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ADULT PACIFIC LAMPREY PASSAGE AND BEHAVIOR STUDY
(Adult Lamprey Passage Study)

WELLS HYDROELECTRIC PROJECT

FERC NO. 2149

SECOND YEAR
FINAL REPORT
REQUIRED BY FERC

February 2009

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ABSTRACT

In 2008, Douglas PUD conducted lamprey passage research at Wells Dam using radio-tagged fish collected at Wells and Rocky Reach dams as a voluntary effort to supplement results from the 2007 study. Thirty-eight radio-tagged adult Pacific lamprey were released in the tailrace (n = 18) and fishways (n = 20) of Wells Dam. The goal of the 2008 study was to evaluate adult lamprey behavior and passage performance in the collection gallery and fishway entrances of Wells Dam.

In 2008, up to half of the radio-tagged lamprey displayed uncharacteristic behaviors indicative of death, tag shed, or abandonment of migration. Decreasing water temperatures may have also contributed to the abandonment of migration as lamprey approach Wells Dam near the known overwintering period. Of the remaining fish that appeared active, 15 approached the fishway from the tailrace and five entered (entrance efficiency of 33%). Lamprey activity within the collection gallery indicated that movement was not restricted by flows in this portion of the fishway. At least 11 of 19 (58%) lamprey that volitionally entered or were released in the collection gallery ascended the lower fishway to the trapping area. Fishway modifications to increase trapping efficiency for this study effectively blocked migration for 12 of 14 fish (86%) that encountered the trap (including one fish that ascended the lower fishway twice). The presence of the lamprey trapping structures substantially reduced lower fishway passage efficiency, and substantially reduced recruitment of tagged fish into the upper fishway.

Upper fishway passage times for the four radio-tagged lamprey that ascended the upper fishway were relatively fast (< 4 hours), except for one fish that hesitated during daylight hours. Three of these lamprey (75%) also bypassed the adult counting station undetected, supporting findings in 2007 that a majority (73%, n = 11) of lamprey that ascend Wells Dam are uncounted. No fallbacks of fish that successfully ascended the fishway were observed for the second consecutive year. Overall, results indicate that any potential areas of impediment are restricted to the entrance and the temporary lamprey trapping structure, as upper fishway passage efficiency was 100% for the second consecutive year.

The uncharacteristic behaviors observed with several fish were likely related to handling and tagging effects that are amplified in lamprey collected at Wells Dam because they are considerably thinner than those used in downriver studies. Increasing tag to body mass ratios has been shown to substantially reduce swimming performance in Pacific lamprey. Trapping efforts implemented to achieve the tagging goals of the study also had a significant effect by effectively blocking or impeding a majority (86%) of lamprey during their ascent through the fishways, thus reducing escapement of fish to the upper fishway where passage success has been 100%. These results suggest that future lamprey passage and behavior studies at Wells Dam should use alternative monitoring technology that would reduce or eliminate trapping, tagging, and handling effects.

Passage efficiency from this study is comparable or superior to results from other radio-telemetry studies conducted in the Columbia River during 2008. For example, entrance efficiencies of radio-tagged lamprey at Bonneville Dam ranged from 6% to 32%, compared to 33% at Wells Dam. Fallback at Bonneville was 19% compared to no documented fall back events at Wells

Dam. Median project passage times at Bonneville exceeded 180 hours compared to Wells where lower fishway passage time was 6.1 hours, upper fishway passage time was 5.9 hours, and time spent in or at the trap was 20 hours (32 hours total).

The results from the 2007 and 2008 passage studies at Wells Dam indicate that adult lamprey experience difficulty negotiating water velocities produced by head differentials at the fishway entrances ($\leq$ 3.4 m/s) established as attraction flows for migrating adult salmon. A reduction in head differential to reduce entrance velocities may be warranted to enhance adult lamprey passage at the Project, specifically during nighttime hours to capitalize on the nocturnal behavior of lamprey and avoid interference with salmon.

1.0 INTRODUCTION

1.1 General Description of the Wells Hydroelectric Project

The Wells Hydroelectric Project (Wells Project) is located at river mile (RM) 515.6 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, owned and operated by the United States Army Corps of Engineers (COE); and 42 miles upstream from the Rocky Reach Hydroelectric Project 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 the Wells Dam.

The Wells Project is the chief generating resource for 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 the hydrocombine. Fish passage facilities reside on both sides of the hydrocombine, which is 1,130 feet long, 168 feet wide, with a top of dam elevation of 795 feet above mean sea level (msl).

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 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 the normal maximum water surface elevation of 781 feet (Figure 1.1-1).

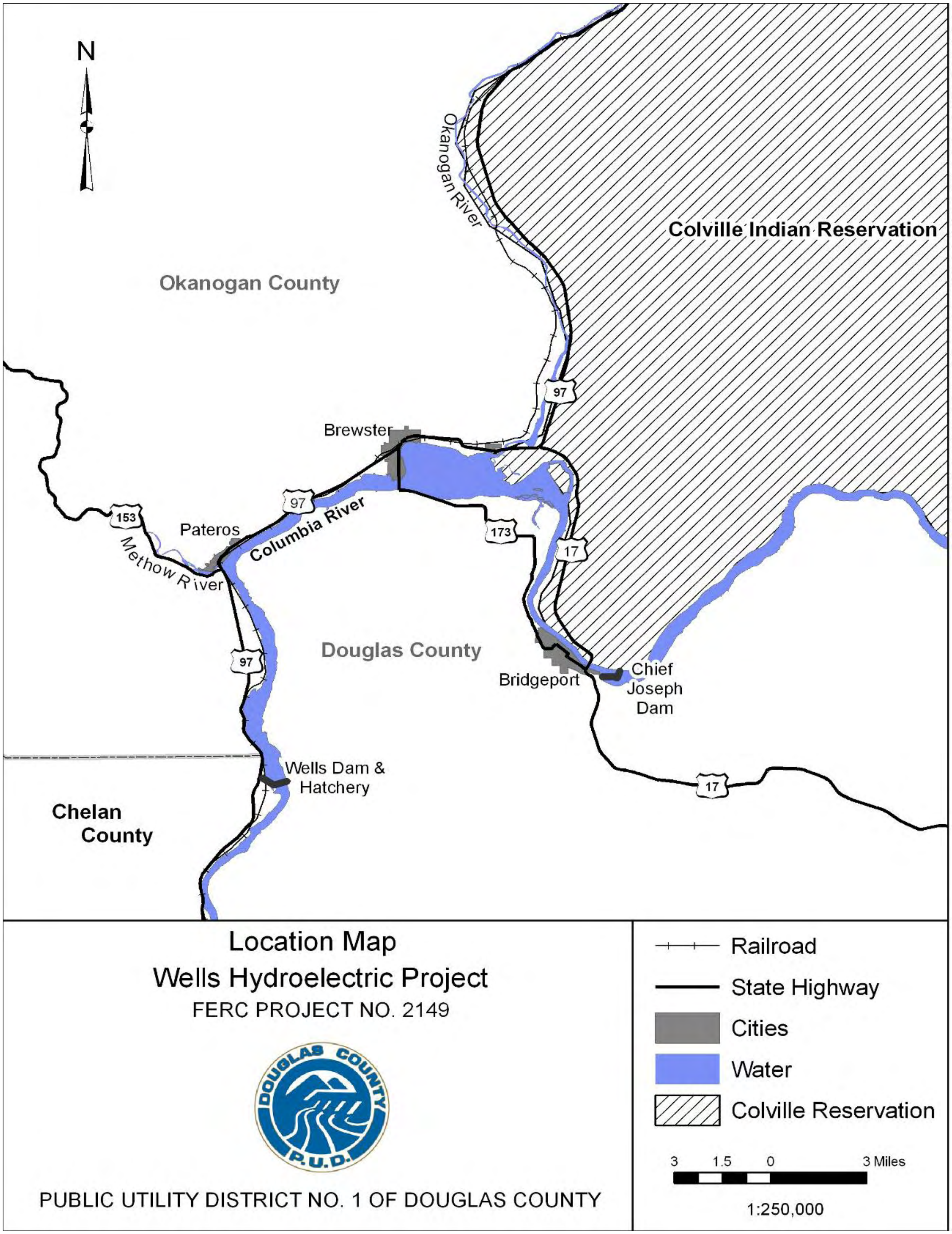

Figure 1.1-1 Location map of the Wells Project

1.2 Relicensing Process

The current Wells Project license will expire on May 31, 2012. Douglas PUD is using the Integrated Licensing Process (ILP) promulgated by the Federal Energy Regulatory Commission (FERC) Order 2002 (18 CFR Part 5). Stakeholders, including representatives from state and federal agencies, tribes, local governments, non-governmental organizations and the general public have participated in the Wells Project ILP, from a very early stage, to identify information needs related to the relicensing of the Wells Project.

In August 2005, Douglas PUD initiated a series of Resource Work Group (RWG) meetings with stakeholders regarding the upcoming relicensing of the Wells Project. This voluntary effort was initiated to provide stakeholders with information about the Wells Project, to identify resource issues, and to develop preliminary study plans prior to filing the Notice of Intent (NOI) and Pre-Application Document (PAD). The RWGs were formed to discuss issues related to the Wells Project and its operations, identify information needs, and develop agreed-upon study plans.

The primary goals of the RWGs were to identify resource issues and potential study needs in advance of Douglas PUD filing the NOI and PAD. Through 35 meetings, each RWG cooperatively developed a list of Issue Statements, Issue Determination Statements and Agreed-Upon Study Plans. An Issue Statement is an agreed-upon definition of a resource issue raised by a stakeholder. An Issue Determination Statement reflects the RWGs' efforts to apply the FERC's seven study criteria to mutually determine the applicability of each individual Issue Statement. Agreed-Upon Study Plans are the finished products of the informal RWG process.

Douglas PUD submitted the NOI and PAD to the FERC on December 1, 2006. The PAD included the RWGs' 12 Agreed-Upon Study Plans. The filing of these documents initiated the relicensing process for the Wells Project under the FERC's regulations governing the ILP.

On May 16, 2007, Douglas PUD submitted a Proposed Study Plan (PSP) Document. The PSP Document consisted of the Applicant's Proposed Study Plans, Responses to Stakeholder Study Requests and a schedule for conducting the Study Plan Meeting. The ILP required Study Plan Meeting was conducted on June 14, 2007. The purpose of the Study Plan Meeting was to provide stakeholders with an opportunity to review and comment on Douglas PUD's PSP Document, to review and answer questions related to stakeholder study requests and to attempt to resolve any outstanding issues with respect to the PSP Document.

On September 14, 2007, Douglas PUD submitted a Revised Study Plan (RSP) Document. The RSP Document consisted of a summary of each of Douglas PUD's RSPs and a response to stakeholder comments on the PSP Document.

On October 11, 2007, the FERC issued its Study Plan Determination based on its review of the RSP Document and comments from stakeholders. The FERC's Study Plan Determination required Douglas PUD to complete 10 of the 12 studies included in its RSP Document. Douglas PUD has opted to complete all 12 studies to better prepare for the 401 Water Quality Certification process conducted by the Washington State Department of Ecology and to fulfill its commitment to the RWGs who collaboratively developed the 12 Agreed-Upon Study Plans with

Douglas PUD. On October 15, 2008, Douglas PUD filed with the FERC the ISR Document that contained final reports for eight of the 12 studies and contained interim progress reports for four of the 12 studies. The ISR Document included results from all ten of the studies required by the FERC in the October 11, 2007 Study Plan Determination. The ISR Document contained final reports for eight of the studies and contained interim progress reports for four of the studies. The ISR Document also included results from two studies voluntarily conducted by Douglas PUD for the reasons stated above. On November 24, 2008, Douglas PUD filed a letter correcting a water temperature figure within the original ISR Document. On December 2, 2008, Douglas PUD filed the final Traditional Cultural Property Study for the Wells Project, which was prepared by the Confederated Tribes of the Colville Reservation under a contract with Douglas PUD.

The deadline for stakeholder comment on the ISR Document was December 15, 2008 pursuant to the approved Process Plan and Schedule for the Wells Project. Comments were filed by the City of Pateros on November 7, 2008 and by the City of Brewster on December 5, 2008.

On January 14, 2009, Douglas PUD filed a letter containing its responses to the comments from the cities on the ISR Document and proposed revisions to the schedule for the Wells ILP. On February 4, 2009, the FERC issued a determination on the requests for modification to the Wells Study Plan and on Douglas PUD's proposed revisions to the schedule. The FERC concluded that there was no need to modify the Wells Study Plan. The FERC also approved Douglas PUD's proposed modifications to the Wells ILP schedule.

This report is the second year of study and final report for the Adult Lamprey Passage Study.

2.0 GOALS AND OBJECTIVES

The goal of the voluntary second season of study was to evaluate the effect of the Wells Project on adult lamprey behavior and passage performance in the collection gallery and fishways entrances of Wells Dam. Other investigations conducted during the 2008 study included gathering information related to fishway passage, timing, and downstream passage events (drop back).

Objectives identified in the 2007 report were as follows:

1. Conduct a literature review of existing adult Pacific lamprey passage studies at Columbia and Snake river dams (see 2007 report);
2. Identify methods for capturing adult Pacific lamprey at Wells Dam (see 2007 report);
3. Document the timing and abundance of radio-tagged lamprey passage through Wells Dam (see 2007 report);
4. Determine whether adult lamprey are bypassing the adult counting windows at Wells Dam (see 2007 report);
5. Where sample size is adequate, estimate passage metrics including fishway passage times and efficiencies, residence time between detection zones, and downstream passage events (drop back); and

6. If warranted, identify potential areas of improvement to existing upstream fish passage facilities for the protection and enhancement of adult lamprey at the Wells Project.

The 2008 study focused on augmenting the sample size needed to meet objectives 5 and 6.

3.0 STUDY AREA

The study area includes Wells Dam, the Wells Dam tailrace, and the Wells Dam forebay (Figure 1.1-1).

4.0 BACKGROUND AND EXISTING INFORMATION

4.1 Life History

Pacific lamprey are present in most tributaries of the Columbia River and in the mainstem Columbia River during their migration. Lamprey have cultural, utilitarian and ecological significance in the basin since Native Americans have historically harvested them for subsistence, ceremonial and medicinal purposes (Close et al., 2002). 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 and recently have been captured during juvenile trapping operations in the Okanogan River (BioAnalysts, 2000).

