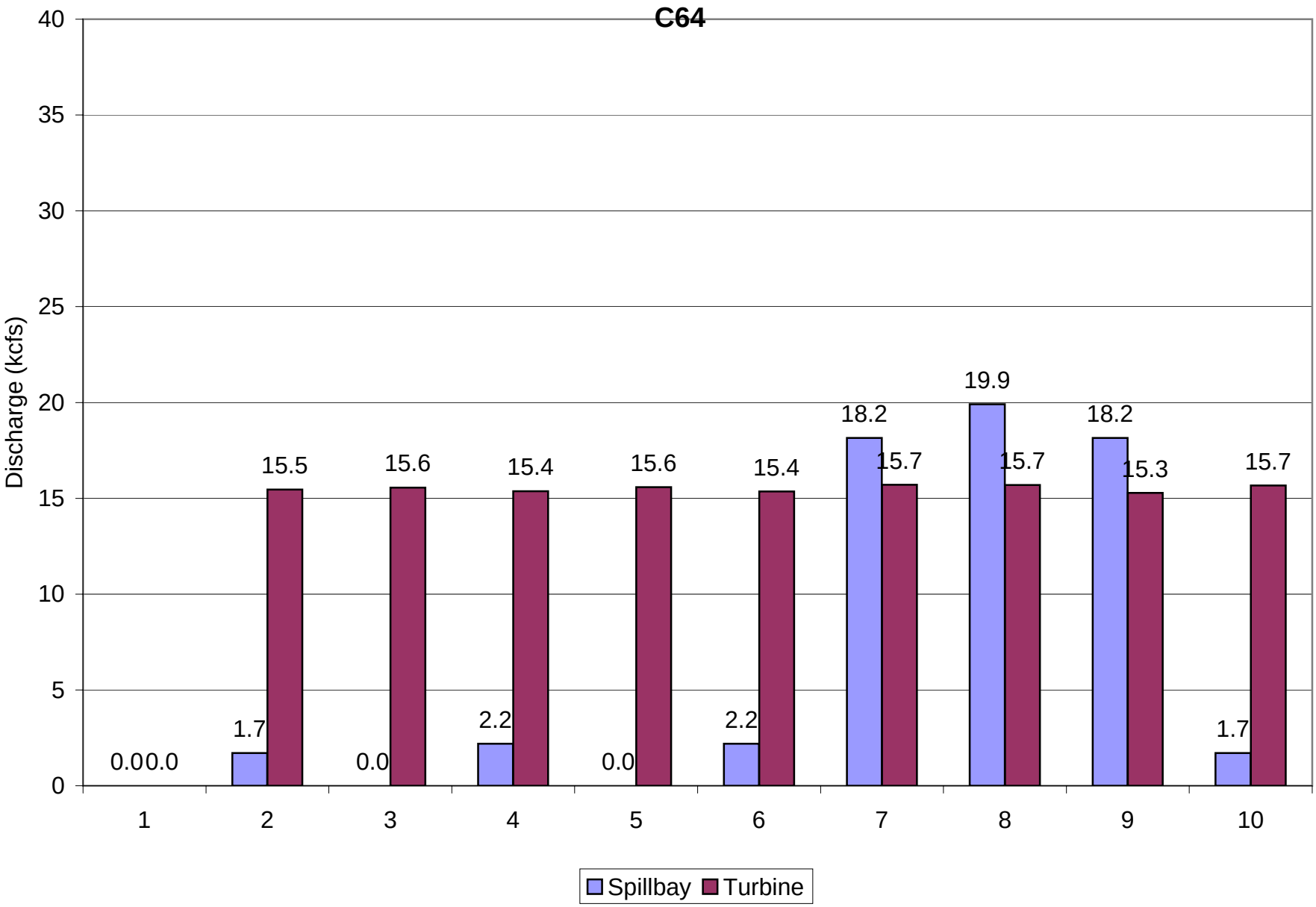

C6
Discharge (kcfs)
40
35
30
25
20
15
10
5
0
0.0
0.0
1.1
15.1
0.0
15.1
2.2
14.9
21.2
15.2
8.4
15.0
21.2
15.3
2.2
15.3
0.0
14.9
1.1
15.2
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

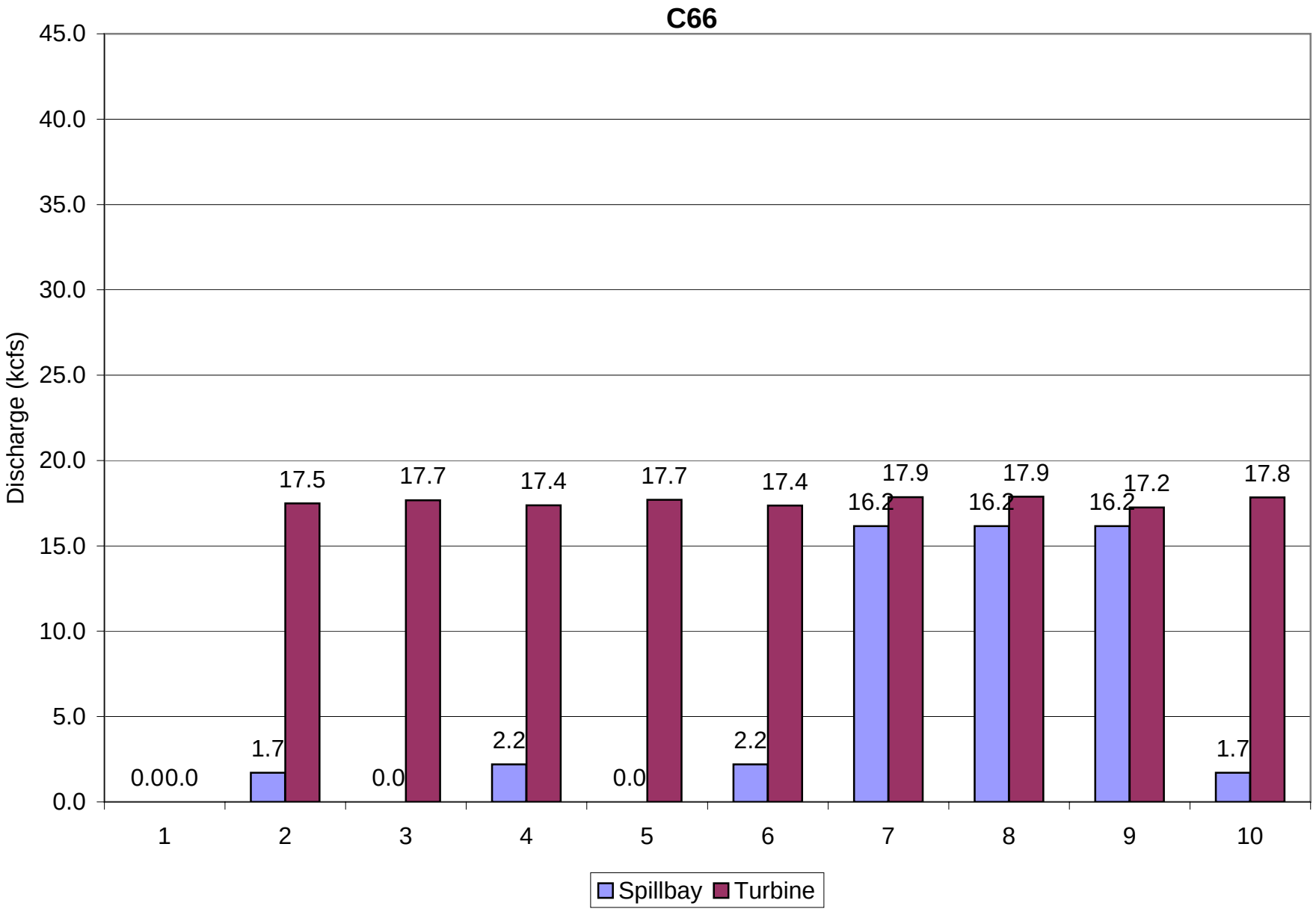

C15
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
2.8
16.5
0.0
16.9
2.1
16.5
21.2
16.9
7.9
16.5
21.1
17.0
2.1
16.9
0.0
16.4
2.8
16.9
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

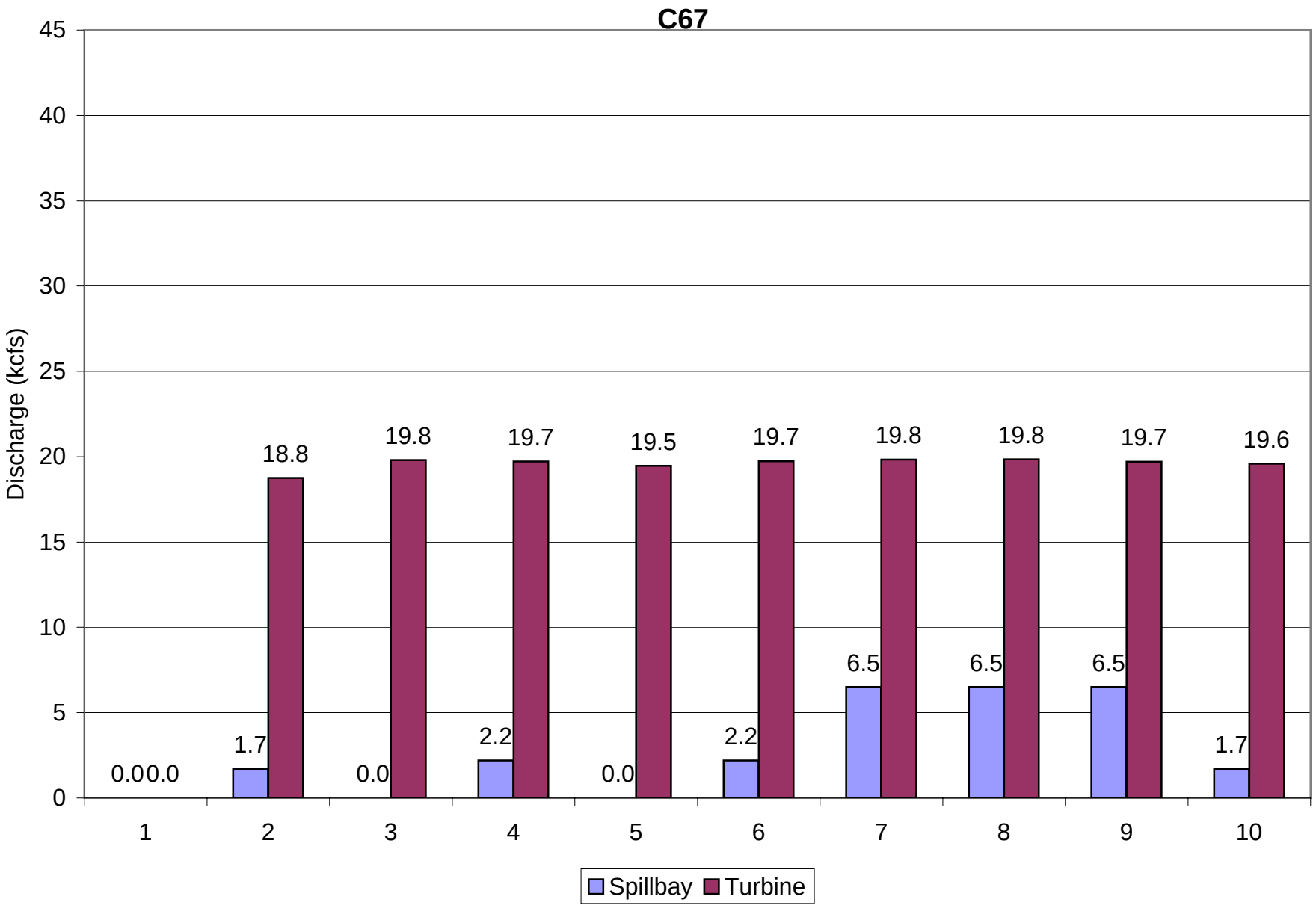

C35
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
3.3
19.9
0.0
16.0
2.2
19.1
26.4
18.8
8.4
18.2
25.6
19.9
2.2
18.6
0.0
20.4
3.3
18.8
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

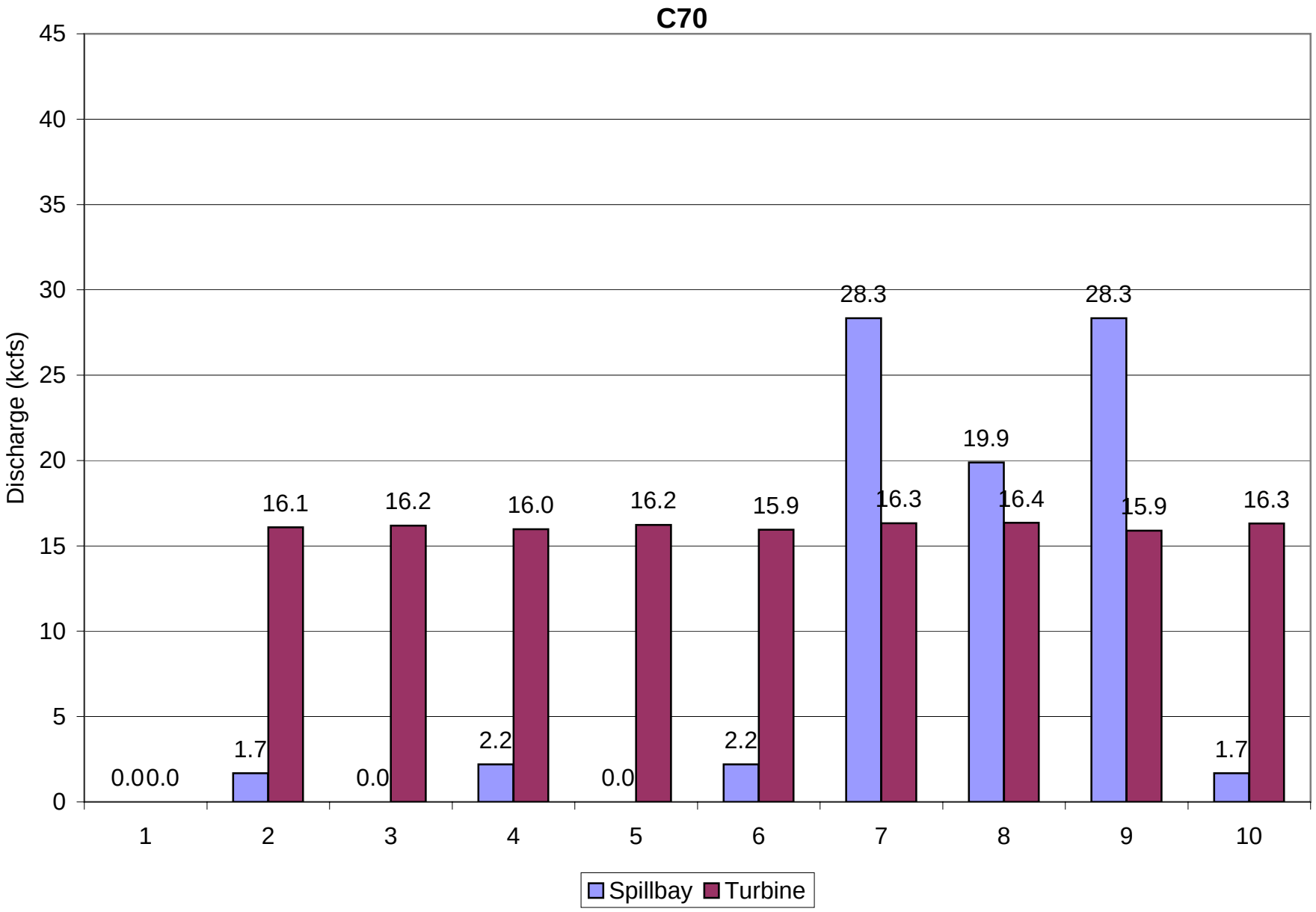

C61
Discharge (kcfs)
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
0.0
0.0
1.7
17.1
0.1
18.7
2.2
16.9
0.1
18.7
2.2
17.1
18.1
18.9
18.0
19.0
18.1
17.5
1.7
18.9
Spillbay
Turbine

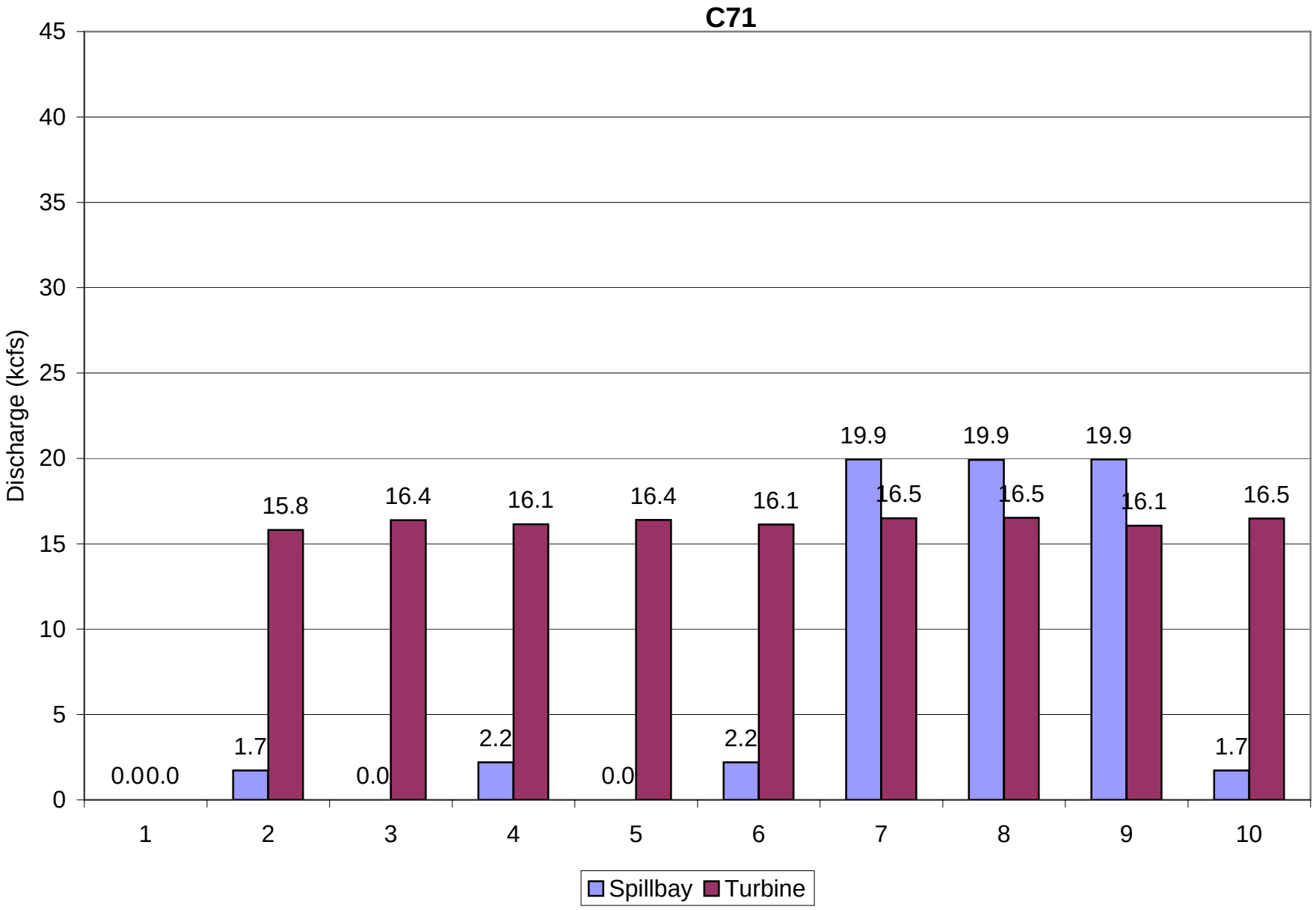

C63
Discharge (kcfs)
40
35
30
25
20
15
10
5
0
0.0
0.0
1.7
13.0
0.0
13.0
2.2
12.9
0.0
13.0
2.2
13.0
29.8
13.1
19.9
13.1
29.8
12.8
1.7
13.1
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

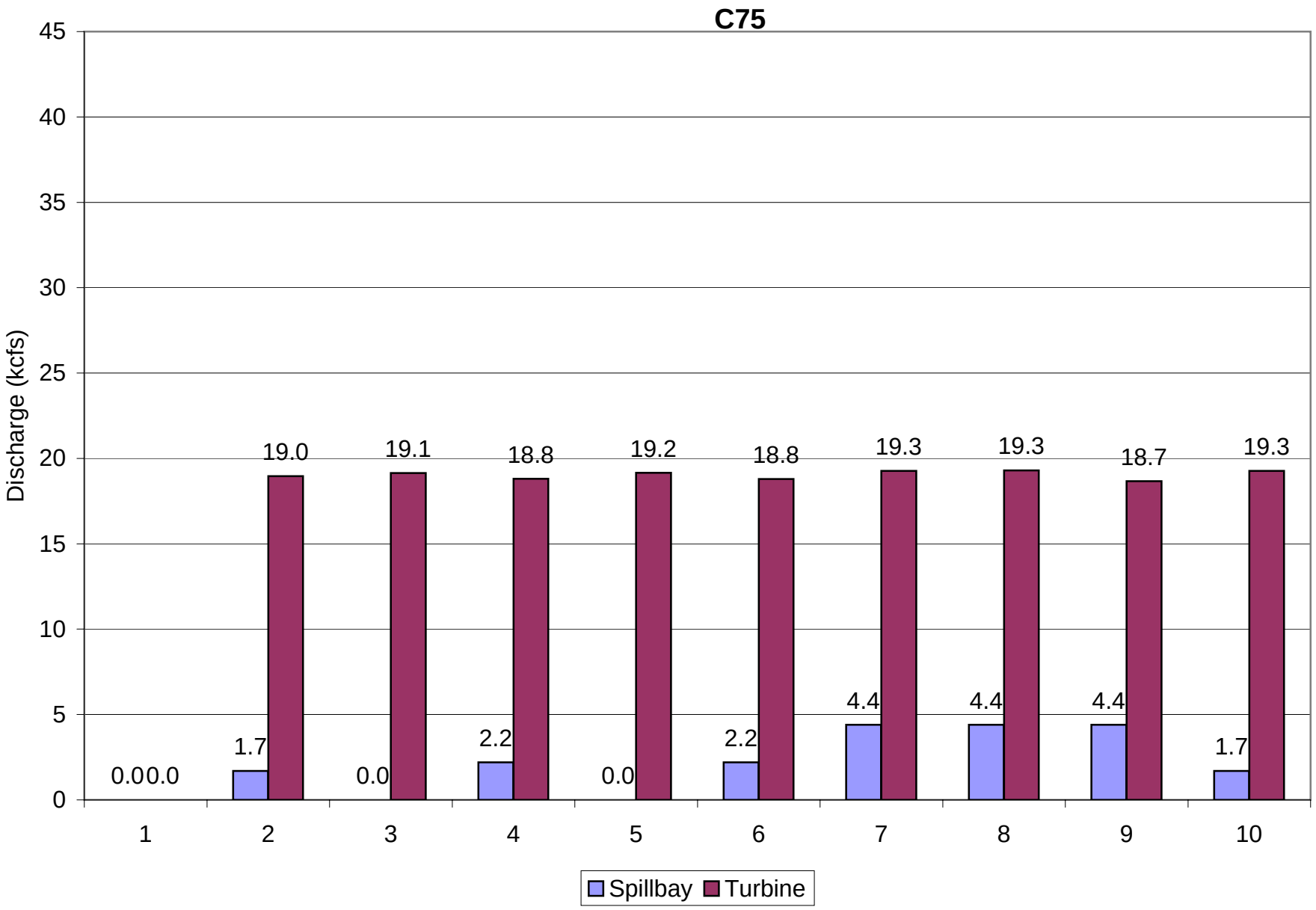

C64
Discharge (kcfs)
40
35
30
25
20
15
10
5
0
0.0
0.0
1.7
15.5
0.0
15.6
2.2
15.4
0.0
15.6
2.2
15.4
18.2
15.7
19.9
15.7
18.2
15.3
1.7
15.7
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

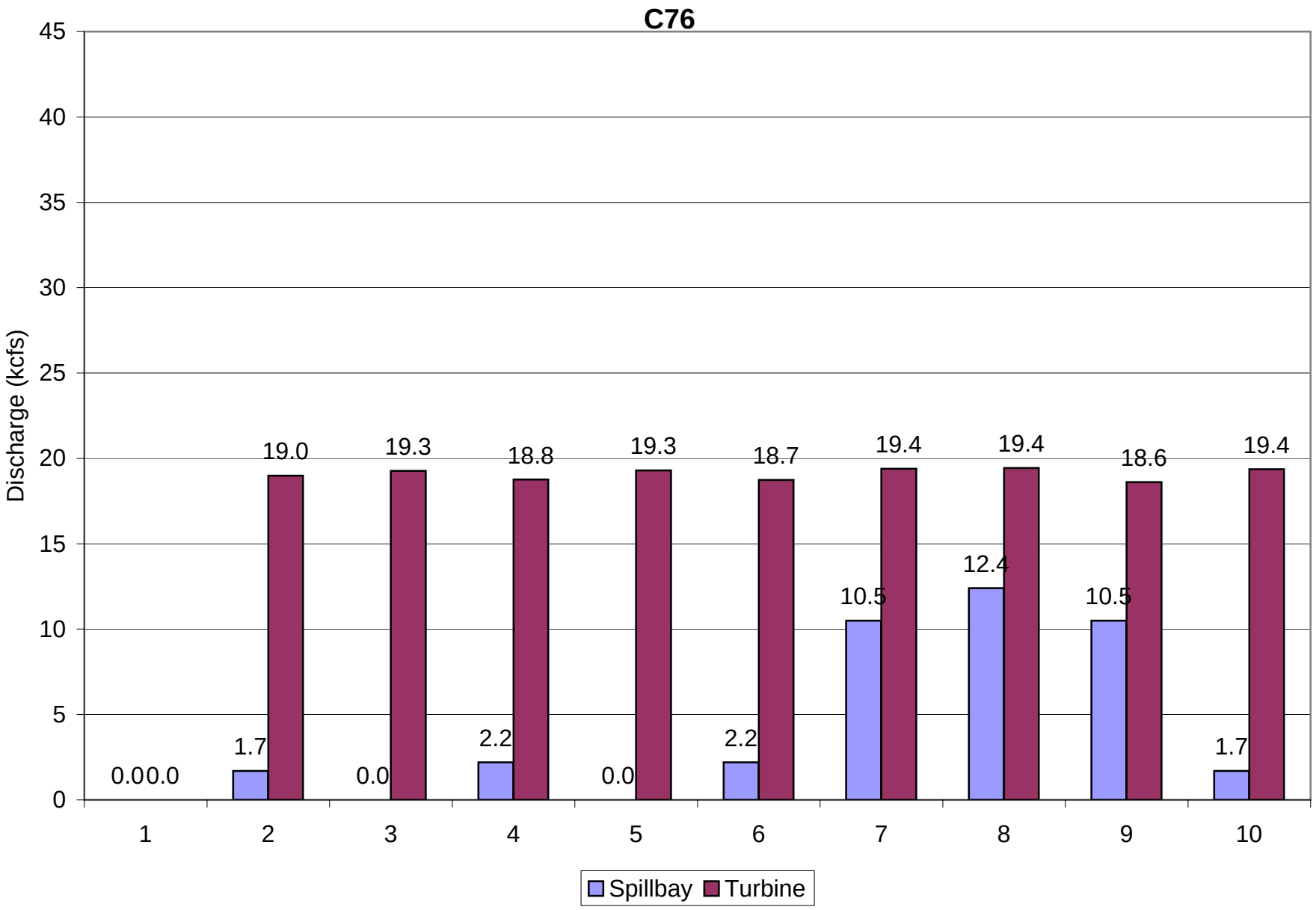

C66
Discharge (kcfs)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0.0
0.0
1.7
17.5
0.0
17.7
2.2
17.4
0.0
17.7
2.2
17.4
16.2
17.9
16.2
17.9
16.2
17.2
1.7
17.8
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine


C67
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.00.0
1.7
18.8
0.0
19.8
2.2
19.7
0.0
19.5
2.2
19.7
6.5
19.8
6.5
19.8
6.5
19.7
1.7
19.6
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine


C70
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.00.0
1.7
16.1
0.0
16.2
2.2
16.0
0.0
16.2
2.2
15.9
28.3
16.3
19.9
16.4
28.3
15.9
1.7
16.3
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine


C71
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.0
0.0
1.7
15.8
0.0
16.4
2.2
16.1
0.0
16.4
2.2
16.1
19.9
16.5
19.9
16.5
19.9
16.1
1.7
16.5
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

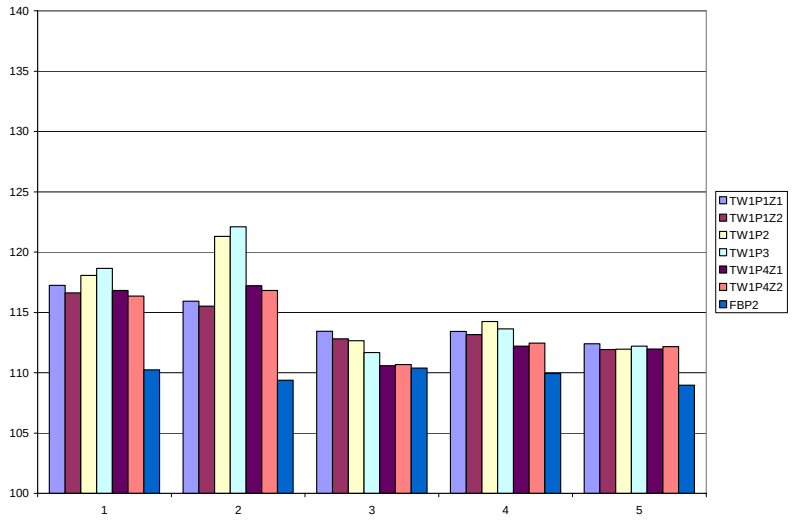

C75
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.00.0
1.7
19.0
0.0
19.1
2.2
18.8
0.0
19.2
2.2
18.8
4.4
19.3
4.4
19.3
4.4
18.7
1.7
19.3
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine


C76
Discharge (kcfs)
45
40
35
30
25
20
15
10
5
0
0.00.0
1.7
19.0
0.0
19.3
2.2
18.8
0.0
19.3
2.2
18.7
10.5
19.4
12.4
19.4
10.5
18.6
1.7
19.4
1
2
3
4
5
6
7
8
9
10
Spillbay
Turbine

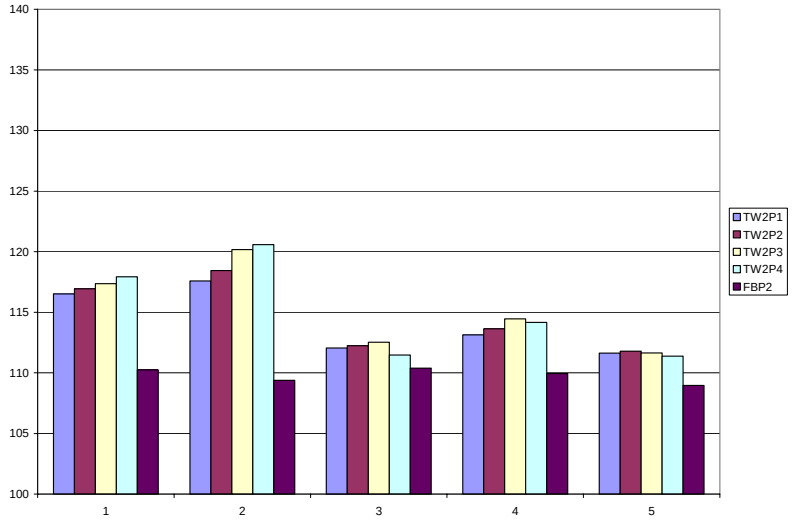
Appendix C

TDG Test Treatment Results

Transect TW1 TDG % Saturation



Transect TW2 TDG % Saturation



Transect TW3 TDG % Saturation

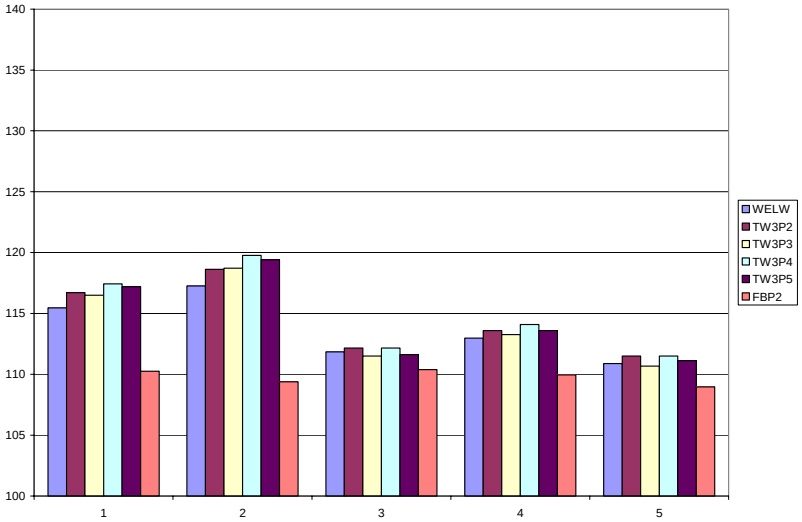
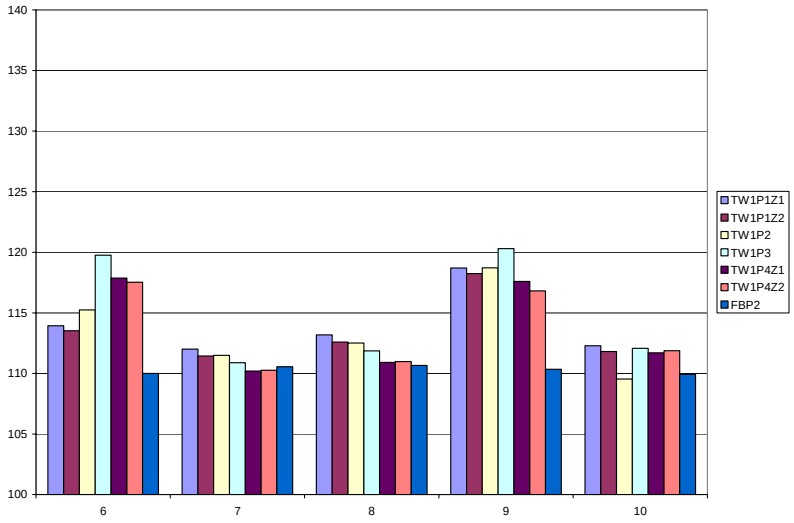
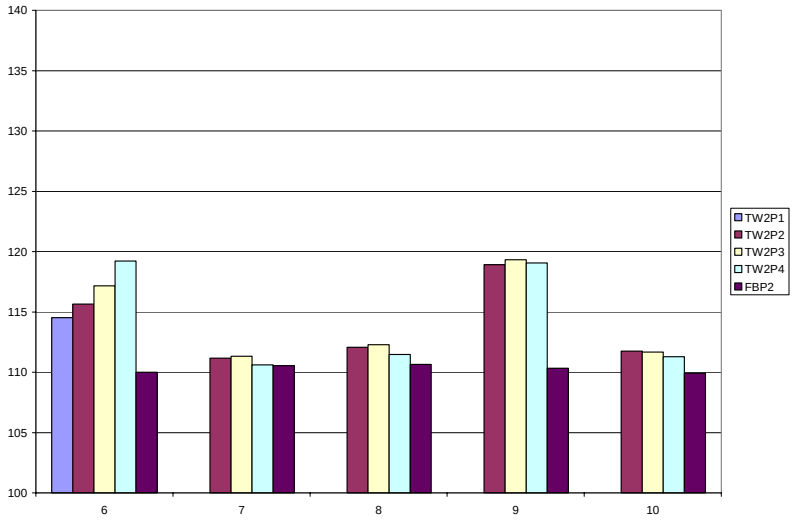


Figure C1 – Tests 1 – 5 - TDG Saturations Averaged by Spill Test

Transect TW1 TDG % Saturation



Transect TW2 TDG % Saturation



Transect TW3 TDG % Saturation

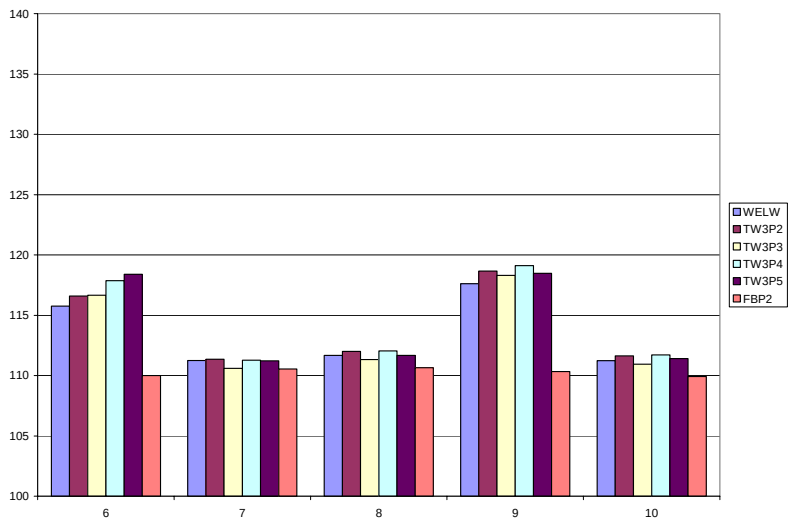
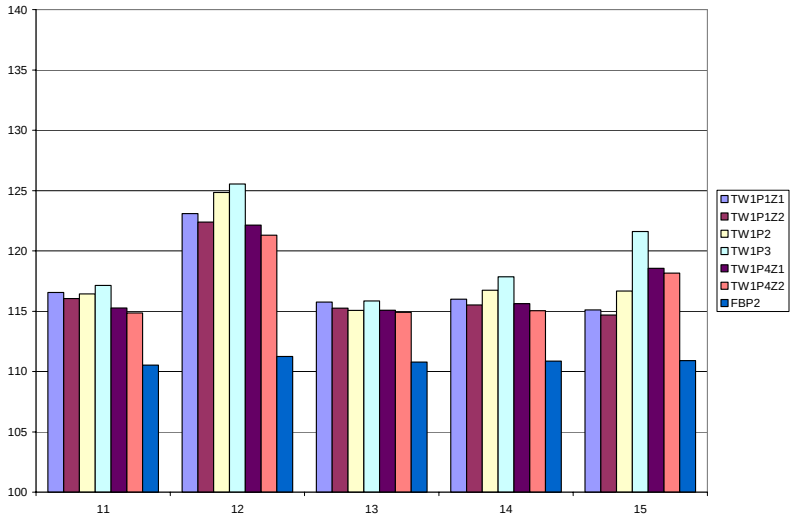
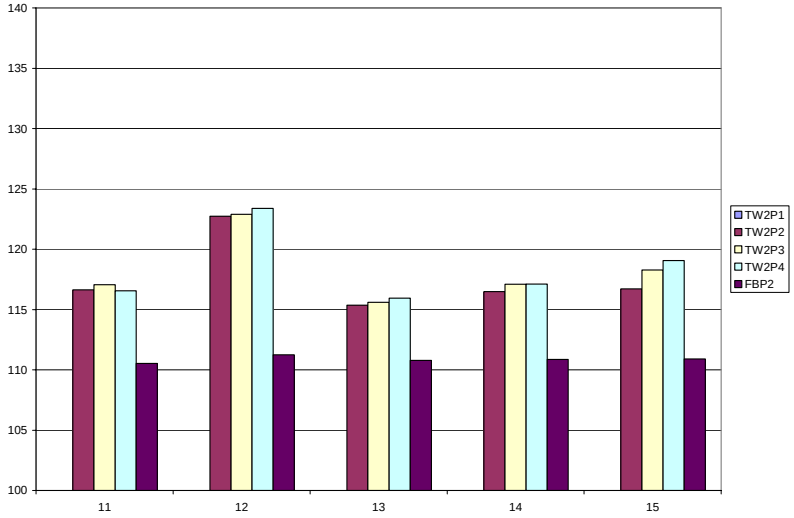


Figure C2 – Tests 6 – 10 - TDG Saturations Averaged by Spill Test

Transect TW1 TDG % Saturation



Transect TW2 TDG % Saturation



Transect TW3 TDG % Saturation

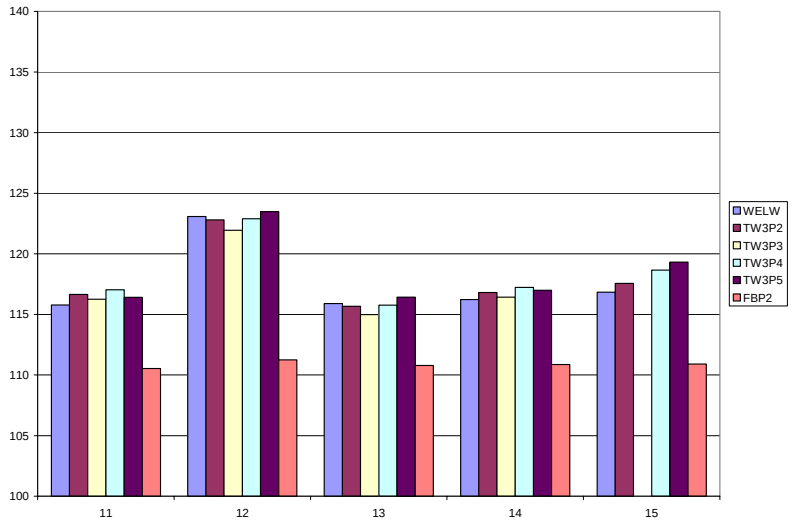
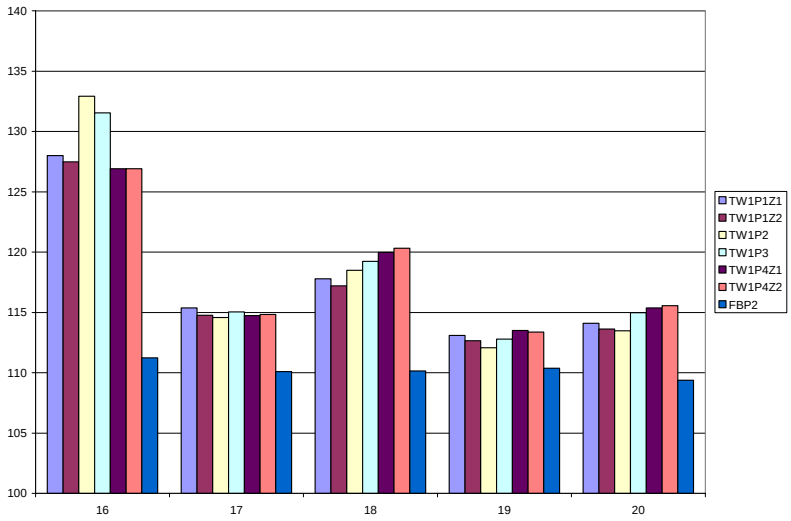
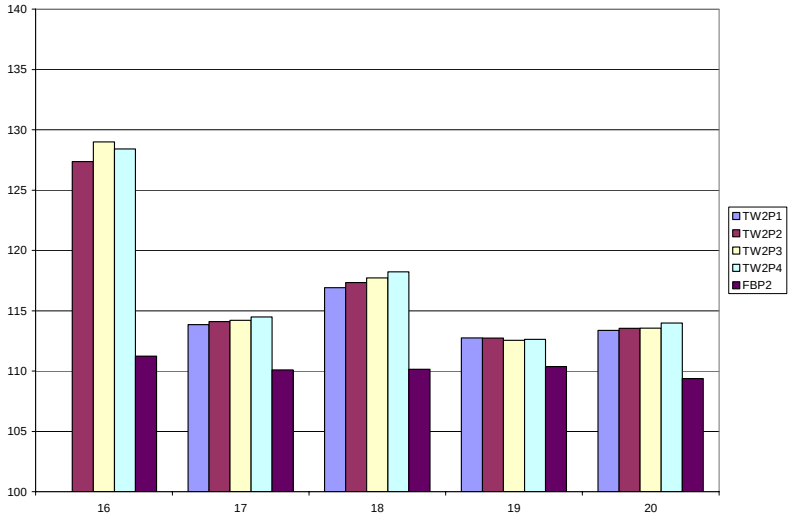


Figure C3 – Tests 11 – 15 - TDG Saturations Averaged by Spill Test

Transect TW1 TDG % Saturation



Transect TW2 TDG % Saturation



Transect TW3 TDG % Saturation

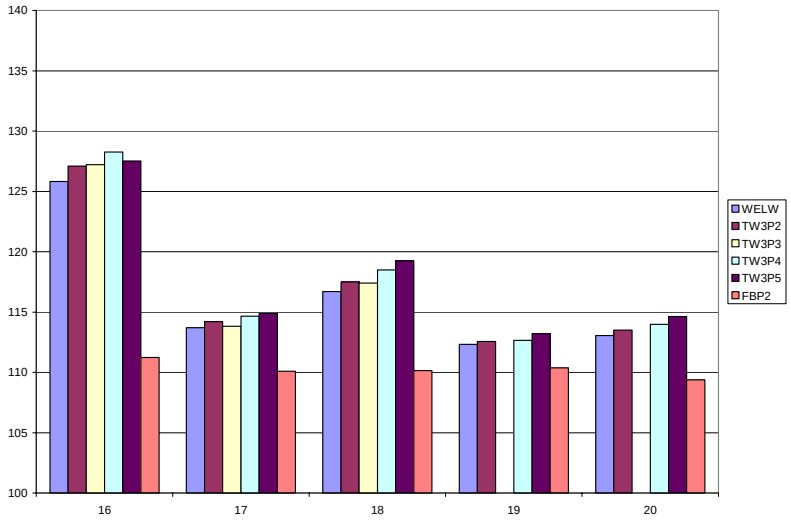
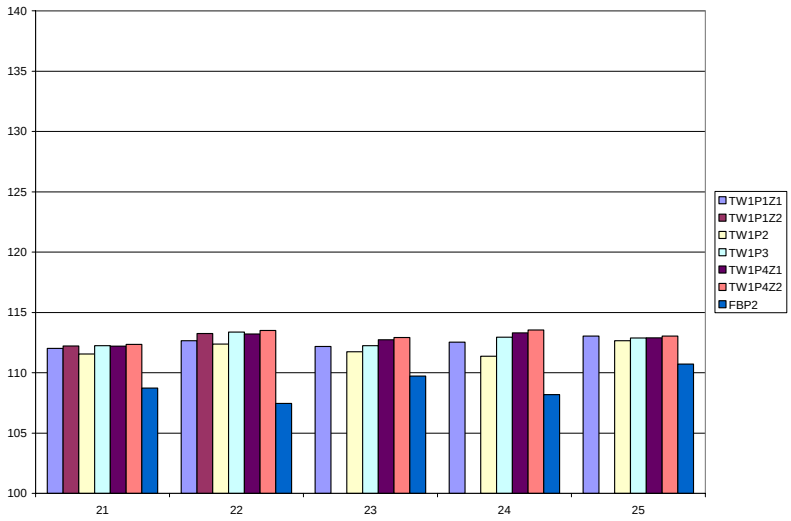
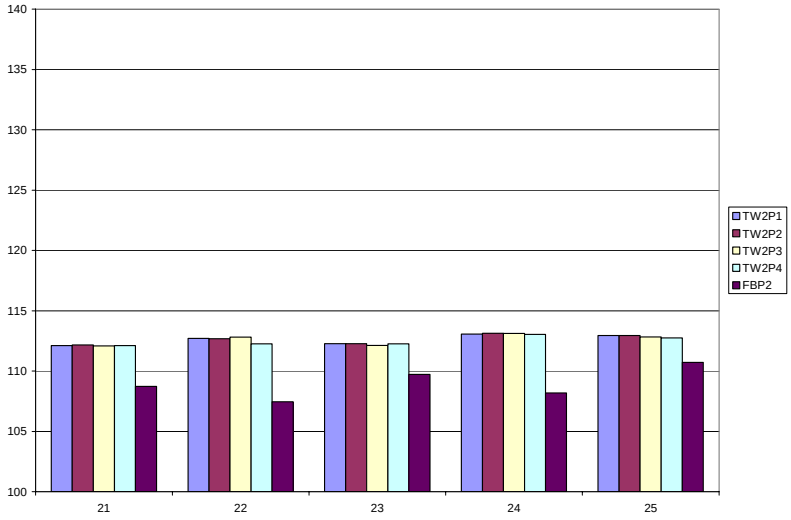


Figure C4 – Tests 16 – 20 - TDG Saturations Averaged by Spill Test

Transect TW1 TDG % Saturation



Transect TW2 TDG % Saturation



Transect TW3 TDG % Saturation

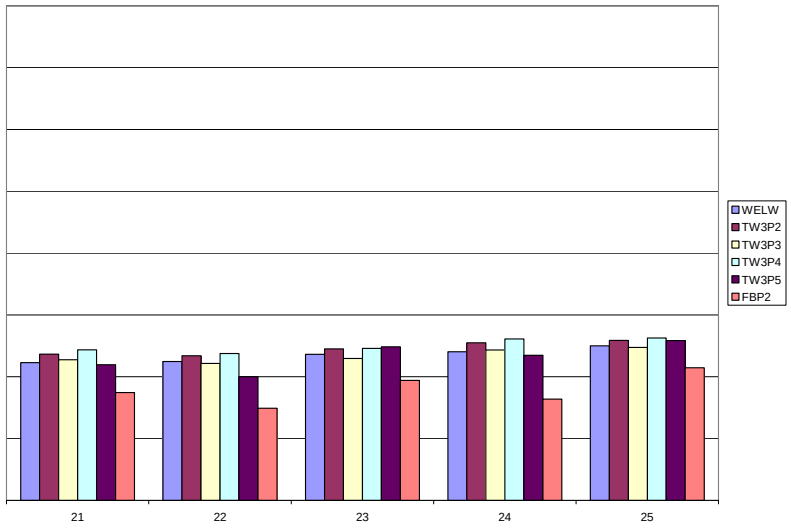
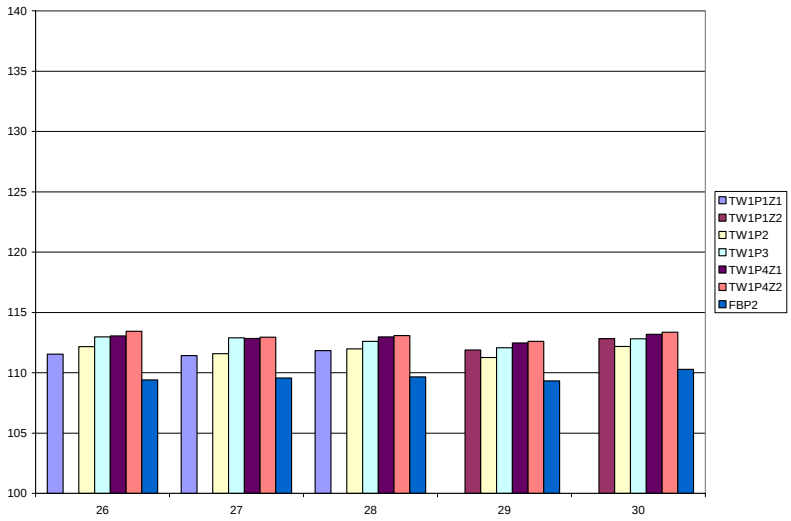
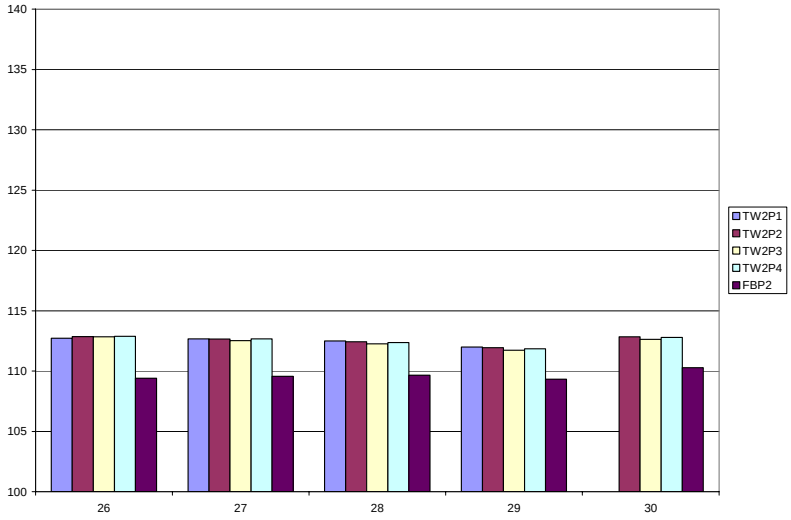


Figure C5 – Tests21 – 25 - TDG Saturations Averaged by Spill Test

Transect TW1 TDG % Saturation



Transect TW2 TDG % Saturation



Transect TW3 TDG % Saturation

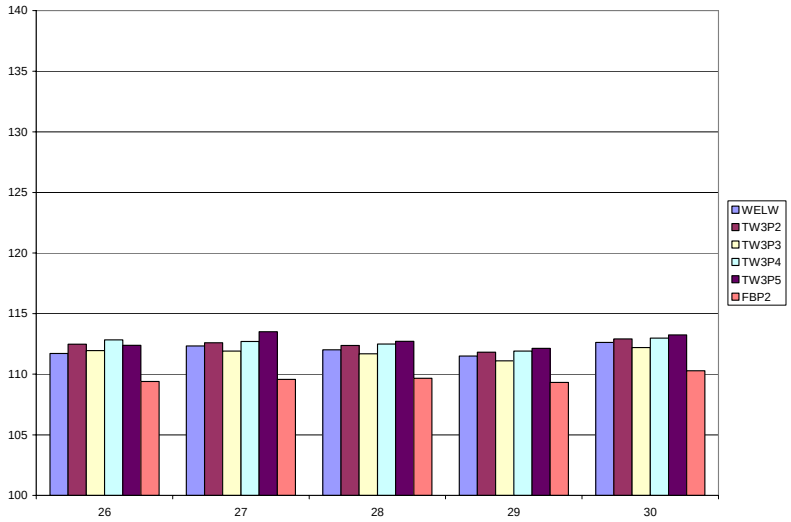
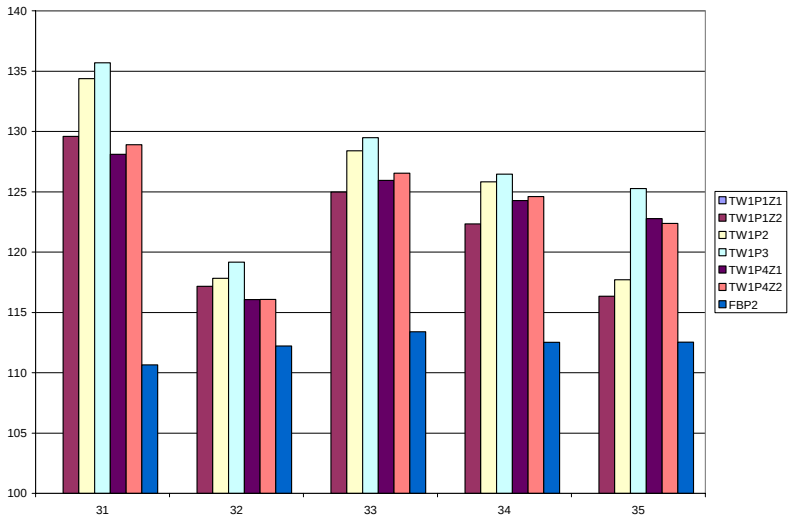
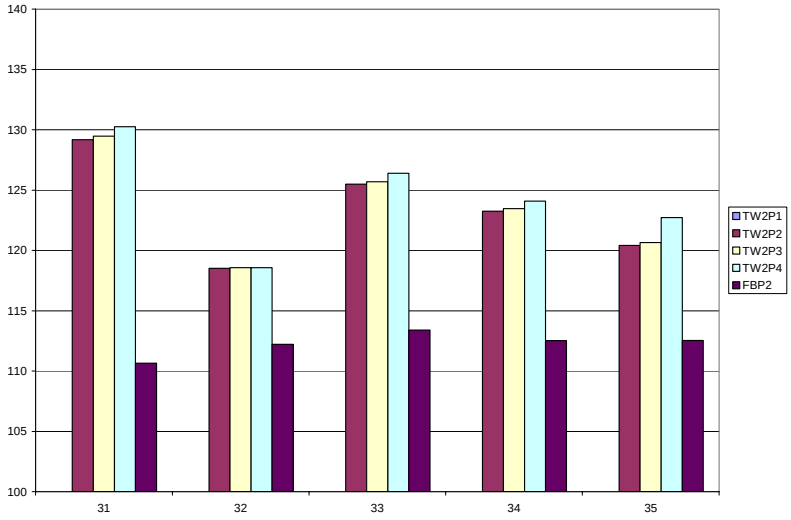


Figure C6 – Tests 26 – 30 - TDG Saturations Averaged by Spill Test

Transect TW1 TDG % Saturation



Transect TW2 TDG % Saturation



Transect TW3 TDG % Saturation

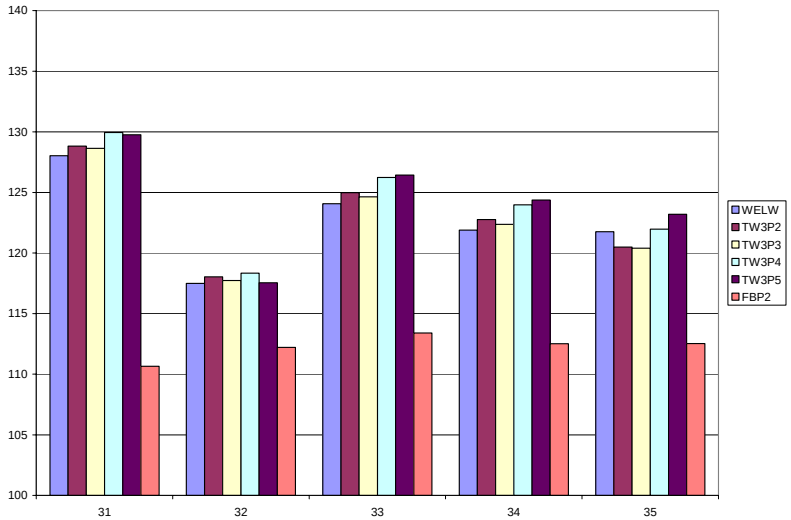
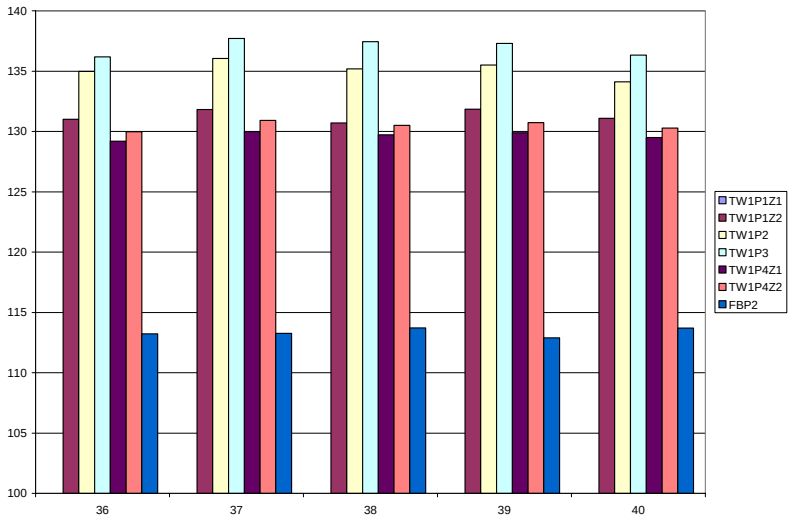
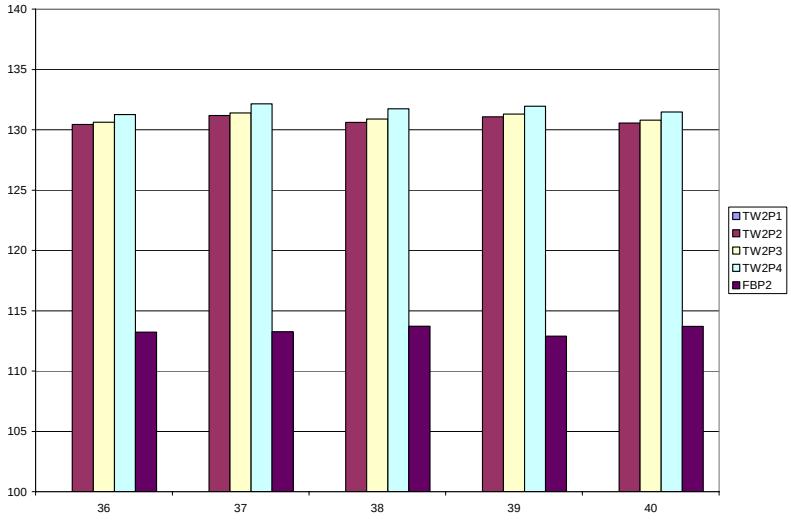


Figure C7 – Tests 31 – 35 - TDG Saturations Averaged by Spill Test

Transect TW1 TDG % Saturation



Transect TW2 TDG % Saturation



Transect TW3 TDG % Saturation

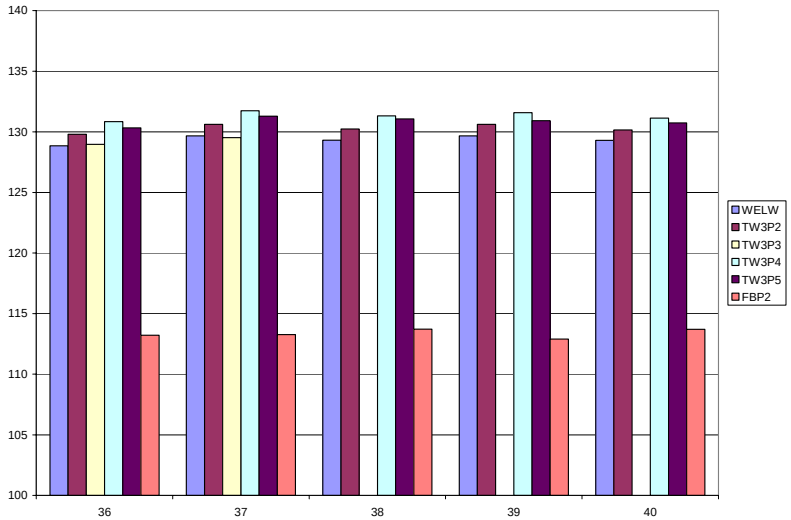
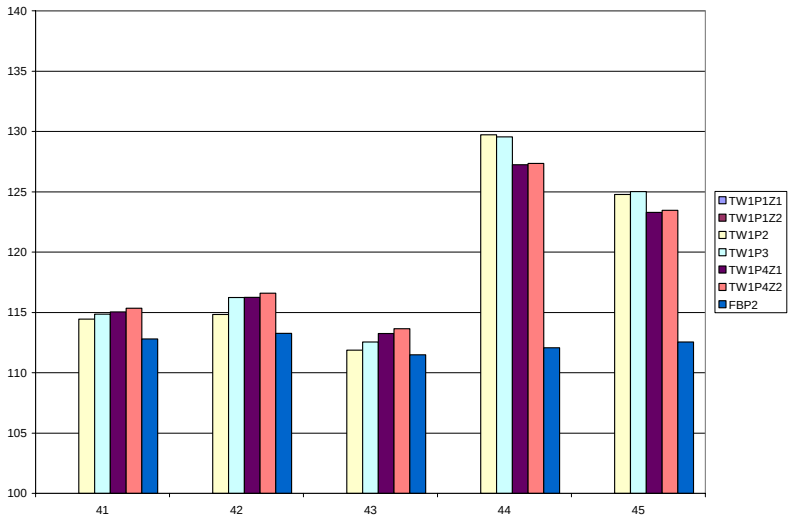
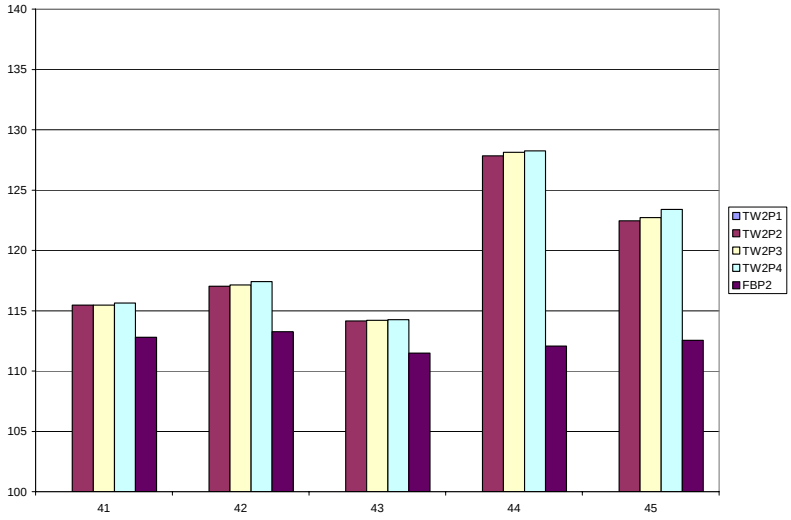


Figure C8 – Tests 36 – 40 - TDG Saturations Averaged by Spill Test

Transect TW1 TDG % Saturation



Transect TW2 TDG % Saturation



Transect TW3 TDG % Saturation

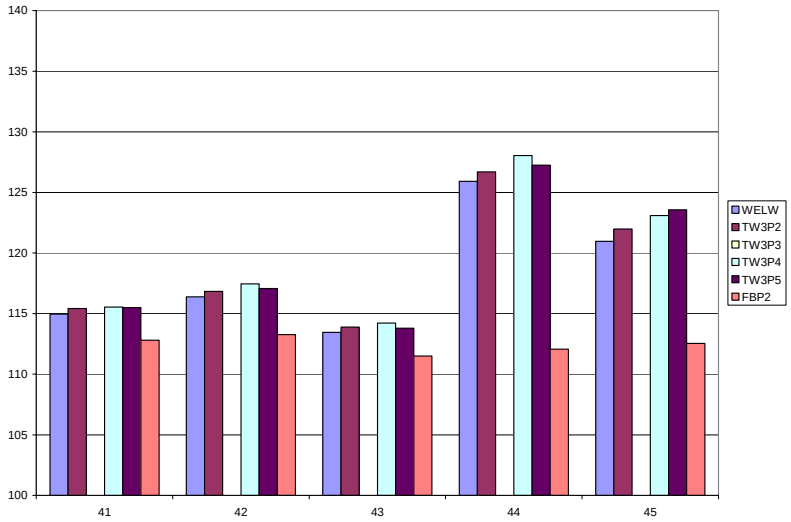
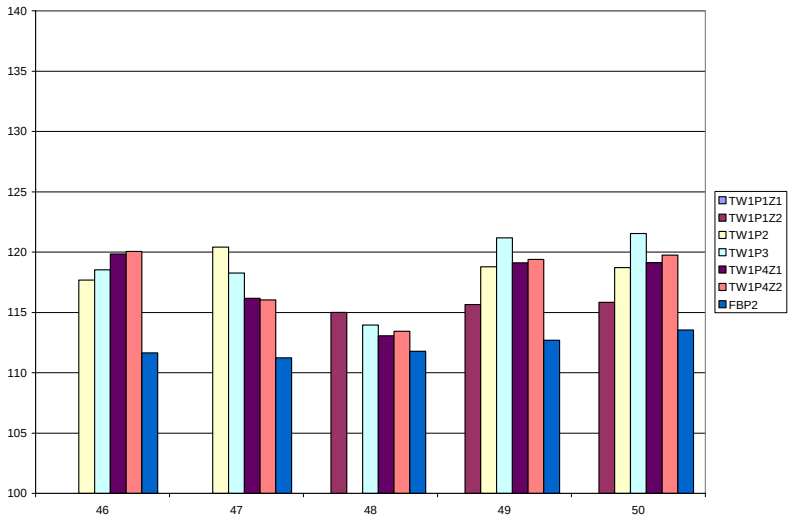
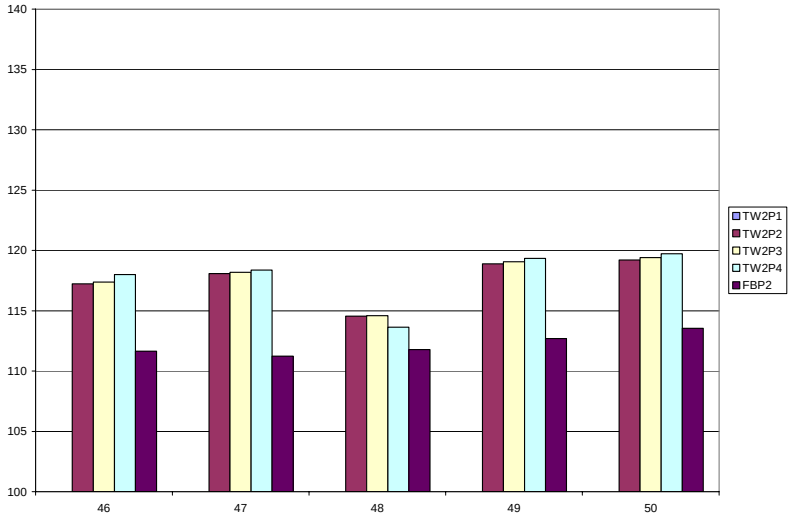


Figure C9 – Tests 41 – 45 - TDG Saturations Averaged by Spill Test

Transect TW1 TDG % Saturation



Transect TW2 TDG % Saturation



Transect TW3 TDG % Saturation

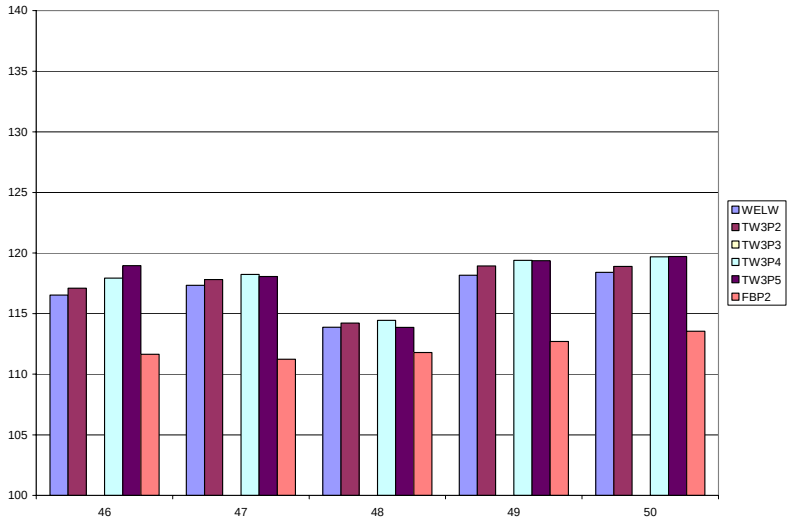
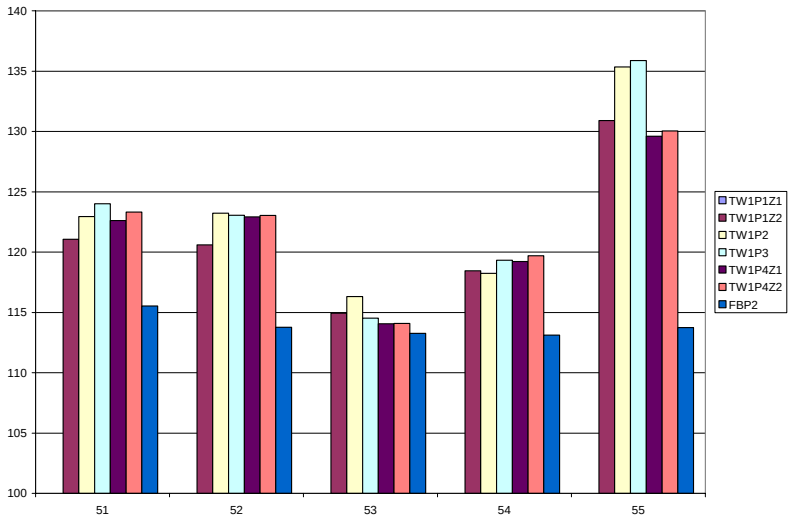
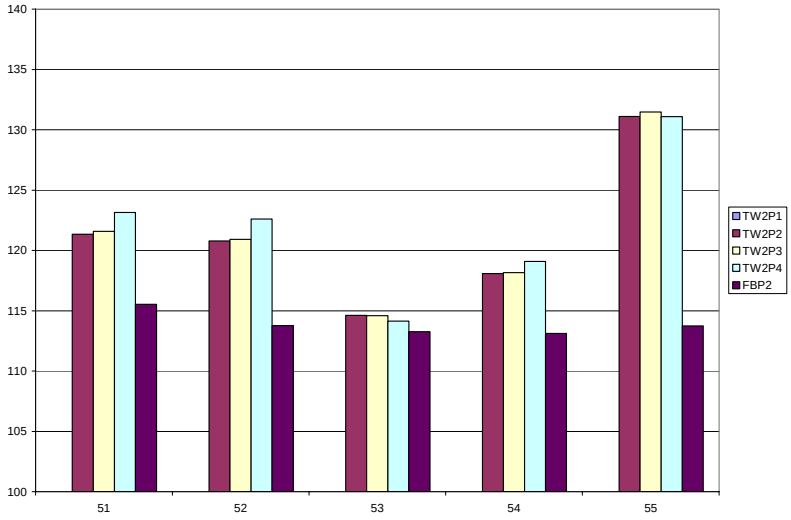


Figure C10 – Tests 46 – 50 - TDG Saturations Averaged by Spill Test

Transect TW1 TDG % Saturation



Transect TW2 TDG % Saturation



Transect TW3 TDG % Saturation

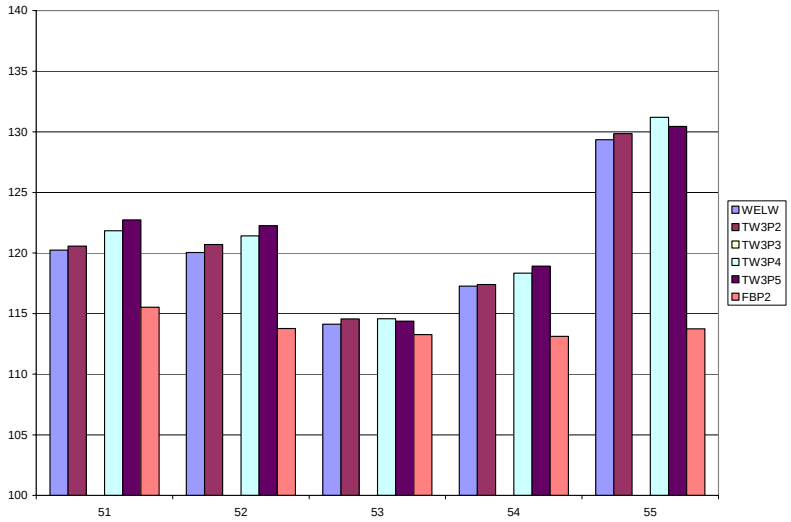
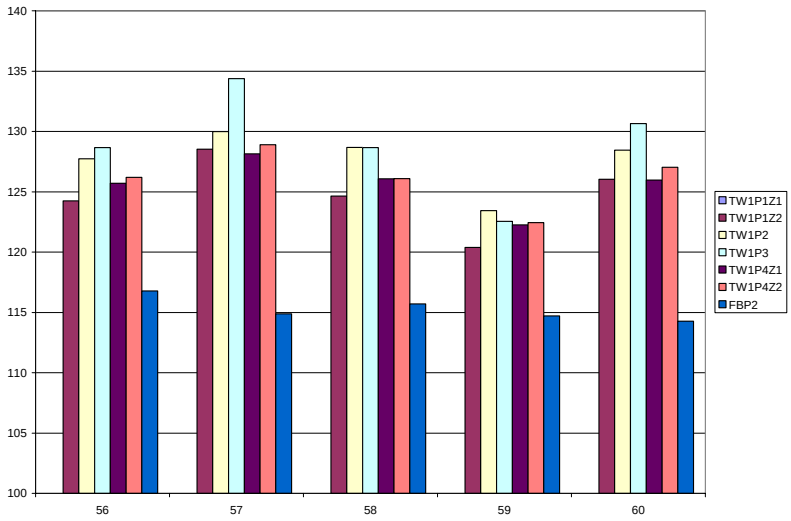
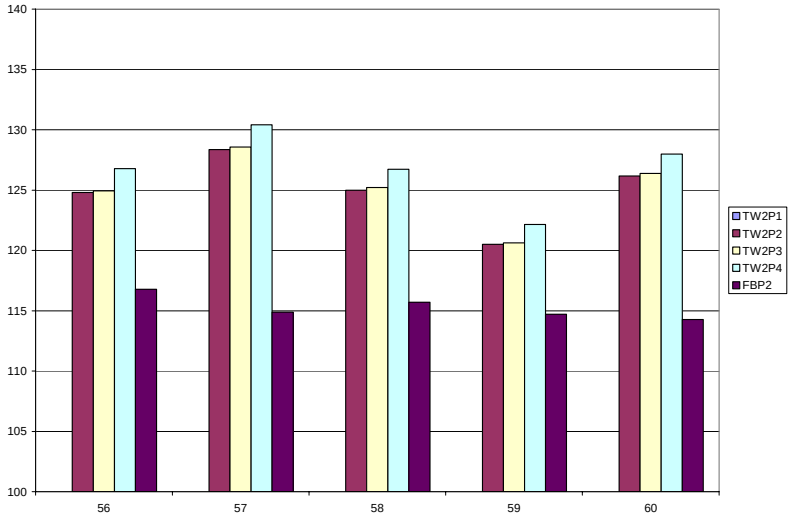


Figure C11 – Tests 51 – 55 - TDG Saturations Averaged by Spill Test

Transect TW1 TDG % Saturation



Transect TW2 TDG % Saturation



Transect TW3 TDG % Saturation

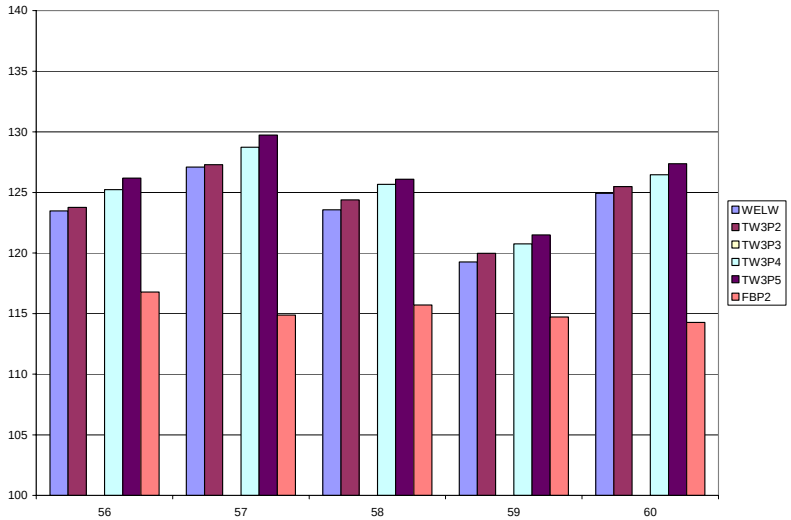
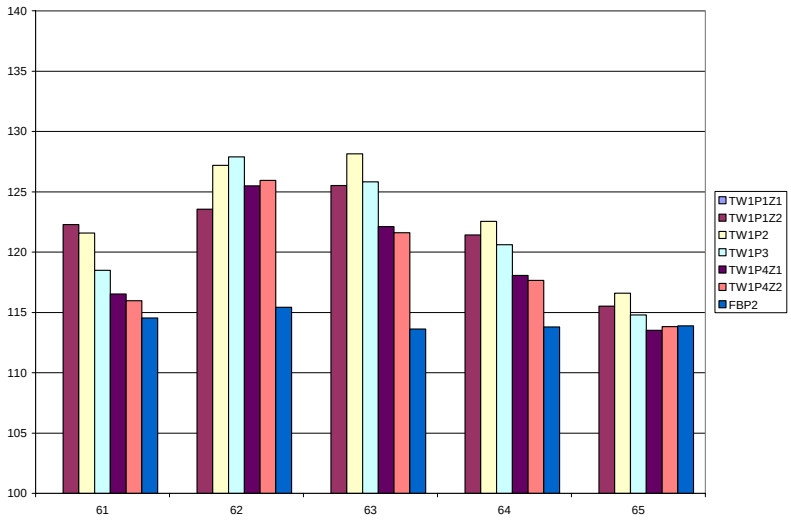
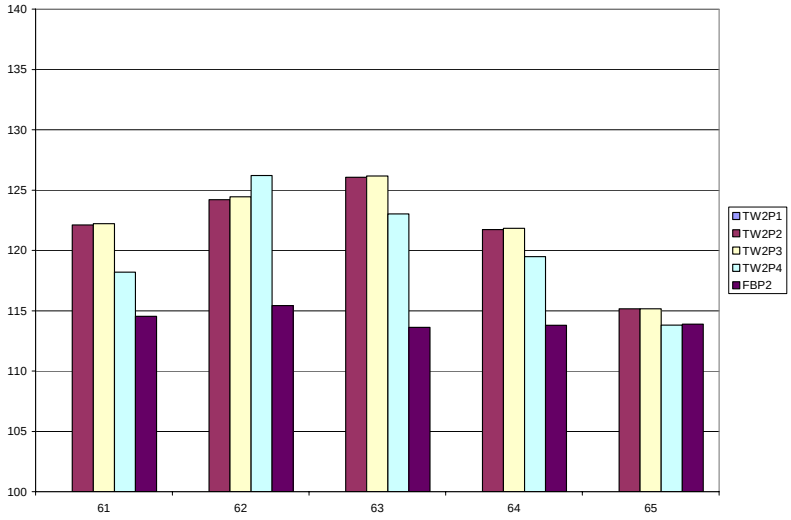


Figure C12 – Tests 56 – 60 - TDG Saturations Averaged by Spill Test

Transect TW1 TDG % Saturation



Transect TW2 TDG % Saturation



Transect TW3 TDG % Saturation

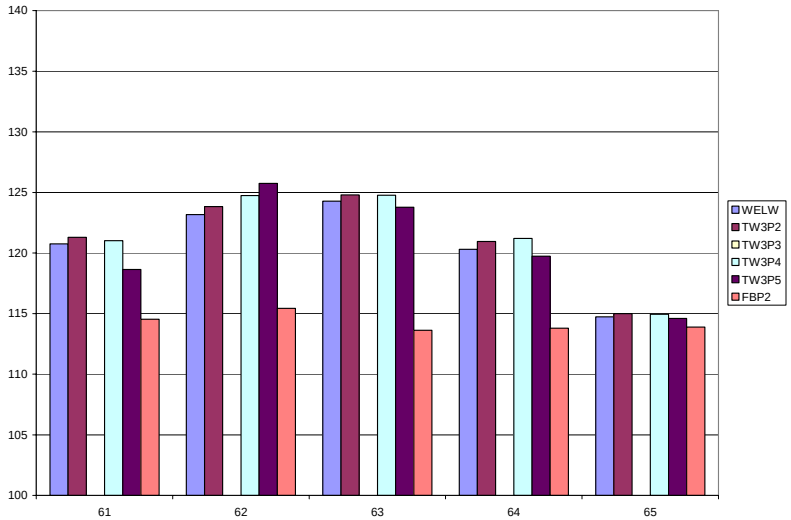
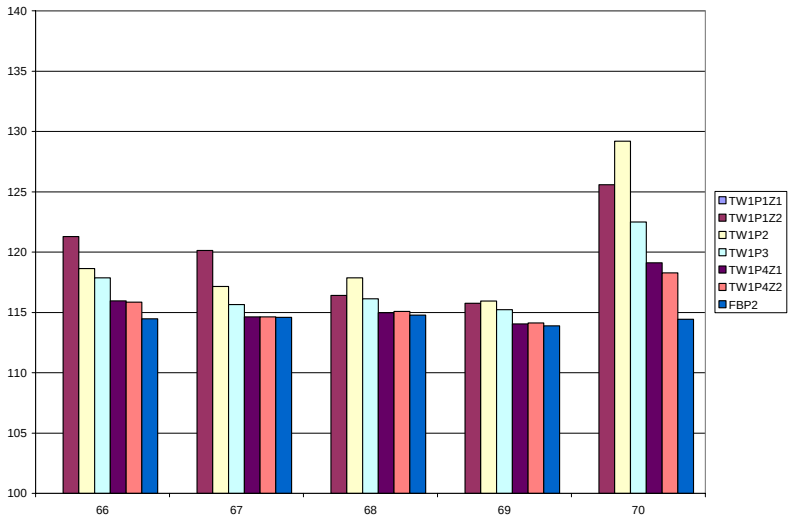
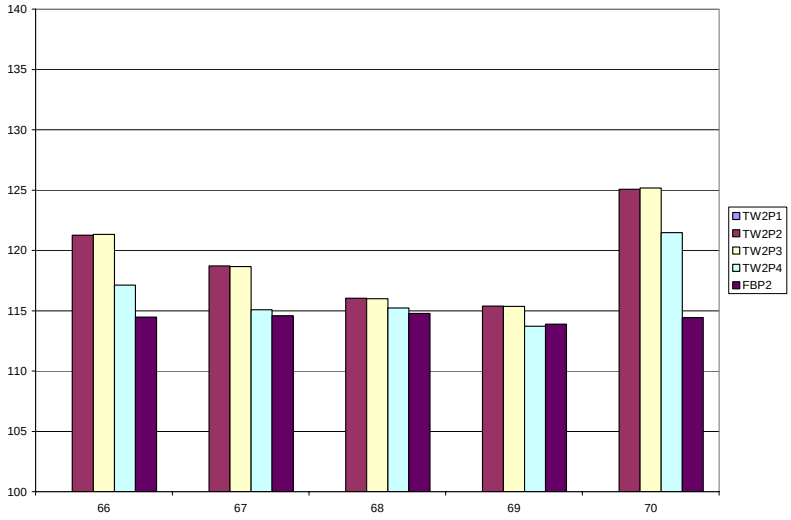


Figure C13 – Tests 61 – 65 - TDG Saturations Averaged by Spill Test

Transect TW1 TDG % Saturation



Transect TW2 TDG % Saturation



Transect TW3 TDG % Saturation

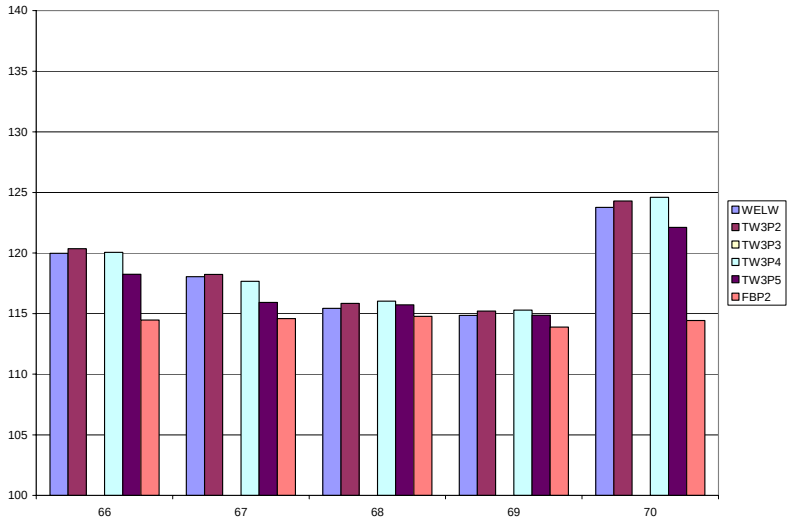
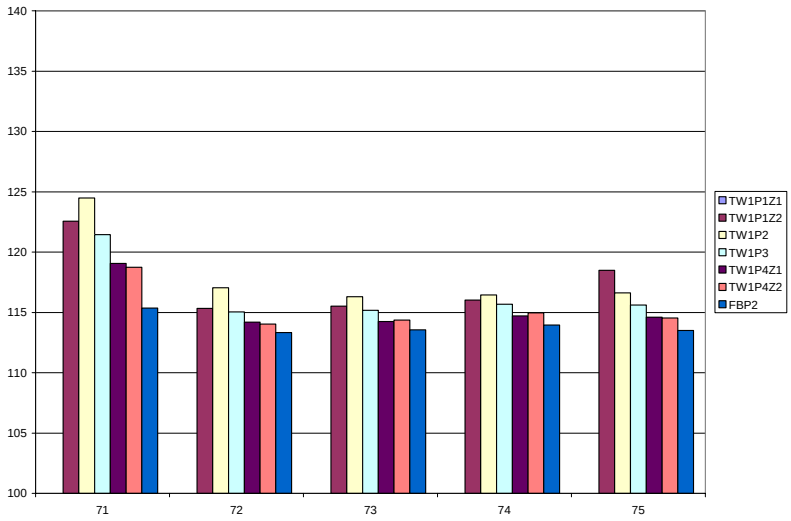
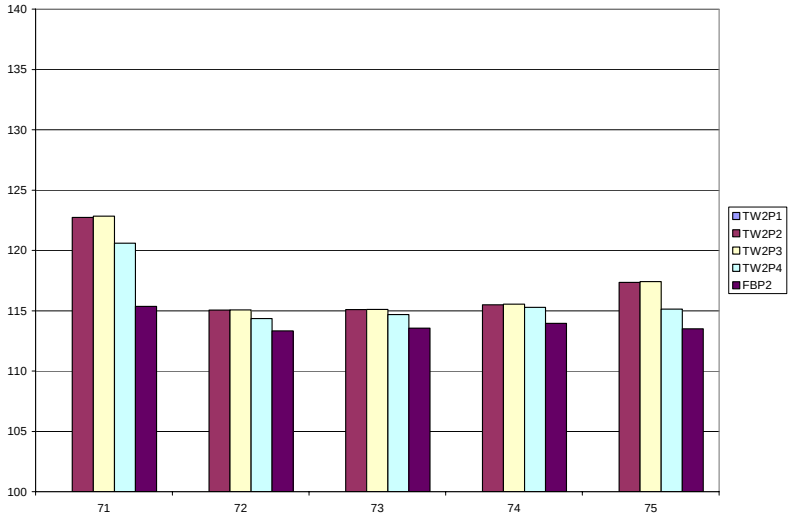


Figure C14 – Tests 66 – 70 - TDG Saturations Averaged by Spill Test

Transect TW1 TDG % Saturation



Transect TW2 TDG % Saturation



Transect TW3 TDG % Saturation

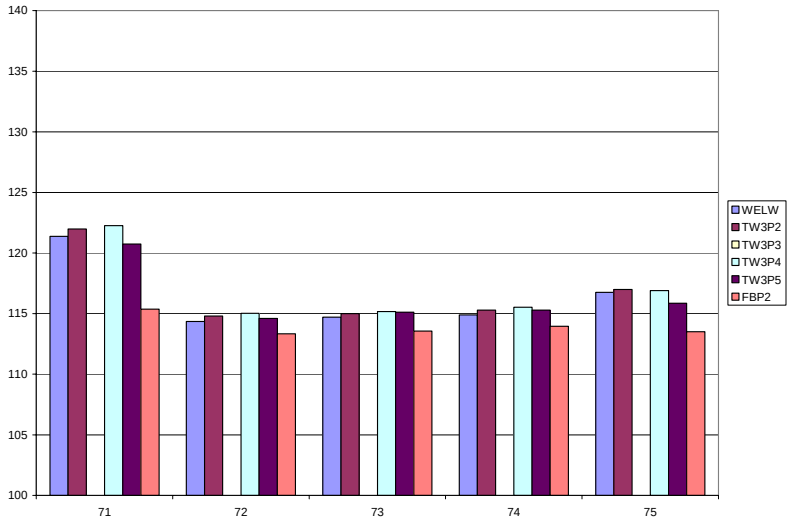
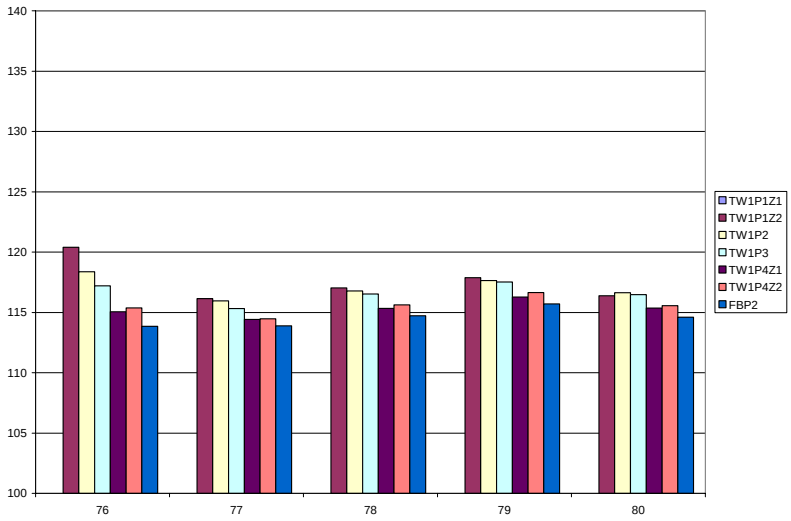
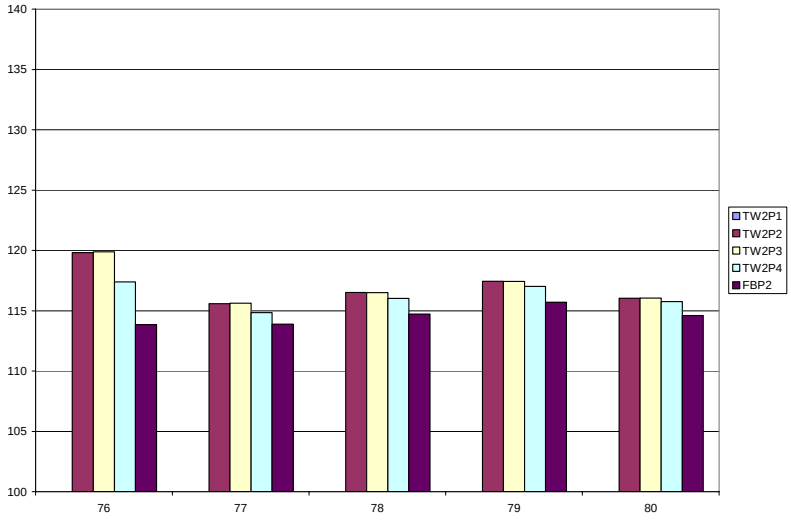


Figure C15 – Tests 71 – 75 - TDG Saturations Averaged by Spill Test

Transect TW1 TDG % Saturation



Transect TW2 TDG % Saturation



Transect TW3 TDG % Saturation

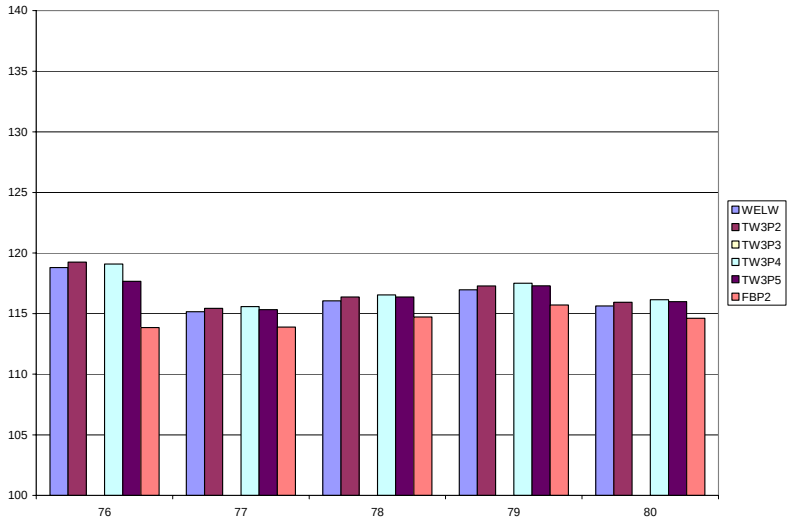


Figure C16 – Tests 76 – 80 – TDG Saturations Averaged by Spill Test

Figure C17 – Mean TDG Saturations by Test for WEL, Transects TW1, TW2, and TW3

Appendix D

Calibration Protocol for Hydrolabs

QA/QC and Calibration Procedures for Hydrolab DataSonde

Verification (optional)

Prior to removing instrument from the water, deploy the calibrated auxiliary Hydrolab unit in the river at close proximity to the fixed unit probe. The auxiliary unit probe should be held at depth equivalent to the fixed station probe. Wait for the auxiliary probe to equilibrate (approximately 15 minutes). Record one set of readings on the quarter hour. These readings can then be compared to fixed instrument concurrent data during data processing.

Calibration (Mandatory)

Total Dissolved Gas

1. Record local barometric pressure (not standard pressure (STP) but absolute ambient air pressure) for nearest weather station and handheld digital barometer. The handheld digital barometer will have been verified relative to a NIST traceable mercurial barometer prior to and subsequent to each field application.
2. Inspect the membrane that is on the unit recently deployed for damage or internal moisture. If membrane is damaged; mark it accordingly and discard.
3. Check readings for previously deployed unit before proceeding to re-calibrate. See Calibration form. Record hydrolab TDG reading at ambient (barometric pressure). Set up TDG probe to a pressure source (TDG membrane must be removed). Add 100 mm Hg of pressure. Accurately record coinciding pressure meter value (expected) and hydrolab TDG value (measured). Repeat at BP + 200 mmHg (Note: 200 mm Hg is equal to approximately 125% saturation). Repeat at BP + 300 mmHg. If expected and measured for any one of the post deployment checks (ambient BP; BP + 100 mmHg, or BP + 200) mmHg differ by more than 3 mmHg, then proceed to recalibrate Hydrolab. If expected and measured are $\leq$ 3 mmHg, simply attach new dry membrane and deploy programmed unit.
4. To calibrate: Ccalibrate to ambient barometric pressure with no membrane attached: barometric pressure = total dissolved gas pressure (Units = mm/Hg). Temporarily remove new membrane.
5. Check for leaks. Attach new dry membrane. TDGP reading should go up 100-300 mmHg before slowly beginning to drop again. Dip probe into a solution of seltzer water. Readings should climb rapidly to 900-1000 mm Hg. If probe does not respond or responds slowly, there is a leak in the membrane. Membrane needs to be replaced.
6. Set up TDG probe to pressure source (TDG membrane must be removed). Add 100 mm Hg of pressure. Calibrate hydrolab to the exact pressure meter reading. Repeat at BP + 200 mmHg (Note: 200 mm Hg is equal to approximately 125% saturation). Repeat for 300 mmHg. If expected and measured for any one of the post deployment checks (ambient BP; BP + 100 mmHg, or BP + 200 mmHg) differ by more than 3 mmHg, repeat Hydrolab calibration.
7. Inspect hydrolab batteries for moisture or corrosion. If voltage (IBV) is less than **, replace all the batteries prior to deploying. Program hydrolab to record at ¼ hour (15 minute intervals). Replace all the batteries prior to deploying. Program hydrolab to record at ¼ hour (15 minute) intervals starting on the hour.

8. Verify that calibration form is fully completed.

.

Depth

1. Calibrate the Sonde for 0 m depth when the unit is fully out of the water.

Total Dissolved Gas Calibration Data Sheet

Date: _____ Time: _____ Researchers: _____

Project:_____Site:_____ Hydrolab Instrument ID_____

.....

Download File Name: _____ Data Download Period: _____
Barometric Pressure: weather station _____mmHg
Mercury Barometer _____mHg
Handheld digital Barometer _____mmHg

.....