Adult lamprey 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). Macrophthalmia is an intermediary life stage, when lamprey migrate to the ocean. Adults spawn in low-gradient stream reaches, generally 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. The ammocoetes undergo a metamorphosis, between 3 and 7 years after hatching, and migrate from their parent streams to the ocean (Close et al., 2002). In the mid-Columbia River macrophthalmia migrate during the spring and early summer (Douglas PUD and LGL, 2008). Adults typically spend 1-4 years in the ocean before returning to freshwater tributaries to spawn.

Columbia River Basin Pacific lamprey populations have declined in abundance over the last 40 years according to adult counts at dams (Close et al., 2002). Starke and Dalen (1995) reported that adult lamprey counts at Bonneville Dam regularly exceeded 100,000 fish in the 1960s. Counts since 1997 have averaged much lower, at roughly 45,000 fish (range 14,562 to 117,035; DART 2008). Close et al. (2002) attributed several factors accounting for these declines, including juvenile and adult passage at dams, reduction in spawning and rearing habitat, pollution, reduction of ocean food sources, and predation by introduced species.

4.2 Adult Counts

Returning adult Pacific lamprey have been counted at Wells Dam since 1998. Between 1998 and 2007, the number of lamprey passing Wells Dam annually has averaged 350 fish (Table 4.0-1). The relatively small number of adult lamprey observed at Wells Dam can be attributed to the location of the Wells Project (last passable dam on the Columbia River, over 500 miles upstream from the Pacific Ocean) and the estimated 73% of the lamprey that bypass adult fish counting stations in the fish ladders at Wells Dam (LGL and Douglas PUD, 2008). Pacific lamprey counts for Columbia and Snake river dams are presented in Table 4.0-1 and 4.0-2. Although counts at Wells Dam have been identified as underestimated, an average of 0.67% of the total adult lamprey run observed at Bonneville Dam is counted passing Wells Dam (based on the sum of same-year counts at Bonneville and Wells dams 2000-2007).

Table 4.0-1 Pacific lamprey counts at Columbia River mainstem dams (listed in order by river mile), by dam and year, 1997-2008.

Year	Bonneville	The Dalles	John Day	McNary	Priest Rapids	Rock Island	Rocky Reach	Wells
1997	20,891	6,066	9,237	.	.	.	.	.
1998	.	.	.	.	.	.	.	343
1999	.	.	.	.	.	.	.	73
2000	19,002	8,050	5,844	1,281	.	822	767	155
2001	27,947	9,061	4,005	2,539	1,624	1,460	805	262
2002	100,476	23,417	26,821	11,282	4,007	4,878	1,842	342
2003	117,035	28,995	20,922	13,325	4,340	5,000	2,521	1,410
2004	61,780	14,873	11,663	5,888	2,647	2,362	1,043	647
2005	26,667	8,361	8,312	4,158	2,598	2,267	404	214
2006	38,941	6,894	9,600	2,459	4,383	1,326	370	21
2007	19,304	6,083	5,753	3,454	6,593	1,300	696	35
2008	14,562	4,599	6,625	1,530	5,083	880	368	
Total	446,605	116,399	108,782	45,916	31,275	20,295	8,816	3,502
Min	14,562	4,599	4,005	1,281	1,624	822	368	21
Max	117,035	28,995	26,821	13,325	6,593	5,000	2,521	1,410
Average	44,661	11,640	10,878	5,102	3,909	2,255	980	350
SD	36,598	8,264	7,330	4,344	1,583	1,612	738	416

Table 4.0-2 Pacific lamprey counts at Snake River mainstem dams, by dam and year, 1996-2008.

Year	Ice Harbor	Lower Monumental	Little Goose	Lower Granite
1996	737	.	.	490
1997	668	.	.	1,122
1998	.	.	.	.
1999	.	.	.	.
2000	315	94	71	28
2001	203	59	104	27
2002	1,127	284	365	138
2003	1,702	476	660	282
2004	805	194	243	122
2005	461	222	213	42
2006	277	175	125	35
2007	290	138	72	34
2008	264	145	104	61
Total	6,849	1,787	1,957	2,381
Min	203	59	71	27
Max	1,702	476	660	1,122
Average	623	199	217	216
SD	461	124	192	333

Adult lamprey pass Wells Dam from early July until late November with peak passage times between mid-August and late October (Figure 4.0-1). In all years since counting was initiated, Pacific lamprey counts at the east fish ladder were greater than at the west fish ladder. 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. Further complicating the comparison of lamprey dam counts, Beamish (1980) 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 to the Columbia River Basin. While it is unknown to what degree these concerns are reflected in Columbia River lamprey passage data, it is important to consider these factors when examining historic lamprey count data at Wells Dam.

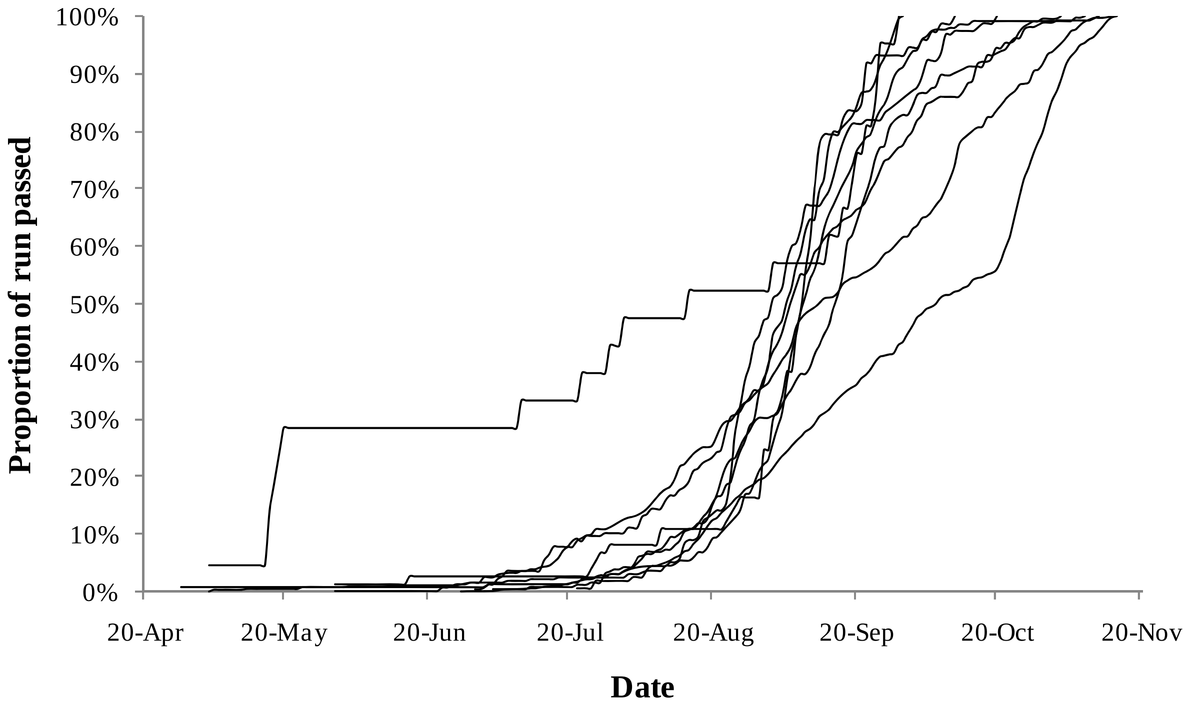

Figure 4.0-1 Run timing of Pacific lamprey at Wells Dam by year, 1998-2006.

Until recently, relatively little information was available on Pacific lamprey in the mid-Columbia River Basin. Two recent reviews of Pacific lamprey (Hillman and Miller 2000; Golder Associates Ltd. 2003) in the mid-Columbia River indicated that little specific information is known regarding population status (Stevenson et. al., 2005). However, with increased interest in the species coupled with a need to collect information for the license application for the Wells Project, Douglas PUD has initiated several studies to investigate Pacific lamprey spawning, juvenile predation and adult passage behaviors.

4.3 Passage Studies

The study of adult Pacific lamprey migration patterns past dams and through reservoirs in the lower Columbia River provided the first data sets on lamprey passage timing, travel times, and passage success at hydroelectric projects (Moser et al., 2002a; Moser et al., 2002b). These studies have shown that less than 50% of the lamprey that encountered a fishway entrance actually passed through the ladder to the forebay (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 lamprey 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 Dam fishway, 55.5% exited the ladder.

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

In 2004, Douglas PUD hired 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). The release site was over 50 miles downstream of Wells Dam: the value of the study was limited by the relatively small numbers of tagged fish observed at Wells Dam (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 Wells Dam and tributary mouths. Collectively, these monitoring sites were used to determine migration and passage characteristics of lamprey entering the Wells Project area. Of the 150 adult lamprey released at or below Rocky Reach Dam 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. Two of the 10 lamprey approached both fishways to produce 12 total entry events. Three 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). This estimate probably underestimates actual fishway efficiency, as it is likely that some of the remaining 15 tagged fish detected in the Wells Dam tailrace passed Wells Dam subsequent to battery operational life.

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 days 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) is insufficient to address the objectives set forth in Section 2.0 with statistical confidence.

4.4 Aquatic Resource Work Group

As part of the relicensing process for the Wells Project, Douglas PUD established an Aquatic Resource Work Group (Aquatic RWG) which began meeting informally in November, 2005. This voluntary effort was initiated to provide stakeholders with information about the Wells Project, to collaboratively identify potential resource issues related to Project operations and relevant to relicensing, and to develop preliminary study plans to be included in the Wells Pre-Application Document (PAD) (DCPUD, 2006).

Through a series of meetings, the Aquatic RWG cooperatively developed a list of Issue Statements, Issue Determination Statements and Agreed-Upon Study Plans. Based upon these meeting and discussions, the Aquatic RWG proposed to include a radio-telemetry study to assess lamprey behavior as it relates to passage, timing, drop back and upstream migration. The need for this study was agreed to by all of the members of the Aquatic RWG, including Douglas PUD. This study will help to inform future relicensing decisions and will fill data gaps that have been identified by the Aquatic RWG.

The Issue Statement and Issue Determination Statement listed below were included in the PAD (section number included) filed with the FERC on December 1, 2006:

4.4.1 Issue Statement (PAD Section 6.2.1.3)

The Wells Project may affect adult Pacific lamprey behavior related to ladder passage, timing, drop back and upstream migration.

4.4.2 Issue Determination Statement (PAD Section 6.2.1.3)

Work group members have determined that this issue has a tie to the Project as it relates to lamprey migration through Wells Dam. Preliminary passage information has been collected at Wells Dam (LGL and Douglas, 2008); however, the sample size of the study was limited and additional information is needed. A radio-telemetry study would be feasible to address passage, timing, drop back and upstream migration. The results of an adult lamprey passage study would also be useful during the development of Protection, Mitigation and Enhancement (PME) measures.

The resource work group agreed that a radio-telemetry study to assess lamprey behavior as it relates to passage, timing, drop back and upstream migration should be conducted at Wells Dam during the two-year ILP study period.

4.5 Project Nexus

The Wells Project may affect adult Pacific lamprey behavior related to ladder passage, timing, drop back and upstream migration. Potential problems facing successful passage of adult Pacific lamprey at dams may be related to their unique method of movement and specific areas within fishways: specifically, adult Pacific lamprey at other projects have experienced difficulty passing over diffusion gratings and through areas of high velocity, bright light and through orifices with squared, un-rounded edges. Typically, lamprey move through an adult fishway in a repeated series of motions consisting of attaching to the ladder floor with their mouths, surging forward, and re-attaching. The physiological response of adult Pacific lamprey to exhaustive exercise may be immediate, sometimes severe, but short-lived (Mesa el al., 2003). This may suggest that lamprey have difficulty negotiating fishways with high current velocities.

The proposed lamprey radio-telemetry study will assist in providing the information needed as identified by the Aquatic RWG and will inform the development of future license requirements.

5.0 METHODOLOGY

The study methodology used in 2007 for Objectives 1 through 4 (see 2.0 for description) is described in the first annual report *Adult Pacific Lamprey Passage and Behavior Study (Adult Lamprey Passage Study): Wells Hydroelectric Project, FERC No. 2149* (LGL and DCPUD, 2008). In both 2007 and 2008, radio-telemetry techniques were used to address Objective 5 (estimation of lamprey residence times and fishway passage times; and documentation of downstream passage events). Lamprey were captured, handled, tagged and released, and were subsequently tracked using radio-receivers. The specific methods used in 2007 are outlined in LGL and DCPUD (2008). Methods employed in 2008 are described in detail below.

5.1 Capture, Tagging, and Release of Lamprey

5.1.1 Trapping

Four lamprey traps were deployed at Wells Dam to capture adult lamprey for tagging. Lamprey traps were designed by Douglas PUD and LGL in the spring of 2007 and then modified in the spring of 2008 to increase trapping efficiency. Each aluminum holding box (0.6×0.4×0.6 m) was deployed along the fishway wall on the upstream side of an overflow weir. The traps passively captured fish that traveled over the weir through an overflow slot adjacent to the fishway's outer wall. The trap's funnel served to guide lamprey from the wall and weir sill into a chute and then into a holding box. Traps were affixed to the fishway wall by tracks that allowed operators to raise the unit out of the water for fish removal and cleaning (Figure 5.1-1). Two traps were located between Pools #39 and #40 in each fishway. The traps were numbered in ascending order, from the westernmost (Trap 1) to the easternmost (Trap 4) trap.

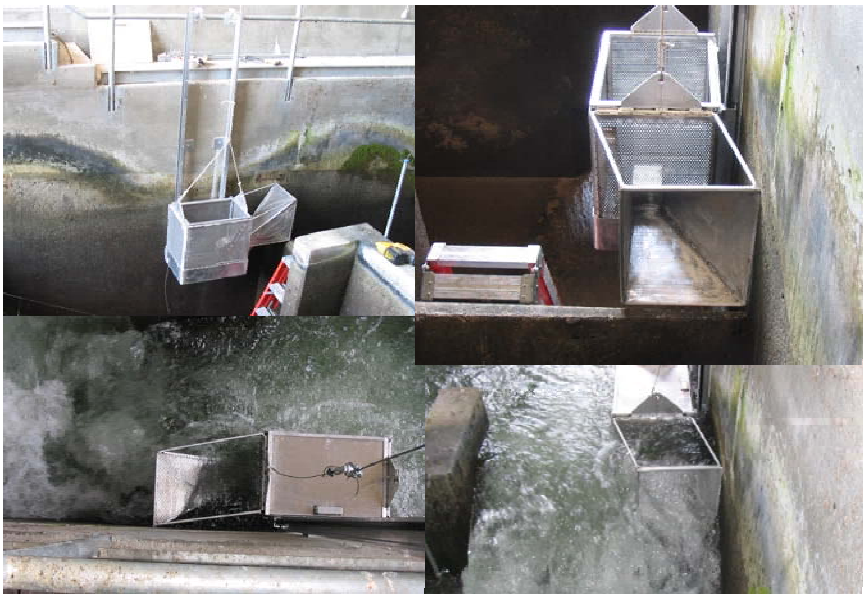

Figure 5.1-1 Douglas PUD adult lamprey trap. Views (clockwise from top left) from the side (at installation), front (at installation), front (active), and top (active) in the east fishway of Wells Dam.

Expected trap efficiencies were based on the following assumptions: 1) only a small portion of lamprey will utilize the weir orifice to pass between fishway pools; 2) lamprey will be attracted to the reduced flow and ease of travel along the fishway wall; 3) trap escapement will be negligible; and 4) lamprey will not drop back upon encountering the trap. These assumptions were based on flow measurements, documented swimming capabilities of adult lamprey (see literature cited), and observed lamprey behavior at fishways of other hydroelectric projects (Chris Peery, University of Idaho, personal communication).

Results from the 2007 study indicated that trapping efficiency was lower than expected (less than 25%, LGL and DCPUD, 2008). Since passage over the middle of the weir or around the trap seemed unlikely, lamprey were presumed to have passed through the orifices at greater proportions than initially anticipated. In an attempt to improve trapping efficiency and reach proposed sample size in 2008, the Aquatic Resource Work Group agreed to the installation of a perforated plate on the floor of the weir orifice. This would effectively eliminate orifice passage (by preventing burst and attach swimming), forcing lamprey to resort to passing into the trap. Video of lamprey behavior at federal projects document similar actions at blocked orifices (Chris Peery, University of Idaho, personal communication).

Trapping was initiated following the first observed lamprey at the Wells Dam fish counting stations, and continued over a ten week period (2 August to 15 October, 2008). In 2008, traps were fished daily. Except when extraneous circumstances prevented it, all traps were checked twice each day: once in the morning (6:00-10:00 hrs) and once in the evening (15:00-17:00 hrs). All fish were identified, enumerated, and bycatch was released into the fishway upstream of the trapping location. Lamprey were immediately transferred by covered buckets into insulated holding tanks to await the next tagging session (taggers worked three days per week). Holding tanks (113L Igloo MaxCold 120 coolers, 1.0×0.5×0.5 m) and were hooked-up to circulating flow-through river water. Tanks were maintained at ± 2°C fishway temperature, and dissolved oxygen was kept within 9-12 mg/L). The maximum capacity for each tank was set at eight lamprey (roughly 30 grams of fish per liter of water), and maximum holding time prior to tagging was set at 36 hours (M. Moser, NOAA, personal communication; Molly Haddock, WDFW, personal communication).

Additional lamprey were obtained from concurrent trapping efforts at Rocky Reach Dam (42 miles downstream). The supplementation was in response to the low numbers of lamprey observed at Wells Dam and to meet the proposed sample size target of the study (40 lamprey tagged each year). Lamprey captured at Rocky Reach Dam were moved to holding tanks by Chelan or Douglas PUD employees. LGL biologists visited Rocky Reach Dam on 5 occasions in 2008 (13 and 15 August; 2, 5 and 6 September) to transport fish to Wells Dam for tagging. Fish were transported by truck in a 113 L cooler filled with river water. An air tank and air stones were used to maintain proper oxygen levels. The 42-mile trip generally took an hour and lamprey were tagged as soon as possible (20-60 minutes after arrival at Wells Dam), always adhering to the 36 hour maximum holding time criterion.

5.1.2 Tagging and Release

Model NTC-4-2L Nano Tags (Lotek® Newmarket, Ontario) with an 87 day battery life were used for all lamprey. The tags were set up in 5.0 second burst rates on a frequency of 148.320 or 148.780 MHz. Tag dimensions were 18.3 mm (length) by 8.3 mm (diameter), with a dry weight of 2.1 grams – less than 0.8% of total body weight for all lamprey. Tags were sequenced, activated, and tested prior to each surgery.

Surgical tagging methods were based on techniques described by Moser et al. (2002a), Close et al. (2003), and Stevenson et al. (2005), in combination with LGL Limited guidelines for surgical tag implantation. The tagging area was prepared with a tub containing a heavy sedation mixture and two surgery buckets, one containing a light sedation mixture and the other river water. Tricaine methane sulfonate (MS 222) was used as an anesthetic in 2008, with the heavy and light sedation mixtures prepared at 70 mg/L and 49 mg/L, respectively. A few drops of Stress Coat (Aquarium Pharmaceuticals, Inc. Chalfont, PA) were added to all containers and the surgery trough to minimize effects of handling. The surgery trough was made of sectioned PVC tubing, angled to allow pooling near the head and gills of the lamprey. Tubing from the surgery buckets to the trough allowed controlled flow of either the light sedation mixture or water over the gills of the lamprey (Figure 5.3-2). Surgery tools were placed alongside the surgery trough and the radio-tag was activated and tested.

Lamprey were tagged by surgically inserting a transmitter into the peritoneal cavity. The surgery began by first transferring an individual lamprey to the heavy sedation tub. Fish would generally lose equilibrium after a few minutes and were usually adequately anesthetized within eight minutes. The lamprey was then removed from the solution, weighed to the nearest gram, measured length (to the nearest 0.5 cm) and girth (to the nearest mm), and placed into the surgery trough. The spout from the light sedation bucket was opened to maintain flow of anesthetic during the procedure. A 1.5-2.0 cm incision was made approximately 1 cm above the ventral midline with the posterior end of the cut ending in line with the anterior insertion of the first dorsal fin. A catheter was inserted into the peritoneal cavity, and pushed through the side of the fish, approximately 3 cm posterior to the incision (Figure 5.3-3). The radio-tag antenna was threaded through the catheter and the tag was inserted into the peritoneal cavity. In 2008, a PIT tag was also inserted into the peritoneal cavity. Following tag insertion, an internal antibiotic (Liquimycin) was pipetted into the peritoneal cavity, and 2-3 sutures were used to close the incision. A 19 mm suture needle was used, with 3-0 absorbable surgical suture thread. A light coat of antibiotic ointment (Polysporin) was applied to the closed incision and the fish was subsequently moved to the recovery tank.

Figure 5.1-2 Lamprey tagging trough, surgery buckets, scale, and platform.

Figure 5.1-3 Radio-tag and data form (left) and incision and catheter prior to tag insertion during the surgery process.

Fish were typically released upon recovery (approximately one hour post-surgery), but in some cases releases were delayed beyond the recovery time. Mean time to release was 1.5 h in the recovery tank, and ranged from 0.7-2.7 h. To release a radio-tagged lamprey, it was placed into a 19 L bucket with 8-10 L of water, and the covered bucket was lowered by rope into the water, the lid was removed, and the lamprey was allowed volitional release from the container. Radio-tagged lamprey were released into the tailrace (into the east or west alcove) or into the fishway (into the east or west collection gallery). One fish was released into the west fishway, mid-ladder. Releases typically took less than 10 minutes.

5.2 Radio-Tracking

5.2.1 Fixed Station Receiver Arrays

The movement and passage of radio-tagged lamprey at Wells Dam were documented by combining detection data collected using both underwater and aerial antenna stationary arrays (Figure 5.2-1). The arrays were designed to detect movements of radio-tagged lamprey from the Columbia River into the fishway entrances and through the exits at Wells Dam, and were also designed to detect downstream passage movements. Aerial antennas were used in the tailrace and at remote stations on tributary mouths. Underwater antennas were used in the fishways. A total of 12 Lotek telemetry receivers, composing multiple arrays (8 at Wells Dam, 1 at the 'Gateway' site in the Columbia River downstream of the Wells Dam tailrace, 1 at the Methow River mouth, 1 at the Okanogan River mouth, and 1 for mobile tracking) were used during the study.

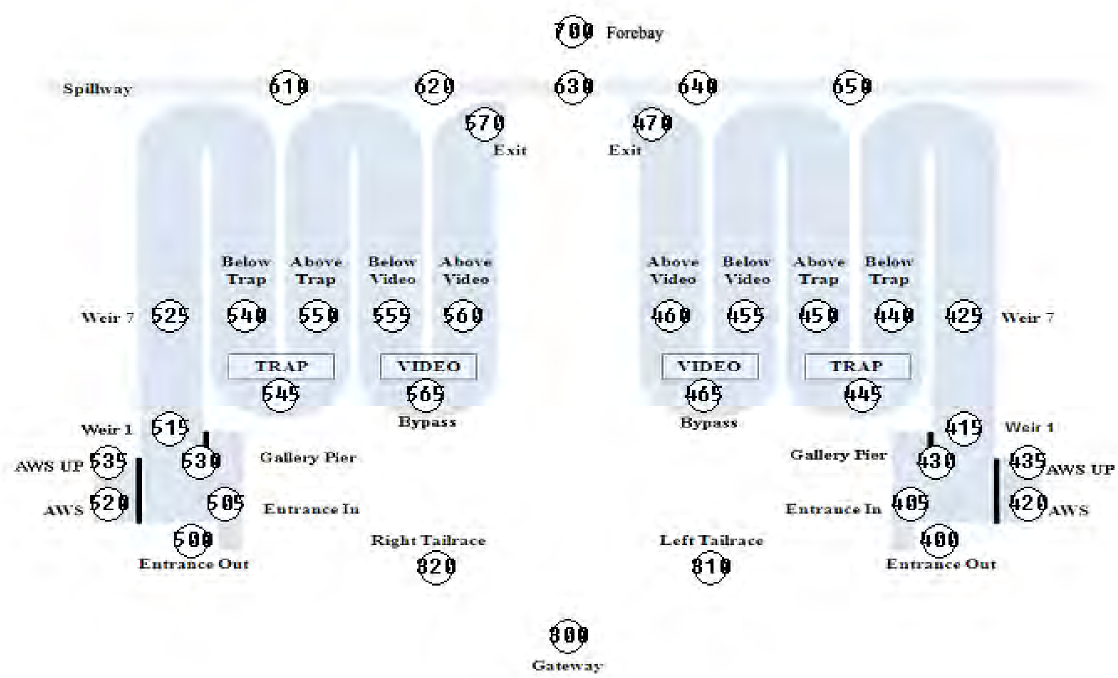

Figure 5.2-1 Fixed-station receiver detection zones used to detect radio-tagged lamprey at Wells Dam by station number, 2008.

5.2.2 Mobile Tracking

Mobile tracking was conducted by foot and by boat. Foot surveys were conducted within the fishways, using a single aerial antenna. Boat tracks were performed by running transect lines (oriented upstream and downstream) in a 2 km reach of the river downstream of Wells Dam. A post was mounted in the boat to secure twin three-element aerial antennas, which were pointed in opposite directions (usually at each bank). Once a tag was detected, a short-range underwater antenna (stripped coaxial cable) was used to accurately locate the tag position. During boat-tracking, the tailrace was partitioned into local area zones (see Figure 5.2-2). Signals of unknown origin, and those obtained prior to developing the detailed zones were classified as 'unknown'.

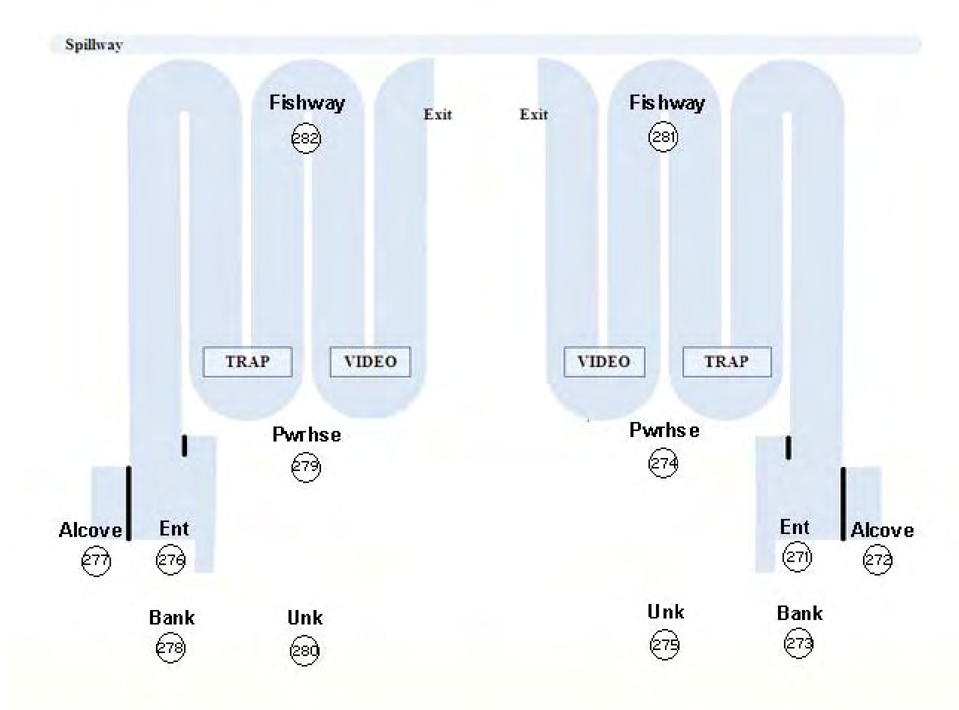

Figure 5.2-2 Mobile-tracking zones used for radio-tracking lamprey at Wells Dam by station number, 2008.

5.3 Data Processing and Analysis

The data collected were managed and analyzed using Telemetry Manager, a program developed in Visual FoxPro by LGL Limited. Individual antennas were grouped into "zones" that define pivotal areas of interest, such as individual fishway entrances and exits.

5.3.1 Detections and Movements

The number of fish detected at each zone was summarized using the Telemetry Manager database. Each time a fish was detected in a zone, the duration of the detection event (the amount of time the fish spent in the zone) was calculated. The operational database was also used to map movements of fish among zones. For every combination of among-zone movements, the number of times a fish performed that movement was calculated, as was the amount of time it took to get from one zone to the next.