Total Dissolved Gas: Local Barometric Pressure (e.g. handheld) _____mmHg Time _____

Procedures upon instrument removal and/or Prior to Calibration:
Inspect membrane for damage or internal moisture, Yes _____ No _____ Remove membrane

Seltzer Water Test: _____ mmHg Passed Failed

Post Deployment Hydrolab TDG Ambient BP expected/measured

_____/_____mmHg

BP + 100.0 expected/measured

_____/_____mmHg

BP + 200.0: expected/measured
_____/_____mmHg

BP + 300.0: expected/measured
_____/_____mmHg

If post deployment expected and measured differ by more than 3 mmHg do 2 point calibration
Put new dry membrane on and proceed to calibrate

Ambient Hydrolab TDG with New Membrane: expected/measured _____/_____mmHg
If new membrane (dry) □ local BP, recalibrate within 1 mmHg

Re-calibrated Membrane (dry): Ambient BP mmHg expected/measured
_____/_____mmHg

Seltzer Water Test: _____ mmHg Passed Failed

Replace membrane before continuing with calibration if Seltzer test failed

BP + 100.0 mmHg expected/measured

_____/_____mmHg

BP + 200.0 mmHg expected/measured

_____/_____mmHg

BP + 300.0: expected/measured

_____/_____mmHg

Repeat calibration if expected measured differ > 3 mmHg

If Hydrolab Depth reading out of water □ 0.0 m; recalibrated depth Yes _____ No _____

.....

Comments:_____

_____ _____

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COMPREHENSIVE LIMNOLOGICAL INVESTIGATION

WELLS HYDROELECTRIC PROJECT

FERC NO. 2149

June, 2006

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ABSTRACT

In preparation for relicensing of the Wells Hydroelectric Project (Wells Project), the Public Utility District No. 1 of Douglas County (Douglas PUD) identified the need for a comprehensive limnological investigation (biological, chemical, and physical water quality parameters) for the waters contained within the Wells Project Boundary. Implementation of the study included identifying data gaps, study design methodology, and data collection and analysis parameters necessary to create a baseline inventory that addresses requirements for Clean Water Act certification and the Wells Project relicensing process. The study objectives were to document existing water quality conditions within the Wells Reservoir and Wells Dam tailrace with reference to the Washington State Department of Ecology (WDOE) water quality standards. The data generated from this study were collected and managed in a manner that supports future water quality modeling efforts, (if modeling is required in the future). The CE-QUAL-W2 model is widely used to support the establishment of Total Maximum Daily Loads (TMDLs) for Washington waters and is a generally accepted model for evaluating the effects of hydroelectric projects. Therefore, the CE-QUAL-W2 model (ver. 3.1) was considered the basis for making decisions regarding study design and data archiving.

The study approach and methods used during this investigation were consistent with WDOE's "Water Quality Certification for Existing Hydropower Dams: Preliminary Guidance Manual (September 2004)." Quality assurance plans were consistent with State and Federal guidelines. The laboratories used to analyze water quality samples were fully certified to conduct the analyses included in this report.

The study design was developed to evaluate the effects of Wells Project operations and structures on water quality. The selection of sample sites was based on the anticipated data needs for future water quality modeling. A total of nine sampling sites, which included mainstem sites, tributaries, and littoral habitats were selected to document the biological, physical, and chemical water quality variability of the Wells Project. Water quality sampling was seasonal with one sample event scheduled during the months of May, August, October, and February. An additional sampling event was scheduled in July and September to provide for monthly sampling frequency in the summer. Phytoplankton sampling occurred concurrently with water chemistry sampling. Periphyton sampling also occurred during all sampling events except October (five total sample events). The sampling scheme used in this study were designed to document water quality conditions during periods when potential exceedance were most probable and focused on periods when water quality was more temporally dynamic.

This report describes the methods and results for this study.

1.0 INTRODUCTION

1.1 General Description of the Wells Hydroelectric Project

The Wells Hydroelectric Project (Wells Project) is located at river mile (RM) 515.8 on the Columbia River in the State of Washington. Wells Dam is located 29.5 river miles downstream from the Chief Joseph Project, which is owned and operated by the United States Army Corps of Engineers, and 42 miles upstream from the Rocky Reach Hydroelectric Project, which is owned and operated by the Public Utility District No. 1 of Chelan County (Chelan County PUD). The nearest town is Pateros, Washington, which is located approximately 8 miles upstream from Wells Dam.

The Wells Project is the chief generating resource for the Public Utility District No. 1 of Douglas County (Douglas County PUD). It includes ten generating units with a nameplate rating of 774,300 kW and a peaking capacity of approximately 840,000 kW. The design of the Wells Project is unique in that the generating units, spillways, switchyard, and fish passage facilities were combined into a single structure referred to as the hydrocombine. Fish passage facilities reside on both sides of the hydrocombine, which is 1,130 feet long and 168 feet wide, with a crest elevation of 795 feet in height.

The Wells Reservoir is approximately 30 miles long. The Methow and Okanogan rivers are tributaries to the Columbia River within the Wells Reservoir. The Wells Reservoir extends approximately 1.5 miles up the Methow River and approximately 15.5 miles up the Okanogan River. The normal maximum surface area of the reservoir is 9,740 acres with a gross storage capacity of 331,200 acre-feet and usable storage of 97,985 acre feet at elevation of 781 feet. The normal maximum water surface elevation of the reservoir is 781 feet (Figure 1.1-1).

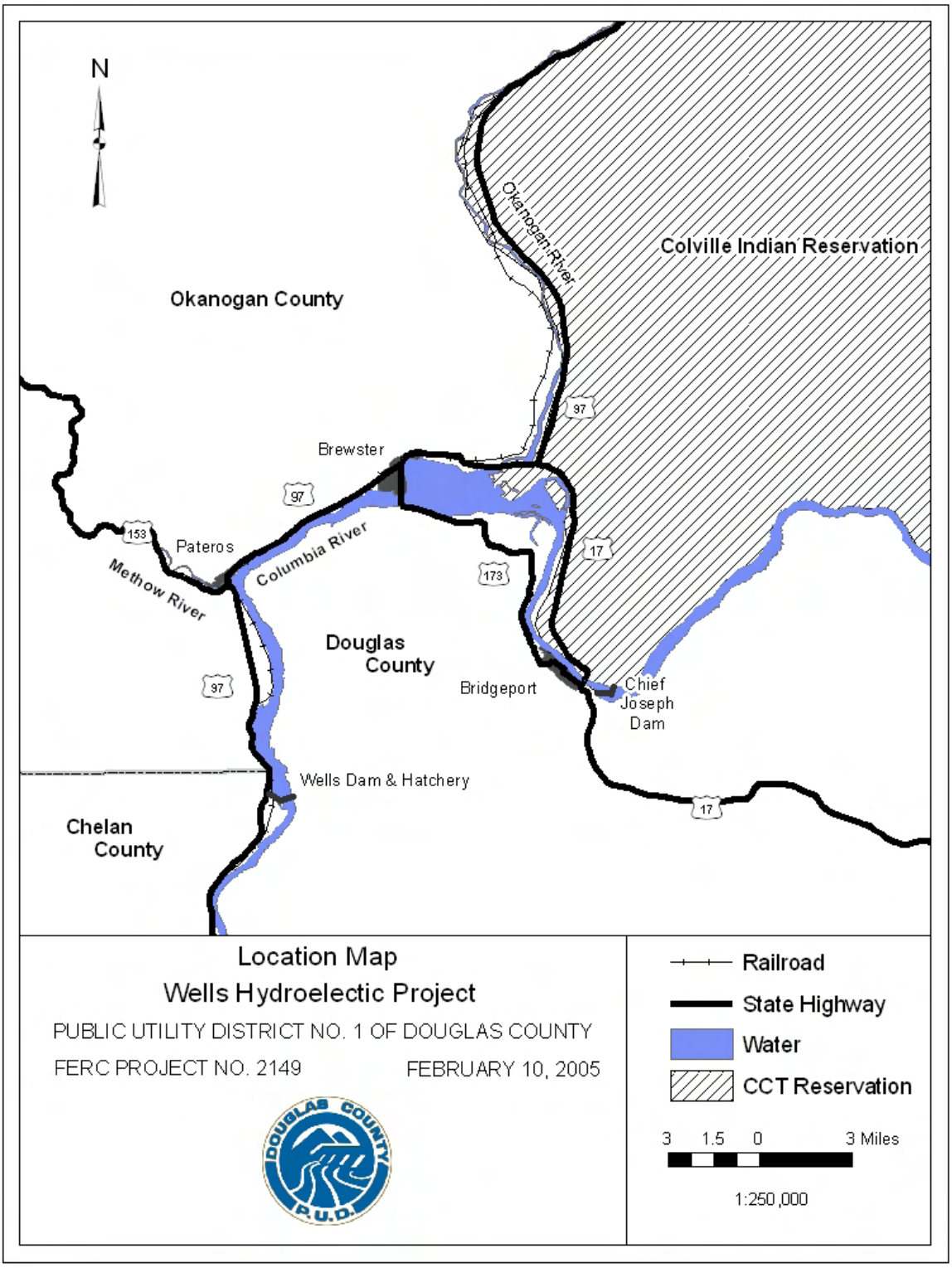

Figure 1.1-1 Location Map of the Wells Project.

1.2 Background Information

1.2.1 Water Quality Standards and Natural Resource Agency Goals

The Washington State Department of Ecology (WDOE) has established water quality standards in an effort to protect the beneficial uses of State water and water bodies. Washington State adopted new water quality standards in July 2003. Approval of these standards is still pending by the Environmental Protection Agency (EPA). The 1997 Washington Water Quality Standards (WAC 201A-173) remain in effect until the new standards are approved by the EPA.

This study documents water quality in Wells Project waters relative to the aforementioned water quality standards. The Washington standards include both numeric and narrative criteria. The narrative standards address beneficial uses that include, but are not limited to, the ecological significance of water quality to aquatic biota. The importance of water quality to the health of rare, threatened, and endangered populations is also described in the narrative standards.

1.2.2 Water Quality

Factors and activities affecting water quality in the Wells Project include 1) nonpoint source pollution from agricultural runoff and irrigation return flow, 2) point source pollution from mines, municipal and industrial sources upstream and outside of the Wells Project Boundary, 3) depletion of instream flows from water diversions and consumptive uses, 4) watershed management in the tributaries and Upper Columbia River above Wells Dam, 5) the operation of large water storage facilities located upstream of Wells Dam on the mainstem Columbia and in the Okanogan watershed, and 6) effects related to operations of the Wells Project.

Every two years, the EPA, as specified in section 305(b) of the Clean Water Act, requires WDOE to compile an assessment of the state's waterbodies. This assessment is called the 305(b) report. The report evaluates and assigns each waterbody into five categories based upon WDOE's evaluation of the water quality parameters collected from within each waterbody. Category 1 states that a waterbody is in compliance of the state water quality standard for the parameter of interest. Category 2 states a waterbody of concern. Category 3 signifies that insufficient data is available to make an assessment. Categories 4a-4c indicate an impaired waterbody that does not require a Total Maximum Daily Load (TMDL) for one of three reasons. Category 4a indicates a waterbody with a finalized TMDL. Category 4b indicates a waterbody with a Pollution Control Program and category 4c indicates a waterbody impaired by a non-pollutant. Category 5 represents all waterbodies within the state that are considered impaired and require a TMDL. The 303(d) list consists of only waterbodies with category 5 listings.

The reach of the Columbia River within the Wells Project is on the State's 2004 303(d) list for temperature impairment. WDOE is currently developing a TMDL for the mainstem Columbia River, including that portion of the Columbia River contained within the Wells Project. The Okanogan River immediately upstream of the Wells Project boundary is listed for temperature based on exceedance at the USGS station 12447200 (Category 5). The lower Okanogan River within the Project boundary was placed on the 303d list by WDOE for high levels of total PCB's,

4,4'-DDE and 4,4'-DDD in fish tissue but has since had a TMDL finalized and was subsequently removed from the 303(d) list.

The lower Methow River just upstream of Project boundary is on the 303(d) list for temperature (category 5). The Methow River within the Project boundary was not listed on the 2004 303(d) list.

1.2.3 Hydrology

The Wells Hydroelectric Project impounds 29.5 miles of the Columbia River from Chief Joseph Dam at river mile (RM) 545.3 to Wells Dam (FERC No. 2149) at RM 515.8. The drainage area of the Columbia River Basin upstream of Wells Dam is approximately 85,300 square miles. The Wells Reservoir has a surface area of 9,740 acres when the water elevation is at 781 feet above mean sea level (MSL). Total storage of Wells Dam at a full pool elevation of 781 feet is 331,000 acre feet with 97,985 acre feet of usable storage. The average annual flow at Wells Dam is 111.2 kcfs based on data collected from 1968 – 2004.

The Columbia River system is primarily fed by snowmelt. Numerous dams and impoundments developed for hydropower and flood control alter the natural flow in the basin. Water is withdrawn from the Columbia River and its tributaries at various locations for agricultural, domestic, municipal, and industrial supply. The two major tributaries within the Wells Reservoir are the Methow and Okanogan rivers.

The Methow River enters the Columbia River (RM 524) at the town of Pateros, Washington. The Wells Project boundary includes the lower 1.5 miles of the Methow River. The Okanogan River enters the Columbia River at approximately RM 534, which is 18 miles upriver from Wells Dam. The Project boundary includes the lower 15.5 miles of the Okanogan River. The Wells Project backwater effect in the Okanogan River extends up to approximately river mile 11 based upon normal operations. The Wells Project boundary extends further upstream to accommodate a backwater effect that may occur when the Okanogan River and Columbia River are simultaneously flooding and the Reservoir elevation is raised to 791 ft in order to provide flood protection to area of the lower Columbia River including the city of Portland.

2.0 STUDY GOAL

The purpose of this study is to develop information to support the water quality certification needed from the WDOE, pursuant to Section 401 of the Clean Water Act, for the operation of the Wells Hydroelectric Project under a new Federal Energy Regulatory Committee (FERC) license. This study documents the existing water quality conditions in the Wells Reservoir and Wells tailrace. Data generated by this study will likely be used during future TMDL modeling efforts. Those parameters for which the WDOE has established numeric or narrative water quality standards (Chapter 173-201A WAC) are addressed in this study report. This study addresses how existing water quality conditions affect existing and potential uses of the Wells Project waters.

Specific objectives of this study include:

1. Documenting the existing physical, biological, and chemical water quality conditions contained within the Wells Project.

2. Archive data in a manner suitable for application to future water quality modeling. The purpose and objectives of future modeling are yet to be defined. The selection of a water quality model, if needed, is unknown. The CE-QUAL-W2 model is widely used to support the establishment of TMDLs for Washington waters and is a widely accepted model for evaluating the effects of hydroelectric projects. Therefore, the CE-QUAL-W2 model (ver. 3.1) was considered the basis for making decisions regarding study design, sampling protocols and data archiving.

3.0 STUDY AREA

The study area included the Wells Reservoir from the Wells Dam forebay to the tailrace of Chief Joseph Dam, and the lower sections of the Okanogan River (15.5miles) and Methow River (1.5 miles). The tailrace waters just below Wells Dam were also included in the study area.

4.0 METHODOLOGY

The study approach and methods are consistent with WDOE's "Water Quality Certification for Existing Hydropower Dams: Preliminary Guidance Manual (September 2004)." Quality assurance plans meet State and Federal guidelines. The laboratories analyzing water quality samples are fully certified to conduct the analyses included in this study.

4.1 Variables of Interest

Sampling included the physical, chemical, and biological water quality characteristics as outlined in Table 4.4-1. A total of 23 water quality characteristics were measured. The parameters measured at each sampling location vary according to the water body type and season.

All procedures used for the purpose of collecting, preserving, and analyzing samples followed protocol established in EPA 40 CFR 136 (EPA Guidelines for Establishing Test Procedures for the Analysis of Pollutants). A discussion on sampling and analytical protocol for each parameter is provided in Sections 4.5 and 4.6.

4.2 Sampling Sites

The sampling design was developed to evaluate the effects of Project operations and structures on water quality. The selection of sample sites is consistent with data needs for future water quality modeling. The five mainstem sites characterize longitudinal variability in water quality as well as document water quality for inflow and outflow boundary conditions. The tributary sampling sites document water quality within the two major tributaries in the Wells Reservoir (Methow and Okanogan rivers). Data from WDOE ambient monitoring stations (http://www.ecy.wa.gov/programs/eap/fw_riv/rv_main.html) located in these tributaries upstream of the Project boundary provide additional information for any future water quality modeling or analysis of Project effects on water quality. Two littoral sites are included to document water quality within important nearshore habitats. The five pelagic mainstem sites included:

- Downstream of Chief Joseph Dam outside the aeration zone,
- Columbia River downstream of Brewster,
- Columbia River downstream of Pateros where the thalweg approaches maximum depth in lower reservoir,
- Wells Dam forebay, and
- Wells Dam tailrace

Tributary sampling stations included:

- Okanogan River upstream of confluence with Columbia River RM 534
- Methow River upstream of confluence with Columbia River RM 524

The two mainstem littoral sites were:

- Bridgeport bar shallows
- Lower reservoir/Starr boat launch

Figure 4.2-1 shows the location of monitoring sites. Table 4.4-1 lists the parameters sampled at each site.

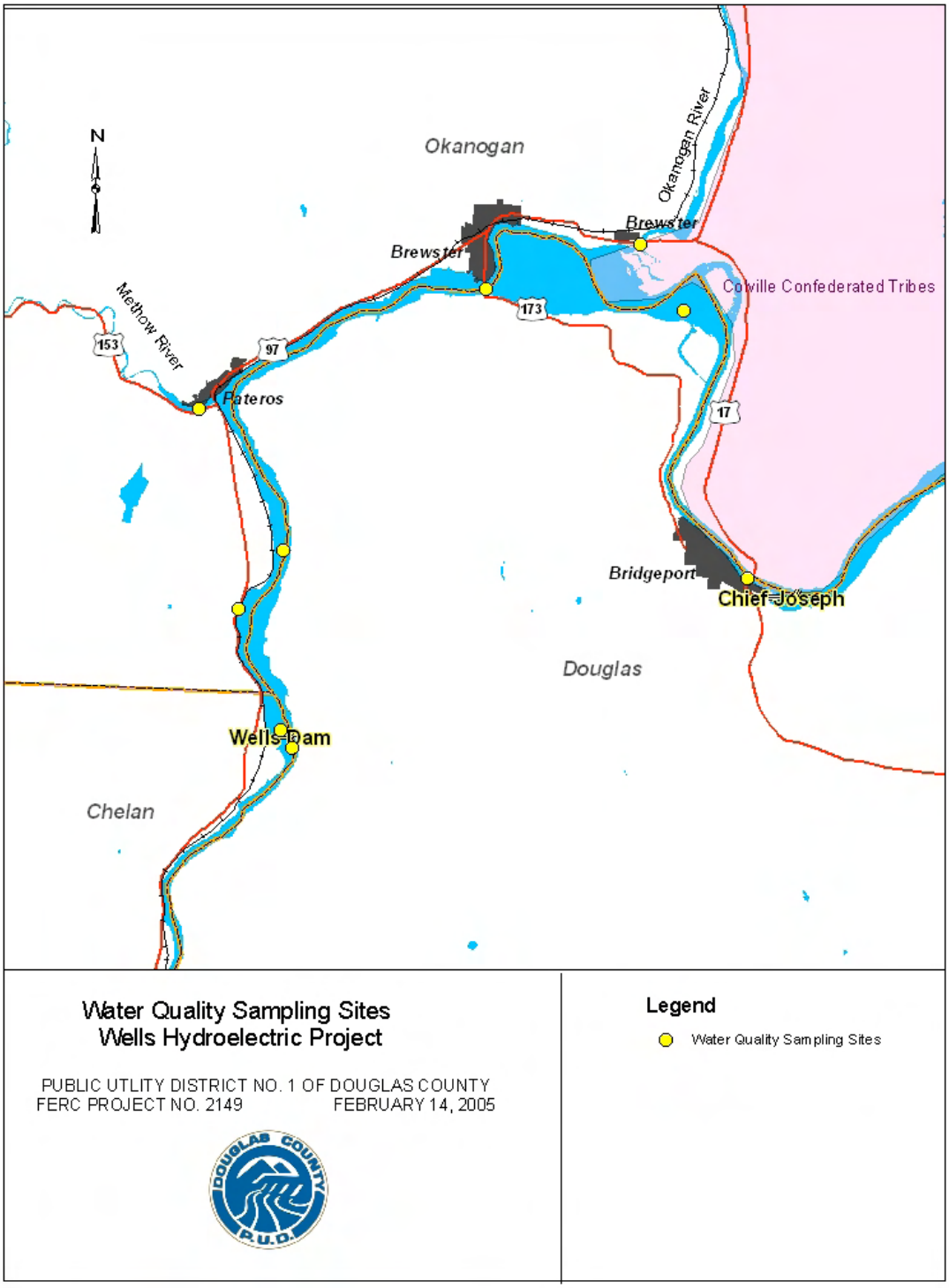

Figure 4.2-1 Water quality monitoring sites for the 2005 Wells Project Comprehensive Limnological Investigation.

4.3 Sample Frequency

Water quality sampling was scheduled seasonally with one sample event scheduled for each season. Spring sampling was conducted in May 2005. Summer sampling was conducted more frequently during summer when water quality exceedances were more likely and temporal changes more dynamic (July, August and September sampling). Fall monitoring was conducted in October, and winter sampling occurred in February 2006. Phytoplankton sampling occurred concurrently with water chemistry sampling. Periphyton and zooplankton sampling occurred concurrently with all sample events except October (five total sample events). See Table 4.4-1 for a listing of sample frequency by parameter.

4.4 Water Quality Parameters

Table 4.4-1 lists the water quality parameters that were investigated in the 2005-2006 Wells Project limnology study.

Table 4.4-1 Water quality parameters, sampling sites and sampling schedule

Parameter	Chief Joseph Tailrace	Bridgeport shallows	Brewster bridge	Lower reservoir at deepest	Littoral at Starr boat launch	Wells forebay	Wells tailrace	Okanogan River	Methow River	Sample Schedule
Chemical:										
Total Phosphorus (TP)	●	●	●		●	●	●	●	●	
Ortho-phosphorus	●	●	●		●	●	●	●	●	
NH_4^+-N	●	●	●		●	●	●	●	●	
TKN	●	●	●		●	●	●	●	●	
$NO_2^-N + NO_3^-N$	●	●	●		●	●	●	●	●	
Total Alkalinity	●	●	●		●	●	●	●	●	
Total Organic Carbon	●	●	●		●	●	●	●	●	
pH	●	●	●	●	●	●	●	●	●	
Total Suspended Solids (TSS)	●	●	●		●	●	●	●	●	
Total Dissolved Solids (TDS)	●	●	●		●	●	●	●	●	
DO (water column)	●	●	●	●	●	●	●	●	●	
Conductivity	●	●	●	●	●	●	●	●	●	
Specific Conductance	●	●	●	●	●	●	●	●	●	Mo (5,7,8,9,10,2)
MTBE	●		●			●			●[1]	Mo (7,8,9)
Physical:										
Temperature	●	●	●	●	●	●	●	●	●	Mo (5,7,8,9,10,2); Continuous[3]
Turbidity	●	●	●	●	●	●	●	●	●	Mo (5,7,8,9,10,2)
Secchi Transparency	●	●	●	●	●	●	●	●	●	Mo (5,7,8,9,10,2)
Aesthetics[2]	●	●	●	●	●	●	●	●	●	Mo (5,7,8,9,10,2)
Biological:										
Total Fecal Coliform		●			●			●	●	Mo (5,8,9)
Zooplankton (biomass and taxonomic)		●	●	●	●	●			●	Mo (5,7,8,9,2)
Chlorophyll *a* (phytoplankton)	●	●	●		●	●	●	●	●	Mo (5,7,8,9,10,2)
Taxonomic (phytoplankton)	●	●	●		●	●	●	●	●	Mo (5,7,8,9,10,2)
Taxonomic (periphyton)	●	●			●		●	●	●	Mo (5,7,8,9,2)

[1] Monthly July through September 2005 for mainstem pelagic sites.
[2] Odors, fungi or other growths, sludge/deposits, discoloration, scum, oily slick, floating solids.
[3] Continuous temperature monitoring being conducted by Douglas PUD

4.5 Sampling Protocol

Samples were collected with either a Van Dorn sampler (single depth point) or depth integrated hose sampler (range of depths). Sample devices were triple rinsed with water from the sample point before the sample was collected. Samplers were also subjected to acid rinse before and after each field effort. All samples were collected and aliquots transferred directly into pre-cleaned, amber Nalgene containers provided by the laboratory. Samples were placed immediately in the dark on ice and shipped to the laboratory within 36 hours. Sample handling, preservation, and holding times were consistent with guidelines reported in WDOE (2003).

Reservoir water samples intended for laboratory processing were collected from a boat. Except for littoral sites, stations were located over the approximate thalweg (based on existing bathymetry and reconnaissance level depth sounding). All sampling locations were mapped using Global Positioning Systems (GPS) technology ($\pm$ 1m accuracy). Water chemistry sampling consisted of one depth-integrated hose grab sample (2.5-liter sample) collected over the photic zone to a maximum depth of 5 m and one grab sample from 1 m above the bottom; maximum sampling depth was 1 m above the bottom to avoid contamination.

4.5.1 Physical and Chemical Water Quality Parameters

Depth was measured using a Hydrolab minisonde or sounding line.

Temperature, Dissolved oxygen (DO), specific conductance, conductivity, and pH profiles were measured using a Hydrolab minisonde or YSI 610 at each site. Instruments were calibrated prior to each field visit according to the manufacturer's specifications. Instrument calibration procedures are summarized in Appendix A. Winkler titrations were performed at the start of each day to ensure the dissolved oxygen probe was functioning properly. Winkler titrations were also completed for 10% of the grab samples as to further verify the accuracy of dissolved oxygen probe readings. The probe was re-calibrated if the result of the Winkler titration and probe reading differed by more than 0.2 mg/L. For pelagic water sites, measurements were taken at vertical increments of 1 m (3.3 ft) in water less than 15 m (49 ft), 2 m (6.6 ft) in water 15 - 30 m (49 - 98 ft) deep, and 3 m (10 ft) intervals in water 30 - 50 m deep (98 - 164 ft).

Total Alkalinity was analyzed from grab samples by the certified laboratory.

Turbidity was measured in the field using a HACH 2100P Portable Turbidometer.

Transparency was measured in the reservoir with a standard 20 cm (7.9 in) Secchi disk. Two observers independently measured Secchi depth. Measurements were repeated until the difference between paired measurements was no more than 0.25 m.

Nutrients were sampled and laboratory analyzed using methods appropriate for low productivity waters. A one-liter sub sample for subsequent analysis of nitrate-nitrite, Total Kjeldahl Nitrogen (TKN), total phosphorous, orthophosphorus, and silica were appropriately marked and preserved (H_2SO_4) if necessary. The sample was placed on ice and delivered to the laboratory within 36

hours. Table 4.6-1 details the minimal detection levels for ammonia, nitrate, TKN, total phosphorous, and orthophosphorus that were established for the study.

Total organic carbon samples were collected in baked glass jars and analyzed in the laboratory.

Total suspended solids were analyzed by laboratory filtering of a one-liter sample and then oven drying the filter for weighing.

Total dissolved solids were analyzed as a composite sample. In general, the major ions such as calcium, magnesium, sodium, potassium, bicarbonate (and/or carbonate), sulphate, and chloride account for most of the total dissolved solids in western U.S. surface waters. The major ions occur naturally in water as a result of geochemical weathering of rocks, surface runoff, and atmospheric deposition. In addition, carbonates are affected by carbon dioxide exchange between the atmosphere and water and by respiration and photosynthesis. Most of the major ions are conservative (i.e., their concentration is dependent on dilution and downstream transport); however, calcium, magnesium, and bicarbonate levels may be affected by changes in pH and temperature. Hardness was also analyzed in the laboratory.

MTBE (Methyl tert-butyl ether) is a fuel additive to two-stroke engines and is a known carcinogen. Surface grab samples collected from the three mainstem pelagic sites during the summer months (July, August and September) were analyzed in the laboratory.

4.5.2 Biological Water Quality Parameters

Phytoplankton and periphyton were monitored in the Project waters. Upstream to downstream algal production was assessed. Correlations among nutrients, light, temperature, and flow were examined. Trends in algal biomass for both phytoplankton and periphyton (attached benthic algae) were compared with nutrient trends in order to establish the role of nutrient dynamics with algal biomass.

Sampling for phytoplankton occurred at all sites including the mouths of the Okanogan and Methow rivers.

Periphyton is algae that is on or attached to a substrate, i.e., not free-floating in the water column. Periphyton was studied in littoral and tailrace sites as well as the site at the mouth of the Methow River.

The overall study objective for algae assessment was to determine the effect of Project operations on algal production in the Project waters. Specific objectives included:

- Characterize the species composition and relative abundance of periphyton in the study area,
- Assess upstream to downstream phytoplankton production and species composition in the Project waters,
- Determine correlations among phytoplankton chlorophyll *a* and biomass versus nutrients, light, and temperature,

- Provide phytoplankton data for incorporation into future water quality and productivity modeling, and
- Determine the productivity index level of Project waters.

Periphyton were sampled concurrently with other water quality parameters. Natural substrates were collected at the site to determine seasonal periphyton. Three medium cobbles were selected from the bed at each sample site in an area that was determined to be inundated at all times given the daily fluctuation of the reservoir. The top surface of each rock was scrubbed to remove all algae growth outside a 22 cm^2 circular area. The algae growth within this circular sample area was then scraped and rinsed into a 500 ml brown Nalgene container. This process was repeated for each of the three sample cobbles to provide a composite sample. The sample was preserved with 1% Lugol's iodine solution.

Phytoplankton were sampled at all sites. One water sample was collected with an integrated hose sampler over the depth of the photic zone (Straskraba and Javornicky 1973). Generally, the reservoir waters were well mixed (no stratification) so phytoplankton were only sampled over the depth of the photic zone.

For phytoplankton, one composite sample, consisting of three combined replicate water samples, was collected for each sample site/time. Two distinct sub-samples from each composite sample were processed separately for chlorophyll *a* (corrected for pheophytin) and taxonomic biovolume evaluations. All samples were held in the dark on ice until delivery to the laboratory for analysis.

Chlorophyll *a* was analyzed for phytoplankton samples. At the laboratory, a homogenized filtered sample was prepared and put through a blender or grinder, pigments extracted with an acetone solution, followed by analysis with a fluorometer (APHA 1995; 2005). Pheophytin-corrected chlorophyll *a* is reported as mg/m^3 for phytoplankton or mg/m^2 for periphyton.

Samples preserved with Lugol's iodine were homogenized and aliquots placed in a plankton sedimentation chamber such as a Palmer-Maloney counting chamber. Identification to at least genus, and counts of natural units (may be a unit with multiple cells) were made with a microscope equipped with least-phase contrast optics at a magnification of 1000x. Only algae that were live at the time of preservation, based on cell contents, were enumerated. Algae were identified to the lowest practical taxonomic level and enumerated in sequentially viewed fields along transects of the counting chamber. Counting was continued until at least 100 units were counted and until no new taxa had been observed. A unit is defined as a discrete algal particle (cell, filament or colony). A sub-sample was processed with fuming concentrated nitric acid to generate a permanent diatom Naphrax-mounted slide. Phytoplankton samples were measured for both density and biovolume. Densities ($units/cm^2$) for periphyton or units/ml for phytoplankton were determined for each taxon for community composition analysis. An estimate of algal biomass was determined by converting unit densities to biovolumes ($\mu m^3/cm^2$ for periphyton or μm^3/ml for phytoplankton) based on average unit areas of 20 specimens for each taxon (APHA 2005).

A Shannon-Weaver diversity index was calculated for each phytoplankton and periphyton sample. This index is calculated as the sum of percents for each species times the log (base 2) of the percent for each species.

Data analysis included a comparison among sample locations and an evaluation of temporal changes using analysis of variance (ANOVA). Exploratory data analysis using linear regression was used in order to determine correlations among algal indicators and physico-chemical parameters, such as temperature, light, and nutrient concentrations. Phytoplankton chlorophyll *a* data were used to assess the Carlson's Trophic Status Index.

Zooplankton samples were collected in May, July, August, September, and February. A Wisconsin Net (200 micron mesh) was vertically towed at twice the photic depth or the entire water column above the thermocline (whichever is greater) at a rate of 0.5 m/s. Two replicate tows were made to create one composite sample. Samples were preserved with 70% ethanol and a 5% glycerin solution until laboratory processing.

Samples were brought to a known volume and stained with 0.1 ml Eosin Y and 0.1 ml Lugol's solution to aid in visual resolution. Organisms were enumerated and identified to species based on published taxonomic references. Data from taxonomic efforts were summarized to determine species diversity (Shannon-Weaver Index) at each sampling location. The enumeration of zooplankton determined the density of organisms at each sampling site as number/m^3. As with the phytoplankton samples, data analysis considered temporal trends within the reservoir and used appropriate statistical analysis for detecting differences between sample sites.

Coliform contamination is not a direct result of the Project; however, Project induced modifications on retention and water travel time could indirectly influence coliform levels within Project waters. Sampling was limited to littoral sites and the mouths of the Methow and Okanogan rivers for the May, August, and October sampling events. Samples collected from each of these sites consisted of a 125 mL water sample. At least one field replicate per sampling event was collected for quality assurance purposes. Samples were collected from the surface directly into sterilized and sealed polyethylene sample bottles provided by the laboratory for coliform analysis. The sampler wore clean latex gloves during sample collection and took care to avoid disturbing the lakebed sediments. Samples were placed on ice for transport to the laboratory. Ideally, fecal coliform samples were delivered to the laboratory within 12 hours; however, logistics occasionally necessitated a transport time of up to 36 hours. Holding times for all samples were documented.

There are three main types of bacterial analyses used as water quality indicators: total coliforms, fecal coliforms, and fecal streptococci. The coliform group comprises all aerobic and facultative anaerobic, gram-negative, rod-shaped bacteria that ferment lactose, with gas and acid formation within 48 h at 35^{o}C (APHA 1992; 2005). Total coliforms include heterotrophic bacteria of both fecal and nonfecal origin.

The fecal coliform test is used to differentiate between coliforms of fecal origin (those originating in the intestine of warm-blooded animals) and coliforms from other sources; *Escherichia coli* usually comprises a high portion of the fecal coliform count. Other bacteria that

are not of fecal origin (e.g., *Klebsiella* spp.) show up in counts of fecal coliforms. *Klebsiella* are common in organically rich water such as soil drainage, pulp and paper mill effluents.

The normal habitat for fecal streptococci is the gastro-intestinal tract of warm-blooded animals. The ratio of fecal coliforms to fecal streptococci has been used to provide information about the source of bacterial contamination; however, the use of this ratio is no longer recommended (APHA 1992; 2005).

Sampling focused on compliance with Washington State water quality standards, which are based on fecal coliform levels. Microbiological determinations were performed by a laboratory certified by the Washington Health Department and WDOE for bacterial analyses in drinking water using MPN methods. Based on probability tables presented in APHA (2005), the uncertainty in MPN determinations may span as much as an order of magnitude. Therefore occurrence or non-occurrence is considered along with estimated counts.

4.6 Quality Control/Quality Assurance

The Quality Control and Quality Assurance (QA/QC) plan for this study was consistent with methods fully described in EPA 2002. QA/QC procedures address both field and laboratory methods. Desired data accuracy is defined in Measurement Quality Objectives.

Clean sampling techniques were applied throughout the sampling effort. All sample bottles were prepared by the laboratory with an acid rinse. The Van Dorn sampler, carboy, and integrated hose sampler were triple rinsed with a portion of the sample water before filling for sample collection.

All personnel responsible for sample collecting and data analysis were familiar with this study plan including quality control/quality assurance (QA/QC) protocol. A qualified scientist was responsible for all phases of the study and ensuring that other personnel were sufficiently trained.

The labeled samples were placed in closed, lightproof coolers filled with ice. The maximum holding times are indicated in Table 4.6-1. Iced samples were delivered to the laboratory within 24 hours and typically within 12 hours of sample collection.

Quality control in the field was assured by accurate and thoroughly completed sample labels, field sheets, chain of custody and sample log forms. Sample labels included: sample identification code, date, time, stream name, sampling location, collector's name, sample type and preservative, if applicable. All sample containers were clearly labeled with date, time of sample, and sample location. Chain of custody letters for samples were routine procedure for all samples submitted to the laboratories.

Calibration of instrumentation for field measurements including: dissolved oxygen, temperature, pH, conductivity, and turbidity were performed daily according to the manufacturer's instructions. Where appropriate, a two-point calibration was applied, i.e., the instrument was calibrated relative to two known standards. Calibration procedures for the Hydrolab are described in Appendix A.

QA/QC of water quality samples for water chemistry analysis, phytoplankton and bacterial analysis were tracked by collecting field replicates. Field replicates for at least ten percent of the total number of samples sent to the lab for water chemistry analysis were processed during each sample trip. At least one replicate sample and one field blank were collected for each sample trip. One field replicate per sample event was collected for fecal coliform analysis. Replicates were chosen based on the probability of the sample exceeding the reporting limits for the total phosphorus and total nitrate/nitrite. There is no benefit for selecting replicate samples at random if the sample metric is below the reporting limits for the parameters of interest (WDOE 2001).

One replicate sample from 10% of the algae samples was collected per sample event and analyzed to evaluate precision or repeatability of sampling technique, sample analysis, and taxonomy. Common algal species should be the same for the two wet mount replicates. The percent community similarity index (Whittaker 1952 as referenced in U.S. EPA 1999) calculated from proportional counts of the two replicate diatom slides should exceed 75%. Any differences in identification were reconciled and bench sheets were corrected.

The laboratory maintained a voucher collection of all algae samples and diatom slides that were accurately and completely labeled, preserved, and stored for future reference. A record of the voucher specimens was maintained.

One field blank for water chemistry was submitted for each sampling trip. Field blanks were prepared by first rinsing the sampler with de-ionized water and then filling it with 500 ml of de-ionized water; half of this sample serves to rinse the opening before filling the blanks. Blanks and duplicates were submitted with other samples for laboratory analysis. Throughout the study, the comparison of the standard deviation of blind field replicates provided a check of laboratory precision. Field blanks were collected at the same rate and submitted with the laboratory samples to measure any background contamination of containers and sampling techniques. Duplicate samples were submitted for ten percent of the samples for water chemistry analysis to estimate field and lab precision. A cautionary note was appended to data collected on days when a blank sample submitted to the lab reported values at or above the laboratory reporting limit for one or more analytes (Table 4.6-1). For any given chemical analyte, field sampling practices were reviewed when the results for duplicate samples differ by a value more than this standard error. Unless there was a reasonable explanation for the difference, a cautionary note was appended to the water chemistry data collected on days when results for duplicate samples show a significant discrepancy. The cautionary note was waived if one or both analyte values for the duplicate samples were below the laboratory reporting limits. The laboratory routinely evaluates laboratory accuracy, a measure of the reported value relative to the true value by analyzing known standard samples.

Measurement Quality Objectives (MQOs) answer the question of how accurate the measurements need to be in order to get accurate data. The Environmental Protection Agency (EPA) defines MQOs as “acceptance criteria” for the quality attributes measured by project data quality indicators (EPA 2002). The MQOs are based on methods and the Data Quality Objectives, which guide how accurate data need to be in order to make correct decisions. MQOs

include precision, bias and accuracy guidelines against which the laboratory and some field Quality Control results are compared. The MQOs for this study are reported in Table 4.6-12.

Precision is estimated as the standard deviation of the results of *n* replicate measurements. If more than one estimate of the standard deviation of a population is available, a pooled estimate may be calculated based on *m* pairs of duplicate results as:

$$sp = \sqrt{\frac{\sum D\text{^}2}{2m}}$$

where: s_p = pooled standard deviation
D = difference between two paired results

Precision is often reported as the Relative Standard Deviation (RSD) of the results of replicate measurements (WDOE 2001), which is calculated as a percentage of the mean by:

$$RSD = \frac{s}{\bar{x}} * 100$$

where: x = the mean of the replicate measurements

Careful adherence to procedures should maintain bias within acceptable limits. For this study, bias in laboratory results was likely to be primarily a function of sample concentrations that were near or below the reporting limits. This situation is especially true for nutrients, which can be expected to be at very low concentrations in Project waters. The results of analysis of check standards can be used to estimate bias due to calibration error. The laboratory uses check standards as well as matrix spikes to detect interference effects due to the sample matrix for analyzing bias.

WDOE (2001) describes accuracy as a measure of the magnitude of the total error (E) and accuracy is a function of precision and bias such that:

Accuracy = Bias + 2 * RSD when accuracy and bias are expressed as percentages of the true value and RSD is the percent relative standard deviation.

Typical laboratory reporting limits are also listed in Table 4.6-1. Reporting limits are defined as the minimum value that there is 95% confidence that the reported lab value is within one standard error of the actual value for a sample. All actual instrument values were recorded regardless of whether they are below reporting limits. Negative values were reported as zero.

Table 4.6-1 Measurement Quality Objectives for Accuracy, Precision, Bias and Stated Reported Limits

Parameter	Maximum Laboratory Holding Time (Days)	Method	Accuracy	Precision	Bias	Reporting Limit	Expected Range
Water Temperature	NA	Onset Continuous	±0.18°C	0.025 °C[1]	0.05 °C[1]	0.01 C	1 – 24 C
Air Temperature	NA	Onset Continuous	±0.18 °C	0.025 °C[1]	0.05 °C[1]	0.01 C	-5 – 30 C
Relative Humidity	NA	Onset Continuous	±3%	<10%RSD	5%	0.1%	10 – 100%
Sample Depth	NA	Hydrolab-lake Topset rod-riv	±0.2 m	<5RSD	1%	0.1 m	< 32 m
Dissolved Oxygen[5]	NA	Modified Winkler/ Hydrolab	±0.4 mg/L	<5%RSD	1%	0.01 mg/L	2.0 – 14 mg/L
pH[2]	NA	Hydrolab	0.2 s.u.	0.05 s.u.	0.1 s.u.	0.01 s.u.	7 – 9 s.u.
Conductivity[2]	NA	Hydrolab	7%	<10%RSD	5%	1 umhos/cm	50 -130 umhos/cm
MTBE	14 days	EPA 1664		NA	NA		Non-detect
Turbidity[2]	NA	Nephelometric SM 2130	±5%	<10%RSD	NA	0.01 NTU	< 10 NTU
Secchi Transparency	NA	Stnd Secchi Disk	±0.5 m	NA	NA	0.2 m	3 – 9 m
Total Dissolved Gas Pressure[2]	NA	Hydrolab	±10mmHg @ 200mmHg	NA	NA	1.0 mmHg	95 – 150% sat.
Phytoplankton (taxonomic units)[4]	1 year	Identification to lowest possible taxon	NA	NA	NA	NA	NA
Chlorophyll *a* (phytoplankton)[4]	2	APHA 1995; 2005 (flourometric)	NA	20	NA	0.1 µg/L	<6 ug/L
TKN[4]	28	SM4500 Norg	25%	10% RSD	10	500 µg/L	50 - 200 µg/L
NH_4[4]	28	SM 4500 NH_3	30%	10%RSD	15	10µg/L	<15 µg/L
Nitrate - Nitrite[4]	2	SM4500 NO_3	25%	10%RSD	5	5 µg/L	50 – 100 µg/L

Table 4.6-1 Measurement Quality Objectives for Accuracy, Precision, Bias and Stated Reported Limits

Ortho phosphorus[4]	2	L10-115-01-1-B	25%	10%RSD	5	0.5 µg/L	1-4 µg/L
Total phosphorus (ICP) [4]	28	SM4500-PE	20%	10%RSD	5	10 µg/L	5-35 µg/L
Total Organic Carbon[4]	28	SM 5310C	20%	<10	10	0.5 mg/L	0.2 - 0.5 mg/L
Total suspended solids[4]	7	EPA 160.2	20%	<10	10	1 mg/L	0.2 -4 mg/L
Total dissolved solids[4]	7	SM 2540C	20%	<10	10	5 mg/L	20 -85 mg/L
Alkalinity, Bicarbonate & Carbonate[4]	14	SM 2320B	NA	<10	NA	10 mg/L	15 - 65 mg/L
Fecal Coliform[4,6]	12 hrs.	SM 9221E	NA	<25	NA	1MPN/100 ml	2 – 50 mpn/100ml

EPA = Environmental Protection Agency

SM = Standard Methods for the Examination of Water and Wastewater, 19th Edition (APHA 1995; 2005)

[1] Based on manufacturer's reported calibration of instrument for Onset thermologgers; Hydrolab calibration precision acceptance is 0.3°C

[2] Based on calibration of check standards

[3] Based on replicate field measurements

[4] Based on laboratory analysis of field replicates

[5] Based on comparison of instrument reading and Modified Winkler titration results

[6] Logistics may require holding times up to36 hrs for transport

Quality control also applies to analytes measured in the field. Precision, the degree of agreement between replicate samples, was measured at the time of instrument calibration. Accuracy of field instruments is also established at the time of calibration. An instrument is considered properly calibrated when the reading for a known standard meets the criteria established in Table 4.6-2. Instruments were calibrated daily according to the manufacturer's guidelines. Multiple point calibration procedures were followed where applicable.

Table 4.6-2 Calibration Criteria for Field Measured Water Quality Parameters

Parameter	Temperature	Dissolved Oxygen	Conductivity	Turbidity
Instrument Precision (agreement between duplicate readings)	$\pm$0.18 ^{o}C	$\pm$0.3 Mg/L	$\pm$2% std. value	$\pm$5% std. value
Instrument Accuracy (calibration agreement with a known standard)	$\pm$0.18 ^{o}C	$\pm$0.2 Mg/L	$\pm$7% std. value	$\pm$5% std. value

Meeting the MQOs is a measure of quality control. MQOs for field parameters were reviewed concurrently with instrument calibration at the time of sample collection. The corrective action for not meeting the MQOs for field parameters was the recalibration of instruments. In the event that instruments cannot be properly calibrated to meet the MQOs, the data were labeled as suspect. The MQOs for laboratory analyzed parameters based on replicate sample results were reviewed monthly as data became available. In addition, the laboratory continually monitored for quality control sample determinations and took appropriate action to correct problems. If data were compromised due to poor precision, the source of variability was sought and corrective actions implemented. Possible actions included: modifying methods or instrumentation for field sampling; informing the laboratory of possible errors; and reevaluating the required precision, when it appears that the target cannot be met. Data failing to meet MQOs were flagged. Methods were reviewed to determine possible causes, which were documented. Not meeting the MQOs does not necessarily mean that the data do not provide useful information. Very low concentrations that are below detection limits can lead to a relatively large bias in the results. For the purposes of assessing Project compliance with the water quality standards, this type of failure to meet MQOs does not pose a substantial problem. The confidence interval for the mean of the very low values would likely not overlap with the water quality numeric criteria. Interpretation of MQOs relative to Project results was addressed on a case-by-case basis for each parameter and is fully discussed in this study report.

5.0 RESULTS

Water quality sampling was conducted seasonally with one sample event scheduled for May, August, October and February. An additional sampling event was scheduled in July and September to provide for monthly sampling frequency in the summer. Table 5.0-1 lists the sampling dates and respective hydrologic conditions for the reservoir.

Table 5.0-1 Water quality sampling dates

Dates	Average Daily Total Discharge at Wells Dam (kcfs)	Average Water Elevation at Wells Dam (ft AMSL)
May 17-18 2005	121.1	780.43
July 12-13 2005	151.9	780.82
August 19 2005	118	779.98
September 7-8 2005	87.8	780.43
October 17-18 2005	79.1	779.52
February 7 2006	113.2	779.74

5.1 Data Quality

Table 5.1-1 lists the number of samples for each parameter and the number of samples below the laboratory detection limit. With the exception of ammonia and total suspended solids, the detection limits were sufficiently low as to result in few samples with non-detects. The laboratory provided instrument readings regardless of whether or not values were below the detection limit; however, these readings were flagged. Ammonia levels are typically very low during the growing season in low nutrient waters that are not stratified. Total suspended solids are low for the Wells Reservoir since upstream reservoirs tend to settle out suspended solids.

Table 5.1-1 Number of samples and samples below detection limit

Parameter	Samples	Non-Detect	%Non-Detect	Detection Limit (mg/L)
Total Alkalinity	70	0	0	0.5
Ammonia as N	70	30	42.9	0.01
Nitrate + Nitrite as N	70	3	4.3	0.01
Total Nitrogen	70	0	0	0.01
Phosphate, Ortho as P	70	0	0	0.003
Phosphorus, Total	70	5	7.1	0.005
Solids, Total Dissolved	70	0	0	5
Solids, Total Suspended	70	44	62.9	2
Total Organic Carbon	24	0	0	0.5
MTBE	9	9	100	0.00012

Sample size does not include field blanks and duplicates

The management quality objectives (MQOs) as defined in the study plan were met with several exceptions. Field instrumentation accuracy complied with criteria established in the study plan.

Table 5.1-2 summarizes the results for Relative Standard Deviation (%RSD), which is the MQO for precision. The MQOs for %RSD were not met in the following situations.

- MQO for ammonia (NH_4) was exceeded for all months except July.
- MQO for Orthophosphorus was exceeded for all months except July.
- MQO for Total Phosphorus was exceeded for all months except October.
- MQO for total suspended solids was exceeded in May and July.

Table 5.1-2 Relative Standard Deviation (%RSD) for duplicate water quality samples

Parameter	Water Temperature	Dissolved Oxygen	pH	Turbidity	Secchi Transparency	Conductivity	NH_4
Mean %RSD	0.19	1.11	0.04	1.0	0	0	24.27
Maximum %RSD	0.55	1.61	0.18	3.14	0	0	76.85
Target Precision	0.025C	<5%RSD	<5%RSD	<10%RSD	NA	<10%RSD	10%RSD

	Nitrate	Total Nitrogen	Ortho phosphorus	Total phosphorus	Total suspended solids	Total dissolved solids	Total Organic Carbon
Mean %RSD	0.4	2.2	27.6	17	11.0	1.54	
Maximum %RSD	1.03	2.58	60.9	22.63	22.81	2.1	
Target Precision	10%RSD	10%RSD	10%RSD	10%RSD	<10	<10	<10

	Total Alkalinity	Fecal Coliform
Mean %RSD	0.8	
Maximum %RSD	3.17	
Target Precision	<10	<25

The reason for the exceedances of MQOs was attributed to very low concentration levels. The concentrations were below the detection levels. Since the detection levels are set low relative to levels that would likely cause water quality impairment, not meeting the MQOs is not considered a major problem.

Paired laboratory replicates were also analyzed, which identify potential error due to laboratory technique and/or instrumentation. There were no significant differences between any of the paired laboratory replicates. Similarly, the reported results for laboratory reference samples analyzed were not significantly different from the true values for reference samples. The

laboratory blanks reported constituent levels below detection limits.

The results for some of the field blanks reported nutrient levels above detection levels. These field blanks were prepared with distilled water. Changing procedures by preparing field blanks with deionized water provided by the laboratory corrected this problem. Nutrient levels were below detection levels when field blanks were prepared with deionized water, which indicates that field contamination of samples was not a problem.

5.2 Weather and Hydrology

Climate conditions and river hydrology both affect the physical, chemical and biological processes for a reservoir. This section summarizes general conditions by month for the sampling period and specific conditions for the dates of sampling.

The National Climate Data Center (NCDC) maintains climate records around the county. Air temperature data for the NCDC Coop station at Chief Joseph Dam are reported in Table 5.2-1. The monthly average of the daily maximum air temperature was slightly warmer in July and August, 2005.

Table 5.2-1 Monthly Normal and average daily air temperatures at Chief Joseph Dam

		MAY	JUN	JUL	AUG	SEP	OCT
Max	Normal	22.94	27.17	31.67	31.78	26.11	17.50
	2005	23.87	26.24	32.74	33.30	25.83	17.44
	Difference	0.93	-0.93	1.08	1.52	-0.28	-0.06
Min	Normal	7.44	11.39	14.17	13.94	8.83	2.83
	2005	8.82	10.91	14.23	13.67	8.94	5.47
	Difference	1.37	-0.48	0.06	-0.27	0.11	2.63

Data are from NCDC Coop Station No. 451400

Average monthly river flows in the Columbia River as measured at Wells Dam during the study period are reported in Table 5.2-2. With the exception of October, when there was a relatively low flow, average monthly flows in the Columbia River during the months that water quality was monitored were within the two middle quartiles (25% - 75%) of exceedance flows (based on flow duration curves 1968 – 2005 at Wells Dam). A gage station that is located near Pateros measures flow in the Methow River (USGS Gage No. 12449950). Average monthly discharge at the Methow River gage station for the study period is reported in Table 5.2-3. A gage station located near the town of Malott, WA, measures flow in the Okanogan River (USGS Gage No. 12447200). Average monthly discharge at the Okanogan River gage station is reported in Table 5.2-4.

Table 5.2-2 Average monthly total river flow (kcfs) at Wells Dam: 2005 - 2006

Month	Total Discharge (kcfs)	Month	Total Discharge (kcfs)
May	122.1	September	78.5
June	130.8	October	67.6
July	136.8	February 2006	104.5
Aug	107.9		

Table 5.2-3 Average monthly river flow (cfs) Methow River near Pateros (USGS No. 12449950)

Month	Total Discharge (cfs)	Month	Total Discharge (cfs)
May 2005	3,203	September 2005	235
June 2005	1,634	October 2005	321
July 2005	717	February 2006	325
Aug 2005	283		

Table 5.2-4 Average monthly river flow (cfs) Okanogan River near Malott (USGS No. 12447200)

Month	Total Discharge (cfs)	Month	Total Discharge (cfs)
May 2005	4,850	September 2005	608
June 2005	2,934	October 2005	1,119
July 2005	2,673	February 2006	1,304
Aug 2005	839		

5.3 Water Temperature

Vertical profiles of water temperature were measured at each of the sample sites. The reservoir was homeothermous vertically throughout the monitoring period. Mean daily water temperatures showed minimal downstream warming for May through August with a 0.3^{o}C average increase between average daily temperatures at Chief Joseph tailrace (bottom measurement) and Wells Dam tailrace (bottom measurement located approximately 4.8 km downstream of dam). Douglas PUD deployed Onset Tidbit thermographs at several locations and multiple depths throughout the reservoir and in the lower Okanogan River and lower Methow River. These thermographs were programmed to record hourly water temperatures. Table 5.3-1 summarizes monthly water temperatures based on the thermograph data. The thermograph data were consistent with the instantaneous vertical temperature profile measurements. Vandalism and loss of thermograph instruments was a common problem in 2005.

Table 5.3-1 Average daily water temperatures for the Wells Project (2005-2006)

		May '05	Jly '05	Aug '05	Sep '05	Oct '05	Feb '06
Chief Joseph tailrace[5]	Max	12.3	17.8	19.5	19.3	18.2	
	Min	8.0	15.1	16.5	18.4	15.1	
	Mean	9.8	16.1	18.4	19.0	16.9	
Wells Reservoir at RM 532	Max	12.5	17.9	18.9[1]			
	Min	8.1	15.2	17.7[1]			
	Mean	10.0	16.4	18.4[1]			
Wells Reservoir at Brewster Br.	Max	12.5	18	19.1[1]			
	Min	8.1	15.4	17.8[1]			
	Mean	10.1	16.5	18.5[1]			
Wells Forebay[2]	Max	12.9	18.2	19.4	19.6	18.1[3]	
	Min	8.5	15.5	18.1	18.2	17.2[3]	
	Mean	10.3	16.7	19.0	18.9	17.5[3]	
Wells Tailrace[6]	Max	12.9	18.1	19.4	19.5	NA	
	Min	8.4	15.5	17.9	18.7	NA	
	Mean	10.2	16.6	18.9	19.1	NA	
Okanogan R near Mouth	Max			23.1[4]	21.8	16.2	
	Min			21.4[4]	16.5	10.2	
	Mean			22.1[4]	18.8	13.4	
Methow R at RM 1.2	Max		22.2	23.0[1]			
	Min		16.6	19.5[1]			
	Mean		19.5	21.2[1]			

Data are from thermographs operated by Douglas PUD
[1] *Based on data from 8/1/2005 to 8/16/2005*
[2] *Measured at 1.5 m below water surface*
[3] *Based on data from 10/1/2005 to 10/10/2005*
[4] *Based on data from 8/17/2005 to 8/31/2005*
[5] *Data are from instrument deployed on bottom of channel*
[6] *Data are from TDG monitoring station located approximately 4.8 km downstream of Wells Dam*

Water temperature in the Wells Reservoir is mostly governed by the temperature of inflowing water at Chief Joseph Dam. Temperature in the Wells Reservoir varied little longitudinally between the furthest upstream site at Chief Joseph tailwater and the Wells Dam forebay at the downstream end of the reservoir. The difference in monthly mean of the daily average water temperature for August between Chief Joseph tailrace and Wells forebay was 0.13°C with a range of -0.2 to 0.49°C. The reservoir showed essentially no vertical temperature stratification (see Appendix B for charts and tables for vertical profile data). The only site to show even weak vertical temperature stratification was the Okanogan River near its mouth for July and August. Figure 5.3-1 shows monthly temperature vertical profiles as measured in the reservoir just

downstream of Brewster Bridge. Figure 5.3-2 shows the monthly vertical temperature profiles for the lower Okanogan River.

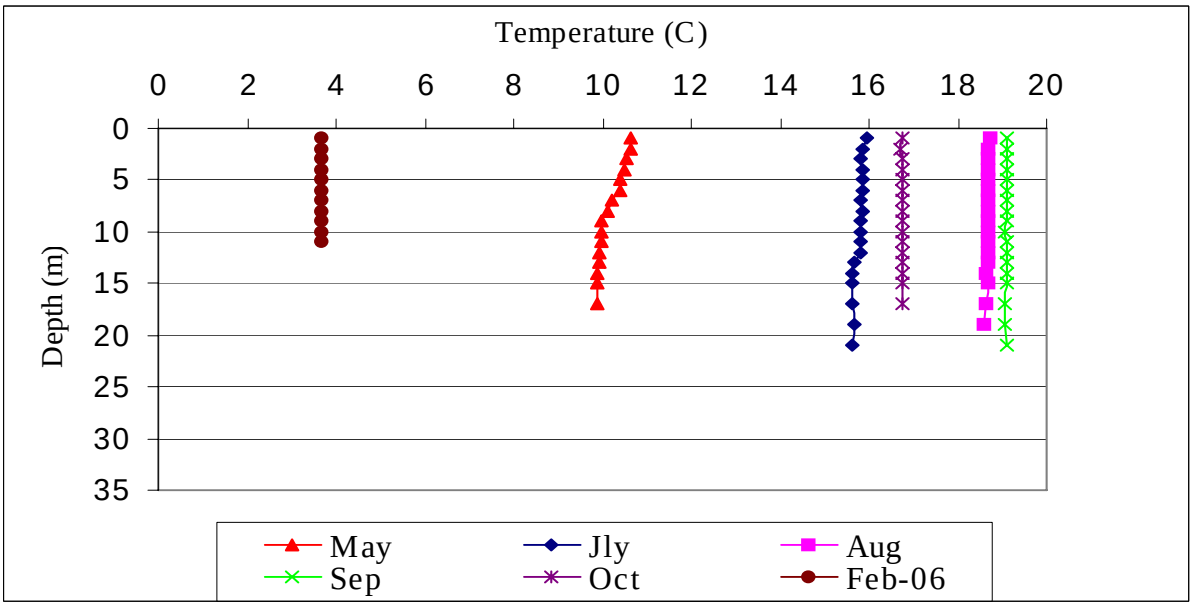

Figure 5.3-1 Vertical temperature profiles for Wells Reservoir at Brewster Bridge (2005)

The Okanogan River had a vertical temperature gradient in July and August but was not fully stratified. On July 12, 2005 (10:30am) the surface temperature was 21.25°C and the bottom temperature at 9m depth was 17.57°C. On August 17, 2005 (1:30pm), the surface temperature in the lower Okanogan River was 22.46°C and the bottom temperature (8 m depth) was 19.45°C (Figure 5.3-2).

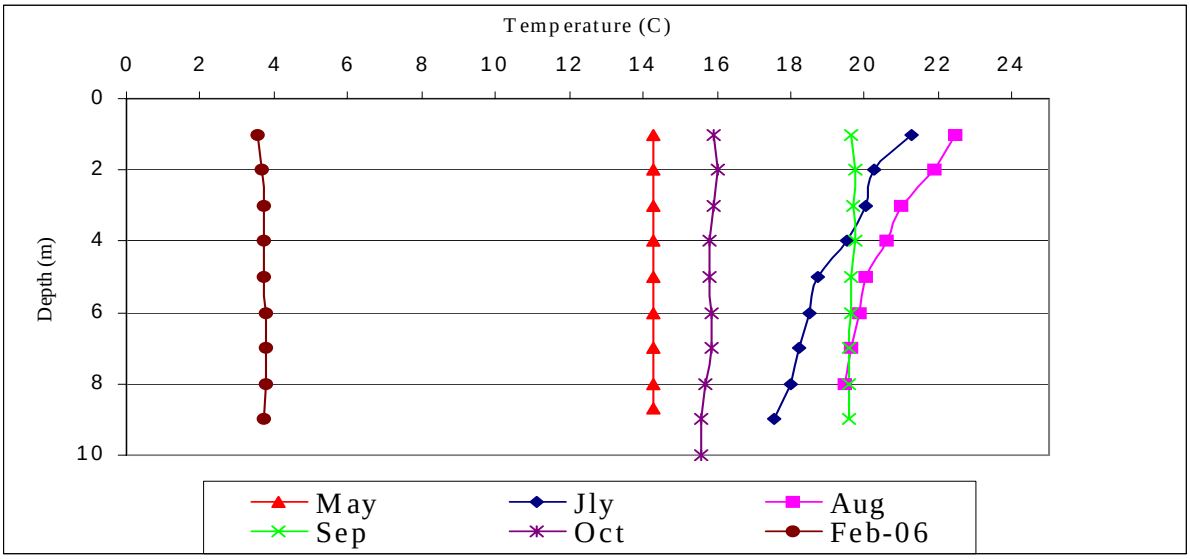

Figure 5.3-2 Vertical temperature profiles for the lower Okanogan River (2005)

5.4 Dissolved Oxygen

Dissolved oxygen (DO) levels are an extremely important variable for aquatic life and govern the chemical dynamics of a water body. DO levels are influenced by the level of biological activity in the water. High photosynthesis can elevate DO while respiration by plants and animals lowers DO levels. Turbulence in the tailrace of a dam can also increase DO. Temperature affects reservoir DO in several ways. Colder water has a higher saturation level for dissolved oxygen. When reservoirs become temperature stratified, vertical mixing is reduced and respiration at depth can deplete DO. Wells Project waters remained unstratified throughout the study period and were vertically homogenous for DO. Figure 5.4-1 shows the vertical profile for the deepest portion of the thalweg in the reservoir downstream of the Brewster Bridge. Low respiration rates at depth and short retention through the reservoir resulted in very little oxygen depletion at depth in the Wells Reservoir.

Dissolved oxygen levels at 1m depth increased from upriver to downriver; the average difference (May through October) was 1.07 mg/L. The difference was more pronounced during May through August (figure 5.4-2). The difference in September and October was only 0.3 mg/L, which is similar to instrument reliability. The DO at the surface within the littoral sites was similar to or slightly higher than the DO for surface waters at pelagic sites. DO saturation levels were equal or greater than 100% for all sites and all depths in all months except October when DO percent saturation for surface waters ranged from 110% to 91% saturation. The lower saturation levels in October may be due to reduced primary productivity while water temperatures were still relatively warm.

All surface water measurements had DO values greater than 8.0 mg/L, which are the water quality numeric criteria (WAC 173-201A as amended July 1, 2003) for dissolved oxygen levels within non-core rearing freshwater habitat. Table 5.4-1 lists DO data.

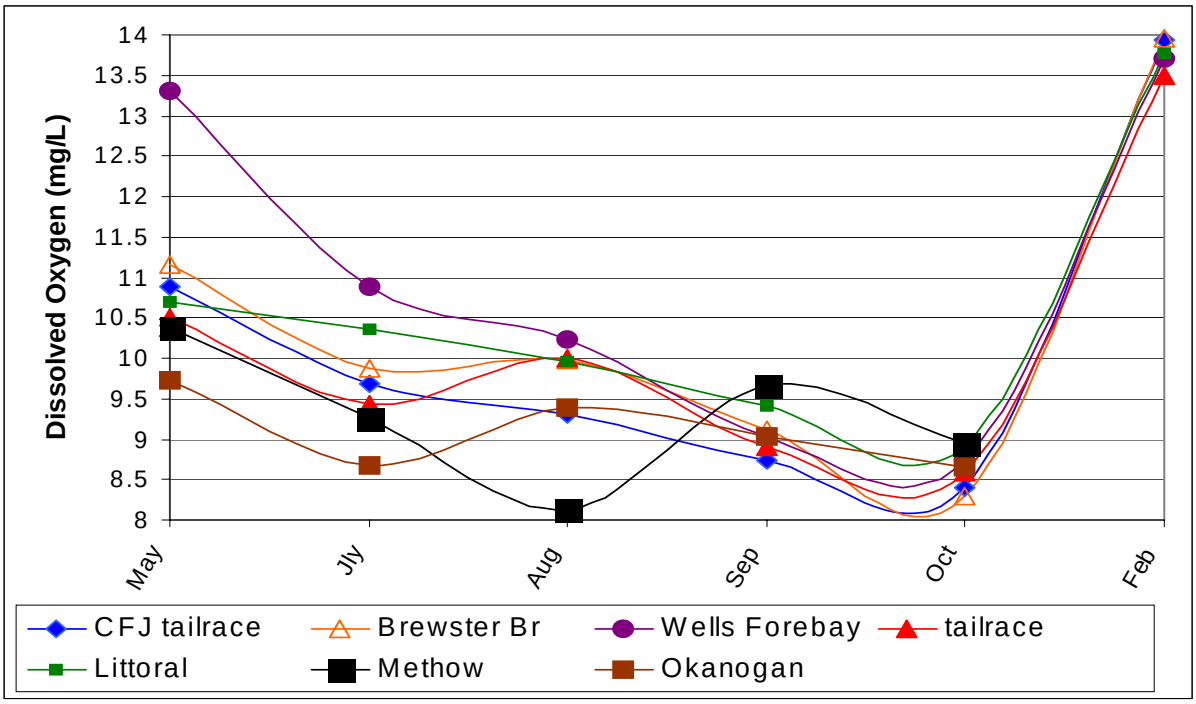

Figure 5.4-1 Dissolved oxygen for Wells Project waters (2005)

Table 5.4-1 Comparison of Dissolved Oxygen Measurements (mg/L) in the Wells Project, 2005-2006

Location	May	July	August	Sept.	October	Feb. '06
Chief Joe tailrace	10.89	9.68	9.30	8.74	8.39	13.94
Brewster bridge photic zone	11.16	9.88	9.97	9.11	8.29	13.96
Brewster bridge off bottom						13.42
Forebay photic zone	13.31	10.89	10.24	9.04	8.74	13.71
Forebay off bottom						13.24
Wells tailrace	10.50	9.44	10.01	8.90	8.60	13.5
Bridgeport shallows littoral	11.19	10.31	10.08	8.71	8.14	13.7
Starr boat launch littoral	10.20	10.39	9.82	10.10	9.71	13.82
Methow R photic zone	10.38	9.26	8.13	9.66	8.95	14.35
Methow R off bottom						
Okanagan R photic zone	9.73	8.68	9.39	9.04	8.65	13.89
Okanagan R off bottom						13.70

5.5 Secchi Disk Transparency and Turbidity

Transparency is a measure of the penetration of light into the water column. After light enters water, it is absorbed by dissolved organic substances, pigmented (phytoplankton) and colored particulates and by the water itself. Light is scattered by inorganic particulates (Effler, 1988). Transparency is a good indicator of a waterbodies trophic status when combined with nutrient and chlorophyll data. Transparency also regulates macrophyte growth. There is a direct relationship between Secchi depth (transparency) and the depth at which macrophytes grow.

Macroscopic plants generally do not grow past a point where available light is less than 1% of the available light at the water surface (Olem and Flock, 1990).

Average Secchi depth for the Wells Project varied minimally during May through August with only a slight increase as the season progressed (range 4.1 m to 4.5 m). Secchi depth (transparency) increased to a seasonal peak in September of 6.25 m before slightly decreasing in October to a mean depth of 5.3 m. Secchi depth in February averaged 3.75 m for pelagic waters but varied from 3.0 m at Chief Joseph tailrace to 6.3 m at the Wells forebay. Figure 5.5-1 shows the seasonal trend of transparency in the Wells Reservoir. Table 5.5-1 provides site specific Secchi depth data.

Transparency increased downstream at Brewster Bridge and Wells forebay relative to the head of the reservoir at Chief Joseph Dam tailrace for all months (Figure 5.5-2). Water transparency in the lower Okanogan River gradually increased to peak in September at 2.7 m. Transparency for the Methow River varied between 1.3 m (August) and 3.2 m (September). The reduced water transparency in August is likely due to phytoplankton growth in the backwater of the Methow River.

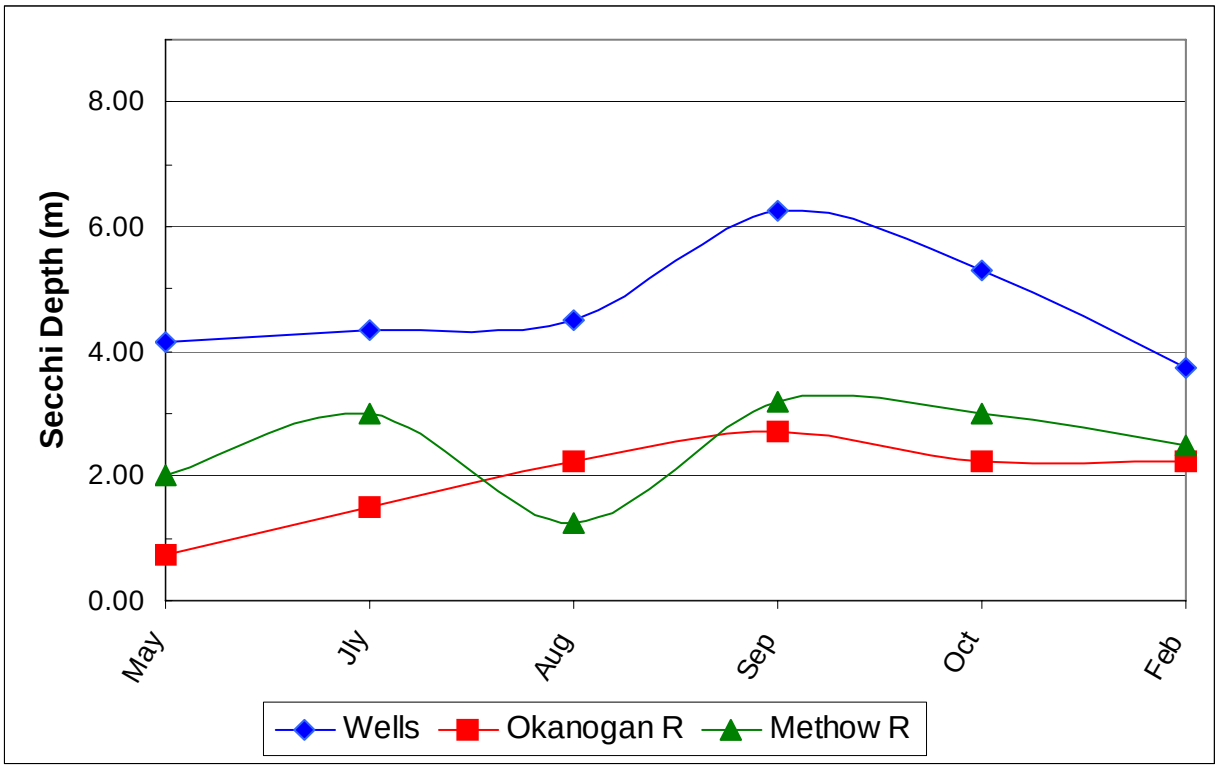

Figure 5.5-1 Secchi depth for the Wells Reservoir (monthly mean of pelagic sites) and tributaries (2005)

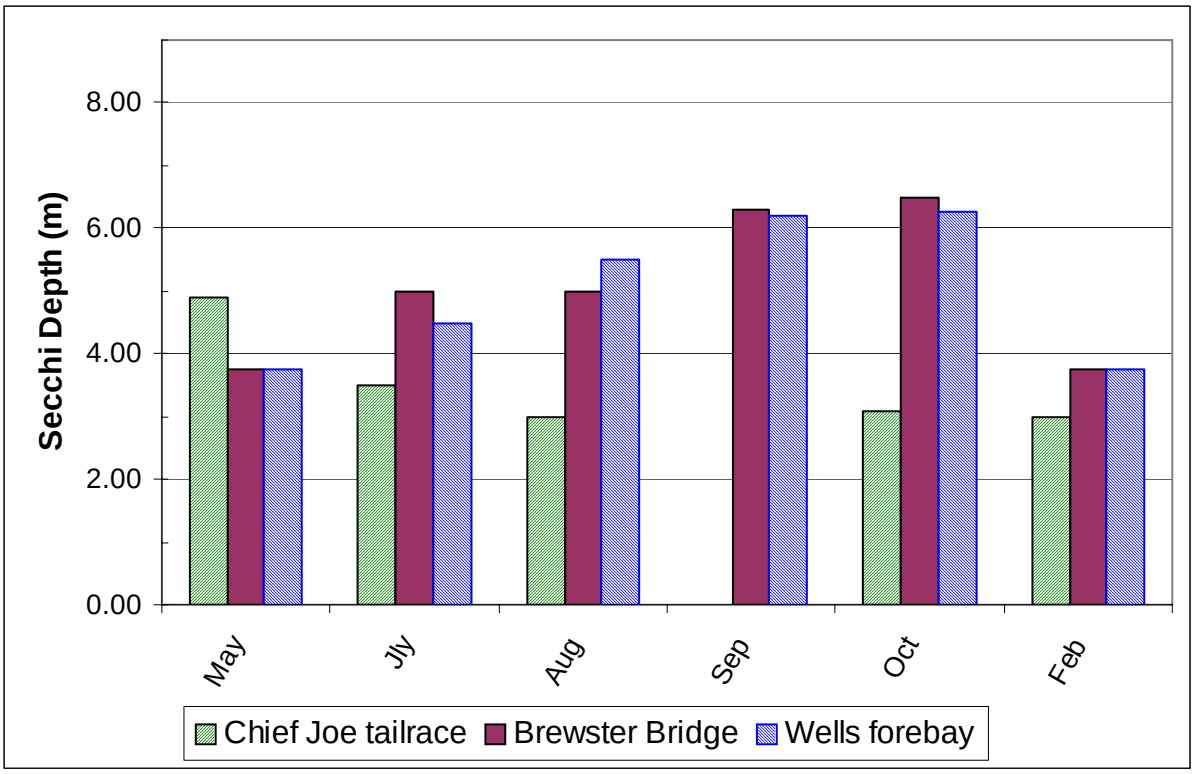

Figure 5.5-2 Longitudinal trend for Secchi depth in the Wells Reservoir (2005-2006)

Turbidity is also a measure of the light scattering from suspended particles in water. Turbidity measurements were performed in the field using a HACH 2100P Portable Turbidometer that passes a beam of light through a water sample and measures the scattering of the light. Washington Administrative Code 173-210A allows for no more than a 5 NTU (Nephelometric Turbidity Units) increase over background when background turbidity is 50 NTU or less. Turbidity in the Wells Reservoir showed relatively little seasonal variation with an annual average of 0.98 NTU. Longitudinal variation in turbidity was also minimal; sampling did not occur within the mixing zone plume of the Okanogan River. Low turbidity in the reservoir is partially due to the large upstream storage reservoir capacity that allows fines to settle out. Turbidity in the Okanogan River was consistently higher than in the Wells Reservoir (Figure 5.5-3). Turbidity in the Methow River was higher than in the Wells Reservoir in May (due to sediment load) and in August due to phytoplankton growth. The only turbidity reading over 5 NTU was in the Methow River during May. Turbidity data are reported in Table 5.5-2. Secchi depth and turbidity are inversely related (Figure 5.5-4). This correlation for the Wells Project area is moderate ($R^2 = 0.76$).

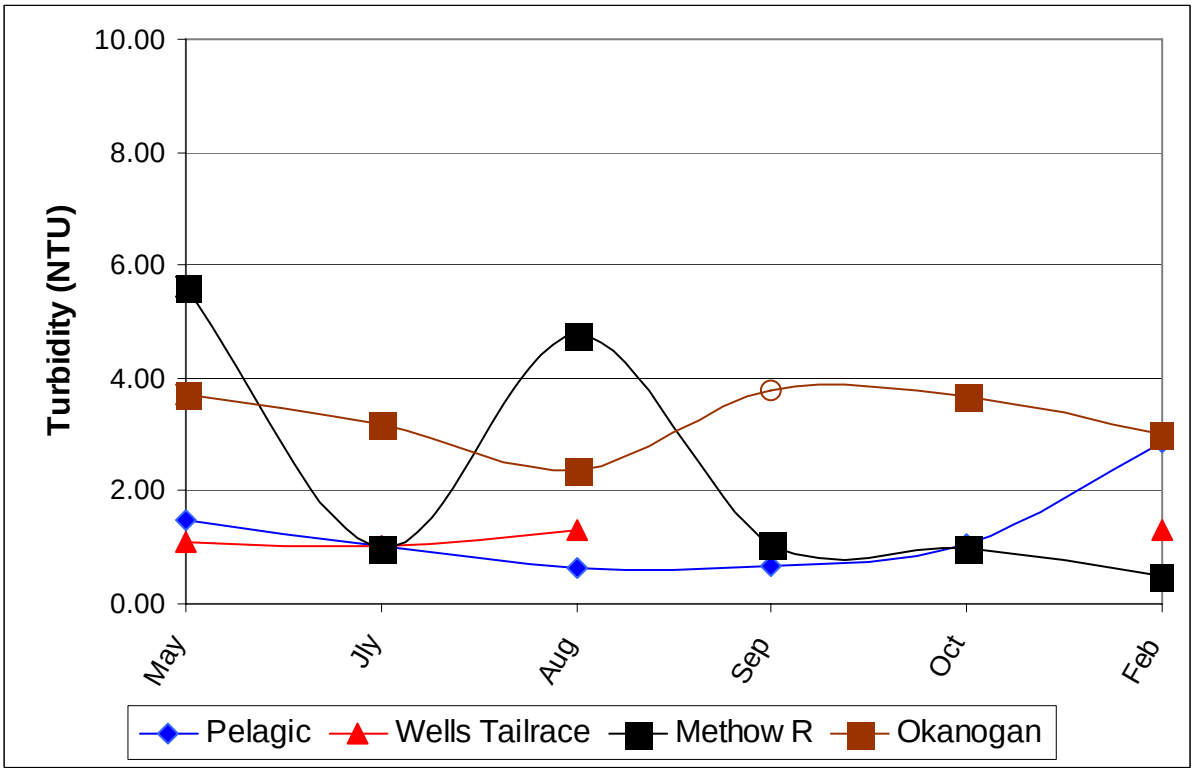

Figure 5.5-3 Turbidity (NTU) for Wells Project waters (2005-2006)

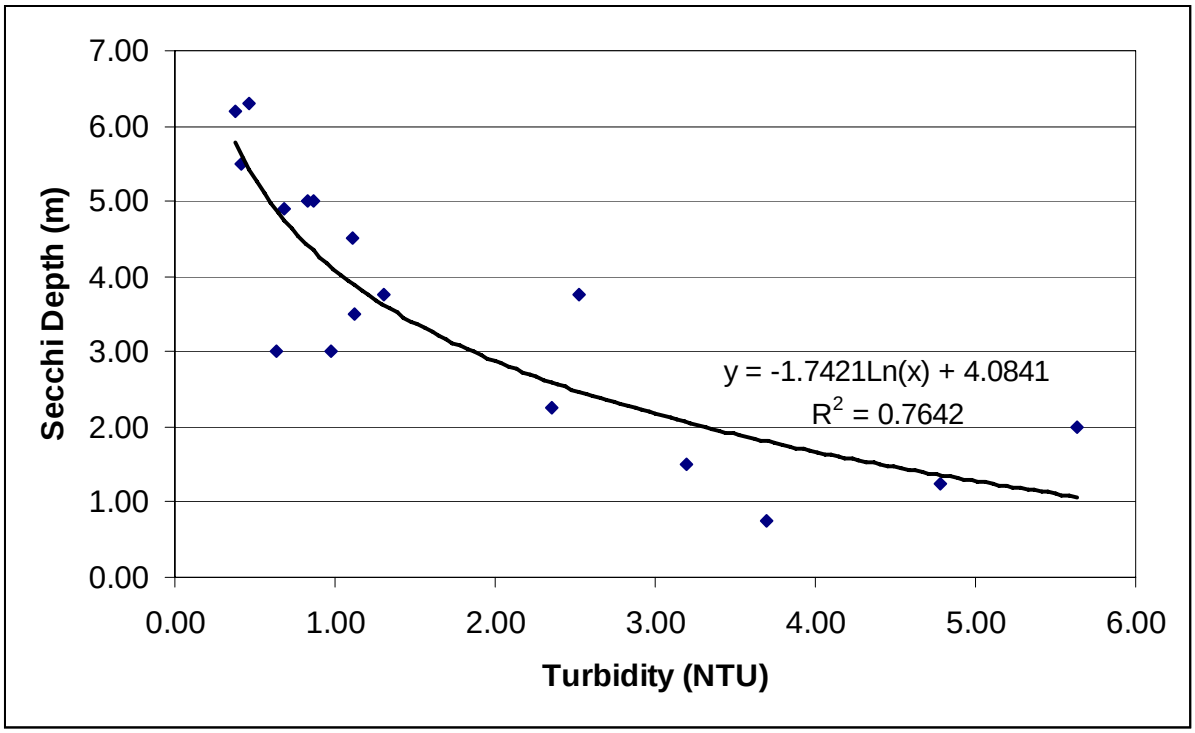

Figure 5.5-4 Wells Project Secchi depth (m) data as a function of turbidity (NTU)

Table 5.5-1 Secchi depth (m) for Wells Reservoir, 2005-2006

Location	May	July	August	Sept.	October	Feb. '06
Chief Joe tailrace	4.9	3.50	3.00		3.10	3.00
Brewster bridge	3.0	5.00	5.00	6.30	6.50	3.75
Forebay	3.75	4.50	5.50	6.20	6.25	3.75
Methow River	2.0	3.00	1.25	3.20	3.00	2.5
Okanagan River	0.75	1.50	2.25	2.70	2.25	2.25

Table 5.5-2 Turbidity (NTU) for Wells Reservoir, 2005-2006

Location	May	July	August	Sept.	October	Feb. 06
Chief Joe tailrace	0.68	1.12	0.63	0.87	0.79	2.71
Brewster bridge	2.52	0.83	0.86	0.46	1.36	3.81
Forebay	1.30	1.11	0.41	0.38		2.11
Tailrace	1.10	1.02	1.31			1.32
Methow River	5.63	0.98	4.78	1.06	0.99	.50
Okanagan River	3.70	3.19	2.35	3.78	3.66	3.01

5.6 pH and Alkalinity

The term pH is used to describe the acidity or hydrogen ion level of a liquid. Factors influencing the pH of a water body include the chemical composition of soils in the watershed, photosynthetic activity, pollutants, and respiration of organisms. pH for Project waters generally varied between 7.5 and 8.25, which is slightly above neutral. pH in the tributaries and littoral waters was slightly higher than pelagic waters (Figure 5.6-1), and is associated with higher productivity of these waters. pH was vertically homogeneous for all months at all sampling stations as evidenced by the charts in Appendix B. There were no measured exceedances of the water quality standard for pH.

Total alkalinity is an indicator of the buffering capacity of water to resist change in pH. Buffering capacity is determined by the concentration of carbonate, bicarbonate, hydroxide, and several inorganic ions. Total alkalinity showed very little seasonal or spatial variation within the reservoir (annual average 57 mg/L with a range of 53.3 to 59.8). Total alkalinity in the Methow and Okanogan rivers was less than the reservoir in May and then increased to be higher than the reservoir during August through October (Figure 5.6-2). Decreased total alkalinity in the tributaries in May is attributed to higher discharge rates from snowmelt, which dilutes ionic concentration. Increases during the summer are likely due to higher photosynthetic activity in the tributaries. Tables 5.6-1 and 5.6-2 list monthly pH and alkalinity data, respectively.

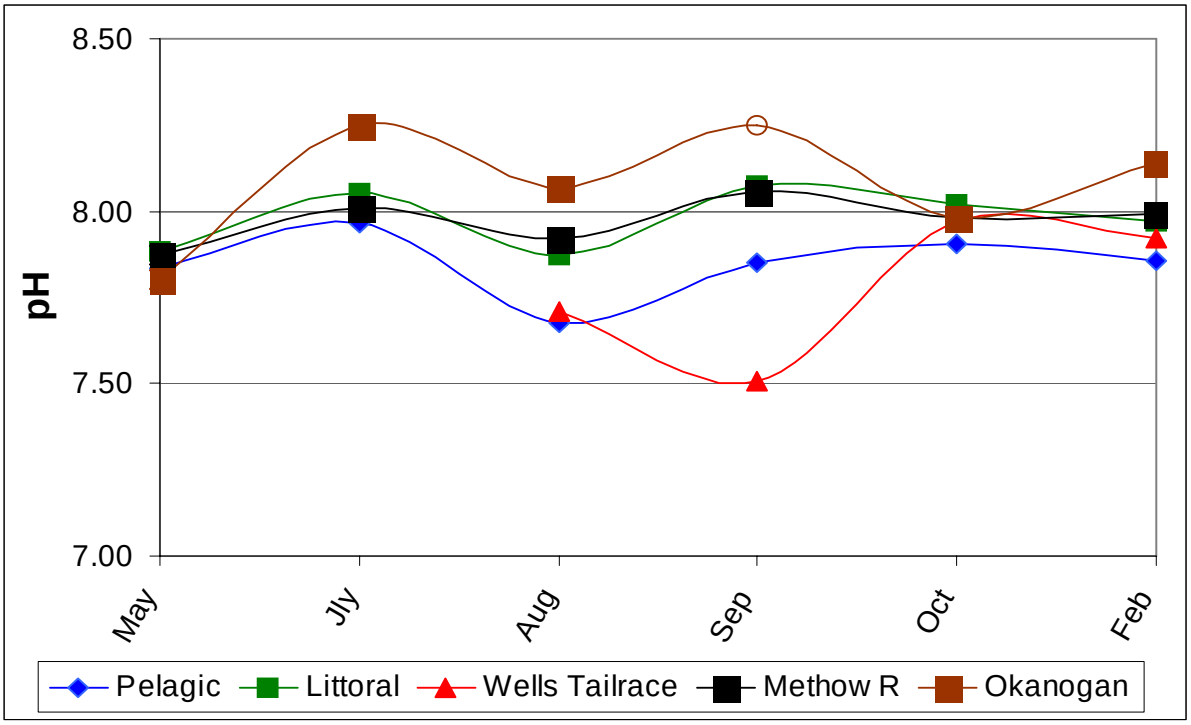

Figure 5.6-1 pH for Wells Project waters (2005)

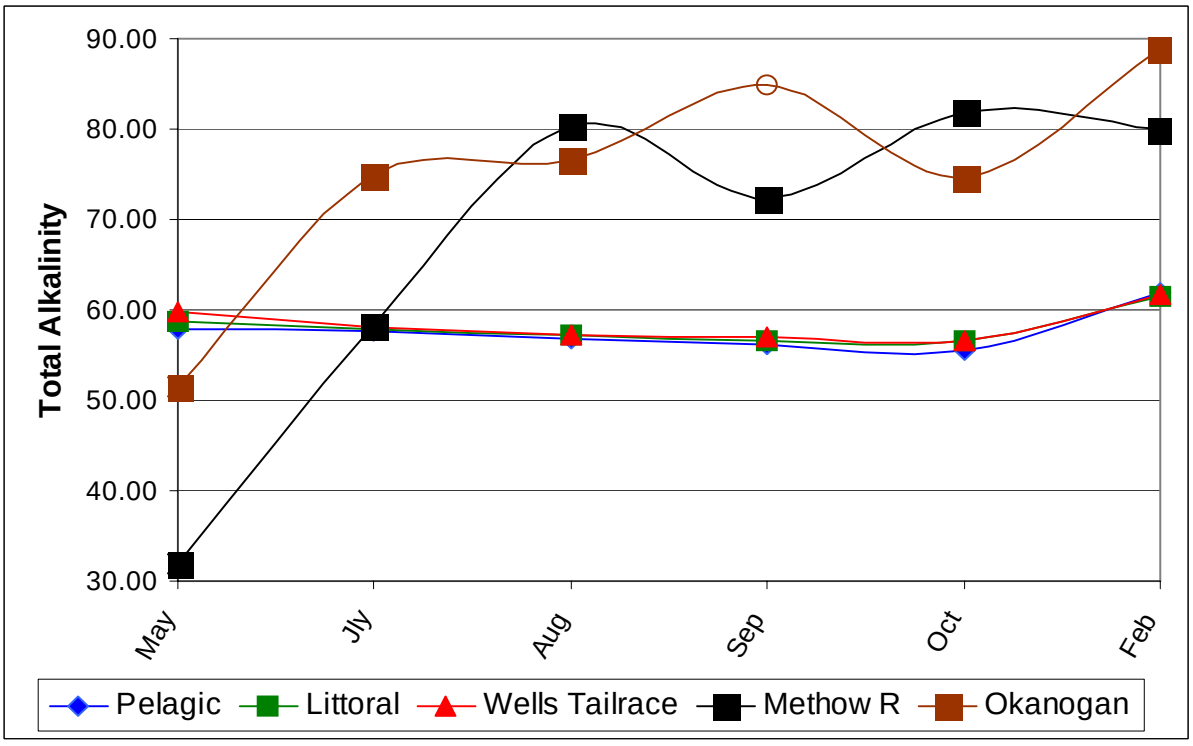

Figure 5.6-2 Total Alkalinity for Wells Project waters (2005-2006)

Table 5.6-1 Comparison of pH Measurements in the Wells Reservoir, 2005-2006

Location	May	July	August	Sept.	October	Feb. 06
Chief Joe tailrace	7.91	7.95	7.70	7.83	7.90	7.62
Brewster bridge photic zone	7.89	7.94	7.64	7.89	7.92	7.88
Brewster bridge off bottom	7.82	7.96	7.72	7.84	7.95	7.92
Forebay photic zone	7.70	8.00	7.69	7.83	7.89	7.96
Forebay off bottom	7.85	8.05	7.88	7.84	7.91	7.94
Wells tailrace			7.71	7.51	7.97	7.94
Bridgeport shallows littoral	7.89	8.10	7.87	7.86	7.80	7.92
Starr boat launch littoral	7.88	8.21	7.88	8.29	8.24	8.05
Methow R photic zone	7.87	8.01	7.92	8.06	7.98	8.03
Methow R off bottom	7.80		7.87			
Okanagan R photic zone	7.80	8.25	8.07	8.25	7.98	8.14
Okanagan R off bottom	7.73	8.19	7.81	8.16	8.11	7.92

Table 5.6-2 Comparison of Total Alkalinity Measurements (mg/L) in the Wells Reservoir, 2005-2006

Location	May	July	August	Sept.	October	Feb. 06
Chief Joe tailrace	59.6	57.2	56.7	56.0	53.3	61.4
Brewster bridge photic zone	58.0	57.7	57.0	56.1	59.0	62.2
Brewster bridge off bottom	58.4	57.5	56.9	56.1	56.3	61.6
Forebay photic zone	56.3	57.9	57.0	56.6	54.6	61.9
Forebay off bottom	57.1	57.8	57.0	56.7	57.2	61.4
Wells tailrace	59.8	58.1	57.3	57.1	56.6	61.7
Bridgeport shallows littoral	59.3	57.6	56.8	56.2	56.6	61.3
Starr boat launch littoral	58.0	58.0	57.8	56.8	56.4	61.6
Methow R photic zone	32.0	58.3	80.5	72.4	82.0	80.0
Methow R off bottom	30.2		81.2			
Okanagan R photic zone	51.4	74.9	76.7	84.8	74.6	89.0
Okanagan R off bottom	51.6	64.3	61.0	86.2	85.8	102.8

5.7 Suspended Solids, Dissolved Solids and Specific Conductivity

Total suspended solids (TSS) in the Wells Project were near or below detection limits for all months (Table 5.7-1). Total suspended solids in the Methow River were highest in May (7.2 mg/L) and subsequently at or below detection limits. Total suspended solids in the Okanogan River were also highest in May (16.5 mg/L), decreased during the summer and then rose slightly in September and October (Figure 5.7-1). Low suspended solids in the Wells Reservoir are typical of this reach of the Columbia River and are a result of the large upstream storage reservoir capacity where solids settle out.

Total dissolved solids (TDS) are a measure of the concentration of dissolved material in the water. Major cations contributing to TDS include calcium, magnesium, sodium, chlorides, carbonates, iron and manganese. Other trace materials are also dissolved in water. Minimal seasonal or spatial variation was observed for dissolved solids in the Wells Project (Figure 5.7-

2). The annual average for TDS was 78 mg/L for the Wells Project, which is similar to results previously reported for the downstream Rocky Reach Project (Chelan PUD 2001). Dissolved solids in both tributaries peaked in August; the peak is attributed to reduced flow and higher evaporation rates, which concentrate dissolved material. Monthly TDS data are reported in Table 5.7-2.

Specific conductivity is a measure of the ability of a water body to conduct an electric current. Pure water is a very poor conductor, but water becomes a good conductor when ions are added. Watershed soil chemistry, evaporation rates, retention time and flow all influence specific conductance. Conductivity is often directly related to TDS and nutrients. Conductivity is also proportionate to the concentration of major ions such as calcium (Ca), sodium (Na), magnesium (Mg) and potassium (K). The annual average for specific conductivity in the Wells Project averaged 0.304 μs/cm for pelagic surface waters and 0.111 μs/cm for littoral waters. There was relatively little horizontal or vertical variation in specific conductivity as documented in the vertical profile data (Appendix B).

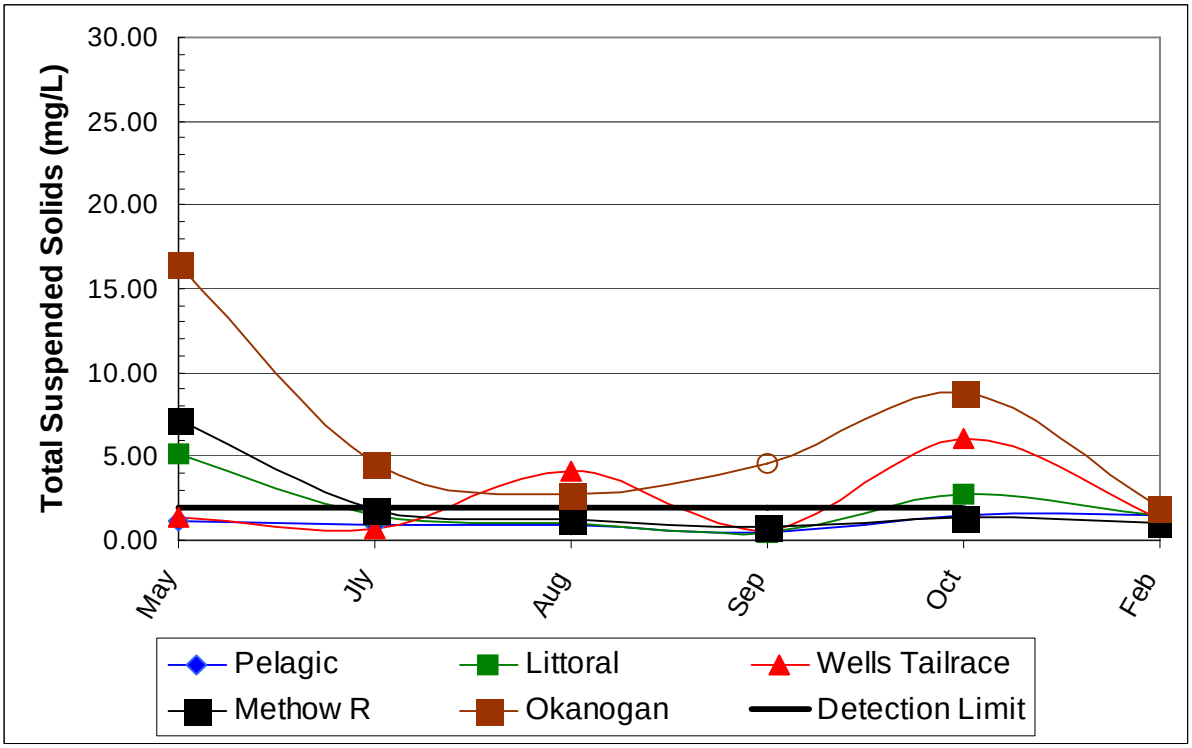

Figure 5.7-1 Total suspended solids (mg/L) for Wells Project waters (2005-2006)

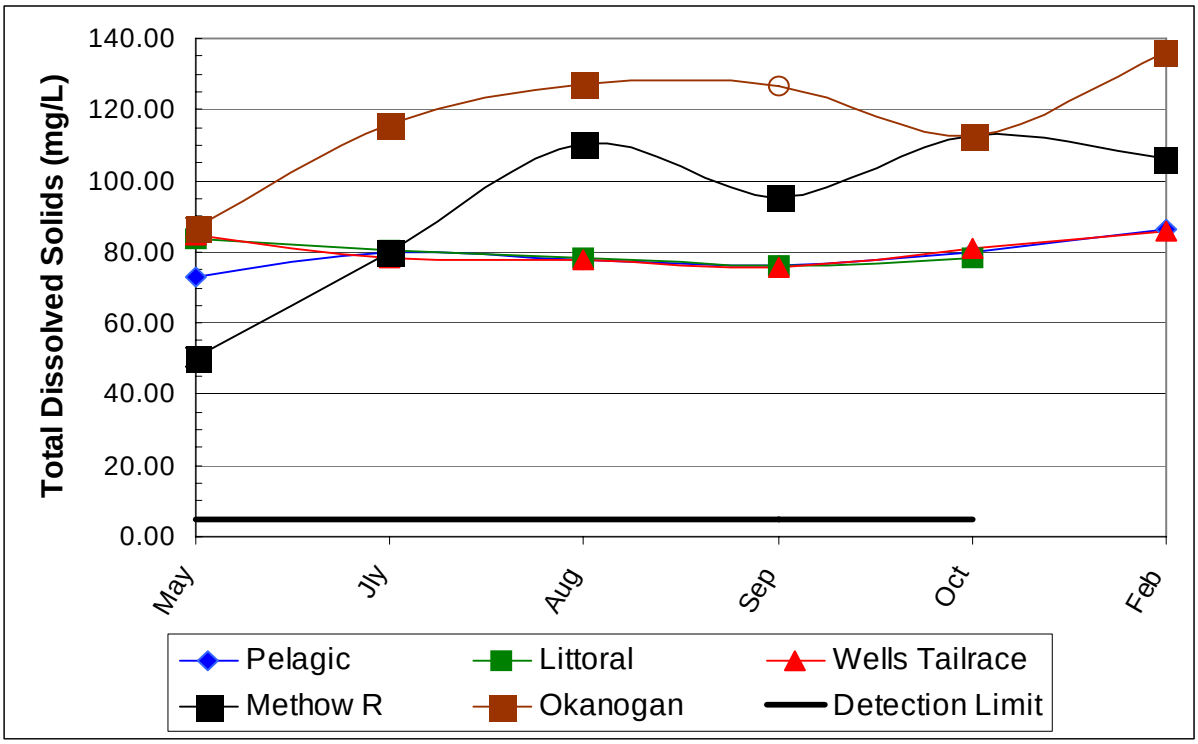

Figure 5.7-2 Total dissolved solids for Wells Project waters (2005-2006)

Table 5.7-1 Comparison of Total Suspended Solids Measurements (mg/L) in the Wells Project, 2005-2006

Location	May	July	August	Sept.	October	Feb. 06
Chief Joe tailrace	0.6	0.6	0.4	0.5	1.3	2.0
Brewster bridge photic zone	2.4	1.0	0.8	0.4	1.6	1.5
Brewster bridge off bottom	1.0	0.6	0.8	0.4	1.1	1.3
Forebay photic zone	0.6	1.3	1.6	0.4	1.6	1.1
Forebay off bottom	1.2	1.2	0.4	0.4	1.3	1.5
Wells tailrace	1.4	0.7	4.1	0.6	6.1	1.3
Bridgeport shallows littoral	1.0	1.1	0.6	0.4	1.9	2.0
Starr boat launch littoral	10.9	1.2	1.5	0.6	3.7	0.9
Methow R photic zone	7.2	1.8	1.3	0.8	1.4	1.0
Methow R off bottom	6.8		4.0			
Okanagan R photic zone	16.5	4.6	2.7	4.6	8.8	2.0
Okanagan R off bottom	16.3	4.5	0.5	4.8	27.6	3.5

Table 5.7-2 Comparison of Total Dissolved Solids (mg/L) Measurements in the Wells Project, 2005-2006

Location	May	July	August	Sept.	October	Feb. 06
Chief Joe tailrace	82.8	79.3	76.3	75.6	78.7	85.5
Brewster bridge photic zone	54.2	81.2	79.4	74.0	81.3	88.4
Brewster bridge off bottom	86.0	76.8	76.8	76.5	78.8	86.4
Forebay photic zone	82.3	79.4	77.1	78.3	79.8	84.7
Forebay off bottom	85.0	78.3	80.2	75.6	82.6	86.2
Wells tailrace	84.9	78.4	77.8	75.9	80.8	85.9
Bridgeport shallows littoral	85.0	80.9	78.8	75.5	76.2	85.7
Starr Boat launch littoral	81.9	78.0	77.9	76.5	80.1	86.2
Methow R photic zone	50.5	79.9	110.7	95.5	112.6	106.3
Methow R off bottom	50.1		103.8			
Okanagan R photic zone	87.1	115.7	127.3	126.7	112.8	136.3
Okanagan R off bottom	85.7	64.4	87.0	115.2	126.5	164.9

5.8 Macronutrients

Nitrogen and phosphorus are the two essential macronutrients needed for plant growth. Silica is important for diatomaceous phytoplankton. Although not considered a macronutrient, carbon is essential for all biological productivity. Carbon is rarely limiting to plant growth except in highly eutrophic waters. Plants also use trace amounts of certain metals that are necessary for growth.

5.8.1 Nitrogen

Biosphere nitrogen is most abundant in the gaseous form (N2) but small quantities exist in the combined forms of ammonia (NH_4), nitrate (NO_3-), nitrite (NO_2-) and organic compounds. Total nitrogen (TN) includes all forms of nitrogen; particulate and dissolved, organic and inorganic. The three forms of inorganic nitrogen (nitrate, nitrite and ammonia) are dissolved nitrogen sources that are referred to as inorganic nitrogen (TIN) and represent that portion of the nitrogen cycle that is readily available for plant use. The concentration of nitrogen in aquatic systems usually follows a seasonal pattern of depletion by plants including plankton during the summer growing months and replenishment during the fall and winter from sediment release, tributary inflow and precipitation (Wetzel 2001). Ammonia is a byproduct of biological respiration and is the preferred form of nitrogen for aquatic plant and phytoplankton growth (Horne and Goldman 1994). Nitrate is an important nutrient source for phytoplankton and is typically the most common form of inorganic nitrogen in aquatic systems.

Ammonia levels were near or below detection levels ($\leq 10 \mu g/L$) for pelagic and littoral reservoir waters as well as the Okanogan River for May through August and only slightly higher in September and October (Figure 5.8-1). There was not an appreciable accumulation of ammonia for bottom waters due to respiration, which is expected since the entire reservoir water column is well oxygenated and not stratified. The only exception was the Wells forebay August sample,

which had an exceptionally high ammonia level of 205.7 μg/L. This unusual spike in ammonia may have been caused by accidental disturbance of bottom sediments when deploying the sampler 1 m off the bottom. In general, the ammonia level in the Methow River was higher than the rest of the reservoir with a peak of ammonia being observed in August. Ammonia (NH3-N) levels at the WDOE long term monitoring station on the Methow River near Pateros (Station 48A070) and upstream of the Project boundary reported ammonia levels below a laboratory detection limit of 0.01 mg/L for all monthly sampling events in 2005.

Nitrate/Nitrite levels for reservoir waters were much higher in February than other months (Figure 5.8-2). Nitrate/Nitrite within littoral waters were lower than pelagic waters, which may be attributed to aquatic plant uptake in shallow areas. Nitrate/Nitrite in both the Okanogan and Methow rivers showed an increasing trend during the growing season. This increase may be a function of reduced streamflow.

Total nitrogen levels for reservoir pelagic and littoral waters were similar and relatively constant during the spring, summer and fall. Total nitrogen levels in February 2006 were slightly higher. It is not clear why the reported total nitrogen level in the tailrace, for the October sampling event, was considerably higher. Total nitrogen in the Okanogan River was similar to slightly higher than the reservoir. The highest total nitrogen levels were measured in the Methow River for August through October (Figure 5.8-3). Tables 5.8-1 through 5.8-3 list monthly nitrogen data for Wells Project waters.

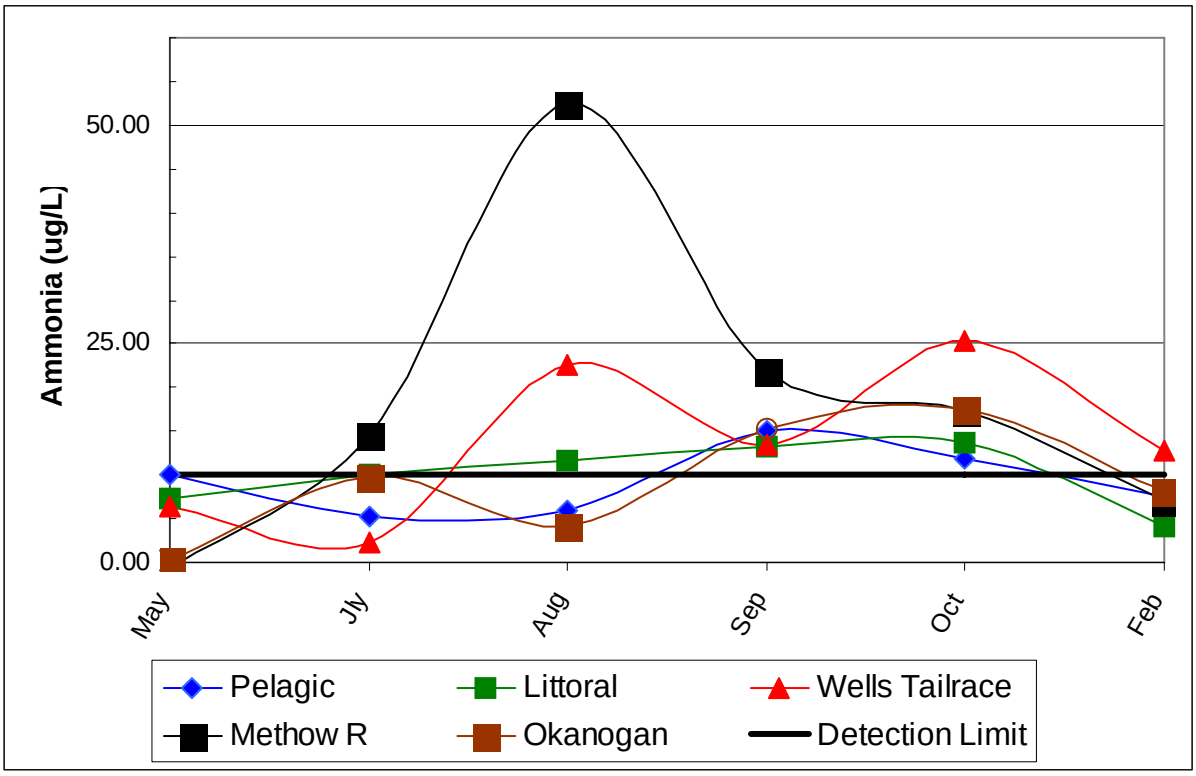

Figure 5.8-1 Ammonia concentration for Wells Project waters (2005-2006)

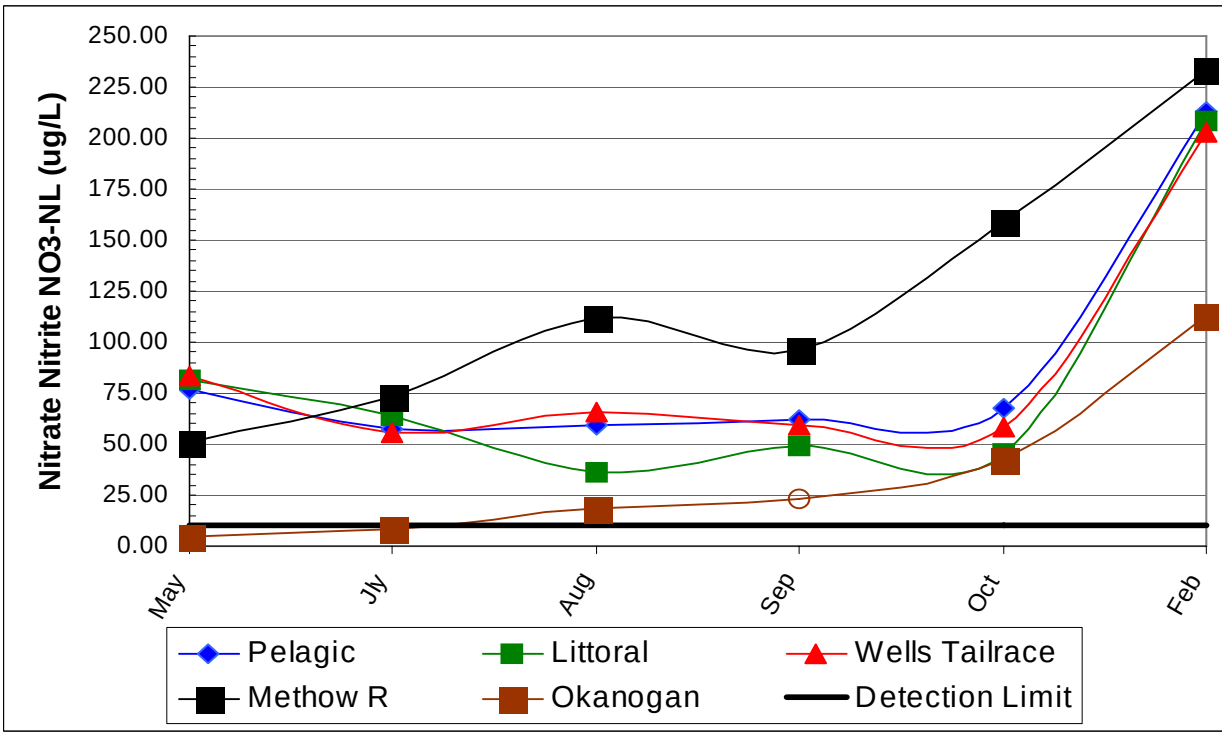

Figure 5.8-2 Nitrate/Nitrite concentration for Wells Project waters (2005-2006)

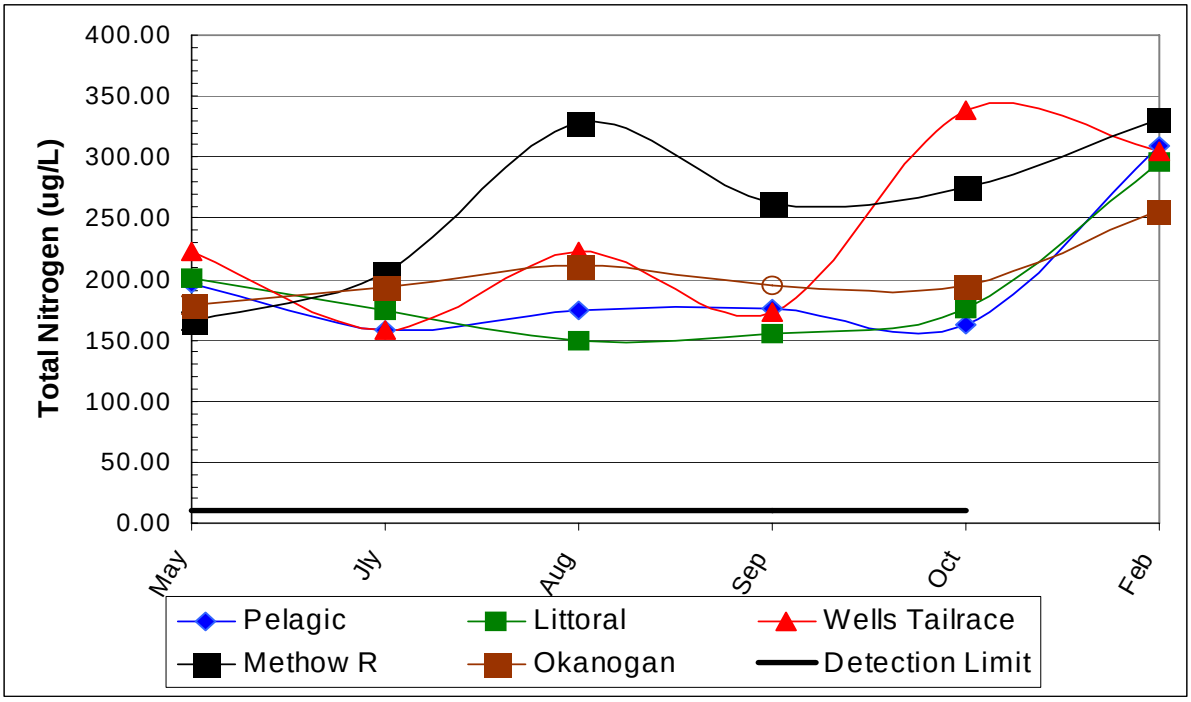

Figure 5.8-3 Total Nitrogen concentration for Wells Project waters (2005-2006)

Table 5.8-1 Comparison of Ammonia Measurements (μg/L) in the Wells Project, 2005-2006

Location	May	July	August	Sept.	October	Feb. 06
Chief Joe tailrace	12.7	6.2	4.2	16.2	13.3	12.8
Brewster bridge photic zone	9.4	5.5	5.8	14.0	8.9	3.8
Brewster bridge off bottom	8.8	8.1	2.5	12.3	10.0	2.1
Forebay photic zone	8.1	4.0	8.1	14.9	13.5	3.0
Forebay off bottom	6.7	5.0	205.7	13.2	11.1	1.3
Wells tailrace	6.5	2.3	22.6	13.5	25.3	9.8
Bridgeport shallows littoral	8.1	5.4	6.5	15.3	16.7	6.5
Starr boat launch littoral	6.5	2.9	16.9	11.3	10.8	1.5
Methow R photic zone	5.0	14.5	52.4	22.0	17.4	7.1
Methow R off bottom	1.9		43.5			
Okanagan R photic zone	0.2	9.7	4.2	15.3	17.5	8.1
Okanagan R off bottom	3.9	5.5	2.1	10.3	14.8	9.7

Table 5.8-2 Comparison of Nitrate/Nitrite Measurements (μg/L) in the Wells Project, 2005-2006

Location	May	July	August	Sept.	October	Feb. 06
Chief Joe tailrace	83.7	61.3	60.9	69.4	71.9	225.1
Brewster bridge photic zone	67.3	53.6	58.4	62.4	62.8	209.4
Brewster bridge off bottom	74.2	59.1	58.4	61.9	66.5	212.1
Forebay photic zone	79.4	56.3	57.6	54.9	67.1	205.1
Forebay off bottom	80.4	58.9	55.4	55.5	66.6	207.0
Wells tailrace	83.7	55.4	65.7	59.0	58.7	203.0
Bridgeport shallows littoral	85.1	55.4	62.0	62.5	35.3	217.6
Starr boat launch littoral	77.4	24.7	10.6	36.4	55.6	233.4
Methow R photic zone	50.7	72.7	112.1	96.6	159.0	233.4
Methow R off bottom	48.2		115.8			
Okanagan R photic zone	4.3	8.3	18.8	23.0	42.7	113.1
Okanagan R Off bottom	5.7	29.0	51.4	26.3	31.9	68.5

Table 5.8-3 Comparison of Total Nitrogen (μg/L) Measurements in the Wells Project, 2005-2006

Location	May	July	August	Sept.	October	Feb. '06
Chief Joe tailrace	182.8	148.70	190.30	167.20	168.50	336.0
Brewster bridge photic zone	208.9	153.00	161.60	159.20	153.90	295.1
Brewster bridge off bottom	191.8	149.40	148.90	156.20	158.20	295.4
Forebay photic zone	197.3	173.20	170.40	199.80	166.50	297.9
Forebay off bottom	187.80	160.30	160.50	156.10	162.50	293.0
Wells tailrace	222.30	158.90	223.20	172.20	338.60	304.8
Bridgeport shallows littoral	208.80	142.00	154.50	146.20	169.00	304.7
Starr Boat launch littoral	192.30	135.60	145.10	164.80	183.90	286.7
Methow R photic zone	166.00	205.70	327.60	262.20	275.10	331.7
Methow R off bottom	165.00		307.80			
Okanagan R photic zone	179.00	192.70	211.70	194.20	194.30	256.3
Okanagan R off bottom	183.00	162.00	161.90	180.10	236.10	240.4

5.8.2 Phosphorus

Phosphorus occurs in natural waters almost exclusively as phosphates. Phosphate occurs in solution, in detritus, adsorbed onto suspended particles and in the bodies of aquatic organisms. Phosphorus also occurs in bottom sediments where it can be reintroduced to the water column through aquatic plant uptake, current disturbance or diagenisis (chemical release). Phosphorus low levels often limit algae growth in freshwater environments. Two forms of phosphorus were analyzed in this study. Orthophosphorus is dissolved and the portion that is readily available for plant uptake. Orthophosphorus is the equivalent of total inorganic phosphorus (TIP). Total phosphorus includes organic and inorganic forms that may be dissolved or particulate.

Orthophosphorus peaked for all stations in July (Figure 5.8-4). Orthophosphorus levels for pelagic and littoral waters were similar in all months except July when littoral orthophosphorus concentrations were significantly higher than in pelagic areas. Orthophosphorus levels in the Methow and Okanogan rivers were higher than in the reservoir. Orthophosphorus was partially depleted in the Okanogan River in August but concentrations in the Methow River remained stable. The WDOE reported orthophosphorus levels at the long term monitoring station just upstream on the Methow River at RM 5 (Station 48A070) as 0.003 mg/L for all samples collected in 2005 during the same time period (sample day within month differed between WDOE and this study). WDOE also reported orthophosphorus data for summer months 2005 levels at 0.003 mg/L for the Okanogan River at Mallot (Station 49A070) (preliminary data http://www.ecy.wa.gov/apps/watersheds/riv/station.asp?theyear=&tab=prelim_data&scrolly=70&wria=49&sta=49A070). Orthophosphorus levels measured within the backwater area were considerably higher than data reported for the upstream WDOE station on the Okanogan River at Mallott (RM 17); direct comparison is limited since sample day within a month differs between sites).

Total phosphorus was slightly higher in littoral waters than in pelagic waters (Figure 5.8-5). Wave disturbance to bottom sediments may be a factor for this difference. Total phosphorus

levels in pelagic surface waters ranged from below detection limits to 30.8 μg/L. Generally, total phosphorus levels for near bottom samples in the Wells Project did not differ significantly from surface waters. A spike in total phosphorus for the near bottom October sample in the Wells forebay could be a result of bottom sediment disturbance during sampling since accumulations were not seen elsewhere and aerobic conditions prevailed that do not favor phosphorus chemical release from the sediments. Total phosphorus was highest in the Okanogan River, which is likely due to the higher sediment load. Total phosphorus for all stations peaked in July before gradually declining throughout the rest of the growing season. Table 5.8-4 and Table 5.8-5 report monthly data for orthophosphorus and total phosphorous.

Total phosphorus levels as reported by WDOE for the long term monitoring station upstream of the backwater effect on the Okanogan River (Station 49A070) were approximately half the values measured near the mouth of the Okanogan for months of May through October 2005. Total phosphorus levels as reported by WDOE for the long term monitoring station upstream of the backwater effect on the Methow River (Station 48A070) were significantly higher than measured near the mouth of the Methow River.

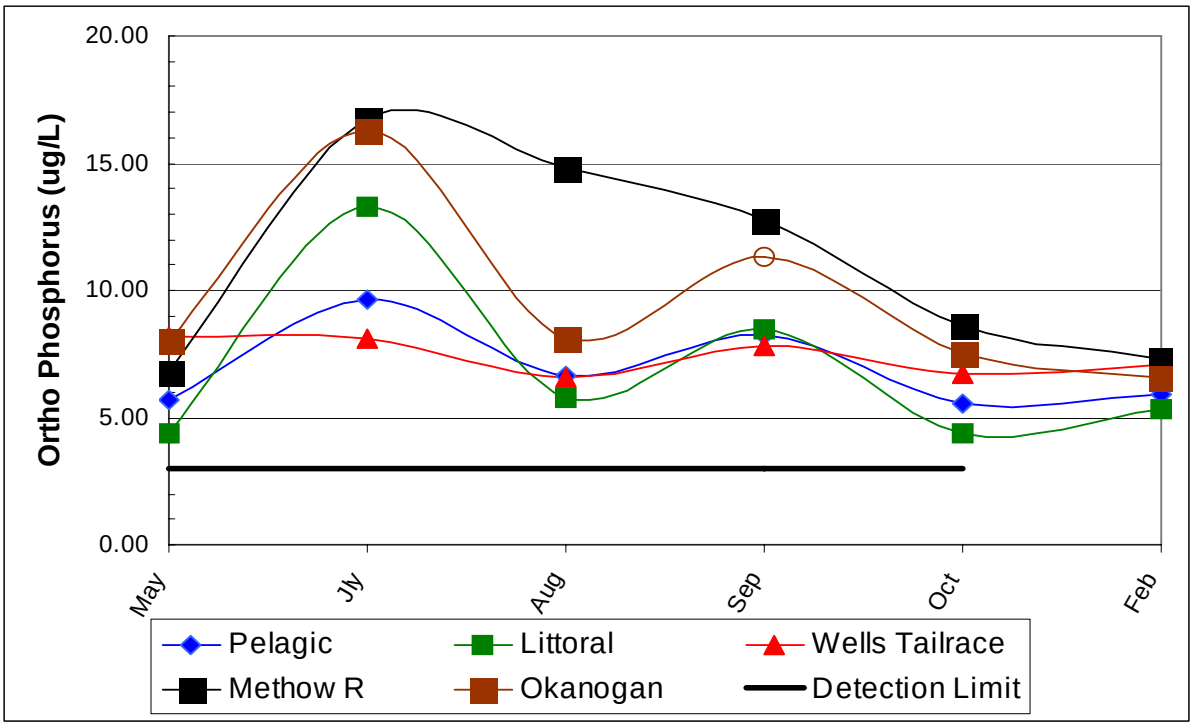

Figure 5.8-4 Orthophosphorus concentration for Wells Project waters (2005-2006)

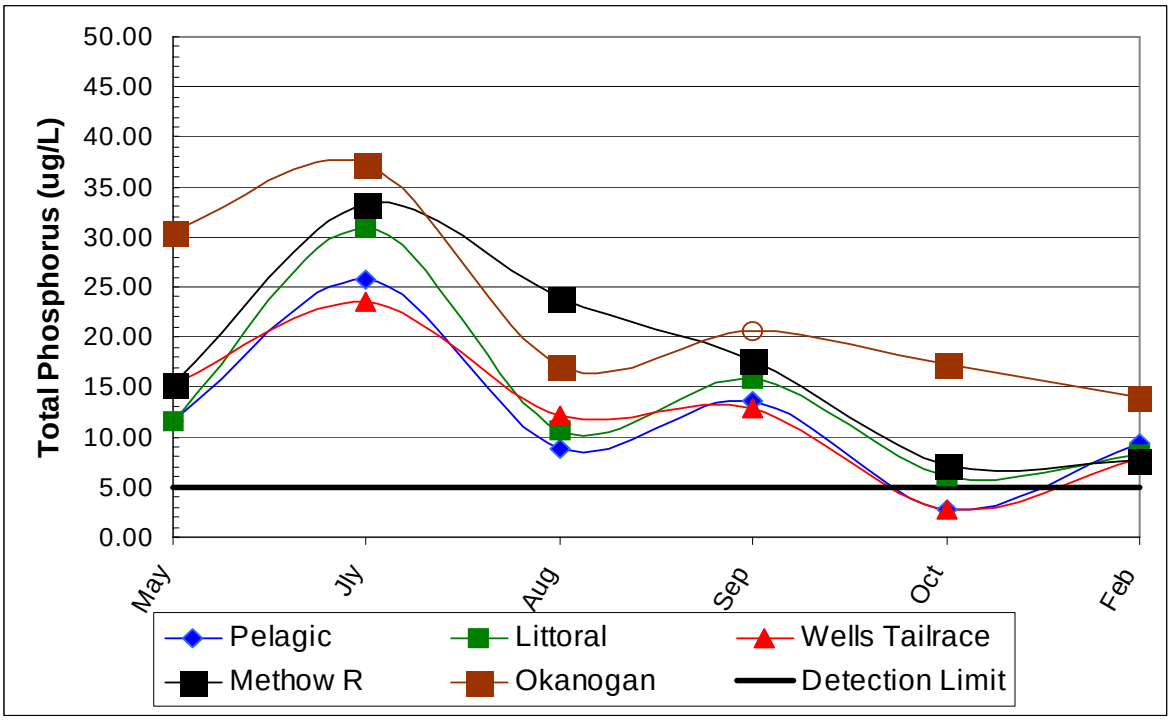

Figure 5.8-5 Total phosphorus concentration for Wells Project waters (2005-2006)

Table 5.8-4 Comparison of Orthophosphorus Measurements (*µ*g/L) in the Wells Project, 2005-2006

Location	May	July	August	Sept.	October	Feb. '06
Chief Joe tailrace	5.70	8.70	6.30	7.10	5.70	6.1
Brewster bridge photic zone	3.50	10.30	5.50	9.30	5.20	5.5
Brewster bridge off bottom	6.40	10.00	6.60	8.70	6.60	5.0
Forebay photic zone	7.80	9.80	8.10	8.30	5.70	6.2
Forebay off bottom	6.00	9.00	7.00	6.40	11.10	4.4
Wells tailrace	8.20	8.10	6.60	7.80	6.70	7.1
Bridgeport shallows littoral	3.50	9.90	7.90	8.60	4.50	5.4
Starr boat launch littoral	5.30	8.10	3.60	8.40	4.30	5.2
Methow R photic zone	6.80	16.70	14.80	12.80	8.60	7.3
Methow R off bottom	5.70		10.40			
Okanagan R photic zone	8.00	16.30	8.10	11.30	7.50	6.6
Okanagan R off bottom	10.00	11.10	7.10	9.70	7.20	9.9

Table 5.8-5 Comparison of Total Phosphorus (μg/L) Measurements in the Wells Project, 2005-2006

Location	May	July	August	Sept.	October	Feb. 06
Chief Joe tailrace	14.50	30.80	12.20	16.30	1.70	9.3
Brewster bridge photic zone	11.40	24.80	5.70	10.80	3.60	7.5
Brewster bridge off bottom	13.20	21.60	13.50	12.00	2.50	7.5
Forebay photic zone	8.70	21.60	8.70	13.80	3.00	11.5
Forebay off bottom	12.20	23.00	9.10	9.50	66.60	8.6
Wells tailrace	15.20	23.60	12.20	12.90	2.80	7.1
Bridgeport shallows littoral	13.40	28.60	11.40	17.60	5.30	9.2
Starr boat launch littoral	9.60	23.40	9.90	13.90	6.70	7.3
Methow R photic zone	15.30	33.20	23.90	17.70	7.20	7.8
Methow R off bottom	18.70		25.60			
Okanagan R photic zone	30.60	37.30	17.10	20.60	17.20	13.9
Okanagan R off bottom	32.00	31.20	14.10	21.10	33.70	18.2

5.8.3 Nitrogen to Phosphorus Ratios

The mass ratio of total nitrogen to total phosphorus (TN:TP) is an indicator of nutrient conditions that define factors potentially limiting lake productivity. Lower TN:TP ratios indicate possible nitrogen limitation relative to available phosphorus. Current literature suggests that nitrogen limitation in terms of TN:TP ratios vary, but generally TN:TP ratios less than 10:1 can indicate nitrogen limitation (Horne and Goldman 1994). Smith (1983) found that non-nitrogen fixing algae tended to be dominant at TN:TP ratios that were less than 29:1. Hillebrand and Sommer (1999) found nitrogen to be limited at ratios less than 13:1 along with Downing and McCauley (1992) who determined nitrogen-fixing alga were favored at TN:TP ratios of 14:1.

In comparison, the annual mean TN:TP ratios in the Wells Reservoir was 13.7 for the photic zone and 14.8 over all depths for samples from all depths (Table 5.8-6). These values are barely within the suggested literature ranges for phosphorus limitation. The TN:TP ratios peaked in July with pelagic and littoral waters showing similar trends (Figure 5.8-6). A decreasing TN:TP ratio through the major part of the algae growing season is typical of moderate to low nutrient waters as algae assimilate available nutrients. The range in TN:TP ratios for the Wells Project was 2.5 to 30.8. The mean TN:TP ratio for pelagic waters during the study period was 12.45, which indicates a marginal phosphorus limitation and pronounced nitrogen limitation in the fall. The TN:TP ratios were higher in the Okanogan and Methow River tributaries relative to the mainstem Columbia within the Wells Project. The TN:TP ratios are an indicator but not an absolute confirmation of limiting factors. Active transport in the Wells Project, which is a result of wind driven circulation and river flow, may play a significant role in nutrient cycling. In addition, aquatic plants are also capable of assimilating nutrients from the bottom sediment.

Inorganic nitrogen includes ammonia, nitrite and nitrate. The TIN:TIP ratios were analyzed (where TIN = sum of all inorganic nitrogen: ammonia+nitrite+nitrate and TIP = ortho-phosphorus), resulting in much lower nitrogen to phosphorus ratios with an annual mean of 11.1 (Table 5.8-7). As evidenced in Figure 5.8-7, the TIN:TIP ratios suggest that inorganic

phosphorus may not be limiting productivity during the growing season since ratios are below 10. The spring TIN:TIP ratios are higher for the Wells Project. Barica (1990) determined that spring-minima TIN:TIP ratios of 6:1 or less were the best indicator of nitrogen limitation despite seasonal TIN:TIP means as high as 20:1 and 30:1. A spring TIN:TIP ratio of 16.1 for pelagic waters in the Wells Project indicates that phosphorus is limiting. Only the Okanogan River had a TIN:TIP ratio for May in the range indicating a strong nitrogen limitation (Table 5.8-7), even though strong phosphorus limitation was indicated in the Okanogan River based on TN:TP ratios.

Macronutrient ratios suggest that phosphorus is limiting primary productivity in the two major tributaries to Wells Reservoir and marginally limiting elsewhere within the Wells Project. Other factors including retention time and abiotic factors could be equally important for governing primary productivity. TN:TP ratios were less than 10 for the Mid-Columbia region in past decades. A decline in orthophosphate occurred with the shutdown of phosphorus releases from a large fertilizer plant into Lake Roosevelt near Trail, British Columbia in the mid 1990's (Rensel 1997). Nuisance algae observed as large floating mats of mostly *Cladophora spp*. and other indications of moderate eutrophication of Lake Roosevelt declined with the reduction in phosphorus inputs. Chelan PUD (2001) reported TN:TP ratios greater than 50 suggesting phosphorus limitation relative to nitrogen in the downstream Rocky Reach Reservoir.

Table 5.8-6 Annual and Seasonal Mean TN:TP ratios in the Wells Project, 2005

(ratios listed are inclusive of all sampling depths, where applicable)

	Annual Mean[1]	Seasonal Mean		
		Spring	Summer	Fall
Pelagic	12.45	11.53	16.08	2.5
Littoral	14.96	11.50	19.10	6.0
Tailrace	13.28	15.2	16.23	2.5
Okanogan River	24.56	30.60	25.00	17.20
Methow River	19.46	15.30	24.93	7.20

[1]Annual mean is inclusive of May through October samples

Table 5.8-7 Annual and Seasonal Mean TIN:TIP ratios in the Wells Project, 2005-2006

(ratios listed are inclusive of all sampling depths, where applicable)

	Annual Mean	Seasonal Mean		
		Spring	Summer	Fall
Pelagic	11.23	16.13	8.66	14.04
Littoral	11.05	20.65	7.03	13.5
Tailrace	10.70	10.82	10.04	12.54
Okanogan River	3.24	1.25	2.31	8.03
Methow River	10.86	8.19	8.53	20.51

[1]Annual mean is inclusive of May through October samples

5.8.4 Total Organic Carbon

Table 5.8-8 Comparison of Total Organic Carbon Measurements in the Wells Project, 2005-2006

Location	May	July	August	September	October
Chief Joe tailrace			2.00	1.60	1.20
Brewster bridge photic zone			1.70	1.40	1.30
Brewster bridge off bottom					
Forebay photic zone			1.60	1.90	1.60
Forebay off bottom					
Wells tailrace			1.30	1.20	1.00
Bridgeport shallows littoral			1.60	1.20	1.20
Starr boat launch littoral			1.40	1.20	1.20
Methow R photic zone			1.50	1.60	0.87
Methow R off bottom					
Okanagan R photic zone			2.30	2.40	1.90
Okanagan R off bottom					

5.8.5 Chlorophyll a

Chlorophyll *a* is a measure of the concentration of photosynthetic pigment in phytoplankton. When combined with macronutrient data and transparency data, chlorophyll *a* is a good indicator of trophic status of the water body (Wetzel 2001).

Moderate to low chlorophyll *a* concentrations occurred throughout the sample period with peaks in July and October for Wells Project waters. Concentrations were lowest in August and also had the least variability among sites for the August sampling event. Pelagic and littoral waters were similar for chlorophyll *a* concentrations in most months except October when littoral sites reported twice as high *c*hlorophyll *a* levels (Table 5.8-9). Variability for chlorophyll *a* concentration was greatest at the tailraces sites (Chief Joseph Dam and Wells Dam). In the

Methow River, chlorophyll *a* was lowest in July. The Okanogan River showed a trend similar to littoral sites for chlorophyll *a* concentrations with a sharp peak in October.

Chlorophyll *a* concentrations reported in this study are similar to those reported for previous years in Rufus Lake, which is located upstream of the Wells Project (Rensel 1997). Chelan PUD (2001) reported slightly higher chlorophyll *a* concentrations for the Rocky Reach Project in 2000; however, comparison between years without long term data is unreliable when attempting to detect a true difference.

Table 5.8-9 Average chlorophyll *a* concentrations (*u*g/L) for Wells Project waters (2005-2006)

Area	**May**	**Jly**	**Aug**	**Sep**	**Oct**
Pelagic	2.8	3.3	1.6	1.9	2.3
Littoral	2.4	2.9	1.5	2.2	5.5
Methow R	2.9	0.5	1.7	1.5	2.2
Okanogan R	3.0	2.7	1.2	2.2	4.8
Tailrace	NA	1.5	3.9	1.8	2.7
Area	**Spring**	**Summer**	**Fall**	**Annual**	
Pelagic	2.8	2.3	2.3	2.4	
Littoral	2.4	2.2	5.5	2.9	
Methow R	2.9	1.2	2.2	1.8	
Okanogan R	3.0	2.0	4.8	2.8	
Tailrace	NA	2.4	2.7	2.5	

Multiple stepwise regression analysis with chlorophyll *a* concentration as the dependent variable was completed to assess its relationship to other measured water quality parameters. No predictive relationships were noted between chlorophyll *a* and physical or chemical parameters. Density and biovolume were not significantly correlated to chlorophyll *a.*

5.8.6 Trophic Status Index

Trophic Status Index (TSI) developed by Carlson (1977, 1996) and modified for nitrogen by Kratzer and Brezonik (1981) is an indication of the productivity of a lake based on Secchi depth, TP, TN and chlorophyll *a* concentrations for summer months (June through September). TSI works best for temperate lakes and reservoirs where transparency is a function of phytoplankton growth and not inputs of sediment-rich waters from inorganic turbidity sources (U.S. EPA 1990).

Table 5.8-7 lists TSI scores for the Wells Project, which is generally classified as oligo-mesotrophic (low to moderate primary productive) based on TSI scores. Mean TSI scores in the range of 40-50 are indicative of mestrophic condition. Carlson (1996) suggests that the TSI derived from chlorophyll *a* be the primary determinant of trophic status with the other TSI values qualifying the index status.

This result appears to match with the overall TSI score (averaged for Secchi depth, chlorphyl *a* and total phosphorus TSI scores) for the downstream Rocky Reach Reservoir reported by Chelan PUD (2001) was 40.4 (marginally mesotrophic). This score did not include a TSI for TN and

data were inclusive of a June sampling; the TSI scores in Table 5.8-10 are based on July through September. The TSI score for the reach of the Columbia River between Rock Island Dam to below Priest Rapids Dam was 42.3 based on 1999 data (Normandeau Associates 2000). TSI scores are, at best, a relative indicator of productivity. A four year study of Lake Osoyoos in the Okanogan River watershed (Rensel 1997, 1998) determined the TSI score for that water body to be 43. They also noted blooms of toxic blue-green algae and significant eutrophication. The comparison demonstrates the shortcomings of TSI scores since Lake Osoyoos is considerably more eutrophic than the Columbia River Reach between Chief Joseph Dam and Priest Rapids Dam. TSI scores are best considered a quantitative indicator of productivity; however, some judgment is necessary to evaluate if the trophic status is consistent with the ecological understanding of a water body.

Table 5.8-10 Trophic State Indices (TSI) for the Wells Project 2005-2006

	TSI Secchi	**TSI TP (ug/L)**	**TSI TN (ug/L)**	**TSI Chlorophyll *a* (ug/L)**
Trophic Status	Oligotrophic	Mesotrophic	Oligotrophic	Oligo-Mesotrophic
TSI Formula	TSI= 60-14.41*ln(SD)	TSI= 14.42*ln(TP)+4.15	TSI= 54.45+14.43ln(TN)	TSI= 9.81*ln(Chl)+30.6
Mean Value	5.67	16.08	169.27	2.3
TSI Score	35	44.2	28.2	38.77

5.9 Phytoplankton

Phytoplankton are microscopic, unicellular and multi-cellular free-floating aquatic plants that provide much of the primary productivity in lakes and reservoirs. Phytoplankton are often the dominant primary producer in lentic habitats (Lowe 1996).

The characteristics of major phytoplankton taxa are:

Bacillophyta (Diatoms) are typically very abundant in freshwater systems. They are mostly non-motile and are characterized by their silica cell walls. Diatoms are among the largest contributors to the global food web and form the base of the aquatic food web in most freshwater and marine systems. Diatoms are considered a desirable food group. They are closely related to chrysophytes.

Chlorophyta (green algae) are a large and diverse division. Green algae possess high amounts of chlorophyll *a*. They may be unicellular or form large colonies, some of which have a gelatinous sheath that reduces their quality as a food source for zooplankton. Many chlorophyta are flagellated.

Cyanophyta (blue-green bacteria) are notorious for causing large blooms that negatively affect swimming, drinking water supplies and other beneficial uses. They can produce hepto- and neurotoxins which may adversely affect other organisms, either aquatic or terrestrial, including mammals. At high bloom levels, they may also produce an odor and taste-causing organic compound called geosmin. Many of the species in this phylum are capable of processing nitrogen gas from the atmosphere into forms (NO_3) to support higher levels of phytoplankton production. Some species are motile and often migrate between the metalimnion where they avoid predation and the upper water column.

Cryptophyte are small unicellular algae. They propel themselves by two flagellae and are a good food source for zooplankton.

5.9.1 Phytoplankton Trends

A total of 59 samples were analyzed for phytoplankton. One hundred and fifty-four taxa of phytoplankton were identified in these samples. Overall, the most dominant taxa based on total average density were the Crytophyta, *Rhodomonas minuta* (26.2% and present in 40 out of 59 samples), the diatom, *Acnanthes minutissima* (12.2% and present in 58 out of 59 samples) and the diatom, *Cymbella minuta* (5.95 and present in 47 out of 59 samples). A complete taxa listing is provided in Appendix C.

Phytoplankton samples were dominated by diatoms for all months at all sites sampled with Cryptophyta (small unicellular flagellates) being secondary based on biovolume. Diatoms and Cryptophytes are both considered a good food source for the rest of the aquatic food web. Diatoms comprised 75% to 84% of the total phytoplankton biomass for the waters surrounding the Wells Project. Chlorophytes (Green algae) were sub-dominant in the tailrace but only a minor component elsewhere. Total phytoplankton biomass was relatively low for all pelagic and littoral sample sites. Similar percentage composition for dominant phyla was reported for Rocky Reach Reservoir pelagic waters and tailrace (Chelan PUD 2001). In the Wells reservoir and tailrace, the monthly average total biomass for pelagic waters ranged from 137,667 μm^3/mL in October to 332,031 μm^3/mL in July. The monthly average total biomass for littoral waters ranged from 161,438 μm^3/mL in August to 433,388 μm^3/mL in October (Figure 5.9-1). The timing of peaks varied among all stations and peaks in biomass differed from peaks in density (Figure 5.9-2). Biovolume peaked in July for pelagic and littoral waters with a second peak in biomass for littoral waters occurring in October. The October peak for littoral waters is due to an increase in the diatom *Cocconeis placentula* and the cryptophyte *Chryptomonas erosa*. While these two taxa were also dominant in pelagic waters, their abundance was less in the littoral samples. Phytoplankton density did not vary significantly between months for pelagic waters. Density in the littoral sample areas peaked in October. The discrepancies between peaks in biomass and density are due to large multicellular colonies contributing to the biomass while each being counted as a single unit in the density count.

Phytoplankton biovolume was at a minimum in September for the Methow River with a very large spike in both biovolume and density occurring in August. An algae bloom composed of mostly diatoms, particularly *Acnanthes minutissima* occurred in the lower Methow River in

August. Peak biomass (145,158 μm^3/mL) in August was an order of magnitude higher than in other months (Figure 5.9-1).

Biovolume in the Okanogan River was at a minimum in July and highest in May and October. Density showed low variability between months. The density of diatoms decreased in the July sample but was offset by increases in density for cryptophytes, chrysophytes and chlorophytes. With the exception of the algae bloom in the Methow River during August, the total phytoplankton biomass patterns were similar for the Methow River and Okanogan River. There were some differences in species composition. The presence of blue-green algae in the October sample for the Okanogan River is the most notable difference. A single species of Dinophyta was also present in the August sample for the Okanogan River; this phylum was relatively uncommon for all sites.

A Trophic State Index (TSI) based upon phytoplankton biovolume has been developed from a data set of several hundred lakes located throughout the Pacific Northwest (Sweet 1986). The index was derived in a similar fashion as Carlson (1977) derived indices for Secchi depth, chlorophyll concentration, and total phosphorus concentration. The biovolume index ranges from 1 for ultraoligotrophic lakes to 100 for hypereutrophic lakes. Values for other waterbodies in the region agree well with Carlson's indices. The formula for this TSI is:

TSI (biovolume) = (Log-base 2 (B+1)) * 5

Where B is the phytoplankton biovolume in cubic micrometers per milliliter divided by 1000.

A TSI score was assigned to each sample and then aggregated by month according to a pelagic, littoral or tributary water source. TSI scores, averaged by season are reported in Table 5.9-1. The TSI score compares well with other TSI scores for the Wells Reservoir and again indicates that the Columbia River portion of the Wells Reservoir is oligo-mesotrophic. The backwater area in the Methow and Okanogan rivers within the Wells Reservoir are classified as mesotrophic based on phytoplankton biomass.

Table 5.9-1 Trophic Status Index (TSI) based on phytoplankton biomass (μm3/mL) for the Wells Project (2005-2006)

	TSI			
	Spring[3]	**Summer[3]**	**Fall[3]**	**Annual[3]**
Pelagic[1]	37.7	38.2	35.4	37.5
Littoral[2]	38.8	39.0	43.5	39.8
Methow R.	46.5	45.5	44.6	45.5
Okanogan R.	45.8	39.9	44.6	42.0

[1]Pelagic sites include Chief Joseph tailrace; Wells Reservoir at Brewster Bridge and Wells forebay. Values are average for these three sites

[2]Littoral sites include Bridgeport shallows and shallows near Starr boat launch. Values are average for these two sites

[3]Spring = May; Summer is average for July, August and September
Annual is average for May, July, August, September and October

Table 5.9-2 lists the monthly biomass by phylum. Additional tables and charts for phytoplankton density and biomass for individual sites are provided in Appendix C. Tables 5.9-3 through 5.9-10 list the dominant phytoplankton by month for each of the sample sites.

Cyanophytes (blue-green bacteria) were only recorded in the reservoir for the July sample at Brewster bridge where they comprised 16% of the total biomass; however, the biomass of cyanophytes were comprised of relatively few but very large multicellular units. Cyanophytes were not present in the duplicate sample collected at the same time. The taxa included *Anabaena spp*. and *Aphanizomenon flos-aquae*. Cyanophytes were also recorded in the Wells Dam Tailrace (4.7% biomass) in July. Cyanophytes were a small proportion of the August biomass sample for the Okanogan River. Chelan PUD (2001) reported similar biovolumes of cyanophytes for pelagic waters in the downstream Rocky Reach Reservoir with the same species occurring. Cyanophytes were present in all months for samples collected in the Rocky Reach study with peaks in February, June and August. Other historical data (Rensel 1997, 1998) suggests that Lake Osoyoos and upper reaches of the Okanogan River may be sources of blue-green algae.

Differences in nutrients and phytoplankton density, biovolume and chlorophyll *a* were determined using ANOVA and Tukey's and Scheffe's analysis for all pairwise comparisons. Tests were determined significant at $p<0.05$. Secchi depth was moderately inversely related to both density and biovolume ($R^2 = 0.38$ and 0.53, respectively). The relationship of phosphorus and total nitrogen (independent variables) and biovolume (dependent variable) were significant ($R^2 = 0.4$ and 0.37, respectively). Total nitrogen data were also significantly related to phytoplankton biovolume and density ($R^2 = 0.5$ and 0.37, respectively). Total phosphorus only showed a significant relationship to biovolume ($R^2 = 0.36$). Though significant ($p < 0.05$), the relationships were moderately weak when considered separately as well as aggregated. Biovolume and density are closely correlated ($R^2 = 0.87$) but neither was significantly correlated to chlorophyll *a* levels.

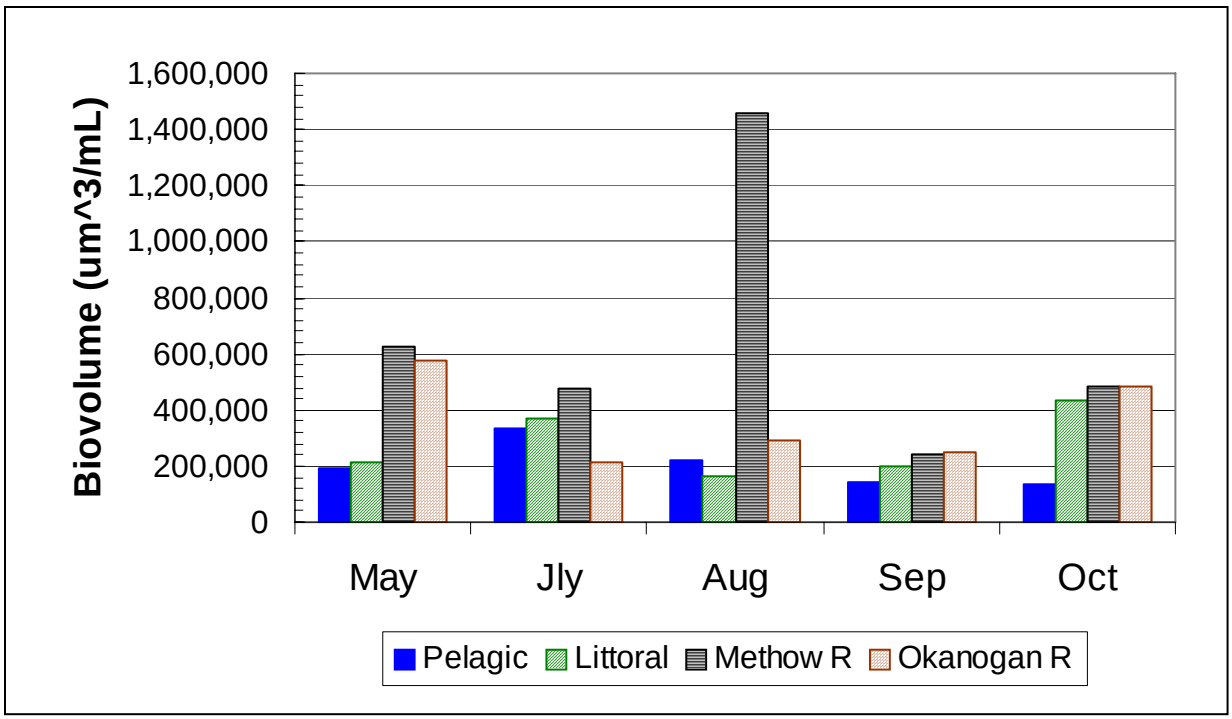

Figure 5.9-1 Phytoplankton biovolume (μm^3/mL) for the Wells Project (2005-2006)

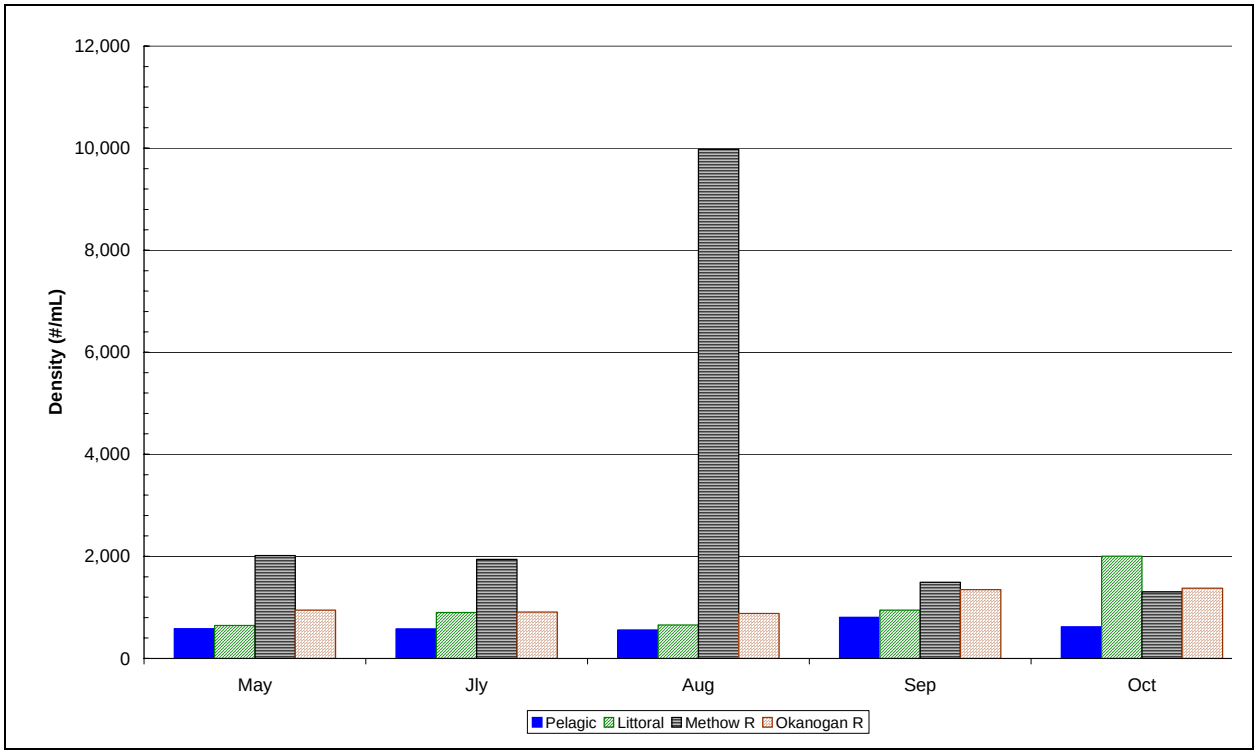

Figure 5.9-2 Phytoplankton density (units/mL) for the Wells Project (2005-2006)

Table 5.9-2 Phytoplankton biomass (μm^3/mL) for Wells Project 2005

	Bacillariophyceae	Chlorophyta	Chrysophyta	Cryptophyta	Cyanophyta	Dinophyta
Wells Dam Forebay						
May	152,284		5,175	36,336		
July	156,486	112	1,705	16,335		
Aug	421,515	141	537	26,450		
Sept	70,643	13,623		86,322		
Oct	112,957	2,758	488	27,003		
Starr boat launch littoral site						
May	184,683	805	5,187	34,147		
July	341,431			30,858		
Aug	186,923	2,885		41,948		
Sept	183,394	5,230	1,440	47,980		
Oct	478,475			88,498		
Methow River near mouth						
May	624,838					
July	475,059			311		
Aug	1,400,492	17,767		36,900		
Sept	166,811			73,742		
Oct	482,048	3,679				
Wells Reservoir at Brewster Bridge						
May	221,650	2,159	914			
July	310,148	19,507		17,307	67,877	
Aug	77,510	144	364	15,942		
Sept	84,623	2,451		48,107		
Oct	131,032	183		44,000		
Okanogan River near mouth						
May	573,754					
July	160,428	11,556	10,220	32,336		
August	243,794	1,025	830	21,086	9,762	6,833
Sept	232,293	1,915	4,695	13,098		
Oct	371,070	396	3,988	23,737	79,534	1,899
Bridgeport Shallows Littoral Site						
May	176,250		1,075	31,182		
Aug	65,902	2,887		22,332		
Sept	119,048	0	1,517	44,382		
Oct	215,522	470		83,811		
Chief Joseph Dam tailrace						
May	86,586	2,093	2,565	54,120		2,105
July	160,428	10,067	10,220	32,336		
Aug	114,329	2,042	449	10,211		
Sept	91,639	1,804	264	3,842		
Oct	65,449	1,634	828	26,581		
Wells Dam tailrace						
May	170,982		3,166	1,296		
July	395,459		1,452	1,210		
Aug	106,662	106,662		334	1,411	
Sept	152,383	152,383		11,116		4,373
Oct	74,873	74,873		1,967		

Table 5.9-3 Dominant three phytoplankton species by phyla, measured as biovolume (μm^3/mL), Wells Reservoir at Chief Joseph Dam Tailrace. Phytoplankton obtained over the depth of the photic zone using an integrated sampler

Date	May-05	July-05	August-05	September-05	1-Oct-05
Bacillariophyceae	*Asterionella formosa*	*Synedra radians*	*Fragilaria crotonensis*	*Melosira ambigua*	*Cyclotella comta*
	Synedra radians	*Melosira ambigua*	*Tabellaria fenestrata*	*Synedra radians*	*Cocconeis placentula*
	Melosira italica	*Cymbella tumida*	*Cyclotella comta*	*Synedra ulna*	*Stephanodiscus hantzschii*
Chlorophyta	*Crucigenia quadrata*	*Oocystis pusilla*	*Oocystis pusilla*	*Oocystis pusilla*	*Chlamydomonas* sp.
	Ankistrodesmus falcatus	*Chlamydomonas* sp.			*Ankistrodesmus falcatus*
		Tetrastrum staurogeniaforme			
Chrysophyta	*Chrysococcus rufescens*	*Kephyrion littorale*	*Kephyrion littorale*	*Kephyrion littorale*	*Rhizosolenia eriensis*
	Kephyrion littorale	*Kephyrion sp.*			
		Kephyrion spirale			
Cryptophyta	*Cryptomonas erosa*	*Cryptomonas erosa*	*Rhodomonas minuta*	*Rhodomonas minuta*	*Cryptomonas erosa*
	Rhodomonas minuta	*Rhodomonas minuta*	*Cryptomonas erosa*	*Cryptomonas erosa*	*Rhodomonas minuta*
Dinophyta	*Dinobryon sertularia*				

* Note: Duplicate samples at site.

Table 5.9-4 Dominant three phytoplankton species by phyla, measured as biovolume (μm^3/mL), Wells Reservoir at Brewster Bridge. Phytoplankton obtained over the depth of the photic zone using an integrated sampler

Date	May-05	July-05	August-05	September-05	1-Oct-05
Bacillariophyceae	*Asterionella formosa*	*Fragilaria crotonensis*	*Synedra radians*	*Synedra ulna*	*Cocconeis placentula*
	Fragilaria crotonensis	*Melosira ambigua*	*Melosira ambigua*	*Cocconeis placentula*	*Melosira ambigua*
	Synedra ulna	*Cyclotella comta*	*Gomphonema acuminatum*	*Synedra radians*	*Tabellaria fenestrata*
Chlorophyta	*Crucigenia quadrata*	*Ulothrix* sp.	*Ankistrodesmus falcatus*	*Oocystis pusilla*	*Ankistrodesmus falcatus*
		Selenastrum minutum			
Chrysophyta	*Kephyrion littorale*		*Kephyrion* sp.		
	Chrysococcus rufescens				
Cryptophyta		*Cryptomonas erosa*	*Cryptomonas erosa*	*Cryptomonas erosa*	*Cryptomonas erosa*
		Rhodomonas minuta	*Rhodomonas minuta*	*Rhodomonas minuta*	*Rhodomonas minuta*
Cyanophyta		*Anabaena circinalis*			
		Anabaena sp.			
		Aphanizomenon flos-aquae			

Table 5.9-5 Dominant three phytoplankton species by phyla, measured as biovolume (μm^3/mL), Wells Dam Forebay. Phytoplankton obtained over the depth of the photic zone using an integrated sampler

Date	May-05	July-05	August-05	September-05	1-Oct-05
Bacillariophyceae	*Asterionella formosa*	*Diatoma tenue elongatum*	*Fragilaria crotonensis*	*Cocconeis placentula*	*Fragilaria crotonensis*
	Synedra radians	*Fragilaria crotonensis*	*Cocconeis placentula*	*Synedra delicatissima*	*Cocconeis placentula*
	Melosira italica	*Melosira ambigua*	*Synedra radians*	*Melosira granulata*	*Stephanodiscus hantzschii*
Chlorophyta		*Ankistrodesmus falcatus*	*Ankistrodesmus falcatus*	*Sphaerocystis schroeteri*	*Sphaerocystis schroeteri*
				Chlamydomonas sp.	*Ankistrodesmus falcatus*
				Oocystis pusilla	
Chrysophyta	*Dinobryon sertularia*	*Kephyrion littorale*	*Kephyrion littorale*		*Chrysococcus rufescens*
	Kephyrion littorale				
Cryptophyta	*Cryptomonas erosa*	*Cryptomonas erosa*	*Cryptomonas erosa*	*Cryptomonas erosa*	*Cryptomonas erosa*
	Rhodomonas minuta	*Rhodomonas minuta*	*Rhodomonas minuta*	*Rhodomonas minuta*	*Rhodomonas minuta*

Table 5.9-6 Dominant three phytoplankton species by phyla, measured as biovolume (μm^3/mL), Wells Dam Tailrace. Phytoplankton obtained over the depth of the photic zone using an integrated sampler

Date	May-05	July-05	August-05	September-05	1-Oct-05
Bacillariophyceae	*Asterionella formosa* *Cymbella minuta* *Synedra radians*	*Fragilaria crotonensis* *Diatoma tenue elongatum* *Fragilaria vaucheria*	*Cyclotella comta* *Synedra ulna* *Synedra radians*	*Melosira granulate angustissima* *Synedra radians* *Hannaea arcus*	*Cymbella affinis* *Fragilaria crotonensis* *Melosira varians*
Chlorophyta			*Sphaerocystis schroeteri* *Ankistrodesmus falcatus*	*Scenedesmus quadricauda* *Scenedesmus acuminatus*	*Scenedesmus quadricauda* *Oocystis pusilla* *Ankistrodesmus falcatus*
Chrysophyta	*Chrysococcus rufescens* *Kephyrion littorale*	*Kephyrion littorale* *Kephyrion* sp.	*Chromulina* sp.		
Cryptophyta	*Cryptomonas erosa* *Rhodomonas minuta*	*Cryptomonas erosa* *Rhodomonas minuta*	*Cryptomonas erosa* *Rhodomonas minuta*	*Cryptomonas erosa* *Rhodomonas minuta*	*Cryptomonas erosa* *Rhodomonas minuta*
Cyanophyta			*Aphanizomenon flos-aquae* *Oscillatoria* sp.		

Table 5.9-7 Dominant three phytoplankton species by phyla, measured as biovolume (μm^3/mL), Wells Reservoir at Bridgeport Shallows (Littoral sample). Phytoplankton obtained over the depth of the photic zone using an integrated sampler

Date	May-05	July-05	August-05	September-05	1-Oct-05
Bacillariophyceae	*Asterionella formosa*		*Synedra ulna*	*Cocconeis placentula*	*Cocconeis placentula*
	Melosira italica		*Nitzschia linearis*	*Tabellaria fenestrata*	*Achnanthes minutissima*
	Synedra radians		*Synedra radians*	*Epithemia sorex*	*Achnanthes linearis*
Chlorophyta			*Ulothrix* sp.		*Ankistrodesmus falcatus*
			Scenedesmus quadricauda		
Chrysophyta	*Kephyrion littorale*			*Kephyrion littorale*	
	Chrysococcus rufescens				
Cryptophyta	*Cryptomonas erosa*		*Cryptomonas erosa*	*Cryptomonas erosa*	*Cryptomonas erosa*
	Rhodomonas minuta		*Rhodomonas minuta*	*Rhodomonas minuta*	*Rhodomonas minuta*

* Note: Duplicate samples at site.

Table 5.9-8 Dominant three phytoplankton species by phyla, measured as biovolume (μm^3/mL), Wells Reservoir at Starr Boat Launch (Littoral sample). Phytoplankton obtained over the depth of the photic zone using an integrated sampler

Date	May-05	July-05	August-05	September-05	1-Oct-05
Bacillarioph-yceae	*Asterionella formosa*	*Tabellaria fenestrata*	*Melosira ambigua*	*Fragilaria crotonensis*	*Cocconeis placentula*
	Melosira ambigua	*Asterionella formosa*	*Tabellaria fenestrata*	*Cocconeis placentula*	*Tabellaria fenestrata*
	Melosira italica	*Fragilaria crotonensis*	*Synedra ulna*	*Melosira granulata angustissima*	*Fragilaria crotonensis*
Chlorophyta	*Ankistrodesmus falcatus*		*Scenedesmus quadricauda*	*Sphaerocystis schroeteri*	
			Oocystis pusilla	*Scenedesmus quadricauda*	
Chrysophyta	*Chrysococcus rufescens*			*Kephyrion littorale*	
	Kephyrion littorale			*Rhizosolenia eriensis*	
Cryptophyta	*Cryptomonas erosa*	*Cryptomonas erosa*	*Cryptomonas erosa*	*Cryptomonas erosa*	*Cryptomonas erosa*
	Rhodomonas minuta	*Rhodomonas minuta*	*Rhodomonas minuta*	*Rhodomonas minuta*	*Rhodomonas minuta*

* Note: Duplicate samples at site.

Table 5.9-9 Dominant three phytoplankton species by phyla, measured as biovolume (μm^3/mL), Methow River near mouth. Phytoplankton obtained over the depth of the photic zone using an integrated sampler

Date	May-05	July-05	August-05	September-05	1-Oct-05
Bacillariophyceae	*Diatoma vulgare*	*Cymbella minuta*	*Achnanthes minutissima*	*Achnanthes minutissima*	*Cymbella delicatula*
	Cymbella minuta	*Cymbella cistula*	*Diatoma vulgare*	*Melosira granulata*	*Diatoma vulgare*
	Achnanthes minutissima	*Diatoma vulgare*	*Cymbella affinis*	*Cymbella minuta*	*Denticula elegans*
Chlorophyta			*Scenedesmus quadricauda*		*Scenedesmus quadricauda*
					Ankistrodesmus falcatus
Cryptophyta		*Rhodomonas minuta*	*Cryptomonas erosa*	*Cryptomonas erosa*	
			Rhodomonas minuta	*Cryptomonas ovata*	
Cyanophyta				*Rhodomonas minuta*	

* Note: Duplicate samples at site.

Table 5.9-10 Dominant three phytoplankton species by phyla, measured as biovolume (μm^3/mL), Okanogan River near mouth. Phytoplankton obtained over the depth of the photic zone using an integrated sampler

Date	May-05	July-05	August-05	September-05	1-Oct-05
Bacillariophyceae	*Cymbella affinis*	*Synedra radians*	Fragilaria crotonensis	*Stephanodiscus hantzschii*	*Melosira ambigua*
	Diatoma vulgare	*Melosira ambigua*	*Diatoma vulgare*	*Tabellaria fenestrata*	*Cocconeis placentula*
	Cymbella minuta	*Cymbella tumida*	*Cymbella affinis*	*Diatoma vulgare*	*Cymbella minuta*
Chlorophyta		*Oocystis pusilla*	*Crucigenia quadrata*	*Scenedesmus quadricauda*	*Ankistrodesmus falcatus*
		Chlamydomonas sp.	*Selenastrum minutum*	*Ankistrodesmus falcatus*	
		Tetrastrum staurogeniaforme			
Chrysophyta		*Kephyrion littorale*	*Chrysococcus rufescens*	*Kephyrion littorale*	*Kephyrion* sp.
		Kephyrion sp.			
		Kephyrion spirale			
Cryptophyta		*Cryptomonas erosa*	*Cryptomonas erosa*	*Rhodomonas minuta*	*Cryptomonas erosa*
		Rhodomonas minuta	*Rhodomonas minuta*	*Cryptomonas erosa*	*Rhodomonas minuta*
Cyanophyta			*Oscillatoria* sp.		*Anabaena planctonica*
Dinophyta			*Glenodinium* sp.		*Dinobryon bavaricum*
Euglenaphyta			*Euglena* sp.		

* Note: Duplicate samples at site.

5.10 Periphyton

Periphyton is the film of attached benthic algae, fungi, bacteria, and protozoans that grow on the substrate. Provided it has adequate nutrients and light, periphyton will grow on any exposed surface. Attached algae, provided it has enough nutrients and light, will grow on any exposed surface. Periphyton can be a major contributor to productivity in lakes when there is enough light penetrating to the bottom (Lowe 1996). Dominant factors contributing to the net attached benthic algal growth are nutrient concentrations, light availability, water velocity, substrate availability, temperature and insect grazing. High nutrient concentrations, increased temperature, and light penetration can cause an increase in periphyton productivity (Bothwell et al. 1988; Lohman et al. 1992). Increased water velocity during high flows will induce algal loss by sloughing or scour (Biggs 1996). Yet, slow to moderate flow within a stream can stimulate attached benthic algal growth, compared to still water, as the flow provides constant replenishment of nutrients across the algal mat. Periphyton sampling focused on littoral habitats and tailraces. In previous studies, tailrace areas have been shown to influence benthic algal production due to modification in nutrient and temperature regimes and variation in diel water discharge (Blinn et al., 1998).

Diatoms dominated periphyton communities in the Wells Project. Generally, periphyton within littoral habitat sites had greater biomass than in the tailrace of either Chief Joseph Dam or Wells Dam. An exception to this trend was the July sample for Wells Dam tailrace; robust periphyton growth (biovolume of approximately 1.5 billion μm^3/mL) occurred in the tailrace in July with *Cymbella spp., Fragilaria spp., Gomphoneis herculeana and Tabellaria fenestrate* (all diatoms) being the dominant species. Seasonal trends were variable among sites. Figure 5.10-1 and Figure 5.10-2 show monthly periphyton data for biovolume and density, respectively. The periphyton samples represent the season's cumulative growth since natural substrates were scraped to collect the sample. The net periphyton volume is a function of both growth and sloughing of the benthic algae. The variability in seasonal biovolume trends among sites is likely due to differing sloughing rates associated with higher velocities, especially in the tailraces. A sharp reduction in both biovolume and density occurred at all the sample sites from May to July. The increased growth in August varied among sites and then periphyton abundance decreased again in September. The cyanophyte *Oscillatoria* sp. occurred in nearly all months at all the sites except the littoral site near the Starr boat launch. Chloropyta were only observed at very low levels (less than 1% biovolume) in September for the littoral sites. A complete listing of periphyton data is provided in Appendix D. Charts showing seasonal trends in periphyton growth are also provided in Appendix D.

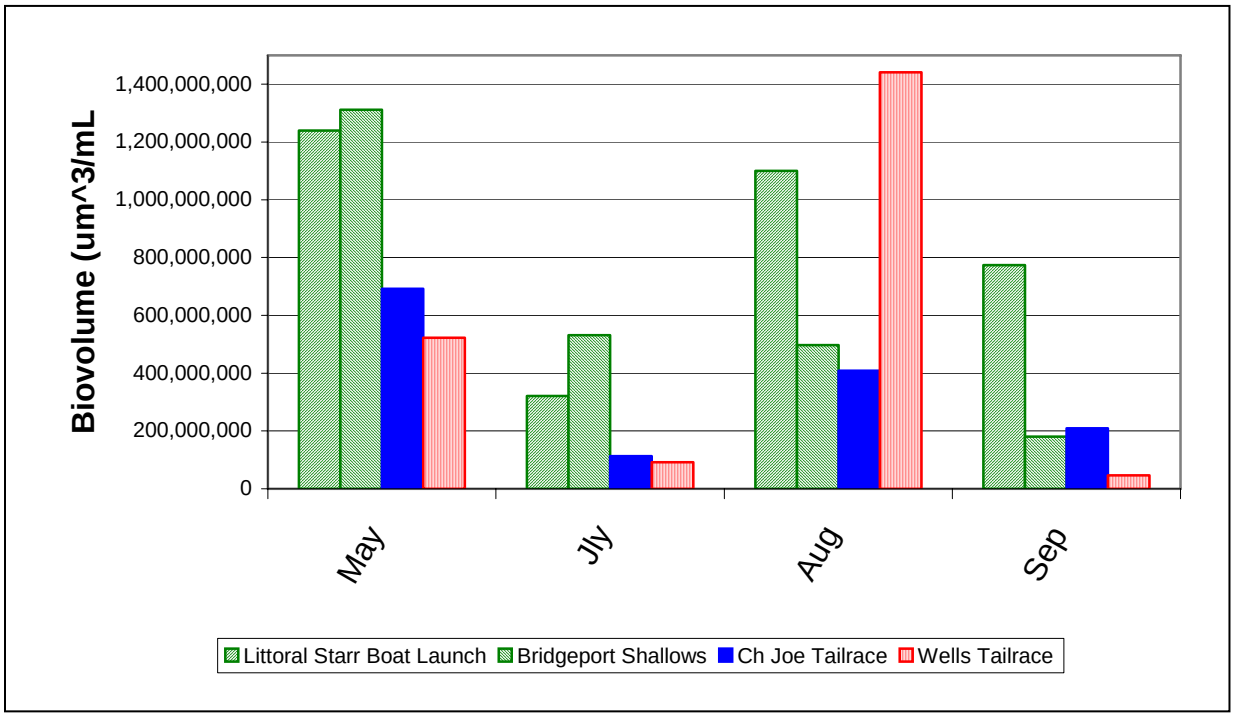

Figure 5.10-1 Periphyton Biomass for the Wells Project (2005-2006)

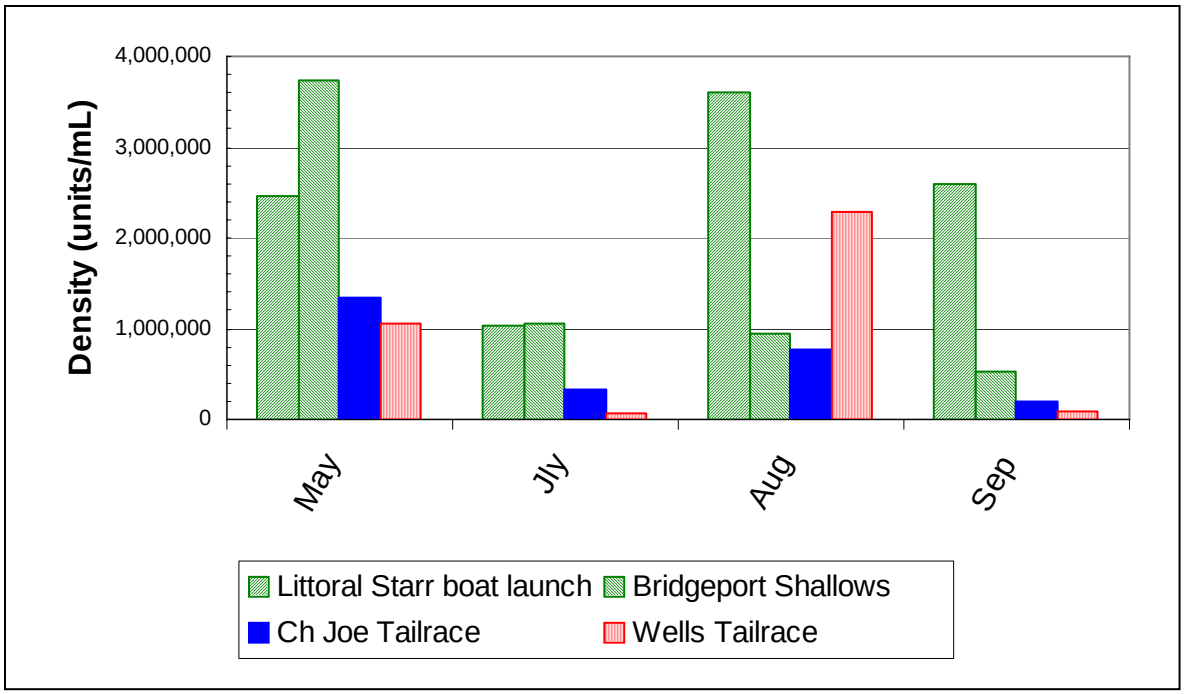

Figure 5.10-2 Periphyton density for the Wells Project (2005-2006)

5.11 Zooplankton

Zooplankton are the primary consumers of phytoplankton in lakes and reservoirs. Zooplankton are an important food component in the lower and mid Columbia River for resident and anadromous fish; larval and juvenile salmonids are particularly dependent on zooplankton for food (Wydoski and Whitney 1979).

5.11.1 Major Zooplankton Taxa

The following is a description of the major zooplankton taxa documented in the Wells Project.

Cladocerans: both Cladocerans and Copepoda are crustacean zooplankton. The genera Daphnia, Bosmina and to a lesser extent Alona comprise the majority of cladocerans in the Wells Project. Daphnia are an ideal food source for smaller salmonids in freshwater due to the relatively large size of individual Daphnia and their protein composition.

Copepoda: Copepoda are usually the dominant large zooplankton in the pelagic zone and are separated into three distinct groups; the suborders Calanoida, Cyclopoida and Harpacticoida. The three sub-orders are distinguishable by the general structure of the first antennae, urosome and fifth leg (Wetzel 2001). Copepoda create a localized current by movement of their legs in order to filter phytoplankton.

Rotifers: Planktonic rotifers feed primarily by filtering seston particles in the mouth orifice. The size of food they consume is variable. Rotifers are relatively small. High abundance of rotifers is often associated with eutrophic conditions. Rotifers are too small to be prey items for salmonids, as the latter primarily feed by visually selecting individual food items.

5.11.2 Zooplankton Species Composition

Shannon Weaver diversity indices were computed to determine the degree of similarity among sampling sites. Tables for similarity indices and species lists of zooplankton are provided in Appendix E. Low species diversity, especially in September, limited the utility of applying a Shannon Weaver diversity index. Generally, the pelagic sites showed greater similarity than sites within littoral or riverine habitat; however, zooplankton populations appear to be opportunistic and highly variable among all sites. Differences between pelagic and littoral sites were often less than differences among sites within the same habitat type. Copepoda were dominant in zooplankton density counts for all months for both pelagic sites and in samples collected from the lower Okanogan and Methow rivers. Although rotifer density is probably under-represented due to large mesh size of the net, rotifers were dominant within pelagic waters for May and September. The rotifer, *Kellicottia longispina,* was the only zooplankton species present in the September sample for the Methow River but rotifers were absent for the September sample collected from the Okanogan River. Tables 5.11-1, 5-11-2 and 5.11-3 report zooplankton density by major taxa and month for pelagic, tributary and littoral sites. Samples at the littoral sites were inadvertently omitted for July. Figures 5.11-1 and 5.11-2 show the

seasonal progression of zooplankton density distribution for pelagic and tributary sites, respectively.

Zooplankton density peaked in May. Zooplankton density in the Methow and Okanogan rivers rapidly declined from an average of 7,875/m^3 in May to 2,980/ m^3 July and continued to decrease to a low of 1,280/ m^3 in September. Zooplankton density rebounded slightly in February mostly due to an increased copepod density (Table 5.11-1). The density of zooplankton in pelagic waters also sharply decreased between May and July. Pelagic zooplankton densities further decreased in September. Total density for September was slightly higher than recorded for August due to increased rotifer density. The lowest zooplankton density for pelagic waters occurred in February (Table 5.11-2). Chelan PUD (2001) reported similar peak densities for May in Rocky Reach (different years) with a less appreciable decline during the rest of the summer. Higher zooplankton densities in the mainstem compared to the tributary mouths is likely attributable to longer water residence time during which the zooplankton population can grow.

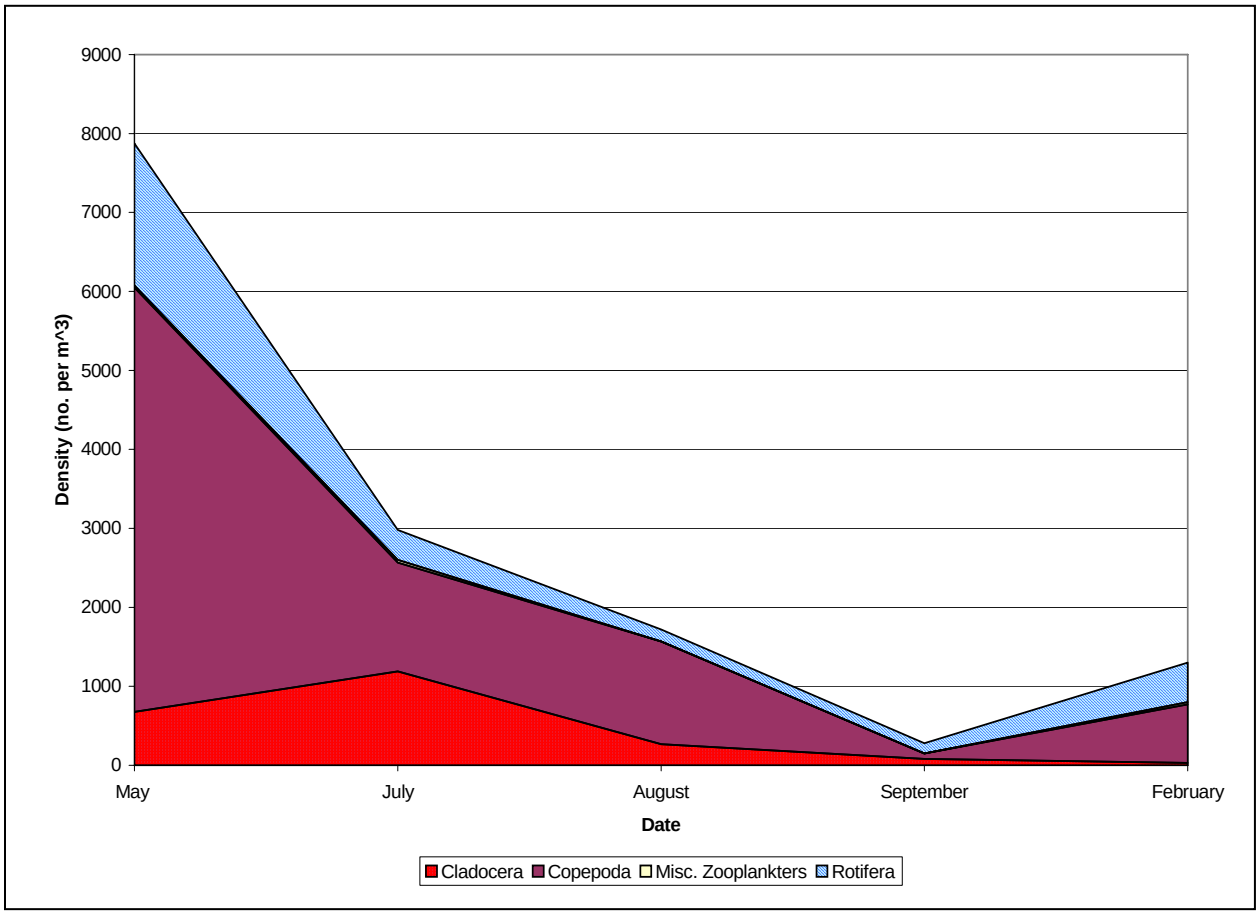

Figure 5.11-1 Zooplankton density averaged for the Okanogan River and Methow River

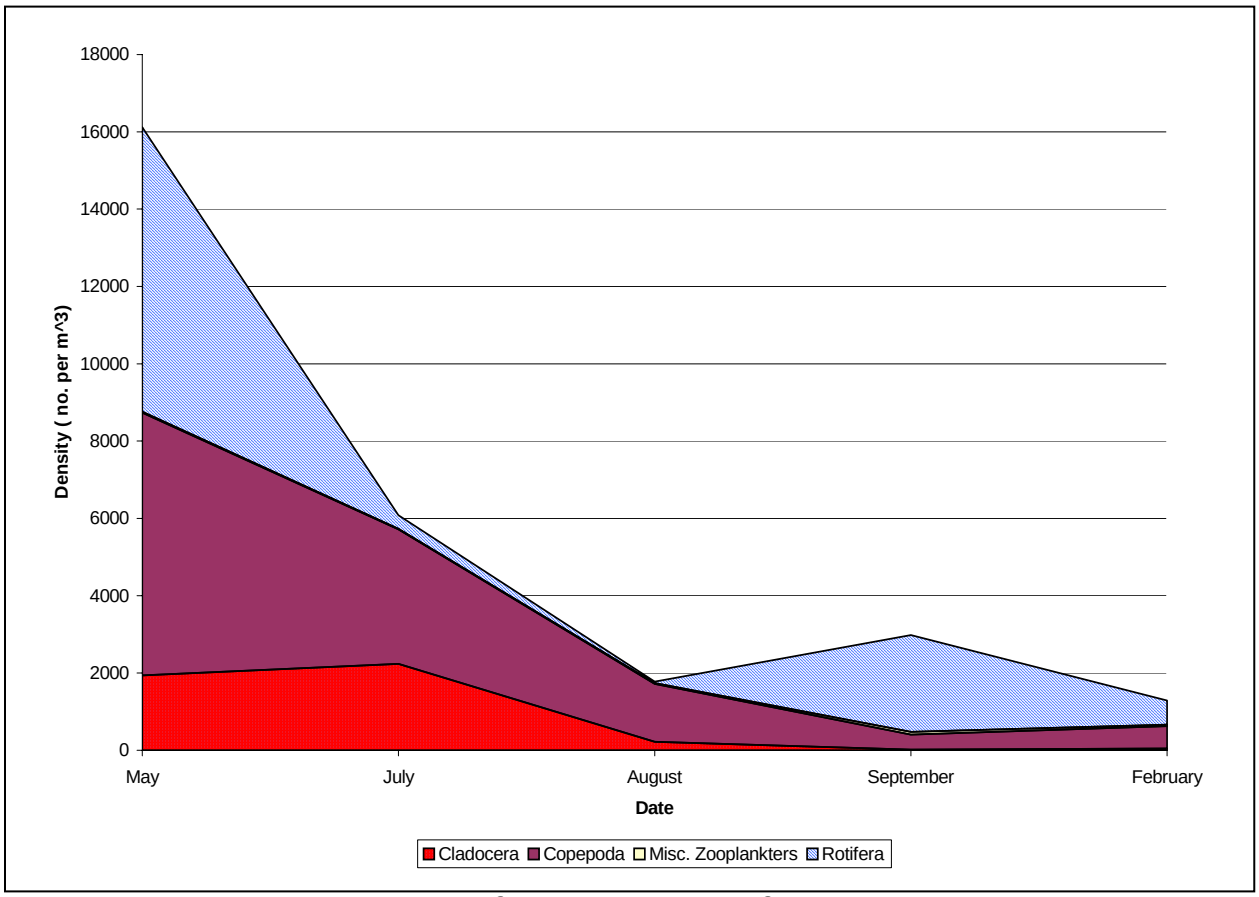

Figure 5.11-2 Zooplankton density for pelagic waters of the Wells Project

Table 5.11-1 Zooplankton density (#/m^3) averaged for the Okanogan and Methow rivers

	May	July	August	September	February
CLADOCERA	675	1187	267	80	29
Percent of Total	8.6	39.8	15.5	28.6	2.2
COPEPODA	5375	1380	1300	70	741
Percent of Total	68.3	46.3	75.6	25.0	57.0
MISC. ZOOPLANKTERS	25	33	0	0	29
Percent of Total	0.3	1.1	0.0	0.0	2.2
ROTIFERA	1800	380	153	130	501
Percent of Total	22.9	12.8	8.9	46.4	38.5
Total	**7875**	**2980**	**1720**	**280**	**1299**

Table 5.11-2 Zooplankton density (#/m^3) for pelagic waters of the Wells Project

	May	July	August	September	February
CLADOCERA	1940	2240	220	20	48
Percent of Total	12.0	36.8	12.4	0.7	3.7
COPEPODA	6790	3480	1500	390	578
Percent of Total	42.1	57.2	84.3	13.1	44.8
MISC. ZOOPLANKTERS	30	10	20	70	39
Percent of Total	0.2	0.2	1.1	2.3	3.0
ROTIFERA	7360	350	40	2500	626
Percent of Total	45.7	5.8	2.2	83.9	48.5
Total	16120	6080	1780	2980	1290

5.12 Fecal Coliform

Fecal coliform samples were collected for laboratory analysis from the two littoral habitat sites and the mouths of the Methow and Okanogan rivers during the May, August and October sampling events. The holding time for the May samples exceeded 24 hours, which rendered the samples not suitable for analysis. All samples analyzed that were collected from the littoral habitat of the mainstem reported less than 1 fecal coliform/100 mL. The samples from the lower Methow also reported less than 1 fecal coliform/100 mL. The August and October samples from the Okanogan River reported 23 and 36 coliform/100mL, respectively. None of the samples exceeded a value of 100 colonies /100 mL, which is a criteria for the State water quality standard (WAC 173-201A-200 (2) (b)).

Fecal coliform monthly sampling is conducted outside of the Wells Project boundary by the WDOE at the Mallot monitoring station (Station 49A070) on the Okanogan River. Data reported from this site indicated that upstream of the Wells Project on the Okanogan River fecal coliform levels ranged from 1 to 210 fecal coliform/100 mL for the May through October 2005 monitoring period. The only reported exceedance of the 100 colonies/ mL State water quality criteria occurred outside of the Project boundary at the Mallot station on October 3, 2005.

5.13 MTBE

Methyl tert-butyl ether (MTBE) is a fuel additive to two-stroke engines and is a known carcinogen. Surface grab samples were taken from the three mainstem pelagic sites for summer months July, August and September and were analyzed in the laboratory. All samples reported levels below detection limits for MTBE.

6.0 CONCLUSIONS

A comprehensive limnological investigation (biological, chemical, and physical water quality parameters) for the waters contained within the Wells Project Boundary was completed. The primary study objective was to document existing water quality conditions within the Wells Reservoir and Wells Dam tailrace with reference to the Washington State Department of Ecology (WDOE) water quality standards.

The study approach and methods used during this investigation were consistent with WDOE's "Water Quality Certification for Existing Hydropower Dams: Preliminary Guidance Manual (September 2004)".

A total of 23 water quality characteristics were measured. A total of nine sampling sites, which included mainstem sites, tributaries, and littoral habitats were selected to document the biological, physical, and chemical water quality variability of the Wells Project. Water quality sampling was seasonal with one sample event scheduled during the months of May, August, October (2005), and February (2006). An additional sampling event was scheduled in July and September to provide for monthly sampling frequency in the summer. The sampling scheme used in this study were designed to document water quality conditions during periods when potential exceedance were most probable and focused on periods when water quality was more temporally dynamic.

Laboratory methods and detection limits were sufficiently low to result in relatively few samples reported parameter levels below detection. Ammonia and total suspended solids were the only two parameters that consistently reported levels below detection limits for the majority of samples.

Water temperature was the only measured parameter that exceeded the water quality standards (total dissolved gas monitoring was not part of this study). Temperature exceedances occurred at the mouth of the Methow River in July through September and in the mouth of the Okanagan in August and September. Temperature exceedances of the 18°C numeric criteria were recorded at all of the monitoring sites in the mainstem during August and September. Slight temperature exceedances were also reported for the Chief Joseph tailrace and Wells forebay in October; these are the only two mainstem monitoring sites with reliable thermograph data for October 2005.

Water temperature in the Wells Reservoir is mostly governed by the temperature of inflowing water at Chief Joseph Dam. Temperature in the Wells Reservoir varied little longitudinally between the furthest upstream site at Chief Joseph tailwater and the Wells Dam forebay at the downstream end of the reservoir. The difference in monthly mean of the daily average water temperature for August between Chief Joseph tailrace and Wells forebay was 0.13^{o}C with a range of -0.2 to 0.49^{o}C. The reservoir showed essentially no vertical temperature stratification. The only site to show even weak vertical temperature stratification was the Okanogan River near its mouth for July and August.

All surface water measurements had dissolved oxygen (DO) values greater than 8.0 mg/L, which is the water quality criteria (WAC 173-201A as amended July 1, 2003) for dissolved oxygen levels within non-core salmonid rearing waters. DO levels at 1m depth increased from upriver to downriver; the average difference (May through October) was 1.07 mg/L. The difference was more pronounced during May through August. The difference in September and October was only 0.3 mg/L, which is similar to instrument reliability. The DO at the surface within the littoral sites was similar to or slightly higher than the DO for surface waters at pelagic sites.

Average Secchi depth for the Wells Project varied minimally during May through August with only a slight increase as the season progressed (range 4.1 m to 4.5 m). Secchi depth (transparency) increased to a seasonal peak in September of 6.25 m before slightly decreasing in October to a mean depth of 5.3 m. Water transparency in the lower Okanogan River gradually increased to peak in September at 2.7 m. Transparency for the Methow River varied between 1.3 m (August) and 3.2 m (September). The reduced water transparency in August is likely due to phytoplankton growth in the backwater of the Methow River. The only turbidity reading over 5 NTU was in the Methow River during May.

The pH for Project waters generally varied between 7.5 and 8.25, which is slightly above neutral. pH in the tributaries and littoral waters was slightly higher than pelagic waters. pH was vertically homogeneous for all months at all sampling

Total suspended solids (TSS) in the Wells Project were near or below detection limits for all months. Total suspended solids in the Methow River were highest in May (7.2 mg/L) and subsequently at or below detection limits. Total suspended solids in the Okanogan River were also highest in May (16.5 mg/L), decreased during the summer and then rose slightly in September and October. Low suspended solids in the Wells Reservoir are typical of this reach of the Columbia River and are a result of the large upstream storage reservoir capacity where solids settle out

Ammonia levels were near or below detection levels ($\leq$10μg/L) for pelagic and littoral reservoir waters as well as the Okanogan River for May through August and only slightly higher in September and October. There was not an appreciable accumulation of ammonia for bottom waters due to respiration, which is expected since the entire reservoir water column is well oxygenated and not stratified

Total nitrogen (TN) levels for reservoir pelagic and littoral waters were similar and relatively constant during the spring, summer and fall. Total nitrogen levels in February 2006 were slightly higher. The highest total nitrogen levels were measured in the Methow River for August through October.

Orthophosphorus peaked for all stations in July. Orthophosphorus levels for pelagic and littoral waters were similar in all months except July when littoral orthophosphorus concentrations were significantly higher than in pelagic areas. Orthophosphorus levels in the Methow and Okanogan rivers were higher than in the reservoir; reservoir levels were below 10 μg/L. Orthophosphorus was partially depleted in the Okanogan River in August but concentrations in the Methow River remained stable.

Total phosphorus (TP) levels in pelagic surface waters ranged from below detection limits to 30.8 μg/L. Generally, total phosphorus levels for near bottom samples in the Wells Project did not differ significantly from surface waters.

The annual mean TN:TP ratios in the Wells Reservoir was 13.7 for the photic zone and 14.8 over all depths for samples from all depths. These values are barely within the suggested literature ranges for phosphorus limitation. The TN:TP ratios peaked in July with pelagic and littoral waters showing similar trends. A decreasing TN:TP ratio through the major part of the algae growing season is typical of moderate to low nutrient waters as algae assimilate available nutrients. The range in TN:TP ratios for the Wells Project was 2.5 to 30.8. The mean TN:TP ratio for pelagic waters during the study period was 12.45, which indicates a marginal phosphorus limitation and pronounced nitrogen limitation in the fall. The TN:TP ratios were higher in the Okanogan and Methow River tributaries relative to the mainstem Columbia within the Wells Project.

The TIN:TIP ratios suggest that inorganic phosphorus may not be limiting productivity during the growing season since ratios are below 10. The spring TIN:TIP ratios are higher for the Wells Project. Barica (1990) determined that spring-minima TIN:TIP ratios of 6:1 or less were the best indicator of nitrogen limitation despite seasonal TIN:TIP means as high as 20:1 and 30:1. A spring TIN:TIP ratio of 16.1 for pelagic waters in the Wells Project indicates that phosphorus is limiting. Only the Okanogan River had a TIN:TIP ratio for May in the range indicating a strong nitrogen limitation, even though strong phosphorus limitation was indicated in the Okanogan River based on TN:TP ratios.

Macronutrient ratios suggest that phosphorus is limiting primary productivity in the two major tributaries to Wells Reservoir and marginally limiting elsewhere within the Wells Project. Other factors including retention time and abiotic factors could be equally important for governing primary productivity.

Moderate to low chlorophyll *a* concentrations occurred throughout the sample period with peaks in July and October for Wells Project waters. Concentrations were lowest in August and also had the least variability among sites for the August sampling event. Pelagic and littoral waters were similar for chlorophyll *a* concentrations in most months except October when littoral sites reported twice as high *c*hlorophyll *a* levels. Variability for chlorophyll *a* concentration was greatest at the tailraces sites (Chief Joseph Dam and Wells Dam). In the Methow River, chlorophyll *a* was lowest in July. The Okanogan River showed a trend similar to littoral sites for chlorophyll *a* concentrations with a sharp peak in October.

Trophic Status Index (TSI) is an indication of the productivity of a lake based on Secchi depth, TP, TN and chlorophyll *a* concentrations for summer months (June through September). Mean TSI scores in the range of 40-50 are indicative of mestrophic condition. The Phytoplankton TSI score compares well with other TSI scores for the Wells Reservoir and again indicates that the Columbia River portion of the Wells Reservoir is oligo-mesotrophic. The backwater area in the Methow and Okanogan rivers within the Wells Reservoir are classified as mesotrophic based on phytoplankton biomass.

A total of 59 samples were analyzed for phytoplankton. One hundred and fifty-four taxa of phytoplankton were identified in these samples. Phytoplankton samples were dominated by diatoms for all months at all sites sampled with Cryptophyta (small unicellular flagellates) being secondary based on biovolume. Diatoms and Cryptophytes are both considered a good food source for the rest of the aquatic food web. Diatoms comprised 75% to 84% of the total phytoplankton biomass for the waters surrounding the Wells Project. Chlorophytes (Green algae) were sub-dominant in the tailrace but only a minor component elsewhere. Total phytoplankton biomass was relatively low for all pelagic and littoral sample sites.

In the Wells reservoir and tailrace, the monthly average total biomass for pelagic waters ranged from 137,667 μm^3/mL in October to 332,031 μm^3/mL in July. The monthly average total biomass for littoral waters ranged from 161,438 μm^3/mL in August to 433,388 μm^3/mL in October. The timing of peaks varied among all stations and peaks in biomass differed from peaks in density.

Phytoplankton biovolume was at a minimum in September for the Methow River with a very large spike in both biovolume and density occurring in August. An algae bloom composed of mostly diatoms, particularly *Acnanthes minutissima* occurred in the lower Methow River in August. Peak biomass (145,158 μm^3/mL) in August was an order of magnitude higher than in other months. Biovolume in the Okanogan River was at a minimum in July and highest in May and October. Density showed low variability between months.

Periphyton is the film of attached benthic algae, fungi, bacteria, and protozoans that grow on the substrate. Diatoms dominated periphyton communities in the Wells Project. Generally, periphyton within littoral habitat sites had greater biomass than in the tailrace of either Chief Joseph Dam or Wells Dam. An exception to this trend was the July sample for Wells Dam tailrace; robust periphyton growth (biovolume of approximately 1.5 billion μm^3/mL) occurred in the tailrace in July.

Copepoda were dominant in zooplankton density counts for all months for both pelagic sites and in samples collected from the lower Okanogan and Methow rivers. Although rotifer density is probably under-represented due to large mesh size of the net, rotifers were dominant within pelagic waters for May and September. Zooplankton density peaked in May. Zooplankton density in the Methow and Okanogan rivers rapidly declined from an average of 7,875/m^3 in May to 2,980/m^3 July and continued to decrease to a low of 1,280/m^3 in September. Zooplankton density rebounded slightly in February mostly due to an increased copepod density. The density of zooplankton in pelagic waters also sharply decreased between May and July. Pelagic zooplankton densities further decreased in September. The lowest zooplankton density for pelagic waters occurred in February.

Fecal coliform samples were collected for laboratory analysis from the two littoral habitat sites and the mouths of the Methow and Okanogan rivers during the May, August and October sampling events. All samples analyzed that were collected from the littoral habitat of the mainstem reported less than 1 fecal coliform/100 mL. The samples from the lower Methow also reported less than 1 fecal coliform/100 mL. The August and October samples from the

Okanogan River reported 23 and 36 coliform/100mL, respectively. None of the samples exceeded a value of 100 colonies /100 mL, which is a criteria for the State water quality standard.

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Appendix A

Calibration Protocol

QA/QC and Calibration Procedures for Hydrolab DataSonde

Dissolved Oxygen

1. Conduct modified winkler titration for surface water sample near the monitoring point.
2. Measure and record surface DO with hydrolab (mm/L and % Sat) at the point and time of the sample collection for Winkler analysis. Winkler value and hydrolab value should be within 0.3 mm/L.
3. Determine local barometric pressure.
4. Rinse dissolved oxygen probe.
5. Fill storage cup (Hydrolab should be inverted) to just below the O-ring of dissolved oxygen membrane.
6. Gently wipe any moisture on the dissolved oxygen membrane using KimWipes or Q-tips.
7. Put cap on storage cup and wait 5 minutes. This method is set-up so that the air surrounding the dissolved oxygen membrane is in a 100% humid environment and therefore will be in a 100% dissolved oxygen saturated environment.
8. After 5 minutes, record the hydrolab %saturation reading, which should be very close to 100% if instrument is in calibration.
9. While maintaining the hydrolab unit so the DO membrane stays dry within the air saturated calibration cup, enter in 100.0% dissolved oxygen saturation in the calibration menu. Record the subsequent %DO reading on the hydrolab main menu. If value differs by more than 0.5%; repeat calibration. If calibration fails, inspect and replace DO membrane. Let unit stand for at least 1 hr before resuming DO calibration.

pH

1. Record hydrolab pH value using the reference standard for 10.0 followed by the 7.0 standard. (Note: changes in temperature will change pH by 0.01-0.10, see container for details). If expected and measured values differ by more than 0.1 then proceed with replacing electrode solution, as necessary, and calibration.
2. Replace reference electrode solution if necessary. Reference solution needs to be replaced every 2-4 weeks in the integrated pH probe, versus 2-3 months for the stand-alone electrode.
3. The top surface of the reference electrode contains a “teflon junction” which allows for the pH reference solution to escape. Do not handle by this teflon junction.
4. Stand-alone version: Remove the reference electrode probe. Rinse and re-fill with new pH reference solution. Fill almost to the top of the probe and gently re-place onto Hydrolab. The excess reference solution will leak out the sides and the top of the teflon junction. This probe does not thread – and will be slightly “loose” in comparison to the other probes.
5. Integrated version: Using a small Philips screwdriver, remove teflon junction cap on reference electrode. Rinse and re-fill with new pH reference solution. Fill almost to the top of the probe and gently re-place onto Hydrolab. The excess reference solution will leak out the sides and the top of the teflon junction.
6. Depending upon local conditions, a 2-point calibration, rather than a 3-point calibration can be used.
7. Use pH=7, pH=10 for a 2-point, and pH=4, pH=7, and pH=10 for a 3-point calibration. (Note: changes in temperature will change pH by 0.01-0.10, see container for details).
8. Go to calibration menu. Starting with pH=7, submerge probes into buffer solution. Allow to equilibrate. Enter in calibration values (i.e. 4, 7 or 10), compensating for temperature as needed.
9. Rinse 1-2x prior to calibration with the appropriate buffer solution.