5.3.2 Passage Times and Ascent Rates

Passage times were calculated from benchmark dates and times corresponding to the first and last detection of a given radio-tagged lamprey at specific locations. At Wells Dam, the benchmark times for lamprey that passed the Project were:

1. first detection in the tailrace,
2. first detection at the fishway entrance (outside antenna),
3. last detection at the fishway entrance (inside antenna),
4. first detection at the 'Above Trap' zone,
5. first detection at the 'Below Video' zone,
6. first detection at the 'Above Video' zone,
7. first detection at the 'Video Bypass' zone,
8. last detection at the 'Video Bypass' zone,
9. first detection at the fishway exit, and
10. last detection at the fishway exit.

From these benchmark times, passage times were calculated for each radio-tagged lamprey for the following passage segments:

Segment	Time	Name
A)	1 to 2	Tailrace Passage time
B)	2 to 3	Entrance Passage time
C)	3 to 10	Fishway Passage time
D)	1 to 10	Project Passage time

Passage times were also calculated for segments of each fishway:

Segment	Time	Name
E)	3 to 4	Lower Fishway Passage time
F)	4 to 10	Upper Fishway Passage time

In addition, the upper fishway was further segmented, and passage times were calculated for the following:

Segment	Time	Name
G)	4 to 5	Above Trap to Below Video
H)	5 to 6	Below Video to Above Video
I)	6 to 9	Above Video to Exit
J)	9 to 10	Residence time in Exit zone

For fish that used the video bypass, the following passage times were calculated:

K)	5 to 7	Below Video to Video Bypass
L)	7 to 8	Residence time in Video Bypass zone
M)	7 to 9	Video Bypass zone to Exit

The residence and passage times for each radio-tagged lamprey were determined by working backwards through a sequence of detections. The fishway of ultimate passage and the respective passage time were determined by identifying a sequence of detections in the ascent of a fishway, starting with detections in a fishway exit zone.

5.3.3 Definition of Downstream Passage Events and Drop Back

A downstream passage event was defined as a tag that is detected at a fishway exit and subsequently detected in the tailrace or a fishway entrance without any detections at antennas monitoring the inside fishway zones. Drop back is defined as those tags in a fishway detection zone that are subsequently detected in zones directly downstream within the fishway.

5.3.4 Definition of Approach, Entrance, and Passage Efficiencies

For the purpose of analysis, a fishway was ‘approached’, if a lamprey was detected at the fishway entrance (by the antennas outside the entrance), or anywhere inside the fishway. A fishway was ‘entered’ if a lamprey was detected by the antenna on the inside of the fishway entrance, or anywhere inside the fishway. ‘Entrance Efficiency’ was defined as the proportion of fish that approached a fishway that subsequently entered it. ‘Fishway passage’ occurred when a lamprey that entered a fishway successfully exited into the forebay. Any fish that was detected at the fishway exit zone was considered to have successfully passed the dam. ‘Passage Efficiency’ was defined as the proportion of fish that entered a fishway that successfully reached the exit.

5.3.5 Video Bypass and Trapping Efficiency

Video bypass rates were calculated from the radio-tagged lamprey tracking histories. All lamprey that passed though the vicinity of the counting area were detected by the radio-telemetry equipment. They were detected either: 1) at the video counting detection zone; 2) in the video bypass detection zone; or 3) in both. No radio-tagged fish passed through the area undetected (i.e., no fish were detected farther upstream without being detected at one of these two zones). The total number of radio-tagged lamprey that passed through the area was known, and the video bypass rate was calculated as the proportion of the total that bypassed the counting station.

Trapping efficiency was assessed by dividing the number of fish caught in the traps by the number known to have encountered them. The number known to have encountered the traps included the number that was trapped, the number of radio-tagged fish that passed without being recaptured, and the number of ‘untagged’ fish that passed without being captured. The number of untagged fish that passed without being captured was estimated from the video-counting data: The timestamp assigned by the video-counting staff to each lamprey passing the count window was compared to the radio-detection data to determine how many of the observed fish were tagged and how many were untagged. Then, the number of untagged fish at the count window was divided by the video-bypass rate to calculate the total number of untagged lamprey in the upper fishway.

6.0 RESULTS

The study conducted in 2007 sufficiently addressed questions related to Objectives 1 through 4. The results from the 2007 report are detailed in the first annual report *Adult Pacific Lamprey Passage and Behavior Study (Adult Lamprey Passage Study): Wells Hydroelectric Project, FERC No. 2149* (LGL and DCPUD, 2008). The 2008 radio-tracking study was performed to address remaining questions related to entrance efficiency and collection gallery behavior (see LGL and DCPUD, 2008). The results from the second year of study are detailed in the results below.

6.1 Capture, Tagging, and Release of Lamprey

6.1.1 Trapping

Each adult lamprey trap was checked twice daily over the 75 day trapping period. In total, 206 fish were caught representing six identified species (see Table 6.1-1), including 22 jack Chinook salmon (*Oncorhynchus tshawytscha*), 38 Chinook smolts, 51 chub/suckers (peamouth *Mylocheilus caurinus,* chiselmouth (*Acrocheilus alutaceus*), and suckers (Catostomids)), 24 Pacific lamprey, 1 rainbow trout/steelhead smolt (*O. mykiss*), 54 northern pikeminnow (*Ptychocheilus oregonensis*), and 15 sockeye salmon (*O. nerka*). Roughly half (51%) of the catch was composed of chubs, suckers, and northern pikeminnow. Catches were highest in the third week of trapping (week ending 22 August, Table 6.1-1), largely due to a surge in northern pikeminnow catch. In 2008, 88% of the lamprey were removed during the morning trap checks (i.e., fish were captured overnight and early morning), and the majority of the Chinook (82%) and sockeye (100%) were removed during the afternoon trap checks.

Table 6.1-1 Total fish captured by species and week of trapping at Wells Dam, 2008.

	Week of trapping (end date)											
Fish taxa	8/8	8/15	8/22	8/29	9/5	9/12	9/19	9/26	10/3	10/10	10/17	Total
Chinook - jack		3	1	3	4	1	1	3	3	3		22
Chinook - smolt	2	1		7	9	10	3	3	3			38
Chub/Sucker	8	5	11	1	2	10	10	3		1		51
Pacific lamprey	1	3	6	6	2	5	1					24
Rainbow/steelhead					1							1
N. pikeminnow	3	1	32	1		3	5	3	4	1	1	54
Sockeye		6	7	1	1							15
Species unrecorded					1							1
Total	14	19	57	19	20	29	20	12	10	5	1	206

From 6 August to 17 September, a total of 24 lamprey were caught at Wells Dam (Table 6.1-1), including 13 in the east ladder, and 11 in the west ladder. All lamprey were in excellent condition at the time of capture except two: one individual with a damaged eye, and one individual with an open wound behind the dorsal fin. Eight of the collected individuals were recaptured radio-tagged lamprey from this study, with one fish recaptured twice. Recaptures were released into the fishway mid-ladder (7 fish) or into the collection gallery (1 fish). In one case, a recaptured lamprey was re-anesthetized to replace some missing sutures. Otherwise,

adequate healing from the surgery had occurred. Of the remaining 16 lamprey, 15 were radio-tagged.

From 12 August to 5 September, 25 lamprey were collected at Rocky Reach Dam and transported to Wells Dam. Twenty-three of these were of adequate size and tagged. Despite the additional handling and collection location, there were no obvious differences in tracking history that would suggest that Rocky Reach Dam lamprey behaved differently from those captured at Wells Dam. The mean length, weight and girth of lamprey from the two dams differed by 1.3% or less (length: $t_{38} = 0.79$, $P = 0.43$; weight: $t_{34} = 0.16$, $P = 0.87$; girth: $t_{37} = 0.29$, $P = 0.77$).

6.1.2 Tagging and Release

In 2008, thirty-eight lamprey were radio-tagged between 6 August and 19 September (Appendix A). These fish averaged 63.9 cm in total length (58-72 cm), and 0.38 kg in weight (0.30-0.56 kg). The girth of these fish averaged 10.1 cm, ranging from 9.1 to 12.0 cm. Sex was only determined for one female fish when oocytes were noticed during surgery. Total surgery time averaged 10.7 minutes (8-16 min), including an average 4.8 minutes (3-7 min) of heavy sedation and 5.9 minutes (4-11 min) of light sedation/surgery. Fish were held in the recovery tote for an average of 90.2 min (40-161 min). Fish generally showed immediate signs of recovery and appeared to be in vigorous condition prior to release.

Eighteen fish were released into the Wells Dam tailrace, and 20 fish were released into the fishway. Of the 18 tailrace fish, 9 were released into the east alcove (7 trapped in east ladder, 2 at Rocky Reach Dam), and 9 into the West Alcove (7 trapped in west ladder, 2 at Rocky Reach Dam). Of the remaining fish, 9 were released into the east collection gallery (all trapped at Rocky Reach Dam), 10 into the west collection gallery (1 trapped in west ladder, 9 at Rocky Reach Dam), and 1 into the West Fishway mid-ladder (trapped at Rocky Reach Dam).

6.2 Radio-tracking

Fixed stations were operated from the first week of August through the first week of November. Stations were downloaded at least weekly throughout the study period. A single receiver in the lower west fishway malfunctioned and was offline during the period 13 through 20 August, which could have resulted in missed detections at the fishway entrance. Otherwise, all stations were functional throughout the study.

Six boat-based mobile tracking events were performed in the Wells Dam tailrace (5 and 18 September; 2, 8 and 23 October; 12 November). Foot-based mobile tracking events around the dam were performed on 15 occasions over the duration of the study period (18, 20, 22, and 25 August; 1, 8, 12, 19, 22, 24, 26, and 29 September; 3, 6, and 8 October). Thirty-five detections of twenty-seven individual radio-tagged lamprey occurred during mobile tracking efforts (24 during boat-based tracks, and 11 during foot-based tracks). Two lamprey detected during mobile tracking were never detected by fixed station receivers.

6.2.1 Detections

All 38 radio-tagged lamprey were detected at some point subsequent to their release. The 38 radio-tagged lamprey were detected a total of 583 separate times at fixed and mobile stations. The duration of each detection ranged from a few hits over a couple seconds to as many as 24,168 hits over a 67.8-hour period (Fish 1 remained inactive outside the entrance of the left fishway from 25 to 28 August). The earliest fixed station detection occurred on 6 August (at 11 PM outside the entrance of the left fishway) and the last occurred 4 November (at 4 AM in the right side of the tailrace). The period of detections coincides approximately with the migratory activity of lamprey in the immediate area (lamprey observations at the fish counting window ranged from 11 July to 5 October).

6.3 Lamprey Movement and Passage Behavior

6.3.1 Movements

The 38 tagged lamprey made a total of 284 directional movements between detection zones subsequent to the first detection after release, averaging 7.5 moves per fish (range 0-39; Tables 6.3-1 to 6.3-3). The most frequent moves were between left and right tailrace arrays (Table 6.3-1), between the left inside entrance and the left collection gallery pier, and between the left Pier 1 and the upstream AWS (Table 6.3-2). Movements in the tailrace ranged from 3.3 minutes between the left tailrace and the left outside entrance, to 8.9 days between left tailrace and the zone outside the right fishway entrance (Table 6.3-1). Movements within the fishways ranged from 4 seconds in the left fishway between the inside entrance and the collection gallery pier zones, to 2.2 days in the left fishway between the ‘below trap’ and ‘above trap’ zones (Table 6.3-2).

Table 6.3-1 Duration of lamprey movements (h:mm:ss) within the tailrace at Wells Dam, by frequency of occurrence, 2008.

Direction	From (detection zone) → to (detection zone)	Count	Min	Max	Average
Up	Gateway → E. Tailrace	4	17:57:02	44:05:25	33:09:06
	Gateway → W. Entrance Out	1	119:34:47	119:34:47	119:34:47
	E. Tailrace → E. Entrance Out	3	03:19	16:11:52	5:27:23
	E. Tailrace → W. Entrance Out	1	214:52:18	214:52:18	214:52:18
	W. Tailrace → W. Entrance Out	1	45:14:22	45:14:22	45:14:22
Down	W. Entrance Out → W. Tailrace	1	11:32	11:32	11:32
	W. Entrance Out → E. Tailrace	3	2:41:43	194:07:17	66:54:35
	E. Entrance Out → W. Tailrace	1	21:40	21:40	21:40
	E. Entrance Out → E. Tailrace	3	55:11	25:44:26	9:44:08
	W. Tailrace → Gateway	3	1:38:41	1:46:31	1:41:35
	E. Tailrace → Gateway	2	2:14:13	2:16:27	2:15:20
Across	E. Tailrace → W. Tailrace	28	10:42	44:06:41	6:12:37
	W. Tailrace → E. Tailrace	23	05:04	49:53:03	11:30:05
	E. Entrance Out → W. Entrance Out	1	140:28:43	140:28:43	140:28:43

Table 6.3-2 Duration of lamprey movements (h:mm:ss) within the fishways at Wells Dam, by frequency of occurrence, 2008.