Total Dissolved Gas

1. Record local barometric pressure for nearest weather station and handheld digital barometer.
2. Inspect the membrane that is on the unit recently deployed for damage or internal moisture. If membrane is damaged; mark it accordingly and discard. Loosen the membrane and note if the hydrolab TDGP reading reports a quick drop in pressure. If no, then the membrane may be

damaged. Re-tighten the membrane and note if a pressure spike is reported followed by a gradual descent. If yes, then the membrane is good. If no, then the membrane may be damaged. Note the condition of the membrane on the calibration sheet under the post deployment notes.

3. Check readings for previously deployed unit before proceeding to re-calibrate. See Calibration form. Record hydrolab TDG reading at ambient (barometric pressure). Set up TDG probe to a pressure source (TDG membrane must be removed). Add 100 mm Hg of pressure. Accurately record coinciding pressure meter value (expected) and hydrolab TDG value (measured). Repeat at BP + 200 mmHg (Note: 200 mm Hg is equal to approximately 125% saturation). If expected and measured for any one of the post deployment checks (ambient BP; BP + 100 mmHg, or BP + 200) mmHg differ by more than 3 mmHg, then proceed to recalibrate Hydrolab. If expected and measured are $\leq$ 3 mmHg, simply attach new dry membrane, verify that the TDGP readings with the new membrane attached quickly spike upwards by approximately 100 mmHG or more followed by a gradual descent. If yes, the unit is ready for programming and deployment.

TDG Calibration

4. First calibrate to ambient barometric pressure without a membrane attached: barometric pressure = total dissolved gas pressure (Units = mm/Hg). With no membrane attached, the hydrolab should read within 2mmHG of the local barometric pressure. If not, calibrate the hydrolab to the exact local barometric pressure.
5. Set up TDG probe to pressure source (TDG membrane must be removed). Add 100 mm Hg of pressure. Calibrate hydrolab to the exact pressure meter reading. Repeat at BP + 200 mmHg (Note: 200 mm Hg is equal to approximately 125% saturation). If expected and measured for any one of the post deployment checks (ambient BP; BP + 100 mmHg, or BP + 200 mmHg) differ by more than 2 mmHg, repeat Hydrolab calibration.
6. Replace new dry membrane. Inspect hydrolab batteries for moisture or corrosion. If voltage (IBV) is less than 10.5, replace all the batteries prior to deploying.
7. Attach a dry membrane. The TDGP reading should spike upwards by at least a 100 mmHG followed by a gradual descent towards ambient pressure. If not, the new membrane may have a leak. Check for leaks. Dip probe into a solution of seltzer water. Readings should climb rapidly to 900-1000 mm Hg. If probe does not respond or responds slowly, there is a leak in the membrane. Membrane needs to be replaced.
8. Verify that calibration form is fully completed.
9. Program the hydrolab to record at ¼ hour (15 minute intervals).

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Conductivity

1. For a two-point calibration, fill storage cup with distilled water. Allow to equilibrate, unit should be reading 0.
2. Use a known conductivity standard that is the range of the sampling water. Rinse with standard, then fill storage cup with standard, and allow to equilibrate. Enter calibration value in the calibration menu if necessary.

Storage/Maintenance

Total Dissolved Gas

1. Gently clean dissolved gas membrane – rinse with water and scrub *softly* with a soft bristle tooth brush.
2. Gently wipe off excess water around probe. Replace probe with storage cap. TDG membrane needs to be stored dry!
3. Allow membrane to dry for 1-2 days and store in plastic container. For best results, replace with a clean dissolved gas membrane.

Conductivity

1. Gently clean conductivity probe with alcohol and Q-tips.

Dissolved Oxygen

Changing Membrane:

1. Position Hydrolab in a vice so that it is in a sturdy, upright position.
2. Remove O-ring and membrane. Rinse probe with distilled water. Fill probe with electrolyte solution, form a large meniscus on the probe.
3. Gently place dissolved oxygen membrane onto the top surface of the meniscus. Allow the membrane to gently fall over the probe so that no air bubbles are introduced into the solution. Handle membrane by the corners!
4. In one motion, fit the O-ring around the probe to keep the membrane in place. If done incorrectly, air bubbles will form under the surface of the membrane. If air bubbles form, re-do the procedure.
5. Allow membrane to sit on the Hydrolab for 24 hours before calibration. (Recommended by manufacturer--it is possible to do within 1-2 hours).

Cleaning:

1. Over long term use, the gold ring surrounding the probe may need to be sanded. Also check the "cathode" – the probe may become oxidized (very black in color) and a new probe may need to be ordered.

Long term storage:

1. Hydrolab recommends removing the electrolyte solution from the dissolved oxygen probe. Fill probe with distilled water and replace membrane.

pH

1. Clean bulb with alcohol and soft Q-tips. Do not use an abrasive scrubbing agent as you could scratch bulb.
2. pH probe needs to remain moist. Fill ¼ of storage cap with tap water (do not fill with distilled water!)

Slow probe response time is most likely due to a dirty or scratched pH probe or new reference electrode solution may be needed.

Calibration Data Sheet

Date: _____ Time: _____ Researchers: _____

Project:_____Site:_____ Hydrolab Instrument ID_____

.....

Download File Name: _____ Data Download Period: _____
Barometric Pressure: weather station _____mmHg
Mercury Barometer _____mHg
Handheld digital Barometer _____mmHg

.....

I Calibration readings post removal:.

Dissolved Oxygen: Damage/biofouling of membrane? Y N Membrane Replaced? Y N
Readings to be done before changing membranes or re-calibrating instrument
Surface water DO Winkler Method _____mg/L

Surface water hydrolab DO reading _____mg/L (do at time of winkler sample collection)

Air Calibration Procedure: Prior to Calibration DO _____ %
Next, Calibrate instrument to 100.0% air saturation
After Calibrating DO: _____ %

BP value entered at time of DO calibration _____ mmHg

.....

pH: Damage / bio-fouling of probe? Y N Reference Solutions Replaced? Y N

Readings for post deployment check before calibration:
Ref Stnd pH 10.00 Adjusted* (_____), Hydrolab pH _____ ,Temp._____(^{o}C) Difference _____

Ref Stnd pH 7.00 Adjusted*(_____), Hydrolab pH _____ , Temp.____ (^{o}C) Difference _____
If instrument reading differs by more than 0.1 then do 2-point calibration

Calibration: pH 7 ( )*, Hydrolab pH _____ , Temp._____ (^{o}C)

pH 10( )*, Hydrolab pH _____ , Temp._____ (^{o}C)

***Enter solution value adjusted for temp. in ( )**

.....

Notes:

_____

_____

_____

_____

Project _____ Date _____ Site _____ P ____ of ____

Total Dissolved Gas: Local Barometric Pressure (e.g. handheld) _____mmHg Time _____

Procedures upon instrument removal and/or Prior to Calibration:
Inspect membrane for damage or internal moisture, Yes _____ No _____
Loosen membrane: Does pressure immediately drop? Yes _____ No _____
Re-tighten membrane: Does pressure spike upwards followed by slow decline Yes _____ No _____
If membrane suspected, complete Seltzer Water Test and note max TDGP: _____ mmHg
Old membrane (post deployment) Circle one Passed Failed
Post Deployment Hydrolab TDG Ambient BP expected/measured _____/_____mmHg

BP + 100.0 expected/measured _____/_____mmHg

BP + 200.0: expected/measured _____/_____mmHg

If post deployment expected and measured differ by more than 3 mmHg do 2 point calibration
Put new dry membrane on and proceed to calibrate

Pre-Deployment Hydrolab TDG Ambient BP expected/measured _____/_____mmHg

BP + 100.0 expected/measured _____/_____mmHg

BP + 200.0: expected/measured _____/_____mmHg

Calibrate unit and then note instrument reading. Repeat calibration if expected measured differ > 2 mmHg

Attach dry membrane; Does TDGP quickly spike by at least 100 mmHG followed by slow decline , Yes __ No __
Complete Seltzer Water Test and note max TDGP: _____ mmHg
New membrane passed QAQC Yes _____ No _____
Carefully attach sensor guard and check TDGP reading to ensure membrane was not nicked.

If Hydrolab Depth reading out of water □ 0.0 m; recalibrate to depth 0.0 Yes _____ No _____

Comments:_____
_____
_____

Appendix B

Reservoir Water Quality Profile Data

Site Code	Site Name	Date	Time	Sample Depth (m)	Temperature (C)	pH	Dissolved Oxygen (mg/L)	% Dissolved Oxygen Saturation	Sp. Conductance (uS/cm)	ORP
										418.0
Wells 01	Forebay	5/17/2005	12:25	1.0	10.34	7.70	13.31		0.1309	
Wells 01	Forebay	5/17/2005		2.0	10.37	7.09	13.31		0.1309	274.0
Wells 01	Forebay	5/17/2005		3.0	10.30	7.84	12.72	117.1	0.1306	273.0
Wells 01	Forebay	5/17/2005		4.0	10.27	7.85	12.12	112.0	0.1311	273.0
Wells 01	Forebay	5/17/2005		5.0	10.29	7.85	12.23	112.6	0.1307	273.0
Wells 01	Forebay	5/17/2005		6.0	10.29	7.85	12.26	112.8	0.1312	272.0
Wells 01	Forebay	5/17/2005		7.0	10.29	7.85	12.30	113.2	0.1309	272.0
Wells 01	Forebay	5/17/2005		8.0	10.28	7.85	12.29	113.1	0.1310	272.0
Wells 01	Forebay	5/17/2005		9.0	10.28	7.85	12.28	113.0	0.1316	272.0
Wells 02	Starr Launch	5/17/2005	14:20	1.0	11.61	7.88	10.20		0.1304	255.0
Wells 02	Starr Launch	5/17/2005		2.0	11.58	7.79	10.40			255.0
Wells 02	Starr Launch	5/17/2005		2.3	11.50	7.78	10.20		0.1289	255.0
Wells 03	Methow Mouth	5/17/2005	16:25	0.5	10.89	7.90	10.76	100.10	0.0648	254.0
Wells 03	Methow Mouth	5/17/2005		1.0	10.87	7.87	10.38	96.40	0.0647	253.0
Wells 03	Methow Mouth	5/17/2005		2.0	10.86	7.81	10.44	97.50	0.0651	254.0
Wells 03	Methow Mouth	5/17/2005		3.0	10.85	7.80	10.35	96.40	0.1	255.0
Wells 03	Methow Mouth	5/17/2005	16:40	3.5	10.56	7.80	10.22	95.50	0.0651	256.0

Site Code	Site Name	Date	Time	Sample Depth (m)	Temperature (C)	pH	Dissolved Oxygen (mg/L)	% Dissolved Oxygen Saturation	Sp. Conductance (uS/cm)	ORP
Wells 04	Bewster Bridge	5/18/2005	9:00	1.0	10.62	7.89	11.16	104.6	0.1298	283.0
Wells 04	Bewster Bridge	5/18/2005		2.0	10.65	7.85	10.97	103.0	0.1305	271.0
Wells 04	Bewster Bridge	5/15/2005	9:03	3.0	10.55	7.84	10.94	102.2	0.1315	267.0
Wells 04	Bewster Bridge	5/15/2005	9:04	4.0	10.49	7.84	10.93	102.2	0.1312	264.0
Wells 04	Bewster Bridge	5/15/2005		5.0	10.41	7.83	10.97	102.4	0.1313	261.0
Wells 04	Bewster Bridge	5/15/2005		6.0	10.38	7.83	10.97	102.3	0.1319	260.0
Wells 04	Bewster Bridge	5/15/2005		7.0	10.19	7.83	10.97	101.7	0.1320	258.0
Wells 04	Bewster Bridge	5/15/2005	9:09	8.0	10.10	7.82	10.96	101.9	0.1317	258.0
Wells 04	Bewster Bridge	5/15/2005		9.0	9.96	7.82	11.00	101.5	0.1324	257.0
Wells 04	Bewster Bridge	5/15/2005		10.0	9.98	7.82	11.01	101.6	0.1327	257.0
Wells 04	Bewster Bridge	5/15/2005		11.0	9.97	7.82	10.99	101.7	0.1326	256.0
Wells 04	Bewster Bridge	5/15/2005		12.0	9.92	7.81	10.99	101.6	0.1327	256.0
Wells 04	Bewster Bridge	5/15/2005	9:13	13.0	9.91	7.81	11.00	101.3	0.1327	256.0
Wells 04	Bewster Bridge	5/15/2005		14.0	9.89	7.82	10.99	101.4	0.1329	255.0
Wells 04	Bewster Bridge	5/15/2005		15.0	9.88	7.82	11.00	101.3	0.1327	255.0
Wells 04	Bewster Bridge	5/15/2005	9:14	17.0	9.88	7.82	10.97	101.2	0.1324	254.0
Wells 05	Okanogan	5/18/2005	9:50	1.0	14.27	7.80	9.73	99.2	0.1251	282.0
Wells 05	Okanogan	5/18/2005		2.0	14.28	7.77	9.68	98.9	0.1252	280.0
Wells 05	Okanogan	5/18/2005	9:54	3.0	14.29	7.76	9.70	98.9	0.1253	276.0
Wells 05	Okanogan	5/18/2005		4.0	14.28	7.75	9.70	98.9	0.1249	274.0
Wells 05	Okanogan	5/18/2005	9:56	5.0	14.28	7.74	9.75	99.4	0.1256	272.0
Wells 05	Okanogan	5/18/2005		6.0	14.28	7.73	9.73	99.1	0.1257	270.0
Wells 05	Okanogan	5/18/2005		7.0	14.27	7.73	9.08	92.5	0.1258	266.0
Wells 05	Okanogan	5/18/2005	10:01	8.0	14.26	7.73	9.07	92.5	0.1256	265.0
Wells 05	Okanogan	5/18/2005	10:04	8.7	14.26	7.73	9.08	92.5	0.1253	263.0
Wells 6	Bridgeport Bar	5/18/2005	10:38	0.5	9.81	7.89	11.41	105.1	0.1324	277.0
Wells 06	Bridgeport Bar	5/18/2005		1.0	9.81	7.89	11.19	103.9	0.1319	274.0

Site Code	Site Name	Date	Time	Sample Depth (m)	Temperature (C)	pH	Dissolved Oxygen (mg/L)	% Dissolved Oxygen Saturation	Sp. Conductance (uS/cm)	ORP
Wells 07	Bridgeport Bridge	5/18/2005	11:55	1.0	9.89	7.91	10.89	104.0	0.1320	283.0
Wells 07	Bridgeport Bridge	5/18/2005		2.0	9.89	7.88	11.07	102.2	0.1322	282.0
Wells 07	Bridgeport Bridge	5/18/2005		3.0	9.88	7.87	11.09	102.4	0.1327	281.0
Wells 07	Bridgeport Bridge	5/18/2005		4.0	9.89	7.86	11.05	101.9	0.1326	281.0
Wells 07	Bridgeport Bridge	5/18/2005		5.0	9.88	7.86	11.03	101.9	0.1327	280.0
Wells 07	Bridgeport Bridge	5/18/2005		6.0	9.89	7.85	10.86	100.6	0.1322	280.0
Wells 01	Forebay	7/13/2005	8:05	1.0	16.11	8.00	10.89	132.9	0.1287	357.0
Wells 01	Forebay	7/13/2005		2.0	16.09	8.01	10.82	131.9	0.1289	360.0
Wells 01	Forebay	7/13/2005		3.0	16.08	8.02	10.80	131.8	0.1290	364.0
Wells 01	Forebay	7/13/2005		4.0	16.08	8.03	10.77	131.4	0.1290	368.0
Wells 01	Forebay	7/13/2005		5.0	16.08	8.03	10.77	131.5	0.1294	370.0
Wells 01	Forebay	7/13/2005		6.0	16.07	8.04	10.75	131.1	0.1294	373.0
Wells 01	Forebay	7/13/2005		7.0	16.08	8.04	10.74	131.1	0.1291	375.0
Wells 01	Forebay	7/13/2005		8.0	16.07	8.04	10.73	130.9	0.1293	377.0
Wells 01	Forebay	7/13/2005		9.0	16.08	8.04	10.69	130.3	0.1291	378.0
Wells 01	Forebay	7/13/2005		10.0	16.08	8.04	10.72	130.8	0.1286	380.0
Wells 01	Forebay	7/13/2005		11.0	16.07	8.04	10.69	130.4	0.1291	381.0
Wells 01	Forebay	7/13/2005		12.0	16.07	8.04	10.68	130.2	0.1291	382.0
Wells 01	Forebay	7/13/2005		13.0	16.07	8.04	10.68	130.2	0.1286	383.0
Wells 01	Forebay	7/13/2005		14.0	16.07	8.05	10.65	130.0	0.1286	384.0
Wells 01	Forebay	7/13/2005		15.0	16.07	8.05	10.65	129.9	0.1291	385.0
Wells 02	Starr	7/13/2005	9:11	0.5	16.47	8.21	10.82	133.0	0.1283	394.0
Wells 02	Starr	7/13/2005		1.0	16.45	8.22	10.39	127.7	0.1289	394.0
Wells 03	Methow	7/12/2005	14:15	1.0	18.79	8.09	9.26	119.1	0.1231	403.0
Wells 03	Methow	7/12/2005		2.0	18.40	8.07	9.25	118.5	0.1249	403.0
Wells 03	Methow	7/12/2005		3.0	18.22	8.07	8.86	113.4	0.1246	403.0

Site Code	Site Name	Date	Time	Sample Depth (m)	Temperature (C)	pH	Dissolved Oxygen (mg/L)	% Dissolved Oxygen Saturation	Sp. Conductance (uS/cm)	ORP
Wells 04	Brewster Bridge	7/12/2005		1.0	15.94	7.96	9.88	119.6	0.1318	339.0
Wells 04	Brewster Bridge	7/12/2005	9:28	2.0	15.84	7.95	9.81	119.2	0.1306	343.0
Wells 04	Brewster Bridge	7/12/2005		3.0	15.83	7.95	9.78	118.7	0.1312	346.0
Wells 04	Brewster Bridge	7/12/2005		4.0	15.85	7.95	9.75	118.2	0.1320	349.0
Wells 04	Brewster Bridge	7/12/2005		5.0	15.84	7.93	9.72	118.2	0.1316	351.0
Wells 04	Brewster Bridge	7/12/2005		6.0	15.84	7.96	9.72	118.0	0.1317	353.0
Wells 04	Brewster Bridge	7/12/2005		7.0	15.81	7.93	9.70	117.8	0.1311	355.0
Wells 04	Brewster Bridge	7/12/2005		8.0	15.85	7.96	9.70	117.8	0.1319	357.0
Wells 04	Brewster Bridge	7/12/2005	9:35	9.0	15.80	7.96	9.70	117.9	0.1318	358.0
Wells 04	Brewster Bridge	7/12/2005		10.0	15.80	7.96	9.71	117.8	0.1311	360.0
Wells 04	Brewster Bridge	7/12/2005		11.0	15.79	7.96	9.68	117.5	0.1311	361.0
Wells 04	Brewster Bridge	7/12/2005		12.0	15.79	7.95	9.67	117.2	0.1307	362.0
Wells 04	Brewster Bridge	7/12/2005		13.0	15.69	7.95	9.68	116.9	0.1308	363.0
Wells 04	Brewster Bridge	7/12/2005		14.0	15.63	7.94	9.67	116.8	0.1311	365.0
Wells 04	Brewster Bridge	7/12/2005		15.0	15.63	7.94	9.64	116.9	0.1294	366.0
Wells 04	Brewster Bridge	7/12/2005		17.0	15.61	7.93	9.63	116.3	0.1289	367.0
Wells 04	Brewster Bridge	7/12/2005		19.0	15.66	7.94	9.62	116.2	0.1295	368.0
Wells 04	Brewster Bridge	7/12/2005	9:41	21.0	15.61	7.94	9.62	116.5	0.1272	370.0
Wells 05	Okanogan River	7/12/2005	10:36	1.0	21.25	8.25	8.68	118.6	0.1930	348.0
Wells 05	Okanogan River	7/12/2005		2.0	20.28	8.25	8.90	119.3	0.1822	360.0
Wells 05	Okanogan River	7/12/2005		3.0	20.05	8.26	8.55	112.9	0.1788	367.0
Wells 05	Okanogan River	7/12/2005	10:40	4.0	19.51	8.27	8.87	115.5	0.1693	371.0
Wells 05	Okanogan River	7/12/2005		5.0	18.72	8.27	9.18	118.5	0.1607	376.0
Wells 05	Okanogan River	7/12/2005		6.0	18.49	8.26	9.14	117.3	0.1574	380.0
Wells 05	Okanogan River	7/12/2005	10:43	7.0	18.22	8.26	9.04	115.5	0.1555	382.0
Wells 05	Okanogan River	7/12/2005		8.0	18.00	8.23	9.17	116.4	0.1514	384.0
Wells 05	Okanogan River	7/12/2005		9.0	17.57	8.19	9.14	114.7	0.1470	386.0
Wells 06	Bridgeport Shallows	7/12/2005		1.0	16.15	8.11	10.31	126.70	0.1265	398.0
Wells 06	Bridgeport Shallows	7/12/2005		2.0	16.05	8.07	10.15	123.60	0.1279	399.0

Site Code	Site Name	Date	Time	Sample Depth (m)	Temperature (C)	pH	Dissolved Oxygen (mg/L)	% Dissolved Oxygen Saturation	Sp. Conductance (uS/cm)	ORP
Wells 07	CJ Tailrace	7/12/2005	12:04	1.0	15.82	7.95	9.68	118.7	0.1273	364.0
Wells 07	CJ Tailrace	7/12/2005		2.0	15.81	7.92	9.67	117.4	0.1282	365.0
Wells 07	CJ Tailrace	7/12/2005		3.0	15.79	7.92	9.30	112.9	0.1280	368.0
Wells 09	Above Starr Launch	7/12/2005	15:50	1.0	16.02	7.87	9.44	114.9	0.1300	410.0
Wells 09	Above Starr Launch	7/12/2005		2.0	16.03	7.89	9.35	114.0	0.1302	407.0
Wells 09	Above Starr Launch	7/12/2005		3.0	16.03	7.90	9.42	114.8	0.1304	407.0
Wells 09	Above Starr Launch	7/12/2005	15:55	4.0	16.02	7.90	9.30	113.4	0.1306	406.0
Wells 09	Above Starr Launch	7/12/2005		5.0	16.02	7.91	9.24	112.5	0.1302	407.0
Wells 09	Above Starr Launch	7/12/2005		6.0	16.00	7.92	9.39	114.5	0.1300	407.0
Wells 09	Above Starr Launch	7/12/2005		7.0	16.02	7.93	9.29	113.3	0.1299	407.0
Wells 09	Above Starr Launch	7/12/2005		8.0	16.02	7.95	9.47	115.4	0.1298	408.0
Wells 09	Above Starr Launch	7/12/2005		9.0	16.01	7.95	9.49	115.7	0.1303	408.0
Wells 09	Above Starr Launch	7/12/2005		10.0	16.04	7.95	9.47	115.6	0.1306	409.0
Wells 09	Above Starr Launch	7/12/2005		11.0	16.02	7.95	9.47	115.4	0.1304	408.0
Wells 09	Above Starr Launch	7/12/2005	14:05	12.0	16.03	7.95	9.43	115.0	0.1303	409.0
Wells 09	Above Starr Launch	7/12/2005		13.0	16.00	7.97	9.57	116.6	0.1295	409.0
Wells 09	Above Starr Launch	7/12/2005		14.0	16.02	7.97	9.53	116.2	0.1306	409.0
Wells 09	Above Starr Launch	7/12/2005		15.0	16.04	7.97	9.51	116.1	0.1306	409.0
Wells 09	Above Starr Launch	7/12/2005		17.0	16.03	7.97	9.50	116.0	0.1310	409.0
Wells 09	Above Starr Launch	7/12/2005		19.0	16.03	7.98	9.48	115.6	0.1311	409.0
Wells 09	Above Starr Launch	7/12/2005		21.0	16.02	7.98	9.48	115.7	0.1310	410.0

Site Code	Site Name	Date	Time	Sample Depth (m)	Temperature (C)	pH	Dissolved Oxygen (mg/L)	% Dissolved Oxygen Saturation	Sp. Conductance (uS/cm)	ORP
Wells 01	Forebay	8/17/2005	9:26	1.0	19.21	7.69	10.24	113.5	0.1015	339.0
Wells 01	Forebay	8/17/2005		2.0	19.20	7.72	10.14	112.8	0.1018	342.0
Wells 01	Forebay	8/17/2005		3.0	19.17	7.75	10.05	111.7	0.1016	342.0
Wells 01	Forebay	8/17/2005		4.0	19.18	7.77	9.88	110.0	0.1018	343.0
Wells 01	Forebay	8/17/2005	9:29	5.0	19.16	7.80	9.88	109.5	0.1014	343.0
Wells 01	Forebay	8/17/2005		6.0	19.16	7.81	9.82	109.1	0.1015	344.0
Wells 01	Forebay	8/17/2005		7.0	19.15	7.82	9.83	109.2	0.1015	344.0
Wells 01	Forebay	8/17/2005		8.0	19.15	7.83	9.82	109.1	0.1014	345.0
Wells 01	Forebay	8/17/2005		9.0	19.15	7.83	9.80	108.8	0.1018	346.0
Wells 01	Forebay	8/17/2005		10.0	19.15	7.85	9.78	108.7	0.1016	346.0
Wells 01	Forebay	8/17/2005		11.0	19.15	7.85	9.75	108.4	0.1014	347.0
Wells 01	Forebay	8/17/2005	9:35	12.0	19.15	7.85	9.79	108.9	0.1018	348.0
Wells 01	Forebay	8/17/2005		13.0	19.15	7.86	9.77	108.6	0.1017	349.0
Wells 01	Forebay	8/17/2005		14.0	19.15	7.87	9.80	109.0	0.1014	349.0
Wells 01	Forebay	8/17/2005		15.0	19.14	7.87	9.74	108.1	0.1014	350.0
Wells 01	Forebay	8/17/2005	9:35	16.0	19.14	7.88	9.70	108.2	0.1014	350.0
Wells 02	at Starr Boat Launch	8/17/2005	10:07	1.0	19.89	7.97	9.82	110.8	0.1019	362.0
Wells 02	at Starr Boat Launch	8/17/2005		2.0	19.85	7.96	9.79	109.7	0.1019	366.0
Wells 03	Methow Mouth	8/17/2005	12:02	1.0	21.88	7.92	8.13	95.1	0.1357	315.0
Wells 03	Methow Mouth	8/17/2005		2.0	21.80	7.89	7.95	93.2	0.1370	323.0
Wells 03	Methow Mouth	8/17/2005	10:06	3.0	21.49	7.87	7.38	86.1	0.1380	325.0

Site Code	Site Name	Date	Time	Sample Depth (m)	Temperature (C)	pH	Dissolved Oxygen (mg/L)	% Dissolved Oxygen Saturation	Sp. Conductance (uS/cm)	ORP
Wells 04	Brewster Bridge	8/17/2005	12:49	1.0	18.72	7.64	9.97	109.1	0.1011	325.0
Wells 04	Brewster Bridge	8/17/2005		2.0	18.70	7.63	9.87	108.5	0.1008	326.0
Wells 04	Brewster Bridge	8/17/2005		3.0	18.67	7.63	9.81	108.0	0.1009	326.0
Wells 04	Brewster Bridge	8/17/2005		4.0	18.69	7.64	9.80	107.9	0.1012	327.0
Wells 04	Brewster Bridge	8/17/2005		5.0	18.70	7.65	9.77	107.0	0.1012	327.0
Wells 04	Brewster Bridge	8/17/2005		6.0	18.68	7.65	9.76	107.6	0.1011	327.0
Wells 04	Brewster Bridge	8/17/2005		7.0	18.68	7.66	9.75	107.3	0.1012	328.0
Wells 04	Brewster Bridge	8/17/2005		8.0	18.70	7.67	9.72	107.0	0.1012	329.0
Wells 04	Brewster Bridge	8/17/2005		9.0	18.69	7.67	9.70	107.1	0.1012	329.0
Wells 04	Brewster Bridge	8/17/2005		10.0	18.69	7.68	9.71	106.9	0.1014	329.0
Wells 04	Brewster Bridge	8/17/2005		11.0	18.68	7.68	9.69	106.9	0.1012	330.0
Wells 04	Brewster Bridge	8/17/2005		12.0	18.69	7.69	9.65	106.6	0.1011	331.0
Wells 04	Brewster Bridge	8/17/2005	12:55	13.0	18.68	7.69	9.66	106.5	0.1012	332.0
Wells 04	Brewster Bridge	8/17/2005		14.0	18.64	7.70	9.69	106.9	0.1012	332.0
Wells 04	Brewster Bridge	8/17/2005		15.0	18.66	7.71	9.66	106.8	0.1008	333.0
Wells 04	Brewster Bridge	8/17/2005		17.0	18.62	7.71	9.67	106.5	0.1012	334.0
Wells 04	Brewster Bridge	8/17/2005		19.0	18.60	7.72	9.67	106.3	0.1010	334.0
Wells 05	Okanogan Mouth	8/17/2005	13:25	1.0	22.46	8.07	9.39	111.3	0.1704	309.0
Wells 05	Okanogan Mouth	8/17/2005		2.0	21.92	8.04	9.31	108.9	0.1576	316.0
Wells 05	Okanogan Mouth	8/17/2005	13:28	3.0	20.97	7.97	9.11	105.1	0.1396	319.0
Wells 05	Okanogan Mouth	8/17/2005		4.0	20.59	7.95	9.04	102.8	0.1262	321.0
Wells 05	Okanogan Mouth	8/17/2005		5.0	20.06	7.89	8.76	99.2	0.1186	322.0
Wells 05	Okanogan Mouth	8/17/2005	13:31	6.0	19.85	7.86	8.32	93.4	0.1176	324.0
Wells 05	Okanogan Mouth	8/17/2005		7.0	19.65	7.84	8.34	94.1	0.1144	326.0
Wells 05	Okanogan Mouth	8/17/2005		8.0	19.45	7.81	8.66	96.9	0.1117	328.0
Wells 06	at Bridgeport Shallov	8/17/2005	14:00	1.0	18.84	8.87	10.08	111.2	0.1005	309.0
Wells 07	Chief Joe Tailrace	8/17/2005	14:50	1.0	19.15	7.77	9.30	103.3	0.1005	353.0
Wells 07	Chief Joe Tailrace	8/17/2005		2.0	19.10	7.73	9.35	104.0	0.1013	354.0
Wells 07	Chief Joe Tailrace	8/17/2005	14:54	3.0	19.11	7.72	9.34	103.6	0.1012	355.0

Site Code	Site Name	Date	Time	Sample Depth (m)	Temperature (C)	pH	Dissolved Oxygen (mg/L)	% Dissolved Oxygen Saturation	Sp. Conductance (uS/cm)	ORP
Wells 08	Tailrace @ Wells	8/17/2005	8:00	1.0	18.78	7.71	10.01	110.1	0.1031	385.0
Wells 09	Between Starr & Pate	8/17/2005	10:30	1.0	19.19	7.86	10.10	111.1	0.1018	362.0
Wells 09	Between Starr & Pate	8/17/2005		2.0	19.19	7.84	9.97	110.9	0.1013	364.0
Wells 09	Between Starr & Pate	8/17/2005		3.0	19.19	7.83	9.92	110.4	0.1013	365.0
Wells 09	Between Starr & Pate	8/17/2005	10:31	4.0	19.19	7.83	9.90	110.3	0.1013	366.0
Wells 09	Between Starr & Pate	8/17/2005		5.0	19.19	7.84	9.87	109.7	0.1016	366.0
Wells 09	Between Starr & Pate	8/17/2005		6.0	19.19	7.84	9.80	109.0	0.1015	366.0
Wells 09	Between Starr & Pate	8/17/2005		7.0	19.19	7.84	9.80	109.0	0.1015	367.0
Wells 09	Between Starr & Pate	8/17/2005	10:33	8.0	19.19	7.85	9.82	109.7	0.1015	367.0
Wells 09	Between Starr & Pate	8/17/2005		9.0	19.19	7.85	9.95	110.3	0.1016	368.0
Wells 09	Between Starr & Pate	8/17/2005		10.0	19.19	7.86	9.92	110.5	0.1016	368.0
Wells 09	Between Starr & Pate	8/17/2005		11.0	19.20	7.86	9.80	109.0	0.1016	368.0
Wells 09	Between Starr & Pate	8/17/2005		12.0	19.19	7.86	9.80	108.7	0.1015	369.0
Wells 09	Between Starr & Pate	8/17/2005		13.0	19.19	7.86	9.70	107.8	0.1015	369.0
Wells 09	Between Starr & Pate	8/17/2005	10:37	14.0	19.19	7.87	9.76	108.6	0.1011	370.0
Wells 09	Between Starr & Pate	8/17/2005		15.0	19.19	7.87	9.80	109.0	0.1015	370.0
Wells 09	Between Starr & Pate	8/17/2005		17.0	19.19	7.87	9.72	108.3	0.1009	371.0
Wells 09	Between Starr & Pate	8/17/2005		19.0	19.19	7.87	9.69	107.6	0.1014	371.0
Wells 09	Between Starr & Pate	8/17/2005	10:40	21.0	19.19	7.88	9.54	106.1	0.1013	371.0

Site Code	Site Name	Date	Time	Sample Depth (m)	Temperature (C)	pH	Dissolved Oxygen (mg/L)	% Dissolved Oxygen Saturation	Sp. Conductance (uS/cm)	ORP
Wells 01	Forebay	9/7/2005	14:45	1.0	19.22	7.84	9.04	106.5	0.1008	354.0
Wells 01	Forebay	9/7/2005		2.0	19.20	7.85	9.01	105.9	0.1008	355.0
Wells 01	Forebay	9/7/2005	14:48	3.0	19.16	7.83	9.10	107.2	0.1005	357.0
Wells 01	Forebay	9/7/2005		4.0	19.17	7.83	9.11	107.0	0.1008	358.0
Wells 01	Forebay	9/7/2005		5.0	19.14	7.83	9.11	106.8	0.1009	361.0
Wells 01	Forebay	9/7/2005		6.0	19.12	7.82	9.05	106.3	0.1009	362.0
Wells 01	Forebay	9/7/2005		7.0	19.13	7.82	9.03	105.9	0.1007	363.0
Wells 01	Forebay	9/7/2005	14:50	8.0	19.12	7.83	8.97	105.3	0.1011	363.0
Wells 01	Forebay	9/7/2005		9.0	19.12	7.83	8.90	104.6	0.1009	366.0
Wells 01	Forebay	9/7/2005		10.0	19.12	7.83	8.93	104.7	0.1005	367.0
Wells 01	Forebay	9/7/2005		11.0	19.13	7.83	8.95	105.0	0.1006	368.0
Wells 01	Forebay	9/7/2005		12.0	19.11	7.83	8.94	104.9	0.1006	369.0
Wells 01	Forebay	9/7/2005		13.0	19.11	7.82	8.92	104.8	0.1009	371.0
Wells 01	Forebay	9/7/2005		14.0	19.12	7.82	8.95	105.2	0.1007	371.0
Wells 01	Forebay	9/7/2005		15.0	19.11	7.82	8.93	104.8	0.1005	372.0
Wells 01	Forebay	9/7/2005	14:59	16.0	19.11	7.83	8.92	104.7	0.1009	373.0
Wells 02	Starr Launch	9/7/2005	15:11	1.0	20.63	8.29	10.10	122.0	0.1004	380.0
Wells 02	Starr Launch	9/7/2005		1.5	20.25	8.34	10.25	123.1	0.1004	378.0
Wells 03	Methow River Mouth	9/7/2005	16:33	1.6	18.82	8.06	9.66	113.10	0.1190	405.0
Wells 03	Methow River Mouth	9/7/2005		2.0	18.79	8.04	9.71	113.00	0.1231	405.0
Wells 03	Methow River Mouth	9/7/2005		3.0	17.31	8.14	9.92	111.70	0.1278	404.0

Site Code	Site Name	Date	Time	Sample Depth (m)	Temperature (C)	pH	Dissolved Oxygen (mg/L)	% Dissolved Oxygen Saturation	Sp. Conductance (uS/cm)	ORP
Wells 04	Brewster Bridge	9/8/2005	8:30	1.0	19.12	7.89	9.11	106.8	0.0993	396.0
Wells 04	Brewster Bridge	9/8/2005		2.0	19.12	7.92	9.09	106.6	0.0993	398.0
Wells 04	Brewster Bridge	9/8/2005		3.0	19.12	7.90	9.01	105.6	0.0993	399.0
Wells 04	Brewster Bridge	9/8/2005	8:35	4.0	19.12	7.90	9.02	105.9	0.0991	400.0
Wells 04	Brewster Bridge	9/8/2005		5.0	19.12	7.90	9.01	105.7	0.0991	400.0
Wells 04	Brewster Bridge	9/8/2005		6.0	19.12	7.91	9.04	106.1	0.0993	401.0
Wells 04	Brewster Bridge	9/8/2005		7.0	19.12	7.84	8.94	104.9	0.0997	403.0
Wells 04	Brewster Bridge	9/8/2005		8.0	19.10	7.91	9.03	106.0	0.0993	402.0
Wells 04	Brewster Bridge	9/8/2005		9.0	19.11	7.93	9.10	106.8	0.0998	403.0
Wells 04	Brewster Bridge	9/8/2005		10.0	19.08	7.89	8.99	105.3	0.0996	405.0
Wells 04	Brewster Bridge	9/8/2005	8:40	11.0	19.09	7.89	9.04	106.0	0.0997	406.0
Wells 04	Brewster Bridge	9/8/2005		12.0	19.10	7.89	9.01	105.7	0.1001	406.0
Wells 04	Brewster Bridge	9/8/2005		13.0	19.09	7.87	8.94	104.8	0.1002	408.0
Wells 04	Brewster Bridge	9/8/2005		14.0	19.09	7.87	8.92	104.6	0.1000	408.0
Wells 04	Brewster Bridge	9/8/2005		15.0	19.09	7.87	8.85	103.6	0.0999	409.0
Wells 04	Brewster Bridge	9/8/2005		17.0	19.08	7.85	8.72	102.4	0.0997	410.0
Wells 04	Brewster Bridge	9/8/2005		19.0	19.08	7.85	8.63	101.4	0.0998	411.0
Wells 04	Brewster Bridge	9/8/2005	8:50	21.0	19.09	7.85	8.66	101.3	0.0996	411.0
Wellso 05	Okanogan	9/8/2005	10:35	1.0	19.64	8.81	9.04	107.2	0.1584	426.0
Wellso 05	Okanogan	9/8/2005		2.0	19.73	8.25	8.99	106.6	0.1667	425.0
Wellso 05	Okanogan	9/8/2005		3.0	19.71	8.25	9.06	107.8	0.1654	425.0
Wellso 05	Okanogan	9/8/2005		4.0	19.74	8.24	9.12	107.4	0.1670	426.0
Wellso 05	Okanogan	9/8/2005	10:40	5.0	19.65	8.20	8.95	105.4	0.1619	437.0
Wellso 05	Okanogan	9/8/2005		6.0	19.63	8.18	8.65	102.1	0.1564	429.0
Wellso 05	Okanogan	9/8/2005		7.0	19.61	8.17	8.87	104.3	0.1560	428.0
Wellso 05	Okanogan	9/8/2005	10:43	8.0	19.60	8.16	8.90	104.9	0.1537	430.0
Wellso 05	Okanogan	9/8/2005	10:44	9.0	19.61	8.16	8.91	105.4	0.1496	429.0
Wells 06	Bridgeport Shallows	9/8/2005	10:00	1.0	19.00	7.86	8.71	102.1	0.0995	415.0
Wells 06	Bridgeport Shallows	9/8/2005		1.8	19.00	7.90	8.69	101.5	0.0997	413.0

Site Code	Site Name	Date	Time	Sample Depth (m)	Temperature (C)	pH	Dissolved Oxygen (mg/L)	% Dissolved Oxygen Saturation	Sp. Conductance (uS/cm)	ORP
Wells 07	Chief Joe Tail Race	9/8/2005	9:25	1.0	18.97	7.83	8.74	102.2	0.1000	421.0
Wells 07	Chief Joe Tail Race	9/8/2005		2.0	18.97	7.81	8.67	101.8	0.1000	421.0
Wells 07	Chief Joe Tail Race	9/8/2005		3.0	18.98	7.79	8.71	101.9	0.1000	422.0
Wells 07	Chief Joe Tail Race	9/8/2005		4.0	18.98	7.78	8.66	101.5	0.1000	420.0
Wells 08		9/7/2005	13:00	1.5	19.51	7.51	8.90	101.7	0.1016	306.0
Wells 09	Wells Reservoir Thal	9/7/2005	15:40	1.0	19.31	7.89	9.21	108.5	0.1006	399.0
Wells 09	Wells Reservoir Thal	9/7/2005		2.0	19.25	7.88	9.10	106.6	0.1004	399.0
Wells 09	Wells Reservoir Thal	9/7/2005		3.0	19.24	7.89	9.07	107.3	0.1001	400.0
Wells 09	Wells Reservoir Thal	9/7/2005		4.0	19.28	7.89	9.14	107.5	0.1004	399.0
Wells 09	Wells Reservoir Thal	9/7/2005		5.0	19.00	7.88	9.03	106.4	0.1002	400.0
Wells 09	Wells Reservoir Thal	9/7/2005		6.0	19.26	7.88	9.13	107.3	0.1002	401.0
Wells 09	Wells Reservoir Thal	9/7/2005	15:45	7.0	19.24	7.88	9.05	106.5	0.0998	400.0
Wells 09	Wells Reservoir Thal	9/7/2005		8.0	19.25	7.90	8.95	105.6	0.0997	399.0
Wells 09	Wells Reservoir Thal	9/7/2005		9.0	19.27	7.88	8.91	104.9	0.1001	400.0
Wells 09	Wells Reservoir Thal	9/7/2005		10.0	19.25	7.88	8.92	104.9	0.0998	401.0
Wells 09	Wells Reservoir Thal	9/7/2005		11.0	19.25	7.88	8.92	105.1	0.1002	402.0
Wells 09	Wells Reservoir Thal	9/7/2005		12.0	19.25	7.85	8.93	104.8	0.1000	403.0
Wells 09	Wells Reservoir Thal	9/7/2005	15:49	13.0	19.21	7.84	8.90	104.6	0.0999	403.0
Wells 09	Wells Reservoir Thal	9/7/2005		14.0	19.15	7.85	8.80	103.0	0.0993	402.0
Wells 09	Wells Reservoir Thal	9/7/2005		15.0	19.16	7.85	8.69	102.0	0.0993	403.0
Wells 09	Wells Reservoir Thal	9/7/2005		17.0	19.17	7.86	8.82	103.4	0.0996	403.0
Wells 09	Wells Reservoir Thal	9/7/2005		19.0	19.19	7.87	8.77	104.5	0.9990	402.0
Wells 09	Wells Reservoir Thal	9/7/2005		21.0	19.19	7.86	8.92	103.1	0.0997	404.0
Wells 09	Wells Reservoir Thal	9/7/2005	16:00	23.0	19.20	7.82	8.88	104.4	0.0988	407.0
Wells 09	Wells Reservoir Thal	9/7/2005		25.0	19.12	7.84	8.89	104.3	0.0989	407.0
Wells 09	Wells Reservoir Thal	9/7/2005		27.0	19.11	7.84	8.84	103.6	0.0986	407.0
Wells 09	Wells Reservoir Thal	9/7/2005	16:05	29.0	19.11	7.83	8.77	102.8	0.0990	407.0

Site Code	Site Name	Date	Time	Sample Depth (m)	Temperature (C)	pH	Dissolved Oxygen (mg/L)	% Dissolved Oxygen Saturation	Sp. Conductance (uS/cm)	ORP
Wells 01	Forebay	10/17/2005		1.0	16.73	7.89	8.74	100.0	0.0946	450.0
Wells 01	Forebay	10/17/2005		2.0	16.73	7.90	8.60	98.4	0.0948	450.0
Wells 01	Forebay	10/17/2005		3.0	16.71	7.90	8.52	97.4	0.0946	452.0
Wells 01	Forebay	10/17/2005		4.0	16.71	7.89	8.46	96.8	0.0949	454.0
Wells 01	Forebay	10/17/2005		5.0	16.71	7.89	8.47	96.6	0.0945	455.0
Wells 01	Forebay	10/17/2005		6.0	16.72	7.89	8.45	96.7	0.0948	456.0
Wells 01	Forebay	10/17/2005		7.0	16.71	7.89	8.46	96.5	0.0943	456.0
Wells 01	Forebay	10/17/2005	14:00	8.0	16.71	7.89	8.54	97.6	0.0945	458.0
Wells 01	Forebay	10/17/2005		9.0	16.71	7.88	8.55	97.7	0.0945	460.0
Wells 01	Forebay	10/17/2005		10.0	16.72	7.91	8.56	97.8	0.0948	460.0
Wells 01	Forebay	10/17/2005		11.0	16.72	7.88	8.53	97.4	0.0948	463.0
Wells 01	Forebay	10/17/2005		12.0	16.72	7.88	8.46	96.7	0.0942	466.0
Wells 01	Forebay	10/17/2005		13.0	16.71	7.88	8.37	95.7	0.0945	465.0
Wells 01	Forebay	10/17/2005		14.0	16.71	7.88	8.39	95.9	0.0941	467.0
Wells 01	Forebay	10/17/2005		15.0	16.72	7.88	8.39	96.0	0.0943	468.0
Wells 01	Forebay	10/17/2005		17.0	16.71	7.91	8.29	94.0	0.0938	467.0
Wells 01	Forebay	10/17/2005		19.0	16.71	7.91	7.23	81.8	0.0645	468.0
Wells 02	Starr	10/17/2005	16:15	1.0	16.9	8.24	9.71	111.3	0.0935	480.0
Wells 02	Starr	10/17/2005		2.0	16.9	8.27	9.55	109.4	0.0936	481.0
Wells 03	Methow Mouth	10/18/2005	12:25	1.0	12.92	7.98	8.95	94.2	0.1246	496.0
Wells 03	Methow Mouth	10/18/2005		2.0	12.77	7.99	8.95	93.8	0.1254	494.0
Wells 03	Methow Mouth	10/18/2005		3.0	12.67	8.00	8.84	92.7	0.1252	495.0

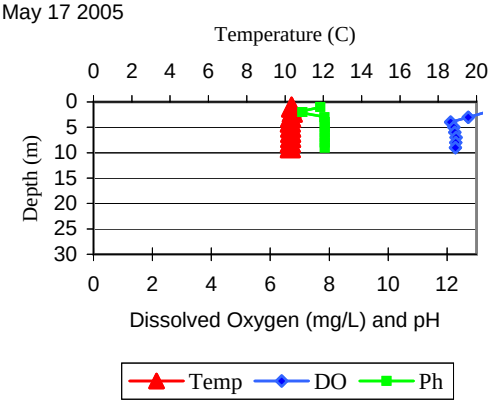
Site Code	Site Name	Date	Time	Sample Depth (m)	Temperature (C)	pH	Dissolved Oxygen (mg/L)	% Dissolved Oxygen Saturation	Sp. Conductance (uS/cm)	ORP
Wells 04	Brewster Bridge	10/18/2005	11:15	1.0	16.75	7.92	8.29	94.8	0.0932	489.0
Wells 04	Brewster Bridge	10/18/2005		2.0	16.72	7.96	8.25	94.1	0.0935	487.0
Wells 04	Brewster Bridge	10/18/2005		3.0	16.73	7.97	8.04	91.9	0.0930	486.0
Wells 04	Brewster Bridge	10/18/2005		4.0	16.74	7.96	8.11	92.2	0.0933	488.0
Wells 04	Brewster Bridge	10/18/2005		5.0	16.74	7.95	8.06	91.6	0.0930	488.0
Wells 04	Brewster Bridge	10/18/2005		6.0	16.75	7.96	8.11	92.8	0.0931	489.0
Wells 04	Brewster Bridge	10/18/2005		7.0	16.75	7.96	7.94	90.3	0.0929	489.0
Wells 04	Brewster Bridge	10/18/2005		8.0	16.75	7.97	7.93	90.8	0.0930	489.0
Wells 04	Brewster Bridge	10/18/2005		9.0	16.75	7.96	8.16	93.5	0.0931	490.0
Wells 04	Brewster Bridge	10/18/2005		10.0	16.75	7.95	8.22	94.2	0.0933	490.0
Wells 04	Brewster Bridge	10/18/2005	11:24	11.0	16.74	7.95	8.22	93.6	0.0932	490.0
Wells 04	Brewster Bridge	10/18/2005		12.0	16.74	7.95	7.91	90.6	0.0933	491.0
Wells 04	Brewster Bridge	10/18/2005		13.0	16.75	7.94	8.10	92.7	0.0931	492.0
Wells 04	Brewster Bridge	10/18/2005		14.0	16.76	7.96	8.16	93.5	0.0930	490.0
Wells 04	Brewster Bridge	10/18/2005		15.0	16.76	7.96	8.25	94.4	0.0931	491.0
Wells 04	Brewster Bridge	10/18/2005	11:27	17.0	16.75	7.95	8.24	94.6	0.0933	491.0
Wells 05	Okanogan	10/18/2005	10:20	1.0	15.92	7.98	8.65	97.2	0.1188	485.0
Wells 05	Okanogan	10/18/2005		2.0	16.02	8.05	8.57	96.3	0.1150	484.0
Wells 05	Okanogan	10/18/2005		3.0	15.91	8.05	8.70	97.4	0.1201	486.0
Wells 05	Okanogan	10/18/2005		4.0	15.82	8.07	8.69	97.5	0.1214	487.0
Wells 05	Okanogan	10/18/2005		5.0	15.82	8.06	8.66	97.3	0.1175	487.0
Wells 05	Okanogan	10/18/2005		6.0	15.86	8.09	8.72	97.9	0.1240	488.0
Wells 05	Okanogan	10/18/2005		7.0	15.83	8.07	8.78	98.30	0.1286	488.00
Wells 05	Okanogan	10/18/2005		8.0	15.70	8.08	8.80	98.5	0.1260	490.0
Wells 05	Okanogan	10/18/2005		9.0	15.55	8.10	8.77	98.1	0.1331	490.0
Wells 05	Okanogan	10/18/2005		10.0	15.56	8.11	8.81	98.2	0.1340	491.0
Wells 06	Bridgeport Bar	10/18/2005		1.0	15.75	7.80	8.14	91.3	0.0920	495.0
Wells 06	Bridgeport Bar	10/18/2005	9:45	2.0	15.77	7.82	7.96	89.3	0.0921	494.0

Site Code	Site Name	Date	Time	Sample Depth (m)	Temperature (C)	pH	Dissolved Oxygen (mg/L)	% Dissolved Oxygen Saturation	Sp. Conductance (uS/cm)	ORP
Wells 07	Chief Joe	10/18/2005	8:30	1.0	16.81	7.90	8.39	96.3	0.0923	491.0
Wells 07	Chief Joe	10/18/2005		2.0	16.82	7.94	8.30	95.2	0.0922	492.0
Wells 07	Chief Joe	10/18/2005		3.0	16.83	7.92	8.30	95.1	0.0922	492.0
Wells 08	Tail race	10/17/2005	15:15	1.0	16.83	7.97	8.60	99.1	0.0931	462.0
Wells 01	Wells Forebay	2/7/2006	11:25	1.0	3.83	7.96	13.79	107.9	0.0998	296.0
Wells 01	Wells Forebay	2/7/2006		2.0	3.82	7.96	13.71	107.1	0.0995	306.0
Wells 01	Wells Forebay	2/7/2006		3.0	3.82	7.96	13.56	106.2	0.0994	311.0
Wells 01	Wells Forebay	2/7/2006		4.0	3.83	7.95	13.54	106.3	0.0995	316.0
Wells 01	Wells Forebay	2/7/2006		5.0	3.82	7.94	13.44	105.2	0.0992	321.0
Wells 01	Wells Forebay	2/7/2006		6.0	3.82	7.96	13.52	105.8	0.0996	325.0
Wells 01	Wells Forebay	2/7/2006		7.0	3.82	7.94	13.49	105.6	0.0992	330.0
Wells 01	Wells Forebay	2/7/2006		8.0	3.82	7.96	13.50	105.7	0.0994	333.0
Wells 01	Wells Forebay	2/7/2006		9.0	3.82	7.95	13.46	105.5	0.0994	337.0
Wells 01	Wells Forebay	2/7/2006		10.0	3.82	7.95	13.47	105.3	0.0997	339.0
Wells 01	Wells Forebay	2/7/2006		11.0	3.82	7.95	13.41	105.1	0.0996	342.0
Wells 01	Wells Forebay	2/7/2006		12.0	3.82	7.97	13.38	104.6	0.0996	344.0
Wells 01	Wells Forebay	2/7/2006		13.0	3.82	7.96	13.38	104.7	0.0995	348.0
Wells 01	Wells Forebay	2/7/2006		14.0	3.82	7.95	13.37	104.7	0.0993	350.0
Wells 01	Wells Forebay	2/7/2006		15.0	3.82	7.94	13.24	103.7	0.0996	352.0
Wells 02	Starr Boat Launch	2/7/2006	11:55	1.0	3.89	8.04	13.82	108.5	0.1006	400.0
Wells 02	Starr Boat Launch	2/7/2006		2.0	3.89	8.05	13.82	108.5	0.1004	400.0
Wells 03	Methow Mouth	2/7/2006	11:00	1.0	2.84	7.99	14.60	110.7	0.1207	431.0
Wells 03	Methow Mouth	2/7/2006		2.0	2.87	8.03	14.35	109.1	0.1210	431.0

Site Code	Site Name	Date	Time	Sample Depth (m)	Temperature (C)	pH	Dissolved Oxygen (mg/L)	% Dissolved Oxygen Saturation	Sp. Conductance (uS/cm)	ORP
Wells 04	Brewster Bridge	2/7/2006	9:30	1.0	3.68	7.94	14.32	110.9	0.1000	444.0
Wells 04	Brewster Bridge	2/7/2006		2.0	3.69	7.88	13.86	108.6	0.1018	445.0
Wells 04	Brewster Bridge	2/7/2006		3.0	3.69	7.97	13.82	108.1	0.1018	445.0
Wells 04	Brewster Bridge	2/7/2006		4.0	3.69	7.90	13.82	107.7	0.1015	446.0
Wells 04	Brewster Bridge	2/7/2006		5.0	3.69	7.96	13.73	107.4	0.1014	445.0
Wells 04	Brewster Bridge	2/7/2006		6.0	3.68	7.96	13.68	106.7	0.1007	446.0
Wells 04	Brewster Bridge	2/7/2006		7.0	3.68	7.91	13.57	105.7	0.1001	446.0
Wells 04	Brewster Bridge	2/7/2006		8.0	3.68	7.91	13.50	105.3	0.0998	446.0
Wells 04	Brewster Bridge	2/7/2006		9.0	3.68	7.92	13.47	105.2	0.1000	446.0
Wells 04	Brewster Bridge	2/7/2006		10.0	3.68	7.92	13.45	105.0	0.0995	446.0
Wells 04	Brewster Bridge	2/7/2006		11.0	3.69	7.92	13.42	104.8	0.0999	447.0
Wells 05	Okanogan Mouth	2/7/2006	9:00	1.0	3.57	8.00	13.85	107.9	0.1591	446.0
Wells 05	Okanogan Mouth	2/7/2006		2.0	3.67	8.14	13.89	108.3	0.1743	445.0
Wells 05	Okanogan Mouth	2/7/2006		3.0	3.70	8.14	13.91	108.7	0.1802	446.0
Wells 05	Okanogan Mouth	2/7/2006		4.0	3.75	8.17	13.97	109.4	0.1850	446.0
Wells 05	Okanogan Mouth	2/7/2006		5.0	3.75	8.18	13.97	109.2	0.1849	446.0
Wells 05	Okanogan Mouth	2/7/2006		6.0	3.76	8.18	13.80	108.2	0.1854	446.0
Wells 05	Okanogan Mouth	2/7/2006		7.0	3.77	8.19	13.91	109.0	0.1867	446.0
Wells 05	Okanogan Mouth	2/7/2006		8.0	3.76	8.19	13.85	108.5	0.1876	446.0
Wells 05	Okanogan Mouth	2/7/2006		9.0	3.75	8.20	13.85	108.2	0.1864	447.0
Wells 06	Bridgeport Shallows	2/7/2006	8:30	1.0	3.70	7.90	13.90	108.0	0.0991	434.0
Wells 06	Bridgeport Shallows	2/7/2006		2.0	3.71	7.92	13.70	107.0	0.0987	433.0
Wells 07	Chief Joe Tailrace	2/7/2006	7:30	1.0	3.74	7.58	14.11	111.3	0.0993	408.0
Wells 07	Chief Joe Tailrace	2/7/2006		2.0	3.75	7.67	13.74	107.8	0.0991	411.0
Wells 07	Chief Joe Tailrace	2/7/2006		3.0	3.76	7.62	13.66	106.7	0.0994	412.0
Wells 08	Wells Tailrace	2/7/2006	14:40	1.0	4.09	Failed	13.50	106.1	0.0	700.0

Site Code	Site Name	Date	Time	Sample Depth (m)	Temperature (C)	pH	Dissolved Oxygen (mg/L)	% Dissolved Oxygen Saturation	Sp. Conductance (uS/cm)	ORP
Wells 09	Wells Reservoir Thal	2/7/2006	11:45	1.0	3.79	7.95	13.82	107.90	0.0993	364.0
Wells 09	Wells Reservoir Thal	2/7/2006	11:45	2.0	3.79	7.96	13.64	106.80	0.0995	366.0
Wells 09	Wells Reservoir Thal	2/7/2006	11:45	3.0	3.79	7.92	13.49	105.60	0.0993	369.0
Wells 09	Wells Reservoir Thal	2/7/2006	11:45	4.0	3.79	7.94	13.54	106.00	0.0993	370.0
Wells 09	Wells Reservoir Thal	2/7/2006	11:45	5.0	3.83	7.93	13.53	106.00	0.0997	371.0
Wells 09	Wells Reservoir Thal	2/7/2006	11:45	6.0	3.82	7.93	13.52	105.80	0.0992	372.0
Wells 09	Wells Reservoir Thal	2/7/2006	11:45	7.0	3.82	7.93	13.47	105.00	0.0996	374.0
Wells 09	Wells Reservoir Thal	2/7/2006	11:45	8.0	3.83	7.93	13.39	104.90	0.0991	374.0
Wells 09	Wells Reservoir Thal	2/7/2006	11:45	9.0	3.82	7.95	13.37	104.60	0.0991	374.0
Wells 09	Wells Reservoir Thal	2/7/2006	11:45	10.0	3.82	7.93	13.35	104.50	0.0994	376.0
Wells 09	Wells Reservoir Thal	2/7/2006	11:45	11.0	3.81	7.93	13.35	104.70	0.0993	377.0
Wells 09	Wells Reservoir Thal	2/7/2006	11:45	12.0	3.82	7.94	13.31	104.40	0.0990	377.0
Wells 09	Wells Reservoir Thal	2/7/2006	11:45	13.0	3.82	7.94	13.31	104.40	0.0993	380.0
Wells 09	Wells Reservoir Thal	2/7/2006	11:45	14.0	3.82	7.94	13.24	104.00	0.0993	382.0
Wells 09	Wells Reservoir Thal	2/7/2006	11:45	15.0	3.81	7.94	13.31	104.00	0.0990	383.0
Wells 09	Wells Reservoir Thal	2/7/2006	11:45	17.0	3.83	7.95	13.19	103.20	0.0991	383.0
Wells 09	Wells Reservoir Thal	2/7/2006	11:45	19.0	3.82	7.95	13.11	102.60	0.0990	384.0
Wells 09	Wells Reservoir Thal	2/7/2006	11:45	21.0	3.82	7.95	13.15	102.80	0.0991	385.0

May 17 2005



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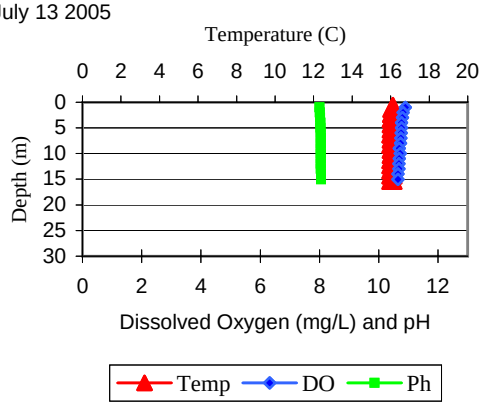

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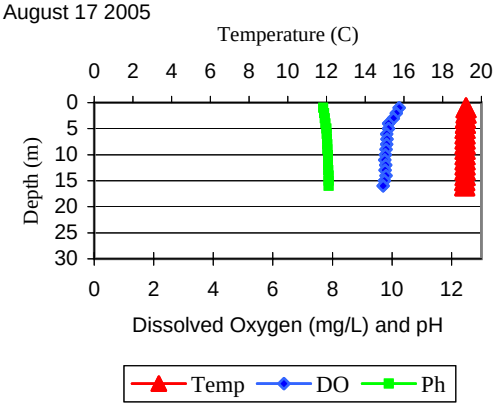

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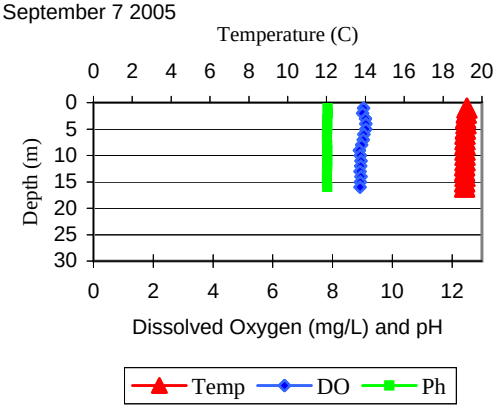

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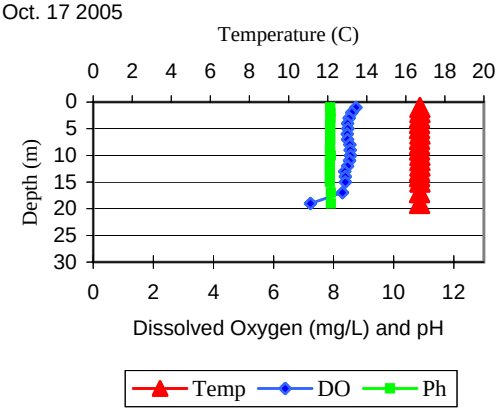

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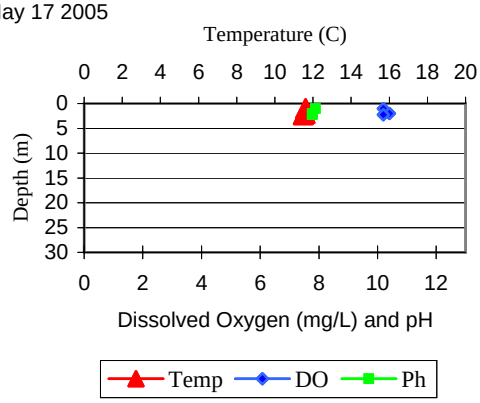

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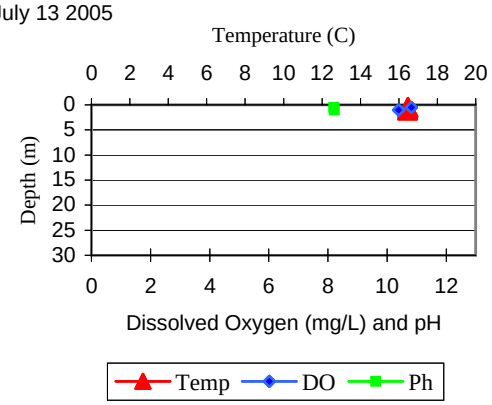

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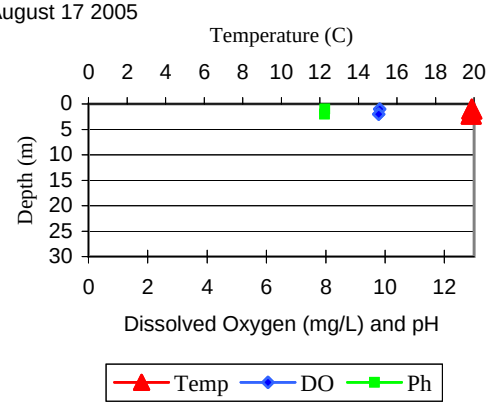

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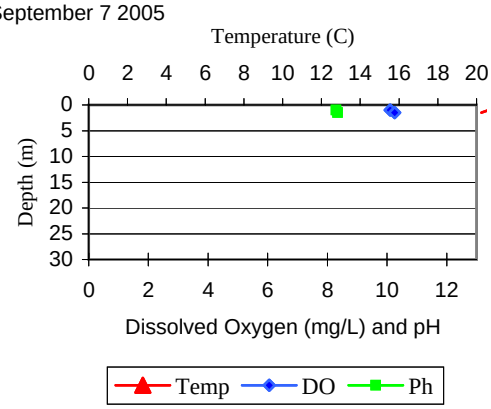

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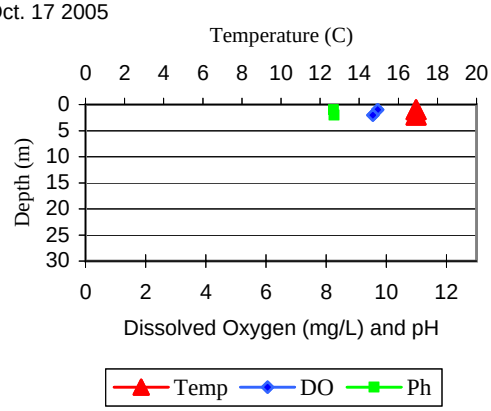

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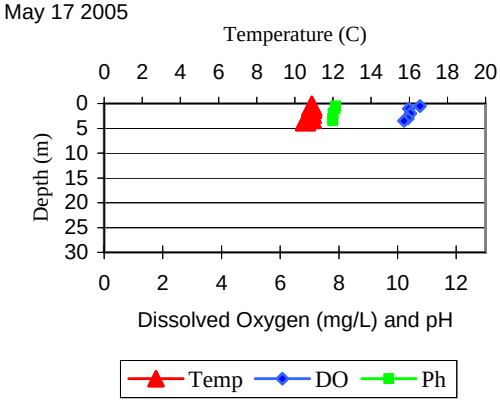

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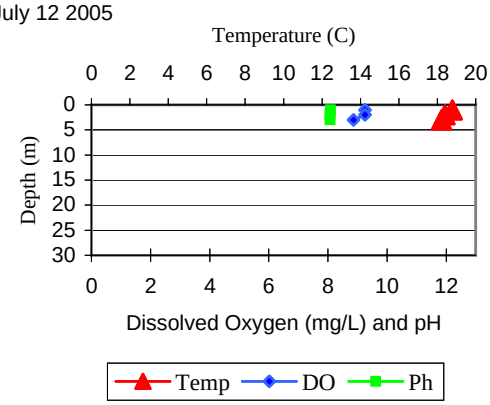

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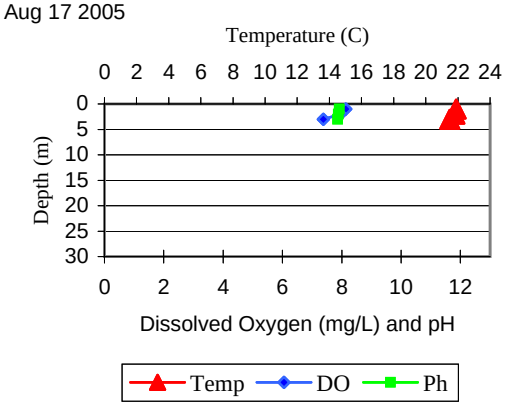

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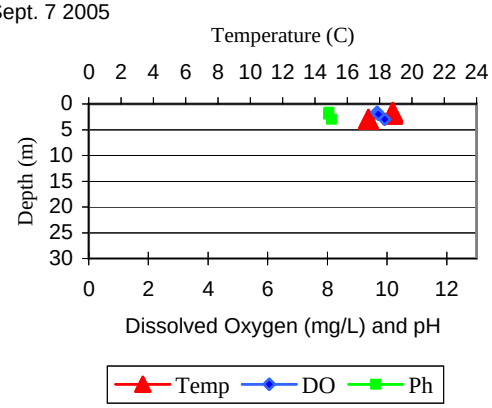

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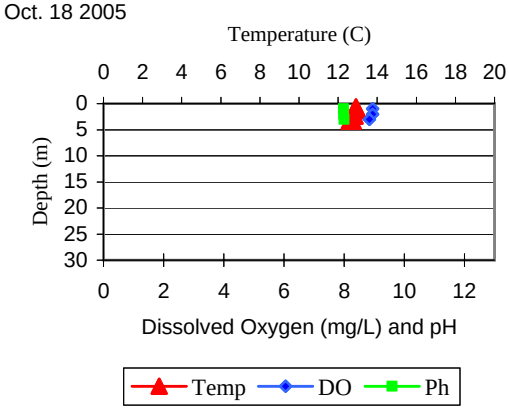

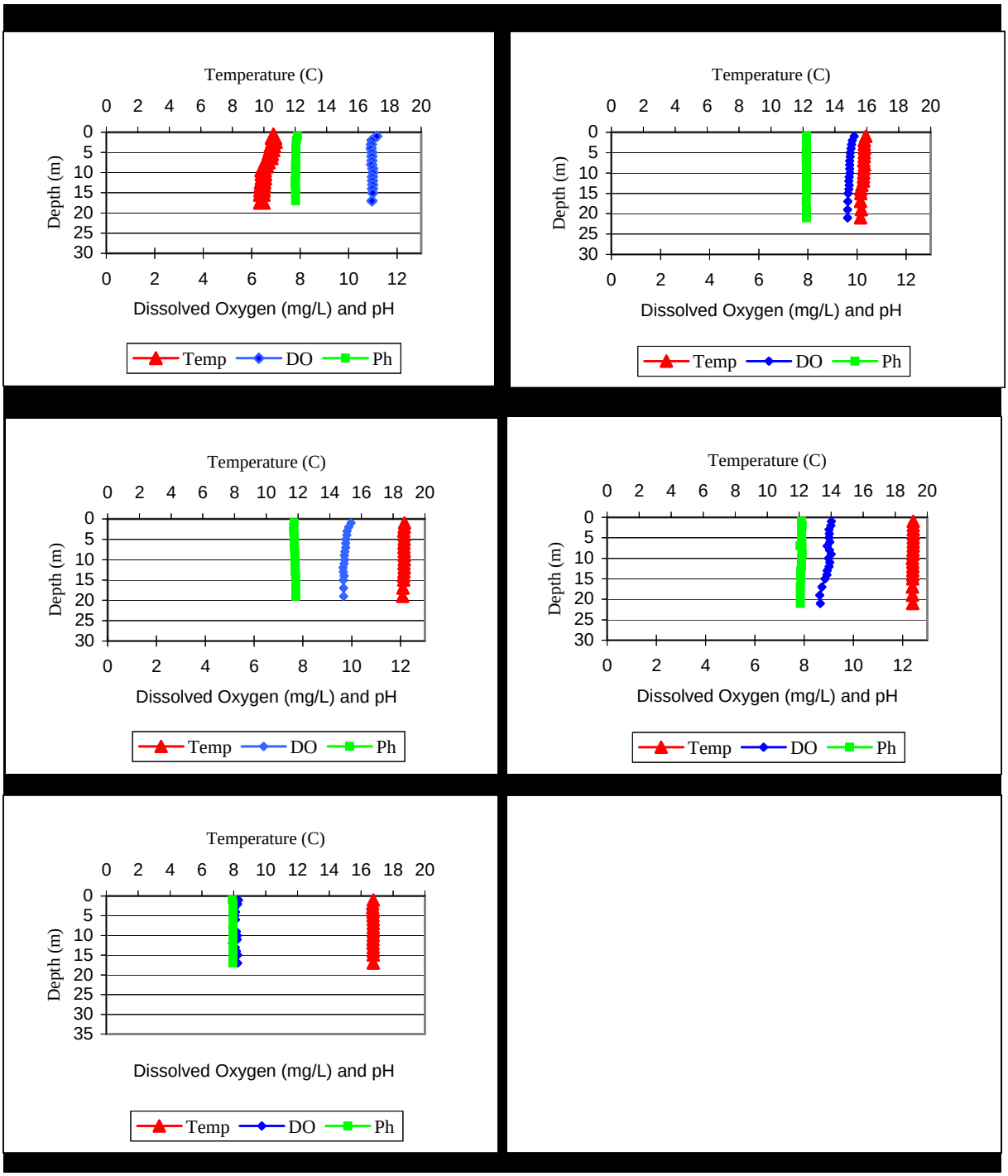
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Depth (m)
0 5 10 15 20 25 30
0 2 4 6 8 10 12
Dissolved Oxygen (mg/L) and pH
Temp DO Ph
Temperature (C)
0 2 4 6 8 10 12 14 16 18 20
Depth (m)
0 5 10 15 20 25 30
0 2 4 6 8 10 12
Dissolved Oxygen (mg/L) and pH
Temp DO Ph
Temperature (C)
0 2 4 6 8 10 12 14 16 18 20
Depth (m)
0 5 10 15 20 25 30
0 2 4 6 8 10 12
Dissolved Oxygen (mg/L) and pH
Temp DO Ph
Temperature (C)
0 2 4 6 8 10 12 14 16 18 20
Depth (m)
0 5 10 15 20 25 30
0 2 4 6 8 10 12
Dissolved Oxygen (mg/L) and pH
Temp DO Ph
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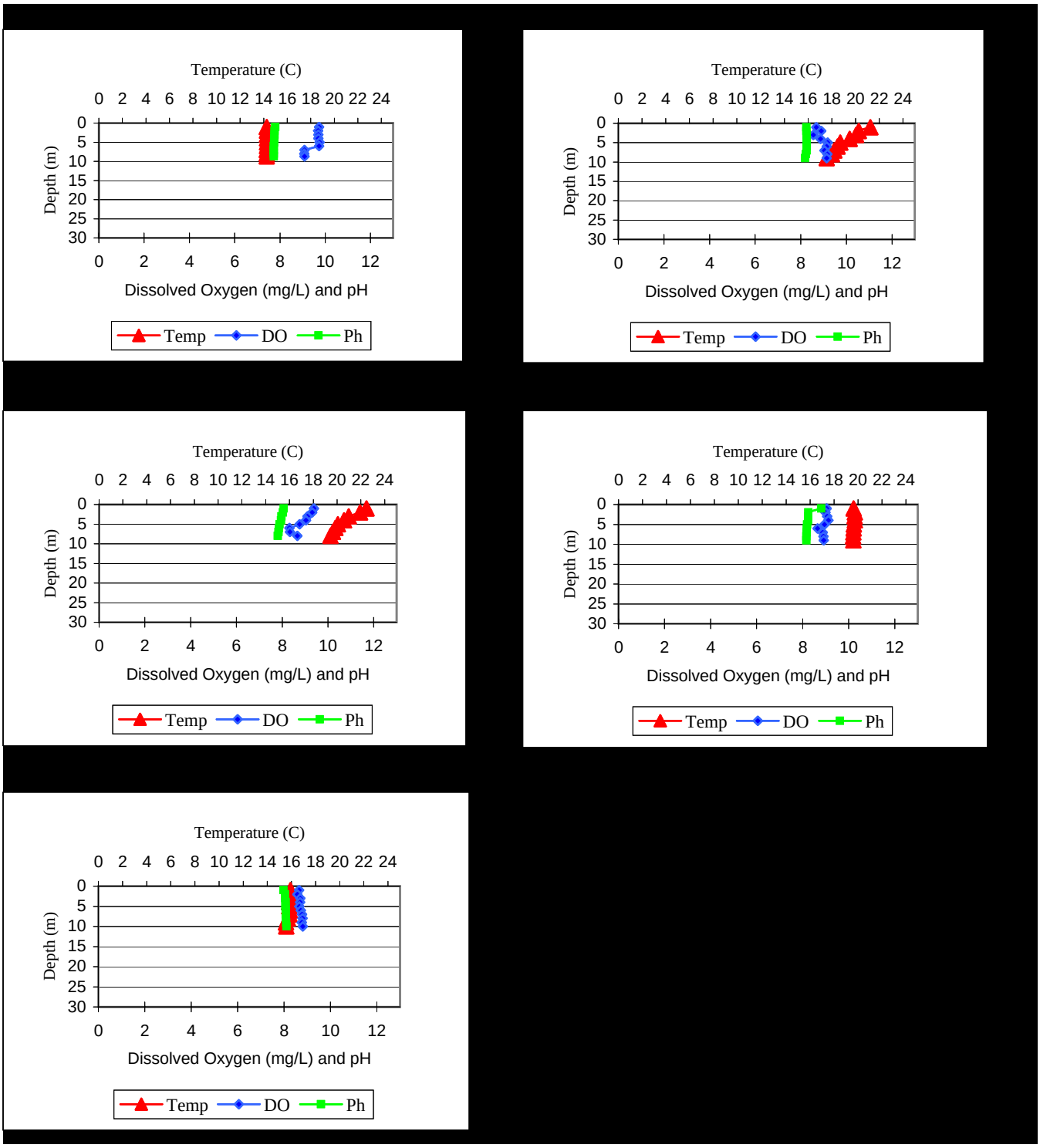
Dissolved Oxygen (mg/L) and pH
Temp DO Ph


Temperature (C)
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Depth (m)
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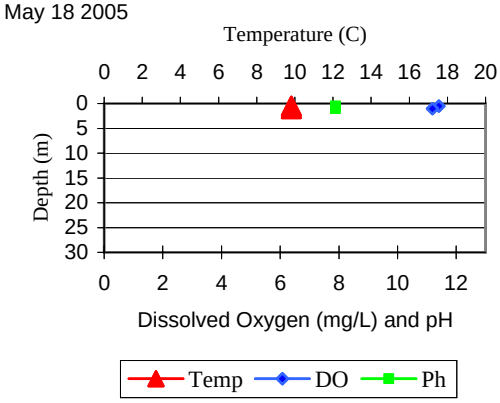
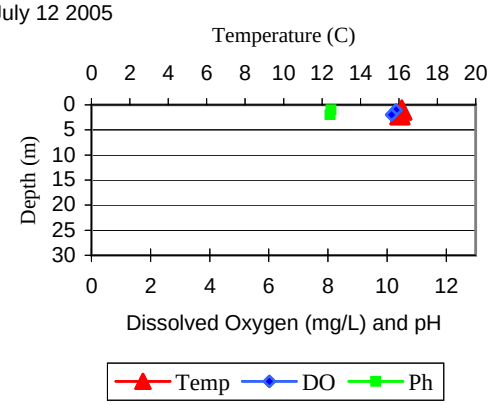
0 2 4 6 8 10 12
Dissolved Oxygen (mg/L) and pH
Temp DO Ph

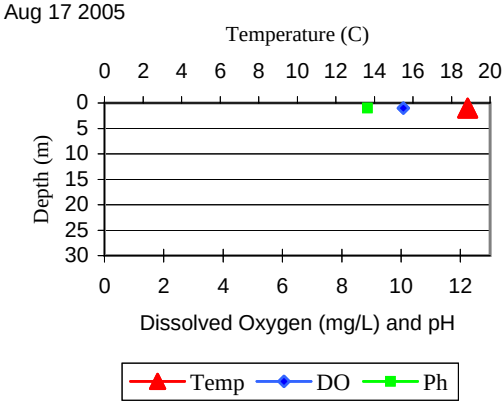
May 18 2005



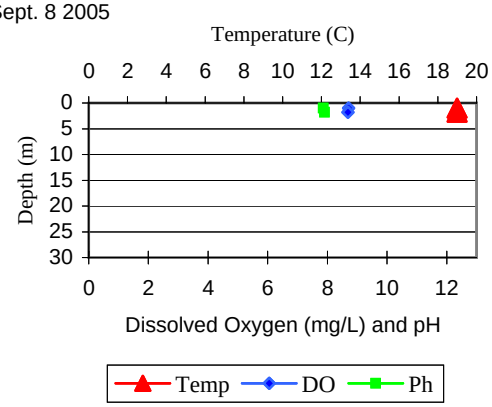
July 12 2005



Aug 17 2005



Sept. 8 2005



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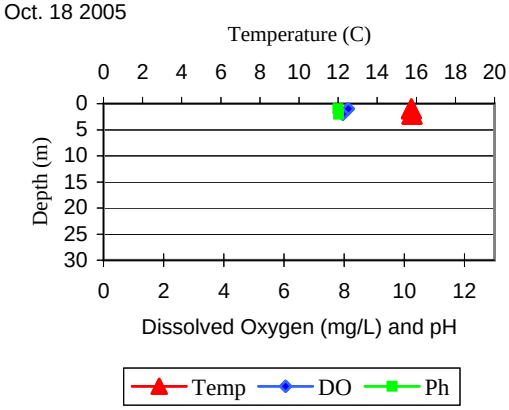

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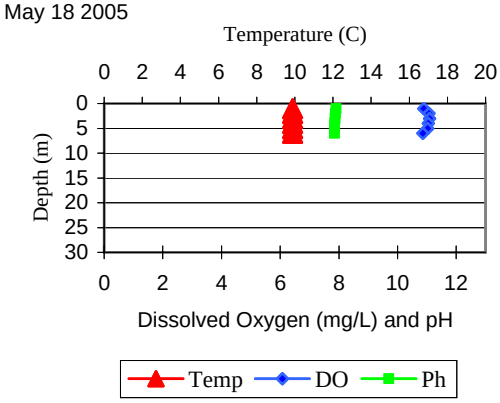

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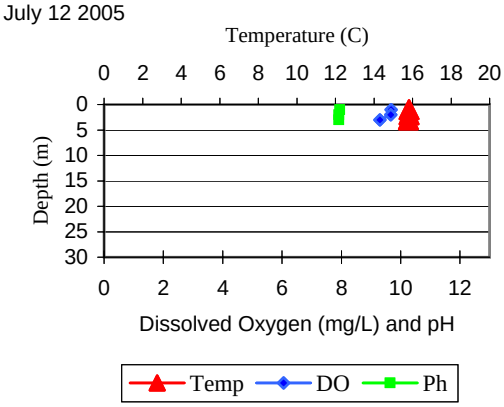

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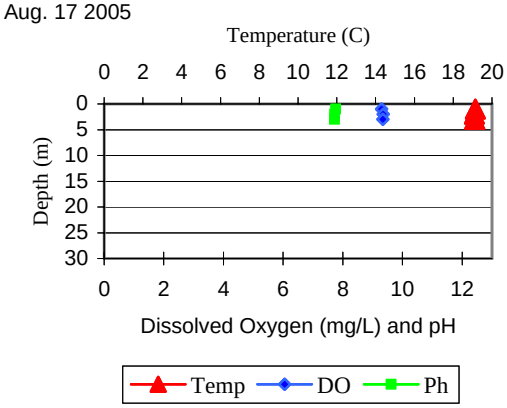

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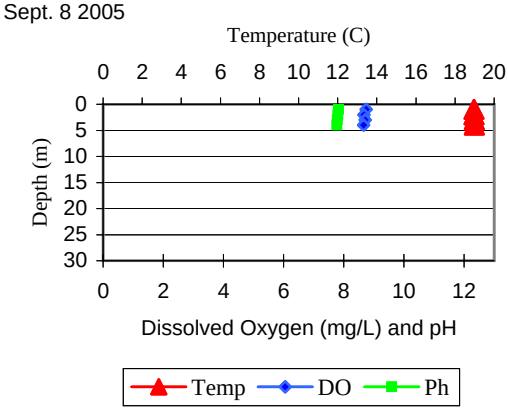

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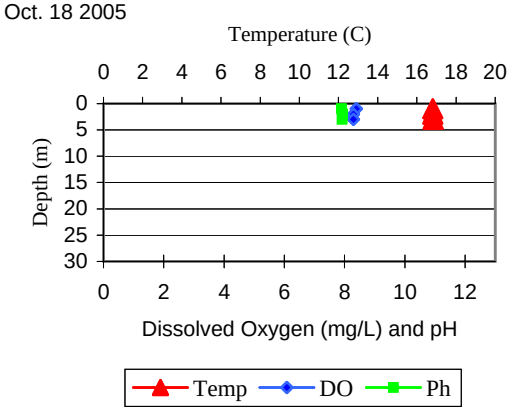

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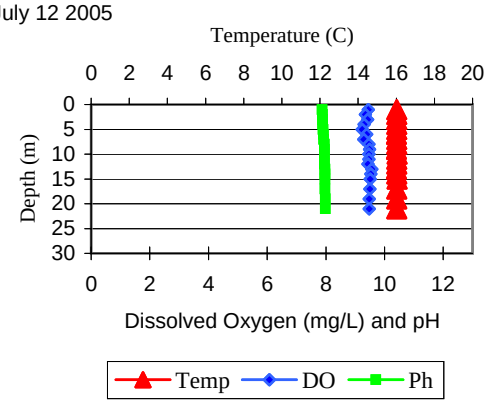
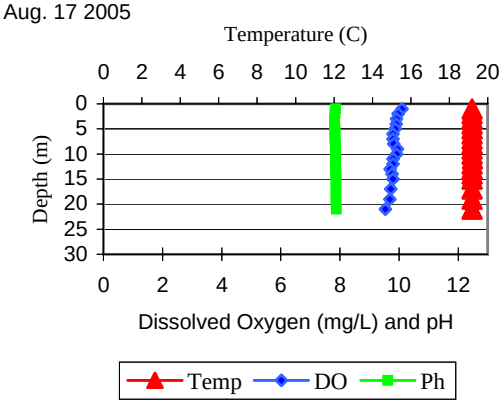
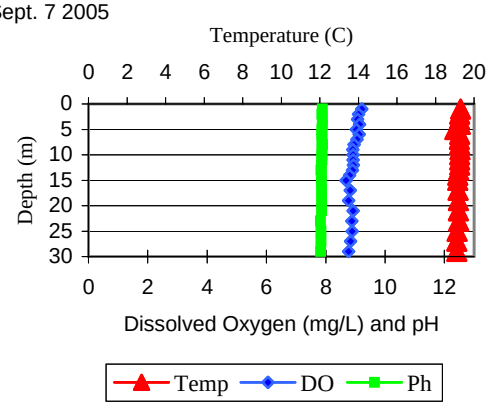


Aug. 17 2005



Sept. 7 2005



Appendix C

Phytoplankton Species Lists and Charts

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: WELLS 01 Photic
Sample Depth:
Sample Date: 17-May-05

Total Density (#/mL): 704
Total Biovolume (um^3/mL): 193,796
Trophic State Index: 38.0

	Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
1	Asterionella formosa	115	16.4	50,666	26.1
2	Synedra radians	77	10.9	27,636	14.3
3	Stephanodiscus hantzschii	58	8.2	6,909	3.6
4	Achnanthes minutissima	38	5.5	1,919	1.0
5	Nitzschia acicularis	32	4.5	8,956	4.6
6	Nitzschia paleacea	13	1.8	1,254	0.6
7	Cyclotella ocellata	6	0.9	800	0.4
8	Cymbella minuta	6	0.9	2,367	1.2
9	Amphora perpusilla	6	0.9	1,062	0.5
10	Navicula capitata	6	0.9	3,071	1.6
11	Melosira ambigua	6	0.9	7,536	3.9
12	Melosira italica	6	0.9	12,052	6.2
13	Nitzschia fonticola	6	0.9	537	0.3
14	Nitzschia sigmoidea	6	0.9	5,438	2.8
15	Fragilaria construens venter	6	0.9	1,228	0.6
16	Nitzschia capitellata	6	0.9	2,303	1.2
17	Navicula tripunctata	6	0.9	7,165	3.7
18	Synedra rumpens	6	0.9	896	0.5
19	Diatoma tenue elongatum	6	0.9	4,606	2.4
20	Navicula sp.	6	0.9	960	0.5
21	Navicula viridula	6	0.9	2,879	1.5
22	Cymbella sinuata	6	0.9	896	0.5
23	Gomphonema angustatum	6	0.9	1,151	0.6
24	Dinobryon sertularia	38	5.5	4,568	2.4
25	Kephyrion littorale	6	0.9	608	0.3
26	Rhodomonas minuta	154	21.8	3,071	1.6
27	Cryptomonas erosa	64	9.1	33,265	17.2

Aquatic Analysts **Sample ID:** HY41

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: WELLS 01 Photic
Sample Depth:
Sample Date: 12-Jul-05

Total Density (#/mL): 435
Total Biovolume (um^3/mL): 174,638
Trophic State Index: 37.3

	Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
1	Synedra radians	63	14.4	22,617	13.0
2	Asterionella formosa	45	10.3	13,822	7.9
3	Diatoma tenue elongatum	40	9.3	29,079	16.7
4	Achnanthes minutissima	27	6.2	1,750	1.0
5	Nitzschia acicularis	18	4.1	5,026	2.9
6	Cyclotella ocellata	13	3.1	1,683	1.0
7	Melosira ambigua	13	3.1	23,789	13.6
8	Tabellaria fenestrata	9	2.1	21,540	12.3
9	Fragilaria construens	9	2.1	3,518	2.0
10	Fragilaria crotonensis	9	2.1	26,387	15.1
11	Cymbella minuta	4	1.0	1,660	1.0
12	Amphora perpusilla	4	1.0	745	0.4
13	Nitzschia frustulum	4	1.0	2,154	1.2
14	Stephanodiscus hantzschii	4	1.0	539	0.3
15	Achnanthes flexella	4	1.0	2,176	1.2
16	Ankistrodesmus falcatus	4	1.0	112	0.1
17	Kephyrion littorale	18	4.1	1,705	1.0
18	Rhodomonas minuta	117	26.8	2,334	1.3
19	Cryptomonas erosa	27	6.2	14,001	8.0

Aquatic Analysts **Sample ID:** HY54

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: WELLS 01 Photic
Sample Depth:
Sample Date: 17-Aug-05

Total Density (#/mL): 633
Total Biovolume (um^3/mL): 448,643
Trophic State Index: 44.1

	Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
1	Cocconeis placentula	45	7.1	20,798	4.6
2	Synedra radians	40	6.3	14,242	3.2
3	Achnanthes minutissima	34	5.4	1,695	0.4
4	Fragilaria crotonensis	17	2.7	327,568	73.0
5	Cyclotella ocellata	11	1.8	1,413	0.3
6	Cyclotella stelligera	11	1.8	622	0.1
7	Synedra rumpens	11	1.8	1,582	0.4
8	Stephanodiscus hantzschii	11	1.8	1,356	0.3
9	Nitzschia frustulum	11	1.8	1,356	0.3
10	Nitzschia fonticola	11	1.8	475	0.1
11	Melosira ambigua	11	1.8	13,315	3.0
12	Rhoicosphenia curvata	6	0.9	661	0.1
13	Synedra tenera	6	0.9	1,695	0.4
14	Amphora perpusilla	6	0.9	938	0.2
15	Gomphonema angustatum	6	0.9	1,017	0.2
16	Gomphonema clevei	6	0.9	509	0.1
17	Gomphonema subclavatum	6	0.9	3,391	0.8
18	Tabellaria fenestrata	6	0.9	13,564	3.0
19	Melosira italica	6	0.9	10,648	2.4
20	Navicula cryptocephala veneta	6	0.9	537	0.1
21	Achnanthes linearis	6	0.9	746	0.2
22	Nitzschia palea	6	0.9	1,017	0.2
23	Nitzschia dissipata	6	0.9	1,520	0.3
24	Achnanthes clevei	6	0.9	848	0.2
25	Ankistrodesmus falcatus	6	0.9	141	0.0
26	Kephyrion littorale	6	0.9	537	0.1
27	Rhodomonas minuta	294	46.4	5,878	1.3
28	Cryptomonas erosa	40	6.3	20,572	4.6

Aquatic Analysts **Sample ID:** HY66

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: WELLS 01 Photic
Sample Depth:
Sample Date: 7-Sep-05

Total Density (#/mL): 1,003
Total Biovolume (um^3/mL): 170,588
Trophic State Index: 37.1

	Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
3	Stephanodiscus hantzschii	34	3.4	4,046	2.4
4	Cocconeis placentula	34	3.4	15,511	9.1
5	Synedra radians	17	1.7	6,070	3.6
6	Cyclotella stelligera	17	1.7	927	0.5
8	Cyclotella ocellata	17	1.7	2,107	1.2
9	Synedra delicatissima	17	1.7	11,127	6.5
10	Cyclotella kutzingiana	8	0.8	969	0.6
11	Tabellaria flocculosa	8	0.8	4,974	2.9
12	Cymbella minuta	8	0.8	3,119	1.8
14	Fragilaria construens	8	0.8	5,665	3.3
15	Amphora perpusilla	8	0.8	1,399	0.8
16	Melosira granulata	8	0.8	9,273	5.4
17	Achnanthes linearis	8	0.8	1,113	0.7
18	Achnanthes minutissima	8	0.8	421	0.2
19	Navicula cryptocephala	8	0.8	1,560	0.9
23	Nitzschia acicularis	8	0.8	2,360	1.4
7	Sphaerocystis schroeteri	17	1.7	7,081	4.2
13	Oocystis pusilla	8	0.8	1,821	1.1
20	Cosmarium sp.	8	0.8	1,770	1.0
21	Ankistrodesmus falcatus	8	0.8	211	0.1
22	Chlamydomonas sp.	8	0.8	2,740	1.6
1	Rhodomonas minuta	590	58.8	11,802	6.9
2	Cryptomonas erosa	143	14.3	74,520	43.7

Aquatic Analysts **Sample ID:** HY79

Phytoplankton Sample

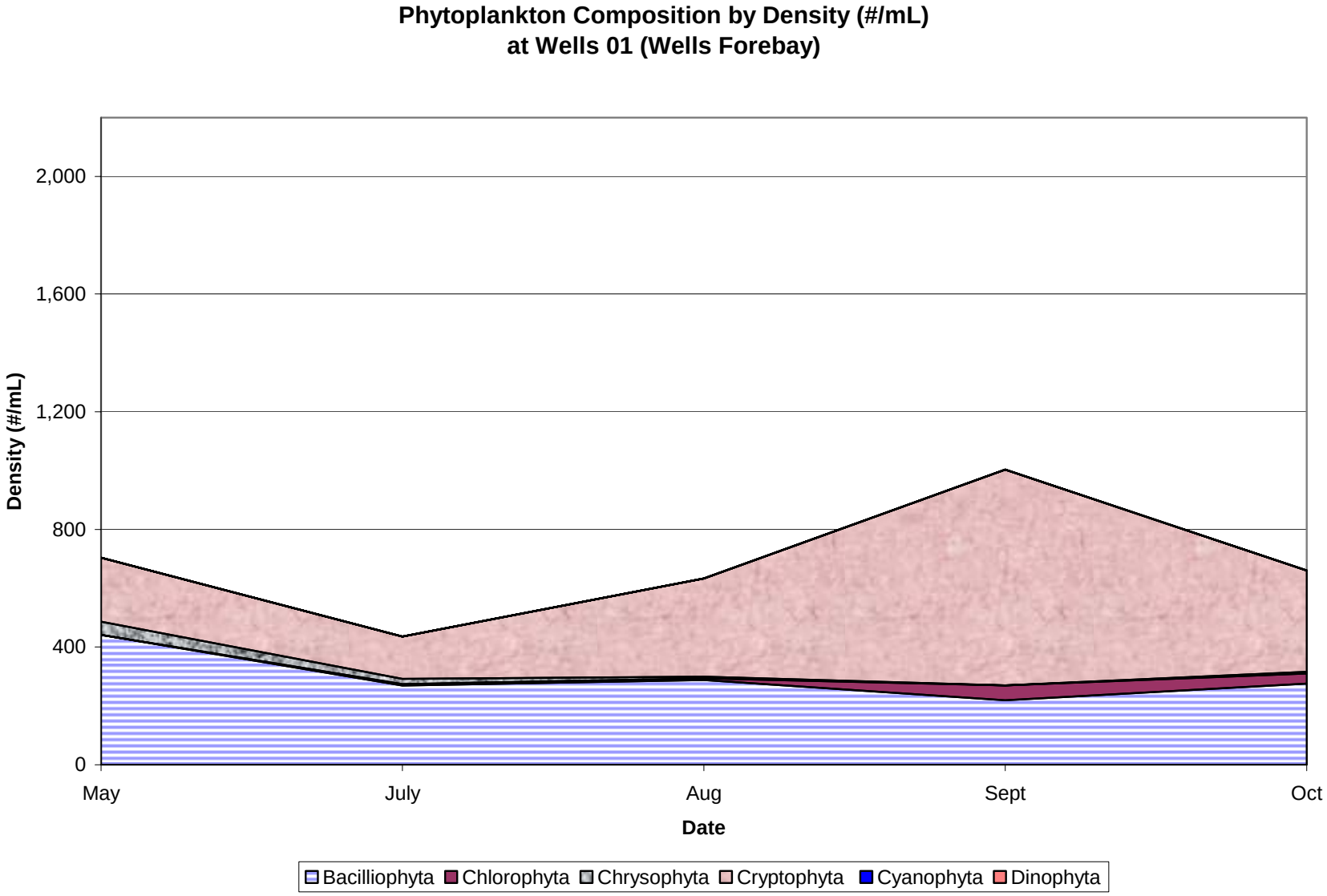
Analysis

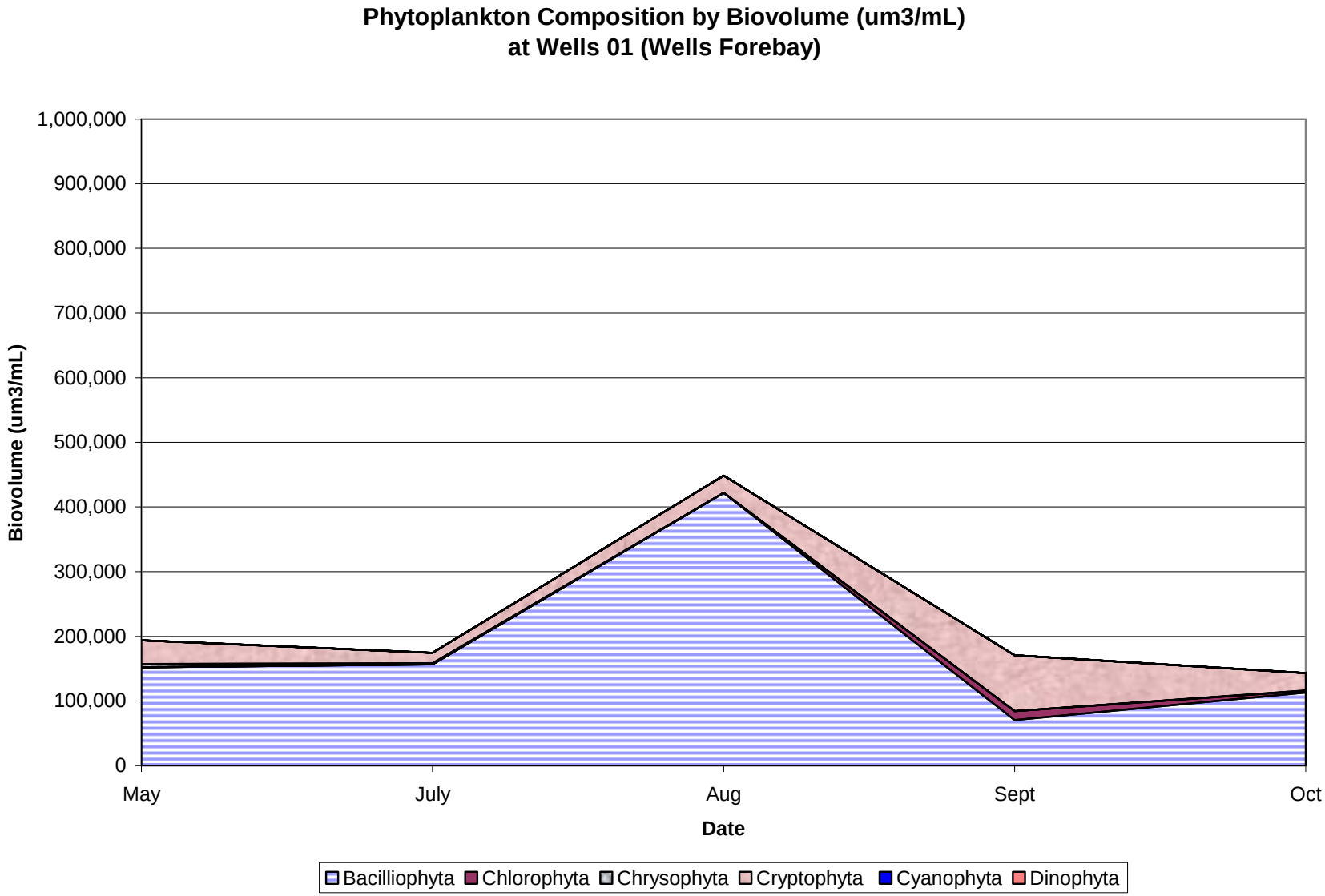
Sample: Wells Res
Sample Station: WELLS 01 Photic
Sample Depth:
Sample Date: 18-Oct-05

Total Density (#/mL): 661
Total Biovolume (um^3/mL): 143,205
Trophic State Index: 35.9

	Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
2	Stephanodiscus hantzschii	80	12.2	9,652	6.7
5	Cyclotella stelligera	29	4.3	1,580	1.1
6	Cocconeis placentula	23	3.5	10,571	7.4
7	Achnanthes minutissima	23	3.5	1,149	0.8
8	Cyclotella ocellata	17	2.6	2,154	1.5
9	Cyclotella kutzingiana	11	1.7	1,321	0.9
10	Synedra radians	11	1.7	4,137	2.9
11	Achnanthes clevei	11	1.7	1,724	1.2
12	Navicula cryptocephala veneta	6	0.9	546	0.4
13	Cyclotella pseudostelligera	6	0.9	373	0.3
14	Amphora perpusilla	6	0.9	954	0.7
17	Fragilaria crotonensis	6	0.9	67,564	47.2
18	Nitzschia capitellata	6	0.9	2,068	1.4
19	Achnanthes lanceolata	6	0.9	1,034	0.7
20	Navicula cryptocephala	6	0.9	1,063	0.7
21	Synedra rumpens	6	0.9	804	0.6
22	Diploneis elliptica	6	0.9	1,494	1.0
23	Nitzschia frustulum	6	0.9	689	0.5
24	Achnanthes linearis	6	0.9	758	0.5
25	Amphora ovalis	6	0.9	3,321	2.3
4	Ankistrodesmus falcatus	29	4.3	1,149	0.8
15	Sphaerocystis schroeteri	6	0.9	1,609	1.1
16	Chrysococcus rufescens	6	0.9	488	0.3
1	Rhodomonas minuta	304	46.1	6,090	4.3
3	Cryptomonas erosa	40	6.1	20,913	14.6

Aquatic Analysts **Sample ID:** HY92


Phytoplankton Composition by Density (#/mL)
at Wells 01 (Wells Forebay)
Density (#/mL)
2,000
1,600
1,200
800
400
0
May
July
Aug
Sept
Oct
Date
Bacilliophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta
Dinophyta


Phytoplankton Composition by Biovolume (um3/mL)
at Wells 01 (Wells Forebay)
Biovolume (um3/mL)
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
May
July
Aug
Sept
Oct
Date
Bacilliophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta
Dinophyta

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 02 Photic
Sample Depth:
Sample Date: 17-May-05

Total Density (#/mL): 664
Total Biovolume (um^3/mL): 224,822
Trophic State Index: 39.1

	Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
1	Asterionella formosa	135	20.4	68,462	30.5
2	Synedra radians	45	6.8	16,236	7.2
3	Nitzschia paleacea	19	2.9	1,894	0.8
4	Nitzschia acicularis	19	2.9	5,412	2.4
5	Melosira italica	19	2.9	23,670	10.5
6	Melosira ambigua	19	2.9	53,507	23.8
7	Fragilaria construens venter	13	1.9	3,402	1.5
8	Fragilaria vaucheria	13	1.9	3,711	1.7
9	Navicula minuscula	6	1.0	290	0.1
10	Achnanthes minutissima	6	1.0	322	0.1
11	Cocconeis disculus	6	1.0	483	0.2
12	Nitzschia capitellata	6	1.0	2,319	1.0
13	Fragilaria leptostauron	6	1.0	1,185	0.5
14	Fragilaria construens	6	1.0	2,165	1.0
15	Achnanthes linearis	6	1.0	850	0.4
16	Fragilaria pinnata	6	1.0	773	0.3
17	Ankistrodesmus falcatus	13	1.9	805	0.4
18	Chrysococcus rufescens	32	4.9	2,738	1.2
19	Kephyrion littorale	26	3.9	2,448	1.1
20	Rhodomonas minuta	200	30.1	3,995	1.8
21	Cryptomonas erosa	58	8.7	30,153	13.4

Aquatic Analysts **Sample ID:** HY42

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 02 Photic
Sample Depth:
Sample Date: 12-Jul-05

Total Density (#/mL): 902
Total Biovolume (um^3/mL): 372,447
Trophic State Index: 42.7

	Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
2	Asterionella formosa	95	10.5	45,955	12.3
3	Synedra radians	47	5.3	17,091	4.6
5	Tabellaria fenestrata	32	3.5	205,086	55.1
6	Achnanthes minutissima	32	3.5	1,582	0.4
7	Diatoma tenue elongatum	16	1.8	11,394	3.1
8	Melosira ambigua	16	1.8	18,641	5.0
9	Cyclotella ocellata	16	1.8	1,978	0.5
10	Fragilaria construens venter	8	0.9	760	0.2
12	Synedra delicatissima	8	0.9	5,222	1.4
13	Fragilaria pinnata	8	0.9	475	0.1
14	Fragilaria crotonensis	8	0.9	19,939	5.4
15	Navicula mutica	8	0.9	435	0.1
16	Cocconeis placentula	8	0.9	3,640	1.0
17	Navicula decussis	8	0.9	1,519	0.4
18	Nitzschia acicularis	8	0.9	2,215	0.6
19	Cymbella minuta	8	0.9	2,928	0.8
20	Navicula cryptocephala	8	0.9	1,464	0.4
21	Synedra rumpens	8	0.9	1,108	0.3
1	Rhodomonas minuta	514	57.0	10,286	2.8
4	Cryptomonas erosa	40	4.4	20,572	5.5
11	Unidentified flagellate	8	0.9	158	0.0

Aquatic Analysts **Sample ID:** HY55

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 02 Photic
Sample Depth:
Sample Date: 17-Aug-05

Total Density (#/mL): 752
Total Biovolume (um^3/mL): 231,756
Trophic State Index: 39.3

	Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
2	Achnanthes minutissima	97	12.9	4,849	2.1
4	Fragilaria construens venter	30	4.0	3,492	1.5
5	Tabellaria fenestrata	24	3.2	58,194	25.1
6	Melosira ambigua	18	2.4	64,268	27.7
7	Synedra radians	18	2.4	6,547	2.8
8	Achnanthes lanceolata	12	1.6	2,182	0.9
9	Cocconeis placentula	12	1.6	5,577	2.4
10	Fragilaria leptostauron	12	1.6	2,231	1.0
11	Synedra rumpens	12	1.6	2,546	1.1
12	Stephanodiscus hantzschii	12	1.6	1,455	0.6
13	Eunotia pectinalis	6	0.8	4,365	1.9
14	Navicula cryptocephala veneta	6	0.8	576	0.2
15	Navicula gregaria	6	0.8	1,061	0.5
16	Fragilaria pinnata	6	0.8	364	0.2
17	Fragilaria crotonensis	6	0.8	10,184	4.4
18	Navicula radiosa	6	0.8	1,970	0.9
21	Cyclotella stelligera	6	0.8	333	0.1
22	Synedra ulna	6	0.8	12,063	5.2
23	Cymbella muelleri	6	0.8	2,425	1.0
24	Cymbella minuta	6	0.8	2,243	1.0
19	Scenedesmus quadricauda	6	0.8	1,576	0.7
20	Oocystis pusilla	6	0.8	1,309	0.6
1	Rhodomonas minuta	364	48.4	7,274	3.1
3	Cryptomonas erosa	67	8.9	34,674	15.0

Aquatic Analysts **Sample ID:** HY67

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 02 Photic
Sample Depth:
Sample Date: 17-Aug-05

Total Density (#/mL): 940
Total Biovolume (um^3/mL): 322,013
Trophic State Index: 41.7

	Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
2	Achnanthes minutissima	117	12.5	5,872	1.8
4	Fragilaria construens venter	41	4.4	5,919	1.8
5	Cocconeis placentula	35	3.8	16,208	5.0
6	Stephanodiscus hantzschii	29	3.1	3,523	1.1
7	Tabellaria fenestrata	23	2.5	95,838	29.8
8	Synedra radians	23	2.5	8,456	2.6
9	Melosira italica	12	1.3	49,786	15.5
10	Synedra rumpens	12	1.3	1,644	0.5
11	Fragilaria pinnata	12	1.3	1,057	0.3
12	Fragilaria construens	12	1.3	7,893	2.5
13	Nitzschia acicularis	12	1.3	3,289	1.0
14	Fragilaria crotonensis	12	1.3	49,328	15.3
15	Diatoma tenue elongatum	6	0.6	4,228	1.3
16	Cymbella microcephala	6	0.6	311	0.1
17	Amphora perpusilla	6	0.6	975	0.3
18	Navicula cryptocephala veneta	6	0.6	558	0.2
19	Cymbella minuta	6	0.6	2,173	0.7
20	Synedra parasitica	6	0.6	822	0.3
22	Navicula gregaria	6	0.6	1,028	0.3
23	Gomphonema subclavatum	6	0.6	3,523	1.1
24	Nitzschia frustulum	6	0.6	705	0.2
25	Nitzschia paleacea	6	0.6	575	0.2
26	Fragilaria leptostauron	6	0.6	1,081	0.3
21	Oocystis pusilla	6	0.6	5,074	1.6
27	Ankistrodesmus falcatus	6	0.6	147	0.0
28	Kephyrion littorale	6	0.6	558	0.2
1	Rhodomonas minuta	435	46.3	8,691	2.7
3	Cryptomonas erosa	82	8.8	42,751	13.3

Aquatic Analysts **Sample ID:** HY68

Sample: Wells Res
Sample Station: Wells 02 Photic
Sample Depth:
Sample Date: 7-Sep-05

Total Density (#/mL): 1,008
Total Biovolume (um^3/mL): 238,045
Trophic State Index: 39.5

	Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
2	Stephanodiscus hantzschii	91	9.0	10,915	4.6
4	Achnanthes minutissima	53	5.3	2,653	1.1
5	Cocconeis placentula	38	3.8	17,434	7.3
6	Synedra radians	30	3.0	10,915	4.6
7	Cyclotella stelligera	30	3.0	1,668	0.7
8	Synedra rumpens	23	2.3	4,139	1.7
9	Achnanthes linearis	23	2.3	3,002	1.3
10	Navicula gregaria	8	0.8	1,326	0.6
12	Gomphonema angustatum	8	0.8	1,364	0.6
14	Cymbella minuta	8	0.8	2,805	1.2
15	Diatoma tenue elongatum	8	0.8	5,457	2.3
17	Fragilaria crotonensis	8	0.8	101,873	42.8
18	Fragilaria leptostauron	8	0.8	2,789	1.2
19	Melosira granulata angustissima	8	0.8	17,055	7.2
13	Scenedesmus quadricauda	8	0.8	985	0.4
16	Sphaerocystis schroeteri	8	0.8	4,245	1.8
11	Kephyrion littorale	8	0.8	720	0.3
20	Rhizosolenia eriensis	8	0.8	720	0.3
1	Rhodomonas minuta	568	56.4	12,507	5.3
3	Cryptomonas erosa	68	6.8	35,474	14.9

Aquatic Analysts **Sample ID:** HY80

Phytoplankton Sample

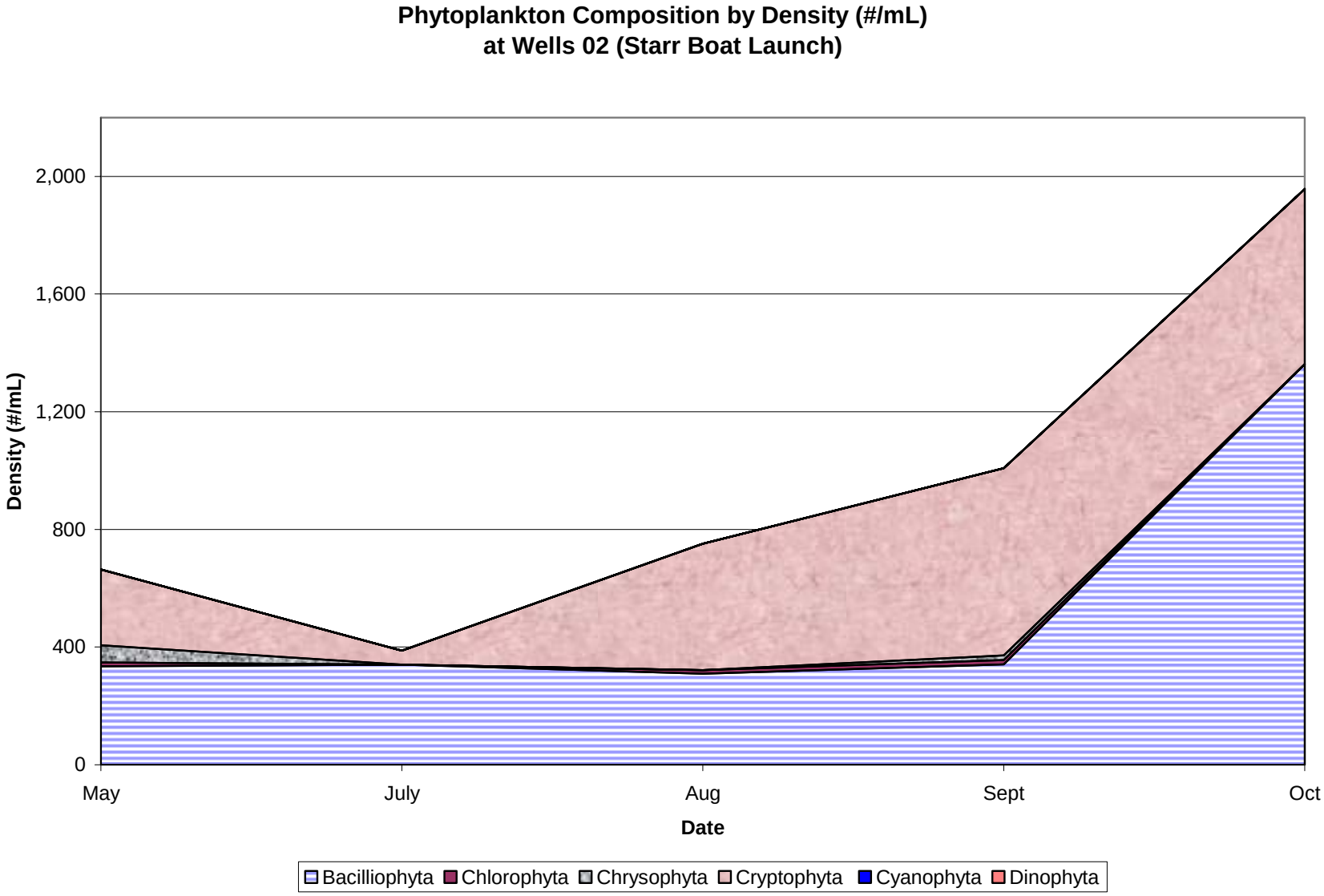
Analysis

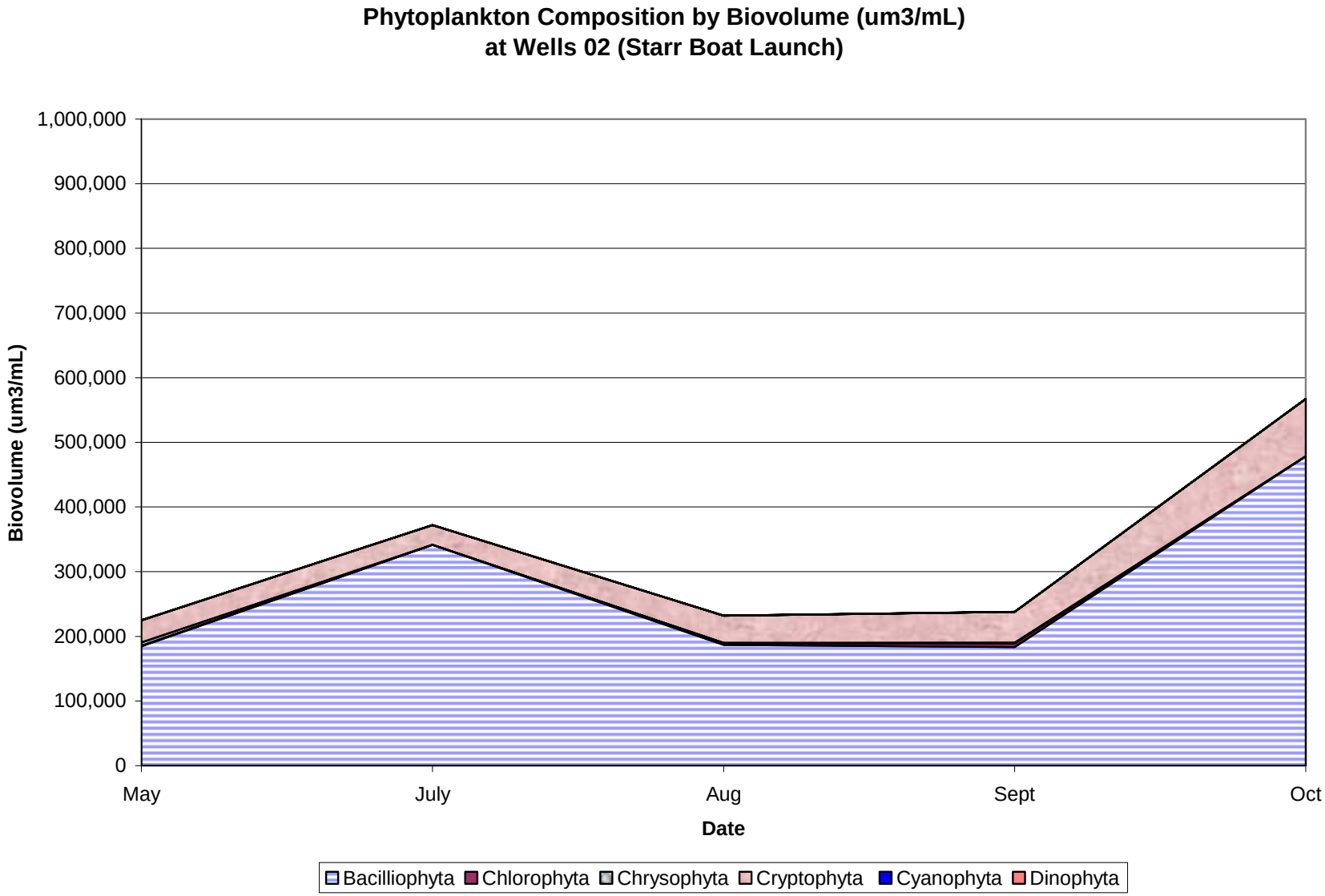
Sample: Wells Res
Sample Station: Wells 02 Photic
Sample Depth:
Sample Date: 18-Oct-05

Total Density (#/mL): 1,957
Total Biovolume (um^3/mL): 566,973
Trophic State Index: 45.8

	Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
2	Achnanthes minutissima	357	18.3	17,870	3.2
3	Cocconeis placentula	272	13.9	125,259	22.1
5	Gomphonema angustatum	85	4.3	15,317	2.7
6	Fragilaria construens venter	68	3.5	13,724	2.4
7	Navicula cryptocephala veneta	51	2.6	4,850	0.9
8	Tabellaria fenestrata	51	2.6	122,536	21.6
9	Cymbella minuta	51	2.6	18,891	3.3
10	Stephanodiscus hantzschii	51	2.6	6,127	1.1
11	Achnanthes lanceolata	34	1.7	6,127	1.1
12	Synedra radians	34	1.7	18,380	3.2
13	Tabellaria flocculosa	34	1.7	20,082	3.5
14	Nitzschia sp.	34	1.7	4,085	0.7
15	Achnanthes clevei	17	0.9	2,553	0.5
16	Navicula decussis	17	0.9	3,268	0.6
17	Asterionella formosa	17	0.9	7,488	1.3
18	Nitzschia dissipata	17	0.9	4,578	0.8
19	Anomoeoneis vitrea	17	0.9	2,042	0.4
20	Melosira varians	17	0.9	11,062	2.0
21	Melosira ambigua	17	0.9	20,048	3.5
22	Amphora perpusilla	17	0.9	2,825	0.5
23	Fragilaria vaucheria	17	0.9	4,901	0.9
24	Fragilaria pinnata	17	0.9	1,021	0.2
25	Navicula cryptocephala	17	0.9	3,148	0.6
26	Melosira granulata angustissima	17	0.9	12,764	2.3
27	Fragilaria crotonensis	17	0.9	28,592	5.0
28	Cyclotella stelligera	17	0.9	936	0.2
1	Rhodomonas minuta	442	22.6	8,850	1.6
4	Cryptomonas erosa	153	7.8	79,648	14.0

Aquatic Analysts **Sample ID:** HY93


Phytoplankton Composition by Density (#/mL)
at Wells 02 (Starr Boat Launch)
Density (#/mL)
2,000
1,600
1,200
800
400
0
May
July
Aug
Sept
Oct
Date
Bacilliophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta
Dinophyta


Phytoplankton Composition by Biovolume (um3/mL)
at Wells 02 (Starr Boat Launch)
Biovolume (um3/mL)
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
May
July
Aug
Sept
Oct
Date
Bacilliophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta
Dinophyta

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 03 Photic
Sample Depth:
Sample Date: 17-May-05

Total Density (#/mL): 2,016
Total Biovolume (um^3/mL): 624,838
Trophic State Index: 46.5

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Achnanthes minutissima	990	49.1	54,474	8.7
Achnanthes linearis	336	16.7	44,357	7.1
Cymbella minuta	301	14.9	122,371	19.6
Diatoma vulgare	124	6.1	242,656	38.8
Nitzschia linearis	35	1.8	53,908	8.6
Cymbella sinuata	35	1.8	4,952	0.8
Navicula cryptocephala	18	0.9	3,272	0.5
Achnanthes hauckiana	18	0.9	849	0.1
Cymbella microcephala	18	0.9	937	0.2
Nitzschia microcephala	18	0.9	1,769	0.3
Fragilaria leptostauron	18	0.9	3,254	0.5
Cymbella affinis	18	0.9	31,835	5.1
Fragilaria vaucheria	18	0.9	5,094	0.8
Amphora perpusilla	18	0.9	2,936	0.5
Cymbella tumida	18	0.9	44,216	7.1
Gomphonema angustatum	18	0.9	3,184	0.5
Navicula pupula	18	0.9	4,775	0.8

Aquatic Analysts **Sample ID:** HY43

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 03 Photic
Sample Depth:
Sample Date: 12-Jul-05

Total Density (#/mL): 1,944
Total Biovolume (um^3/mL): 475,370
Trophic State Index: 44.5

	Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
1	Achnanthes minutissima	1,322	68.0	66,095	13.9
2	Cymbella minuta	311	16.0	115,083	24.2
3	Cymbella microcephala	47	2.4	2,473	0.5
4	Navicula cryptocephala veneta	47	2.4	4,432	0.9
5	Diatoma vulgare	47	2.4	91,444	19.2
6	Cymbella affinis	31	1.6	55,986	11.8
7	Navicula gregaria	16	0.8	2,722	0.6
8	Achnanthes linearis	16	0.8	2,053	0.4
9	Achnanthes hauckiana	16	0.8	746	0.2
10	Navicula tripunctata	16	0.8	17,418	3.7
11	Cymbella cistula	16	0.8	93,310	19.6
12	Denticula elegans	16	0.8	11,664	2.5
13	Fragilaria construens venter	16	0.8	4,479	0.9
15	Cocconeis placentula	16	0.8	7,154	1.5
14	Rhodomonas minuta	16	0.8	311	0.1

Aquatic Analysts **Sample ID:** HY56

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 03 Photic
Sample Depth:
Sample Date: 17-Aug-05

Total Density (#/mL): 9,977
Total Biovolume (um^3/mL): 1,455,158
Trophic State Index: 52.6

	Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
1	Achnanthes minutissima	6,833	68.5	341,667	23.5
2	Achnanthes linearis	888	8.9	117,260	8.1
3	Cymbella minuta	615	6.2	227,550	15.6
4	Gomphonema angustatum	205	2.1	36,900	2.5
5	Synedra rumpens	137	1.4	19,133	1.3
6	Cymbella sinuata	137	1.4	19,133	1.3
7	Diatoma tenue	137	1.4	39,633	2.7
8	Cymbella affinis	137	1.4	246,000	16.9
9	Diatoma vulgare	137	1.4	267,867	18.4
10	Navicula cryptocephala veneta	137	1.4	12,983	0.9
12	Pinnularia sp.	68	0.7	27,333	1.9
13	Amphora perpusilla	68	0.7	11,343	0.8
16	Cymbella microcephala	68	0.7	3,622	0.2
17	Cymbella sp.	68	0.7	23,917	1.6
18	Nitzschia fonticola	68	0.7	2,870	0.2
19	Achnanthes hauckiana	68	0.7	3,280	0.2
11	Scenedesmus quadricauda	68	0.7	17,767	1.2
14	Rhodomonas minuta	68	0.7	1,367	0.1
15	Cryptomonas erosa	68	0.7	35,533	2.4

Aquatic Analysts **Sample ID:** HY69

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 03 Photic
Sample Depth:
Sample Date: 7-Sep-05

Total Density (#/mL): 1,493
Total Biovolume (um^3/mL): 240,553
Trophic State Index: 39.6

	Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
1	Achnanthes minutissima	518	34.7	25,877	10.8
4	Cymbella minuta	59	4.0	21,885	9.1
5	Stephanodiscus hantzschii	59	4.0	7,098	3.0
6	Cocconeis placentula	30	2.0	13,604	5.7
7	Cymbella microcephala	30	2.0	1,567	0.7
8	Navicula tripunctata	15	1.0	16,561	6.9
9	Navicula cryptocephala veneta	15	1.0	1,405	0.6
10	Cymbella delicatula	15	1.0	11,830	4.9
11	Melosira granulata	15	1.0	24,398	10.1
12	Synedra rumpens	15	1.0	2,070	0.9
13	Diatoma tenue	15	1.0	4,288	1.8
15	Denticula elegans	15	1.0	11,090	4.6
16	Nitzschia capitellata	15	1.0	5,323	2.2
17	Synedra radians	15	1.0	5,323	2.2
18	Nitzschia frustulum	15	1.0	1,774	0.7
19	Fragilaria construens venter	15	1.0	710	0.3
20	Cyclotella ocellata	15	1.0	1,848	0.8
21	Cyclotella stelligera	15	1.0	813	0.3
22	Achnanthes linearis	15	1.0	1,952	0.8
23	Melosira granulata angustissima	15	1.0	7,393	3.1
2	Rhodomonas minuta	488	32.7	9,759	4.1
3	Cryptomonas erosa	74	5.0	38,446	16.0
14	Cryptomonas ovata	15	1.0	25,537	10.6

Aquatic Analysts **Sample ID:** HY81

Phytoplankton Sample

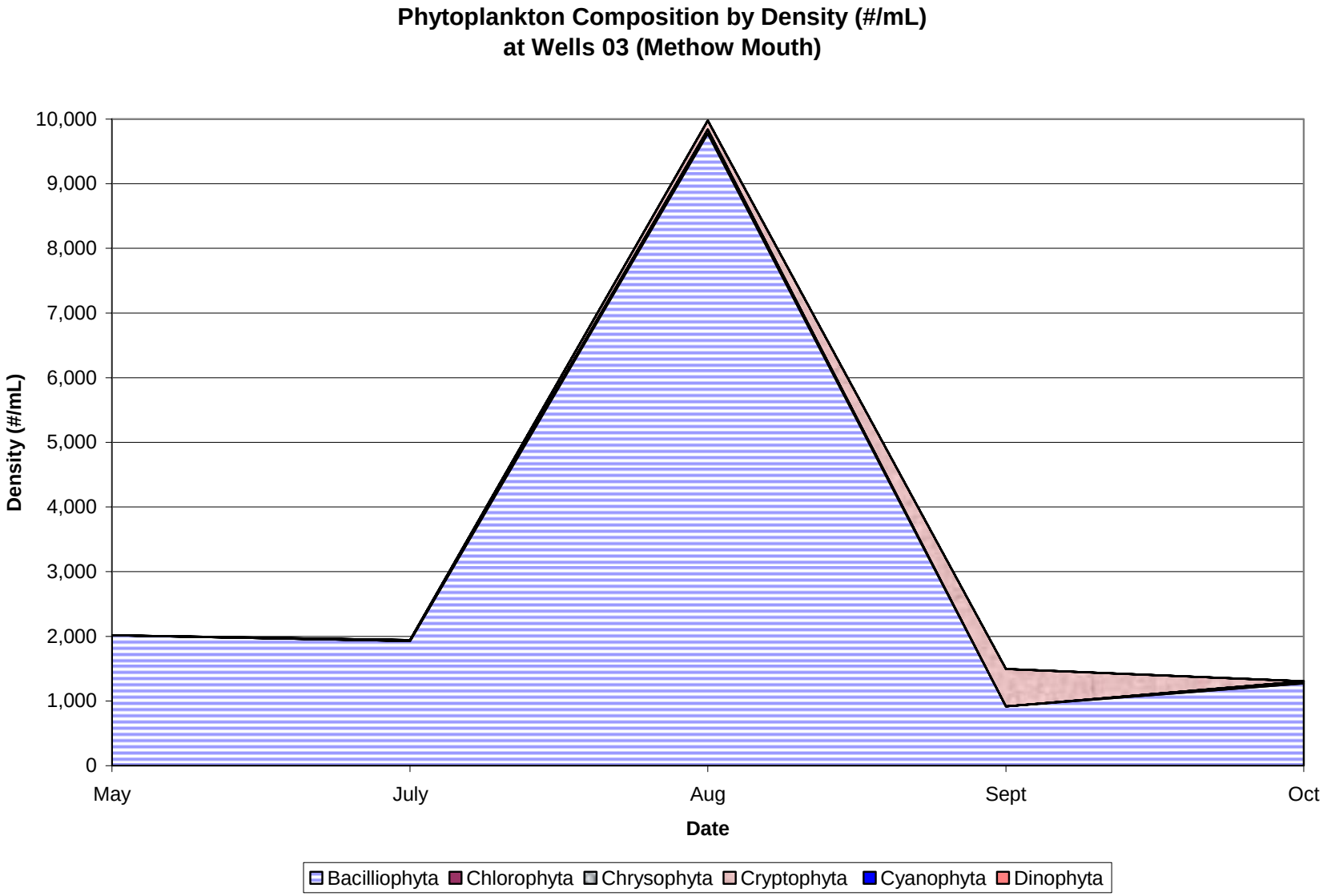
Analysis

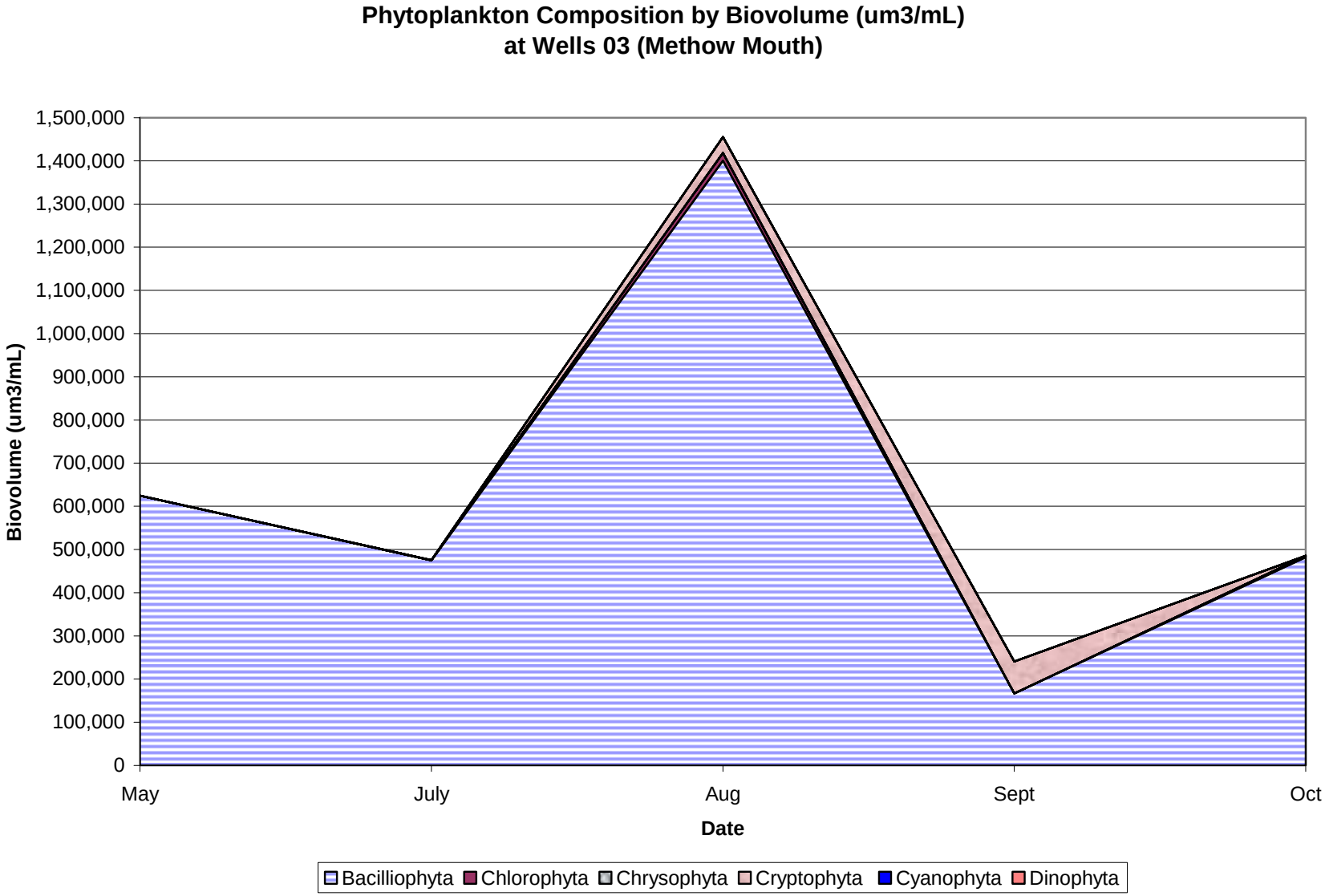
Sample: Wells Res
Sample Station: Wells 03 Photic
Sample Depth:
Sample Date: 18-Oct-05

Total Density (#/mL): 1,306
Total Biovolume (um^3/mL): 485,727
Trophic State Index: 44.6

	Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
1	Achnanthes minutissima	653	50.0	32,638	6.7
2	Cymbella delicatula	285	21.8	227,874	46.9
3	Diatoma vulgare	59	4.5	116,311	23.9
4	Denticula elegans	47	3.6	35,605	7.3
5	Cocconeis placentula	36	2.7	16,378	3.4
7	Cymbella minuta	24	1.8	8,783	1.8
8	Nitzschia paleacea	24	1.8	2,326	0.5
9	Cymbella microcephala	24	1.8	1,258	0.3
10	Nitzschia frustulum	24	1.8	2,848	0.6
11	Gomphonema angustatum	24	1.8	4,273	0.9
12	Synedra ulna	12	0.9	23,618	4.9
13	Fragilaria leptostauron	12	0.9	2,184	0.4
14	Synedra rumpens	12	0.9	1,662	0.3
15	Stephanodiscus hantzschii	12	0.9	1,424	0.3
16	Navicula pupula	12	0.9	3,204	0.7
17	Cymbella sinuata	12	0.9	1,662	0.3
6	Ankistrodesmus falcatus	24	1.8	593	0.1
18	Scenedesmus quadricauda	12	0.9	3,086	0.6

Aquatic Analysts **Sample ID:** HY94


Phytoplankton Composition by Density (#/mL)
at Wells 03 (Methow Mouth)
Density (#/mL)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
May
July
Aug
Sept
Oct
Date
Bacilliophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta
Dinophyta


Phytoplankton Composition by Biovolume (um3/mL)
at Wells 03 (Methow Mouth)
Biovolume (um3/mL)
1,500,000
1,400,000
1,300,000
1,200,000
1,100,000
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
May
July
Aug
Sept
Oct
Date
Bacilliophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta
Dinophyta

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 04 Photic
Sample Depth:
Sample Date: 17-May-05

Total Density (#/mL): 427
Total Biovolume (um^3/mL): 224,723
Trophic State Index: 39.1

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Asterionella formosa	112	26.2	61,454	27.3
Synedra radians	46	10.7	16,455	7.3
Cymbella minuta	36	8.3	13,154	5.9
Achnanthes minutissima	30	7.1	1,524	0.7
Synedra rumpens	20	4.8	2,844	1.3
Stephanodiscus astraea minutula	10	2.4	3,555	1.6
Melosira ambigua	10	2.4	17,949	8.0
Fragilaria pinnata	10	2.4	914	0.4
Navicula decussis	10	2.4	1,950	0.9
Synedra ulna	10	2.4	20,214	9.0
Fragilaria construens venter	10	2.4	1,219	0.5
Cymbella affinis	10	2.4	18,284	8.1
Synedra delicatissima	5	1.2	3,352	1.5
Achnanthes clevei	5	1.2	762	0.3
Gomphonema olivaceum	5	1.2	1,143	0.5
Nitzschia frustulum	5	1.2	609	0.3
Nitzschia capitellata	5	1.2	1,828	0.8
Achnanthes lanceolata	5	1.2	914	0.4
Nitzschia paleacea	5	1.2	498	0.2
Navicula anglica	5	1.2	1,828	0.8
Amphora perpusilla	5	1.2	843	0.4
Navicula cryptocephala veneta	5	1.2	482	0.2
Nitzschia sp.	5	1.2	1,219	0.5
Cymbella sinuata	5	1.2	711	0.3
Navicula cryptocephala	5	1.2	940	0.4
Gomphonema angustatum	5	1.2	914	0.4
Navicula pupula	5	1.2	1,371	0.6
Diatoma vulgare	5	1.2	9,955	4.4
Fragilaria crotonensis	5	1.2	34,130	15.2
Cyclotella ocellata	5	1.2	635	0.3
Crucigenia quadrata	10	2.4	2,159	1.0
Kephyrion littorale	5	1.2	482	0.2
Chrysococcus rufescens	5	1.2	432	0.2

Aquatic Analysts **Sample ID:** HY44

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 04 Photic
Sample Depth:
Sample Date: 12-Jul-05

Total Density (#/mL): 733
Total Biovolume (um^3/mL): 414,839
Trophic State Index: 43.5

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Synedra radians	81	11.0	31,944	7.7
Asterionella formosa	51	7.0	22,587	5.4
Amphora perpusilla	29	4.0	4,869	1.2
Fragilaria vaucheria	22	3.0	6,336	1.5
Achnanthes minutissima	22	3.0	1,100	0.3
Melosira ambigua	22	3.0	47,945	11.6
Fragilaria crotonensis	22	3.0	123,816	29.8
Diatoma tenue elongatum	15	2.0	10,560	2.5
Nitzschia paleacea	15	2.0	1,437	0.3
Cyclotella kutzingiana	15	2.0	1,687	0.4
Cyclotella comta	15	2.0	33,293	8.0
Nitzschia dissipata	7	1.0	1,973	0.5
Fragilaria construens	7	1.0	1,643	0.4
Navicula capitata	7	1.0	3,520	0.8
Synedra cyclopum	7	1.0	12,393	3.0
Fragilaria leptostauron	7	1.0	2,699	0.7
Synedra rumpens	7	1.0	1,027	0.2
Achnanthes lanceolata	7	1.0	1,320	0.3
Ulothrix sp.	22	3.0	19,360	4.7
Selenastrum minutum	7	1.0	147	0.0
Rhodomonas minuta	293	40.0	5,867	1.4
Cryptomonas erosa	22	3.0	11,440	2.8
Anabaena circinalis	15	2.0	44,000	10.6
Aphanizomenon flos-aquae	7	1.0	9,211	2.2
Anabaena sp.	7	1.0	14,667	3.5

Aquatic Analysts **Sample ID:** HY57

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 04 Photic
Sample Depth:
Sample Date: 12-Jul-05

Total Density (#/mL): 482
Total Biovolume (um^3/mL): 279,195
Trophic State Index: 40.7

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Synedra radians	28	5.9	10,211	3.7
Asterionella formosa	23	4.7	8,487	3.0
Fragilaria crotonensis	17	3.5	142,958	51.2
Diatoma tenue elongatum	11	2.4	8,169	2.9
Nitzschia paleacea	11	2.4	1,112	0.4
Amphora perpusilla	11	2.4	10,359	3.7
Achnanthes minutissima	11	2.4	567	0.2
Melosira varians	6	1.2	18,437	6.6
Tabellaria fenestrata	6	1.2	27,230	9.8
Navicula cryptocephala veneta	6	1.2	539	0.2
Nitzschia palea	6	1.2	1,021	0.4
Navicula tripunctata	6	1.2	6,354	2.3
Melosira italica	6	1.2	5,344	1.9
Navicula minima	6	1.2	250	0.1
Achnanthes clevei	6	1.2	851	0.3
Fragilaria vaucheria	6	1.2	1,634	0.6
Nitzschia dissipata	6	1.2	1,526	0.5
Fragilaria construens venter	6	1.2	817	0.3
Synedra rumpens	6	1.2	794	0.3
Ankistrodesmus falcatus	6	1.2	284	0.1
Chlamydomonas sp.	6	1.2	1,844	0.7
Kephyrion littorale	11	2.4	1,078	0.4
Kephyrion obliquum	6	1.2	823	0.3
Chrysococcus rufescens	6	1.2	482	0.2
Rhodomonas minuta	221	45.9	4,425	1.6
Cryptomonas erosa	45	9.4	23,599	8.5

Aquatic Analysts **Sample ID:** HY58

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 04 Photic
Sample Depth:
Sample Date: 17-Aug-05

Total Density (#/mL): 624
Total Biovolume (um^3/mL): 93,960
Trophic State Index: 32.9

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Achnanthes minutissima	64	10.2	3,177	3.4
Synedra radians	40	6.5	14,556	15.5
Stephanodiscus hantzschii	17	2.8	2,079	2.2
Diatoma tenue elongatum	12	1.9	8,318	8.9
Cymbella minuta	12	1.9	4,274	4.5
Cocconeis placentula	12	1.9	5,314	5.7
Achnanthes linearis	12	1.9	1,525	1.6
Achnanthes hauckiana	6	0.9	277	0.3
Achnanthes clevei	6	0.9	866	0.9
Achnanthes flexella	6	0.9	2,801	3.0
Cyclotella ocellata	6	0.9	722	0.8
Melosira ambigua	6	0.9	13,609	14.5
Fragilaria crotonensis	6	0.9	4,852	5.2
Gomphonema acuminatum	6	0.9	10,050	10.7
Nitzschia paleacea	6	0.9	566	0.6
Nitzschia communis	6	0.9	260	0.3
Navicula cryptocephala	6	0.9	1,069	1.1
Navicula cryptocephala veneta	6	0.9	549	0.6
Fragilaria vaucheria	6	0.9	1,664	1.8
Cyclotella stelligera	6	0.9	318	0.3
Cyclotella kutzingiana	6	0.9	664	0.7
Ankistrodesmus falcatus	6	0.9	144	0.2
Kephyrion sp.	6	0.9	364	0.4
Rhodomonas minuta	347	55.6	6,931	7.4
Cryptomonas erosa	17	2.8	9,011	9.6

Aquatic Analysts **Sample ID:** HY70

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 04 Photic
Sample Depth:
Sample Date: 7-Sep-05

Total Density (#/mL): 635
Total Biovolume (um^3/mL): 135,294
Trophic State Index: 35.5

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Cocconeis placentula	34	5.4	15,657	11.6
Synedra radians	34	5.4	12,254	9.1
Stephanodiscus hantzschii	28	4.5	3,404	2.5
Achnanthes minutissima	23	3.6	1,135	0.8
Cyclotella stelligera	11	1.8	624	0.5
Cocconeis pediculus	11	1.8	5,900	4.4
Cymbella minuta	11	1.8	4,198	3.1
Navicula capitata	11	1.8	5,446	4.0
Synedra ulna	11	1.8	22,578	16.7
Achnanthes clevei	6	0.9	851	0.6
Diatoma vulgare	6	0.9	11,119	8.2
Navicula cryptocephala veneta	6	0.9	539	0.4
Nitzschia fonticola	6	0.9	238	0.2
Fragilaria pinnata	6	0.9	681	0.5
Oocystis pusilla	6	0.9	2,451	1.8
Rhodomonas minuta	340	53.6	6,808	5.0
Cryptomonas erosa	79	12.5	41,299	30.5
Unidentified flagellate	6	0.9	113	0.1

Aquatic Analysts **Sample ID:** HY82

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 04 Photic
Sample Depth:
Sample Date: Sept. 7, 2005

Total Density (#/mL): 777
Total Biovolume (um^3/mL): 128,347
Trophic State Index: 35.1

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Synedra radians	33	4.2	11,851	9.2
Synedra rumpens	20	2.5	2,765	2.2
Achnanthes minutissima	13	1.7	988	0.8
Cyclotella stelligera	13	1.7	724	0.6
Cocconeis placentula	13	1.7	6,057	4.7
Diploneis elliptica	7	0.8	1,712	1.3
Gomphonema subclavatum	7	0.8	3,950	3.1
Fragilaria pinnata	7	0.8	790	0.6
Stephanodiscus hantzschii	7	0.8	790	0.6
Nitzschia palea	7	0.8	1,185	0.9
Frustulia rhomboides	7	0.8	7,111	5.5
Oocystis pusilla	13	1.7	5,689	4.4
Sphaerocystis schroeteri	7	0.8	3,687	2.9
Ankistrodesmus falcatus	7	0.8	165	0.1
Kephyrion littorale	20	2.5	1,876	1.5
Rhodomonas minuta	467	60.2	9,349	7.3
Cryptomonas erosa	125	16.1	65,049	50.7
Glenodinium sp.	7	0.8	4,609	3.6

Aquatic Analysts **Sample ID:** HY83

Phytoplankton Sample

Analysis

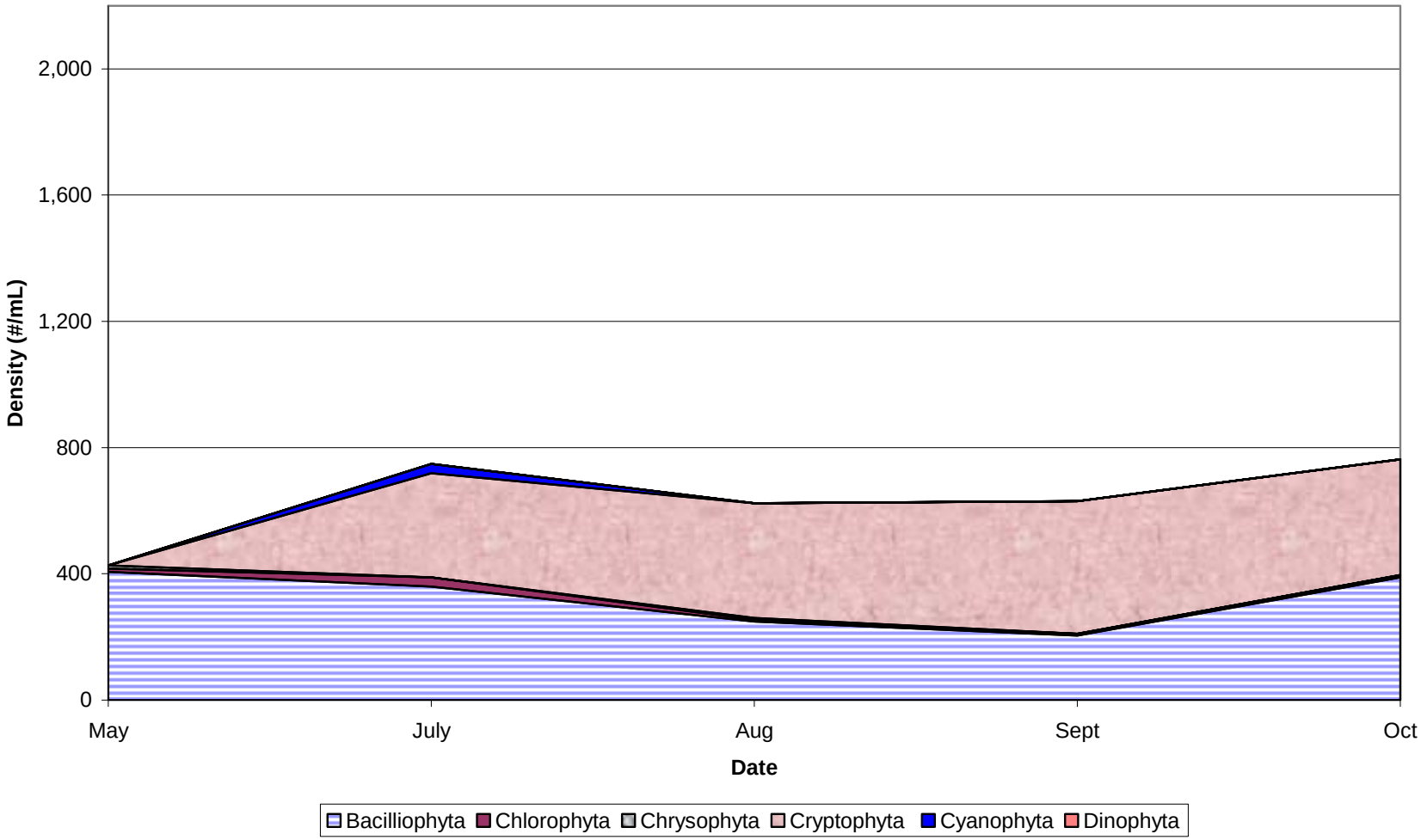
Sample: Wells Res
Sample Station: Wells 04 Photic
Sample Depth:
Sample Date: 18-Oct-05

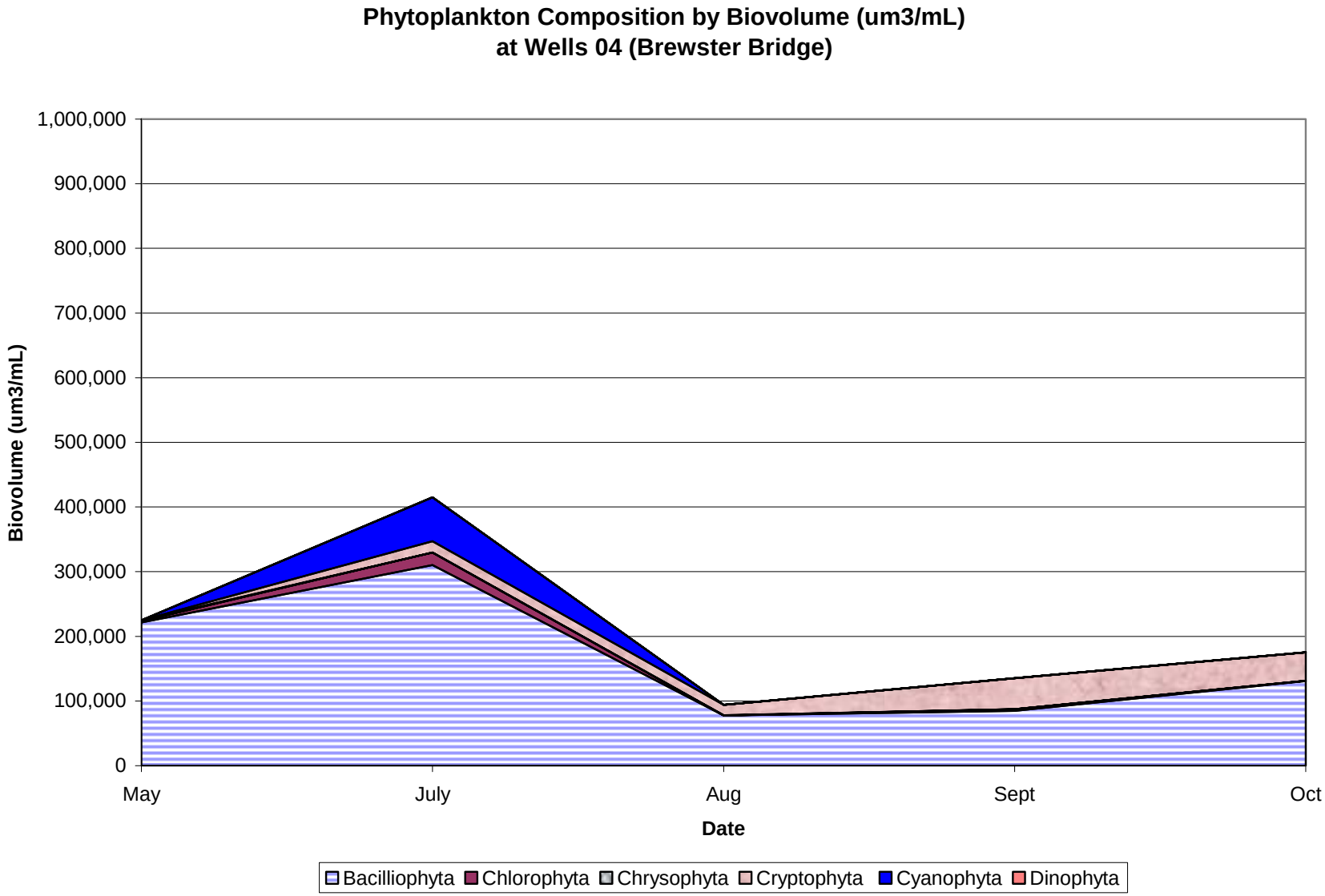
Total Density (#/mL): 763
Total Biovolume (um^3/mL): 175,215
Trophic State Index: 37.3

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Achnanthes minutissima	73	9.6	3,667	2.1
Cocconeis placentula	66	8.7	30,360	17.3
Synedra radians	29	3.8	10,560	6.0
Synedra rumpens	22	2.9	3,080	1.8
Achnanthes clevei	15	1.9	2,200	1.3
Fragilaria vaucheria	7	1.0	2,112	1.2
Fragilaria pinnata	7	1.0	440	0.3
Achnanthes linearis	7	1.0	968	0.6
Fragilaria construens venter	7	1.0	352	0.2
Melosira varians	7	1.0	9,533	5.4
Diatoma tenue elongatum	7	1.0	10,560	6.0
Tabellaria fenestrata	7	1.0	17,600	10.0
Cyclotella stelligera	7	1.0	403	0.2
Gomphonema clevei	7	1.0	660	0.4
Melosira ambigua	7	1.0	21,597	12.3
Asterionella formosa	7	1.0	4,840	2.8
Navicula cryptocephala veneta	7	1.0	697	0.4
Cyclotella kutzingiana	7	1.0	843	0.5
Stephanodiscus hantzschii	88	11.5	10,560	6.0
Ankistrodesmus falcatus	7	1.0	183	0.1
Rhodomonas minuta	293	38.5	5,867	3.3
Cryptomonas erosa	73	9.6	38,133	21.8

Aquatic Analysts **Sample ID:** HY95

Phytoplankton Composition by Density (#/mL)
at Wells 04 (Brewster Bridge)




Phytoplankton Composition by Biovolume (um3/mL)
at Wells 04 (Brewster Bridge)
Biovolume (um3/mL)
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
May
July
Aug
Sept
Oct
Date
Bacilliophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta
Dinophyta

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 05 Photic
Sample Depth:
Sample Date: 17-May-05

Total Density (#/mL): 948
Total Biovolume (um^3/mL): 573,754
Trophic State Index: 45.8

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Cymbella minuta	217	22.9	80,267	14.0
Achnanthes minutissima	91	9.6	4,567	0.8
Cymbella affinis	80	8.4	143,863	25.1
Diatoma vulgare	57	6.0	111,894	19.5
Navicula gregaria	46	4.8	7,992	1.4
Cocconeis placentula	46	4.8	21,009	3.7
Navicula cryptocephala veneta	34	3.6	3,254	0.6
Fragilaria construens	34	3.6	10,358	1.8
Fragilaria vaucheria	23	2.4	9,865	1.7
Navicula pupula	23	2.4	6,166	1.1
Gomphonema olivaceum	23	2.4	7,707	1.3
Stephanodiscus hantzschii	23	2.4	2,740	0.5
Cyclotella ocellata	23	2.4	2,854	0.5
Fragilaria construens venter	23	2.4	3,836	0.7
Tabellaria fenestrata	11	1.2	27,403	4.8
Navicula cascadensis	11	1.2	685	0.1
Diatoma tenue	11	1.2	3,311	0.6
Synedra ulna	11	1.2	22,721	4.0
Navicula decussis	11	1.2	2,192	0.4
Synedra rumpens	11	1.2	1,598	0.3
Nitzschia paleacea	11	1.2	1,119	0.2
Navicula tripunctata	11	1.2	12,788	2.2
Gomphonema subclavatum	11	1.2	6,851	1.2
Fragilaria pinnata	11	1.2	685	0.1
Gomphonema angustatum	11	1.2	2,055	0.4
Fragilaria leptostauron	11	1.2	2,101	0.4
Cymbella tumida	11	1.2	28,544	5.0
Fragilaria virescens	11	1.2	2,740	0.5
Navicula sp.	11	1.2	1,713	0.3
Achnanthes linearis	11	1.2	1,507	0.3
Cyclotella comta	11	1.2	25,918	4.5
Melosira ambigua	11	1.2	13,450	2.3

Aquatic Analysts **Sample ID:** HY45

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 05 Photic
Sample Depth:
Sample Date: 12-Jul-05

Total Density (#/mL): 911
Total Biovolume (um^3/mL): 214,540
Trophic State Index: 38.8

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Synedra radians	111	12.1	39,824	18.6
Achnanthes minutissima	51	5.6	2,553	1.2
Cymbella minuta	26	2.8	9,445	4.4
Melosira ambigua	17	1.9	35,084	16.4
Synedra parasitica	17	1.9	2,383	1.1
Amphora perpusilla	17	1.9	2,825	1.3
Asterionella formosa	9	0.9	1,872	0.9
Navicula graciloides	9	0.9	3,702	1.7
Nitzschia fonticola	9	0.9	357	0.2
Cocconeis placentula	9	0.9	3,914	1.8
Nitzschia paleacea	9	0.9	834	0.4
Achnanthes flexella	9	0.9	4,127	1.9
Gomphonema angustatum	9	0.9	1,532	0.7
Achnanthes lanceolata	9	0.9	1,532	0.7
Cymbella microcephala	9	0.9	451	0.2
Cymbella tumida	9	0.9	21,274	9.9
Diatoma vulgare	9	0.9	16,678	7.8
Navicula tripunctata	9	0.9	9,531	4.4
Melosira distans alpigena	9	0.9	1,489	0.7
Nitzschia frustulum	9	0.9	1,021	0.5
Ankistrodesmus falcatus	43	4.7	1,489	0.7
Oocystis pusilla	17	1.9	3,676	1.7
Tetrastrum staurogeniaforme	9	0.9	1,838	0.9
Cosmarium sp.	9	0.9	1,787	0.8
Chlamydomonas sp.	9	0.9	2,766	1.3
Kephyrion littorale	68	7.5	6,467	3.0
Kephyrion sp.	43	4.7	2,680	1.2
Kephyrion spirale	17	1.9	1,072	0.5
Rhodomonas minuta	289	31.8	5,786	2.7
Cryptomonas erosa	51	5.6	26,549	12.4

Aquatic Analysts **Sample ID:** HY59

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 05 Photic
Sample Depth:
Sample Date: 17-Aug-05

Total Density (#/mL): 879
Total Biovolume (um^3/mL): 288,991
Trophic State Index: 40.9

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Stephanodiscus hantzschii	127	14.4	15,229	5.3
Achnanthes minutissima	49	5.6	2,440	0.8
Nitzschia paleacea	39	4.4	3,827	1.3
Cyclotella stelligera	20	2.2	1,074	0.4
Diatoma vulgare	20	2.2	38,267	13.2
Navicula anglica	20	2.2	7,029	2.4
Cymbella affinis	20	2.2	35,143	12.2
Cymbella minuta	20	2.2	7,224	2.5
Navicula cryptocephala	20	2.2	3,612	1.2
Nitzschia frustulum	20	2.2	2,343	0.8
Diatoma tenue	20	2.2	5,662	2.0
Cyclotella ocellata	10	1.1	1,220	0.4
Cymbella sinuata	10	1.1	1,367	0.5
Fragilaria construens	10	1.1	8,747	3.0
Cymbella tumida	10	1.1	24,405	8.4
Synedra rumpens	10	1.1	1,367	0.5
Melosira distans alpigena	10	1.1	1,708	0.6
Tabellaria flocculosa	10	1.1	5,760	2.0
Synedra radians	10	1.1	3,514	1.2
Gomphonema angustatum	10	1.1	1,757	0.6
Amphora perpusilla	10	1.1	1,620	0.6
Stephanodiscus astraea minutula	10	1.1	3,417	1.2
Fragilaria crotonensis	10	1.1	65,600	22.7
Achnanthes clevei	10	1.1	1,464	0.5
Selenastrum minutum	10	1.1	195	0.1
Crucigenia quadrata	10	1.1	830	0.3
Chrysococcus rufescens	10	1.1	830	0.3
Rhodomonas minuta	293	33.3	5,857	2.0
Cryptomonas erosa	29	3.3	15,229	5.3
Oscillatoria sp.	10	1.1	9,762	3.4
Glenodinium sp.	10	1.1	6,833	2.4
Euglena sp.	10	1.1	5,662	2.0

Aquatic Analysts **Sample ID:** HY71

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 05 Photic
Sample Depth:
Sample Date: 7-Sep-05

Total Density (#/mL): 1,347
Total Biovolume (um^3/mL): 252,002
Trophic State Index: 39.9

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Stephanodiscus hantzschii	581	43.1	69,689	27.7
Cyclotella stelligera	49	3.7	2,718	1.1
Synedra radians	37	2.8	13,345	5.3
Fragilaria construens venter	37	2.8	3,025	1.2
Cocconeis placentula	25	1.8	11,368	4.5
Achnanthes minutissima	25	1.8	1,236	0.5
Navicula cryptocephala	25	1.8	4,572	1.8
Navicula cryptocephala veneta	25	1.8	2,348	0.9
Cymbella affinis	12	0.9	22,241	8.8
Tabellaria fenestrata	12	0.9	29,655	11.8
Melosira distans alpigena	12	0.9	4,325	1.7
Gomphonema olivaceum	12	0.9	2,780	1.1
Cymbella minuta	12	0.9	4,572	1.8
Nitzschia sinuata	12	0.9	3,089	1.2
Cyclotella meneghiniana	12	0.9	4,695	1.9
Melosira granulata angustissima	12	0.9	12,356	4.9
Melosira varians	12	0.9	16,063	6.4
Diatoma vulgare	12	0.9	24,218	9.6
Ankistrodesmus falcatus	12	0.9	309	0.1
Scenedesmus quadricauda	12	0.9	1,606	0.6
Kephyrion littorale	49	3.7	4,695	1.9
Rhodomonas minuta	334	24.8	6,672	2.6
Cryptomonas erosa	12	0.9	6,425	2.5

Aquatic Analysts **Sample ID:** HY84

Phytoplankton Sample

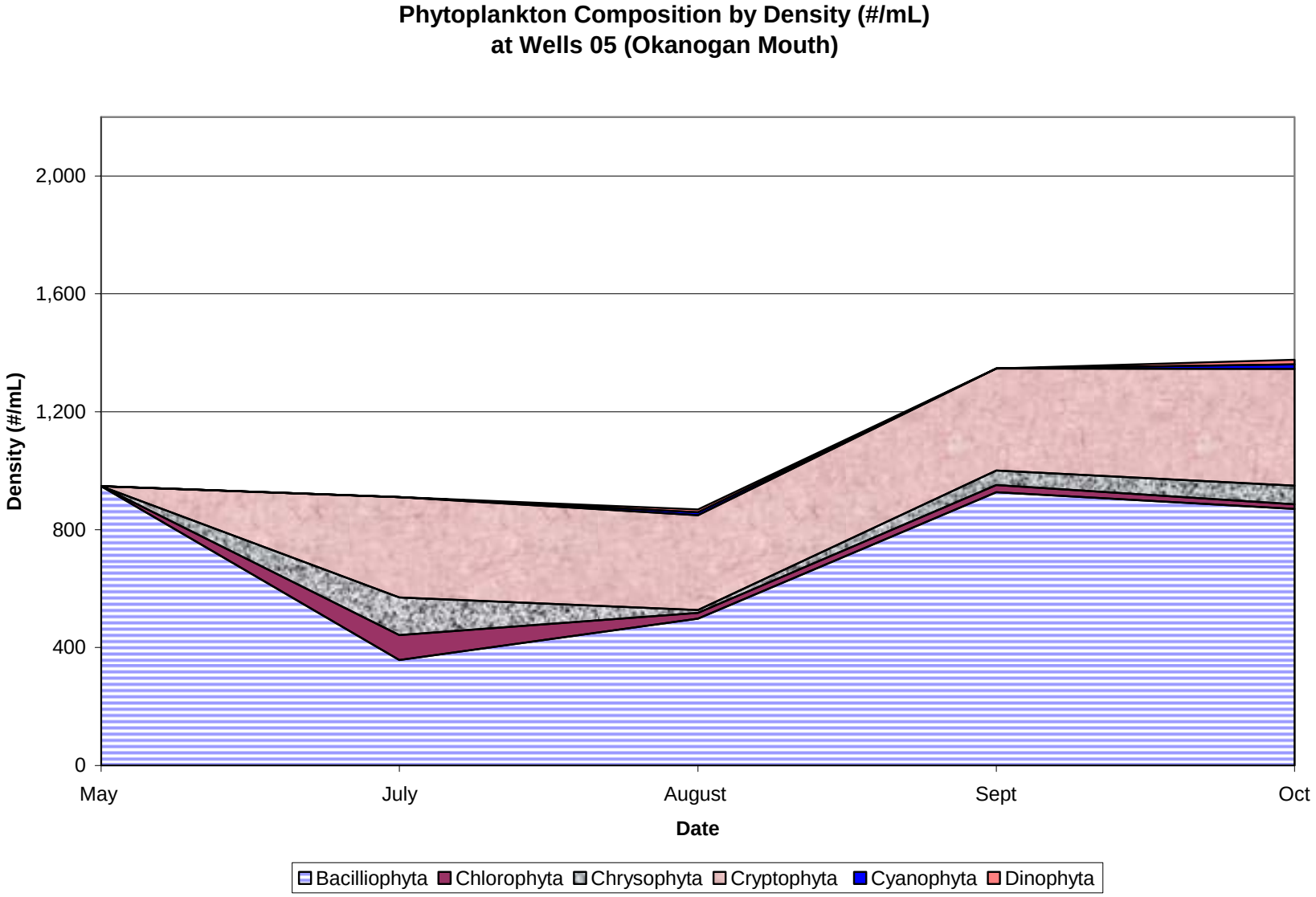
Analysis

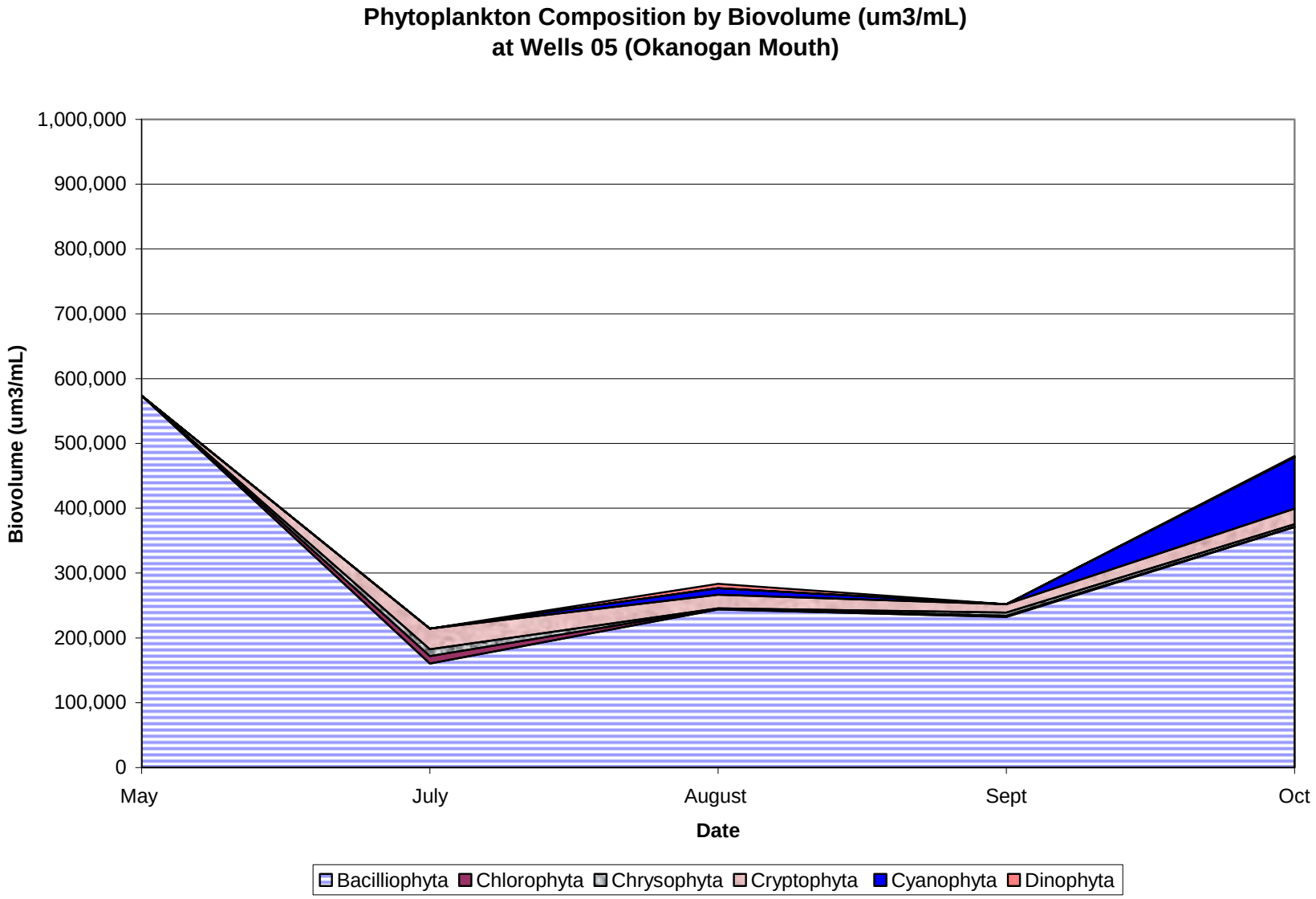
Sample: Wells Res
Sample Station: Wells 05 Photic
Sample Depth:
Sample Date: 18-Oct-05

Total Density (#/mL): 1,377
Total Biovolume (um^3/mL): 480,624
Trophic State Index: 44.6

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Achnanthes minutissima	127	9.2	6,330	1.3
Cocconeis placentula	127	9.2	58,234	12.1
Stephanodiscus hantzschii	111	8.0	13,293	2.8
Cymbella minuta	95	6.9	35,131	7.3
Navicula cryptocephala veneta	32	2.3	3,007	0.6
Cyclotella stelligera	32	2.3	1,741	0.4
Navicula cryptocephala	32	2.3	5,855	1.2
Fragilaria construens venter	32	2.3	2,279	0.5
Navicula pupula	16	1.1	4,273	0.9
Achnanthes lanceolata	16	1.1	2,848	0.6
Cymbella microcephala	16	1.1	839	0.2
Melosira ambigua	16	1.1	74,565	15.5
Nitzschia frustulum	16	1.1	1,899	0.4
Fragilaria vaucheria	16	1.1	4,557	0.9
Pinnularia sp.	16	1.1	6,330	1.3
Navicula tripunctata	16	1.1	17,724	3.7
Synedra delicatissima	16	1.1	10,444	2.2
Nitzschia palea	16	1.1	2,848	0.6
Neidium sp.	16	1.1	6,330	1.3
Navicula anglica	16	1.1	5,697	1.2
Navicula decussis	16	1.1	3,038	0.6
Synedra ulna	16	1.1	31,491	6.6
Synedra radians	16	1.1	5,697	1.2
Diatoma vulgare	16	1.1	31,016	6.5
Rhopalodia musculus	16	1.1	7,121	1.5
Cymbella affinis	16	1.1	28,484	5.9
Ankistrodesmus falcatus	16	1.1	396	0.1
Kephyrion sp.	63	4.6	3,988	0.8
Rhodomonas minuta	364	26.4	7,279	1.5
Cryptomonas erosa	32	2.3	16,458	3.4
Anabaena planctonica	16	1.1	79,534	16.5
Dinobryon bavaricum	16	1.1	1,899	0.4

Aquatic Analysts **Sample ID:** HY96


Phytoplankton Composition by Density (#/mL)
at Wells 05 (Okanogan Mouth)
Density (#/mL)
2,000
1,600
1,200
800
400
0
May
July
August
Sept
Oct
Date
Bacilliophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta
Dinophyta


Phytoplankton Composition by Biovolume (um3/mL)
at Wells 05 (Okanogan Mouth)
Biovolume (um3/mL)
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
May
July
August
Sept
Oct
Date
Bacilliophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta
Dinophyta

Phytoplankton Sample Analysis

Sample: Wells Res
Sample Station: Wells 06 Photic
Sample Depth:
Sample Date: 17-May-05

Total Density (#/mL): 627
Total Biovolume (um^3/mL): 208,507
Trophic State Index: 38.6

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Asterionella formosa	161	25.7	70,965	34.0
Synedra radians	78	12.4	27,956	13.4
Nitzschia paleacea	30	4.8	2,927	1.4
Cymbella minuta	24	3.8	10,609	5.1
Nitzschia acicularis	24	3.8	6,690	3.2
Melosira italica	18	2.9	28,698	13.8
Cocconeis placentula	12	1.9	5,496	2.6
Nitzschia sp.	12	1.9	1,434	0.7
Achnanthes minutissima	6	1.0	299	0.1
Fragilaria construens	6	1.0	1,338	0.6
Cyclotella ocellata	6	1.0	747	0.4
Nitzschia palea	6	1.0	1,075	0.5
Cymbella affinis	6	1.0	10,752	5.2
Fragilaria construens venter	6	1.0	573	0.3
Navicula tripunctata	6	1.0	6,690	3.2
Kephyrion littorale	6	1.0	567	0.3
Chrysococcus rufescens	6	1.0	508	0.2
Rhodomonas minuta	161	25.7	3,226	1.5
Cryptomonas erosa	54	8.6	27,956	13.4

Aquatic Analysts **Sample ID:** HY46

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 06 Photic
Sample Depth:
Sample Date: 17-Aug-05

Total Density (#/mL): 561
Total Biovolume (um^3/mL): 91,121
Trophic State Index: 32.6

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Achnanthes minutissima	27	4.9	1,362	1.5
Amphora perpusilla	22	3.9	3,617	4.0
Synedra radians	16	2.9	5,883	6.5
Asterionella formosa	11	1.9	2,397	2.6
Cyclotella ocellata	11	1.9	1,362	1.5
Achnanthes clevei	11	1.9	1,634	1.8
Fragilaria leptostauron	11	1.9	2,004	2.2
Gomphonema sp.	11	1.9	3,268	3.6
Gomphonema olivaceum	11	1.9	2,451	2.7
Stephanodiscus hantzschii	11	1.9	1,307	1.4
Achnanthes linearis	11	1.9	1,438	1.6
Achnanthes lanceolata	11	1.9	1,961	2.2
Synedra rumpens	5	1.0	763	0.8
Cymbella microcephala	5	1.0	289	0.3
Gomphonema angustatum	5	1.0	980	1.1
Cymbella minuta	5	1.0	2,015	2.2
Navicula cascadensis	5	1.0	327	0.4
Fragilaria pinnata	5	1.0	327	0.4
Fragilaria construens venter	5	1.0	3,137	3.4
Cocconeis placentula	5	1.0	2,506	2.7
Synedra ulna	5	1.0	10,839	11.9
Nitzschia linearis	5	1.0	8,301	9.1
Navicula sp.	5	1.0	817	0.9
Nitzschia acicularis	5	1.0	1,525	1.7
Achnanthes sp.	5	1.0	654	0.7
Navicula cryptocephala veneta	5	1.0	517	0.6
Diatoma tenue elongatum	5	1.0	3,922	4.3
Cyclotella stelligera	5	1.0	300	0.3
Scenedesmus quadricauda	5	1.0	708	0.8
Ulothrix sp.	5	1.0	2,179	2.4
Rhodomonas minuta	267	47.6	5,338	5.9
Cryptomonas erosa	33	5.8	16,994	18.7

Aquatic Analysts **Sample ID:** HY72

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 06 Photic
Sample Depth:
Sample Date: 7-Sep-05

Total Density (#/mL): 886
Total Biovolume (um^3/mL): 164,946
Trophic State Index: 36.9

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Achnanthes minutissima	80	9.0	8,781	5.3
Cocconeis placentula	72	8.1	33,047	20.0
Asterionella formosa	16	1.8	17,561	10.6
Synedra radians	16	1.8	5,747	3.5
Cymbella minuta	16	1.8	5,907	3.6
Cyclotella stelligera	8	0.9	439	0.3
Melosira granulata angustissima	8	0.9	7,982	4.8
Tabellaria fenestrata	8	0.9	19,158	11.6
Fragilaria leptostauron	8	0.9	1,469	0.9
Epithemia sorex	8	0.9	18,200	11.0
Navicula cryptocephala veneta	8	0.9	758	0.5
Kephyrion littorale	16	1.8	1,517	0.9
Rhodomonas minuta	559	63.1	11,175	6.8
Cryptomonas erosa	64	7.2	33,206	20.1

Aquatic Analysts **Sample ID:** HY85

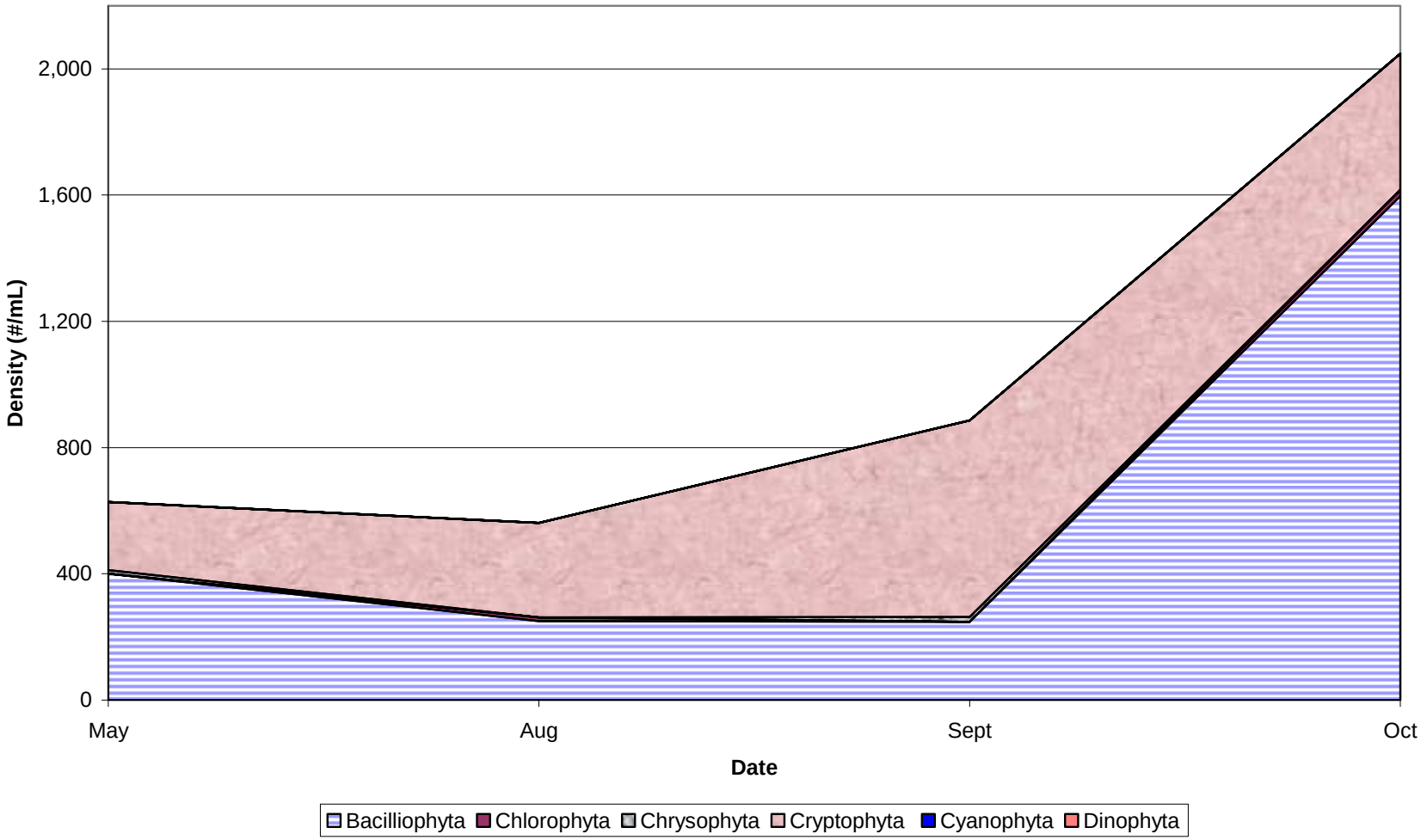
Sample Station: Wells 06 Photic
Sample Depth:
Sample Date: 18-Oct-05

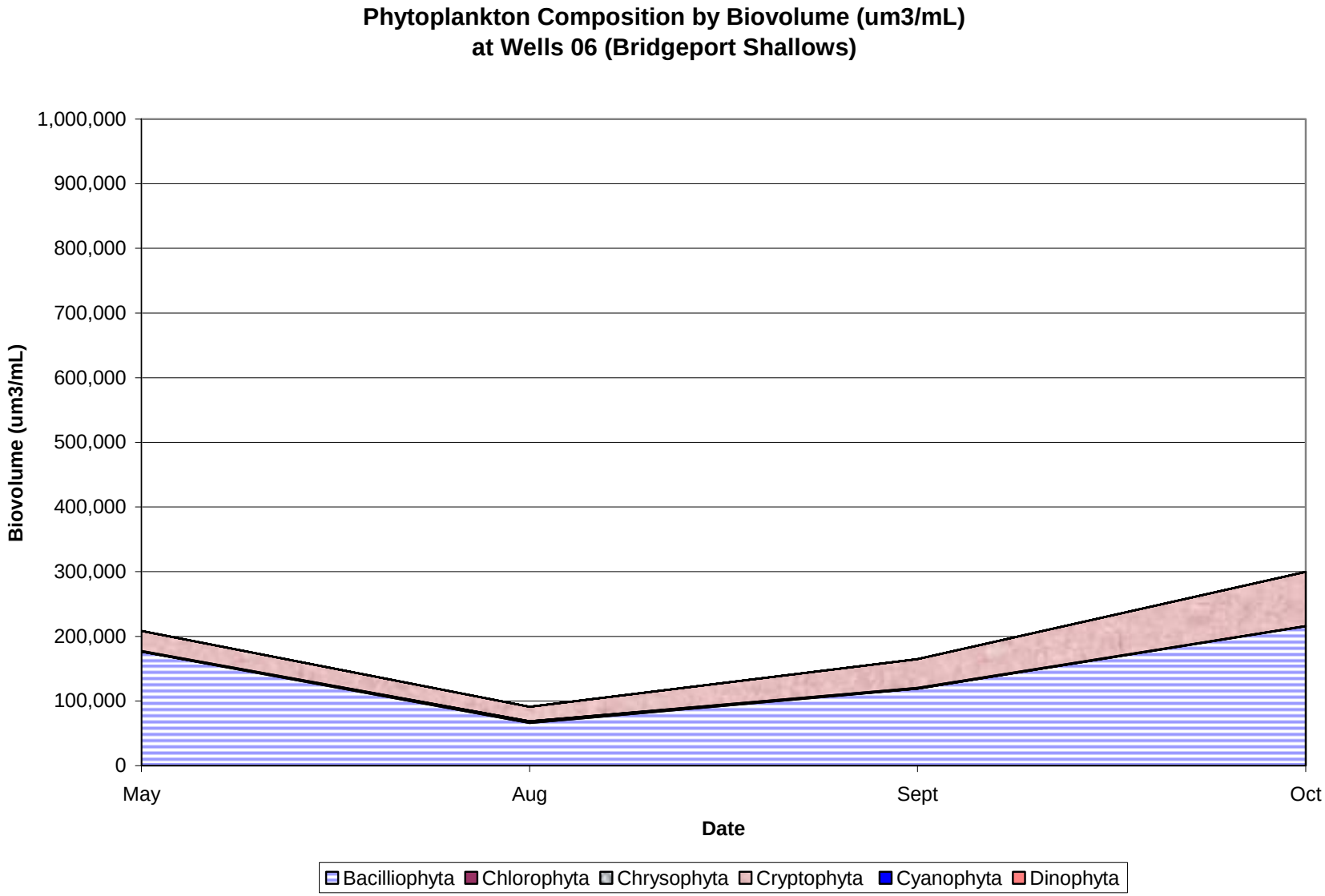
Total Density (#/mL): 2,048
Total Biovolume (um^3/mL): 299,802
Trophic State Index: 41.2

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Achnanthes minutissima	902	44.0	54,120	18.1
Cocconeis placentula	188	9.2	86,442	28.8
Achnanthes linearis	132	6.4	17,364	5.8
Stephanodiscus hantzschii	56	2.8	6,765	2.3
Fragilaria pinnata	38	1.8	2,255	0.8
Nitzschia paleacea	38	1.8	3,683	1.2
Gomphonema angustatum	19	0.9	3,383	1.1
Amphora perpusilla	19	0.9	3,119	1.0
Navicula pupula	19	0.9	5,074	1.7
Navicula cryptocephala veneta	19	0.9	1,785	0.6
Fragilaria construens venter	19	0.9	902	0.3
Navicula anglica	19	0.9	6,765	2.3
Fragilaria vaucheria	19	0.9	5,412	1.8
Cyclotella ocellata	19	0.9	2,349	0.8
Navicula decussis	19	0.9	3,608	1.2
Cyclotella stelligera	19	0.9	1,034	0.3
Cymbella minuta	19	0.9	6,953	2.3
Nitzschia sp.	19	0.9	2,255	0.8
Nitzschia frustulum	19	0.9	2,255	0.8
Ankistrodesmus falcatus	19	0.9	470	0.2
Rhodomonas minuta	282	13.8	5,638	1.9
Cryptomonas erosa	150	7.3	78,173	26.1

Aquatic Analysts **Sample ID:** HY97

Phytoplankton Composition by Density (#/mL)
at Wells 06 (Bridgeport Shallows)




Phytoplankton Composition by Biovolume (um3/mL)
at Wells 06 (Bridgeport Shallows)
Biovolume (um3/mL)
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
May
Aug
Sept
Oct
Date
Bacilliophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta
Dinophyta

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 07 Photic
Sample Depth:
Sample Date: 17-May-05

Total Density (#/mL): 619
Total Biovolume (um^3/mL): 147,468
Trophic State Index: 36.1

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Asterionella formosa	83	13.3	39,947	27.1
Synedra radians	41	6.7	14,856	10.1
Nitzschia paleacea	18	2.9	1,733	1.2
Achnanthes minutissima	12	1.9	590	0.4
Cymbella minuta	12	1.9	4,363	3.0
Melosira italica	12	1.9	11,107	7.5
Amphora perpusilla	6	1.0	979	0.7
Fragilaria construens	6	1.0	660	0.4
Cyclotella ocellata	6	1.0	737	0.5
Diatoma tenue	6	1.0	1,710	1.2
Fragilaria crotonensis	6	1.0	9,904	6.7
Ankistrodesmus falcatus	12	1.9	590	0.4
Crucigenia quadrata	6	1.0	1,503	1.0
Chrysococcus rufescens	24	3.8	2,004	1.4
Kephyrion littorale	6	1.0	560	0.4
Rhodomonas minuta	254	41.0	5,070	3.4
Cryptomonas erosa	94	15.2	49,050	33.3
Dinobryon sertularia	18	2.9	2,105	1.4

Aquatic Analysts **Sample ID:** HY47

Sample: Wells Res
Sample Station: Wells 07 Photic
Sample Depth:
Sample Date: 17-May-05

Total Density (#/mL): 535
Total Biovolume (um^3/mL): 187,101
Trophic State Index: 37.8

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Synedra radians	109	20.4	39,360	21.0
Asterionella formosa	74	13.9	27,747	14.8
Synedra rumpens	35	6.6	4,920	2.6
Achnanthes minutissima	20	3.6	976	0.5
Nitzschia acicularis	16	2.9	4,373	2.3
Melosira italica	12	2.2	29,794	15.9
Fragilaria crotonensis	8	1.5	26,240	14.0
Cymbella minuta	8	1.5	2,890	1.5
Cyclotella ocellata	8	1.5	976	0.5
Synedra ulna	4	0.7	7,770	4.2
Diatoma tenue elongatum	4	0.7	2,811	1.5
Navicula decussis	4	0.7	750	0.4
Stephanodiscus hantzschii	4	0.7	469	0.3
Synedra delicatissima	4	0.7	2,577	1.4
Navicula cryptocephala veneta	4	0.7	371	0.2
Ankistrodesmus falcatus	4	0.7	98	0.1
Kephyrion littorale	31	5.8	2,968	1.6
Chrysococcus rufescens	12	2.2	996	0.5
Kephyrion sp.	4	0.7	246	0.1
Rhodomonas minuta	117	21.9	2,343	1.3
Cryptomonas erosa	55	10.2	28,427	15.2

Aquatic Analysts **Sample ID:** HY48

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 07 Photic
Sample Depth:
Sample Date: 12-Jul-05

Total Density (#/mL): 911
Total Biovolume (um^3/mL): 214,540
Trophic State Index: 38.8

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Synedra radians	111	12.1	39,824	18.6
Achnanthes minutissima	51	5.6	2,553	1.2
Cymbella minuta	26	2.8	9,445	4.4
Melosira ambigua	17	1.9	35,084	16.4
Synedra parasitica	17	1.9	2,383	1.1
Amphora perpusilla	17	1.9	2,825	1.3
Asterionella formosa	9	0.9	1,872	0.9
Navicula graciloides	9	0.9	3,702	1.7
Nitzschia fonticola	9	0.9	357	0.2
Cocconeis placentula	9	0.9	3,914	1.8
Nitzschia paleacea	9	0.9	834	0.4
Achnanthes flexella	9	0.9	4,127	1.9
Gomphonema angustatum	9	0.9	1,532	0.7
Achnanthes lanceolata	9	0.9	1,532	0.7
Cymbella microcephala	9	0.9	451	0.2
Cymbella tumida	9	0.9	21,274	9.9
Diatoma vulgare	9	0.9	16,678	7.8
Navicula tripunctata	9	0.9	9,531	4.4
Melosira distans alpigena	9	0.9	1,489	0.7
Nitzschia frustulum	9	0.9	1,021	0.5
Ankistrodesmus falcatus	43	4.7	1,489	0.7
Oocystis pusilla	17	1.9	3,676	1.7
Tetrastrum staurogeniaforme	9	0.9	1,838	0.9
Cosmarium sp.	9	0.9	1,787	0.8
Chlamydomonas sp.	9	0.9	2,766	1.3
Kephyrion littorale	68	7.5	6,467	3.0
Kephyrion sp.	43	4.7	2,680	1.2
Kephyrion spirale	17	1.9	1,072	0.5
Rhodomonas minuta	289	31.8	5,786	2.7
Cryptomonas erosa	51	5.6	26,549	12.4

Aquatic Analysts **Sample ID:** HY59

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 07 Photic
Sample Depth:
Sample Date: 17-Aug-05

Total Density (#/mL): 421
Total Biovolume (um^3/mL): 127,032
Trophic State Index: 35.0

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Achnanthes minutissima	43	10.1	2,127	1.7
Cyclotella ocellata	24	5.6	2,955	2.3
Synedra radians	14	3.4	5,106	4.0
Navicula cryptocephala veneta	9	2.2	898	0.7
Caloneis ventricosa minuta	5	1.1	1,324	1.0
Synedra delicatissima	5	1.1	3,120	2.5
Nitzschia dissipata	5	1.1	1,272	1.0
Gomphonema angustatum	5	1.1	851	0.7
Amphora perpusilla	5	1.1	1,570	1.2
Fragilaria crotonensis	5	1.1	47,653	37.5
Cyclotella comta	5	1.1	10,731	8.4
Stephanodiscus hantzschii	5	1.1	567	0.4
Fragilaria construens	5	1.1	2,118	1.7
Tabellaria fenestrata	5	1.1	34,038	26.8
Oocystis pusilla	5	1.1	2,042	1.6
Kephyrion littorale	5	1.1	449	0.4
Rhodomonas minuta	265	62.9	5,295	4.2
Cryptomonas erosa	9	2.2	4,917	3.9

Aquatic Analysts **Sample ID:** HY73

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 07 Photic
Sample Depth:
Sample Date: 7-Sep-05

Total Density (#/mL): 262
Total Biovolume (um^3/mL): 97,550
Trophic State Index: 33.1

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Synedra radians	33	12.8	12,027	12.3
Achnanthes minutissima	31	11.7	1,531	1.6
Cocconeis placentula	11	4.3	5,122	5.3
Stephanodiscus hantzschii	8	3.2	1,002	1.0
Synedra ulna	6	2.1	11,080	11.4
Cyclotella ocellata	6	2.1	696	0.7
Melosira granulata angustissima	6	2.1	8,352	8.6
Melosira ambigua	6	2.1	36,074	37.0
Nitzschia palea	3	1.1	501	0.5
Navicula capitata	3	1.1	1,336	1.4
Tabellaria flocculosa	3	1.1	1,643	1.7
Navicula cryptocephala veneta	3	1.1	264	0.3
Synedra rumpens	3	1.1	390	0.4
Fragilaria construens	3	1.1	3,742	3.8
Navicula tripunctata	3	1.1	3,118	3.2
Gomphonema angustatum	3	1.1	501	0.5
Fragilaria capucina mesolepta	3	1.1	4,259	4.4
Oocystis pusilla	6	2.1	1,804	1.8
Kephyrion littorale	3	1.1	264	0.3
Rhodomonas minuta	120	45.7	2,394	2.5
Cryptomonas erosa	3	1.1	1,448	1.5

Aquatic Analysts **Sample ID:** HY86

Phytoplankton Sample

Analysis

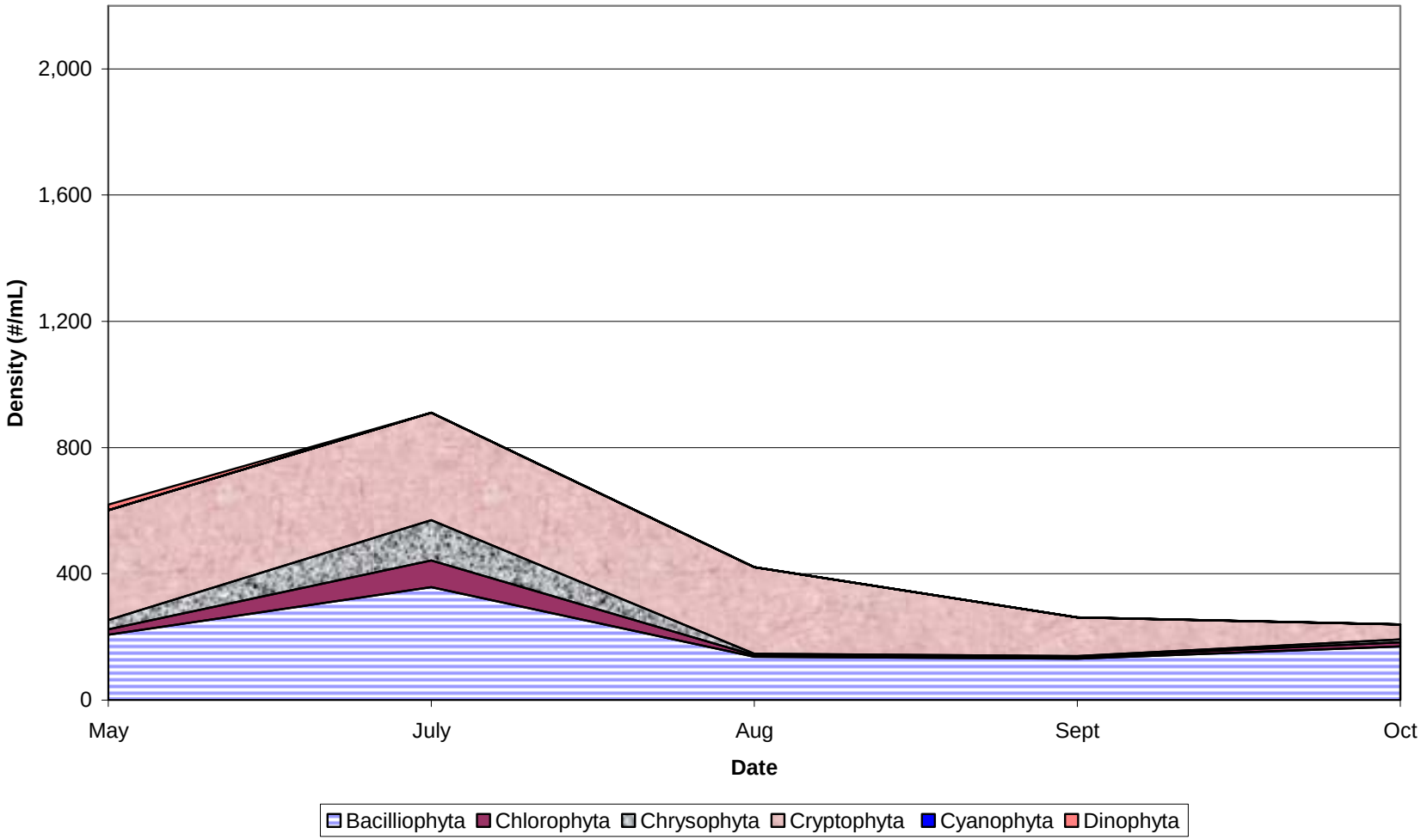
Sample: Wells Res
Sample Station: Wells 07 Photic
Sample Depth:
Sample Date: 18-Oct-05

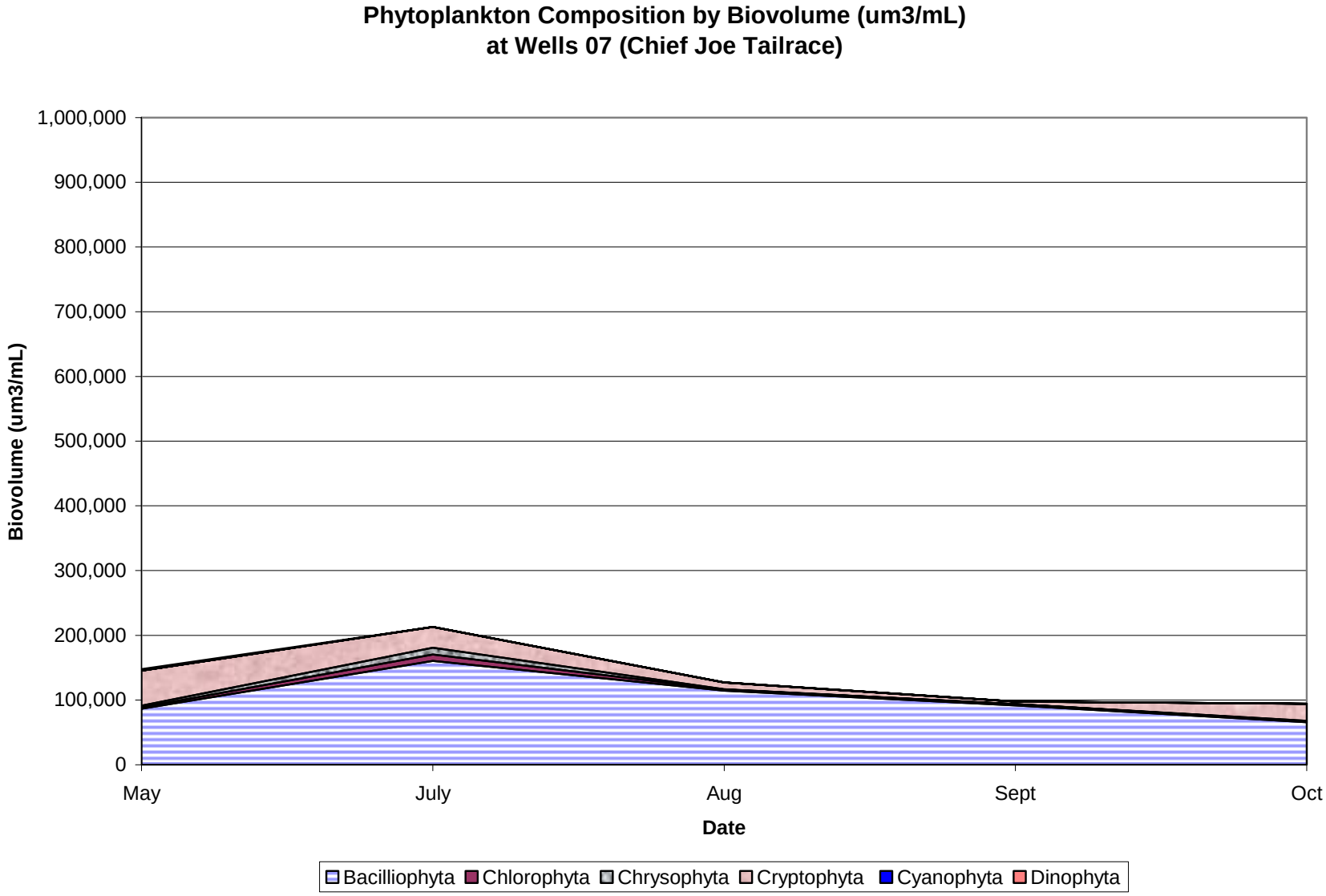
Total Density (#/mL): 436
Total Biovolume (um^3/mL): 94,579
Trophic State Index: 32.9