Direction	From (detection zone) → to (detection zone)	Count	Min	Max	Average
Up	E. Entrance In → E. Gallery	14	00:04	11:21	01:31
	E. Weir 1 → E. Weir 7	9	00:15	07:55	02:29
	E. Weir 1 → E. Gallery	2	00:25	01:55	01:10
	E. Weir 1 → E. AWS up	10	00:20	07:40	02:40
	E. AWS down → E. AWS up	2	58:51	1:20:41	1:09:46
	E. Weir 7 → E. Below Trap	8	1:39:23	4:24:55	2:37:45
	E. Gallery → E. AWS up	3	04:40	17:54	09:33
	E. Below Trap → E. Above Trap	3	27:19	52:53:53	17:58:09
	E. Above Trap → E. Below Video	2	1:55:32	13:53:35	7:54:33
	E. Above Trap → E. Above Video	1	1:32:02	1:32:02	1:32:02
	E. Below Video → E. Video Bypass	2	05:30	06:05	05:48
	E. Above Video → E. Fishway Exit	2	16:39	1:26:25	51:32
	E. Video Bypass → E. Fishway Exit	1	49:09	49:09	49:09
	W. Entrance In → W. Gallery	4	00:20	10:50:51	2:44:34
	W. Weir 1 → W. Weir 7	2	01:07	05:35	03:21
	W. Weir 1 → W. Gallery	2	00:29	01:30	01:00
	W. Weir 1 → W. AWS up	3	03:02	25:45	13:31
	W. Weir 7 → W. Gallery	1	01:00	01:00	01:00
	W. Weir 7 → W. Below Trap	2	3:31:25	5:19:23	4:25:24
	W. Below Trap → W. Above Trap	1	11:53:14	11:53:14	11:53:14
	W. Above Trap → W. Below Video	1	2:45:15	2:45:15	2:45:15
	W. Below Video → W. Video Bypass	1	02:10	02:10	02:10
	W. Video Bypass → W. Fishway Exit	1	29:29	29:29	29:29
Down	E. Video Bypass → E. Above Video	1	02:45	02:45	02:45
	E. Below Trap → E. AWS up	2	12:56:04	20:18:03	16:37:03
	E. Below Trap → E. Gallery	1	1:49:51	1:49:51	1:49:51
	E. Below Trap → E. Weir 7	1	23:23	23:23	23:23
	E. AWS up → E. Gallery	4	00:20	21:07	07:14
	E. AWS up → E. AWS down	1	1:21:57	1:21:57	1:21:57
	E. AWS up → E. Weir 1	12	00:10	18:09	03:19
	E. Gallery → E. AWS down	2	10:14	16:42	13:28
	E. Gallery → E. Weir 1	6	00:25	03:16	01:08
	E. Gallery → E. Entrance In	16	00:04	02:45	00:23
	E. Weir 7 → E. Weir 1	2	02:35	05:00	03:48
	E. AWS down → E. Entrance In	1	01:30	01:30	01:30
	W. Below Trap → W. Weir 7	2	10:47	13:37	12:12
	W. AWS up → W. Weir 1	3	02:00	04:00	02:54
	W. Gallery → W. Weir 1	4	00:30	03:19	01:30
	W. Gallery → W. Entrance In	4	00:05	3:53:43	58:51
	W. Weir 7 → W. Weir 1	2	01:50	03:40	02:45
	W. Weir 1 → W. Entrance In	1	05:50	05:50	05:50

Table 6.3-3 Duration of lamprey movements (h:mm:ss) between the tailrace and fishways at Wells Dam, by frequency of occurrence, 2008.

Direction	From (detection zone) → to (detection zone)	Count	Min	Max	Average
Down	E. Gallery → E. Entrance Out	1	00:10	00:10	00:10
	E. Entrance In → E. Entrance Out	6	00:05	23:46:57	3:58:06
	E. Entrance In → W. Tailrace	1	365:00:31	365:00:31	365:00:31
	E. Entrance In → E. Tailrace	1	00:03	00:03	00:03
	W. Entrance In → W. Entrance Out	6	00:04	07:31	02:51
Up	E. Tailrace → E. Entrance In	1	01:54	01:54	01:54
	E. Entrance Out → E. Entrance In	4	00:05	03:27	00:55
	W. Entrance Out → W. Entrance In	4	01:55	24:33	09:04
	W. Entrance Out → E. AWS up	1	99:18:43	99:18:43	99:18:43

6.3.2 Fishway Passage Metrics

Entrance and Passage Efficiency

Tailrace releases

Of the 18 lamprey released into the tailrace, five were stationary throughout the study period, and were presumably mortalities or shed tags. An additional lamprey was only detected twice, and yielded insufficient data for characterization of movements. The remaining 12 lamprey were examined for entrance and passage efficiency.

Over the study period, 11 of the 12 (91.7%) 'active' tailrace-released lamprey approached a fishway entrance. Several of the lamprey made multiple approaches (maximum for one fish was 3), and a total of 17 separate approaches occurred at the west (n = 6) and east (n =11) fishways. The fishway entrance that was approached was significantly associated with the tailrace side on which the lamprey was released ($\chi^2 = 6.8$, df = 1, Fisher's exact test $P = 0.018$). Specifically, the eastern releases approached the east fishway 9 times, and the west fishway once; whereas the western releases approached the east fishway 2 times, and the west fishway 5 times (note that lamprey trapped at Wells Dam were released on the same side of the tailrace as the ladder in which they were caught, thus it was impossible to separate the effects of capture location from those of release location when assessing entrance rates).

Only two tailrace-released lamprey successfully entered a fishway collection gallery (one on the east side, one on the west side), as indicated by detections on the antenna located on the inside of the fishway entrance.

Fishway releases

Of the 20 lamprey released into the fishway, three fish either died or shed their tags based upon insufficient detections for characterization of their tracks. Passage efficiency was evaluated for the remaining lamprey. Of the 17 'active' fishway-released lamprey, 4 passed the dam (23.5%), with the remaining fish either rejecting the fishway (many of which did so after encountering the trapping area) or ceasing migration. One of these lamprey (Tag #6) moved downstream out of the fishway, re-entered, commenced an ascent, encountered the trap, dropped back to 'Weir 1', then resumed its upstream movements and ascended successfully. Two of the successful lamprey ascended the fishway upon release (Tags #2 and #8), were recaptured en-route, and resumed their ascent upon re-release. The last of these lamprey (Tag #22) successfully ascended the fishway without being recaptured en route.

Seven of the remaining 'active' lamprey ascended the fishway at least as far as the 'below trap' zone, but were ultimately not successful at dam passage. Two of these seven fish (Tags #7 and #9) ascended to the 'below trap' zone, and then dropped back out of the fishway (Tag #7 dropped out directly; Tag #9 dropped back to the first turn for 53 days, and took a total of 73 days to reach the tailrace). Three others (Tags #18, #25 and #32) ascended to the trap, were recaptured, were released into the fishway mid-ladder, and then dropped out of the fishway (Tag #18 was back into the tailrace within 18 minutes of release; Tag #25 dropped back into the AWS/'Weir 1' area where it was detected for 8 days and then disappeared; Tag #32 dropped back into the collection gallery, milled in the collection gallery, and then exited into the tailrace over 37 hours after release). Another lamprey (Tag #4) ascended to the trap, was recaptured, re-released in the collection gallery, resumed its ascent until it reached the 'below trap' zone, and then dropped back out of the fishway. The last of these lamprey (Tag #3) exited into the tailrace upon release, but later re-entered, started ascending the fishway, was recaptured, released, recaptured again, re-released, and then dropped back out into the tailrace.

The remaining six 'active' lamprey exited into the tailrace without ascending the ladder. These six lamprey took from < 1 hr to 2.6 d to leave the fishway into the tailrace. Their farthest upstream detection zones were 'Weir 1' (Tag #5), the collection gallery pier (Tags #26, #27 and #28), or the entry zone (Tags #10 and #31). One of these six subsequently re-entered the fishway, reached only as far as the 'entry inside' zone, and was back in the tailrace within half a minute.

Efficiencies

A total of 25 'active' lamprey were tracked in the tailrace during the study period (12 released there, 13 dropped back there after being released into the fishway). Of these, 15 approached a fishway entrance (11 tailrace releases, and 4 fishway releases) at least once, and 5 entered successfully (2 tailrace releases, and 3 fishway releases). This resulted in an entrance efficiency of 33% (18% for tailrace releases, 75% for fishway releases). The low sample size precluded meaningful comparisons of success rate between the west and east fishway entrances.

Each of the four fish that entered the upper fishway subsequently exited the fishway into the forebay. Thus the upper fishway passage efficiency was 100%.

Complete Fishway Passage

One fish (Tag #6) made a complete ascent of the east fishway (Appendix A). This fish was released into the east collection gallery, and within 8 hours had dropped out into the tailrace. It then returned to the fishway, and took 3.6 hours to move as far as the 'below trap' zone. It subsequently dropped back down into the collection gallery (possibly through the AWS), and it took 22.4 hours before it resumed its ascent. During this second attempt, the fish took 3 hours to reach the upper fishway. After an additional 2.5 hours passed, it had exited the fishway into the forebay.

Lower Fishway Passage

A total of 19 'active' lamprey were tracked through the lower fishways (17 'active' fishway releases, and 2 tailrace fish that entered volitionally). Examination of the detection histories of these fish revealed a total of 20 sequences that included drop back (Table 6.3-4). In one sequence, a fish (Tag #3) was released mid-ladder (above the trap) after recapture, it moved downstream and was recaptured a second time. In another sequence, a fish (Tag #25) was released mid-ladder after recapture, it moved down to the AWS/'Weir 1' area, and was not detected 8 days later (its fate is unknown). There were ten instances in which a fish moved directly downstream and out of the fishway upon release (7 had been released into the collection gallery, and 3 had been released mid-ladder after recapture). There were eight instances in which a fish was moving upstream, but then dropped back. In six of these instances, the fish dropped all the way into the tailrace (two had reached the 'below trap' zone, one had reached Weir 1, one had reached the 'collection gallery pier' zone, and two had gotten only as far as the entrance). In the other two instances, the fish reached the 'below trap' zone, and then dropped to either Weir 1 (this fish later resumed ascent and passed into the forebay), or to the first turn in the fishway (this fish waited 53 days then resumed its drop back into the tailrace).

Table 6.3-4 Types (and numbers) of observed drop back movements in the lower fishways of Wells Dam, 2008.

			Duration (d)		
Direction	Drop back Sequence	n	Min	Max	Average
Downstream	Release → out	7	0.00	2.59	0.56
	Re-release → out	3	0.01	1.55	0.53
	Re-release → vanish	1	8.61	8.61	8.61
Down, then Upstream	Re-release, drop to trap, recap	1	0.00	0.00	0.00
Up, then Downstream	Moved upstream to Below Trap → Weir 1	1	0.00	0.00	0.00
	Moved upstream to Below Trap → 1st Turn	1	53.17	53.17	53.17
	Moved upstream to Below Trap → out	2	0.00	0.73	0.37
	Moved upstream to Weir 1 → out	1	0.08	0.08	0.08
	Moved upstream to Gallery Pier → out	1	0.00	0.00	0.00
	Moved upstream into the Entry → out	2	0.00	0.00	0.00

A majority (12 of 14, or 85.7%) of radio-tagged lamprey that encountered the trapping area were effectively blocked, indicated by either a recapture (8 fish) or by drop back (4 fish were subsequently detected on downstream receivers). The remaining lamprey (2 fish) passed the trapping area without being captured (both successfully ascended the fishway).

The trapping area caused problems for lower fishway passage. Passage success from release to the 'above trap' zone was 21% (4 of 19 lamprey), yet 58% of the lamprey successfully ascended as far as the 'below trap' zone. Median passage time from release to the 'above trap' zone was 1.8 d (range 0.4 – 2.9 d; n= 4), including time spent in traps, and time spent dropping back and recovering from encounters with traps. In contrast, median passage time during periods of committed upstream movement (measured from the collection gallery pier to the 'below trap' zone) was 3.2 h (range 1.7 – 5.5 h; n = 8).

Upper Fishway Passage

A total of four tagged lamprey successfully ascended through an upper fishway (3 in the east ladder, 1 in the west ladder) at Wells Dam in 2008. One fish (Tag #2) was released on 13 August into the west collection gallery. It was later recaptured, and on 15 August it was re-released mid-ladder. It resumed its ascent, and reached the fishway exit on 16 August. Another fish (Tag #6) was released into the east collection gallery on 15 August. On 16 August, it dropped out of the fishway into the tailrace, on 17 August, it re-entered, ascended to the trap area, and then dropped back to 'Weir 1', and on 18 August, it resumed its ascent and exited the fishway. A third fish (Tag #8) was released into the east collection gallery on 15 August. It was recaptured on 16 August, re-released on 18 August, and exited the fishway on 19 August. The fourth fish (Tag #22), released into the east collection gallery on 3 September, progressed upwards and exited on 4 September.

Upper fishway passage times for the four successful fish, in ascending order, were 2.6, 3.4, 3.7 and 15.1 hours (Table 6.3-5). Given that the upper fishway is comprised of 27 pools, these passage times translate into average ascent rates of 5.7, 7.6, 8.3 and 33.6 minutes per pool. One lamprey was notably slower than the other three. Examination of passage times within individual fishway segments (Table 6.3-6) showed that biggest difference between the slow and fast lamprey occurred in the 'above trap' to 'below video' reach, which took the slow lamprey ~14 h to pass, and which the fast fish passed in 2-3 h. The slow lamprey's travel times through other reaches of the upper fishway were similar to those of the three other fish (Table 6.3-6). Three of the four lamprey were detected in the video bypass zone, but none showed the prolonged delays that were observed for some fish in the bypass in 2007 (LGL and DCPUD, 2008): in 2008, lamprey passage times between the first detection in the bypass and the first detection at the fishway exit ranged from 19.5 to 49.5 minutes (Table 6.3-6). The slow lamprey was the only one of the four fish whose upper fishway passage included daylight hours. As lamprey are nocturnal, the extended period of time required for this fish to reach the 'below video' detection zone could have included some daylight hours spent resting. This same fish passed the above video zone just after midnight, and quickly passed through the remaining part of the upper fishway in a few night-time hours.

Table 6.3-5 Benchmark times during upper fishway passage for radio-tagged lamprey that successfully passed Wells Dam, 2008.

		Benchmark Times						Upper
Tag	Fish-way	1st detection Above Trap	1st detection Below Video	1st detection at Video Bypass	1st detection Above Video	1st detection at Exit	Last detection at Exit	Fishway Passage time (h)
2	West	15 Aug 21:44	16 Aug 0:36	16 Aug 0:42	-	16 Aug 1:19	16 Aug 1:28	3.7
6	East	18 Aug 2:21	18 Aug 4:22	18 Aug 4:28	18 Aug 4:31	18 Aug 4:48	18 Aug 4:56	2.6
8	East	18 Aug 10:45	19 Aug 0:44	19 Aug 0:50	-	19 Aug 1:39	19 Aug 1:54	15.1
22	East	3 Sep 23:13	-	-	4 Sep 0:54	4 Sep 2:23	4 Sep 2:37	3.4

Table 6.3-6 Segmented upper fishway passage times (h:mm:ss) of radio-tagged lamprey that successfully passed Wells Dam, 2008.

		Passage Times					
Tag	Fish-way	Above Trap → Below Video	Below Video → Video Bypass	Previous zone → Above Video	Previous zone → Exit	Residence at Exit	Total
2	West	2:52:40	0:05:55	-	0:36:14 [c]	0:09:34	3:44:23
6	East	2:00:22	0:06:39	0:02:55 [a]	0:16:39 [d]	0:08:30	2:35:05
8	East	13:59:20	0:05:30	-	0:49:29 [c]	0:14:39	15:08:58
22	East	-	-	1:41:28 [b]	1:28:30 [d]	0:14:14	3:24:12

a: video bypass to above video; b: above trap to above video; c: video bypass to exit; d: above video to exit.