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Stephanodiscus hantzschii	44	10.0	5,229	5.5
Cyclotella stelligera	22	5.0	1,198	1.3
Cocconeis placentula	17	4.0	8,018	8.5
Cyclotella ocellata	13	3.0	1,634	1.7
Cyclotella comta	13	3.0	29,674	31.4
Achnanthes minutissima	13	3.0	654	0.7
Synedra radians	13	3.0	4,706	5.0
Navicula menisculus upsaliensis	9	2.0	1,787	1.9
Asterionella formosa	9	2.0	4,793	5.1
Cocconeis pediculus	4	1.0	2,266	2.4
Cymbella delicatula	4	1.0	3,486	3.7
Synedra rumpens	4	1.0	1,220	1.3
Nitzschia palea	4	1.0	784	0.8
Ankistrodesmus falcatus	9	2.0	218	0.2
Chlamydomonas sp.	4	1.0	1,416	1.5
Rhizosolenia eriensis	9	2.0	828	0.9
Rhodomonas minuta	196	45.0	3,922	4.1
Cryptomonas erosa	44	10.0	22,659	24.0
Unidentified flagellate	4	1.0	87	0.1

Aquatic Analysts **Sample ID:** HY98

Phytoplankton Composition by Density (#/mL)
at Wells 07 (Chief Joe Tailrace)




Phytoplankton Composition by Biovolume (um3/mL)
at Wells 07 (Chief Joe Tailrace)
Biovolume (um3/mL)
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
May
July
Aug
Sept
Oct
Date
Bacilliophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta
Dinophyta

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 08 Photic
Sample Depth:
Sample Date: 17-May-05

Total Density (#/mL): 581
Total Biovolume (um^3/mL): 175,444
Trophic State Index: 37.3

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Chrysococcus rufescens	14	2.3	1,148	0.7
Kephyrion littorale	7	1.2	641	0.4
Cryptomonas erosa	34	5.8	17,554	10.0
Rhodomonas minuta	149	25.6	2,971	1.7
Asterionella formosa	128	22.1	87,486	49.9
Cymbella minuta	68	11.6	24,981	14.2
Synedra radians	41	7.0	14,583	8.3
Diatoma tenue elongatum	7	1.2	4,861	2.8
Nitzschia acicularis	14	2.3	3,781	2.2
Cocconeis placentula	7	1.2	3,106	1.8
Synedra rumpens	20	3.5	2,836	1.6
Nitzschia paleacea	27	4.7	2,647	1.5
Nitzschia palea	14	2.3	2,431	1.4
Diatoma tenue	7	1.2	1,958	1.1
Nitzschia dissipata	7	1.2	1,816	1.0
Achnanthes minutissima	27	4.7	1,350	0.8
Achnanthes clevei	7	1.2	1,013	0.6
Nitzschia fonticola	7	1.2	284	0.2

Aquatic Analysts **Sample ID:** HY49

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 08 Photic
Sample Depth:
Sample Date: 12-Jul-05

Total Density (#/mL): 546
Total Biovolume (um^3/mL): 398,121
Trophic State Index: 43.2

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Kephyrion littorale	5	0.9	489	0.1
Kephyrion sp.	5	0.9	324	0.1
Cryptomonas erosa	57	10.4	29,449	7.4
Rhodomonas minuta	257	47.2	5,148	1.3
Fragilaria crotonensis	26	4.7	281,103	70.6
Diatoma tenue elongatum	31	5.7	22,241	5.6
Fragilaria vaucheria	5	0.9	11,862	3.0
Synedra ulna	5	0.9	10,245	2.6
Synedra radians	21	3.8	7,414	1.9
Cocconeis placentula	10	1.9	4,737	1.2
Asterionella formosa	21	3.8	4,531	1.1
Cymbella minuta	10	1.9	3,810	1.0
Melosira ambigua	5	0.9	3,032	0.8
Navicula capitata	5	0.9	2,471	0.6
Achnanthes minutissima	36	6.6	1,802	0.5
Fragilaria construens	5	0.9	1,730	0.4
Synedra tenera	5	0.9	1,545	0.4
Nitzschia acicularis	5	0.9	1,442	0.4
Gomphonema olivaceum	5	0.9	1,158	0.3
Achnanthes lanceolata	5	0.9	927	0.2
Achnanthes clevei	5	0.9	772	0.2
Achnanthes linearis	5	0.9	680	0.2
Stephanodiscus hantzschii	5	0.9	618	0.2
Cyclotella kutzingiana	5	0.9	592	0.1

Aquatic Analysts **Sample ID:** HY61

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 08 Photic
Sample Depth:
Sample Date: 17-Aug-05

Total Density (#/mL): 425
Total Biovolume (um^3/mL): 109,829
Trophic State Index: 34.0

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Aphanizomenon flos-aquae	4	0.9	4,991	4.5
Oscillatoria sp.	4	0.9	3,974	3.6
Chromulina sp.	8	1.9	159	0.1
Cryptomonas erosa	28	6.5	14,464	13.2
Rhodomonas minuta	179	42.1	3,576	3.3
Cyclotella comta	8	1.9	18,040	16.4
Synedra ulna	8	1.9	15,815	14.4
Synedra radians	32	7.5	11,444	10.4
Melosira varians	8	1.9	7,748	7.1
Cocconeis placentula	12	2.8	5,484	5.0
Navicula tripunctata	4	0.9	4,450	4.1
Cymbella minuta	8	1.9	2,940	2.7
Synedra delicatissima	4	0.9	2,623	2.4
Tabellaria flocculosa	4	0.9	2,344	2.1
Nitzschia paleacea	16	3.7	1,558	1.4
Nitzschia acicularis	4	0.9	1,113	1.0
Nitzschia dissipata	4	0.9	1,069	1.0
Achnanthes minutissima	20	4.7	993	0.9
Cyclotella ocellata	8	1.9	993	0.9
Stephanodiscus hantzschii	8	1.9	954	0.9
Gomphonema angustatum	4	0.9	715	0.7
Amphora perpusilla	4	0.9	660	0.6
Synedra rumpens	4	0.9	556	0.5
Achnanthes linearis	4	0.9	525	0.5
Nitzschia sp.	4	0.9	477	0.4
Cymbella microcephala	8	1.9	421	0.4
Navicula minima	4	0.9	175	0.2
Cyclotella atomus	8	1.9	159	0.1
Sphaerocystis schroeteri	4	0.9	1,113	1.0
Ankistrodesmus falcatus	12	2.8	298	0.3

Aquatic Analysts **Sample ID:** HY74

Phytoplankton Sample

Analysis

Sample: Wells Res
Sample Station: Wells 08 Photic
Sample Depth:
Sample Date: 7-Sep-05

Total Density (#/mL): 929
Total Biovolume (um^3/mL): 169,676
Trophic State Index: 37.1

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Cryptomonas erosa	64	6.9	33,164	19.5
Rhodomonas minuta	547	58.8	12,027	7.1
Melosira granulata angustissima	18	2.0	18,222	10.7
Synedra radians	46	4.9	16,400	9.7
Hannaea arcus	9	1.0	15,944	9.4
Gomphonema truncatum	9	1.0	12,391	7.3
Fragilaria construens	9	1.0	10,204	6.0
Asterionella formosa	9	1.0	10,022	5.9
Stephanodiscus hantzschii	64	6.9	7,653	4.5
Melosira granulata	9	1.0	5,011	3.0
Cocconeis placentula	9	1.0	4,191	2.5
Achnanthes clevei	18	2.0	2,733	1.6
Cyclotella stelligera	36	3.9	2,004	1.2
Synedra rumpens	9	1.0	1,276	0.8
Cyclotella ocellata	9	1.0	1,139	0.7
Achnanthes minutissima	18	2.0	911	0.5
Nitzschia paleacea	9	1.0	893	0.5
Glenodinium sp.	9	1.0	6,378	3.8
Scenedesmus quadricauda	18	2.0	4,738	2.8
Scenedesmus acuminatus	9	1.0	4,373	2.6

Aquatic Analysts **Sample ID:** HY87

Phytoplankton Sample

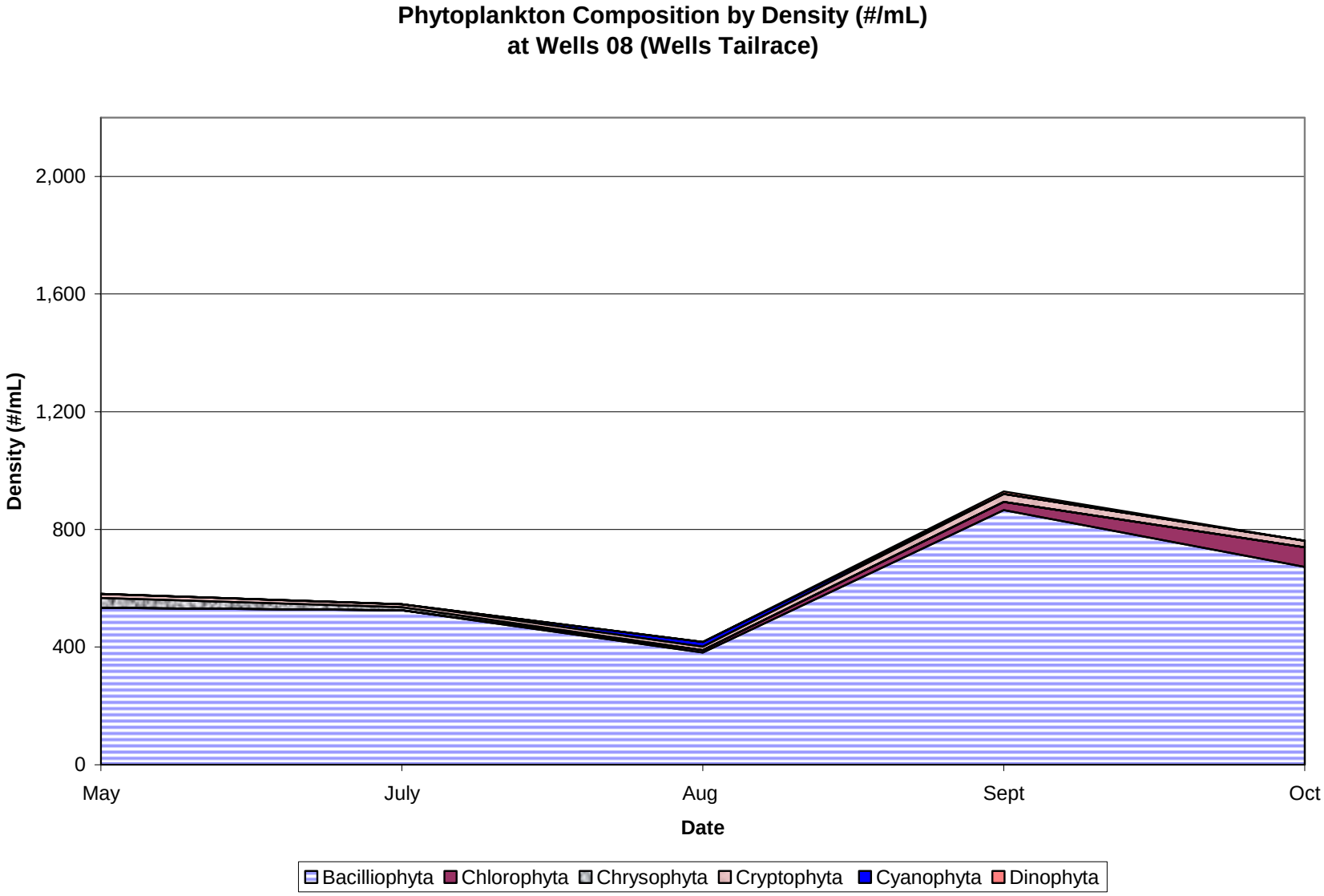
Analysis

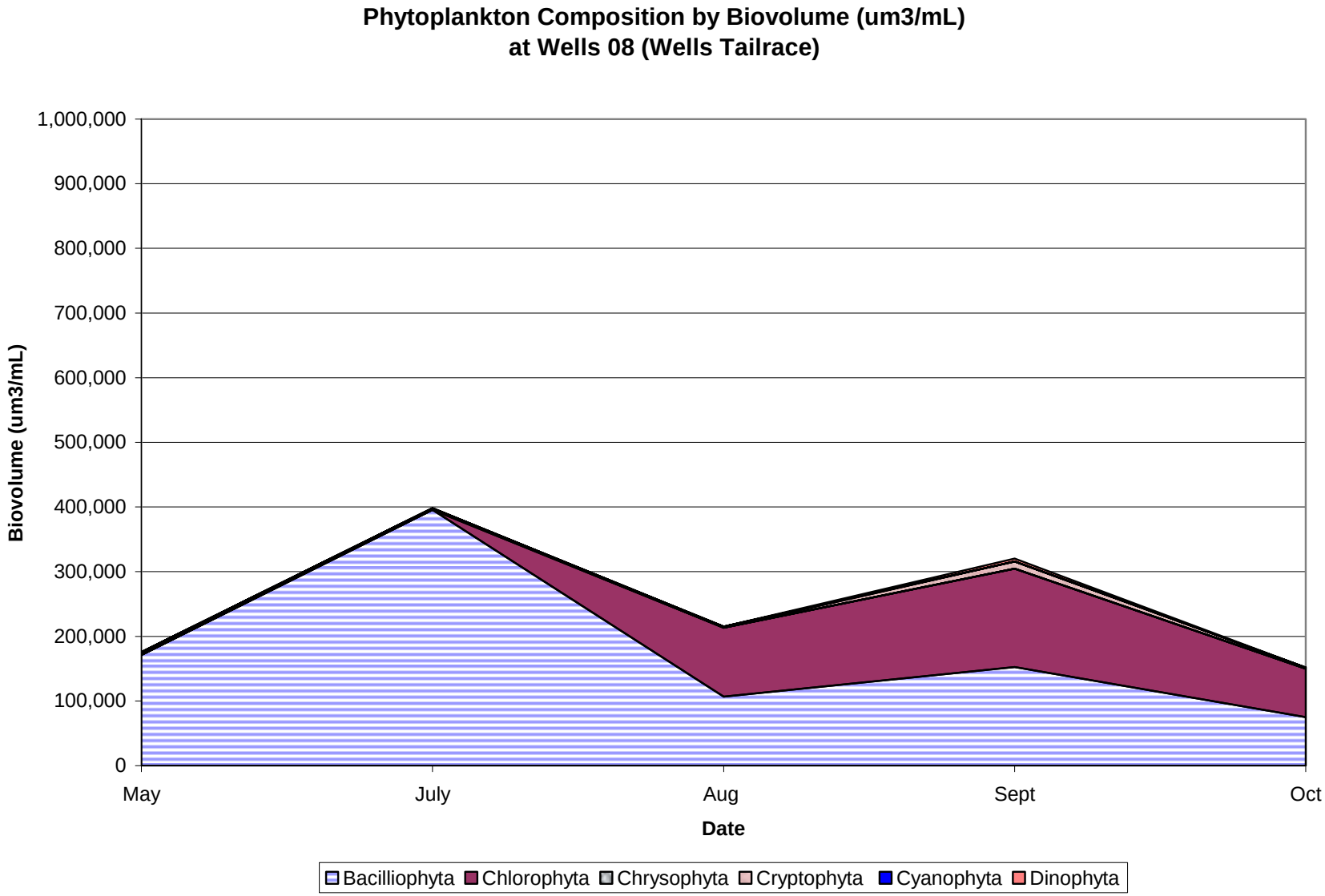
Sample: Wells Res
Sample Station: Wells 08 Photic
Sample Depth:
Sample Date: 18-Oct-05

Total Density (#/mL): 821
Total Biovolume (um^3/mL): 127,115
Trophic State Index: 35.0

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Cryptomonas erosa	59	7.2	30,757	24.2
Rhodomonas minuta	370	45.0	7,393	5.8
Cymbella affinis	7	0.9	13,308	10.5
Fragilaria crotonensis	7	0.9	12,421	9.8
Melosira varians	7	0.9	9,611	7.6
Stephanodiscus hantzschii	52	6.3	6,210	4.9
Achnanthes minutissima	81	9.9	4,066	3.2
Cocconeis placentula	7	0.9	3,401	2.7
Cyclotella stelligera	59	7.2	3,253	2.6
Achnanthes linearis	22	2.7	2,928	2.3
Cymbella minuta	7	0.9	2,736	2.2
Synedra radians	7	0.9	2,662	2.1
Navicula sp.	15	1.8	2,218	1.7
Synedra rumpens	15	1.8	2,070	1.6
Navicula cryptocephala	7	0.9	1,368	1.1
Amphora perpusilla	7	0.9	1,227	1.0
Nitzschia frustulum	7	0.9	887	0.7
Glenodinium sp.	7	0.9	5,175	4.1
Scenedesmus quadricauda	52	6.3	13,456	10.6
Oocystis pusilla	7	0.9	1,597	1.3
Ankistrodesmus falcatus	15	1.8	370	0.3

Aquatic Analysts **Sample ID:** HY99


Phytoplankton Composition by Density (#/mL)
at Wells 08 (Wells Tailrace)
Density (#/mL)
2,000
1,600
1,200
800
400
0
May
July
Aug
Sept
Oct
Date
Bacilliophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta
Dinophyta


Phytoplankton Composition by Biovolume (um3/mL)
at Wells 08 (Wells Tailrace)
Biovolume (um3/mL)
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
May
July
Aug
Sept
Oct
Date
Bacilliophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta
Dinophyta

Appendix D

Periphyton Species Lists and Charts

Periphyton Sample Analysis

Sample: Wells Res
Sample Station: Wells 02 Photic
Sample Depth:
Sample Date: 17-May-05

Total Density (#/mL): 2,460,000
Total Biovolume (um^3/mL): 1239662333
Trophic State Index: 101.2

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Cymbella minuta	911,111	37.0	337,111,111	27.2
Achnanthes minutissima	364,444	14.8	18,222,222	1.5
Fragilaria construens venter	205,000	8.3	81,672,000	6.6
Fragilaria vaucheria	136,667	5.6	165,312,000	13.3
Synedra rumpens	91,111	3.7	12,755,556	1.0
Nitzschia frustulum	45,556	1.9	8,200,000	0.7
Cocconeis placentula	45,556	1.9	20,955,556	1.7
Navicula cryptocephala veneta	45,556	1.9	4,327,778	0.3
Nitzschia dissipata	45,556	1.9	12,254,444	1.0
Nitzschia sp.	45,556	1.9	5,466,667	0.4
Navicula cryptocephala	45,556	1.9	8,427,778	0.7
Synedra ulna	45,556	1.9	90,655,556	7.3
Asterionella formosa	45,556	1.9	15,033,333	1.2
Synedra radians	45,556	1.9	16,400,000	1.3
Navicula capitata	45,556	1.9	21,866,667	1.8
Melosira varians	45,556	1.9	88,833,333	7.2
Cymbella tumida	22,778	0.9	56,944,444	4.6
Achnanthes lanceolata	22,778	0.9	4,100,000	0.3
Nitzschia palea	22,778	0.9	4,100,000	0.3
Fragilaria construens	22,778	0.9	7,653,333	0.6
Fragilaria pinnata	22,778	0.9	1,366,667	0.1
Nitzschia paleacea	22,778	0.9	2,232,222	0.2
Gomphonema subclavatum	22,778	0.9	13,666,667	1.1
Fragilaria capucina mesolepta	22,778	0.9	232,333,333	18.7
Nitzschia amphibia	22,778	0.9	2,186,667	0.2
Cymbella microcephala	22,778	0.9	1,207,222	0.1
Nitzschia acicularis	22,778	0.9	6,377,778	0.5

Aquatic Analysts **Sample ID:** HY50

Periphyton Sample Analysis

Sample: Wells Res
Sample Station: Wells 02 Photic
Sample Depth:
Sample Date: 12-Jul-05

Total Density (#/mL): 1,030,062
Total Biovolume (um^3/mL): 321,410,811
Trophic State Index: 91.5

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Fragilaria construens venter	352,634	34.2	77,861,531	24.2
Achnanthes minutissima	111,358	10.8	5,567,901	1.7
Fragilaria leptostauron	102,078	9.9	18,782,387	5.8
Fragilaria pinnata	74,239	7.2	7,572,346	2.4
Fragilaria construens	64,959	6.3	21,826,173	6.8
Fragilaria vaucheria	55,679	5.4	16,035,556	5.0
Cymbella minuta	46,399	4.5	17,167,695	5.3
Synedra rumpens	37,119	3.6	5,196,708	1.6
Tabellaria flocculosa	27,840	2.7	70,628,827	22.0
Nitzschia fonticola	18,560	1.8	779,506	0.2
Tabellaria fenestrata	18,560	1.8	44,543,210	13.9
Navicula capitata	9,280	0.9	4,454,321	1.4
Surirella linearis	9,280	0.9	2,598,354	0.8
Gomphonema angustatum	9,280	0.9	1,670,370	0.5
Synedra radians	9,280	0.9	3,340,741	1.0
Diatoma tenue elongatum	9,280	0.9	6,681,481	2.1
Cyclotella ocellata	9,280	0.9	1,159,979	0.4
Cymbella sinuata	9,280	0.9	1,299,177	0.4
Diploneis elliptica	9,280	0.9	2,412,757	0.8
Melosira varians	9,280	0.9	6,031,893	1.9
Ankistrodesmus falcatus	9,280	0.9	231,996	0.1
Achnanthes lanceolata	9,280	0.9	1,670,370	0.5
Achnanthes clevei	9,280	0.9	1,391,975	0.4
Navicula pupula	9,280	0.9	2,505,556	0.8

Periphyton Sample Analysis

Sample: Wells Res
Sample Station: Wells 02 Photic
Sample Depth:
Sample Date: 17-Aug-05

Total Density (#/mL): 3,608,000
Total Biovolume (um^3/mL): 1100181427
Trophic State Index: 100.4

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Fragilaria construens venter	1,563,467	43.3	247,653,120	22.5
Fragilaria construens	270,600	7.5	87,890,880	8.0
Achnanthes minutissima	240,533	6.7	12,026,667	1.1
Fragilaria leptostauron	210,467	5.8	50,343,627	4.6
Fragilaria pinnata	180,400	5.0	18,400,800	1.7
Cocconeis placentula	180,400	5.0	82,984,000	7.5
Navicula cryptocephala	180,400	5.0	33,374,000	3.0
Fragilaria vaucheria	150,333	4.2	86,592,000	7.9
Cymbella minuta	90,200	2.5	33,374,000	3.0
Tabellaria flocculosa	90,200	2.5	53,218,000	4.8
Nitzschia paleacea	60,133	1.7	5,893,067	0.5
Navicula cryptocephala veneta	60,133	1.7	5,712,667	0.5
Nitzschia palea	30,067	0.8	5,412,000	0.5
Cymbella microcephala	30,067	0.8	1,593,533	0.1
Nitzschia frustulum	30,067	0.8	3,608,000	0.3
Amphora perpusilla	30,067	0.8	4,991,067	0.5
Navicula anglica	30,067	0.8	10,824,000	1.0
Pinnularia sp.	30,067	0.8	12,026,667	1.1
Synedra ulna	30,067	0.8	59,832,667	5.4
Cymbella affinis	30,067	0.8	54,120,000	4.9
Cymbella mexicana	30,067	0.8	165,366,667	15.0
Fragilaria crotonensis	30,067	0.8	50,512,000	4.6
Navicula capitata	30,067	0.8	14,432,000	1.3

Aquatic Analysts **Sample ID:** HY75

Periphyton Sample Analysis

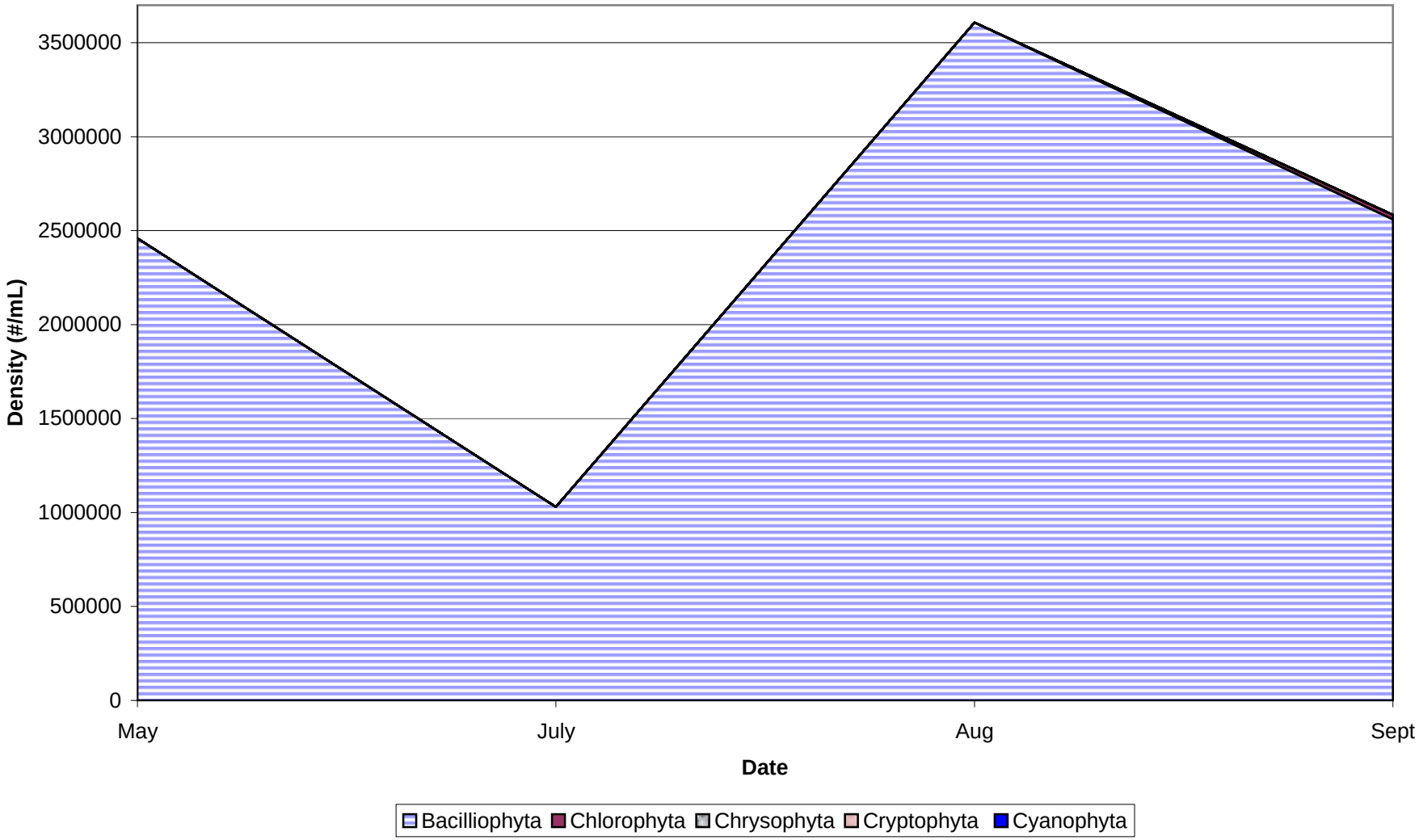
Sample: Wells Res
Sample Station: Wells 02 Photic
Sample Depth:
Sample Date: 7-Sep-05

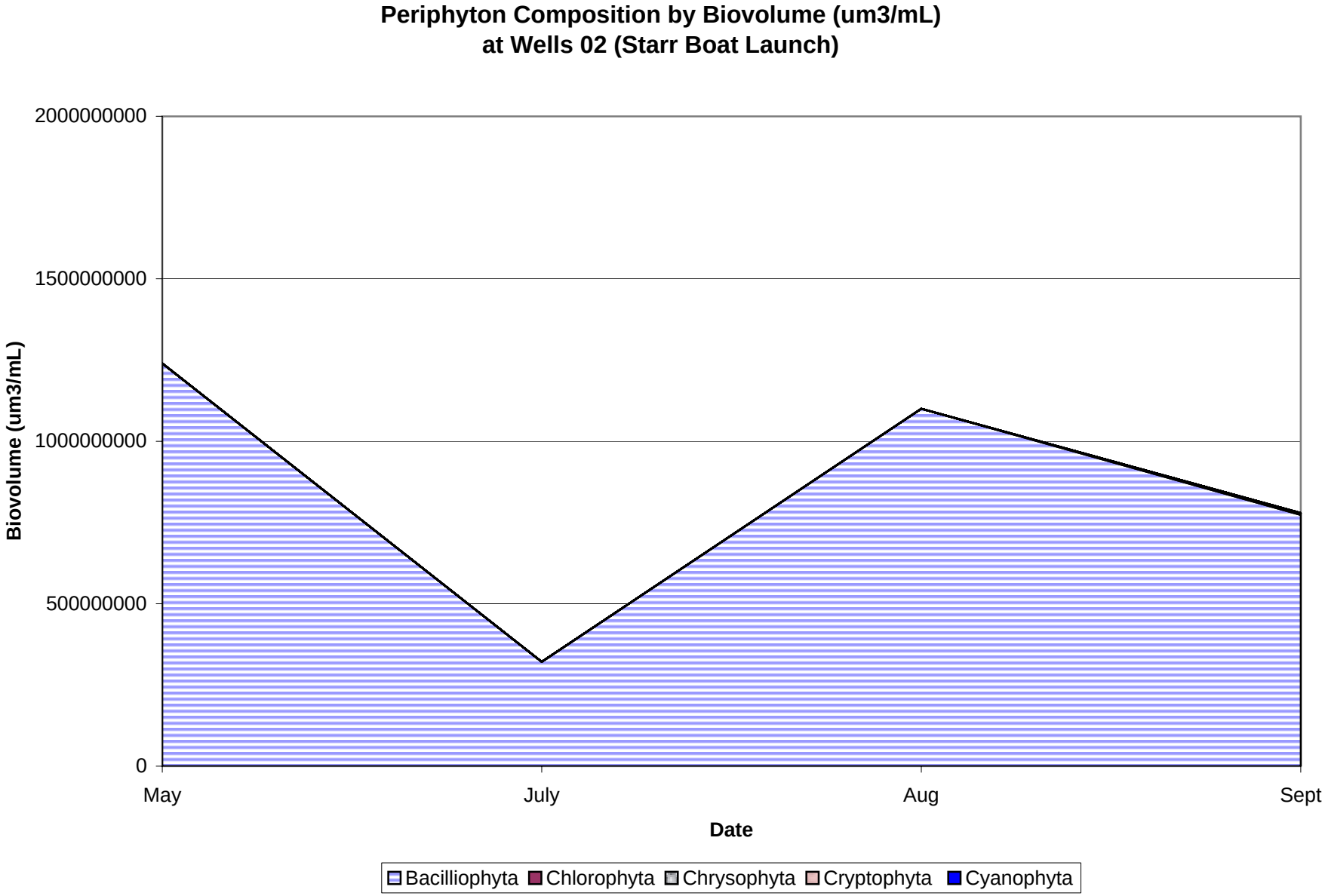
Total Density (#/mL): 2,583,854
Total Biovolume (um^3/mL): 773,408,625
Trophic State Index: 97.8

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Fragilaria construens venter	1,080,521	41.8	243,765,500	31.5
Achnanthes minutissima	234,896	9.1	11,744,792	1.5
Navicula cryptocephala veneta	164,427	6.4	15,620,573	2.0
Fragilaria leptostauron	164,427	6.4	30,254,583	3.9
Fragilaria pinnata	164,427	6.4	13,811,875	1.8
Cymbella minuta	117,448	4.5	43,455,729	5.6
Tabellaria fenestrata	70,469	2.7	169,125,000	21.9
Fragilaria construens	70,469	2.7	86,817,500	11.2
Nitzschia fonticola	46,979	1.8	1,973,125	0.3
Navicula decussis	46,979	1.8	9,020,000	1.2
Navicula pupula	46,979	1.8	12,684,375	1.6
Cymbella microcephala	46,979	1.8	2,489,896	0.3
Cocconeis placentula	46,979	1.8	21,610,417	2.8
Eunotia pectinalis	46,979	1.8	33,825,000	4.4
Navicula cryptocephala	23,490	0.9	4,345,573	0.6
Diploneis elliptica	23,490	0.9	6,107,292	0.8
Nitzschia sp.	23,490	0.9	2,818,750	0.4
Navicula minima	23,490	0.9	1,033,542	0.1
Navicula tripunctata	23,490	0.9	26,308,333	3.4
Gomphonema subclavatum	23,490	0.9	14,093,750	1.8
Navicula sp.	23,490	0.9	3,523,438	0.5
Fragilaria vaucheria	23,490	0.9	6,765,000	0.9
Nitzschia acicularis	23,490	0.9	6,577,083	0.9
Scenedesmus acuminatus	23,490	0.9	5,637,500	0.7

Aquatic Analysts **Sample ID:** HY88

Periphyton Composition by Density (#/mL)
at Wells 02 (Starr Boat Launch)




Periphyton Composition by Biovolume (um3/mL)
at Wells 02 (Starr Boat Launch)
2000000000
1500000000
1000000000
500000000
0
Biovolume (um3/mL)
May
July
Aug
Sept
Date
Bacilliophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta

Periphyton Sample Analysis

Sample: Wells Res
Sample Station: Wells 06 Photic
Sample Depth:
Sample Date: 17-May-05

Total Density (#/mL): 3,725,365
Total Biovolume (um^3/mL): 1311269313
Trophic State Index: 101.6

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Cymbella minuta	1,945,102	52.2	719,687,865	54.9
Fragilaria construens venter	197,807	5.3	85,452,632	6.5
Nitzschia paleacea	164,839	4.4	16,154,240	1.2
Nitzschia palea	164,839	4.4	29,671,053	2.3
Fragilaria vaucheria	131,871	3.5	37,978,947	2.9
Fragilaria leptostauron	131,871	3.5	29,117,193	2.2
Synedra rumpens	131,871	3.5	18,461,988	1.4
Nitzschia frustulum	98,904	2.7	11,868,421	0.9
Nitzschia dissipata	98,904	2.7	26,605,044	2.0
Nitzschia volcanica	65,936	1.8	15,824,561	1.2
Synedra radians	65,936	1.8	23,736,842	1.8
Nitzschia capitellata	65,936	1.8	23,736,842	1.8
Nitzschia sp.	65,936	1.8	7,912,281	0.6
Achnanthes minutissima	65,936	1.8	3,296,784	0.3
Surirella linearis	32,968	0.9	9,230,994	0.7
Cymbella tumida	32,968	0.9	82,419,591	6.3
Nitzschia acicularis	32,968	0.9	9,230,994	0.7
Navicula cryptocephala veneta	32,968	0.9	3,131,944	0.2
Gomphonema olivaceum	32,968	0.9	7,417,763	0.6
Diploneis elliptica	32,968	0.9	8,571,637	0.7
Diatoma vulgare	32,968	0.9	64,616,959	4.9
Navicula tripunctata	32,968	0.9	36,923,977	2.8
Asterionella formosa	32,968	0.9	7,252,924	0.6
Oscillatoria sp.	32,968	0.9	32,967,836	2.5

Aquatic Analysts **Sample ID:** HY51

Periphyton Sample Analysis

Sample: Wells Res
Sample Station: Wells 06 Photic
Sample Depth:
Sample Date: 12-Jul-05

Total Density (#/mL): 1,058,268
Total Biovolume (um^3/mL): 531,198,877
Trophic State Index: 95.1

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Cymbella minuta	148,355	14.0	54,891,447	10.3
Fragilaria leptostauron	138,465	13.1	33,120,807	6.2
Fragilaria pinnata	89,013	8.4	7,477,105	1.4
Fragilaria construens venter	89,013	8.4	12,390,632	2.3
Achnanthes minutissima	69,232	6.5	3,461,623	0.7
Synedra rumpens	59,342	5.6	8,307,895	1.6
Fragilaria construens	49,452	4.7	39,877,895	7.5
Diatoma tenue elongatum	39,561	3.7	34,181,053	6.4
Nitzschia acicularis	39,561	3.7	11,077,193	2.1
Tabellaria flocculosa	39,561	3.7	98,033,158	18.5
Nitzschia paleacea	29,671	2.8	3,780,092	0.7
Synedra radians	29,671	2.8	10,681,579	2.0
Nitzschia frustulum	19,781	1.9	2,373,684	0.4
Achnanthes linearis	19,781	1.9	2,611,053	0.5
Fragilaria vaucheria	19,781	1.9	8,545,263	1.6
Cocconeis placentula	19,781	1.9	9,099,123	1.7
Tabellaria fenestrata	19,781	1.9	71,210,526	13.4
Cymbella affinis	19,781	1.9	35,605,263	6.7
Amphora perpusilla	9,890	0.9	1,641,798	0.3
Fragilaria capucina mesolepta	9,890	0.9	10,088,158	1.9
Nitzschia palea	9,890	0.9	1,780,263	0.3
Navicula gregaria	9,890	0.9	1,730,811	0.3
Navicula cryptocephala	9,890	0.9	1,829,715	0.3
Nitzschia sp.	9,890	0.9	3,560,526	0.7
Fragilaria crotonensis	9,890	0.9	33,231,579	6.3
Navicula cryptocephala veneta	9,890	0.9	939,583	0.2
Achnanthes clevei	9,890	0.9	1,483,553	0.3
Gomphonema ventricosum	9,890	0.9	8,406,798	1.6
Oscillatoria sp.	19,781	1.9	19,780,702	3.7

Aquatic Analysts **Sample ID:** HY63

Periphyton Sample Analysis

Sample: Wells Res
Sample Station: Wells 06 Photic
Sample Depth:
Sample Date: 17-Aug-05

Total Density (#/mL): 939,583
Total Biovolume (um^3/mL): 497,365,306
Trophic State Index: 94.6

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Achnanthes minutissima	175,389	18.7	8,769,444	1.8
Fragilaria construens venter	87,694	9.3	19,362,933	3.9
Cymbella microcephala	62,639	6.7	3,319,861	0.7
Cymbella minuta	50,111	5.3	18,541,111	3.7
Synedra rumpens	50,111	5.3	10,523,333	2.1
Fragilaria leptostauron	37,583	4.0	8,989,933	1.8
Nitzschia palea	37,583	4.0	6,765,000	1.4
Fragilaria vaucheria	37,583	4.0	18,400,800	3.7
Navicula cryptocephala veneta	25,056	2.7	2,380,278	0.5
Nitzschia capitellata	25,056	2.7	9,020,000	1.8
Fragilaria crotonensis	25,056	2.7	84,186,667	16.9
Nitzschia sp.	25,056	2.7	3,006,667	0.6
Navicula cryptocephala	25,056	2.7	4,635,278	0.9
Tabellaria fenestrata	25,056	2.7	120,266,667	24.2
Synedra ulna	25,056	2.7	49,860,556	10.0
Nitzschia frustulum	12,528	1.3	1,503,333	0.3
Cymbella affinis	12,528	1.3	22,550,000	4.5
Navicula anglica	12,528	1.3	4,510,000	0.9
Navicula sp.	12,528	1.3	1,879,167	0.4
Melosira varians	12,528	1.3	8,143,056	1.6
Cocconeis placentula	12,528	1.3	5,762,778	1.2
Achnanthes lewisiana	12,528	1.3	1,565,972	0.3
Nitzschia dissipata	12,528	1.3	3,369,972	0.7
Nitzschia fonticola	12,528	1.3	526,167	0.1
Gomphonema angustatum	12,528	1.3	2,255,000	0.5
Fragilaria virescens	12,528	1.3	6,013,333	1.2
Nitzschia acicularis	12,528	1.3	3,507,778	0.7
Synedra tenera	12,528	1.3	3,758,333	0.8
Achnanthes linearis	12,528	1.3	3,307,333	0.7
Tabellaria flocculosa	12,528	1.3	14,782,778	3.0
Navicula minima	12,528	1.3	551,222	0.1
Cymbella tumida	12,528	1.3	31,319,444	6.3
Navicula tripunctata	12,528	1.3	14,031,111	2.8

Aquatic Analysts **Sample ID:** HY76

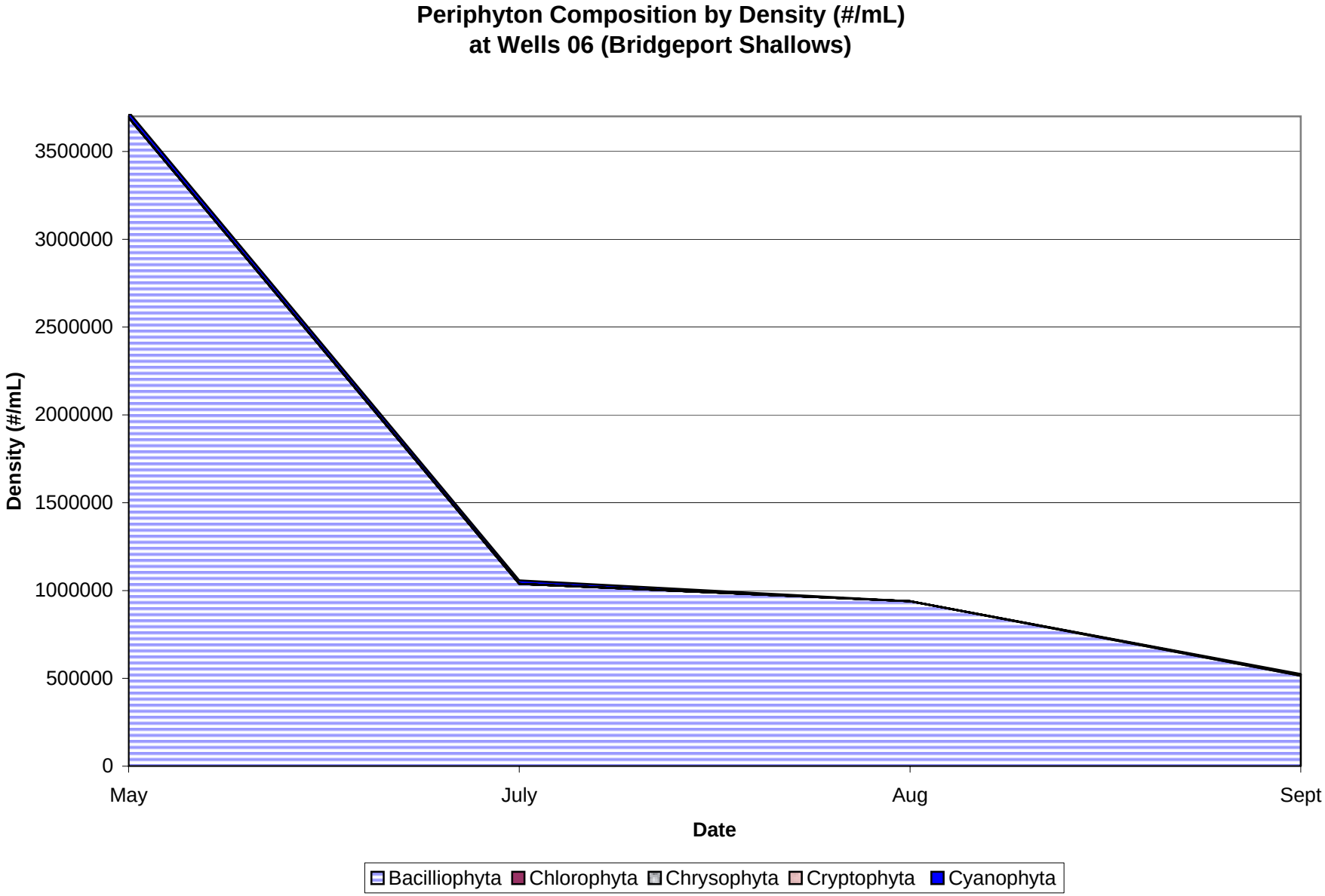
Periphyton Sample Analysis

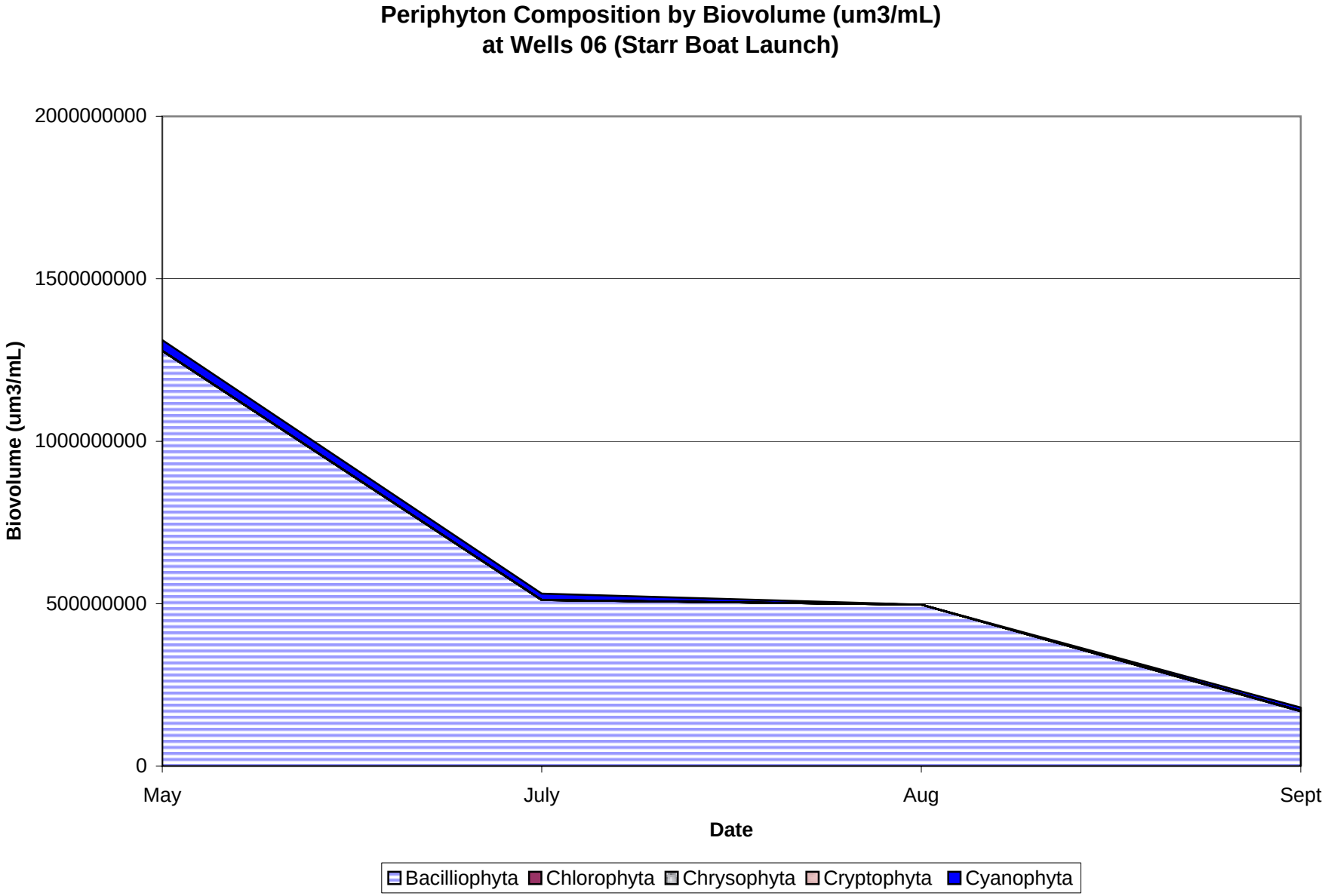
Sample: Wells Res
Sample Station: Wells 06 Photic
Sample Depth:
Sample Date: 7-Sep-05

Total Density (#/mL): 525,159
Total Biovolume (um^3/mL): 180,439,254
Trophic State Index: 87.3

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Achnanthes minutissima	122,007	23.2	6,100,329	3.4
Fragilaria construens venter	74,265	14.1	12,476,500	6.9
Fragilaria construens	68,960	13.1	35,528,318	19.7
Fragilaria leptostauron	31,828	6.1	7,027,579	3.9
Fragilaria pinnata	31,828	6.1	2,864,502	1.6
Cymbella affinis	21,219	4.0	38,193,366	21.2
Cymbella minuta	21,219	4.0	7,850,859	4.4
Nitzschia frustulum	15,914	3.0	1,909,668	1.1
Achnanthes clevei	10,609	2.0	1,591,390	0.9
Cocconeis placentula	10,609	2.0	4,880,263	2.7
Cyclotella ocellata	5,305	1.0	663,079	0.4
Gomphonema angustatum	5,305	1.0	954,834	0.5
Cyclotella kutzingiana	5,305	1.0	610,033	0.3
Navicula decussis	5,305	1.0	1,018,490	0.6
Gomphonema tenellum	5,305	1.0	1,113,973	0.6
Fragilaria capucina mesolepta	5,305	1.0	1,352,682	0.7
Diatoma tenue elongatum	5,305	1.0	3,819,337	2.1
Cymbella delicatula	5,305	1.0	4,243,707	2.4
Tabellaria fenestrata	5,305	1.0	12,731,122	7.1
Navicula cryptocephala	5,305	1.0	981,357	0.5
Nitzschia sp.	5,305	1.0	636,556	0.4
Amphora perpusilla	5,305	1.0	880,569	0.5
Nitzschia acicularis	5,305	1.0	1,485,298	0.8
Tabellaria flocculosa	5,305	1.0	3,129,734	1.7
Cocconeis pediculus	5,305	1.0	2,758,410	1.5
Nitzschia sinuata	5,305	1.0	1,326,159	0.7
Cymbella microcephala	5,305	1.0	281,146	0.2
Synedra ulna	5,305	1.0	10,556,222	5.9
Caloneis ventricosa minuta	5,305	1.0	1,485,298	0.8
Scenedesmus quadricauda	5,305	1.0	1,379,205	0.8
Oscillatoria sp.	10,609	2.0	10,609,268	5.9

Aquatic Analysts **Sample ID:** HY89


Periphyton Composition by Density (#/mL)
at Wells 06 (Bridgeport Shallows)
Density (#/mL)
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
May
July
Aug
Sept
Date
Bacilliophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta


Periphyton Composition by Biovolume (um3/mL)
at Wells 06 (Starr Boat Launch)
2000000000
1500000000
1000000000
500000000
0
Biovolume (um3/mL)
May
July
Aug
Sept
Date
Bacilliophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta

Periphyton Sample Analysis

Sample: Wells Res
Sample Station: Wells 07 Photic
Sample Depth:
Sample Date: 17-May-05

Total Density (#/mL): 1,333,784
Total Biovolume (um^3/mL): 691,522,030
Trophic State Index: 97.0

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Synedra rumpens	259,975	19.5	36,396,491	5.3
Achnanthes minutissima	248,672	18.6	12,433,584	1.8
Cymbella minuta	192,155	14.4	71,097,494	10.3
Nitzschia frustulum	67,820	5.1	8,138,346	1.2
Diatoma tenue	56,516	4.2	16,389,724	2.4
Nitzschia palea	56,516	4.2	10,172,932	1.5
Synedra ulna	56,516	4.2	112,467,419	16.3
Nitzschia sp.	45,213	3.4	5,425,564	0.8
Achnanthes linearis	45,213	3.4	5,968,120	0.9
Fragilaria capucina mesolepta	45,213	3.4	115,293,233	16.7
Nitzschia paleacea	33,910	2.5	3,323,158	0.5
Nitzschia capitellata	22,607	1.7	8,138,346	1.2
Melosira varians	22,607	1.7	22,041,353	3.2
Cymbella cistula	22,607	1.7	135,639,098	19.6
Fragilaria vaucheria	22,607	1.7	6,510,677	0.9
Asterionella formosa	22,607	1.7	7,460,150	1.1
Nitzschia linearis	22,607	1.7	51,678,496	7.5
Fragilaria construens venter	11,303	0.8	4,340,451	0.6
Achnanthes flexella	11,303	0.8	5,482,080	0.8
Nitzschia tryblionella	11,303	0.8	5,990,727	0.9
Cocconeis placentula	11,303	0.8	5,199,499	0.8
Stephanodiscus astraea minutula	11,303	0.8	3,956,140	0.6
Synedra radians	11,303	0.8	4,069,173	0.6
Oscillatoria sp.	22,607	1.7	33,909,774	4.9

Aquatic Analysts **Sample ID:** HY52

Periphyton Sample Analysis

Sample: Wells Res
Sample Station: Wells 07 Photic
Sample Depth:
Sample Date: 12-Jul-05

Total Density (#/mL): 338,547
Total Biovolume (um^3/mL): 112,940,319
Trophic State Index: 83.9

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Achnanthes minutissima	64,050	18.9	3,202,475	2.8
Cymbella minuta	32,025	9.5	11,849,158	10.5
Achnanthes linearis	22,875	6.8	3,019,477	2.7
Fragilaria vaucheria	18,300	5.4	7,905,539	7.0
Fragilaria construens	18,300	5.4	5,533,877	4.9
Fragilaria construens venter	18,300	5.4	2,195,983	1.9
Synedra ulna	13,725	4.1	35,506,299	31.4
Cyclotella kutzingiana	13,725	4.1	1,578,363	1.4
Achnanthes clevei	13,725	4.1	2,058,734	1.8
Navicula cryptocephala veneta	9,150	2.7	869,243	0.8
Synedra rumpens	9,150	2.7	1,280,990	1.1
Achnanthes lanceolata	9,150	2.7	1,646,987	1.5
Gomphonema angustatum	9,150	2.7	1,646,987	1.5
Fragilaria leptostauron	9,150	2.7	1,683,587	1.5
Nitzschia sp.	9,150	2.7	1,097,991	1.0
Cymbella muelleri	9,150	2.7	3,659,972	3.2
Gomphonema sp.	4,575	1.4	914,993	0.8
Melosira varians	4,575	1.4	2,973,727	2.6
Amphora perpusilla	4,575	1.4	759,444	0.7
Nitzschia communis	4,575	1.4	205,873	0.2
Asterionella formosa	4,575	1.4	1,006,492	0.9
Nitzschia frustulum	4,575	1.4	548,996	0.5
Gomphonema subclavatum	4,575	1.4	2,744,979	2.4
Nitzschia fonticola	4,575	1.4	192,149	0.2
Melosira italica	4,575	1.4	4,309,617	3.8
Cocconeis placentula	4,575	1.4	2,104,484	1.9
Cymbella tumida	4,575	1.4	11,437,411	10.1
Cyclotella ocellata	4,575	1.4	571,871	0.5
Rhizosolenia eriensis	4,575	1.4	434,622	0.4

Aquatic Analysts **Sample ID:** HY64

Periphyton Sample Analysis

Sample: Wells Res
Sample Station: Wells 07 Photic
Sample Depth:
Sample Date: 17-Aug-05

Total Density (#/mL): 778,383
Total Biovolume (um^3/mL): 408,497,180
Trophic State Index: 93.2

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Achnanthes minutissima	184,962	23.8	9,248,120	2.3
Cymbella minuta	69,361	8.9	25,663,534	6.3
Achnanthes linearis	53,947	6.9	7,121,053	1.7
Cocconeis placentula	30,827	4.0	14,180,451	3.5
Cymbella microcephala	30,827	4.0	1,633,835	0.4
Melosira varians	23,120	3.0	15,028,195	3.7
Navicula cryptocephala veneta	23,120	3.0	2,196,429	0.5
Cymbella affinis	23,120	3.0	41,616,541	10.2
Fragilaria capucina mesolepta	15,414	2.0	17,687,030	4.3
Fragilaria crotonensis	15,414	2.0	25,894,737	6.3
Nitzschia volcanica	15,414	2.0	2,466,165	0.6
Navicula sp.	15,414	2.0	2,312,030	0.6
Fragilaria construens venter	15,414	2.0	4,439,098	1.1
Cymbella tumida	15,414	2.0	38,533,835	9.4
Synedra rumpens	15,414	2.0	2,157,895	0.5
Navicula tripunctata	7,707	1.0	8,631,579	2.1
Cymbella hustedtii	7,707	1.0	3,082,707	0.8
Nitzschia dissipata	7,707	1.0	2,073,120	0.5
Fragilaria construens	7,707	1.0	1,726,316	0.4
Synedra tenera	7,707	1.0	2,312,030	0.6
Nitzschia sigmoidea	7,707	1.0	6,550,752	1.6
Diatoma vulgare	7,707	1.0	15,105,263	3.7
Nitzschia paleacea	7,707	1.0	755,263	0.2
Navicula pupula	7,707	1.0	2,080,827	0.5
Cymbella sp.	7,707	1.0	2,697,368	0.7
Fragilaria leptostauron	7,707	1.0	1,418,045	0.3
Nitzschia microcephala	7,707	1.0	770,677	0.2
Nitzschia sp.	7,707	1.0	924,812	0.2
Fragilaria vaucheria	7,707	1.0	2,219,549	0.5
Oscillatoria sp.	123,308	15.8	147,969,925	36.2

Aquatic Analysts **Sample ID:** HY77

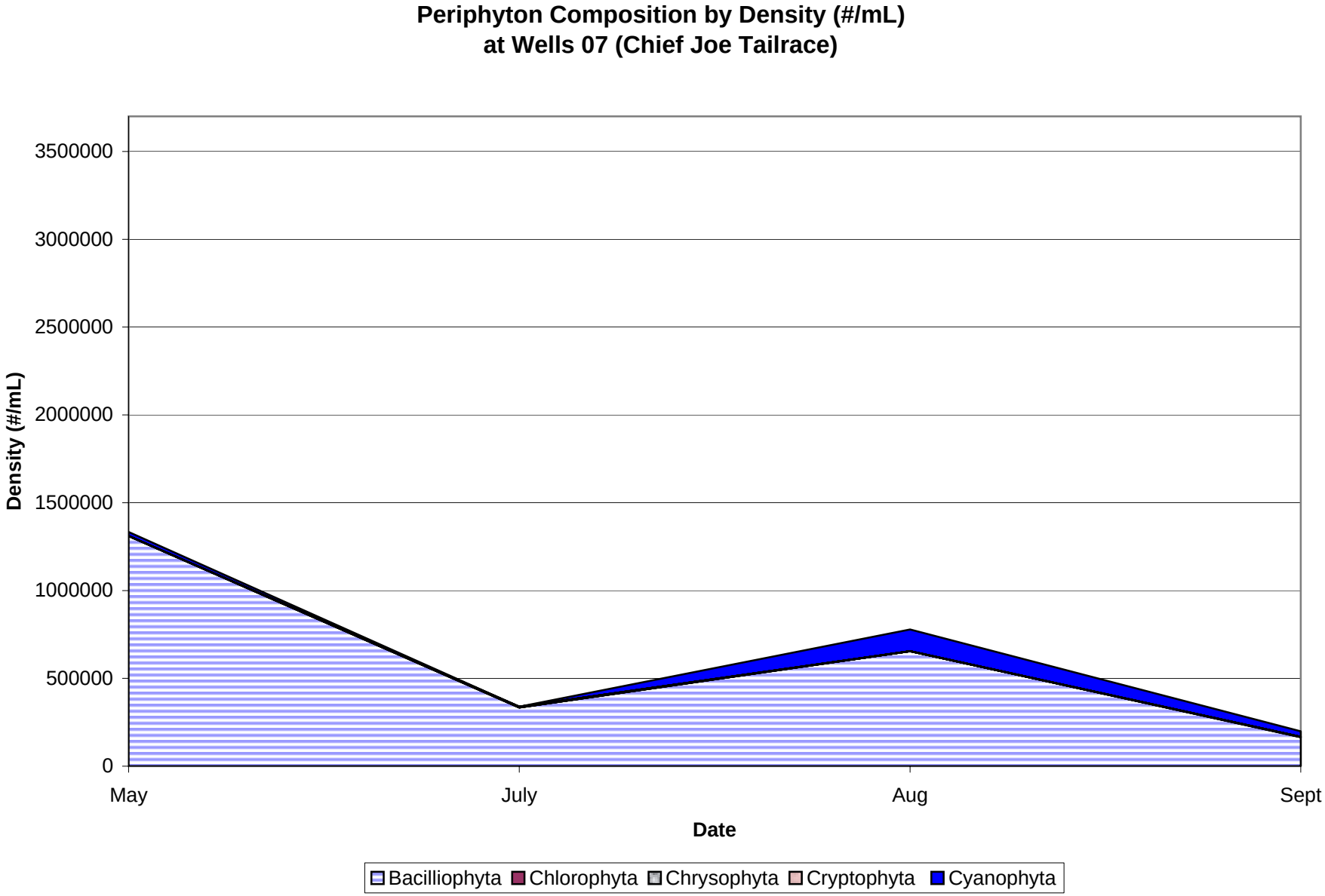
Periphyton Sample Analysis

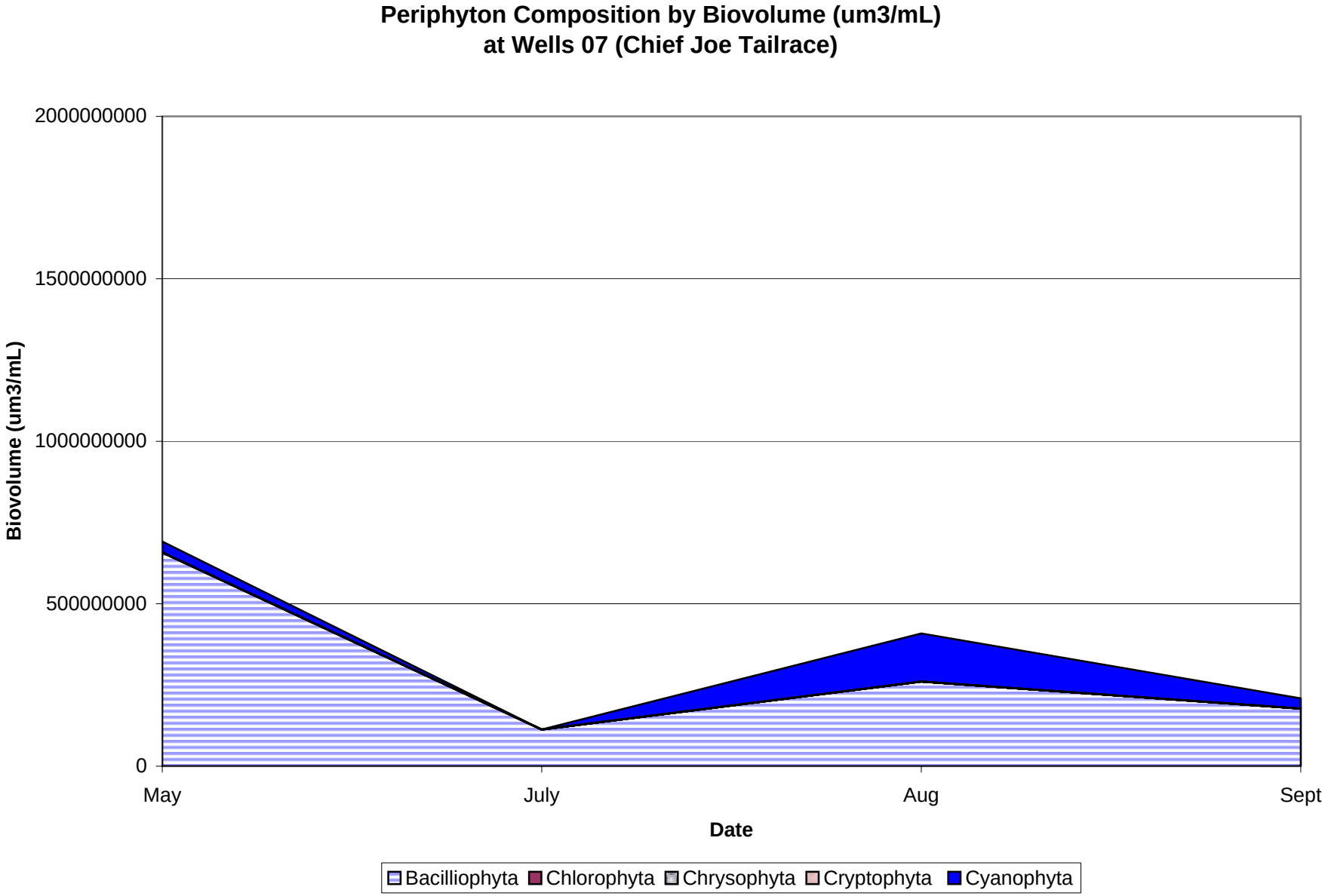
Sample: Wells Res
Sample Station: Wells 07 Photic
Sample Depth:
Sample Date: 7-Sep-05

Total Density (#/mL): 198,327
Total Biovolume (um^3/mL): 208,790,832
Trophic State Index: 88.4

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Cymbella affinis	77,848	39.3	140,126,582	67.1
Achnanthes minutissima	16,682	8.4	834,087	0.4
Cymbella minuta	12,975	6.5	4,800,633	2.3
Cymbella microcephala	9,268	4.7	491,184	0.2
Cocconeis placentula	7,414	3.7	3,410,488	1.6
Fragilaria vaucheria	5,561	2.8	2,081,881	1.0
Nitzschia frustulum	5,561	2.8	667,269	0.3
Gomphonema angustatum	3,707	1.9	1,000,904	0.5
Nitzschia paleacea	3,707	1.9	363,291	0.2
Fragilaria construens venter	3,707	1.9	533,816	0.3
Cymbella delicatula	1,854	0.9	1,482,821	0.7
Fragilaria crotonensis	1,854	0.9	12,455,696	6.0
Navicula minima	1,854	0.9	81,555	0.0
Nitzschia palea	1,854	0.9	333,635	0.2
Melosira granulata angustissima	1,854	0.9	463,382	0.2
Navicula cryptocephala veneta	1,854	0.9	176,085	0.1
Nitzschia sp.	1,854	0.9	222,423	0.1
Fragilaria construens	1,854	0.9	415,190	0.2
Melosira varians	1,854	0.9	2,409,584	1.2
Tabellaria fenestrata	1,854	0.9	4,448,463	2.1
Scenedesmus quadricauda	1,854	0.9	481,917	0.2
Oscillatoria sp.	31,510	15.9	31,509,946	15.1

Aquatic Analysts **Sample ID:** HY90


Periphyton Composition by Density (#/mL)
at Wells 07 (Chief Joe Tailrace)
Density (#/mL)
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
May
July
Aug
Sept
Date
Bacilliophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta


Periphyton Composition by Biovolume (um3/mL)
at Wells 07 (Chief Joe Tailrace)
2000000000
1500000000
1000000000
500000000
0
Biovolume (um3/mL)
May
July
Aug
Sept
Date
Bacilliophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta

Periphyton Sample Analysis

Sample: Wells Res
Sample Station: Wells 08 Photic
Sample Depth:
Sample Date: 17-May-05

Total Density (#/mL): 1,064,472
Total Biovolume (um^3/mL): 522,945,238
Trophic State Index: 95.0

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Cymbella minuta	466,874	43.9	172,743,271	33.0
Synedra rumpens	168,075	15.8	23,530,435	4.5
Diatoma vulgare	46,687	4.4	91,507,246	17.5
Navicula cryptocephala veneta	28,012	2.6	2,661,180	0.5
Nitzschia fonticola	28,012	2.6	1,176,522	0.2
Nitzschia frustulum	28,012	2.6	3,361,491	0.6
Nitzschia paleacea	18,675	1.8	2,745,217	0.5
Achnanthes minutissima	18,675	1.8	933,747	0.2
Nitzschia sp.	18,675	1.8	2,240,994	0.4
Cymbella cistula	18,675	1.8	112,049,689	21.4
Synedra mazamaensis	9,337	0.9	2,390,393	0.5
Navicula sp.	9,337	0.9	1,400,621	0.3
Fragilaria pinnata	9,337	0.9	560,248	0.1
Fragilaria vaucheria	9,337	0.9	5,378,385	1.0
Fragilaria construens	9,337	0.9	8,366,377	1.6
Fragilaria capucina mesolepta	9,337	0.9	7,143,168	1.4
Amphora perpusilla	9,337	0.9	1,550,021	0.3
Synedra socia	9,337	0.9	3,081,366	0.6
Asterionella formosa	9,337	0.9	2,054,244	0.4
Nitzschia capitellata	9,337	0.9	3,361,491	0.6
Navicula gregaria	9,337	0.9	1,634,058	0.3
Navicula menisculus upsaliensis	9,337	0.9	1,914,182	0.4
Ulothrix sp.	65,362	6.1	47,583,768	9.1
Scenedesmus acuminatus	9,337	0.9	2,240,994	0.4
Ankistrodesmus falcatus	9,337	0.9	233,437	0.0
Scenedesmus quadricauda	9,337	0.9	2,427,743	0.5
Oscillatoria sp.	18,675	1.8	18,674,948	3.6

Aquatic Analysts **Sample ID:** HY53

Periphyton Sample Analysis

Sample: Wells Res
Sample Station: Wells 08 Photic
Sample Depth:
Sample Date: 12-Jul-05

Total Density (#/mL): 70,252
Total Biovolume (um^3/mL): 92,004,880
Trophic State Index: 82.5

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Fragilaria construens venter	5,078	7.2	658,167	0.7
Cymbella minuta	4,232	6.0	1,565,855	1.7
Synedra rumpens	3,386	4.8	473,988	0.5
Fragilaria vaucheria	2,539	3.6	1,243,204	1.4
Achnanthes minutissima	2,539	3.6	126,961	0.1
Fragilaria capucina mesolepta	2,539	3.6	1,295,004	1.4
Fragilaria crotonensis	2,539	3.6	11,304,624	12.3
Nitzschia frustulum	1,693	2.4	203,138	0.2
Achnanthes linearis	1,693	2.4	223,452	0.2
Diatoma tenue	1,693	2.4	490,917	0.5
Fragilaria leptostauron	1,693	2.4	311,478	0.3
Synedra ulna	1,693	2.4	3,368,704	3.7
Nitzschia volcanica	846	1.2	135,425	0.1
Tabellaria fenestrata	846	1.2	2,031,379	2.2
Navicula tripunctata	846	1.2	947,977	1.0
Cocconeis pediculus	846	1.2	440,132	0.5
Tabellaria flocculosa	846	1.2	499,381	0.5
Fragilaria construens	846	1.2	379,191	0.4
Diatoma tenue elongatum	846	1.2	609,414	0.7
Achnanthes lanceolata	846	1.2	152,353	0.2
Diatoma vulgare	846	1.2	1,658,960	1.8
Navicula capitata	846	1.2	406,276	0.4
Cocconeis placentula	846	1.2	389,348	0.4
Diatoma hiemale mesodon	846	1.2	677,126	0.7
Melosira ambigua	846	1.2	997,069	1.1
Cymbella affinis	846	1.2	1,523,534	1.7
Cyclotella meneghiniana	846	1.2	321,635	0.3
Ulothrix sp.	5,078	7.2	2,437,655	2.6
Oscillatoria sp.	21,160	30.1	57,132,535	62.1

Aquatic Analysts **Sample ID:** HY65

Periphyton Sample Analysis

Sample: Wells Res
Sample Station: Wells 08 Photic
Sample Depth:
Sample Date: 17-Aug-05

Total Density (#/mL): 2,279,986
Total Biovolume (um^3/mL): 1,441,700,831
Trophic State Index: 102.3

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Achnanthes minutissima	374,792	16.4	18,739,612	1.3
Cymbella microcephala	249,861	11.0	13,242,659	0.9
Cymbella minuta	218,629	9.6	80,892,659	5.6
Cymbella affinis	156,163	6.8	281,094,183	19.5
Melosira varians	93,698	4.1	60,903,740	4.2
Fragilaria construens	62,465	2.7	48,972,853	3.4
Fragilaria construens venter	62,465	2.7	10,494,183	0.7
Synedra rumpens	62,465	2.7	8,745,152	0.6
Nitzschia frustulum	62,465	2.7	7,495,845	0.5
Navicula cryptocephala veneta	62,465	2.7	5,934,211	0.4
Cocconeis placentula	62,465	2.7	28,734,072	2.0
Tabellaria fenestrata	62,465	2.7	149,916,898	10.4
Nitzschia paleacea	62,465	2.7	9,182,410	0.6
Gomphonema angustatum	62,465	2.7	16,865,651	1.2
Tabellaria flocculosa	31,233	1.4	18,427,285	1.3
Cymbella tumida	31,233	1.4	78,081,717	5.4
Synedra ulna	31,233	1.4	62,153,047	4.3
Cymbella delicatula	31,233	1.4	24,986,150	1.7
Nitzschia acicularis	31,233	1.4	8,745,152	0.6
Nitzschia fonticola	31,233	1.4	1,311,773	0.1
Fragilaria capucina mesolepta	31,233	1.4	47,786,011	3.3
Cymbella naviculiformis	31,233	1.4	37,479,224	2.6
Gomphoneis herculeana	31,233	1.4	168,656,510	11.7
Synedra radians	31,233	1.4	11,243,767	0.8
Fragilaria pinnata	31,233	1.4	1,873,961	0.1
Navicula protracta	31,233	1.4	29,671,053	2.1
Fragilaria leptostauron	31,233	1.4	5,746,814	0.4
Navicula sp.	31,233	1.4	4,684,903	0.3
Nitzschia dissipata	31,233	1.4	8,401,593	0.6
Amphora ovalis	31,233	1.4	18,052,493	1.3
Fragilaria crotonensis	31,233	1.4	104,941,828	7.3
Navicula cryptocephala	31,233	1.4	5,778,047	0.4
Oscillatoria sp.	62,465	2.7	62,465,374	4.3

Aquatic Analysts **Sample ID:** HY78

Periphyton Sample Analysis

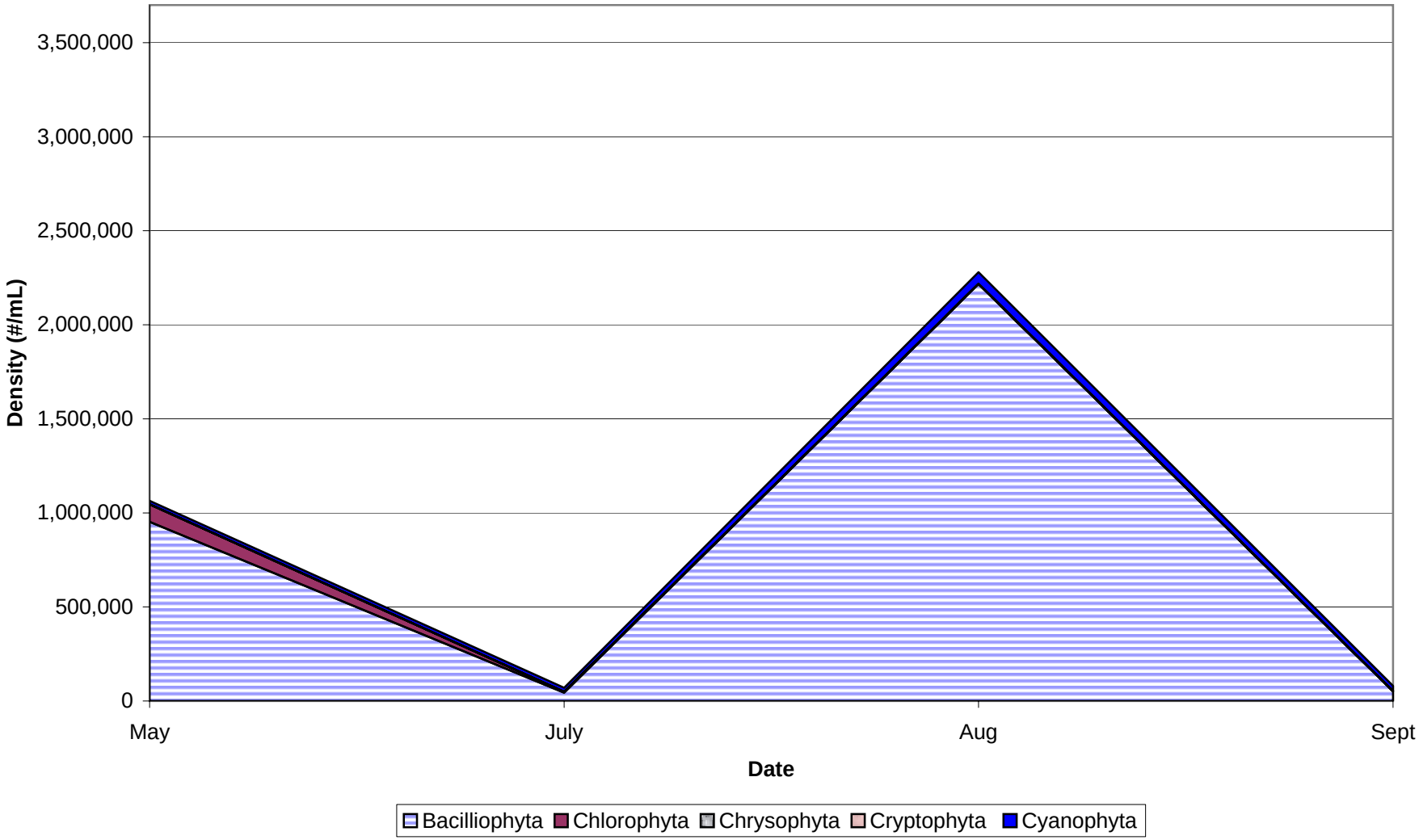
Sample: Wells Res
Sample Station: Wells 08 Photic
Sample Depth:
Sample Date: 7-Sep-05

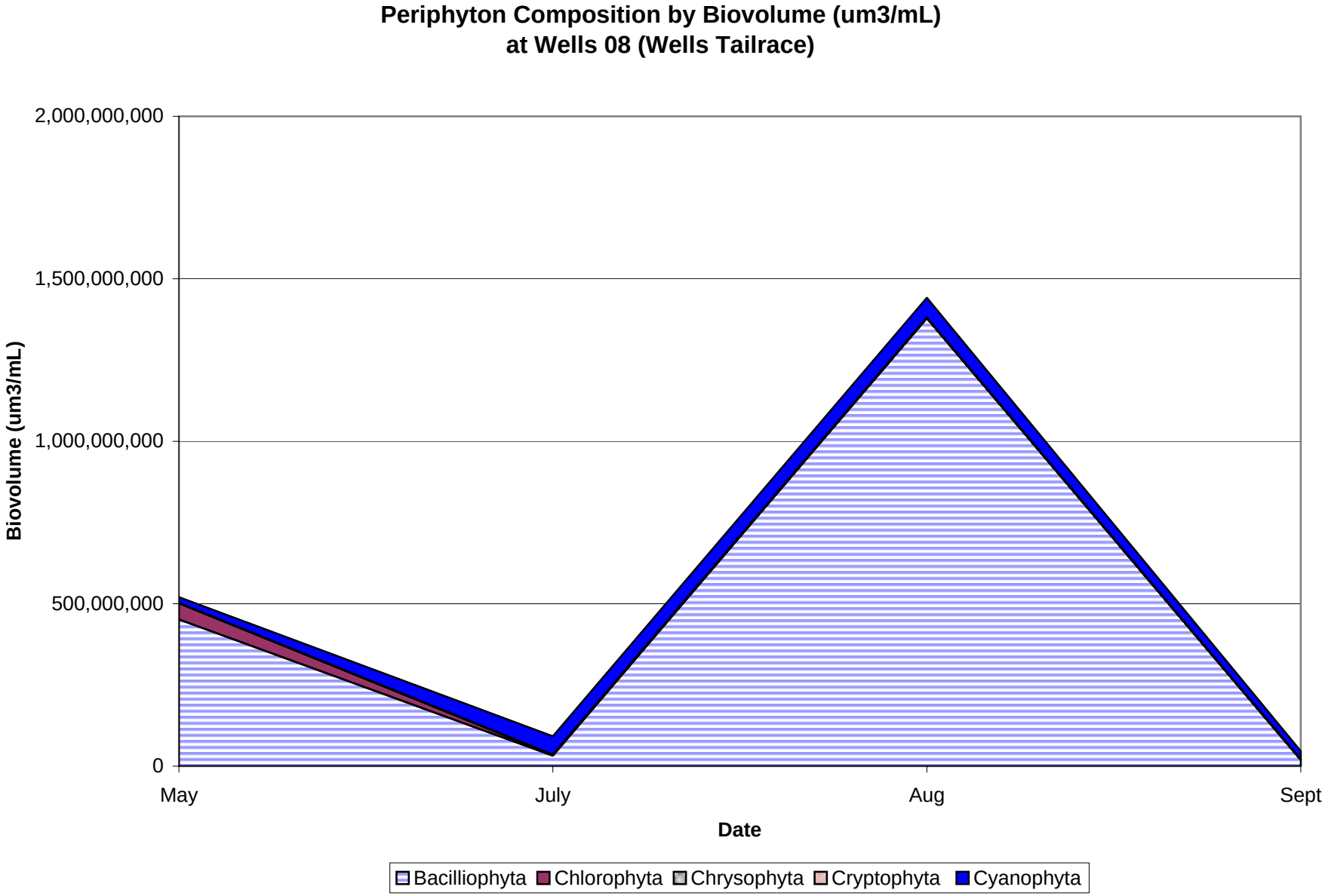
Total Density (#/mL): 80,207
Total Biovolume (um^3/mL): 46,255,692
Trophic State Index: 77.5

Species	Density #/mL	Density Percent	Biovolume um^3/mL	Biovolume Percent
Cocconeis placentula	8,380	10.4	3,854,701	8.3
Fragilaria construens venter	5,986	7.5	746,998	1.6
Fragilaria construens	4,788	6.0	1,501,657	3.2
Achnanthes linearis	3,591	4.5	474,056	1.0
Fragilaria pinnata	2,394	3.0	143,653	0.3
Melosira granulata angustissima	2,394	3.0	2,394,224	5.2
Fragilaria leptostauron	2,394	3.0	660,806	1.4
Amphora perpusilla	2,394	3.0	596,162	1.3
Achnanthes minutissima	2,394	3.0	119,711	0.3
Synedra rumpens	2,394	3.0	335,191	0.7
Synedra radians	1,197	1.5	430,960	0.9
Stephanodiscus astraea minutula	1,197	1.5	418,989	0.9
Fragilaria virescens	1,197	1.5	2,298,455	5.0
Tabellaria fenestrata	1,197	1.5	2,873,069	6.2
Cocconeis klamathensis	1,197	1.5	335,191	0.7
Cyclotella stelligera	1,197	1.5	65,841	0.1
Pinnularia sp.	1,197	1.5	478,845	1.0
Cyclotella meneghiniana	1,197	1.5	454,903	1.0
Tabellaria flocculosa	1,197	1.5	706,296	1.5
Cyclotella ocellata	1,197	1.5	149,639	0.3
Cymbella minuta	1,197	1.5	442,931	1.0
Navicula radiosa	1,197	1.5	389,061	0.8
Rhodomonas minuta	2,394	3.0	47,884	0.1
Oscillatoria sp.	26,336	32.8	26,336,465	56.9

Aquatic Analysts **Sample ID:** HY91

Periphyton Composition by Density (#/mL)
at Wells 08 (Wells Tailrace)




Periphyton Composition by Biovolume (um3/mL)
at Wells 08 (Wells Tailrace)
2,000,000,000
1,500,000,000
1,000,000,000
500,000,000
0
Biovolume (um3/mL)
May
July
Aug
Sept
Date
Bacilliophyta
Chlorophyta
Chrysophyta
Cryptophyta
Cyanophyta

Appendix E

Zooplankton Species Lists

Date	5/17/2006		5/17/2006		5/17/2006	
Time	13:45		14:40		16:40	
Site #	Wells 01		Wells 02		Wells 03	
Volume (m^3)	0.100		0.060		0.040	
EcoAnalysts Sample ID	1		2		3	
CLADOCERA	**Density**	**Std.Error**	**Density**	**Std.Error**	**Density**	**Std.Error**
Daphnia pulex *	0		0		75	43.3
Daphnia rosea *	210	45.8	0		0	
Ceriodaphnia pulchella	0		0		0	
Ceriodaphnia lacustris	0		0		0	
Sida crytallina *	0		0		0	
Diaphanosoma brachyurum	0		16.7	16.7	0	
Bosmina longirostris	770	87.8	33.3	23.6	50	35.4
Chydorus sphaericus	50	22.4	16.7	16.7	0	
Alona costata	30	17.3	0		0	
Alona quadrangularis	0		0		0	
Camptocercus rectirostris	0		0		0	
Total cladocerans	**1060**	**103**	**66.7**	**33.3**	**125**	**55.9**
COPEPODA						
Epischura nevadensis *	0		0		0	
epischurid copepodites *	0		0		0	
Leptodiaptomus ashlandi	260	51	66.7	33.3	0	
diaptomid copepodites	620	78.7	233.3	62.4	75	43.3
Diacyclops thomasi	1170	108.2	250	64.6	125	55.9
Microcyclops varicans	0		16.7	16.7	0	
cyclopoid copepodites	1570	125.3	416.7	83.3	325	90.1
harpacticoid copepods	40	20	0		25	25
copepod nauplii	60	24.5	100	40.8	25	25
Total copepods	**3720**	**192.9**	**1083.3**	**134.4**	**575**	**119.9**
MISC. ZOOPLANKTERS						
water mites	0		0		0	
Chironomid larvae *	10	10	0		25	25
mosquito pupae *	0		0		0	
ostracods	0		0		0	
aquatic oligochaetes	0		0		0	
tardigrades	10	10	0		0	
nematodes	10	10	0		0	
Total misc. zooplankters	**30**	**17.3**	**0**		**25**	**25**
ROTIFERA						
Asplanchna priodonta	0		0		0	
Keratella hiemalis	20	14.1	0		0	
Keratella cochlearis	30	17.3	50	28.9	0	
Keratella quadrata	0		0		0	
Euchlanis dilatata	0		0		0	
Euchlanis triquetra	0		0		0	
Kellicottia longispina	2680	163.7	100	40.8	1000	158.1
Polyarthra vulgaris	20	14.1	0		0	
Synchaeta sp.	1160	107.7	100	40.8	50	35.4
unidentifid bdelloid	0		0		0	
Total rotifers	**3910**	**197.7**	**250**	**64.6**	**1050**	**162**
Total Density	**8720**	**295.3**	**1400**	**152.8**	**1775**	**210.7**
Total Count	**872**		**84**		**71**	
Density of Edible Zooplankton (*)	**220**	**46.9**	**0**		**100**	**50**
% Edible Zooplankton	**4.6**		**0**		**13.8**	

All samples were counted in their entirety
Due to the size of the mesh, the rotifers have been undersampled.

Date	5/18/2006		5/18/2006		5/18/2006	
Time	9:00		10:00		10:40	
Site #	Wells 04		Wells 05		Wells 06	
Volume (m^3)	0.100		0.020		0.030	
EcoAnalysts Sample ID	4		5		6	
CLADOCERA	**Density**	**Std.Error**	**Density**	**Std.Error**	**Density**	**Std.Error**
Daphnia pulex *	560	74.8	250	111.8	66.7	47.1
Daphnia rosea *	0		0		0	
Ceriodaphnia pulchella	0		0		0	
Ceriodaphnia lacustris	0		0		0	
Sida crytallina *	0		0		0	
Diaphanosoma brachyurum	0		0		0	
Bosmina longirostris	320	56.6	250	111.8	233.3	88.2
Chydorus sphaericus	0		0		0	
Alona costata	0		50	50	0	
Alona quadrangularis	0		0		0	
Camptocercus rectirostris	0		0		0	
Total cladocerans	**880**	**93.8**	**550**	**165.8**	**300**	**100**
COPEPODA						
Epischura nevadensis *	60	24.5	50	50	66.7	47.1
epischurid copepodites *	300	54.8	400	141.4	166.7	74.5
Leptodiaptomus ashlandi	80	28.3	150	86.6	33.3	33.3
diaptomid copepodites	190	43.6	400	141.4	300	100
Diacyclops thomasi	980	99	1200	244.9	733.3	156.3
Microcyclops varicans	0		50	50	0	
cyclopoid copepodites	1360	116.6	2450	350	733.3	156.3
harpacticoid copepods	10	10	50	50	233.3	88.2
copepod nauplii	90	30	50	50	100	57.7
Total copepods	**3070**	**175.2**	**4800**	**489.9**	**2366.7**	**280.9**
MISC. ZOOPLANKTERS						
water mites	0		0		0	
Chironomid larvae *	0		0		0	
mosquito pupae *	0		0		0	
ostracods	0		0		0	
aquatic oligochaetes	0		0		0	
tardigrades	0		0		0	
nematodes	0		0		0	
Total misc. zooplankters	**0**		**0**		**0**	
ROTIFERA						
Asplanchna priodonta	0		0		0	
Keratella hiemalis	0		0		0	
Keratella cochlearis	20	14.1	50	50	0	
Keratella quadrata	10	10	0		0	
Euchlanis dilatata	0		0		0	
Euchlanis triquetra	0		0		0	
Kellicottia longispina	3190	178.6	700	187.1	2133.3	266.7
Polyarthra vulgaris	0		0		0	
Synchaeta sp.	230	48	0		200	81.7
unidentifid bdelloid	0		0		0	
Total rotifers	**3450**	**185.7**	**750**	**193.6**	**2333.3**	**278.9**
Total Density	**7400**	**272**	**6100**	**552.3**	**5000**	**408.2**
Total Count	**740**		**122**		**150**	
Density of Edible Zooplankton (*)	**920**	**95.9**	**700**	**187.1**	**300**	**100**
% Edible Zooplankton	**23.3**		**13.1**		**11.3**	

All samples were counted in their en
Due to the size of the mesh, the rotif

Date	7/12/2006		7/12/2006		7/13/2006	
Time	14:25		10:05		8:10	
Site #	Wells 03		Wells 05		Wells 01	
Volume (m^3)	0.100		0.030		0.100	
EcoAnalysts Sample ID	7		8		9	
CLADOCERA	**Density**	**Std.Error**	**Density**	**Std.Error**	**Density**	**Std.Error**
Daphnia pulex *	10	10	200	81.7	150	38.7
Daphnia rosea *	0		0		40	20
Ceriodaphnia pulchella	0		0		0	
Ceriodaphnia lacustris	0		66.7	47.1	0	
Sida crytallina *	0		0		0	
Diaphanosoma brachyurum	10	10	100	57.7	0	
Bosmina longirostris	80	28.3	633.3	145.3	250	50
Chydorus sphaericus	10	10	33.3	33.3	40	20
Alona costata	10	10	33.3	33.3	80	28.3
Alona quadrangularis	0		0		40	20
Camptocercus rectirostris	0		0		10	10
Total cladocerans	**120**	**34.6**	**1066.7**	**188.6**	**610**	**78.1**
COPEPODA						
Epischura nevadensis *	10	10	33.3	33.3	10	10
epischurid copepodites *	30	17.3	0		0	
Leptodiaptomus ashlandi	20	14.1	33.3	33.3	50	22.4
diaptomid copepodites	220	46.9	600	141.4	300	54.8
Diacyclops thomasi	20	14.1	66.7	47.1	180	42.4
Microcyclops varicans	0		0		0	
cyclopoid copepodites	60	24.5	233.3	88.2	280	52.9
harpacticoid copepods	0		0		0	
copepod nauplii	20	14.1	33.3	33.3	20	14.1
Total copepods	**380**	**61.6**	**1000**	**182.6**	**840**	**91.7**
MISC. ZOOPLANKTERS						
water mites	0		0		0	
Chironomid larvae *	0		0		0	
mosquito pupae *	0		0		0	
ostracods	0		0		0	
aquatic oligochaetes	0		0		0	
tardigrades	0		33.3	33.3	0	
nematodes	0		0		0	
Total misc. zooplankters	**0**		**33.3**	**33.3**	**0**	
ROTIFERA						
Asplanchna priodonta	0		0		0	
Keratella hiemalis	0		0		0	
Keratella cochlearis	10	10	33.3	33.3	0	
Keratella quadrata	0		0		0	
Euchlanis dilatata	0		0		10	10
Euchlanis triquetra	0		0		0	
Kellicottia longispina	70	26.5	266.7	94.3	60	24.5
Polyarthra vulgaris	0		0		0	
Synchaeta sp.	0		0		0	
unidentifid bdelloid	0		0		0	
Total rotifers	**80**	**28.3**	**300**	**100**	**70**	**26.5**
Total Density	**580**	**76.2**	**2400**	**282.8**	**1520**	**123.3**
Total Count	**58**		**72**		**152**	
Density of Edible Zooplankton (*)	**50**	**22.4**	**233.3**	**88.2**	**200**	**44.7**
% Edible Zooplankton	**10**		**11.1**		**13.8**	

All samples were counted in their en
Due to the size of the mesh, the rotif

Date	7/12/2006		8/17/2006		8/17/2006	
Time	9:15		9:00		12:10	
Site #	Wells 04		Wells 01		Wells 03	
Volume (m^3)	0.100		0.100		0.030	
EcoAnalysts Sample ID	10		11		12	
CLADOCERA	**Density**	**Std.Error**	**Density**	**Std.Error**	**Density**	**Std.Error**
Daphnia pulex *	330	57.4	0		0	
Daphnia rosea *	0		20	14.1	0	
Ceriodaphnia pulchella	30	17.3	0		0	
Ceriodaphnia lacustris	0		0		0	
Sida crytallina *	0		20	14.1	0	
Diaphanosoma brachyurum	0		0		66.7	47.1
Bosmina longirostris	350	59.2	20	14.1	66.7	47.1
Chydorus sphaericus	180	42.4	90	30	0	
Alona costata	380	61.6	20	14.1	0	
Alona quadrangularis	360	60	0		33.3	33.3
Camptocercus rectirostris	0		0		0	
Total cladocerans	**1630**	**127.7**	**170**	**41.2**	**166.7**	**74.5**
COPEPODA						
Epischura nevadensis *	0		0		0	
epischurid copepodites *	10	10	0		0	
Leptodiaptomus ashlandi	170	41.2	200	44.7	66.7	47.1
diaptomid copepodites	250	50	450	67.1	300	100
Diacyclops thomasi	750	86.6	370	60.8	333.3	105.4
Microcyclops varicans	0		0		0	
cyclopoid copepodites	1450	120.4	320	56.6	233.3	88.2
harpacticoid copepods	0		0		0	
copepod nauplii	10	10	40	20	66.7	47.1
Total copepods	**2640**	**162.5**	**1380**	**117.5**	**1000**	**182.6**
MISC. ZOOPLANKTERS						
water mites	10	10	0		0	
Chironomid larvae *	0		0		0	
mosquito pupae *	0		10	10	0	
ostracods	0		0		0	
aquatic oligochaetes	0		0		0	
tardigrades	0		0		0	
nematodes	0		0		0	
Total misc. zooplankters	**10**	**10**	**10**	**10**	**0**	
ROTIFERA						
Asplanchna priodonta	0		10	10	0	
Keratella hiemalis	0		0		0	
Keratella cochlearis	0		0		0	
Keratella quadrata	0		0		0	
Euchlanis dilatata	0		20	14.1	33.3	33.3
Euchlanis triquetra	0		0		0	
Kellicottia longispina	270	52	0		100	57.7
Polyarthra vulgaris	0		0		0	
Synchaeta sp.	0		0		0	
unidentifid bdelloid	10	10	0		0	
Total rotifers	**280**	**52.9**	**30**	**17.3**	**133.3**	**66.7**
Total Density	**4560**	**213.5**	**1590**	**126.1**	**1300**	**208.2**
Total Count	**456**		**159**		**39**	
Density of Edible Zooplankton (*)	**340**	**58.3**	**50**	**22.4**	**0**	
% Edible Zooplankton	**7.9**		**3.2**		**0**	

All samples were counted in their en
Due to the size of the mesh, the rotif

Date	8/17/2006		8/17/2006		8/17/2006	
Time	12:40		13:20		14:00	
Site #	Wells 04		Wells 05		Wells 06	
Volume (m^3)	0.100		0.050		0.030	
EcoAnalysts Sample ID	13		14		15	
CLADOCERA	**Density**	**Std.Error**	**Density**	**Std.Error**	**Density**	**Std.Error**
Daphnia pulex *	20	14.1	20	20	133.3	66.7
Daphnia rosea *	0		0		0	
Ceriodaphnia pulchella	0		0		33.3	33.3
Ceriodaphnia lacustris	0		0		0	
Sida crytallina *	0		0		0	
Diaphanosoma brachyurum	10	10	0		0	
Bosmina longirostris	10	10	80	40	33.3	33.3
Chydorus sphaericus	10	10	0		0	
Alona costata	0		0		33.3	33.3
Alona quadrangularis	0		0		0	
Camptocercus rectirostris	0		0		0	
Total cladocerans	**50**	**22.4**	**100**	**44.7**	**233.3**	**88.2**
COPEPODA						
Epischura nevadensis *	0		0		0	
epischurid copepodites *	0		60	34.6	0	
Leptodiaptomus ashlandi	20	14.1	0		133.3	66.7
diaptomid copepodites	60	24.5	60	34.6	300	100
Diacyclops thomasi	10	10	20	20	66.7	47.1
Microcyclops varicans	0		0		0	
cyclopoid copepodites	30	17.3	80	40	300	100
harpacticoid copepods	0		0		0	
copepod nauplii	0		80	40	200	81.7
Total copepods	**120**	**34.6**	**300**	**77.5**	**1000**	**182.6**
MISC. ZOOPLANKTERS						
water mites	0		0		33.3	33.3
Chironomid larvae *	10	10	0		0	
mosquito pupae *	0		0		0	
ostracods	0		0		0	
aquatic oligochaetes	0		0		0	
tardigrades	0		0		0	
nematodes	0		0		0	
Total misc. zooplankters	**10**	**10**	**0**		**33.3**	**33.3**
ROTIFERA						
Asplanchna priodonta	0		0		0	
Keratella hiemalis	0		0		0	
Keratella cochlearis	0		0		33.3	33.3
Keratella quadrata	0		0		0	
Euchlanis dilatata	0		0		0	
Euchlanis triquetra	0		20	20	0	
Kellicottia longispina	10	10	0		0	
Polyarthra vulgaris	0		0		0	
Synchaeta sp.	0		0		0	
unidentifid bdelloid	0		0		0	
Total rotifers	**10**	**10**	**20**	**20**	**33.3**	**33.3**
Total Density	**190**	**43.6**	**420**	**91.7**	**1300**	**208.2**
Total Count	**19**		**21**		**39**	
Density of Edible Zooplankton (*)	**30**	**17.3**	**80**	**40**	**133.3**	**66.7**
% Edible Zooplankton	**16.7**		**20**		**10.5**	

All samples were counted in their en
Due to the size of the mesh, the rotif

Date	9/7/2006		9/7/2006		9/7/2006	
Time	14:15		15:10		16:30	
Site #	Wells 01		Wells 02		Wells 03	
Volume (m^3)	0.100		0.040		0.100	
EcoAnalysts Sample ID	16		17		18	
CLADOCERA	**Density**	**Std.Error**	**Density**	**Std.Error**	**Density**	**Std.Error**
Daphnia pulex *	10	10	0		0	
Daphnia rosea *	0		0		0	
Ceriodaphnia pulchella	0		0		0	
Ceriodaphnia lacustris	0		0		0	
Sida crytallina *	0		0		0	
Diaphanosoma brachyurum	0		0		0	
Bosmina longirostris	0		0		0	
Chydorus sphaericus	0		0		0	
Alona costata	0		0		0	
Alona quadrangularis	0		0		0	
Camptocercus rectirostris	0		0		0	
Total cladocerans	**10**	**10**	**0**		**0**	
COPEPODA						
Epischura nevadensis *	0		0		0	
epischurid copepodites *	0		0		0	
Leptodiaptomus ashlandi	0		25	25	0	
diaptomid copepodites	40	20	75	43.3	0	
Diacyclops thomasi	0		0		0	
Microcyclops varicans	0		0		0	
cyclopoid copepodites	50	22.4	200	70.7	0	
harpacticoid copepods	0		0		0	
copepod nauplii	50	22.4	50	35.4	0	
Total copepods	**140**	**37.4**	**350**	**93.5**	**0**	
MISC. ZOOPLANKTERS						
water mites	0		0		0	
Chironomid larvae *	0		0		0	
mosquito pupae *	0		0		0	
ostracods	0		0		0	
aquatic oligochaetes	0		25	25	0	
tardigrades	0		0		0	
nematodes	0		0		0	
Total misc. zooplankters	**0**		**25**	**25**	**0**	
ROTIFERA						
Asplanchna priodonta	0		0		0	
Keratella hiemalis	0		0		0	
Keratella cochlearis	0		0		0	
Keratella quadrata	10	10	0		0	
Euchlanis dilatata	0		0		0	
Euchlanis triquetra	0		0		0	
Kellicottia longispina	2470	157.2	1325	182	130	36.1
Polyarthra vulgaris	0		0		0	
Synchaeta sp.	20	14.1	0		0	
unidentifid bdelloid	0		0		0	
Total rotifers	**2500**	**158.1**	**1325**	**182**	**130**	**36.1**
Total Density	**2650**	**162.8**	**1700**	**206.2**	**130**	**36.1**
Total Count	**265**		**68**		**13**	
Density of Edible Zooplankton (*)	**10**	**10**	**0**		**0**	
% Edible Zooplankton	**6.7**		**0**		**0**	

All samples were counted in their en
Due to the size of the mesh, the rotif

Date	9/8/2006		9/8/2006		9/8/2006	
Time	8:10		10:30		10:00	
Site #	Wells 04		Wells 05		Wells 06	
Volume (m^3)	0.100		0.100		0.040	
EcoAnalysts Sample ID	19		20		21	
CLADOCERA	**Density**	**Std.Error**	**Density**	**Std.Error**	**Density**	**Std.Error**
Daphnia pulex *	10	10	10	10	0	
Daphnia rosea *	0		0		0	
Ceriodaphnia pulchella	0		50	22.4	0	
Ceriodaphnia lacustris	0		0		0	
Sida crytallina *	0		0		0	
Diaphanosoma brachyurum	0		10	10	0	
Bosmina longirostris	0		10	10	0	
Chydorus sphaericus	0		0		0	
Alona costata	0		0		0	
Alona quadrangularis	0		0		0	
Camptocercus rectirostris	0		0		0	
Total cladocerans	**10**	**10**	**80**	**28.3**	**0**	
COPEPODA						
Epischura nevadensis *	0		0		0	
epischurid copepodites *	0		0		0	
Leptodiaptomus ashlandi	180	42.4	30	17.3	25	25
diaptomid copepodites	10	10	20	14.1	0	
Diacyclops thomasi	10	10	0		0	
Microcyclops varicans	0		0		0	
cyclopoid copepodites	40	20	20	14.1	50	35.4
harpacticoid copepods	0		0		0	
copepod nauplii	10	10	0		0	
Total copepods	**250**	**50**	**70**	**26.5**	**75**	**43.3**
MISC. ZOOPLANKTERS						
water mites	0		0		0	
Chironomid larvae *	0		0		0	
mosquito pupae *	0		0		0	
ostracods	70	26.5	0		0	
aquatic oligochaetes	0		0		0	
tardigrades	0		0		0	
nematodes	0		0		0	
Total misc. zooplankters	**70**	**26.5**	**0**		**0**	
ROTIFERA						
Asplanchna priodonta	0		0		0	
Keratella hiemalis	0		0		0	
Keratella cochlearis	0		0		0	
Keratella quadrata	0		0		0	
Euchlanis dilatata	0		0		0	
Euchlanis triquetra	0		0		0	
Kellicottia longispina	0		0		0	
Polyarthra vulgaris	0		0		0	
Synchaeta sp.	0		0		0	
unidentifid bdelloid	0		0		0	
Total rotifers	**0**		**0**		**0**	
Total Density	**330**	**57.4**	**150**	**38.7**	**75**	**43.3**
Total Count	**33**		**15**		**3**	
Density of Edible Zooplankton (*)	**10**	**10**	**10**	**10**	**0**	
% Edible Zooplankton	**3**		**6.7**		**0**	

All samples were counted in their en
Due to the size of the mesh, the rotif

Date	**9/8/2006**	
Time	**9:20**	
Site #	**Wells 07**	
Volume (m^3)	**0.100**	
EcoAnalysts Sample ID	**22**	
CLADOCERA	**Density**	**Std.Error**
Daphnia pulex *	0	
Daphnia rosea *	0	
Ceriodaphnia pulchella	0	
Ceriodaphnia lacustris	0	
Sida crytallina *	0	
Diaphanosoma brachyurum	0	
Bosmina longirostris	0	
Chydorus sphaericus	0	
Alona costata	0	
Alona quadrangularis	0	
Camptocercus rectirostris	0	
Total cladocerans	**0**	
COPEPODA		
Epischura nevadensis *	0	
epischurid copepodites *	0	
Leptodiaptomus ashlandi	10	10
diaptomid copepodites	10	10
Diacyclops thomasi	0	
Microcyclops varicans	0	
cyclopoid copepodites	10	10
harpacticoid copepods	0	
copepod nauplii	10	10
Total copepods	**40**	**20**
MISC. ZOOPLANKTERS		
water mites	0	
Chironomid larvae *	0	
mosquito pupae *	0	
ostracods	0	
aquatic oligochaetes	0	
tardigrades	0	
nematodes	0	
Total misc. zooplankters	**0**	
ROTIFERA		
Asplanchna priodonta	0	
Keratella hiemalis	0	
Keratella cochlearis	0	
Keratella quadrata	0	
Euchlanis dilatata	0	
Euchlanis triquetra	0	
Kellicottia longispina	0	
Polyarthra vulgaris	0	
Synchaeta sp.	0	
unidentifid bdelloid	0	
Total rotifers	**0**	
Total Density	**40**	**20**
Total Count	**4**	
Density of Edible Zooplankton (*)	**0**	
% Edible Zooplankton	**0**	

All samples were counted in their en
Due to the size of the mesh, the rotif

EES Consulting Douglas PUD Wells Zooplankton
EcoAnalysts, Inc.
Zooplankton Densities (in no. per m^3)

Date	2/7/2006		2/7/2006		2/7/2006		2/7/2006	
Time	11:20		12:00		10:15		9:30	
Site #	Wells 01		Wells 02		Wells 03		Wells 04	
Volume (m^3)	0.1039		0.0415		0.1039		0.1039	
Split size	1		1		1		1	
EcoAnlaysts Sample ID	1		2		3		4	
CLADOCERA	**Density**	**Std.Error**	**Density**	**Std.Error**	**Density**	**Std.Error**	**Density**	**Std.Error**
Daphnia pulex *	0		0		0		9.6	9.6
Daphnia rosea *	19.2	13.6	0		9.6	9.6	0	
Bosmina longirostris	0		0		0		0	
Chydorus sphaericus	9.6	9.6	24.1	24.1	0		9.6	9.6
Alona costata	0		24.1	24.1	0		0	
Total cladocerans	**28.9**	**16.7**	**48.2**	**34.1**	**9.6**	**9.6**	**19.2**	**13.6**
COPEPODA								
Leptodiaptomus ashlandi	38.5	19.2	24.1	24.1	9.6	9.6	38.5	19.2
diaptomid copepodites	144.4	37.3	192.8	68.2	77	27.2	134.7	36
Diacyclops thomasi	9.6	9.6	0		9.6	9.6	28.9	16.7
Microcyclops varicans	19.2	13.6	0		0		0	
cyclopoid copepodites	48.1	21.5	0		28.9	16.7	77	27.2
harpacticoid copepods	0		0		0		0	
copepod nauplii	19.2	13.6	24.1	24.1	19.2	13.6	19.2	13.6
Total copepods	**279.1**	**51.8**	**241**	**76.2**	**144.4**	**37.3**	**298.4**	**53.6**
MISC. ZOOPLANKTERS								
tardigrades	0		24.1	24.1	0		0	
peritrich colony	9.6	9.6	0		9.6	9.6	0	
verticelloid protistan	28.9	16.7	0		19.2	13.6	0	
Total misc. zooplankters	**38.5**	**19.2**	**24.1**	**24.1**	**28.9**	**16.7**	**0**	
Rotifer split								
ROTIFERA								
Keratella hiemalis	0		48.2	34.1	0		0	
Keratella cochlearis	28.9	16.7	48.2	34.1	0		28.9	16.7
Keratella quadrata	0		0		0		0	
Notholca acuminata	0		0		0		0	
Kellicottia longispina	182.9	42	265.1	79.9	144.4	37.3	182.9	42
Polyarthra vulgaris	9.6	9.6	0		19.2	13.6	19.2	13.6
Synchaeta sp.	105.9	31.9	96.4	48.2	19.2	13.6	67.4	25.5
Total rotifers	**327.2**	**56.1**	**457.8**	**105**	**182.9**	**42**	**298.4**	**53.6**
Total Density	**673.7**	**80.5**	**771.1**	**136.3**	**365.7**	**59.3**	**616**	**77**
Total Count	**70**		**32**		**38**		**64**	
Density of Edible Zooplankton (*)	**19.2**	**13.6**	**0**		**9.6**	**9.6**	**9.6**	**9.6**
% Edible Zooplankton	**5.6**		**0**		**5.3**		**3**	

EES Consulting Douglas PUD Wells
EcoAnalysts, Inc.
Zooplankton Densities (in no. per m

Date	2/7/2006		2/7/2006	
Time	9:10		8:30	
Site #	Wells 05		Wells 06	
Volume (m^3)	0.1039		0.0571	
Split size	1		1	
EcoAnlaysts Sample ID	5		6	
CLADOCERA	**Density**	**Std.Error**	**Density**	**Std.Error**
Daphnia pulex *	0		0	
Daphnia rosea *	0		0	
Bosmina longirostris	19.2	13.6	17.5	17.5
Chydorus sphaericus	0		0	
Alona costata	0		0	
Total cladocerans	**19.2**	**13.6**	**17.5**	**17.5**
COPEPODA				
Leptodiaptomus ashlandi	38.5	19.2	17.5	17.5
diaptomid copepodites	19.2	13.6	0	
Diacyclops thomasi	144.4	37.3	0	
Microcyclops varicans	0		0	
cyclopoid copepodites	327.2	56.1	0	
harpacticoid copepods	9.6	9.6	0	
copepod nauplii	57.7	23.6	0	
Total copepods	**596.7**	**75.8**	**17.5**	**17.5**
MISC. ZOOPLANKTERS				
tardigrades	0		0	
peritrich colony	0		0	
verticelloid protistan	0		0	
Total misc. zooplankters	**0**		**0**	
Rotifer split				
ROTIFERA				
Keratella hiemalis	0		0	
Keratella cochlearis	9.6	9.6	17.5	17.5
Keratella quadrata	19.2	13.6	17.5	17.5
Notholca acuminata	9.6	9.6	0	
Kellicottia longispina	105.9	31.9	122.6	46.3
Polyarthra vulgaris	19.2	13.6	35	24.8
Synchaeta sp.	154	38.5	35	24.8
Total rotifers	**317.6**	**55.3**	**227.7**	**63.1**
Total Density	**933.6**	**94.8**	**262.7**	**67.8**
Total Count	**97**		**15**	
Density of Edible Zooplankton (*)	**0**		**0**	
% Edible Zooplankton	**0**		**0**	

Jacobs Engineering. 2007. Wells Hydroelectric Project: Spill Prevention Control and Countermeasure (SPCC) Plan. Prepared by Jacobs Engineering, Bellevue, WA. Prepared for Public Utility District No. 1 of Douglas County, East Wenatchee, WA.

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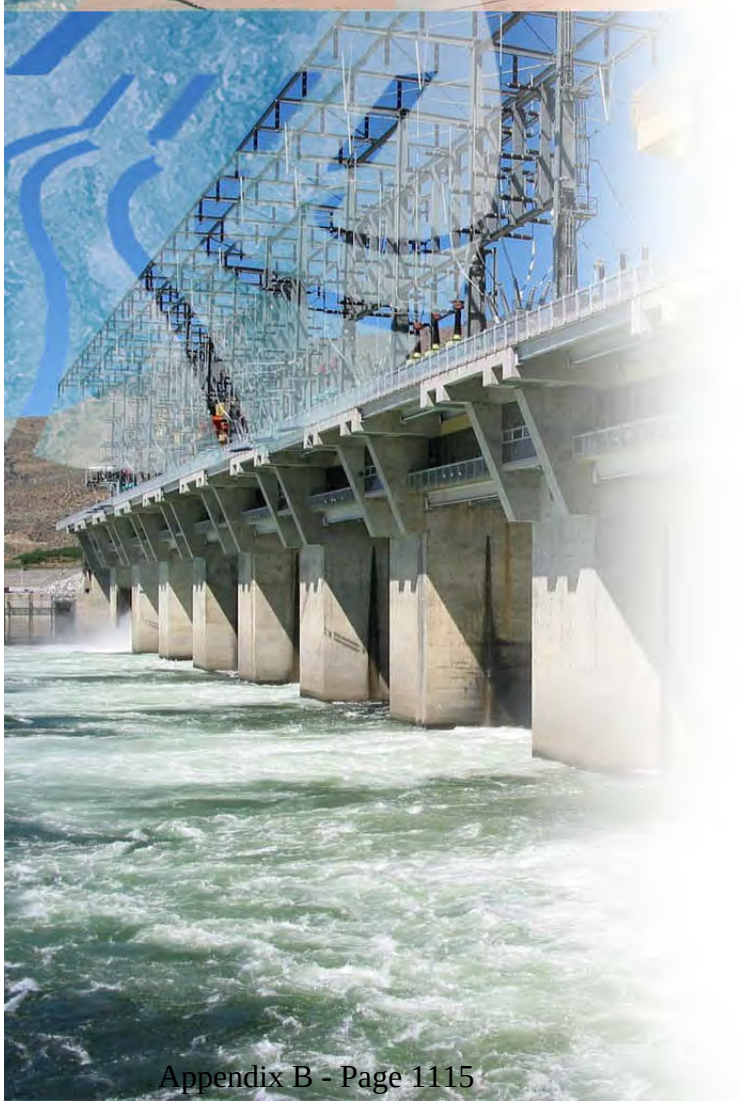

Spill Prevention Control and Countermeasure (SPCC) Plan

Wells Hydroelectric Project

prepared for

Public Utility District No. 1 of Douglas County, WA

October 2007

PUBLIC UTILITY DISTRICT NO. 1 OF DOUGLAS COUNTY
WELLS HYDROELECTRIC PROJECT

SPILL PREVENTION CONTROL AND COUNTERMEASURE (SPCC) PLAN

Date of initial operations:	September 1967
Plan first implemented:	March 1975
Last scheduled amendment	December 2006
Plan last amended:	October 2007 - Plan amended for 40 CFR 112 (2006)
Next scheduled plan review:	October 2012

The **Project Superintendent** is the designated person accountable for oil spill prevention at this facility.

MANAGEMENT APPROVAL

This SPCC Plan will be implemented as herein described and will be amended as necessary due to modifications and improvements at the facility.

Signature: W. C. Dobbins

Name: William C. Dobbins

Title: Chief Executive Officer/Manager
Public Utility District No. 1
of Douglas County

CERTIFICATION

This SPCC Plan was prepared using sound engineering practices. I have examined the facility and this Plan and find this Plan conforms to the guidelines and provisions of 40 CFR 112 (2006).

Engineer: Rolf G. Wielick, PE
JACOBS

Signature: Rolf G. Wielick

License No.: 28939 State: WA

Date: 8/9/07

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1.0 INTRODUCTION

This document is the Spill Prevention Control and Countermeasure (SPCC) Plan for the Wells Hydroelectric Project (Wells Project), owned by Public Utility District No. 1 of Douglas County, Washington (District). In accordance with regulations, this plan was initially implemented no later than the extension date of March 1975. It has been reviewed at 3-year intervals since that date and was reviewed and amended in March 2002. The Environmental Protection Agency (EPA) amended the 1973 Oil Pollution Prevention Regulations with revised rules that became effective August 16, 2002.

The 2002 rules require that an owner or operator review and evaluate his plan at least every 5 years. If the review identifies new field-proven technology that will significantly reduce the likelihood of harmful oil discharges from the facility, the plan must be amended within 6 months of the review. The plan must also be amended if there is a change in the facility design, construction, operation, or maintenance that materially affects its potential for the discharge of oil in quantities that may be harmful. Amendments must be implemented as soon as possible, but not later than 6 months following the preparation of any amendment.

In February 2006, EPA extended the dates by which facilities must prepare or amend SPPC Plans and implement those Plans. According to this extension rule, the Wells Project would have to make any necessary amendments to its SPCC Plan, and implement that Plan, on or before October 31, 2007.

In December 2006, EPA signed a final rule to amend the SPCC rule at 40 CFR Part 112. EPA amended the SPCC rule to address a number of issues raised by its 2002 final rule, including those pertaining to facilities with smaller oil storage capacities, qualified oil-filled operational equipment, and mobile refuelers.

This plan has been reviewed and amended to ensure conformance with the requirements of the 2006 regulations. The next scheduled review of the SPCC Plan for the Wells Project will be before October 2012.

1.1 PURPOSE

The Purpose of this plan is to meet the requirements of the U.S. Environmental Protection Agency Regulations, as defined in Title 40 Code of Federal Regulations, Part 112 (as amended in December 2006), and entitled "Oil Pollution Prevention." Appendix D contains a SPCC Rule Cross-Reference that lists the page(s) of this plan that meet the requirements.

The Spill Prevention Control and Countermeasure (SPCC) Plan contained herein is a comprehensive statement by facility management and is intended to be supported by the facility's Oil Spill Contingency Plan. The SPCC Plan along with the Oil Spill Contingency Plan establishes procedure, methods, equipment, and materials that shall be used to prevent, contain, and/or clean up an oil spill, thereby preventing it from impacting the navigable waters of the United States.

1.2 POLICY

It shall be the policy of Public Utility District No. 1 of Douglas County and all its contractors to recognize that oil contamination of the waters of the State of Washington is harmful to public health, welfare, and the environment. Therefore, it is required that the strongest emphasis be placed on oil spill prevention, and that the latest engineering and safety procedures be used at all times when dealing with oil and its associated equipment.

1.3 DESCRIPTION OF FACILITY

The Wells Project is located on the Columbia River at River Mile 515.8. The power plant has a rating of 840 MW with ten Kaplan units. Operation of the project first started on September 1, 1967.

1.4 OWNER

Public Utility District No. 1 of Douglas County
1151 Valley Mall Parkway
East Wenatchee, Washington 98802-4497

1.5 PROJECT SUPERINTENDENT

Mike Bruno
Wells Hydroelectric Project
28905 US Highway 97
Pateros, Washington 98846-9602

1.6 RESPONSIBLE PARTIES

Bill Dobbins, Chief Executive Officer / Manager
Office (509) 881-2220
Res. (509) 884-1191

Ken Pflueger, Chief Engineer / Assistant Manager
Office (509) 881-2245
Res. (509) 662-6316

Mike Bruno, Project Superintendent
Office (509) 881-2490
Res. (509) 923-9524

Dub Simmons, Operations Supervisor
Office (509) 881-2465
Res. (509) 923-2362

Robert W. Clubb, Chief of Environmental and Regulatory Services
Office (509) 881-2285
Res. (509) 782-3820

Meaghan Vibbert, Public Information Officer
Office (509) 881-2221
Res. (509) 886-5930

Wells Dam Control Room Operator
Telephone: (509) 923-2224 or (509) 923-2150
DCPUD Ext. 3471/3472
Mobile Radio(s)

1.7 RELATED AGENCIES

The following is a list of agencies that the facility may need or want to contact regarding oil spill prevention and cleanup.

Federal

1. U.S. Coast Guard
   Sector Portland
   Portland, Oregon
   Telephone: (503) 240-9310
   (For spill incidents occurring in southern Washington and the Columbia River.)

2. U.S. Environmental Protection Agency
   Seattle, Washington
   Emergency Telephone: (206) 553-1671 or 1(800) 424-4372
   Telephone: (206) 553-1200
   Address: U.S. EPA, Region X
   1200 Sixth Avenue
   Mailcode: ECL 116
   Seattle, Washington 98101
   (The EPA is the pre-designated federal On-Site Coordinator for inland spills under the National Contingency Plan.)

3. National Response Center
   Washington, D.C.
   Telephone: 1-800-424-8802
   (toll calls) (202) 267-2675

State

1. Washington State Department of Ecology
   24-hour Emergency Spill Response
   Central Office, Yakima
   Emergency Telephone: (509) 575-2490
   Address: 15 West Yakima Avenue, Suite 200
   Yakima, Washington 98902-3452

2. Washington State Emergency Management Division (EMD)
   24-hour Emergency Spill Response
   Telephone: 1-800-258-5990
   (Toll calls) (253) 912-4901 or (253) 912-4904

1.8 ENVIRONMENTAL SERVICES

Trained in-house personnel will perform all oil spill containment and cleanup activities. Outside environmental services shall not be used unless deemed necessary by the Project Superintendent.

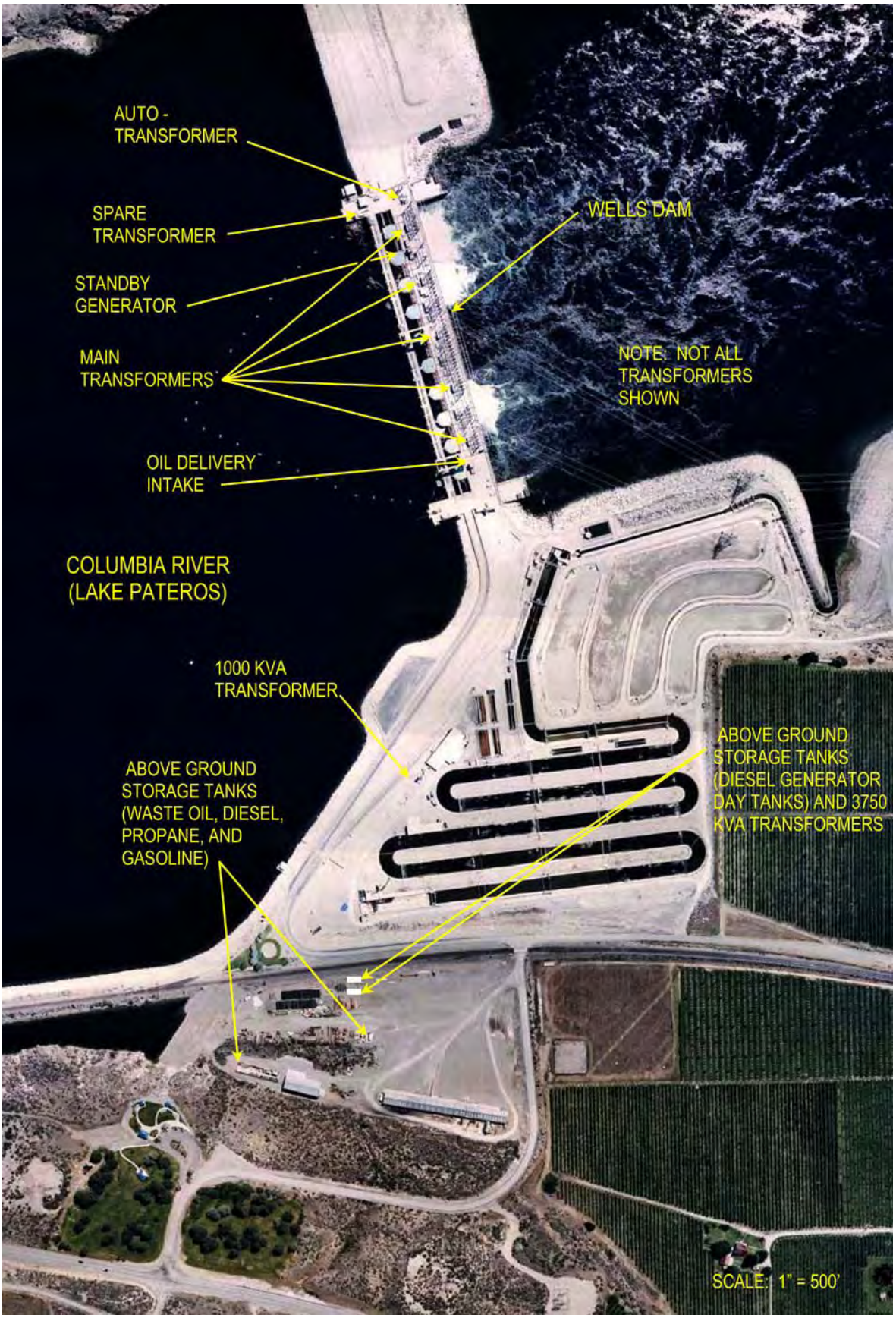


Figure 1: Physical Layout – Wells Dam

2.0 FACILITY ANALYSIS

2.1 PHYSICAL LAYOUT

The project is situated midway between Chief Joseph Dam and Rocky Reach Dam at River Mile 515.8 on the Columbia River in Washington State, and develops a gross head of 76 feet for hydroelectric operation. The right (west) bank development is comprised of a rockfill embankment approximately 40 feet in height and about 1,900 feet long and fish facilities containing spawning channels and rearing ponds. The left (east) bank development consists of a rockfill embankment, approximately 160 feet in height at its maximum section, and about 1,000 feet in length. Concrete structures are situated between the two embankment sections; one fish facility structure at each end separated by a 1,000-foot structure comprised of 11 spillway bays integrated with 10 generating units, known as a "hydrocombine".

As shown in Figure 1, six operational transformers and one spare transformer are located on the top deck of the hydrocombine at Elevation 795. The oil delivery intake for the turbine/governor system is also located on the top deck. Gasoline, waste oil, and propane storage tanks are located near the warehouse on the western side of the project. Day tanks for two emergency diesel generators and a main diesel storage tank are also located in this area. Two transformers are also located near the emergency generators and two transformers located in the vicinity of the fish hatchery.

2.2 OIL SPILL HISTORY

The Wells Project has experienced no oil spill event discharging harmful quantities of oil into navigable waters.

A "harmful quantity" of oil discharge, as defined in 40 CFR 110, is a discharge which:

- violates applicable water quality standards, or
- causes a film or sheen upon or discoloration of the water or adjoining shorelines, or
- causes a sludge or emulsion to be deposited beneath the surface of the water or upon adjoining shorelines.

2.3 POTENTIAL SPILL EVENTS

The probability of an oil spill at the Wells Project is low. A significant oil spill could conceivably occur if there is a major equipment failure or a rupture of an oil storage container. A more likely event would be a slow leak from a piece of equipment due to a failed gasket or seal, cracked bushing, or a leaking oil plug. Other potential events which could result in an oil spill include equipment or oil handling accidents and sabotage.

A listing of the individual oil storage containers and oil-bearing equipment, and their respective maximum spill potential (volume of oil), is listed in Section 2.4. The methods of spill prevention, containment, and countermeasure for oil storage containers and oil-bearing equipment, including physical barriers and procedures to be followed by facility personnel, are described in Section 2.5.

Most oil-containing items have secondary containment. In many instances, the spilled oil would drain to the station drainage sump. However, it is not feasible to install a secondary containment system for

the oil in the turbine runner hubs. Thus, an oil spill contingency plan for the turbine runner hubs has been prepared as required by 40 CFR 112.7 (see Section 5).

2.4 INVENTORY OF OIL-CONTAINING EQUIPMENT AND TYPE OF OIL

The following is a list of the main oil-containing equipment maintained by personnel of the Wells Project:

DESCRIPTION	CAPACITY (gallons each)	QUANTITY
Inside facility		
Turbine Guide Bearings (Shell Turbo-T-68)	90	10
Turbine Runner Hubs (Shell Turbo-T-68)	4,000	10
Turbine Governor Systems (Shell Turbo-T-68)	3,308	10
Generator Thrust Bearings (Shell Turbo-T-68)	3,450	10
Clean Oil/Dirty Oil Tanks (Shell Turbo-T-68)	Max. 9,700	2
Oil Storage Room (Turbine oil, greases, and composites of oil)	Approx. 1,500	1
Grounding Transformers (Transformer oil)	30	11
Potential Transformers (Transformer oil)	1	31
On deck of facility		
Spare Transformer (Shell Diala-AX)	15,230	1
Main Transformers (Shell Diala-AX)	14,400	5
230/115 Autotransformer (Shell Diala-AX)	9,000	1
Standby Generator (Diesel)	250	1
Potential Transformers (Transformer oil)	16	7
Current Transformers (Transformer oil)	35	3
Current Transformers (Transformer oil)	90	5
2000 kVA Transformers (Transformer oil)	735	2
Oil Delivery Truck (Shell Turbo)	Max. 7,000	1
Vickers Oil Pumps (Shell Turbo)	200	2
Onshore		
Gas Tank (Gasoline)	4,000	1
Waste Oil Tank (Turbine oil)	1,000	1
Propane Storage (40’ north of gas tank)	1,000	1
1000 kVA Transformers near Fish Hatchery (Transformer oil)	428	2
3750 kVA Transformers near diesel generator (Transformer oil)	1,058	2
Generator Day Tanks (diesel)	1,250	2
Bulk Storage Tank (diesel)	4,000	1

The five onshore tanks are above ground storage tanks. The gas tank is a double wall steel with a sounding well to detect leaks. The waste oil tank is welded steel and it has secondary containment. The diesel ‘day tanks’ are double-containment UL142 listed steel tanks located on the power modules. The

bulk diesel storage tank is a double wall "FIREGUARD"-type tank. Tanks are compatible with the contents that they hold.

2.5 OIL CLEAN-UP MATERIALS

The Wells Project has the following materials for use in cleaning up and containing spilled oil:

DESCRIPTION	LOCATION
Fiber-Reinforced Rubber Bags:	
- 3,000 Gallon Capacity	Warehouse
- 2,000 Gallon Capacity	Warehouse
- 1,000 Gallon Capacity	Hydrocombine
Floating Skimmer Pump	Hydrocombine
Two Portable Pumps	Hydrocombine
Oil-absorbent Material	Hydrocombine and Warehouse
Oil Spill Response Mobile Unit *:	
- Boom (1000-foot)	Mobile Response Trailer at Warehouse
- Tool Box	Mobile Response Trailer at Warehouse
- PPE Bags	Mobile Response Trailer at Warehouse
- Decon Station	Mobile Response Trailer at Warehouse
- Absorbents	Mobile Response Trailer at Warehouse
- Miscellaneous Supplies	Mobile Response Trailer at Warehouse

* A complete inventory of the Oil Spill Response Mobile Unit (trailer) is contained in Appendix F

The three fiber-reinforced rubber bags are suitable for oil disposal purposes. These bags, when used together, can hold the oil from all but the largest oil-containing item, the transformers. If a transformer fails and results in a large spill, the District will acquire the services of an oil tanker to transport the oil. Individual bags can be used for smaller spills. Two portable pumps are available for pumping spills from containment areas into the fiber-reinforced rubber bags or tanker. Due to the age of the fiber-reinforced bags, the District plans to replace all of the bags. The replacement bags will be inspected at least every 5 years as part of the SPCC plan review and evaluation to determine if the bags should be replaced.

The drainage system for the Wells Project is such that most of the floor drains would convey any oil spills and all other liquids to the station drainage sump. A rope type oil skimmer operates continuously to collect and remove minor amounts of oil that may accumulate in the sump. From the sump, liquid level controls would automatically start one or more pumps to discharge the liquid into the river. A transducer has been installed in the sump to detect the presence of oil and annunciate a signal to the control room.

At this signal, the pumps would be stopped immediately. The water and oil would be allowed to rise to a level so that the floating skimmer pump could pump the floating oil into one of the fiber-reinforced rubber bags. The pumps would be controlled manually to keep the oil in the sump until the oil was removed. The volume of the sump is about 125,000 gallons and normal drainage inflow is minimal. Therefore, if a spill were to occur during the night shift, the cleanup operation could wait until the next day's shift, as long as the pumps were immediately shut off. The oil-detection annunciator is tested routinely.

2.6 SPILL PREVENTION, CONTAINMENT, AND COUNTERMEASURE

Turbine Guide Bearings

If leakage occurs, the oil will drain to the packing box sumps and be pumped to the station drainage sump where it will be contained and recovered. The turbine/generators will shut down automatically with a low oil level alarm.

The best prevention of turbine bearing leakage is through observation by maintenance and operation personnel. Any noticeable drop in the bearings' oil levels or any abnormal vibrations should be reported to the Project Superintendent.

Turbine Runner Hubs

The probability of spillage of runner hub oil is minimal if all valves, ports, etc., are checked out in accordance with the maintenance manual when the turbines are returned to service. If leakage does occur, the affected turbine would be immediately put out of service and the causes repaired. During normal maintenance, the surface of the hubs shall be inspected for damage caused by cavitation. If oil leakage is discovered through normal daily shift inspection, or while returning a turbine unit to service, the leak shall be reported immediately to the Project Superintendent.

If oil leakage is apparent, the affected turbine shall be immediately put out of service and the cause(s) of the leak repaired. Oil shall be cleaned up using sorbent materials and disposed of in properly labeled portable drums or disposable bags.

Oil leakage of the runner hubs creates potential for a spill directly into river waters. Careful observation and communication by facility personnel is essential in keeping this risk to a minimum. An oil level drop in the governor oil system indicates a possible spill to the river waters due to leakage from the turbine runner hubs, and personnel shall be prepared to administer the Oil Spill Contingency Plan. Any noticeable drop in the governor oil system level shall be reported to the Project Superintendent.

Turbine Governor Systems

One turbine governor system is located in each unit at Elevation 705. As presently arranged, if the sump tank or pressure tank bursts, the oil would drain into the station drainage sump to reduce fire hazard.

The oil is directed to the floor drains at Elevation 705 and in the elevator pits. This floor has a 6-inch curb all around except at the elevator door sill. In the event of a tank rupture, oil would be directed to the sump. Maintenance and operations personnel will react to abnormal governor pressure readings and pipe leakages by reporting them to the Project Superintendent.

Generator Thrust Bearings

If leakage occurs, the oil will drain to the packing box sumps and be pumped to the station drainage sump where it will be contained and recovered. The turbine/generators will shut down automatically with a low oil level alarm. In the event of a bursting-type action of the bearing oil reservoir, the unit will shut down automatically. Some of the oil from the reservoir will collect in voids within the unit and can be pumped out and into the dirty oil tank or into fiber reinforced rubber bags stored at the project for cleaning up and containing spilled oil. Some of

the oil will collect in the packing box sumps and be pumped to the station drainage sump where it will be contained and collected.

Any noticeable drop in the level of the thrust bearing reservoir or any abnormal vibration shall be reported to the Project Superintendent.

Clean Oil Tank and Dirty Oil Tank

The clean oil tank and the dirty oil tank are located in a separate oil storage room at Elevation 752 in Unit 4. There are no openings except a four-foot-wide doorway protected by a fire door. The doorway has a concrete curb six inches high and an aluminum plate that extends 31.5 inches above the floor of the room.

A float switch has been installed to detect the presence of oil within the storage room. In the event of a relatively slow leak, this would inform the operator in time to alert the Project Superintendent. A sudden rupture of a nearly full tank will be retained in the oil storage room by the aluminum plate barrier.

Oil Storage Room

The oil storage room is located at Unit 9, Elevation 752 and approximately 1,000 gallons of oil are stored in drums located in the room or immediately outside. The room is curbed and an oil spill will drain to the station drainage sump. Drums stored outside of the room are located on portable two-drum modular spill platforms. Each spill platform has a 30-gallon capacity for each of the two 55-gallon drum platforms.

Grounding and Potential Transformers (inside facility)

There is one grounding transformer in each unit at Elevation 736. A spare grounding transformer is located in Unit 7, Elevation 764. Since the capacity of the grounding transformer is only 30 gallons, a spill from this piece of equipment is not likely to cause a release in harmful quantities. Small leaks would probably be detected before oil reaches the floor drains. Any operator noticing a leak shall notify the Project Superintendent and contain as much oil as possible using absorbent materials. Otherwise, oil spilled from the grounding transformers would drain through floor drains into the station drainage sump, where the spilled oil would be detected and cleaned up as described in Section 2.5. The cause of the leak shall be repaired or the unit shall be replaced as soon as possible.

There are three potential transformers in each unit at Elevation 720 holding approximately one gallon each. Leaks from these units would also reach the station drainage sump. They shall be handled similarly to the grounding transformers.

Main Transformers

The transformers could possibly burst or be struck by an object that could cause leakage of oil onto the deck of the Hydrocombine.

Spilled oil is contained by barrier walls around each main transformer and drainage piping conveys the liquid to unused chambers in the East and West Fish Facilities structures. These chambers are connected with 24-inch-diameter openings between chambers and a final 36-inch-diameter opening to the tailrace, well below the tailwater level. In the event of a spill, the oil

would drain to these chambers and float on the water surface. District personnel would then utilize the floating skimmer pump to pump the floating oil into one of the fiber-reinforced rubber bags.

Spare Transformer

The spare transformer is stored on the deck at the East Fish Facilities (Elevation 795). The transformer could be punctured in an accident. To prevent spilled oil from flowing across the deck and into the forebay, the District has installed a metal barricade around the spare transformer such that spilled oil would drain to unused chambers in the East Fish Facilities.

230/115 Autotransformer

The autotransformer could possibly burst or be struck by an object that could cause leakage of oil onto the deck.

Spilled oil is contained by barrier walls around the autotransformer, and drainage piping conveys the liquid to unused chambers in the East and West Fish Facilities (see Figure 2).

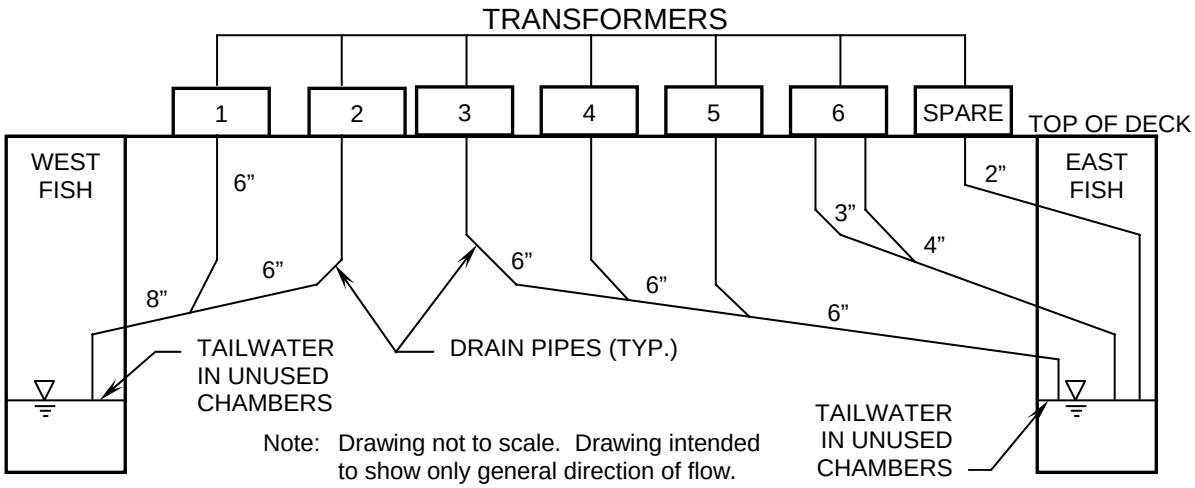


Figure 2: Drainage Schematic for Transformers on Deck

Standby Generator

The standby generator is located on the Elevation 795 deck. The generator is enclosed in a metal building. There are drains in the low points of the floor which lead to the drainage piping that conveys liquid to the East Fish Facilities.

Potential Transformers (on the Elevation 795 Deck and in Warehouse)

There are six potential transformers with an oil capacity of 16 gallons each on the Elevation 795 deck. An added metal housing provides adequate secondary containment. Since the transformers are on poles above the deck surface, a flexible hose connects the secondary containment to 2-inch drainage piping. A flexible hose is used instead of rigid piping, since a vehicle colliding with the hose would not rupture it. Hoses are replaced as needed, approximately every ten years.

The draining system is connected to that of the main transformers, and thus any oil leaks or spills would reach the unused chambers in the East and West Fish Facilities. District personnel would then clean up the spill as previously described.

There is one spare potential transformer, with an oil capacity of 16 gallons, located in the warehouse.

Current Transformers

There are six current transformers on the Elevation 795 deck. Two of the transformers hold 35 gallons and the other four hold 90 gallons. Their secondary containment systems are the same as those used for potential transformers. A spare of each type of transformer is stored at Elevation 705 at Unit 10.

Vickers Oil Pumps

The Vickers Oil Pumps are located on the east and west fish intake decks (Elevation 745) and control the gates that regulate the volume of water that flows out of the east and west fish attraction facilities. If the pumps leaked oil, it could flow into the tailbay of the east and west facilities and into the east fish attraction facilities, around a hatch cover in the deck.

The District has installed a metal barrier around the Vickers pumps to contain oil leaks. The pumps are located under an overhang and do not need a drainage valve for rainwater or snow melt.

Oil Delivery Truck

Any loose hose connection or accidental tank truck rupture will cause a spill on the Elevation 795 deck. The oil could enter the deck drains and be conveyed to the tailrace. District personnel shall direct the delivery truck driver to place a seal over the deck drains so that a spill will be contained on the deck.

Special care shall be taken by operating personnel when connecting and disconnecting hoses from the oil delivery truck. Tank truck loading and unloading procedures shall meet requirements established by the Department of Transportation (see Appendix D). To guard against the possibility of a runaway gantry colliding with the tank truck, the tank truck should not be parked in an area that allows this situation to occur.

Gas Tank

A gasoline storage tank was installed to the east of the warehouse in the Fall of 1991 and has secondary containment and a sounding well to detect leaks. The tank area is not fenced, but the tank is locked and the area is lighted.

Waste Oil Tank

The waste oil tank is relocated in a fenced and locked concrete pad to the north of the warehouse, and a metal barrier around the tank provides secondary containment. The waste oil tank has ¼-inch thick steel walls and is pressure rated to 85 psi. The tank is suitable for the

storage of waste oil. A manually-operated, non-flapper type valve has been provided to periodically drain rainwater or snow melt from the containment area.

Diesel Tanks

The diesel 'day tanks' are double-containment UL142 listed steel tanks located on the power modules.

The bulk diesel storage tank is a double wall "FIREGUARD"-type tank located in the same area as the Gas Tank. The tank area is not fenced, but the tank is locked and the area is lighted.

2.7 SECURITY

The facility is manned 24 hours a day and is monitored by video camera. Monitors are located in the office and the control room. The entrance has a gate which is normally closed. Once past this initial screening, a person intent on vandalism could access the equipment on the deck of the facility and could cause oil to be spilled. This person would probably be noticed, however, since employees are usually on the deck. It would be more difficult to go inside the facility unnoticed. Facility entrances are secured by electronic key pads. No incidents of vandalism have occurred in the history of this facility.

The adjacent onshore storage facilities are accessible by the public, but all facilities there are locked. The 4,000-gallon gasoline tank has locked valves and the area is illuminated. The 1,000-gallon waste oil tank is located in the fenced storage area to the north of the general warehouse, which has a locking gate and barbed wire. The tank has secondary containment consisting of a metal barrier constructed around the tank. The gate to this area will be locked when the area is unoccupied.

3.0 MAINTENANCE AND INSPECTION PROCEDURES

Visual inspection of all oil-containing transformer equipment, turbine equipment, oil storage tanks, and oil-carrying pipelines shall be done on a daily work-shift basis. Crews shall be instructed to report any signs of oil leakage to the chief operator on duty as soon as possible. The chief operator will determine the course of action to be taken.

At least annually, thorough routine inspection of the oil-containing equipment, storage tanks, and related support systems shall take place. At minimum, this in-depth inspection shall include the following areas:

- Storage tank seams and pipe openings shall be observed for leakage, corrosion, or other questionable deterioration.
- The floating skimmer and portable sump pumps shall be cleaned and mechanically tested.
- Sump pumps shall be cleaned and mechanically tested.
- All oil-carrying pipelines shall be subjected to examination and routine maintenance including flange joints, expansion joints, valve glands and bodies, catch pans, valve locking devices, and metal surfaces of any kind.
- Piping supports shall be observed for corrosion and abrasion, and for the proper expansion and contraction. Supports that have deteriorated or do not meet original design considerations shall be replaced or repaired.

- The facility security system shall be tested, and fencing and signs shall be inspected and repaired as needed.
- Governor oil pressure and sump level alarms and trip circuits shall be tested during biennial inspection and maintenance of each generating unit. Pressure vessels are also inspected by state inspectors every two years.
- The gasoline storage tank stilling well sounded with a dipstick to detect the presence of fluid.
- Test the float switch located in the oil storage room on Elevation 752 at Unit 4.

All inspection activities shall be recorded in a log and signed by the appropriate supervisor and inspector. The inspection records shall be maintained for a minimum period of three years. Detailed written inspection and recording procedures are given in the Standard Operating Procedures Manual, which shall be kept with the SPCC Plan in the locations listed in Section 6.6 of the SPCC Plan.

These records are incorporated in this report by reference.

4.0 TRAINING OF PERSONNEL

The Project Superintendent shall be responsible for providing an annual training program for the Wells Project facility oil-handling personnel.

Training programs and periodic briefings shall review the SPCC Plan, the Oil Spill Contingency Plan, and the Standard Operating Procedures Manual, and shall describe actual experiences, recent spill events or failures, and new or preventative control and cleanup measures. Training shall also include review of all District forms and documentation procedures. Crews must understand the SPCC Plan, the Oil Spill Contingency Plan, and the Standard Operating Procedures Manual.

5.0 OIL SPILL CONTINGENCY PLAN

The purpose of Sections 5.0 and 6.0 of this SPCC Plan is to meet the U.S. Environmental Protection Agency requirements for oil spill contingency planning as defined in 40 CFR 112. Sections 5.0 and 6.0 comprise the Oil Spill Contingency Plan for the Wells Hydroelectric Facility.

5.1 COMMITMENT TO CONTINGENCY PLAN

The District is committed to providing the manpower, equipment, and materials required to expeditiously control and remove any harmful quantity of oil discharged. This will include hiring an oil spill response contractor if needed.

5.2 NEED FOR CONTINGENCY PLAN

The Wells Project Hydrocombine is located over the Columbia River. Therefore, any uncontained spills that occur on or in the Hydrocombine could drain directly into the Columbia River. Of all of the oil-containing structures at the Wells Project, it is not feasible to provide complete secondary containment for the turbine runner hubs or an oil delivery truck during a delivery period.

ITEM	CAPACITY (gallons each)	QUANTITY
Turbine Runner Hubs	4,000	10
Oil Delivery Truck	Max. 7,000	1

Thus, a contingency plan is required under 40 CFR 112.7 (d).

5.3 TURBINE RUNNER HUBS

It is not feasible to prevent oil from the turbine runner hubs from reaching river waters in the case of a leak. As with any hydroelectric facility, large quantities of river water are rushing past and turning the turbine blades while the turbine is in operation. Thus, the turbine runner hubs are necessarily in contact with the water. Also, it is impossible to place an appropriate alarm (flowmeter or oil detector) in connected oil piping, since oil is circulating continuously between the turbine runners and the oil tanks.

In the case of a complete failure of the runner hub (which is highly unlikely), the pressure alarm in the oil storage tank would notify operators of the problem and contingency measures would start immediately. A slow leak in a turbine runner hub would not be noticed immediately. In such an event, it may be several weeks before the oil tank level has lowered noticeably, even though oil levels are carefully monitored. However, it is highly unlikely that a leak of this sort would cause oil water quality standards to be exceeded, due to the immediate dilution of oil.

Once a small or large leak is discovered, the turbine will be shut down, the gates to that turbine will be closed, and the cause of the leak repaired. If it is determined that water quality standards may have been exceeded due to the spill, then clean-up actions will be initiated as described in Section 5.5.

5.4 OIL DELIVERY TRUCK

At the Wells Project, oil is used for insulating and lubricating purposes only. Therefore, "consumption" consists only of replacing dirty oil with clean oil and is a rare occurrence. A 7,000-gallon oil delivery is needed approximately once every ten years.

Containment is not feasible due to the design of the drainage system and the need to keep the area accessible to large vehicles. Nearby drains lead directly to the river and cannot be connected to the other containment systems on the deck. The following control measures should prevent oil from reaching river waters.

The oil delivery truck shall be supervised while it is in the Wells Project area. The truck operators will be given the “Notice to Tank Truck Drivers” (Appendix D) and directed to the oil pumping station. Before oil transfer begins, the truck shall be visually inspected for obvious defects. A Wells Project employee or the delivery person shall plug up the drains closest to the pumping station to provide some secondary containment volume in the sloped areas on the deck of the hydrocombine. Minor leaks or spills will be contained within this volume. A portable pump and fiber-reinforced rubber bags shall be on hand. Unless the truck suddenly bursts, the portable pump should be able to handle the flow of oil from a major spill. After oil transfer is complete, the supervisor shall make sure that the truck is completely disconnected and connecting hoses properly stored before the truck will be allowed to leave the oil transfer area.

If, in spite of the above measures, oil is not contained, then the contingency measures described in Section 5.5 shall be followed.

5.5 CONTINGENCY PROCEDURES

The importance of oil spill prevention, containment, and clean-up shall be stressed during the annual safety training meetings. As discussed in Section 4.0, "Training of Personnel," all work crews will be familiar with the SPCC Plan and the Oil Spill Contingency Plan. As soon as an employee notices an oil spill of any kind, he or she will notify the Control Room at the dam. Notification of all interested parties shall then follow the notification procedures outlined in Section 6.0. If the spill is not contained within the facility, the oil spill discoverer shall recover as much oil as is feasible using the oil-containing equipment stored on site while waiting for further instruction.

Once notified, the Project Superintendent shall concurrently follow the notification plan described in Section 6.0 while organizing oil containment, recovery, and clean-up operations. For extended clean-up operations, the Control Room at the dam shall be the communication center.

Wells Project personnel shall provide the emergency containment and oil collection procedures of which they are capable with the supplies on hand (see Section 2.4). When it is determined that a thorough clean-up of any oil spill in harmful amounts is beyond the capabilities of the on-site resources of the Wells Project, an oil spill response contractor shall be hired. The Department of Ecology's "Hazmat Spill Contractor List", updated in October 2006, is contained in Appendix B of this plan.

The most recent updated list can be obtained through the Department of Ecology's web page: http://www.ecy.wa.gov/programs/spills/response/hazmatspillcontractlist.

5.6 COMPATIBILITY WITH STATE AND REGIONAL PLANS

The current state and regional oil spill contingency plans that are applicable to the Wells Project location have all been incorporated into the Northwest Area Contingency Plan and Geographic Response Plans.

The 2006 Northwest Area Contingency Plan and associated Geographic Response Plans (May 2004) are available on the Internet at http://www.rrt10nwac.com . Wells Project personnel and any contractor hired by the District shall conform to the guidelines of the Northwest Area Contingency Plan. This includes following guidelines on oil dispersant use, in-situ burning, and oily waste treatment and disposal. Oil dispersants should not be used unless explicit permission is given by the Environmental Protection Agency, Region 10. In-situ burning is allowed with permission under certain circumstances outlined in the Northwest Area Contingency Plan.

Wells Project personnel and any contractor will cooperate completely with any on-site coordinator and spill response team provided by the state, regional, or federal government. It is unlikely that regional or federal teams would be provided, since it would be difficult for the Wells Project to produce a spill that would endanger the public health and welfare of the United States.

6.0 NOTIFICATION AND DOCUMENTATION REQUIREMENTS

6.1 IN-HOUSE NOTIFICATION

The discoverer of an oil spill at the Wells Project shall immediately notify the Hydrocombine Control Room. The control room shall notify the day-shift/chief operator. Figure A-1, The SPCC Notification Chart, shows the remaining lines of communication to be followed in the event of an oil spill incident.

It is the responsibility of the day-shift supervisor or night-shift chief operator or designee to notify the appropriate clean-up crews, the Manager, Chief Engineer/Assistant Manager, Project Superintendent, and the Chief of Environmental and Regulatory Services.

Clean-up action shall be taken in accordance with Section 2.5 of the SPCC plan.

6.2 IMMEDIATE REPORTING REQUIREMENTS

The Chief of Environmental and Regulatory Services shall be responsible for oil spill notification to the appropriate State and Federal officials. This shall be done as soon as possible after proper assessment and quantification of the oil spill occurrence.

Federal law requires that all spills of oil in harmful quantities into navigable waters or threat of release be immediately reported by the spiller to the National Response Center (NRC). In addition, Washington State law requires that all spills of oil into Washington State waters must be immediately reported to the Washington State Emergency Management Division (EMD). The Northwest Area Contingency Plan also requires the notification of the U.S. Environmental Protection Agency (EPA), Seattle for spills occurring in inland waters of Washington, Oregon, and Idaho.

The appropriate Federal and State contacts for the Wells Project are as follows:

REQUIRED NOTIFICATION OF OIL SPILLS:

1. National Response Center (NRC) 1-800-424-8802
   Toll Call: (202) 267-2675

2. Emergency Management Division 1-800-258-5990
   (Washington State EMD) Toll Call: (253) 912-4901
   (253) 912-4904

3. US Environmental Protection Agency (EPA) ..... (206) 553-1671
   Region X, Seattle..... 1 (800) 424-4372

RECOMMENDED NOTIFICATION OF OIL SPILLS:

4. Washington State Department of Ecology (DOE) ..... (509) 575-2490
   Yakima

When reporting a spill or release to the above agencies, it is important to collect as much information as possible. That information should include:

- Date and Time of call
- Caller Name, Address, & Phone Number
- Name of Person Taking the Report
- Facility information:
  - Name
  - Type of Facility
  - Location of incident
  - Date and Time the Incident occurred or was discovered
  - Description of spill (i.e. size, color, smell, etc.)
  - Type of Incident (Explosion, Collision, Grounding, etc.)
  - Materials released
  - Source of Materials released
  - Estimated Amount released
  - Total Potential quantity that could be released
  - Environmental media impacted or potentially impacted by spill (i.e. air, water, ground/soil)
  - Weather/Sea Conditions
  - Point of Contact (Responsible Party Name & Phone #)
  - Facility Agent(s) (Name & Phone)
  - Name and contact information of insurance carrier
  - Description of who is on-scene and what response activities are being done or have been completed
  - Have excavations occurred
  - Other Agencies notified

For liability purposes, the calls should be followed with a letter to be filed in the oil spill log and to be sent to the EPA and DOE listing the information given and received during the notification phone calls. There can be civil and criminal charges for not reporting discharges in a timely manner or for reporting false information. Thus, documentation of the notification call is important. The addresses are shown below:

U.S. EPA, Region X
1200 Sixth Ave.
Mailcode: ECL 116
Seattle, Washington 98101

Washington State Department of Ecology

Central Office
15 West Yakima Avenue, Suite 200
Yakima, Washington 98902-3452

6.3 NOTIFICATION TO OTHERS

The local fire department shall be notified by the day-shift chief operator or the night-shift chief operator or designee if there is a potential fire hazard concurrent with the oil spill occurrence.

The local police department shall be notified by the day-shift chief operator or night-shift chief operator or designee if there is evidence of sabotage, misconduct, or other wrongdoing.

The responsibility of contacting and/or responding to the news media shall be the exclusive responsibility of the Public Information Officer.

6.4 DOCUMENTATION OF SPILL EVENT

A log shall be kept of all oil spill events. The log shall contain the date and time of discovery, actions taken, telephone calls, and weather conditions. It shall be a complete account of the spill event through completion of clean-up and restoration. A copy of the log shall be sent to the Project Superintendent and Chief of Environmental and Regulatory Services upon completion. The chief operator shall keep the log on file in the event of any future legal or government action that may result from the spill event.

The log shall be completed by the initial oil spill discoverer along with the operator who was on duty at the time of the spill. All reports of oil spill shall be kept on file for a minimum of three years and shall include the following information:

1. Date and time of the spill, and the location where it was first observed.
2. Type and quantity of the oil spill.
3. Cause of the spill.
4. Personnel and equipment involved.
5. Containment and clean-up action taken.
6. Sequence and time of events.
7. Evidence, such as witnesses, photographs, and samples.
8. Action taken to prevent similar occurrences.
9. Assessment of damage and steps required for restoration.
10. Samples taken and laboratories used.

6.5 OIL SPILL REPORT REQUIREMENTS

Whenever the Wells Project facility has discharged more than 1,000 gallons of oil into or upon navigable waters or adjoining shoreline in a single spill event, or discharged more than 42 gallons of oil upon navigable waters or adjoining shorelines in two spill events occurring within any twelve-month period, the District shall submit within sixty days a report of the spill(s) in accordance with 40 CFR

112.4. Any reports shall also be submitted to state agencies in charge of water pollution control activities.

6.6 SPCC PLAN LOCATIONS

At least one copy of the SPCC Plan and the Oil Spill Contingency Plan shall be kept in the following locations. All personnel shall be informed of these locations:

1. The Project Superintendent's Office (and Residence)
2. The Control Room at the dam
3. The Chief Engineer/Assistant Manager's Office (and Residence)
4. The Chief of Environmental and Regulatory Service's Office (and Residence)
5. The District's Public Relations Office (and Residence)
6. The System Engineer's Office (and Residence)

7.0 Attachment C-II of 40 CFR 112
Certification of the Applicability of the Substantial Harm Criteria

Facility Name: Wells Hydroelectric Project

Facility Address: The Wells Hydroelectric Project is located on the Columbia River at River Mile 515.8. Correspondence can be addressed to Mike Bruno, Wells Hydroelectric Project, 28905 US Highway 97, Pateros, Washington 98846-9602.

1. Does the facility transfer oil over water to or from vessels and does the facility have a total oil storage capacity greater than or equal to 42,000 gallons?

Yes _____ No ✓

2. Does the facility have a total oil storage capacity greater than or equal to 1 million gallons and does the facility lack secondary containment that is sufficiently large to contain the capacity of the largest above-ground oil storage tank plus sufficient freeboard to allow for precipitation within any aboveground oil storage tank area?

Yes _____ No ✓

3. Does the facility have a total oil storage capacity greater than or equal to 1 million gallons and is the facility located at a distance (as calculated using the appropriate formula in Attachment C-III to this appendix or a comparable formula[1]) such that a discharge from the facility could cause injury to fish and wildlife and sensitive environments, see Appendices I, II, and III to DOC/NOAA's "Guidance for Facility and Vessel Response Plans: Fish and Wildlife and Sensitive Environments" (see Appendix E to this part, section 13, for availability) and the applicable Area Contingency Plan.

Yes _____ No ✓

4. Does the facility have a total oil storage capacity greater than or equal to 1 million gallons and is the facility located at a distance (as calculated using the appropriate formula in Attachment C-III to this appendix or a comparable formula[1]) such that a discharge from the facility would shut down a public drinking water intake[2]?

Yes _____ No ✓

5. Does the facility have a total oil storage capacity greater than or equal to 1 million gallons and has the facility experienced a reportable oil discharge in an amount greater than or equal to 10,000 gallons within the last 5 years?

Yes ___ No ✓

Certification

I certify under penalty of law that I have personally examined and am familiar with the information submitted in this document, and that based on my inquiry of those individuals responsible for obtaining this information, I believe that the submitted information is true, accurate, and complete.

Signature

Dr. Robert W. Clubb

Name (please type or print)

Chief of Environmental and Regulatory Services

Title

8/10/07

Date

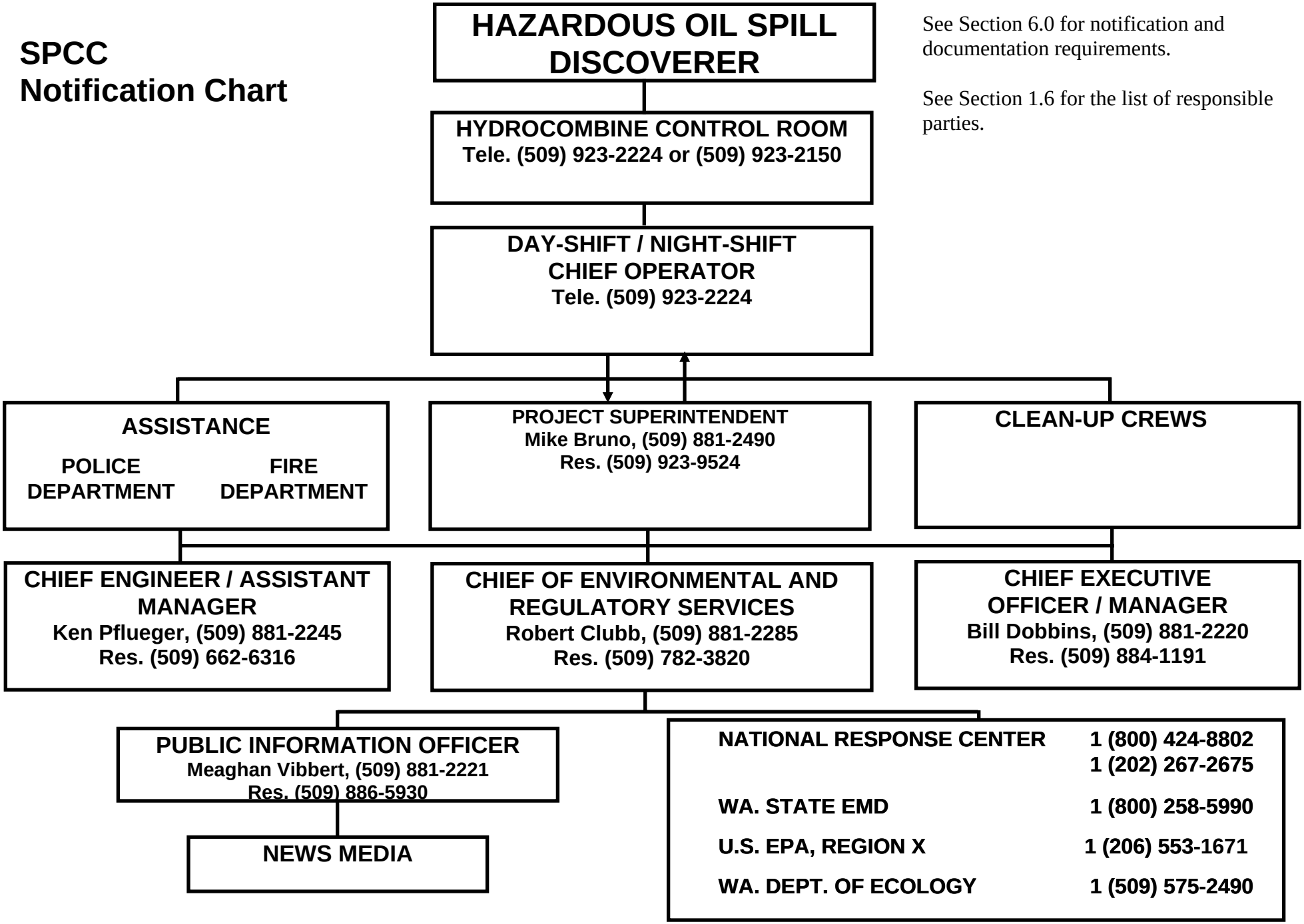
[1] If a comparable formula is used, documentation of the reliability and analytical soundness of the comparable formula must be attached to this form.

[2] For the purposes of 40 CFR part 112, public drinking water intakes are analogous to public water systems as described at 40 CFR 143.2(c).

APPENDIX A

SPCC NOTIFICATION CHART

SPCC
Notification Chart



See Section 6.0 for notification and documentation requirements.

See Section 1.6 for the list of responsible parties.

Figure A-1 SPCC Notification Chart

APPENDIX B

HAZMAT SPILL CONTRACTOR LIST

Hazmat Spill Contractor List

Ecology does not verify or endorse any of the contractors or information on this list . Information on this list is subject to change.

http://www.ecy.wa.gov/programs/spills/response/contractor%20list.htm

COMPANY LOCATION	COMPANY NAME	SPILL NUMBER	OIL SPILL		Haz Mat	Organic**	Reactives Cylinders	Vac Truck	Vessel/ Water	STATE COVERAGE	
			Small*	Large						Eastern	Western
Aberdeen	Apex Environmental	(360) 532-3590	X	X				X			X
Aberdeen	Evergreen Environmental Inc.	(360) 533-6141	X	X							X
Battleground/Waitsburg	3 Kings Environmental	(360) 666-5464	X	X	X		X		X	X	X
Bellingham	Matrix Service	(360) 676-4905	X	Xw							X
Bellingham	Western Refinery Service	(360) 366-3303						X			X
Camas	West Coast Marine Cleaning	(360) 696-3362	X	X		X		X		X	X
Corvallis, The Dalles, OR	NWFF Environmental	800-942-4614	X	X	X	X	X		X	X	X
Everett/Orting	Aspen Environmental, Ltd	800-716-3377	X	X	X			X		X	X
Kent	Rivers Edge Services	(206) 941-1645	X	X	X			X			X
Longview/Portland/Seattle	Accord	(877) 251-8557	X	X	X	X	X	X			X
Longview	All Out Industrial & Env. Serv.	(360) 414-8655	X	Xw	X			X			X
Longview/Astoria/Portland/Aberdeen	Cowlitz Clean Sweep	888-423-6316	X	Xw	X	X		X	X	X	X
Lynnwood	Environmental Quality Mngmt	(425) 673-2900	X		X	X					X
Olympia	Focus Environmental Mgt Group	(815) 621-2398					X			X	X
Pasco/Portland	Tidewater Environmental	(360) 695-8088		X	X					X	X
Portland/Eugene/Vancouver	First Strike Environmental	800-447-3558	X	X	X	X		X	X	X	X
Portland/Kennewick	Oil Re-Refining Company	800-367-8894	X					X		X	X
Portland/Kennewick/Spokane	Harbor Oil	(503) 285-4648	X							X	X
Puyallup	Pro-Vac	(253) 435-4328	X	X				X		X	X
Renton	Aqua Clean Jet-N-Vac, Inc.	(800) 842-5326	X	X		X		X		X	X
Tacoma	Northwest Cascade	(253) 848-2371				X		X	X		X
Tacoma	Certified Cleaning Service	(253) 536-5500	X	Xw	X			X		X	X
Tacoma	Guardian Industrial Services	(253) 536-0455	X	w				X		X	X
Tacoma	Emerald Services	(253) 627-4822		X	X					X	X
Tacoma	PRS Group, Inc.	(253) 383-4175	X		X			X			X
Seattle	Baker Tanks	(425) 487-6503		X	X					X	X
Seattle	Ballard Diving & Salvage	(206) 782-6750	X						X		X
Seattle/Tacoma/Vancouver	Emerald Services Inc.	(206) 832-3000	X	X	X			X		X	X
Seattle	Clean Harbors	800-444-4244			X					X	X
Seattle/Tacoma/Spokane/Astoria	NRC Environmental Services, Inc.	800-337-7455	X	Xw	X		X	X	X	X	X
Seattle	Global Environmental	(206) 623-0621	X	Xw					X	X	X
Seattle	Marine Vacuum Service	(206) 762-0240	X	X				X		X	X
Seattle	ONYX Enviro. Services	(206) 241-3900			X		X			X	X
Seattle/Spokane	Pacific Industrial Resources	(206) 767-3957	X	X	X		X	X		X	X
Seattle/Tacoma/Washougal	Philip Services Corporation	800-547-2436		X	X			X		X	X
Seattle/Portland	RMCAT Enviro. Services	800-930-0011	X	X	X	X				X	X
Snohomish	Whiteside Inc	(360) 668-8282	X	X				X			X
Spokane	Able Clean-up Technoloiges	(509) 466-5255	X	X	X	X	X		X	X	
Spokane	Big Sky Industrial	(509) 624-4949	X	X				X		X	
Sumner/Portland	Spencer Environmental	(253) 863-3310	X	X	X			X		X	X
Woodinville	CADRE	(425) 883-8007					X			X	X

w = PRC: WAC 173-181 Approved Primary Response Contractor (oil) for facilities. ** Organic=sewage, blood, animal waste, etc. **Revised October 2006**

* Small=roadside, home tank, saddle tank, storm drains, 1 drum, etc.

Home Heating Oil Tanks - state of Washington - Pollution Liability Insurance Agency 1-800-822-3905 - Insurance Verification (M-F, 8-5)

APPENDIX C

REGIONAL TREATMENT CENTERS FOR PETROLEUM CONTAMINATED SOILS

The Following is a List of Regional Treatment Centers for Petroleum Contaminated Soil:

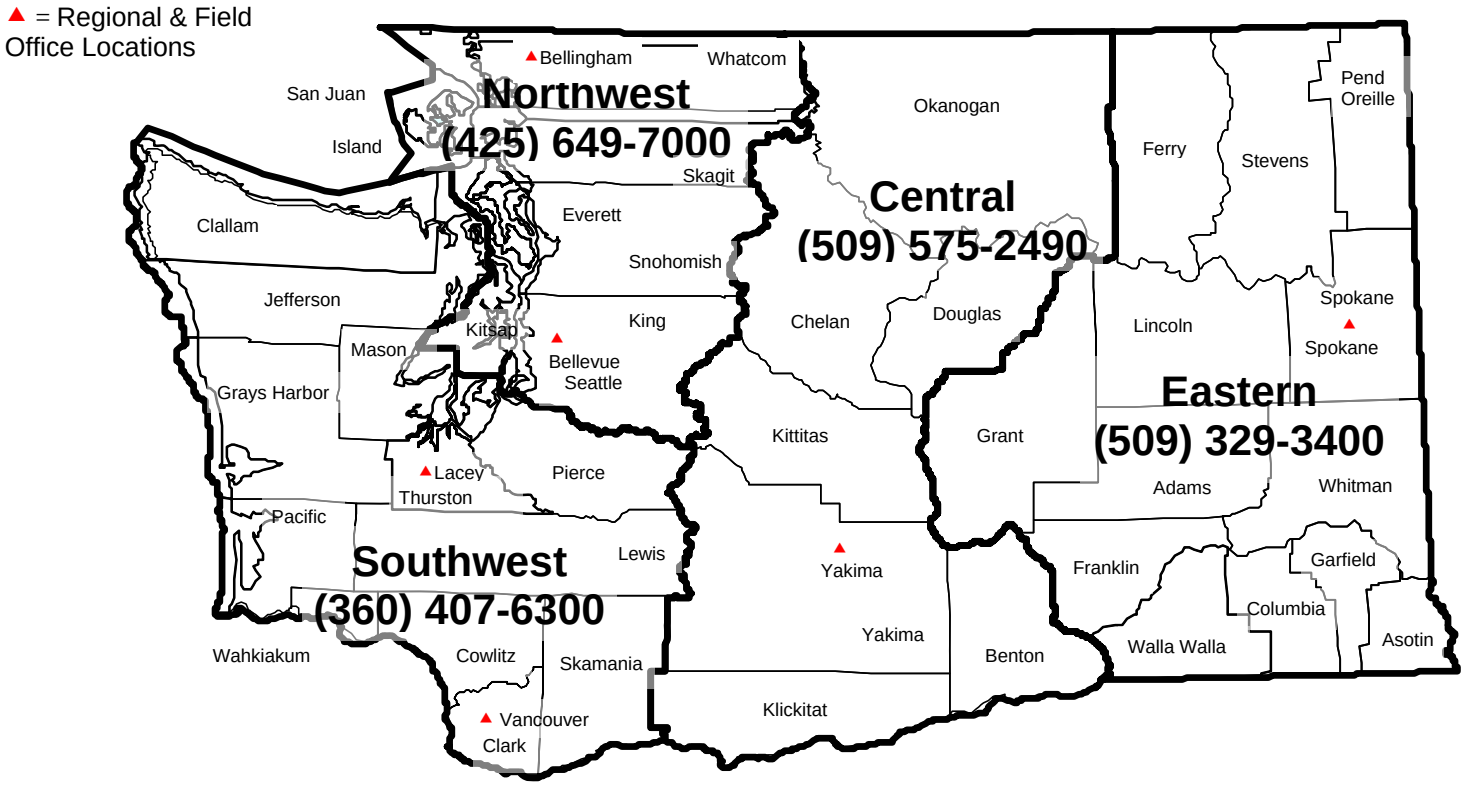
CRO	Roosevelt	Roosevelt Regional Landfill	1-800-275-5641	Disposal Only
ERO	Spokane	Remtech, Inc.	(509) 624-0210	Thermal Desorption
NWRO	Everett	Rinker Materials	(425) 355-2111	Soil Remediation
NWRO	Seattle	Leforge Cement	(206) 937-8025	Cement Incorporation
SWRO	Tacoma	Petroleum Reclaiming Services	(253)383-4175	Stabilization/Disposal
SWRO	Port Angeles	Fields Shotwell Corp.	(360) 457-1417	Thermal Treatment/Recycling
SWRO	Fife	Fife Sand & Gravel	(253) 922-7710	Bio-Remediation

KEY: CRO: Central Region ERO: Eastern Region NWRO: Northwest Region SWRO: Southwest Region

Washington State Department of Ecology Regional Office 24-Hour Oil Spill/Release Reporting Numbers

WHAT WE NEED TO KNOW

- Reporting Party
- Contact Phone(s)
- Responsible Party
- Material Released
- Resource Damages (e.g. dead fish)
- Quantity
- Concentration
- Location
- Cleanup Status



Or call the **Department of Emergency Management 24-hour Number: 1-800-258-5990**

For EPA and US Coast Guard reporting, call the National Response Center: 1-800-424-8802

Idaho: Communications Center (208) 327-7442 ***Oregon***: Emergency Management (503) 378-6377

BC: Provincial Emergency Program (800) 663-3456 ***EPA Region X, Seattle***: (206) 553-1263

APPENDIX D

NOTICE TO TANK TRUCK DRIVERS

NOTICE TO TANK TRUCK DRIVERS

To prevent the release of substances hazardous to the environment, tank truck drivers entering this site are to comply with the following rules:

1. Inspect tank, fitting, and liquid level indicator prior to filling.
2. Place drip pans under all pump hose fittings prior to loading/unloading.
3. Set the handbrake before starting to load/unload.
4. Plug the drains closest to the delivery truck.
5. Remain within 25 feet of the vehicle while loading/unloading.
6. Maintain an unobstructed view of the cargo tank and load/unload hose.
7. Drain loading/unloading line to storage tank when loading/unloading is complete.
8. Verify that all drain valves are closed before disconnecting loading/unloading lines.
9. Inspect vehicle before departure to be sure all loading/unloading lines have been disconnected and vent valves closed.
10. Unplug the drains closest to the delivery truck.
11. Immediately report any leakage or spillage to the Control Room:

    Extension 3471 or (509) 923-2224 or (509) 923-2150

APPENDIX E

SPCC RULE CROSS-REFERENCE

SPCC RULE CROSS-REFERENCE

Final SPCC Rule	1973 SPCC Rule	Description of Section	Page
§ 112.7	§ 112.7	General requirements for SPCC plans for all facilities and all oil types.	
§ 112.7(a)	§ 112.7	General requirements; discussion of facility's conformance with rule requirements; deviations from Plan requirements; facility characteristics that must be described in the Plan; spill reporting information in the Plan; emergency procedures.	§ 1 pgs. 1-3, § 2 pgs. 6-12, § 6 pgs. 17-20
§ 112.7(b)	§ 112.7(b)	Fault analysis.	§ 2.6 pgs. 8-12
§ 112.7(c)	§ 112.7(c)	Secondary containment.	§ 2.6 pgs. 8-12
§ 11.27(d)	§ 112.7(d)	Contingency plans.	§ 5.0 pgs. 14-16
§ 112.7(e)	§ 112.7(e)(8)	Inspections, tests, and records.	§ 3.0 pg. 13
§ 112.7(f)	§ 112.7(e)(10)	Personnel training and discharge prevention procedures.	§ 4.0 pg. 14
§ 112.7(g)	§ 112.7(e)(9)	Security (excluding oil production facilities).	§ 2.7 pg. 13
§ 112.7(h)	§ 112.7(e)(4)	Loading/unloading (excluding offshore facilities).	§ 5.4 pg. 15
§ 112.7(i)	n/a	Brittle fracture evaluation requirements.	n/a
§ 112.7(j)	§ 112.7(e)	Conformance with State requirements.	§ 5.6 pg. 16
§ 112.8 § 112.12	§ 112.7(e)(1)	Requirements for onshore facilities (excluding production facilities).	
§ 112.8(a) § 112.12(a)	n/a	General and specific requirements.	§ 1 pgs. 1-3, § 2 pgs. 6-12, § 6 pgs. 17-20
§ 112.8(b) § 112.12 (b)	§ 112.7(e)(1)	Facility drainage.	§ 2.6 pgs. 8-12
§ 112.8(c) § 112.12(c)	§ 112.7(e)(2)	Bulk storage containers.	Pgs. 8, 10-12
§ 112.8(d) § 112.12(d)	§ 112.7(e)(3)	Facility transfer operations, pumping, and facility process.	§ 3.0 pg. 13
§ 112.9 § 112.13	§ 112.7(e)(5)	Requirements for onshore production facilities.	n/a
§ 112.10 § 112.14	§ 112.7(e)(6)	Requirements for onshore oil drilling and workover facilities.	n/a
§ 112.11 § 112.15	§ 112.7(e)(7)	Requirements for offshore oil drilling, production, or workover facilities.	n/a

APPENDIX F

OIL SPILL RESPONSE MOBILE UNIT - INVENTORY

OIL SPILL RESPONSE MOBILE UNIT - INVENTORY		
BOOM	1000 ft	**4"x 6" Oil Spill Response Containment Boom**
ANCHOR SYSTEM	4 ea	**Anchor Systems** (30 lb anchors, with 10ft of chain, 150ft rode & with orange 15.5" buoy)
BOOM LIGHTS	5 ea	Navigational Lights, Self-floating, amber lens, 48" tall; to attach on or near boom (batteries in tool box)
TOOL BOX	**1 ea**	**Heavy-duty poly toolbox. 24" length (contains the below inventory)**
	2 ea	8" crescent wrench
	1 ea	8" standard pliers
	1 ea	16 oz. claw hammer
	2 ea	4" C-clamp
	1 ea	Flathead screwdriver, small and large
	2 ea	3/8" SPA galvanized shackles, ½" SPA galvanized shackles
	1 ea	Utility knife with extra blade set
	1 ea	Waterproof floatable flashlight with 2 D-cell batteries
	6 sets	Hardware set including: 5/16" x 1 ¼" SS bolts, 2 flat washers, nylock nuts
	1 ea	Duct Tape, Elec Tape
PPE BAGS	**4 bags**	**PPE Waterproof gear bag (each bag contains the below inventory)**
	1 ea	Hard hat with ratcheting head band
	1 pr	16" PVC steel toe work boots, size 11, ASTM F2413-05 MI/75 C/75 compliant
	2 pr	PVC gloves, 12" gauntlet, size 11
	2 pr	Leather work gloves, large size
	2 pr	Safety glasses, meeting ANSI and OSHA specifications
	6 pr	Ear plugs
	2 pr	White Tyvek suit without hood
	1 ea	Duct Tape, 1 roll
DECON STATION		**Decontamination Kit Station (contains the below inventory)**
	2 ea	Poly wash tubs
	1 ea	Degreaser detergent for decontamination
	1 bx	Nitrile glove liners, large size
	4 ea	PVC gloves, 12" gauntlet, size 11
	2 ea	Decontamination scrub brushes with long handles
	1cs	Waste bags, 1 case or 100 bags, 33" x 40", 4 mil
	1 rl	Visqueen sheeting, 20' x 100', 4 mil
	2 ea	Drop tarps, 8' x 10'
	1 ea	5-gallon plastic bucket
ABSORBENTS		
	2 ea	Pads, heavy weight adsorbent pads, 1 bag of 100 pads
	2 ea	Sweep, 100 feet of 19" heavy weight sweep with nylon web strap
	2 ea	Sorbent boom, heavy weight boom containing 4 sections of 5" x 10'
		(each with poly tension line and quick-clips for connecting)
MISC SUPPLIES		
	1 ea	First aid kit (meets WAC 296-800-15020 for at least 10 people)
	2 ea	5-pound class ABC fire extinguishers
Information book (Spill notification sheet, Job Hazard Analysis, tailgate safety, common MSDS's, trailer inventory)		

Jerald, T. 2007. White Sturgeon (Acipenser transmontanus) Population Assessment in Wells Reservoir. MSc Thesis. Central Washington University, Ellensburg, WA.

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WHITE STURGEON (*Acipenser transmontanus*) POPULATION ASSESSMENT IN WELLS RESERVOIR

A Thesis

Presented To

The Graduate Faculty

Central Washington University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

---

by

Tyson Jerald

January 24, 2007

ABSTRACT

WHITE STURGEON (*Acipenser transmontanus*) POPULATION ASSESSMENT AND PREFERRED HABITATS IN WELLS DAM RESERVOIR

By

Tyson Jerald

January 2007

This project focused on acquiring information regarding white sturgeon population structure, movement patterns, and preferred habitats within Wells Reservoir. Prior to this study, no research had been conducted on white sturgeon populations in Wells Reservoir and therefore the status of these fish has been poorly understood.

Set lines were deployed throughout the entire Wells Reservoir during 2001 and 2002. A total of 13 individual white sturgeon were captured on the set line gear. Additionally, 5 recaptures were recorded bringing the total number of captures events to 18. All white sturgeon were captured near the confluence of the Okanogan and Columbia Rivers

Two of the captured fish were classified as juveniles (i.e. less than 90 centimeters fork length) and the remaining 11 fish were classified as adult. White sturgeon ranged in length from 65 centimeters to 202 centimeters. Using pectoral fin analysis, ages ranged from 5 to 30 years, representing the 1972 to 1997 year classes.

A variable capture probability Schnabel abundance estimate from the mark-recapture data was computed at N=31.35. The 95% confidence interval for sturgeon was large due to a small number of recaptured fish CI ($13.15 \leq N \leq 217.50$) =0.95.

A total of 6 white sturgeon were outfitted with radio transmitters. All telemetry observations during boat surveys were recorded near the confluence of the Okanogan and Columbia rivers. One fixed telemetry receiver located within the Okanogan River (10 kilometers upstream from the mouth) recorded two white sturgeon during the spring of 2002 and one white sturgeon during the spring of 2003.

White sturgeon were only observed via set line capture and telemetry in the Okanogan Columbia River confluence area and upstream in the Okanogan River. These areas were defined as preferred holding locations within the study area. However, white sturgeon were not recorded during telemetry surveys or set line surveys in these locations during probable spring spawning periods. White sturgeon may migrate from the confluence area to spawn in the upper portions of the reservoir during the spring. The upper portion of Wells Reservoir is heavily influenced by discharges from Chief Joseph Dam. High flows through Chief Joseph project in June coincide with preferred white sturgeon egg incubation temperatures in the tailrace area. This provides evidence that white sturgeon may utilize the upper reservoir for spawning purposes.

Data collected during this study should provide a strong foundation for future white sturgeon monitoring and management programs in the Wells Reservoir. Future population level monitoring of these fish, as well as the identification of preferred habitats, will be necessary to promote an expansion of the small population that was identified during this study. Future research regarding white sturgeon in Wells reservoir should include an analysis of supplementation options and evaluation of the carrying capacity of white sturgeon in Wells Reservoir. This information will ultimately provide regional biologists with the ability to implement strategies that promote white sturgeon abundance within Wells Reservoir.

ACKNOWLEDGEMENTS

Special thanks to Dr. Paul James for his guidance on this project. Dr. James' in-depth understanding of ichthyology provided a strong background for this Thesis. Dr. Darda and Dr. Bryan are also thanked for their input and support.

I would also like to thank Shane Bickford and Public Utility District No. 1 of Douglas County. Mr. Bickford arranged for funding of this project through Douglas PUD. Mr. Bickford also helped coordinate the field research and provided valuable technical and field collaboration.

Ken LePla at Idaho power is graciously thanked for his instruction regarding telemetry tag application onto white sturgeon. Mr. Lepla provided valuable direction in regards to data analysis, white sturgeon ecology. He also provided valuable length frequency data from sturgeon populations within the Snake River Basin.

Brad James with Washington Department of Fish and Wildlife supplied valuable length frequency data for lower Columbia River fish stocks. Mr. James also provided valuable input on the project and supplied recent life history data white sturgeon on the lower Columbia River.

John Skalski and Richard Townsend are appreciated for their help in developing an accurate white sturgeon population estimate for the project.

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INTRODUCTION

A total of 24 sturgeon species are recognized worldwide. These fish are all restricted to the Northern Hemisphere and spawn in freshwater environments (Helfman et al. 1999). Anadromy (spawning in freshwater and spending a portion of life in saltwater) is exhibited by some (but not all) sturgeon species. White Sturgeon (*Acipensar transmontanus*) have changed little since their appearance in the fossil record. Documentation of these prehistoric fishes has been dated back to the Upper Cretaceous, with these fish evolving approximately 400 million years ago (Hanson 1992).

Historically, white sturgeon populations existed throughout the west coast of North America from the Aleutian Islands to central California. Currently, spawning populations have been identified in three large river systems of their native range (the Sacramento-San Joaquin in California, the Columbia River in Washington State, and the Fraser River in Canada). Tag recovery has shown that some sturgeon may utilize more than one river on the West Coast during different life stages (Kohlhorst et al. 1991). Analysis of mitochondrial deoxyribonucleic acid (mtDNA) has implied that the Columbia River and Fraser River populations are genetically similar (Brown et al. 1990). After the last ice age, the Columbia River population probably provided the founders for the Fraser River population. Small numbers of clonal lines within the mtDNA suggest a recent genetic bottleneck and imply that a small number of females founded the present populations in the Columbia and Fraser river systems (Brown et al. 1990).

White sturgeon are the largest of all North American freshwater fishes. These fish possess an armor like skin that covers a cartilaginous skeleton. Distinct bony plates called scutes run along the body. This anadromous species may complete their life cycle in fresh water or spend a portion of their life in brackish or marine environments. The largest authentic record of a white sturgeon was recorded as a 630 kg specimen taken from the Fraser River in 1897 (Scott and Crossman 1973). White sturgeon are long lived fishes, with fin ray analysis documentation of fish over 100 years in age (Beamesderfer et al. 1995; Rien and Beamesderfer. 1994).

Commercial and sport fishing have impacted Columbia River sturgeon. A commercial fishery was initiated in the 1880's. During the peak, in 1892, approximately 80,000 fish were harvested weighing 2.5 million kg (Rieman and Beamesderfer 1990). By 1900 the extensive white sturgeon population had

collapsed from overexploitation. Over the last 100 years sport angling for white sturgeon has grown dramatically while commercial fishing has been reduced. Most of the fishing activity has been focused on the lower 100 mile stretch of Columbia River, downstream of Bonneville Dam (Devore et al. 1995).

Regional federal, state, and county agencies have expressed growing concern over the status of white sturgeon within the Columbia River. The once free flowing Columbia River has been segmented by a series of hydroelectric projects that have altered habitats within the aquatic ecosystem. White sturgeon historically migrated throughout the entire river system. The construction of Rock Island Dam in 1934 cut off the sturgeon populations in the mid-Columbia from accessing the ocean. Currently Priest Rapids Dam is thought to be the upstream migration terminus for adult white sturgeon in the Lower Columbia River. Upstream of Priest Rapids, resident populations of sturgeon remain between each of the Mid-Columbia River hydroelectric projects. It is estimated that there are as many as 18 landlocked sub populations of white sturgeon within the Columbia and Snake River impoundments (Hanson et al, 1992). Resource managers typically consider sturgeon confined between hydroelectric projects as discrete populations, even if fish passage facilities are available, as white sturgeon do not readily use fish ladders (Kreitman and LaVoy 1989).

Male white sturgeon reach sexually maturity at around 18 to 25 years of age at approximately 120 CM fork length. Females do not reach sexual maturity until 16 to 35 years of age (Devore et al. 1995) at approximately 150 cm fork length. This old age of maturity results in large generation times. Sexually mature female white sturgeon may only spawn every two to five years (Smith, 1985). Female white sturgeon spawn only when environmental conditions are favorable, reabsorbing their eggs during years in which environmental conditions are unfavorable. This ultimately restricts the fish's ability to respond to factors such as altered habitat. During successful spawning events, mature female white sturgeon release from .1 million to 7 million eggs, depending on fish size and age (Hanson et al. 1992). It has been documented that white sturgeon preferred spawning habitats consist of high water velocities over 0.8 m/s and focus spawning activities downstream of hydroelectric projects (Parsley and Kappenman 2000, Parsley et al. 1993). Presently, spawning habitat is restricted to dam tailrace areas and tributary streams. It is in the dam tailrace locations that high water velocities can be found within the impounded Columbia River ecosystem. Moderate to high flow velocities can also be found within tributary streams of the Columbia

River. Confluence areas of tributary streams within the Columbia River have been documented as preferred sturgeon habitats. Haynes et al. (1978) documented white sturgeon movements to the mouths of the Snake and Walla Walla rivers, where the fish remained until transmitter failure. White sturgeon may conduct spawning migrations into tributary rivers or tributary confluences with suitable spawning habitats. Within Wells Reservoir, the Okanogan River and Methow River tributaries have moderate to high flow velocities. Therefore, suitable spawning habitats within the study area are located downstream of Chief Joseph Dam and within the Okanogan and Methow rivers.

It has been observed that white sturgeon spawn at water temperatures from 10 degrees C to 18 degrees C (Parsley et al 1993). The Columbia River reaches these temperatures in the spring of each year and triggers white sturgeon spawning events. Therefore, any observed movements of white sturgeon during this time period may provide evidence of spawning migrations within the study area.

A white sturgeon population assessment was conducted in Rocky Reach Reservoir in 2001. This reservoir is located immediately downstream from Wells Reservoir. The mark recapture population estimate for the Rocky Reach Reservoir was determined to be 29 adult sturgeon with a 95% confidence interval ranging from 11 to 108 fish. From 2000 to 2002, an extensive study was conducted within Wanapum Reservoir and Priest Rapids Reservoir located approximately 110 km downstream from Wells Reservoir. The project involved an extensive mark-recapture evaluation and in-depth analysis of fish movements within both reservoirs. The population estimates derived for the Wanapum and Priest Rapids reservoirs were also relatively low with 134 adult fish (95% CI 48-2,680) estimated for the Wanapum Reservoir and 551 adult fish (95% CI 143-4,746) estimated in the Priest Rapids Reservoir (Golder 2003). These population estimates were relatively small when compared to population estimates for the lower Columbia River.

The Public Utility District No. 1 of Douglas County (PUD) owns and operates the Wells Hydroelectric Project (Wells Project), located at river km 829.8 on the Columbia River (Figure 1). The Wells Project boundary encompasses 47.5 km of the mainstem Columbia River upstream to Bridgeport Bridge which is 0.5 km downstream of the Chief Joseph Hydroelectric Project (Rkm 877.3). The Wells Reservoir has riverine characteristics in the upper 15-km section downstream from the Chief Joseph Dam tailrace. The middle section is more characteristic of a lacustrine environment. The lowermost section of

the reservoir slows and deepens as it nears the forebay of Wells Dam (Beak, 1999). The drainage area of the Columbia River Basin upstream of the Wells Project is approximately 220,900 square kilometers.

Within the Mid-Columbia River, white sturgeon populations have been studied in the Priest Rapids, Wanapum and Rocky Reach reservoirs (Golder 2002, Golder 2003). These studies were conducted as part of the relicensing of those respective hydroelectric projects. The license for the Wells Project expires in May of 2012. Biological data was collected regarding white sturgeon research as part of this relicensing process. The purpose for this study is to analyze the white sturgeon population structure within Wells Reservoir. Because little historical data exists on white sturgeon in the reservoir, it has been difficult for regional biologists to accurately assess hydroelectric impacts on these fish. Prior to this study there was little documentation that a resident population of white sturgeon existed in the reservoir. However, it was assumed that a population of sturgeon was present, as viable populations of these fish were documented within Columbia River reservoirs both immediately upstream and downstream from the study area (Golder 2002, Ward et al. 2003). Additionally, recreational fishing took place for white sturgeon in the Wells Pool up through the 1980's as indicated from punch card returns from Washington Department of Fish and Wildlife (WDFW). These catch cards recorded the presence of white sturgeon in the study area during that time period.

Analysis of the white sturgeon population within the Wells Reservoir was composed of two primary objectives. The first objective was to capture an adequate number of individual white sturgeon to provide a basic analysis of the population abundance, age structure, size, growth, and ecology within the study area. Age structure and population estimates were derived using mark-recapture techniques. The age of each individual fish was determined through the collection and analysis of fin rays. It was of particular interest to determine whether juvenile and sub-adult sturgeon were present within the reservoir. The presence of fish younger than the project, completed in 1967, would indicate that recruitment, either through spawning or entrainment (downstream migration of white sturgeon), is occurring within the population. Lengths of captured fish were recorded to construct a length frequency histogram. The length frequency histogram was then analyzed to determine the age structure of the white sturgeon population in Wells Reservoir.

The second objective of this study was to analyze the movement of radio tagged white sturgeon within the reservoir. This objective was accomplished through the application of external radio transmitter tags onto adult and juvenile white sturgeon. Fixed and mobile telemetry stations were then utilized to track radio tagged fish. Tracked movements were then investigated in regards to possible spawning migrations, feeding activity, and habitat use.

Taking into account the importance of developing a baseline data collection project, this Masters of Science Thesis has been designed to develop an initial assessment of ecological and biological characteristics of white sturgeon populations within Wells Reservoir. A crucial goal for this project is to ensure information contained within is scientifically valuable to regional biologists involved in white sturgeon research and management activities. Information from this study will ultimately promote the development of effective white sturgeon enhancement and research activities within Wells Reservoir.

MATERIALS AND METHODS

Study Area: Wells Reservoir

The Columbia River originates at Columbia Lake in British Columbia and flows approximately 2,000 km to the Pacific Ocean. The Columbia River drains a majority of the inland Pacific Northwest and is fed from over 175 streams and rivers. The Columbia drains more than 650,000 square kilometers and averages a drop of one meter-per-five km drop. The river has been divided into three regions known as the Lower, Mid, and Upper Columbia. The Upper Columbia is described as that portion of the river from the international boundary between United States and Canada upstream to the headwaters of Columbia Lake. The Mid Columbia River is known as that portion of the river from the international boundary downstream to the Snake River Confluence (Figure 1). The Lower Columbia is described as that portion of the river downstream from the Snake River Confluence. The Lower Columbia River forms a deep gorge through the Cascade Mountains on its way to the Pacific Ocean designating the border between Oregon and Washington.

The Mid-Columbia River traverses 589 kilometers from the international boundary to the Snake River and once dropped 315 meters in elevation in a series of 50 rapids and one major waterfall at Kettle Falls. Historically, the Mid-Columbia River was a free flowing system, and it is suspected that white sturgeon migrated throughout the system from the Pacific Ocean and Columbia River estuary as far upstream as Kettle Falls. Upstream migrations of adult white sturgeon have been impeded by the hydroelectric projects following the construction of the Columbia River hydroelectric projects. Dams containing navigation locks and fish ladders presently provide limited upstream passage for adult sturgeon and it is generally accepted that Priest Rapids Dam is the upstream terminus of white sturgeon migrations within the lower Columbia River.

The climate of the Mid-Columbia Region is primarily influenced by the Pacific Ocean and winds from the Arctic. Moisture containing rains from the coast are dispersed on the west slope of the Cascade Mountains, leaving the eastern slopes sunny and dry. The rain shadow effect results in a semi arid inland shrub steppe community with an average of 46 millimeters of rain per year. The Mid-Columbia Region is

a dry land farming area with little water resources other than the Columbia River and Snake River drainages. Over the last century irrigation requirements have played a major role in construction of Hydroelectric projects on the Columbia River.

Wells Reservoir study area is located within the mainstem Columbia River from Wells Dam (river km 829.8) to the tailrace of Chief Joseph Dam (river km 877.9)(Figure 1). Wells Reservoir has two major tributaries, the Okanogan River and Methow River. The Okanogan River flows 185 km beginning at the headwaters of Lake Okanogan near Penticton, British Columbia. The river flows in a southerly direction passing through Osoyoos Lake near the international border. From there the river is a relatively free flowing system to the Confluence with the Columbia River.

The Methow River enters the Columbia River approximately 20 kilometers miles downstream of the Okanogan River and flows 129 km through an irrigated agricultural valley. The river rises from the Cascade mountain range north of Lake Chelan (Cohen 2000).

Figure 1 Mid-Columbia Hydroelectric Operations on the Columbia River in Washington State.

Field Methods

Methodology for the first phase of this study involved the deployment of set lines to capture white sturgeon within Wells Reservoir. Set lines have been used extensively for white sturgeon capture and research activities within the lower Columbia River (Elliott and Beamesderfer, 1990, Nigro et al. 1988, North et al. 1993, Rien et al. 1994). Set lines have also been utilized in recent white sturgeon research activities in the Mid-Columbia (Golder 2002, Golder 2003). A successful application of setline methodology was crucial to the success of this project.

Fish captured on set lines were measured, marked with PIT-tags and secondarily marked by scoot removal. Some of the fish were also radio-tagged and had pectoral fin rays removed for age analysis. The collection of fish information was essential to developing a population estimate, understanding recruitment and population demographics and was used to understand general movement patterns for juvenile and adult white sturgeon. Wells Reservoir was sampled with setline gear over a 2 year period (2001 and 2002). Sampling activities during 2001 were initiated on June 18 and conducted through August 28. Sampling in 2002 was initiated on June 26 and conducted through September 19.

The study area was divided into four sampling locations (Figure 2). Zone 1 included the Columbia River from Wells Dam to the town Pateros, including the Methow River. Zone 2 included waters from Pateros to Brewster Bridge. Zone 3 was designated from Brewster Bridge to Park Island and included the Okanogan Columbia River confluence area. Zone 4 was designated from Park Island to the tailrace of Chief Joseph Dam. These four sampling locations were further sub-divided into 4 locations providing a total of 16 sample locations to ensure all areas and habitat types would be sampled throughout the reservoir.

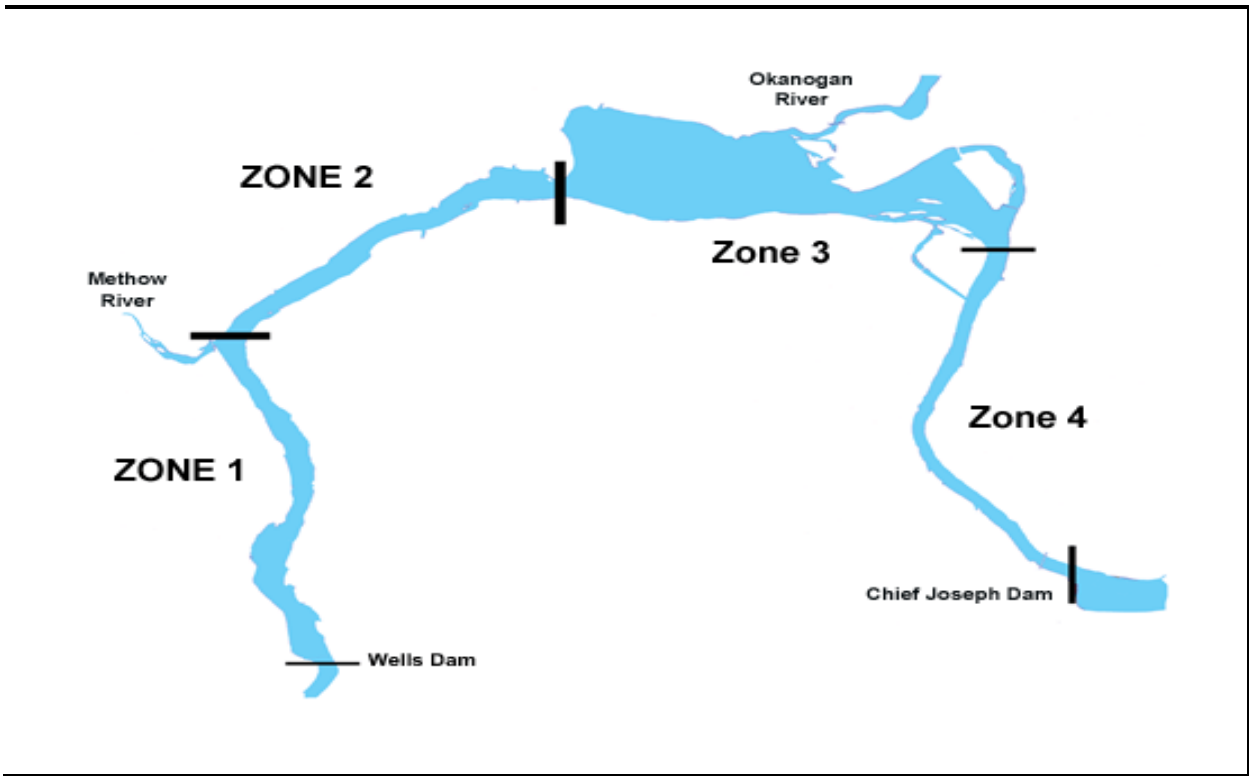


Figure 2 Sampling Zones within Wells Reservoir, Washington State.