Upper fishway passage times can be divided into four segments: 1) the time between the first detection at the above trap antenna and the first detection at the below video count window antenna (17 pools: Pools 47-63); 2) the time between the first detection at the below video count window antenna and the first detection at the above video count window antenna (Pool 64); 3) the time between the first detection at the above video count window antenna and the first detection at the exit (8 pools: Pools 65-72); and, 4) the time between the first detection at the exit and the last detection at the exit (Pool 73). The first segment of the fishway (between the above trap and below video count window antennas) includes 17 of the 27 (63%) pools, and accounted for 77-92 % of the total upper fishway passage times (n=3, Table 6.3-7). Ascent rates in this segment were slower than the overall upper-fishway ascent rates for each lamprey (Table 6.3-8). The time spent in the second segment (between the below video and above video antennas), accounted for 2% of the total upper fishway passage time for the one fish that was detected in both zones (Tag #6; Table 6.3-7). The ascent rate (2 min/pool) for the fish in this segment was faster than its overall upper-fishway ascent rate (5.7 min/pool; Table 6.3-8). Time spent in segment three (between the first detection at the above video count window antenna and the first detection at the exit) accounted for 11 to 43% of the total upper fishway passage time (n = 2; Table 6.3-7), and ascent rates (2 and 11 min/pool) were faster than the overall upper-fishway ascent rates for each lamprey (Table 6.3-8). Time spent in the last segment (within the detection zone of the fishway exit antenna) accounted for 2 to 7% of the total upper fishway passage time (n = 4; Table 6.3-7), and all four fish passed through the zone in under 15 minutes (Table 6.3-8). Ascent rates in this segment ranged from 8 to 14 min/pool (Table 6.3-8).

Table 6.3-7 Segmented upper fishway passage times, shown as a percent of the total passage time for each individual, 2008.

		Percent of Total Passage Times					
Tag	Fish-way	Above Trap → Below Video	Below Video → Video Bypass	Previous zone → Above Video	Previous zone → Exit	Residence at Exit	Total
2	West	77%	3%	-	16% [c]	4%	100%
6	East	78%	4%	2% [a]	11% [d]	5%	100%
8	East	92%	1%	-	5% [c]	2%	100%
22	East	-	-	50% [b]	43% [d]	7%	100%

a: video bypass to above video; b: above trap to above video; c: video bypass to exit; d: above video to exit.

Table 6.3-8 Ascent rates in segmented upper fishway reaches, by individual, 2008.

		Ascent Rate (minutes per pool)				
Tag	Fish-way	Above Trap → Below Video	Below Video → Above Video	Above Video → Exit	Residence at Exit	Total
2	West	10.1	-	-	9.0	8.3
6	East	7.1	2.0	2.0	8.0	5.7
8	East	49.4	-	-	14.0	33.6
22	East	-	-	11.0	14.0	7.6

Video Bypass

In total, four radio-tagged fish passed through the upper fishway. Radio-detections indicated that 3 of the 4 lamprey bypassed the video counting area. The one fish that was detected passing through the video area was in fact counted by the video-data processors. These results indicate that the video-processing is accurate (n = 1) when the fish pass in front of the counting window, but that ~75% of the lamprey do not pass through the field of view. Note that with low sample sizes, one cannot be confident in the precision of the estimates of video-processing accuracy or the video bypass rate, although these results correspond with findings in 2007 (73% bypass rate).

Trapping Efficiency

Trapping efficiency was assessed by dividing the number of fish caught in the traps by the number known to have encountered them. Trapping efforts resulted in 24 lamprey being caught at Wells Dam (16 untagged fish were trapped; and 8 radio-tagged fish were recaptured). In addition, 2 radio-tagged fish passed the trapping area without being caught.

Additionally, several 'untagged' lamprey passed the trap without being caught. Of the 6 lamprey that were recorded by the video-counting staff during the trapping period (2 August to 15 October), one passed at the same time as a radio-tagged fish and was likely the same individual. These data suggest that a minimum of 5 lamprey passed the traps without being captured (thus maximum trapping efficiency = 77%), but the true number should be calculated by dividing this number by the video bypass rate. Since the video bypass rate was relatively uncertain in 2008 (based on a sample size of 4 lamprey), the total trapping efficiency could not be calculated with much certainty. By using 75% as the video-bypass rate, the number of untagged lamprey that passed the traps without being caught would be 20, and the total trapping efficiency would be 52%.

Successful Fishway Passage

Four radio-tagged lamprey successfully passed the dam. All four had been trapped at Rocky Reach Dam. Three were released in collection gallery of the east fishway, and one was released in the collection gallery of the west fishway. No downstream passage events were observed during the monitoring period.

Two of the four successful lamprey were later detected entering the Methow River by Douglas PUD fixed stations or USFWS mobile tracking efforts. One fish (Tag #2) reached the fishway exit on 16 August, was detected entering the Methow River on 21 August, and was last detected on 20 September at the mouth of the Chewuch River. Another fish (Tag #6) exited the fishway on 18 August, was detected entering the Methow River on 20 August, and was last detected downstream of Libby Creek on 29 October.

7.0 DISCUSSION

Discussion of Objectives 1 through 4 is detailed in the 2007 report entitled: *Adult Pacific Lamprey Passage and Behavior Study (Adult Lamprey Passage Study): Wells Hydroelectric Project, FERC No. 2149* (LGL and DCPUD, 2008). The 2008 study specifically focused on Objectives 5 and 6.

7.1 Objective 5: Where Sample Size is Adequate, Estimate Passage Metrics Including Fishway Passage Times and Efficiencies, Residence Time Between Detection Zones, and Downstream Passage Events and Drop Back

Thirty-eight adult lamprey were radio-tagged and released at Wells Dam in 2008 in order to supplement sample size and adequately address the last two objectives of the Adult Lamprey Passage Study. Twenty-one lamprey were tagged in 2007, bringing the two-year total to 59 lamprey; 19 more than the original target in the FERC approved study plan for adult lamprey (LGL and DCPUD, 2008). Fifteen lamprey were tracked in the tailrace near a fishway entrance during 2008, raising the two-year total for assessing entrance efficiency to 22 fish. Four fish ascended through the upper fishway into the Wells Dam forebay during 2008, raising the total sample size for assessing upper fishway passage metrics to 15 fish.

Median passage times through the fishways were fast, especially when excluding daylight hours during which the nocturnal lamprey are less active. The only lower fishway ascent in 2007 took 6.1 h (LGL and DCPUD, 2008), and, though lower fishway ascents were hindered by trapping in 2008, the median time from the collection gallery pier to the 'below trap' zone was 3.2 h. Median upper fishway passage times were 7.9 h in 2007 (LGL and DCPUD, 2008), 3.6 h in 2008, and 6.7 h altogether (n=15). When passage only included night-time hours, median upper fishway passage times were 6.3 h in 2007 (LGL and DCPUD, 2008), 3.4 h in 2008, and 5.2 h altogether (n = 11). Total fishway passage time in 2007 and 2008 took 31.5 h and 32.7 h, respectively (though the ascent in 2007 took only 12.5 h, if time spent at the trapping area was excluded; LGL and DCPUD, 2008). These passage times are excellent compared to studies at other Columbia Basin dams, where median passage times ranged up to 7.6 days (Keefer et al., 2008). These results suggest that once inside the fishway, adult lamprey are able to sufficiently negotiate Wells Dam.

Metrics used to determine potential impediments of the adult lamprey migration through Wells Dam included: approach rate; and entrance, lower fishway, and upper fishway passage efficiencies. Lamprey in the tailrace made multiple approaches to fishway entrances both years, indicating that tailrace conditions and ability to locate the fishways were not a limiting factor to passage success. However, entrance efficiencies ranged from 14% in 2007 (LGL and DCPUD, 2008) to 33% in 2008, for a two-year average of 27%. This result is higher than observed at Bonneville Dam in 2008 (6 to 32%), lower than results from Priest Rapids in 2001-2002 (56%; Nass et al. 2003), and lower than estimates observed at Ice Harbor and McNary in 2007 (59.1% and 61.5% respectively; Cummings et al. 2008).

In 2008, three of the five 'successful entrants' rejected the fishway within ~30 minutes of entry, indicating that lamprey are having difficulty negotiating the fishway entrance. Lower fishway passage efficiency was 33% over the two-year study, though trapping operations in 2008 substantially biased lower fishway performance. The installation of perforated orifice plates for the 2008 season increased trap effectiveness as intended, but the modification also obstructed normal fishway ascent. Twelve of the fourteen lamprey (86%) that encountered the trapping area were ultimately blocked, and 50% of all upstream-moving detection sequences that ended in a drop back did so below the trap. Upper fishway passage success was 100% for the second consecutive year, and no drop back was observed in this part of the fishway (two-year total = 15 fish). This suggests that lamprey are capable of negotiating the upper fishway with a high level of success. Wells Dam fallback rates following fishway exit (0% over 2 years; n = 15) were superior to those reported downstream, such as 17% at John Day Dam (Moser et al., 2002b), or 19% at Bonneville Dam (Johnson et al., 2008). Collectively, these results indicate that passage impediments within the fishways at Wells Dam are largely restricted to the entrance.

Despite these insightful results, there are new and substantive reasons to believe that radio-tagged lamprey do not represent behavior of untagged individuals. New research indicates that past laboratory studies often referenced to justify radio-tagging methodology as benign (Close et al., 2003; Mesa et al., 2003) failed to identify the significance of surgical radio-tag implantation on lamprey swimming performance in field applications. Recent technological advances have allowed researchers to use tagging systems that are much smaller and do not require extensive surgical procedures. These advances are allowing researchers to develop more detailed investigations of potential tag effects in a field setting. For example, Keefer et al. (2008) found that overall passage efficiency at Bonneville Dam was 22% for radio-tagged lamprey (n = 298), compared to 52% for HD PIT-tagged fish (n = 610). These results suggest that radio-telemetry tags substantially affect swim performance. Further, Moser et al. (2007) found that radio-tagged lamprey at lower Columbia dams had approach times and passage success rates that were significantly related to percent tag mass (relative to lamprey mass) and percent tag girth (relative to lamprey diameter). Based on results of their relatively large field study (> 800 fish), Moser et al. (2007) concluded that "the effect of prolonged swimming with relatively large transmitters may have resulted in eventual abandonment of migration or even death…" At Wells Dam, at least 24% of radio-tagged lamprey displayed either a lack of movement (potentially tag shed or mortality) or an absence of detections (indicating uncharacteristic movement out of the study area or tag failure). This relatively high proportion of uncharacteristic detection histories suggests that handling and surgical tagging had a considerable effect on lamprey performance in this study. Moreover, latent tagging effects, such as those described by Moser et al. (2007), may have impacted the performance of the 29 radio-tagged lamprey that were included in calculation of passage metrics, thus biasing results to underestimate passage success and to overestimate passage impediments.

Distance upstream, as related to fish bioenergetics, and seasonality are two additional factors that also should be considered when comparing results to those reported in previous studies at downriver dams. For example, the research conducted at Lower Columbia River dams that led to the establishment of the '~ 50% passage standard' of adult lamprey selectively tagged only the largest adult lamprey collected from the traps at Bonneville Dam. Moser et al. (2005) reported "due to the abundance of lamprey in 2002, we selected the largest fish to minimize tag effects."

The fish used for these studies had a mean weight from 590 g (males) to 627 g (females), and roughly 50% of all tagged fish had girths ≥ 12.5 cm. In comparison, lamprey tagged at Wells Dam averaged 369 g (range 270-560 g) and 10.2 cm in girth (range 9-12 cm). Fish captured at Wells Dam have substantially lower energetic reserves (i.e., thinner fish) due to the distance travelled (370 miles upstream of Bonneville) and the energy used to pass seven additional hydroelectric projects prior to capture. Though researchers are currently exploring the relationship between bioenergetics and passage success in lamprey (Ho et al., 2008), a positive correlation between fish size and swimming performance has already been identified (Moser et al., 2007). Further, different median passage dates at Bonneville Dam (week 31, average temperature = 21.1 °C, increasing temperature regime) compared to Wells Dam (week 37, average temperature = 19.0 °C, decreasing temperature regime) have implications for lamprey migratory behavior, especially as it relates to water temperatures and the time at which migration pauses for the winter (years 2000-2007 from DART, 2008; Groves, 2001). Therefore, radio-telemetry studies of lamprey behavior at Wells Dam is likely substantially more susceptible to tag induced bias when compared to studies conducted at downriver dams with larger and healthier fish.

7.2 Objective 6: If Necessary, Identify Potential Areas of Improvement to Existing Upstream Fish Passage Facilities for the Protection and Enhancement of Adult Lamprey at the Wells Project

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. Data collected during the Fish Passage Center's (FPC, 2008) Fish Facility Inspections at Wells Dam indicated that the head differential averages 0.46 m (range 0.30 to 0.58 m) at both fishway entrances, which produces average velocities in the vicinity of 3.0 m/s (as high as 3.4 m/s; R. Wielick, PE, Jacobs, personal communication). These values are considerably higher than averages from other downstream dams, with lower velocity entrances generally having better entrance efficiencies (FPC, 2008). For example, entrance efficiency measured at Bonneville using the same technology and run of fish as research at Wells Dam ranged from 6 to 32% (Keefer et al. 2008), while velocities from the numerous, and unique, entrances ranged from 2.2 m/s to over 3.6 m/s based on velocity calculations from fishway inspections conducted in 2008 (FPC, 2008). Entrance success documented at Bonneville Dam was clearly lower at higher velocity entrances (e.g., Washington shore entrances). Mesa et al. (2003) estimated the critical swimming speed of radio-tagged lamprey at 0.82 m/s. Similarly, Daigle et al. (2005) reported swimming ability of lamprey from previous studies ranging from sustainable speeds of 0.9 m/s up to bursts of 2.1 m/s. Entrance tests performed by Daigle et al. (2005) showed no lamprey passing through a simulated fishway entrance with 0.46 m of head differential (though lamprey have clearly entered Wells Dam fishways under similar conditions), ultimately stating that "the single most important factor affecting passage success appeared to be water velocity." A reduction in velocity in the Wells Dam fishway could significantly improve lamprey entrance efficiency. The reduction could be restricted to the fishway entrance (i.e., not the remaining portion of the fishways) and nighttime hours during the lamprey migratory period (August to September).

An equally significant impediment to successful passage of adult lamprey at Wells Dam in 2008, but not in 2007, was the installation of perforated plates on the floor of the weir orifices in an effort to increase trapping efficiency. When comparing results between 2007 and 2008 it is apparent that the addition of the perforated plates did increase trapping efficiency but was also responsible for reducing the number of fish recruiting into the upper fishway, decreasing lower fishway passage efficiency. Removal of the perforated plates in the orifice passage ways and reduction or elimination of mid-ladder trapping efforts should provide an improved route of passage for lamprey and will likely enhance upstream passage rates observed in unobstructed areas of the fishway with identical flow characteristics (e.g., upper fishway = 100% passage success over both years).

8.0 RECOMMENDATIONS

The following recommendations are based on results detailed in this report:

- 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 such as half-duplex PIT tags, DISDON and other less intrusive monitoring techniques that 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 and energetic limits.

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Appendix A

Lamprey Tagged at Wells Dam, 2008

Table A1-1 Summary of tagged lamprey release, passage times (h:mm), and location last detected.

Tag #	Release Date	Release Location	Passage times Upper	Lower	Total	Bypass	Last Location	Notes
4	8/13	East Gallery					East Tailrace	recaptured once
5	8/15	East Gallery					West Tailrace	
6	8/15	East Gallery	2:35	28:53	31:28	Yes	Methow	complete ascent
8	8/15	East Gallery	15:08			Yes	Exit	recaptured once
22	9/3	East Gallery	3:24			No	Exit	
25	9/5	East Gallery					East AWS Up	recaptured once
26	9/5	East Gallery					East Tailrace	
27	9/5	East Gallery					East Tailrace	
28	9/5	East Gallery					East Tailrace	
2	8/13	West Gallery	3:44			Yes	Methow	
3	8/13	West Gallery					East Tailrace	recaptured twice
7	8/15	West Gallery					East Tailrace	
9	8/15	West Gallery					W. Entrance	
10	8/15	West Gallery					W. Entrance	
18	8/27	West Gallery					W. Entrance	recaptured once
31	9/6	West Gallery					West Tailrace	
32	9/6	West Gallery					West Tailrace	recaptured once
1	8/6	East Alcove					East Tailrace	
13	8/18	East Alcove					East Tailrace	
19	9/3	East Alcove					W. Entrance	
20	9/3	East Alcove					East Tailrace	
21	9/3	East Alcove					East Tailrace	
36	9/10	East Alcove					West Tailrace	
37	9/12	East Alcove					East Tailrace	
38	9/19	East Alcove					West Tailrace	
16	8/22	West Alcove					East Tailrace	
23	9/3	West Alcove					East Tailrace	
24	9/3	West Alcove					West Tailrace	
30	9/5	West Alcove					West Tailrace	

Table A1-2 Summary of tagging and biometric data for each lamprey radio-tagged at Wells Dam, 2008.

TAG No.	Tag Chan.	Tag Code	Capture Date	Capture Ladder	Trap	Tag Date	TL (cm)	Weight (kg)	Girth (cm)	Start Heavy Anesth.	Start Surg.	Start Recov.	Release Time	Release Location
1	1	131	8/6	East	Trap 4	8/6	58.0	0.334	-	15:43	15:47	15:55	17:03	E. Alcove
2	1	132	8/12	R. Reach	R. Reach	8/13	65.0	0.386	10.5	10:45	10:50	11:01	12:10	W. Gallery
3	1	133	8/12	R. Reach	R. Reach	8/13	64.0	-	10.5	11:18	11:23	11:30	12:10	W. Gallery
4	1	134	8/12	R. Reach	R. Reach	8/13	68.0	0.438	10.5	11:33	11:37	11:46	12:52	E. Gallery
5	1	135	8/14	R. Reach	R. Reach	8/15	63.0	0.342	9.5	10:50	10:56	11:03	13:31	E. Gallery
6	1	136	8/14	R. Reach	R. Reach	8/15	64.0	0.340	9.7	10:59	11:05	11:15	13:30	E. Gallery
7	1	137	8/14	R. Reach	R. Reach	8/15	72.0	0.516	11.5	11:16	11:22	11:29	14:10	W. Gallery
8	1	138	8/14	R. Reach	R. Reach	8/15	68.0	0.408	10.0	11:36	11:41	11:47	13:30	E. Gallery
9	1	139	8/14	R. Reach	R. Reach	8/15	65.0	0.406	10.2	11:55	12:01	12:06	14:10	W. Gallery
10	1	140	8/14	R. Reach	R. Reach	8/15	64.0	0.336	9.3	12:11	12:18	12:24	14:10	W. Gallery
11	1	141	8/14	East	Trap 3	8/15	59.0	0.352	9.9	12:44	12:49	12:54	14:45	E. Alcove
12	1	142	8/17	West	Trap 2	8/18	61.0	0.334	9.5	11:24	11:27	11:35	12:35	W. Alcove
13	1	143	8/18	East	Trap 4	8/18	62.0	0.334	9.5	11:37	11:42	11:47	13:03	E. Alcove
14	1	144	8/19	West	Trap 1	8/20	60.0	0.310	9.2	9:48	9:54	10:00	11:00	W. Alcove
15	1	145	8/21	West	Trap 2	8/22	66.0	0.410	10.2	9:35	9:39	9:44	11:00	W. Alcove
16	1	146	8/22	West	Trap 2	8/22	63.0	0.372	10.0	9:46	9:50	9:56	11:00	W. Alcove
17	1	147	8/23	West	Trap 2	8/25	67.0	0.476	11.1	10:28	10:33	10:38	11:40	W. Alcove
18	1	148	8/26	West	Trap 1	8/27	67.0	0.432	10.4	10:00	10:05	10:11	11:11	W. Gallery
19	1	149	9/3	East	Trap 4	9/3	62.0	0.346	9.5	10:39	10:43	10:48	13:06	E. Alcove
20	224	50	9/2	R. Reach	R. Reach	9/3	62.0	0.338	9.5	10:50	10:55	11:01	13:06	E. Alcove
21	224	51	9/2	R. Reach	R. Reach	9/3	61.0	-	10.0	11:01	11:06	11:13	13:06	E. Alcove
22	224	52	9/2	R. Reach	R. Reach	9/3	70.0	0.556	12.0	11:14	11:19	11:24	12:50	E. Gallery
23	224	53	9/2	R. Reach	R. Reach	9/3	62.0	0.296	9.4	11:46	11:50	11:55	13:34	W. Alcove
24	224	54	9/2	R. Reach	R. Reach	9/3	63.0	0.360	10.1	11:56	12:02	12:06	13:34	W. Alcove
25	224	55	9/4	R. Reach	R. Reach	9/5	65.0	0.392	10.0	11:10	11:16	11:20	13:25	E. Gallery
26	224	56	9/4	R. Reach	R. Reach	9/5	63.0	0.394	10.1	11:22	11:26	11:31	13:26	E. Gallery
27	224	57	9/4	R. Reach	R. Reach	9/5	63.0	0.396	10.4	11:33	11:40	11:45	13:30	E. Gallery
28	224	58	9/4	R. Reach	R. Reach	9/5	60.0	0.304	9.2	11:49	11:54	12:00	13:30	E. Gallery
29	224	59	9/4	R. Reach	R. Reach	9/5	63.0	0.352	9.8	12:10	12:14	12:19	14:00	W. Gallery

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Table A1-2 continued.

TAG No.	Tag Chan.	Tag Code	Capture Date	Capture Ladder	Trap	Tag Date	TL (cm)	Weight (kg)	Girth (cm)	Start Heavy Anesth.	Start Surg.	Start Recov.	Release Time	Release Location
30	224	60	9/3	West	Trap 2	9/5	65.0	0.420	10.6	12:25	12:29	12:34	14:06	W. Alcove
31	224	61	9/5	R. Reach	R. Reach	9/6	68.0	0.424	10.8	8:16	8:21	8:25	10:01	W. Gallery
32	224	62	9/5	R. Reach	R. Reach	9/6	61.0	0.362	9.9	8:26	8:30	8:36	10:01	W. Gallery
33	224	63	9/5	R. Reach	R. Reach	9/6	67.0	0.384	9.8	8:41	8:45	8:51	10:01	W. Gallery
34	224	64	9/5	R. Reach	R. Reach	9/6	61.0	0.312	9.1	8:56	9:00	9:05	10:06	W. In-ladder
35	224	65	9/7	West	Trap 2	9/8	67.0	0.452	10.5	9:50	9:53	9:59	10:59	W. Alcove
36	224	66	9/10	East	Trap 4	9/10	65.0	0.414	10.6	9:55	9:59	10:03	11:03	E. Alcove
37	224	67	9/12	East	Trap 3	9/12	61.0	0.356	10.0	9:11	9:14	9:19	10:19	E. Alcove
38	224	68	9/17	East	Trap 3	9/19	63.0	0.354	9.8	9:19	9:23	9:28	10:36	E. Alcove

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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Analysis of the Douglas County Public Utility District #1 Sturgeon Mark-Recapture Study

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16 February 2005

Introduction

Mark-recapture data from the 2001-2002 PIT-tag sturgeon study in the Wells reservoir were analyzed to estimate population abundance. Thirteen individual sturgeon were captured over a two year period, with three of the sturgeon being recaptured across the five sampling periods (Table 1). Alternative mark-recapture models were examined to provide the most realistic, yet parsimonious model to describe the capture observations.

Statistical Methods

Program RECAP.GLM (Cormack 1985) was used to examine both open and closed population models using the capture histories from the 5 sampling periods (i.e. July 2001, early August 2001, late August 2001, early September 2002, and late September 2002). Program RECAP.GLM was selected because it easily allows examination of alternative mark-recapture models, permits comparisons of models using likelihood-ratio tests, and allows examination of the residuals associated with the lack-of-fit to individual capture histories.

Table 1: Capture histories by fish for the 13 sturgeon captured in 2001-2002. An "X" denotes in which periods a fish was caught.

	Periods				
Fish ID	1	2	3	4	5
3D9.1BFOE220404	X				
3D9.1BF1092483	X		X		
3D9.1BF0FD31EF	X				
3D9.1BF109F2B9	X				
3D9.1BF10916A2	X				
3D9.1BF10920B9	X	X	X		X
3D9.1BF0E473EF		X			
3D9.1BF0DCA36A		X		X	
3D9.1BF0DDD71A		X			
3D9.1BF188EAF				X	
3D9.1BF1890574				X	
3D9.1BF1890404				X	
No tag number					X

Results

Initial analysis of the data found the constant-capture Schnabel model (M_0) to adequately fit the data compared to the variable capture probability Schnabel model (M_t) (P($\chi^2_4 \geq 3.742$) = 0.4420). Subsequent analysis found no significant evidence for recruitment processes (P($\chi^2_3 \geq 4.425$) = 0.2191) or mortality processes (P($\chi^2_3 \geq 2.254$) = 0.5214). Examination of the residuals associated with the various capture histories (Table 2(a)) found history 11101 (i.e. fish # 3D9.1BF10920B9) to have significant lack of fit ($P(|Z| \geq 10.990) \approx 0$). In other words, that fish exhibited "trap-happy" behavior. With the fish in the data set, abundance was estimated to be $\hat{N} = 20.46$ ($\hat{s.e.} = 6.25$) (model M_0) or $\hat{N} = 19.70$ ($\hat{s.e.} = 5.81$) (model M_t) depending on whether constant probability was assumed or not for the Schnabel model.

Treating the individual "trap-happy" fish as an outlier, Program RECAP.GLM estimated an abundance of $\hat{N} = 34.12$ ($\hat{s.e.} = 19.81$) for model M_0, and $\hat{N} = 31.35$ ($\hat{s.e.} = 17.51$) for model M_t. Although model M_t does not significantly improve the fit of the data over model M_0 (P($\chi^2_4 \geq 5.344$) = 0.2538), unequal trapping effort over time suggests model M_t and the abundance estimate of $\hat{N} = 31.35$ is the most appropriate. Residuals for model M_t with the outlier removed are presented in Table 2(b). The profile likelihood confidence interval for sturgeon abundance is calculated to be $CI(13.15 \leq N \leq 217.50) = 0.95$.

Table 2: Observed and fitted values for the number of fish with particular capture histories under Model M_t (a) with and (b) without the “outlier” sturgeon in the data set. Standardized residuals are asymptotically Normally (Z) distributed.

		(a) all data		(b) outlier removed	
History	Observed	Fitted	Residual	Fitted	Residual
11111	0	0.002	-0.043	0.000	-0.007
01111	0	0.005	-0.069	0.000	-0.016
10111	0	0.008	-0.090	0.000	-0.022
00111	0	0.021	-0.144	0.003	-0.052
11011	0	0.018	-0.135	0.002	-0.039
01011	0	0.046	-0.215	0.009	-0.094
10011	0	0.078	-0.280	0.016	-0.125
00011	0	0.199	-0.446	0.090	-0.299
11101	1	0.008	10.990	N/A	N/A
01101	0	0.021	-0.144	0.002	-0.045
10101	0	0.035	-0.187	0.004	-0.060
00101	0	0.089	-0.298	0.020	-0.143
11001	0	0.078	-0.280	0.011	-0.107
01001	0	0.199	-0.446	0.065	-0.255
10001	0	0.337	-0.581	0.116	-0.340
00001	1	0.856	0.155	0.663	0.414
11110	0	0.018	-0.135	0.002	-0.039
01110	0	0.046	-0.215	0.009	-0.094
10110	0	0.078	-0.280	0.016	-0.125
00110	0	0.199	-0.446	0.090	-0.299
11010	0	0.175	-0.418	0.050	-0.224
01010	1	0.444	0.835	0.286	1.334
10010	0	0.753	-0.868	0.510	-0.714
00010	3	1.911	0.788	2.919	0.048
11100	0	0.078	-0.280	0.011	-0.107
01100	0	0.199	-0.446	0.065	-0.255
10100	1	0.337	1.141	0.116	2.597
00100	0	0.856	-0.925	0.663	-0.814
11000	0	0.753	-0.868	0.370	-0.609
01000	2	1.911	0.064	2.118	-0.081
10000	4	3.243	0.421	3.776	0.115

Discussion

Only in zone 3 were sturgeon marked and recaptured. The estimate of abundance $\hat{N} = 31.35$, therefore, applies to this zone, but may or may not apply to the other three zones (i.e. 1, 2, or 4). Lack of captures in the other three areas may indicate no sturgeon present. However, it is also possible there is a year-by-zone interaction, whereby the fish in the other areas are not vulnerable to the fishing gear. In which case, the current abundance estimate will be negatively biased. The PIT-tag data alone cannot discern the cause. Radiotelemetry information suggests sturgeon do not move between zone 3 and the other zones. This information therefore suggests sturgeon may be largely restricted to zone 3, with the calculated abundance of $CI(13.15 \leq N \leq 217.50) = 0.95$ accordingly applicable.