A three person field crew conducted a majority of the collection and research. The crew was equipped with all necessary equipment to complete the project. A majority of the equipment (vehicle, vessel, and gear) was provided by Public Utility District No. 1 of Douglas County. Crews typically operated for 3 days during a designated sampling week. The first day consisted of setting the setline gear. Day 2 consisted of checking, re-baiting, and re-setting the lines. On day 3 the set lines were typically pulled from the water.

Set line configurations were similar to those used by Oregon Department of Fish and Wildlife (ODFW) and WDFW for white sturgeon capture in the lower Columbia River (Elliott and Beamesderfer 1990, North et al. 1996). This capture method has been a successful sampling technique for white sturgeon in the mid Columbia over the last two decades. The system provides high catch rates for adult white sturgeon, and is less size selective than other methods, and has resulted in low levels of non-target catch (Elliot and Beamesderfer, 1990). Even though set lines were less size selective than other techniques, this sampling technique is by no means unbiased. The set lines provide a sampling technique that is successful in capturing white sturgeon over 50 cm in Fork Length (Elliott and Beamesderfer 1990, Nigro 1988).

Smaller white sturgeon are not susceptible to the larger hooks and baits used on the set line gear. As such, set lines do not provide accurate sampling of fish under 50 cm.

Set lines for this study measured 133 meters in length. This is 66 meters less then the standard gear used by WDFW and ODFW for white sturgeon capture. The shorter gear allowed deployment in smaller areas of the Mid-Columbia River and was more manageable when fishing in high velocity sections of the river. The shorter lines were also less likely to tangle when oversized sturgeon were hooked. The mainline or ground line consisted of 1600 lb multi-strand nylon rope. Each circle hook was attached to the mainline with a 2-foot long section of 300 lb. nylon fishing line and a Berkley-McMahon bright snap. The gabions were attached to the mainline by a stainless steel trolling snap. Set lines were typically placed parallel to the river flow. The upstream anchor consisted of an 80 lb rocking chair anchor and the downstream setline was typically held on the bottom with 20 lb. pyramid anchor. Each anchor attached to a surface line terminating at a single buoy. Lower pyramid anchors were attached to 68 pound LD series buoys. The larger upstream anchors were attached to multiple buoys to ensure that the gear would be located.

Size 11/0, 13/0 and 15/0 VMC Circlematic 2000 carbon-steel hooks were baited primarily with commercially available pickled squid *(Loligo spp*). This has been determined to be the best bait for sturgeon capture on similar setline research programs conducted by WDFW (North et al. 1993). Herring (*Misc. clupidae*), salmon fillets, (*Oncorhynchus spp.)* and fresh water clams (*Corbicula manilensis*) were also used to a lesser extent. This hook configuration provided a diverse range of sturgeon lengths in lower Columbia River research activities with sizes of white sturgeon ranging from 34 to 274 cm in fork length (Beamesderfer et al. 1989). Each line was baited with 25 to 35 hooks.

Sturgeon captured on the set lines were tethered to the boat using cotton web rope long enough for the entire body of the fish to remain submerged. Crew members then continued to pull the setline and remove any additional fish from the gear prior to working up the captured fish. Smaller sturgeon were placed in an on-board live well, while larger fish were tethered and brought to shore for processing. Hoods were placed on sturgeon during processing and wet towels were set around the skin to prevent moisture loss. Fresh river water was poured over the gills to further promote respiration. After data collection was complete, technicians applied necessary respiration measures to ensure the healthy release of the fish.

Field data were recorded on standardized sheets and transferred to a computer database. Each setline locations and depth was recorded. Depths were recorded using a Lowrance X135 depth sounder at the beginning of the setline and the end of the setline to provide an overview of the entire water column in which the lines were placed. Total hooks, hook size, and bait types for each setline were recorded. Field data for each white sturgeon capture event consisted of capture location, capture depth, hook size, and bait (if discernable). Size data from each captured white sturgeon consisted of fork length and total length measured to the nearest 1.0 cm.

A small portion of the pectoral fin ray was removed for age sampling. It has been determined that calcified structures of white sturgeon pectoral fins, opercles, clavicles, cleithra, medialnuchals and dorsal scutes do not result in significantly different age estimates (Brennen and Cailliet 1991). Pectoral fins age analysis provided the highest level of accuracy and did not require lethal sampling of the fish. Two perpendicular cuts were made in the rays with a hacksaw. The first cut was made 5 to 10 mm outside of the pectoral fin knuckle. The second cut was made approximately 5 mm outside of the first cut resulting in the removal of approximately 5 mm of pectoral fin. The samples were then placed in sample envelopes and frozen for future lab analysis. Removal of the pectoral fin ray for aging purpose provides a noticeable mark for several years (Rien et al 1994) enabling technicians to identify recaptured fish during future encounters.

Each fish was injected with a Passive Integrated Transponder tag (PIT tag) to identify individual fish. ISO 134 kHz PIT tags were injected under the armor of the head near the dorsal midline. A series of scutes (bony armor-like plates located on sturgeon head and back areas) were also removed to indicate a tag was administered. During the 2001 sample period right scutes 2 and 3 were removed. In 2002 left scutes 2 and 3 were removed. Scutes were removed from different areas in subsequent years to provide a year-specific external mark.

Laboratory Methods

Population Estimate

An adult white sturgeon abundance estimate was developed for the Wells Reservoir population using the University of Washington's RECAP.GLM program. The program RECAP.GLM allowed for the

examination of several mark-recapture models and provided for the comparison of these models using likelihood ratio tests.

The program was used to examine two specific Schnabel methods; the Schnabel constant capture probability (Mo) and the Schnable variable capture probability (Mt). The Schnabel constant capture probability model assumes that all fish within the population have an equal chance of capture throughout the sampling periods. The Schnable variable capture probability assumes variable probability of capture throughout the sampling period. Population estimates were determined using capture data from five sampling periods. (i.e. July 2001, early August 2001, late August 2001, early September 2002, and late September 2002).

Standard assumptions were applied to the Schnabel population estimate. A primary assumption was that a closed population of white sturgeon existed within the study area. For the purpose of this study it was assumed that Chief Joseph hydroelectric project provided a barrier for downstream migrants into the study area. No fish ladder exists at Chief Joseph Dam so upstream migrations do not take place. The downstream terminus of migration into or out of the study area was defined as Well Dam. It was assumed that within a sampling period, each fish had an equal probability of being captured. For the purpose of this study it was assumed that prior capture histories did not affect present or future capture histories.

The RECAP.GLM program provided for examination of the residuals associated with the lack-of-fit to individual capture histories. Examination of these residuals provided information as to whether certain individual white sturgeon exhibited gear selectivity towards the set-lines (Certain individual fish within a sampled population may frequent capture gear, therefore being more prone to capture events than other individuals). Juvenile white sturgeon were expected to be less susceptible to being hooked but more susceptible to capture once hooked. This is the opposite case for very large or oversize adult sturgeon. These fish were susceptible to being hooked but were much less susceptible to direct capture due to their ability to break the gabions, hooks and setline snaps.

Physical Data

Length of each captured white sturgeon was entered into a database to construct a length-frequency histogram. Length frequency histograms were used to determine age class strength, and strong age classes may indicate periods of high recruitment. The histogram was constructed using slot increments

of 15 centimeters. These data were then compared to length frequency histograms constructed for other white sturgeon sub-populations within the Columbia River.

Flow velocity patterns and water temperatures have been linked to white sturgeon spawning intensity in the lower Columbia River (Anders and Beckman 1993, Parsley at al. 1993,). Research has indicated that white sturgeon prefer fast flowing water velocities for spawning activities. Parsley et al. (1993) recorded a fast mean water column velocity of 1.46 m/s at white sturgeon spawning sites within lower Columbia River reservoirs. These high water velocities typically occur within the tailrace section of hydroelectric projects. Parsley et al. also recorded water temperatures during spawning activities from 10C to 18C, with most spawning events occurring at near 14C. Additionally, 13C to 17 C has been identified as the optimal temperature for white sturgeon egg development (Wang et al. 1985). Wang et al. recorded elevated mortality of white sturgeon embryos incubated at 18C and complete mortality of embryos incubated at 20C.

Surface water temperatures were collected for this study during set line sampling activities. Temperatures were also collected from fixed field sites within the tailrace of Chief Joseph Dam, Wells Dam Forebay and the Okanogan River. These data were collected to correlate any existing relationships that may exist between fluctuating water temperatures and white sturgeon movements within the study area (e.g. migrations within the reservoir or use of tributary streams for spawning or feeding activities).

Physical data collected from sampled white sturgeon consisted of pectoral rays. Pectoral fins were air dried for several days and standard methodology for counting growth rings was applied (Cuerrier 1951, Beamesderfer et al. 1989). It was first necessary to section the samples into approximately 0.5 millimeter sections. To accomplish this, the samples were glued with a standard model epoxy onto a wooden dowel. This allowed for the handling of the fins during the sectioning process. A 2 millimeter balsa wood saw was then used to section the fins. The sections were then hand sanded to approximately 0.2mm and mounted on microscope slides using clear epoxy. A dissecting microscope was then used to count the translucent pectoral fin annuli. One year of age was assigned to fish captured in the spring and early summer as these individuals were captured prior to annulus formation for that year.

Discharge and temperature information was obtained from Army Corps of Engineers at Chief Joseph Dam. These data were graphed to form a temperature discharge window. The window represents

the suspected spawning period in Chief Joseph Tailrace or Upper Wells Reservoir based on preferred flow velocities and optimal egg incubation temperatures.

Radio Telemetry

White sturgeon were outfitted with 7 volt Lotek Micro Coded Fish Transmitters. The radio tags had a minimum 18 month life expectancy allowing researchers the ability to acquire telemetry information on the tagged fish for two summer field sessions.

Radio tags were attached externally to the posterior portion of the dorsal fin using 1mm wire cable (Figure 3). This tag application procedure has been used with a high degree of success during white sturgeon telemetry studies conducted throughout the upper Snake River (K. Lepla, personal communication 2000). The process involved running a pair of small tubes through the base of the dorsal fin . A stainless steel wire was then fed through the radio tag and then ran through the tubes. With the wire through the dorsal, the tubes were then backed out and the wire free ends were fed through a 1" PVC and then secured with a crimp.

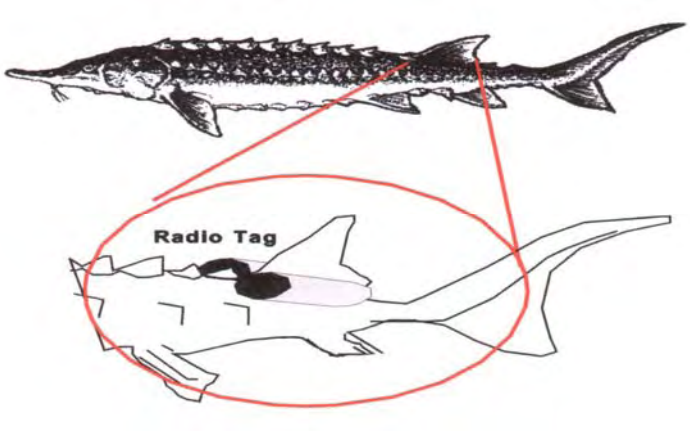


Figure 3 Radio tag placement on white sturgeon (borrowed from Ken LePla, Idaho Power Company).

Movements of radio tagged white sturgeon within the study area were recorded using Lotek Wireless SRX-400 telemetry receivers. Aerial surveys, boat surveys, and fixed land surveys were all attempted to identify activated transmitters. After the capture and outfitting of the first radio tagged fish, bi-monthly aerial surveys were conducted over Wells Reservoir for activated radio tags. These surveys were conducted between July of 2001 and July of 2002. Sweeps of the reservoir study area were

performed approximately 50 feet from each bank. The aerial surveys were conducted in conjunction with the Douglas PUD bull trout survey which typically only reads activated tags within the first 15 meters of the water column. Boat surveys were conducted intermittently throughout the study. The SRX-400 receivers were mounted on the research vessel and transects along the west and east shore of the reservoir were conducted in an attempt to locate tagged fish. Three fixed site receivers were located within the study area. The receivers were functional throughout the study and were downloaded onto a laptop computer every two weeks. One receiver was located approximately 10 kilometers upstream of the Okanogan River near Crazy Rapids Pump Station. Two receivers were located near the mouth of the Methow River. One of these receivers was located approximately 400 meters upstream from the confluence area and one receiver was located approximately two kilometers downstream from the mouth of the Methow River.

RESULTS

Field Sampling Results

A total of 13 individual white sturgeon were captured on the set line gear during the two year mark-recapture study. Additionally, five recaptures were recorded bringing the total number of captures events to 18. Of the 18 events, 13 were recorded in 2001 and five were recorded in 2002. Two of the captured fish were classified as juveniles (i.e. less than 90 centimeters fork length)) and the remaining 11 fish were classified as adult. White sturgeon ranged in length from 65 centimeters to 202 centimeters. Twelve of the fish were injected with PIT tags. One fish was not PIT-tagged because it escaped after being measured but before being PIT-tagged. All 18 of the white sturgeon capture events took place within zone 3 near the Okanogan Columbia rivers confluence. Data collected on the 13 individual fish are summarized in Table 1.

Table 1 Fork length, PIT-tag number, radio tag codes, capture location, number of capture events and estimated age for 13 white sturgeon sampled in Wells Reservoir, Washington State.

Fish #	Fork Length (cm)	Pit Tag #	Radio Tag #	Capture Location	Capture Events	Estimated Age
1	124	3D9.1BFOE220404		3	1	11
2	96	3D9.1BF1092483		3	1	7
3	133	3D9.1BFOFD31EF		3	1	13
4	118	3D9.1BF109F2B9		3	1	11
5	105	3D9.1BF10916A2		3	1	N/A**
6	65	3D9.1BF10920B9	204-209	3	4	6
7	183	3D9.1BFOE473EF	13-6	3	1	27
8	197	3D9.1BFODCA36A	13-5	3	2	23
9	183	3D9.1BFODDD71A	13-7	3	1	26
10	184	3D9.1BF188EAFB	13-4	3	1	28
11	202	3D9.1BF1890574	204-211	3	1	30
12	73	3D9.1BF1890404		3	2	6
13	90	N/A*		3	N/A*	N/A*

*Fish lost at water surface

**Technicians failed to remove sample

Set lines were placed within the study area at surface water temperatures from 9 C to 25 C and placed in depths from 6 to 45 meters. 129 set lines were fished throughout the study. A total of 83 set lines

were fished in 2001 (June 18 to August 28), and 45 set lines fished in 2002 (June 26 to September 27). 3,060 hooks were placed on the 129 set lines resulting in 72,006 hook hours of effort. Hook CPUE was .025 fish per 100 hook hours (18 capture events / 72,006 hook hours).

A total of 15 set-lines were placed in zone 1, 16 set-lines were placed in zone 2, 68 set-lines were placed in zone 3, and 21 set-lines were placed in zone 4. A mimimum of 1 set-line was placed in each of the 16 sub zones. A majority of effort was placed in zone 3 as it was necessary to obtain an adequate sample size for the population assessment and telemetry portion of this study.

Laboratory Results

Population Estimate

The utilization of Program RECAP.GLM provided for the examination and comparison of several versions of the Schnabel population estimate. Due to unequal trapping effort over time, it was determined that the variable capture probability Schnabel Model (Mt) most adequately fit the data compared to the constant-capture Schnabel Model (Mo).

The program provided the ability to examine the residuals associated with the various capture histories (i.e. to determine if certain individual fish were more likely to be encountered due to gear selectivity). Examination of the various capture histories found fish #6 to have significant lack of fit, an indication that the fish was highly susceptible to capture on the set-line gear. White sturgeon #6 was a small juvenile fish that was recaptured three times. Because this fish exhibited capture prone behavior, the recapture information from this fish was excluded from the calculation of the Wells Reservoir population estimate.

With fish #6 not included in the data set, abundance was estimated at N=31.35 and a standard error of 17.51 (Table 2). Factoring in unequal trapping effort over time, the abundance estimate of N= 31.35 is suggested to be the most appropriate. The 95% confidence interval for sturgeon abundance was calculated to be CI($13.15 \leq N \leq 217.50$) =0.95.

Table 2 Modified Schnabel variable capture probability model used to estimate white sturgeon abundance in Wells Reservoir

Session	Number Fish Caught (Ct)	Number of Recaptures (Rt)	Number of Fish Newly Marked	Marked Fish At Large (Mt)	CtMt
July of 2001	5	0	5	0	0
Early August 2001	3	0	3	5	15
Late August 2001	1	1	0	8	8
Early September 2002	4	1	3	8	32
Late September 2002	1	0	1	11	11
Totals	14	2	12	32	66

Population Estimate	N=Sum (CT x Mt) / Sum (Rt)	66	2-Mt Correction factor	N = 31.35

Physical Data

Ages were estimated for 11 white sturgeon captured during the study. These fish were estimated from 5 years to 30 years, representing the 1972 to 1997 year classes. Three groupings within the age class data are apparent. The first grouping was concentrated between the 1972 to 1978 year classes (Figure 4) and was comprised of five individual fish. The second grouping of three fish took place within the 1988 to 1990 age classes. The third grouping took place from 1995 to 1997 (3 fish).

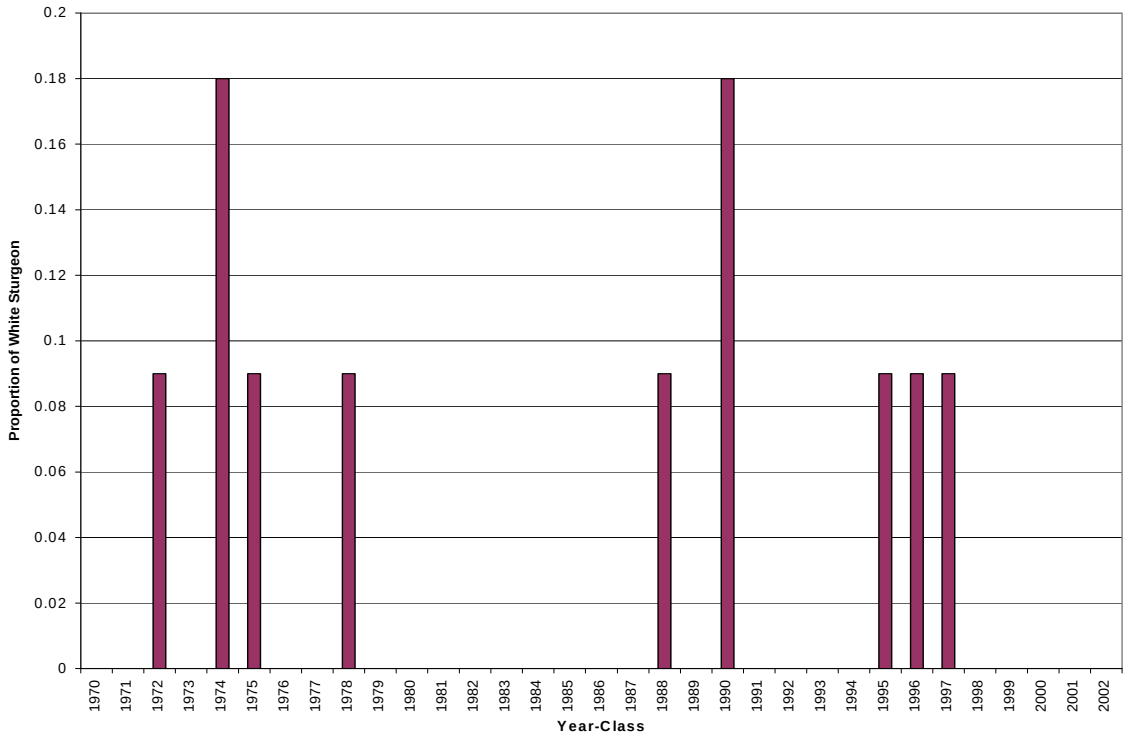


Figure 4 Year class composition of white sturgeon in Wells Reservoir 1970 to 2002

Two white sturgeon were captured and subsequently recovered to provide growth rate information. One Juvenile fish was measured at 65 cm in fork length on July 11, 2001. The fish was again captured on September 26, 2002 and measured 87 cm in fork length. This represented a growth rate of 22 cm in 14 months. One adult fish was captured on August 9, 2001 measuring 197 cm in fork length. The fish was subsequently captured on September 6, 2002 and measured 199 cm in fork length representing a 2 cm growth rate over approximately 13 months. This fish was found deceased in October of 2006 along the west bank of the Columbia River above the town of Brewster. At that time biologists measured the fish at 228.5 cm representing a 29.5 cm increase in length over an approximate four year period, or an average of 7.4 cm of growth per year.

A length frequency histogram was constructed from the white sturgeon length data (Figure 5). Two fish were captured within each of the length slots from 60 to 75 centimeters, 90 to 105 centimeters, 105 to 120 centimeters, and 195 to 210 centimeters. Three fish were captured within the length slot from 165 to 180 centimeters. Catch on the set line gear was dominated by white sturgeon from 60 to 135

centimeters in fork length, and from 180 to 210 centimeters in fork length. These two age class distributions accounted for all captures. The histogram showed a relatively low distribution of juvenile white sturgeon, with 15% of the total catch composed of juvenile fish (i.e. less than 90 cm).

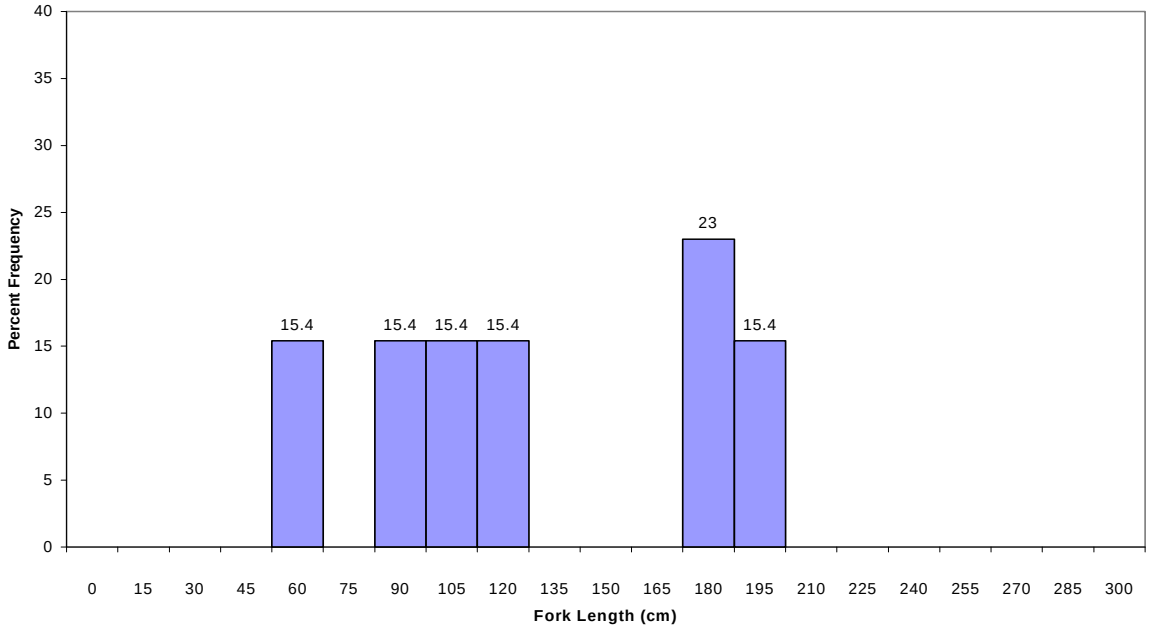


Figure 5 Length frequency distribution for white sturgeon captured by set lines in Wells Reservoir Washington State, during 2001 and 2002.

Radio Telemetry

A total of six white sturgeon were outfitted with radio transmitters (Figure 3). Five of the fish were mature adults (Fork Length 183cm, 183cm, 184cm, 197cm, and 202cm). One juvenile fish was tagged measuring 65cm in fork length. Transmitters were not available for this study until August 8, 2001. At that time the transmitters were administered to the first six captured white sturgeon to ensure a maximum amount of telemetry data could be obtained from the tagged fish.

Table 3 Telemetry information on six radio tagged white sturgeon released in Wells Reservoir, Washington State.

Date	Fish Tag Code	Length (cm)	Capture Zone	Encounters
7/12/01	13-3	65	3	5
8/8/2001	13-6	183	3	11
8/9/2001	13-5	197	3	6
8/9/2001	13-7	183	3	10
9/5/2002	13-4	184	3	2
11/27/2002	204-211	201	3	2

Encounters were recorded as the initial capture of the fish, recapture of the fish, and telemetry observations. Telemetry observations consisted of vessel recordings and fixed telemetry receiver recordings. Four reservoir surveys were conducted by boat. Three of the surveys were conducted in late summer of 2001 (August 27, 2001, August 28, 2001). One survey was conducted in late summer of 2002 (September 6) and one survey was conducted in late winter of 2002 (November 27). The number of boat telemetry surveys was limited by personnel and budget constraints at Douglas PUD as they owned and operated the vessel. During all 4 telemetry surveys, all white sturgeon were recorded within zone 3. The winter survey conducted in November of 2002 identified all outstanding tagged fish within zone 3 and within 100 meters of one another. No white sturgeon were recorded during the aerial surveys. It was suspected that the aerial antennas would not pick up any of the activated tags as the aerial surveys typically only pick up transmissions from water depths less than 15 meters.

A total of 17 encounters were recorded at the fixed telemetry receiver located approximately 10 kilometers upstream from the mouth of the Okanogan River. These 17 encounters were from three individual mature fish. The first two encounter were recorded from May 19 to June 19 of 2002. Two white sturgeon frequented the area passing upstream and downstream of the fixed receiver. The third encounter was recorded from May 10 to May 24 of 2003. No white sturgeon were recorded near the fixed telemetry receiver at the mouth of the Methow River or the fixed telemetry receiver 2 kilometers downstream from the mouth of the Methow River. Capture histories of the six radio tagged white sturgeon are outlined below:

White Sturgeon 13-3

White Sturgeon 13-3 was a juvenile fish approximately 65 cm in length. The fish was first captured on July 12, 2001 approximately 1 kilometer east of the confluence of the Okanogan and Columbia River (Figure 6). The fish was subsequently captured on the set line gear in the same vicinity on August 8, 2001, August 28, 2001, and September 26, 2002. The fish was tracked by boat telemetry to the west bank of the Columbia River approximately 1 kilometer below the Okanogan River confluence on November 27, 2002. It is possible that the boat telemetry observation may have identified a shed tag as the telemetry signal was coming from a vicinity of the shoreline area.

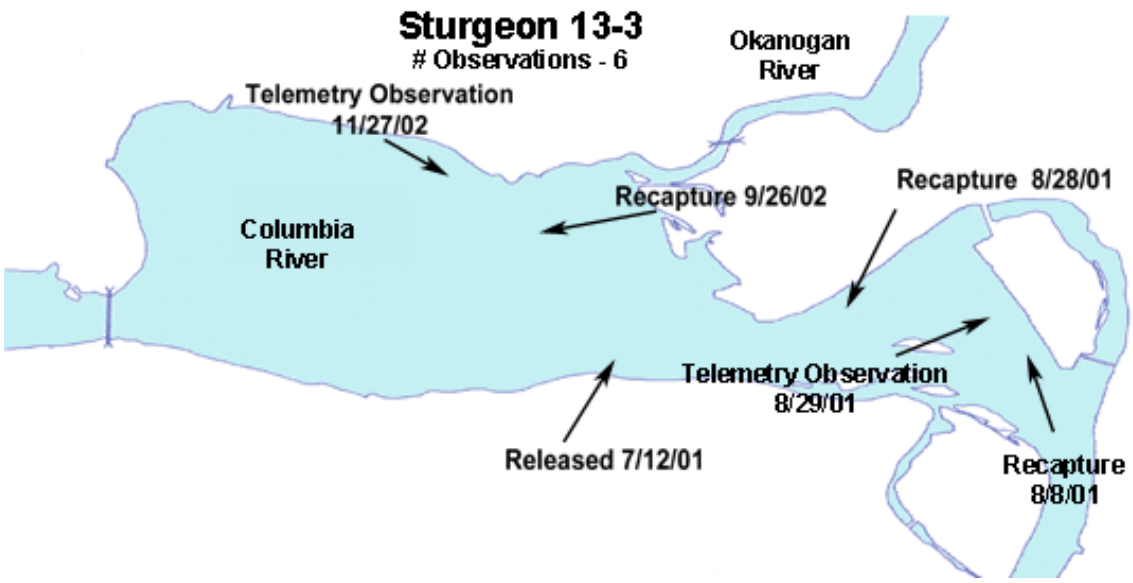


Figure 6 Telemetry observations for radio tag 13-3, Wells Reservoir, Washington

White Sturgeon 13-6

White sturgeon 13-6 was captured on August 8, 2001 and encountered on 10 separate occasions (Figure 7). This fish was 183 cm long and was initially captured and released approximately 1 kilometer south of the Okanogan-Columbia River confluence area. The fish was then recorded during vessel telemetry transects on August 27, 2001. A majority of encounters were recorded at the fixed telemetry station within the Okanogan River. Telemetry observations of the fish moving through the Okanogan River were recorded on May 19, 2002, June 2, 2002, June 8, 2002, June 9, 2002, June 12, 2002, June 18, 2002 and June 19, 2002. The fish was once again recorded during a vessel telemetry survey conducted within Wells Reservoir on November 27, 2002.

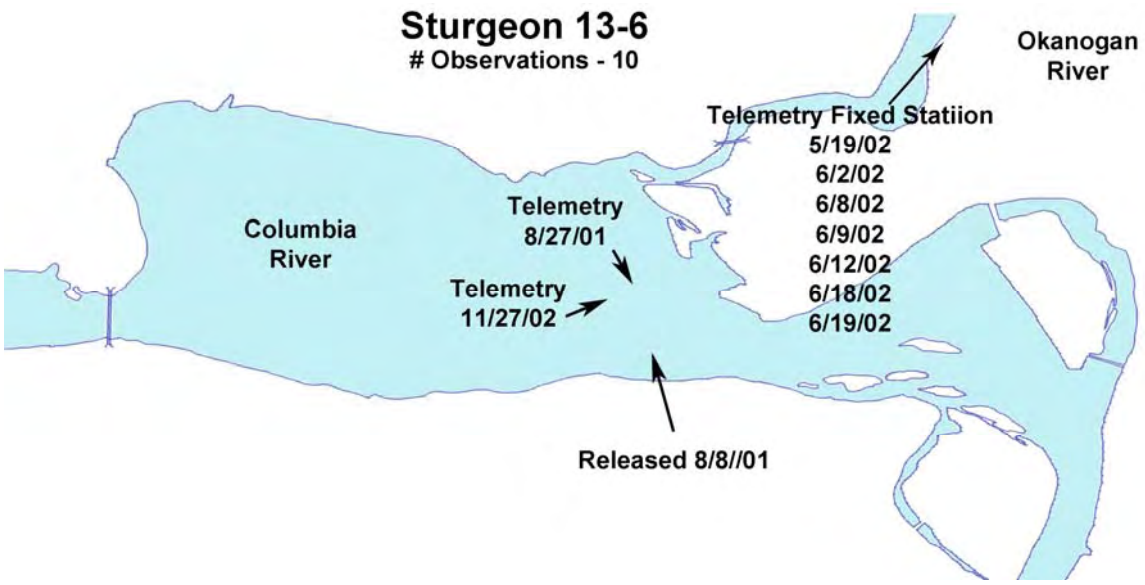


Figure 7 Telemetry observations for radio tag 13-6, Wells Reservoir, Washington

White Sturgeon 13-5

White sturgeon 13-5 was 197 cm in length and was captured and outfitted with a radio transmitter on August 9, 2001. The fish was encountered on seven separate occasions (Figure 8). In the spring of 2002 white sturgeon 13-5 was recorded at the Okanogan River fixed telemetry station on four different dates (May 16, May 29, May 31, and June 3). The fish was again recorded during a vessel telemetry survey conducted on August 1, 2002 approximately 200 meters downstream from the mouth of the Okanogan River. White sturgeon 13-5 was recaptured on September 6, 2002 at which time the radio transmitter was removed. It was assumed the remaining battery life of the transmitter was short and removing the tag would promote the fish's health. During October of 2006 biologists at Douglas PUD received reports of a white sturgeon washed ashore near the east bank of the Columbia River across from the confluence of the Okanogan River**.** Upon investigation and PIT tag confirmation, it was determined that fish was white sturgeon 13-5. White sturgeon 13-5 was the second largest fish sampled during this study at 197 cm (very close in length to the largest fish sampled at 202 cm). The cause of death was undetermined. There were no signs of hemorrhaging or heavy parasite loads on the fish.

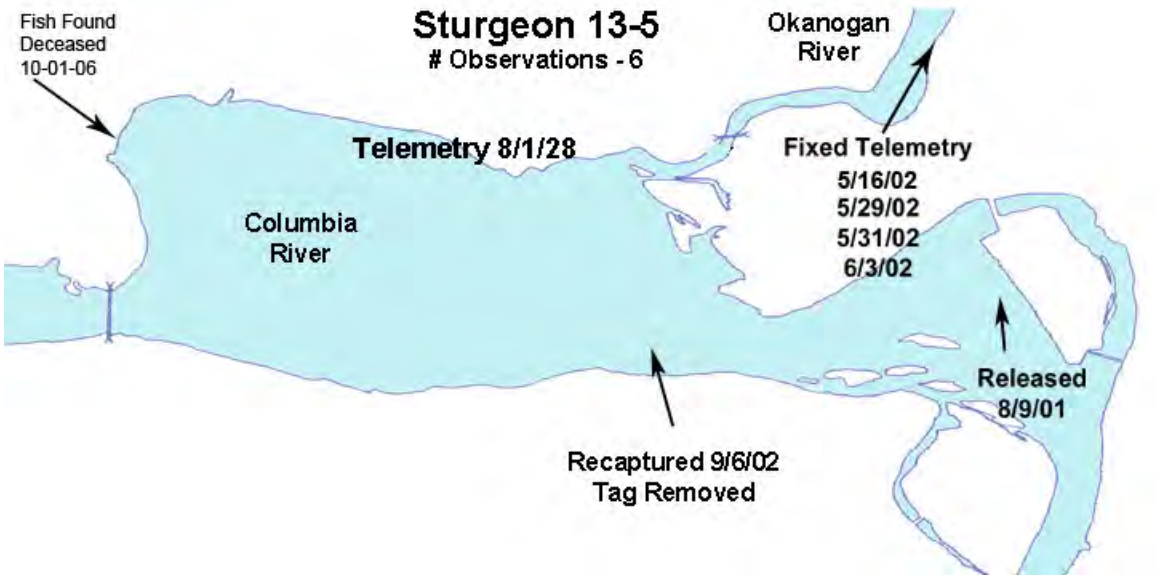


Figure 8 Telemetry observations for radio tag 13-5, Wells Reservoir, Washington

White Sturgeon 13-7

White sturgeon 13-7 was captured and outfitted with a radio transmitter on August 9, 2001. The fish was 183 cm long and was subsequently identified during three vessel telemetry surveys in 2002 (August 8, September 9, and November 27)(Figure 9). During the spring of 2003 white sturgeon 13-7 was recorded at the Okanogan River fixed telemetry site six times within a two week period (May 10, May 14, May 16, May 22, May 23, and May 24).

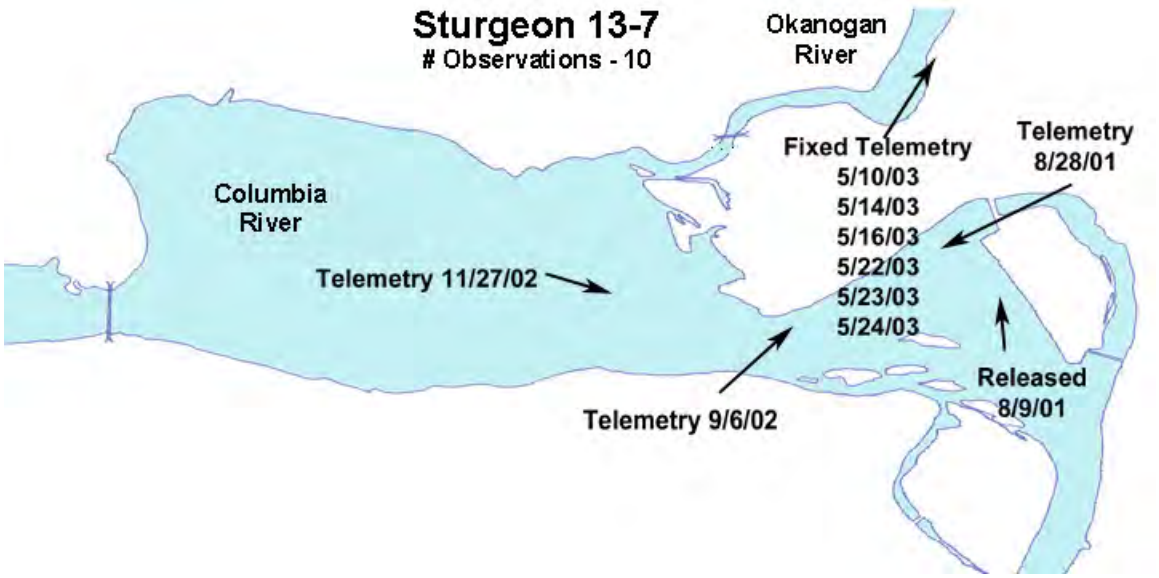


Figure 9 Telemetry observations for radio tag 13-7, Wells Reservoir, Washington

White Sturgeon 13-4

White sturgeon 13-4 was captured and outfitted with a radio transmitter on September 5, 2002. This fish was 184 cm long. The following day a vessel telemetry survey identified the fish near the mouth of the Okanogan River (Figure 10). The fish was once again identified during the final telemetry survey conducted on November 27, 2002.

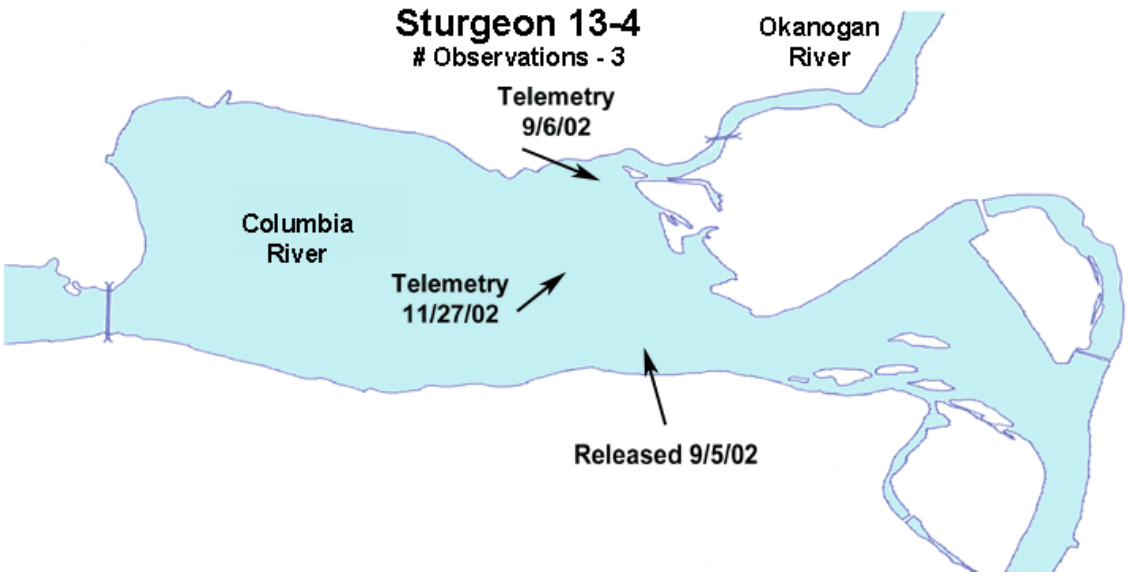


Figure 10 Telemetry observations for radio tag 13-4, Wells Reservoir, Washington

White Sturgeon 204-211

White Sturgeon 204-211 was captured and outfitted with a radio transmitter on September 9, 2002. This fish was 201 cm long. The fish was only recorded one additional time during the final vessel telemetry survey conducted on November 27, 2002 (Figure 11). At that time the fish was recorded within 100 meters of three other tagged fish in the mid-channel of the Columbia River across from the confluence of the Okanogan River.

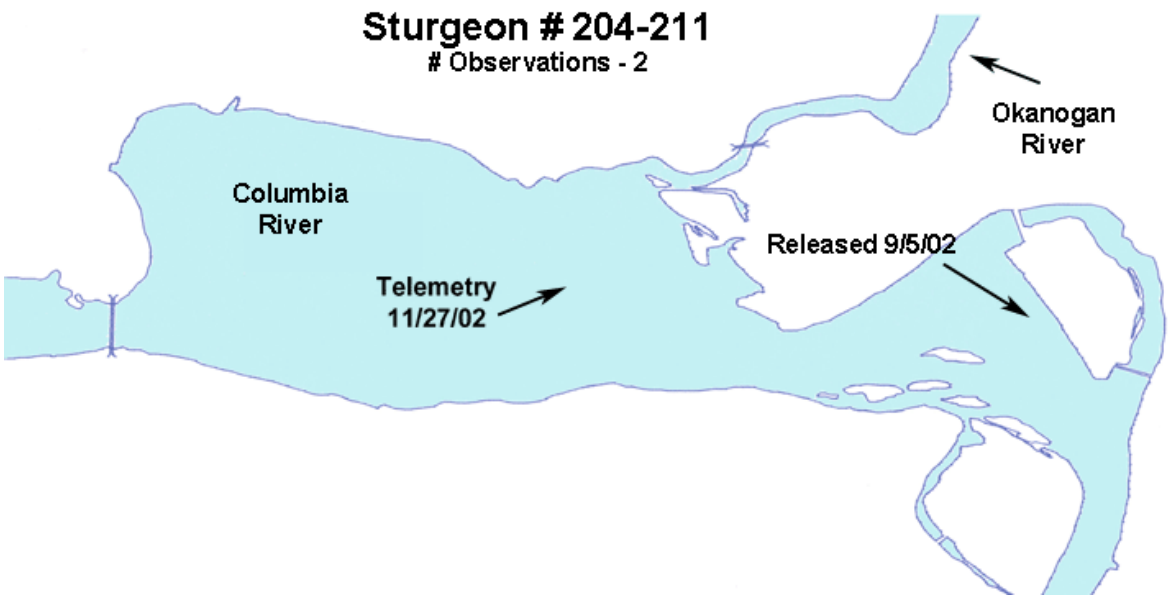


Figure 11 Telemetry observations for radio tag 13-4, Wells Reservoir, Washington

DISCUSSION

Field Sampling

For the purposes of this study, it was necessary to apply effort in the field to accomplish several objectives. The first objective was to sample an adequate number of individual fish that would provide basic information on population abundance, age class structure, growth, and ecology. An additional objective was the capture and outfitting of an adequate number of white sturgeon with radio tags to provide information on movement patterns and possible spawning migrations or feeding patterns within Wells Reservoir.

Success of this project was contingent upon capturing enough individuals within the population to obtain the primary objectives. Application of the set-line system proved to be a successful capture method for this project. However, set-line placement and retrieval was a time consuming and labor intensive process. A crew of three individuals was necessary to operate the vessel and successfully work the gear. Only four to five lines were set and checked during an average eight hour day. A typical sample week consisted of setting the gear on Monday, checking and resetting on Tuesday and Wednesday and retrieving the gear on Thursday. Therefore, only 12 to 15 set-lines were worked each sample week.

Prior to initiating set-line sampling in June of 2001, the white sturgeon distribution within Wells Reservoir was unknown. In an effort to sample the entire study area and ensure that all locations within Wells Reservoir were surveyed, the reservoir was divided into four zones and further into four sub zones. This provided 16 sampling areas within study area. It was surmised that spreading the gear throughout the reservoir it would increase the chances of capturing white sturgeon, as it was unknown which zone, if any, would be the most productive sampling location.

The goal of the sampling effort was to place set-lines within each of the four main zones. It was believed that white sturgeon densities could be highest within zone 4 as it has been documented that white sturgeon frequent high flow velocities in the tailrace areas of hydroelectric projects (Parsley and Beckman 1994). Zone 4 was heavily influenced by Chief Joseph Dam, and of the 4 sub-zones contained the highest flow velocities. Zones 2 and 3 both contained large tributary rivers with moderate flow velocities that white sturgeon may utilize for feeding or spawning migrations. For the first 2 weeks of sampling activities, no white sturgeon were captured. On July 10, three white sturgeon were captured in zone 3. Subsequently,

two fish were captured on July 11 and one fish was captured on July 12. These fish were also captured in zone 3.

For the remainder of the study all white sturgeon were captured in zone 3. An adequate amount of effort was focused there for the remainder of the study to accomplish the objective of capturing white sturgeon for lab analysis and radio tag application. A smaller but consistent amount of effort was continuously applied to the other zones for the remainder of the project in an attempt to capture fish outside of zone 3.

It may have been possible to more intensively sample zones 1, 2, and 4 during this study. However, an increase in effort within these zones would have resulted in a decrease of effort in zone 3 and ultimately compromised the objective of obtaining adequate sample size. It was also unclear as to whether applying additional effort into the other zones would result in the capture of any white sturgeon within these areas. Within zone 3 a total of 68 sets were placed resulting in the capture of 18 white sturgeon translating into one sturgeon capture per 3.77 sets. A total of 15 sets were placed in zone 1, a total of 16 sets were placed in zone 2, and 21 sets were placed in zone 4. These sets were randomly distributed within each sub-zone. At an average of one sturgeon capture per 3.77 sets as recorded in zone 3, the 15 set-lines placed in zone 1 would have resulted in approximately four white sturgeon captures.

Set-lines have been the primary sampling gear utilized for white sturgeon capture in the Columbia River. However, it should be addressed that the set-line sampling efficiency on sturgeon under 50 cm is greatly reduced (Beamesderfer et al. 1989. Beamesderfer and Rien, 1993). Smaller white sturgeon are not generally susceptible to the larger hook sizes used on the gear. Attempts to decrease hook size during this study resulted in broken hooks. During July of 2001, smaller hooks were placed on the gear and when pulled the next day these hooks were straightened or broken at the shank by larger white sturgeon. Similar results have been encountered on other white sturgeon sampling projects (K. LePla, personal communication). It is therefore assumed that sampling bias of the set-line gear resulted in a misrepresentation of younger year class recruitment. This bias was evident in this study and could be observed by the absence of any white sturgeon captured under 50 cm in fork length.

The gear used in this study was also limited in its ability to capture fish in the larger size categories (e.g. greater than 215 cm). This was evident during the study from the relatively high number of

straightened hooks (11), broken snaps (7) and broken gabions (3). It is difficult to estimate the number of fish that were lost as it was not possible to determine whether hooks were snagged on the bottom or broken off by larger white sturgeon. During sampling activities in 2002, smaller hooks on the set line gear were removed to promote the capture of larger hooked fish. This likely resulted in additional bias towards hooking large fish in 2002 and overall skewed the data towards intermediate sized fish. Small fish were not as apt to get hooked due to hook and bait size and very large fish were hooked but not landed due to their ability to break the set line gear.

The set line CPUE for this study (CPUE = 0.025 fish per 100 hook hours) was similar to that of other reported CPUE rates for white sturgeon captures in the Mid Columbia (Golder, 2003). Golder reported 523,204 hook hours of set line sample effort to capture 115 white sturgeon in Wanapum and Priest Rapids Reservoirs resulting in a CPUE of 0.022 fish/100 hook hours. It appears that set line gear efficiency observed during this study was similar to that of other white sturgeon monitoring programs within the Columbia River Region.

The population estimate for the Wells Reservoir (n = 31) was similar to that developed for other Mid-Columbia River white sturgeon populations (Golder 2003, Golder 2002). In 2001 and 2002, a white sturgeon survey was conducted within Rocky Reach Reservoir located immediately downstream from Wells Reservoir (Golder, 2002). During the Rocky Reach study, a total of 24 individual white sturgeon were captured and four fish were recaptured during two years of sampling activities

Population Estimate

. This resulted in a Schnabel population estimate of 47 fish. An extensive white sturgeon study was conducted within Wanapum Pool and Priest Rapids pool from 2000 to 2002 (Golder, 2003). A relatively high number of white sturgeon were captured in the Wanapum Pool (n = 118) with 8 recaptures translating into a population estimate of 551 fish. A total of 29 white sturgeon were captured in the Priest Rapids Pool and only one fish was recaptured translating into a population estimate of 134 fish. These abundance estimates indicate the presence of small localized populations within mid-Columbia Reservoirs.

Initially it was hypothesized that white sturgeon would be captured throughout the study area, as Wells Reservoir has a variety of diverse habitats including two tributary streams and a large section of free-flowing water for 10 kilometers below Chief Joseph Dam. The study area was divided into zones in an

attempt to ensure that all habitat types were sampled within the study area. White sturgeon were only marked and recaptured in zone 3 making it difficult to determine whether the population estimate pertains only to zone 3 or the entire study area. The absence of any white sturgeon encounters within zones 1, 2, and 4 prohibited statistical analysis between the zones. There are currently no statistical models that enable the analysis of fish populations between locations when no fish are captured within one of the locations (R. Townsend, personal communication).

Absence of fish within the sampled zones indicates one of three possibilities. Either there are no fish in the zones or the location was not sampled enough to capture a very small population of fish within the zone. It is also plausible that white sturgeon may utilize zones 1, 2, and 4 on a limited basis. There are no physical barriers between zones and it is possible that at some time white sturgeon travel out of zone 3. The most probable explanation of movements out of zone 3 would be the seasonal movements of fish into zone 4 for feeding or spawning migrations within the Chief Joseph Tailrace. Dam tailrace areas have been documented as preferred locations for white sturgeon spawning activities, and it is possible that flow velocities within Chief Joseph tailrace attract white sturgeon to spawn during the spring months. The limited telemetry data collected during this study does not support movements into zone 4. However, these movements may not have been documented during this study as vessel telemetry sweeps within zone 4 were limited due to personnel and budget constraints.

Additional evidence that white sturgeon may not utilize zones 1, 2 and 4 (or only utilize them occasionally) is present in the telemetry data. A total of four boat telemetry surveys were conducted (limited by personnel and budget). Three of the surveys were conducted in late summer or fall of 2001 and 2002 and one survey was conducted in the winter of 2002. During the telemetry surveys, no white sturgeon were recorded outside zone 3. The telemetry data shows that white sturgeon probably stay within zone 3 during the winter months as the winter survey conducted in late November verified all outstanding tagged fish were in zone 3 and within 100 meters of one another. It has been documented in similar studies that white sturgeon congregate together during the winter months within the deep water pools (Golder, 2003, North et al. 1993). Additionally, no white sturgeon were recorded passing through zone 2 at the fixed receiver sites near the mouth of the Methow River. This provides evidence that white sturgeon do not utilize or rarely utilize habitats in the lower Wells Reservoir.

When analyzing the white sturgeon telemetry data, it is important to take into consideration that white sturgeon do not spawn on an annual basis. Typically, gravid female white sturgeon spawn every two to five years (Smith 1985). It is possible that during the two year time frame of this study, radio tagged white sturgeon were not recorded moving out of zone 3. Spawning movements of the radio tagged fish may have been limited or these fish simply did not conduct spawning migrations during the study.

A primary assumption for the abundance estimate was that a closed population of white sturgeon existed within the study area. Data collected during the set-line sampling and telemetry tracking surveys supports the assumption of no immigration out of the study area. Throughout the study two fixed receivers were present in zone 2. These receivers should have recorded any radio tag transmissions from radio tagged fish that were tagged in zone 3 and were passing through zone 2 and out of the study area. In regards to upstream migrations out of the study area, white sturgeon cannot pass through Chief Joseph Dam as there is no fish ladder at that project.

Sturgeon migrations into the study area may occur. Migrations of white sturgeon have been documented, and the incidences of white sturgeon passing through hydroelectric projects is highly variable (Hanson et al. 1992, Ward et al. 2003). Wells Dam contains two fish ladders. It is possible that white sturgeon could travel upstream from Rocky Reach Reservoir as a white sturgeon population has been documented in that reservoir (Golder 2002). However, there have been few documented observations of white sturgeon moving upstream through Wells Dam fish ladders by fish counting personnel since dam construction in 1967. The most probable route of immigration into the study area is the passage of juvenile or sub-adult individuals from the upstream Chief Joseph Reservoir. Downstream migrations may be a factor in recruitment within Columbia River white sturgeon populations as these fish historically migrated downstream to the Pacific Ocean. Ward et al. (2003) analyzed movements of white sturgeon between lower Columbia River reservoirs from 1987 to 2002. During this time period, 4,294 white sturgeon were recaptured. A total of six white sturgeon were recaptured in reservoirs above the release site (.13%) and 147 fish were captured below the release area (3.3%). These data indicate that migrations between reservoirs in the Columbia River system are limited. Upstream migrations are rare and downstream migrations may occur at a limited rate. Therefore, movements of white sturgeon from upstream or downstream reservoirs into Wells Reservoir may take place but are probably limited events.

The assumption that each white sturgeon within the study area had an equal chance of capture was violated by fish #6 (a juvenile white sturgeon). The RECAP.GLM program provided analysis of the data and examination of the residuals associated with the lack-of-fit to individual capture histories (Skalski et al. 2005). Examination of these residuals provided information as to whether certain individual white sturgeon exhibited gear selectivity towards the set-lines. The program identified fish # 6 as an individual exhibiting gear selectivity towards the set line gear, and therefore the fish was removed from the data set. Fortunately, enough fish were recaptured that a population estimate was possible without using the data from this "capture prone" fish.

Physical Data

Large variances in growth rates were recorded for fish sampled in Wells Reservoir. Related literature has shown similar trends of relatively high growth rates in juvenile white sturgeon compared to adult white sturgeon (Hanson 1992). For this study, one juvenile and one adult white sturgeon were recovered to providing growth data. The small juvenile fish exhibited a high growth rate of 22 cm during 14 months. The adult fish was recorded as only growing 2 cm from August 2001 to September 2002. However, the same fish was found deceased and washed ashore nearly four years later and had grown an average of 7.4 cm per year over the 4 year period. The average growth rate of 7.4 cm per year for this individual fish is consistent with a growth rate of 6.8 cm per year reported in Wanapum Reservoir (Golder, 2003). White sturgeon may exhibit yearly growth fluctuations due to varying environmental variables such as water temperature and food abundance (K. LePla, personal communication).

Presently, fin ray analysis is the most precise method for aging white sturgeon. However, Rien and Beamesderfer (1994) concluded that fin ray analysis to age white sturgeon is not a precise method and determining age for younger individuals is more precise than older individuals. In regards to older aged individuals, assigned ages may underestimate their true age due to crowded annuli. Additionally, some annuli are very small due to environmental variance (e.g. short supplies of prey items during certain years) and may be overlooked by technicians. These factors ultimately lead to discrepancies in age frequencies and year class strengths. For the purpose of this report, sturgeon ages were presented in the form of an exact year class. It should be addressed that ages should be viewed as approximated rather than exact. Fish

aged within one to five years of one another may be from the same age class, with the variance growing larger in older aged individuals.

This effect could be displayed in the data from the population of white sturgeon that are designated within the 1972 to 1978 age classes. Within this time period, five adult white sturgeon were age estimated (one fish from each of years 1972, 1975, and 1978, and two fish from year 1974). It is possible that these fish originated from one or two productive year classes during this time period. Additional studies in the Mid-Columbia have shown strong age classes for these years (Golder 2002, Golder 2003). Within Wanapum and Priest Rapids Reservoirs, Golder (2003) reported that the 1976 age class made up the second largest number of sampled white sturgeon.

In the Golder (2003) study, the highest number of individuals sampled within Wanapum and Priest Rapids Reservoirs were documented to be juvenile white sturgeon from the 1997 age class. Water flows during that spring were the highest on record since the construction of the project in 1961. Golder (2003) suggests that high flow years increase the survival and recruitment of juvenile white sturgeon. Several other studies have documented a positive relationship between white sturgeon year class strength and high flows (Kohlhorst et al. 1991, Miller and Beckman 1995). Three juvenile white sturgeon were sampled during our collection activities in Wells Reservoir and estimated to come from the 1995, 1996, and 1997 year classes. Given the margin for error during fin ray analysis, it is possible that these 3 fish may be from the 1997 age class. Flows through Wells Reservoir were some of the highest on record in 1997 (S. Bickford, personal communication).

All female white sturgeon within a population will not spawn during ideal environmental conditions. However, a certain number of highly gravid white sturgeon will conduct spawning activities during year with such conditions. A combination of high fecundity and inconsistent spawning periods would ultimately result in large year classes. High flows may have produced strong year class recruitment for white sturgeon throughout the mid-Columbia region in 1997. These groups of similarly aged fish present evidence that strong age classes of white sturgeon may have hatched in the mid-Columbia during specific time periods. If these small groups of similarly aged fish represent a few year classes, it is possible that recruitment of white sturgeon within Wells Reservoir is limited by environmental factors such as water temperature, velocity and/or turbidity.

Regional Comparisons

This study was intended to provide an initial assessment of white sturgeon abundance, population structure, and movement patterns within Wells Reservoir. It is difficult to compare the current population to historic populations as no previous data exists on the status of white sturgeon in the study area. However, it is possible to draw inferences when comparing data collected from this project with other regional data. The Wells Reservoir length frequency histogram was compared with data obtained from three regional agencies studying white sturgeon within the Columbia River Region. One histogram was constructed for data assimilated within the Mid-Columbia Region, one histogram was constructed for the Lower-Columbia Region, and one histogram was constructed for a population of white sturgeon studied in the upper Snake River Basin.

The histogram constructed for the Wells Reservoir population of white sturgeon contains a low proportion of juvenile white sturgeon under 90 CM. This is partially a result of the size bias of the long-line gear and the removal of smaller hooks half way through the study. Even though the incidence of juvenile fish was low during the study, the fact that any were captured at all shows that there is recruitment within the Wells Reservoir population either through natural reproduction or immigration from upstream populations.

The Mid-Columbia histogram taken from the Wanapum Pool represents a population of white sturgeon with an age class structure that most resembles the Wells Reservoir population (Figure 12). Two distinct peaks can be identified within both populations. These peaks indicate strong recruitment for white sturgeon from 60 to 105 centimeters and 165 to 195 centimeters, suggesting strong recruitment classes of white sturgeon within the Mid-Columbia in the mid 1970's, the late 1980's, and the mid 1990's. Lepla and Chandler (2001) documented decreased recruitment of white sturgeon upstream of Hells Canyon from 1987 to 1994 that was observed to correspond with a drought that lasted eight consecutive years. Effects of this drought may have impacted white sturgeon populations throughout the Columbia and Snake River basins.

If strong year classes were present throughout the mid-Columbia, white sturgeon in Wells Reservoir may grow faster than those in the Wanapum reservoir. This is demonstrated in the Wells Reservoir length frequency histogram as both peaks are shifted slightly to the right. If the two peaks shown

within each population were from the same age classes then the Wells Reservoir population exhibits a higher growth rate.

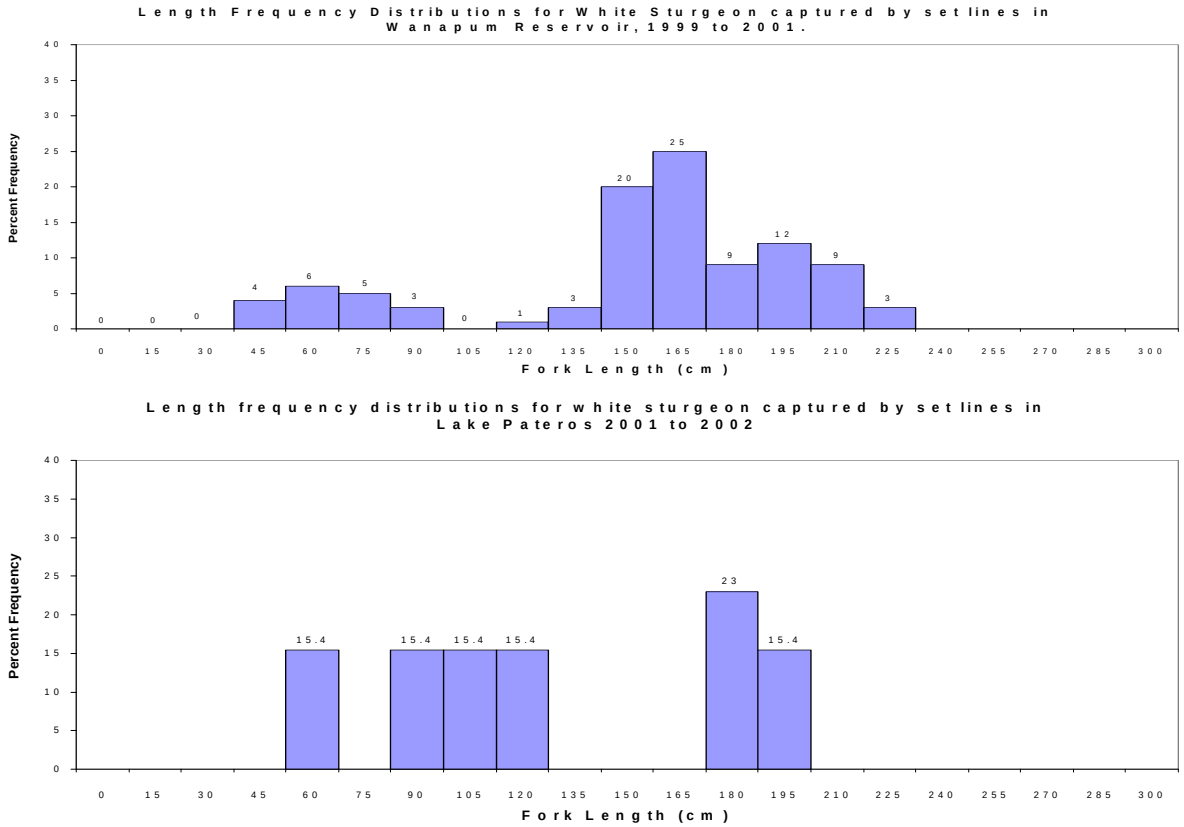
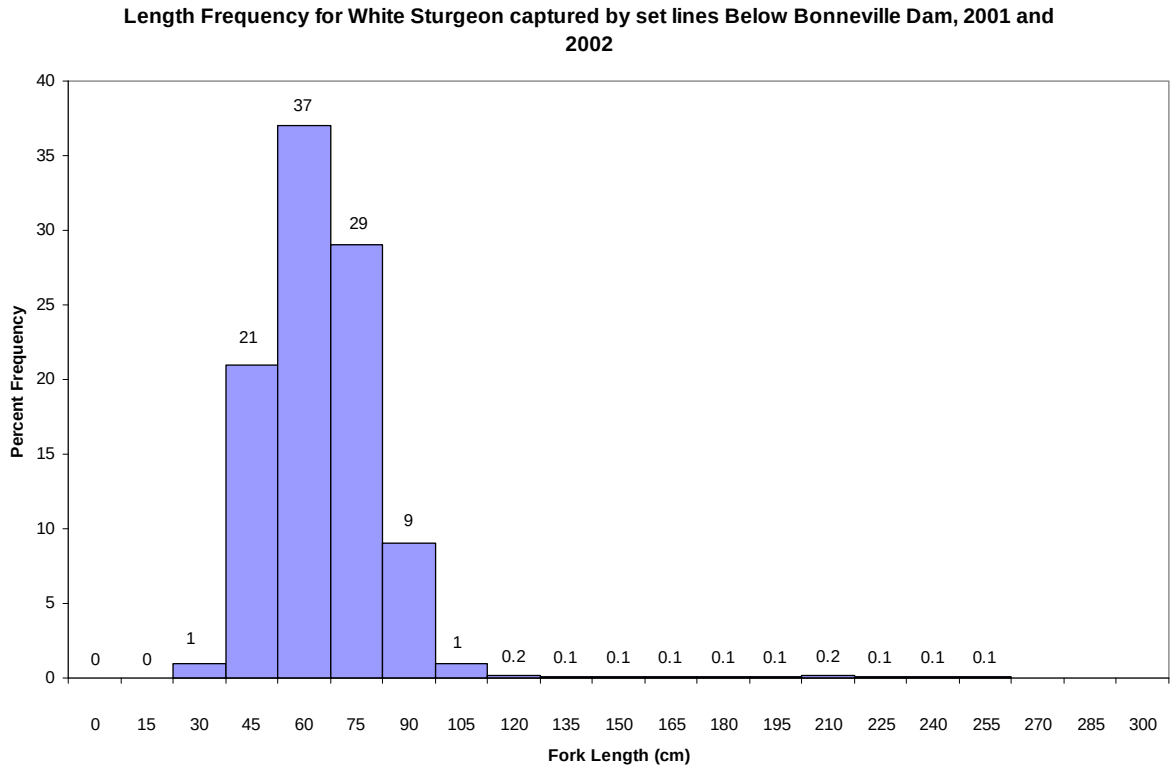


Figure 12 Length frequency histogram comparison for white sturgeon captured in Wanapum Reservoir and white sturgeon captured in Wells Reservoir.

The white sturgeon population in Bonneville Reservoir represents a Lower Columbia River population that has been heavily influenced by sport and tribal set line fisheries (Figure 13). There are currently harvest fisheries for white sturgeon within all lower Columbia River reservoirs. Within Bonneville Reservoir, sport anglers are allowed to retain white sturgeon from 107 centimeters to 152 centimeters. The tribal commercial fishery allows for the harvest of white sturgeon from 114 centimeters to 152 centimeters. These management slot regulation are designed to provide for the take of sub-adult sturgeon. The adult segment of the population then provides recruitment within the population. This management strategy results in a steep decline in the number of adult white sturgeon over 100 cm and can be clearly seen in the Bonneville Reservoir length frequency histogram.

Compared to the Bonneville Reservoir population, the Wells Reservoir population contains a higher portion of adult fish and a smaller portion of juvenile fish. Recruitment within the Wells Reservoir population may be occurring at a lower rate. Only two white sturgeon were captured during this study in the juvenile age bracket from under 90 centimeters. The remaining fish were all over 90 cm in length and classified as sub-adults or adults. The Wanapum Reservoir Length Frequency Histogram (Figure 12) also exhibits a high proportion of adult to juvenile ratios. This is further evidence that low recruitment levels are occurring in the impounded mid-Columbia white sturgeon populations.

The Bonneville reservoir data indicate low numbers of adult spawning white sturgeon can provide high levels of recruitment. White sturgeon are extremely gravid, with large females able to disperse from as many as 7 million eggs (Hanson et al. 1992). It may not take a large number of adults to provide adequate levels of recruitment within white sturgeon populations if favorable spawning conditions and environmental conditions exist on a consistent basis, which may be the case in Bonneville Reservoir. It has been well documented that white sturgeon do not spawn each year and oocyte development may take from two to five years (Smith 1985). If environmental factors are not ideal when female white sturgeon have completed oocyte development, these fish may reabsorb the gametes or spawn in unfavorable environmental conditions. This reproductive strategy may benefit the species, as ideal spawning conditions may not occur each year.



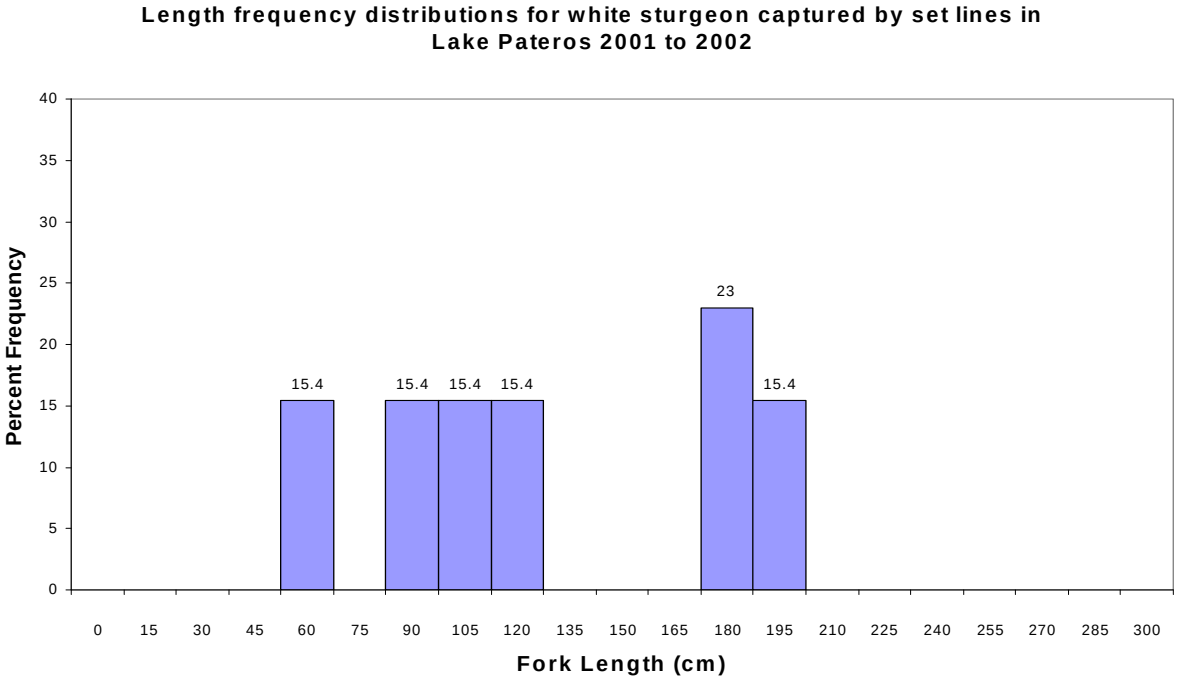
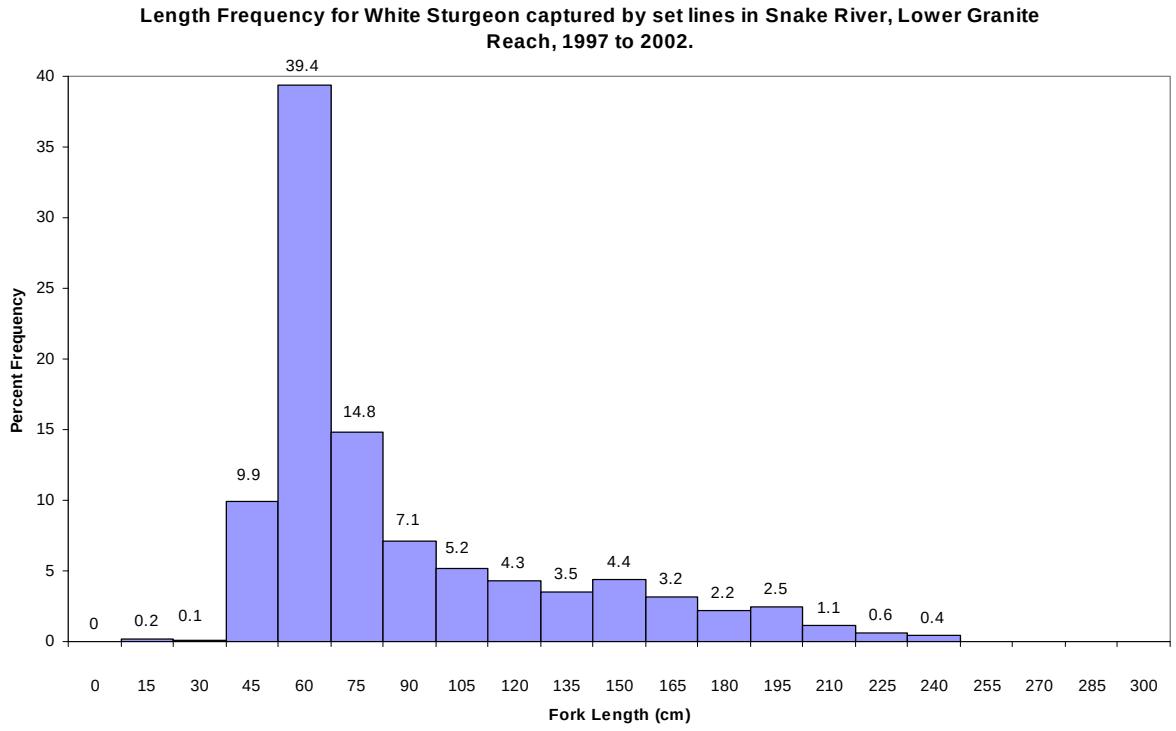


Figure 13 Length frequency histogram comparison for white sturgeon captured in Bonneville reservoir and white sturgeon captured in Wells Reservoir.

The Lower Granite – Hells Canyon sturgeon population exhibits a healthy population structure, based on a current stock structure that is dominated by juveniles and contains a wide range of size classes and stages of maturity from immature juveniles to reproductive adults (Figure 14). A steady down slope curve occurs at slot lengths for older fish, evidence of strong stock structure and a wide range of individuals throughout the population. The last sport fishery that was conducted on the population took place in 1970. From 1970 to present a small tribal fishery has occurred on the reservoir, however the impacts of that fishery are not clear at the present time (Everett et al. 2003).

A high incidence of younger aged individuals within the Snake River population can be observed when compared to the Wells Reservoir population. High levels of recruitment exist within the Snake River population, likely a result of ideal rearing conditions and relatively high rates of productivity in that river compared to the Mid-Columbia River. Additionally, Idaho Power has sporadically stocked white sturgeon within the reservoir. Higher water velocity, temperatures and turbidity in Hells Canyon may promote high levels of recruitment within the Snake River sturgeon population.



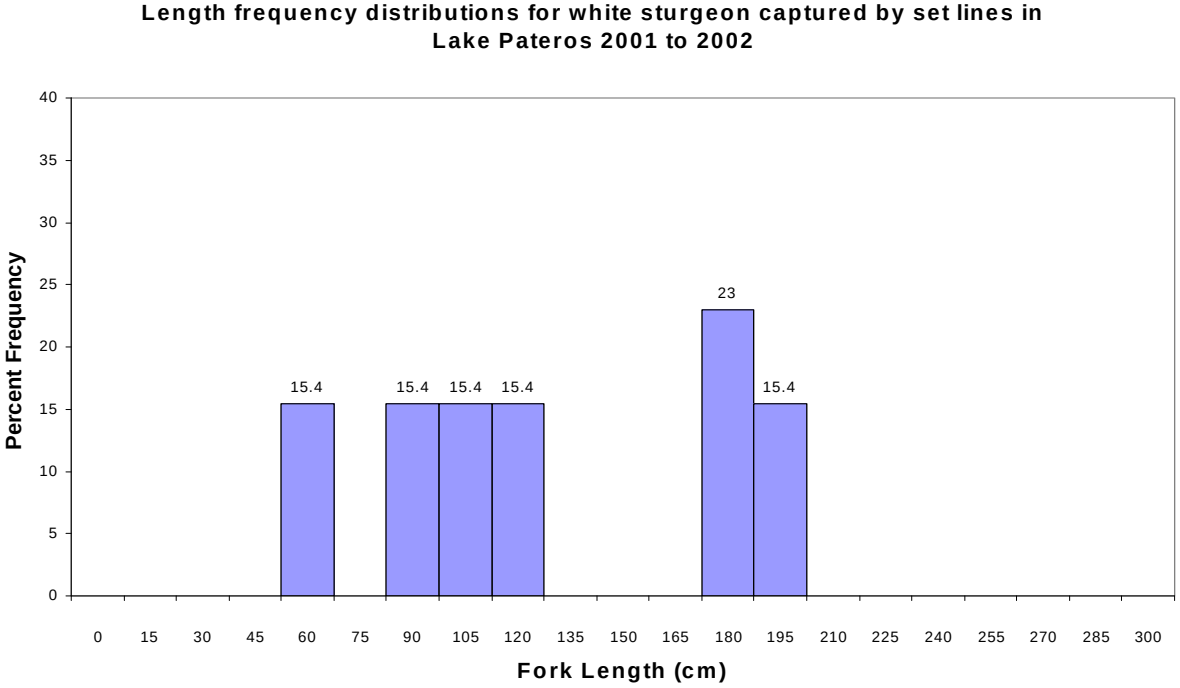


Figure 14 Length frequency histogram comparison for white sturgeon captured in Wells Reservoir and white sturgeon captured in Lower Granite Reservoir, Snake River Idaho.

Analysis of the length frequency data should be interpreted with caution. The identification of year classes based on fish lengths is highly variable (Rien et al. 1994). Once white sturgeon are over one year old, lengths may not be a good predictor of age. As juveniles age, growth variability and age inaccuracy make it increasingly difficult to correlate environmental conditions with specific year classes, particularly when based on lengths of older fish.

Additional caution should be taken when analyzing the Wells Reservoir white sturgeon population as the length frequency graphs assumed age structure are composed of a very small sample size (n=13). This small sample size may result in inaccuracies or gaps in the presented stock structure. If the sample size were increased, more distinct trends in the population could be observed.

Radio Telemetry

The 7 volt Lotek Micro Coded Fish Transmitters can transmit signals up to 20 meters (M. Vandentillart, personal communication). This range of transmittal may be limited by conductivity of the water and the efficiency of the receivers and antenna. Aerial surveys typically locate radio transmitters within 5 to 10 meters of the water surface. All white sturgeon during this project were captured and recorded during boat telemetry surveys at depths greater than 15 meters. Therefore, it is probable that the transmitted signals from the 7 volt tags were not recorded during the aerial surveys due to poor signal strength transmitted from tags at depths greater than 15 meters.

Boat telemetry surveys were the most productive method for locating activated tags. However, only four boat surveys were conducted (this telemetry gathering procedure was limited by funding and availability of the research vessel). White sturgeon were detected during each survey, often within close vicinity of each other and all within zone 3. Several of these fish were located within depths of over 20 meters, an indication that the receiver and antenna setup on the telemetry vessel was functioning with a high degree of accuracy. The final telemetry survey on November 27, 2003 identified four tagged fish within 100 meters of one another near the mid-Channel of the Columbia River across from the confluence of the Okanogan and Columbia rivers. It is presumed that these four tags were the only active tags (of the six applied tags, one radio tag had been removed from a fish three months prior and one tag was presumed to have been shed). The November 27 survey was the only mobile tracking survey that was conducted during the winter months. There is evidence that white sturgeon congregate in specific areas of the Mid-

Columbia River reservoirs during the winter (Golder Associates, 2003). White sturgeon were located in similar "pods" within Wanapum Reservoir during the winter of 2000 and 2001. Movement information collected on white sturgeon within Priest Rapids Reservoir in the Mid-Columbia indicated white sturgeon were relatively inactive from October to early April, and usually remained in one of four overwintering areas. It is probable that the deep channel of the Columbia River near the Okanogan River confluence is a preferred over wintering location for white sturgeon within Wells Reservoir.

The fixed station telemetry data presented in this report indicates white sturgeon were at the Okanogan River telemetry site during May and June of 2002 and May of 2003. In an attempt to correlate white sturgeon movements with environmental factors, discharge flows and water temperatures were collected near the fixed telemetry receiver in the Okanogan River during the spring of 2002 and 2003. Discharge data were collected from the Okanogan River at the USGS gauging station located near Malott Bridge approximately 8 kilometers upstream from the fixed telemetry site. Water temperature data were not available on a consistent basis for the Okanogan River due to temperature probe malfunction in 2002 and 2003. Intermittent temperature readings for the Okanogan River were obtained from the Colville tribe and Department of Ecology

Yearly hydrographs for the Okanogan River consist of low flows from September to April, typically under 4000 cubic feet per second (cfs). Peak spring run-off usually occurs in June when flows may range from 16,000 to 20,000 cfs. From mid-May to mid-July of 2002 peak discharges occurred in the Okanogan River. Two radio tagged white sturgeon were present at the site during this peak flow period from May 19 to June 19 (Figure 15). Water temperatures ranged from approximately 11 C to 12.5 C during this time period. In 2003 peak discharges occurred during the first two weeks of June One radio tagged white sturgeon was present at the fixed telemetry site prior to the peak flow period from May 10 to May 24 (Figure 16). Water temperatures ranged from approximately 10 C to 11.5 C during this time period.

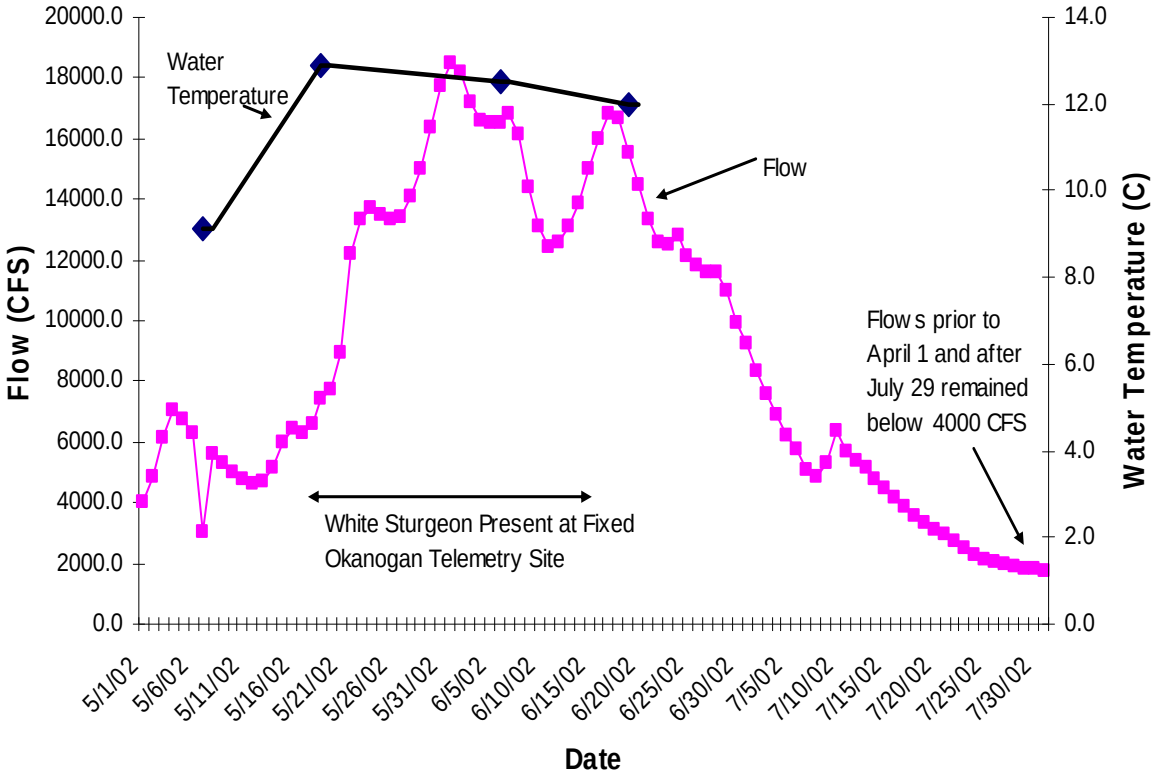


Figure 15 Daily mean discharge (cubic feet per second) from May 1, 2002 to July 30, 2002 within Okanogan River taken at Malott Bridge USGS gauging station approximately 8 kilometers upstream from the Columbia River confluence.

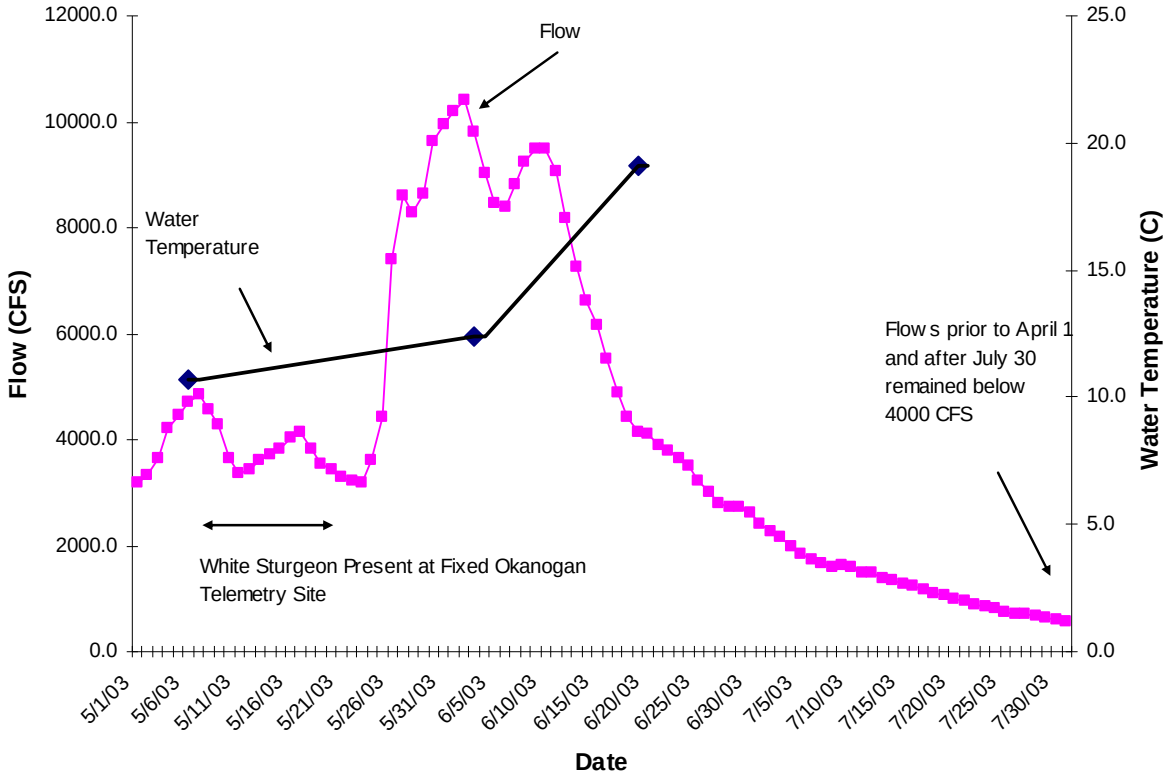


Figure 16 Daily mean discharge (cubic feet per second) from May 1, 2003 to July 30, 2003 within Okanogan River taken at Malott Bridge USGS gauging station approximately 8 kilometers upstream from the Columbia River confluence.

White sturgeon movements are often related to spawning and/or feeding activities (Hynes 1978). The presence of white sturgeon within the relatively shallow depths of the Okanogan River (less then 15 meters) provides evidence of these movements. White sturgeon left the vicinity of the site when water temperatures neared 11 to 12 C. Therefore, it is unlikely that white sturgeon frequented the Okanogan River relative to spawning activities. White sturgeon did exit the Okanogan River just prior to the lower egg incubation temperature of 13 C. Radio tagging studies in the Fraser River document gravid fish moving upstream from 11.3 to 16.1 km per day (Hanson et al. 1992). It is possible that white sturgeon may have been leaving the Okanogan River to conduct spawning activities elsewhere in the study area.

White sturgeon may be utilizing the Okanogan River for foraging purposes in the spring. During the high spring flows, large amounts of decayed material and juvenile salmonids are washed out of the Okanogan River, which may include steelhead carcasses and juvenile sockeye (S. Bickford, personal

communication). White sturgeon may be scavenging on steelhead carcasses, juvenile sockeye or other food sources that are washed downstream during the yearly spring run-off.

Research throughout the Columbia River system has indicated that white sturgeon prefer dam tailrace areas for spawning attempts as these areas contain fast flowing water velocities and suitable spawning habitat (Brannon and Setter 1992, Haynes et al. 1978, Lepla and Chandler 2001, Parsley et al. 1993, Parsley and Beckman 1994). Additionally, changes in hydroelectric facility operations have been documented to effect sturgeon movements in tailrace areas (Auer 1996, Votinov NP and Kas'yanov 1978). Parsley and Kappenman (2000) documented 17 white sturgeon spawning locations on the Snake River. All 17 locations contained high water velocities and were located within five kilometers downstream of hydroelectric projects. It is possible that white sturgeon are migrating out of zone 3 to spawn in or near the tailrace of Chief Joseph Dam. Golder and Associates (2003) observed distinct movements of white sturgeon from over wintering areas upstream to the base of Rock Island Dam within Wanapum Reservoir. These movements occurred during the spawning period in early June, and most fish remained below Rock Island Dam until July.

Chief Joseph Dam heavily influences water velocity and pool levels within Wells Reservoir. All of zone 4 and the upper part of zone 3 within the study area are subject to high water discharges from the project, especially during spring run-off periods. Waters below the tailrace of Chief Joseph Dam are much more heavily influenced by hydroelectric operations than most other dams on the Columbia River due to a narrow river channel that exists there. Water velocities remain high for approximately 15 kilometers below the project and water does not begin to pool within the reservoir until far downstream of the project. This scenario ultimately results in a large section of river that contains high flow velocities and may be suitable white sturgeon spawning habitat.

During this study it was not possible to conclude whether spawning events took place, however it was possible to create a temperature discharge graph and define time periods when white sturgeon spawning events may have occurred within the upper reservoir. A temperature discharge curve was constructed for the upper Wells Reservoir for spring periods in 2002 and 2003. Water temperature and discharge information were obtained from the United States Corps of Engineers for the immediate Chief Joseph Dam Tailrace. Water temperatures from 13 to 18 C that coincide with high spring flows create a

spawning window indicating the most probable time white sturgeon spawning events would occur. Given high water velocities throughout the upper study area, the spawning window is suggested to be appropriate for all areas of the upper reservoir that are influenced by Chief Joseph Dam. This would include the entire section of zone 4 and the upper section of zone 3 near the confluence of the Columbia and Okanogan rivers.

During 2002, the spawning window within the upper reservoir should have taken place from approximately June 25 to July 10 (Figure 17). During this time, period peak discharge occurred from Chief Joseph Dam nearing 20,000 cfs and water temperatures ranged from 13 C to 15 C. The estimated spawning window in 2003 also occurred near the end of June from approximately June 17 To July 8 (Figure 18). Flow velocities were high and water temperatures ranged from 13 C to 15 C.

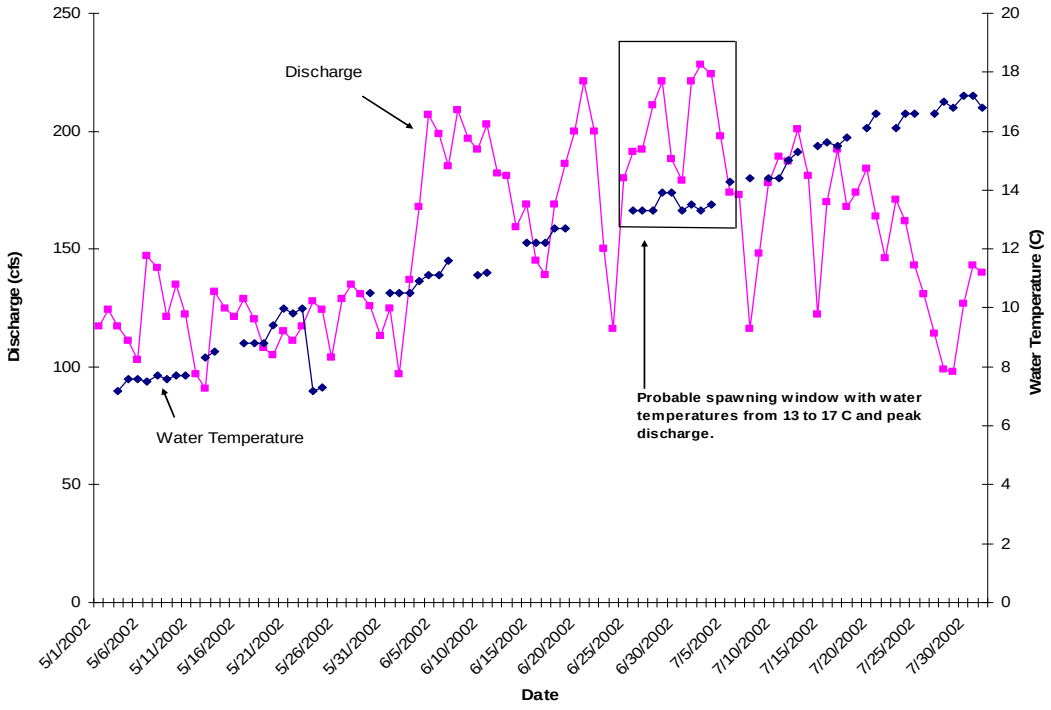


Figure 17 Daily average water temperature (C) and daily average discharge (cfs) in Chief Joseph Dam tailrace from May 1 to July 30, 2002. Spawning window represents optimal white sturgeon egg incubation temperature (13 C to 17 C) and high flow velocities.

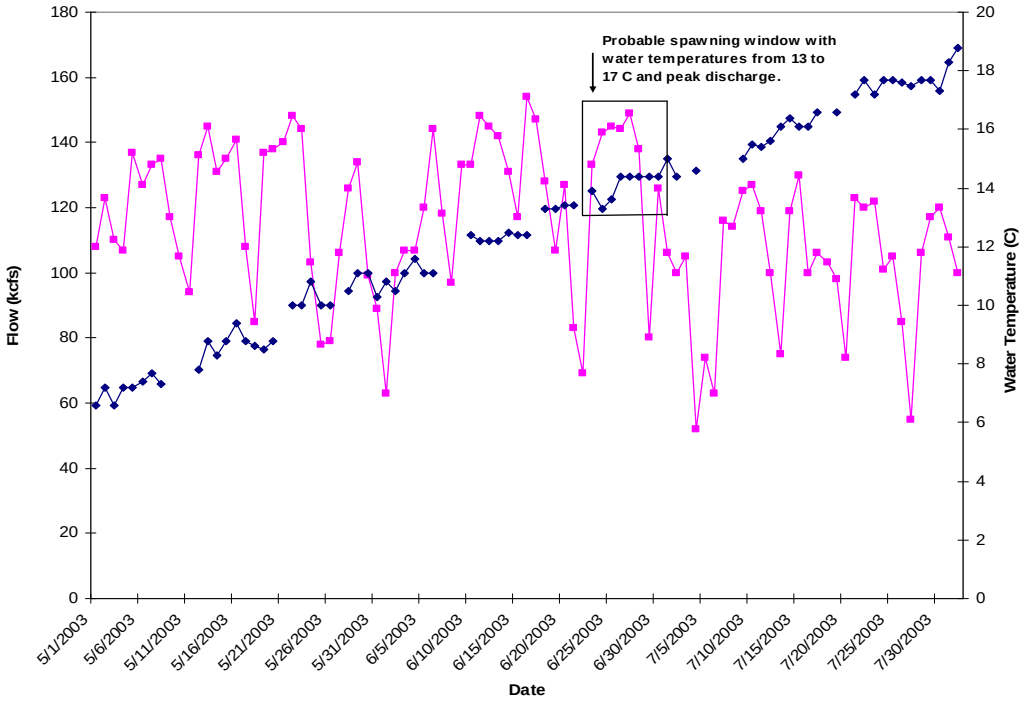


Figure 18 Daily average water temperature (C) and daily average discharge (cfs) in Chief Joseph Dam tailrace from May 1 to July 30, 2003. Spawning window represents optimal white sturgeon egg incubation temperature (13 C to 17 C) and high flow velocities.

White sturgeon were not captured on the set line gear during the spring of 2001 or the spring of 2002 within zone 3. A number of set lines were placed throughout zone 3 from mid to late June of 2001 with no incidence of white sturgeon captures. White sturgeon were only encountered on the set line gear within zone 3 during the summer and fall sampling periods. Golder and Associates (2003) noted low catch rates during the spring and early summer months in mid-Columbia sampling efforts. In Priest Rapids reservoir, no white sturgeon were encountered during sampling efforts during the spring of 2000. However, a total of nine fish were captured during fall sampling of that same year. Lack of captures during the spring periods may indicate white sturgeon are more susceptible to the set line gear during the summer and fall months. Because fish metabolism is related to water temperature, low water temperatures in spring may have inhibited the fish's feeding response to baits placed on the set line gear.

Low incidences of white sturgeon captures in the spring may also indicate that white sturgeon are utilizing habitats within the reservoir that were not sampled or could not be sampled. During high flow, velocities it was not feasible to place set line gear in the immediate Chief Joseph Tailrace due to dangerous

and turbulent water conditions. It is possible that white sturgeon were present within the Chief Joseph tailrace area and not sampled. The absence of fish captures within zone 3 during high flow events and the presence of high flow velocities in the upper reservoir indicate the possibility that white sturgeon may have traveled out of zone 3 to conduct spawning efforts in or below the Chief Joseph tailrace area.

Management Implications

The Schnabel mark-recapture estimate (n=31.35) indicates that the white sturgeon population within Wells Reservoir is composed of a low number of individual fish. This project has verified the presence of a white sturgeon population within Wells Reservoir and future strategies will need to be implemented that will enhance and expand the existing population. Future management objectives should include promoting white sturgeon enhancement and monitoring the effects of these restoration efforts. A larger population of white sturgeon within Wells Reservoir would better withstand variable environmental conditions as a sufficient number of adult spawning individuals would be available to reproduce during productive environmental conditions. Ultimately, strong spawning events during productive environmental conditions should provide recruitment levels that allow the population to exist even during periods of un-favorable environmental conditions (i.e. extended droughts from low snow packs).

Promoting white sturgeon growth within Wells Reservoir will require the collection of brood stock and the culture of juvenile sturgeon. Studies have successfully identified white sturgeon spawning locations throughout the Columbia and Snake Rivers (Anders and Beckman 1993, Parsley and Kappenman 2000, Parsley at al. 1993, Parsley and Beckman 1994). These spawning locations have been discovered through the tagging of mature white sturgeon with radio and sonic tags and the tracking of the fish to spawning sites. Positive verification of spawning sites within Columbia River reservoirs has entailed the use of egg matts (Parsley and Kappenman 2000, Parsley at al. 1993). These matts are deployed downstream of suspected spawning areas to capture eggs or larvae that are dispersed during spawning events.

It is not presently possible to determine whether brood stock could be obtained from the existing Wells Reservoir population. Because the population of fish within Wells Reservoir is relatively low, it may not be feasible to obtain spawners from the existing population. Assuming a population of 31 fish (of which 50% are mature) and a sex ratio of 50% females, there could be up to eight mature females in the

population. However, as white sturgeon females may only spawn every two to five years, it is possible that only one to three females may spawn within Wells Reservoir within a given year. The capture of these ripe females during a limited spring spawning period is highly questionable.

Seven evolutionary significant units (ESUs) for white sturgeon have been defined for white sturgeon on the Pacific Coast of North America. The Columbia River white sturgeon population consists of two ESUs. These two ESUs consist of the Upper Columbia River Population in Canada and the United States and the lower/middle Columbia River in the United States. Because the lower and mid Columbia regions are considered the same ESU, additional options may be available regarding acquisition of brood stock and/or juvenile white sturgeon for stocking purposes. It may not be possible to acquire brood stock from nearby reservoirs within the Mid-Columbia as these populations also contain low numbers of individual fish and similar problems regarding brood stock capture would probably be experienced.

It may be possible to collect white sturgeon within the lower Columbia River for brood stock or transplant purposes. Brood stock could be collected from the lower Columbia River to provide managers with the ability to begin a hatchery supplementation program. Additionally juvenile or adult sturgeon could be trapped within the lower Columbia River and transported for direct release into Wells Reservoir.

Regardless of which future management options is implemented, continued monitoring programs will be vital to evaluate the success of restoration efforts within the study area.

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