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West Consultants, Inc. 2008. Development of a Water Temperature Model Relating Project Operations to Compliance with the Washington State and EPA Water Quality Standards (Water Temperature 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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DEVELOPMENT OF A WATER TEMPERATURE MODEL RELATING PROJECT OPERATIONS TO COMPLIANCE WITH THE WASHINGTON STATE AND EPA WATER QUALITY STANDARDS
(Water Temperature Study)

WELLS HYDROELECTRIC PROJECT

FERC NO. 2149

FINAL REPORT
REQUIRED BY FERC

September 2008

Prepared by:
WEST Consultants, Inc.
Bellevue, Washington

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

For copies of this Study Report, contact:

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ABSTRACT

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.

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.

1.0 INTRODUCTION

1.1 General Description of the Wells Hydroelectric Project

The Wells Hydroelectric Project (Wells Project) is located at river mile (RM) 515.6 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, owned and operated by the United States Army Corps of Engineers (COE); and 42 miles upstream from the Rocky Reach Hydroelectric Project 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 the Wells Dam.

The Wells Project is the chief generating resource for 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 the hydrocombine. 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.

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 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 the normal maximum water surface elevation of 781 above mean sea level (msl) (Figure 1.1-1).

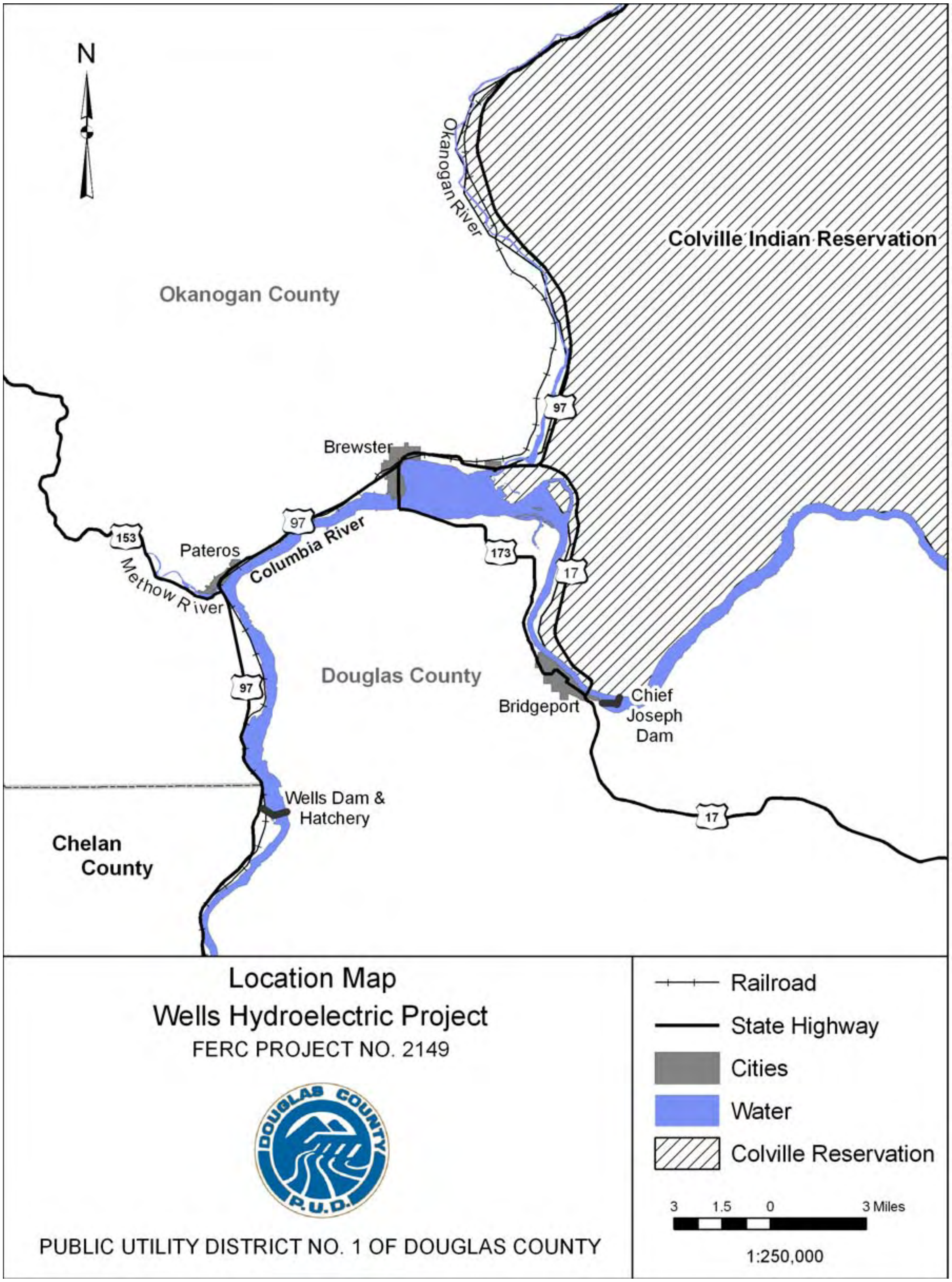

Figure 1.1-1 Location Map of the Wells Project

1.2 Relicensing Process

The current Wells Project license will expire on May 31, 2012. Douglas PUD is using the Integrated Licensing Process (ILP) promulgated by Federal Energy Regulatory Commission (FERC) Order 2002 (18 CFR Part 5). Stakeholders consisting of representatives from state and federal agencies, tribes, local governments, non-governmental organizations and the general public have participated in the Wells Project ILP, from a very early stage, to identify information needs related to the relicensing of the Wells Project.

In August 2005, Douglas PUD initiated a series of Resource Work Group (RWG) meetings with stakeholders regarding the upcoming relicensing of the Wells Project. This voluntary effort was initiated to provide stakeholders with information about the Wells Project, to identify resource issues and to develop preliminary study plans prior to filing the Notice of Intent (NOI) and Pre-Application Document (PAD). The RWGs were formed to discuss issues related to the Wells Project and its operations.

The primary goals of the RWGs were to identify resource issues and potential study needs in advance of Douglas PUD filing the NOI and PAD. Through 35 meetings, each RWG cooperatively developed a list of Issue Statements, Issue Determination Statements and Agreed-Upon Study Plans. An Issue Statement is an agreed-upon definition of a resource issue raised by a stakeholder. An Issue Determination Statement reflects the RWGs' efforts to apply FERC's seven study criteria to mutually determine the applicability of each individual Issue Statement. Agreed-Upon Study Plans are the finished products of the informal RWG process.

Douglas PUD submitted the NOI and PAD to FERC on December 1, 2006. The PAD included the RWGs’ 12 Agreed-Upon Study Plans. The filing of these documents initiated the relicensing process for the Wells Project under FERC’s regulations governing the ILP.

On May 16, 2007, Douglas PUD submitted a Proposed Study Plan (PSP) Document. The PSP Document consisted of the Applicant’s Proposed Study Plans, Responses to Stakeholder Study Requests and a schedule for conducting the Study Plan Meeting. The ILP required Study Plan Meeting was conducted on June 14, 2007. The purpose of the Study Plan Meeting was to provide stakeholders with an opportunity to review and comment on Douglas PUD’s PSP Document, to review and answer questions related to stakeholder study requests and to attempt to resolve any outstanding issues with respect to the PSP Document.

On September 14, 2007, Douglas PUD submitted a Revised Study Plan (RSP) Document. The RSP Document consisted of a summary of each of Douglas PUD’s revised study plans and a response to stakeholder PSP Document comments.

On October 11, 2007, FERC issued its Study Plan Determination based on its review of the RSP Document and comments from stakeholders. FERC’s Study Plan Determination required Douglas PUD to complete 10 of the 12 studies included in its RSP Document. The FERC approved studies include the development of a water temperature model relating project operations to compliance with the Washington State and EPA water quality standards (Water Temperature Study). Douglas PUD has opted to complete all 12 studies to better prepare for the

401 Water Quality Certification process conducted by the Washington State Department of Ecology (Ecology) and to fulfill its commitment to the RWGs who collaboratively developed the 12 Agreed-Upon Study Plans with Douglas PUD. These study plans have been implemented during the designated ILP study period. The results from the study plans will be presented in 12 Study Reports. Each report will be included in Douglas PUD's Initial Study Report (ISR) Document, which is scheduled for filing with FERC on October 15, 2008.

There were no variances from the FERC approved study plan for the Water Temperature Study.

This report completes the Water Temperature Study.

2.0 GOALS AND OBJECTIVES

Consistent with the FERC approved study plan, the goal of the study is to develop two temperature models (using CE-QUAL-W2) to assess the effects of Wells Project operations on water temperatures at Wells Dam and within the Wells Reservoir as they relate to compliance with the Washington State Water Quality Standards and Section 401 of the Clean Water Act certification process.

Ecology is the agency responsible for administering the State Water Quality Standards and for the issuance of Section 401 water quality certificates for hydroelectric relicensing processes in Washington. The information gathered from this modeling effort will assist Ecology in determining if, and to what extent the Project's operations affect water temperature in excess of the narrative and/or numeric criteria.

3.0 STUDY AREA

The study area is defined as the waters within the Wells Reservoir. This consists of the mainstem Columbia River upstream of Wells Dam to the tailrace of Chief Joseph Dam (RM 544.5), and the Okanogan (to RM 15.5) and Methow (to RM 1.5) rivers within Project boundary (Figure 1.1-1).

4.0 BACKGROUND AND EXISTING INFORMATION

In preparation for the development of a temperature model, Douglas PUD assessed the suite of models available. The CE-QUAL-W2 model (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 W2 model was considered the basis for making decisions regarding data needs and data archiving. With guidance from consultants having expertise in water quality modeling, Douglas PUD conducted a review of the types of information being collected within the Wells Project and whether the data currently collected was sufficient to support W2 model development. Based on this data review, Douglas PUD modified existing monitoring programs and in some cases initiated new programs in order to collect the necessary information for the W2 model.

Flow Data

Water flowing into the Wells Project originates from Chief Joseph Dam, on the Columbia River, and from the Okanogan and Methow rivers. Continuous hourly flow data from Chief Joseph Dam, located upstream of Wells Dam, are available from the Columbia River Operational Hydromet Management System (CROHMS) database. A stream gauge station located near the town of Malott, WA, measures flow in the Okanogan River at RM 17.0 (USGS Gauge No. 12447200). The Malott USGS stream gauge is located 1.5 miles upstream of the Wells Project boundary on the Okanogan River. A stream gauge station located near Pateros measures flow in the Methow River (USGS Gauge No. 12449950) at the point where the river enters the Wells Project. All three of the boundary water monitoring stations provides Douglas PUD with hourly flow data.

Water flowing out of the Wells Project must first pass through Wells Dam. Douglas PUD collects and records hourly flow data for the water passing through the turbines, spillways and adult fish ladders at Wells Dam. Additionally, there is a United States Geological Survey (USGS) gauging station downstream of Wells Dam that also collects river flow information and is representative of water passing through Wells Dam.

Temperature Data

Beginning in 2001, an extensive water temperature monitoring effort was initiated to establish the temperature dynamics throughout the Wells Reservoir. Temperature data were collected at seven locations: the Columbia River at RM 544, RM 532, RM 530, and RM 516; at RM 1.5 in the Methow River; and at RM 10.5 (Wakefield Bridge) and RM 1.3 (SR 97 Bridge) in the Okanogan River. Data were collected hourly using Onset TidbiT temperature loggers. Monitoring start and end dates varied among years, but generally began in the 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 (Douglas PUD, 2005). Data at some of these monitoring locations were infrequently discontinuous due to sensor loss or malfunction in some years.

An additional component of the water temperature monitoring effort initiated in 2001 was to measure vertical temperature profiles at the RM 516 location in the Columbia River in the Wells Dam forebay. The temperature station was located along the east portion of the forebay, in what had been the original channel of the Columbia River prior to the construction of the Wells Project. Each year between 2001 and 2005, temperature loggers were deployed at three different depths between 5 and 90 feet, approximately 30 feet apart. Results showed no measurable thermal stratification and reflected the limited storage capacity of the Wells Reservoir.

Starting in 2006 and following the completion of the data review and data gap analysis, Douglas PUD expanded the Wells Reservoir temperature monitoring season to cover the entire year and implemented a more frequent downloading schedule to avoid temperature data gaps. Douglas PUD also added additional monitoring stations at the mouths of the Okanogan (RM 1.3) and Methow (RM 0.1) rivers. Collectively, these data documented the incoming water temperatures to the Wells Project (boundary conditions), as well as other sites throughout the Wells Reservoir including the Wells Dam forebay, and were integral to the development of the W2 temperature models.

Meteorological Data Collection

Site specific weather information is an essential component of water temperature models. Weather information characteristic of the entire Wells Reservoir was unavailable until 2005 when Douglas PUD began collecting site specific meteorological data. Douglas PUD identified three sites that would most effectively characterize the weather trends in the Wells Reservoir at Chief Joseph Dam (upper reservoir area), Bridgeport Bar (mid-reservoir area) and the Wells Project forebay (lower reservoir area). Since reliable meteorological information was already available near Chief Joseph Dam, NRG Systems weather stations were erected at the other two identified sites in order to collect parameters required to support water temperature modeling. The parameters collected were air temperature, relative humidity, dew point temperature, solar incidence, wind speed, and wind direction.

Bathymetric Data Collection

In March 2005, Douglas PUD contracted with GeoEngineers to conduct a detailed bathymetric survey of the Wells Reservoir and tailrace using multibeam sonar and Global Positioning System (GPS) technology. Contour maps of the reservoir bottom were produced at 1-foot contour intervals, and a digital elevation model (DEM) was produced at a pixel resolution of 10-feet. The DEM provides a seamless representation of the riverbed surface.

4.1 Aquatic Resource Work Group

As part of the relicensing process for the Wells Project, Douglas PUD established an Aquatic Resource Work Group (RWG) which began meeting informally in November, 2005. This voluntary effort was initiated to provide stakeholders with information about the Wells Project, to collaboratively identify potential resource issues related to Project operations and relevant to relicensing, and to develop preliminary study plans to be included in the Wells Pre-Application Document (PAD)(DCPUD 2006).

Through a series of meetings, the Aquatic RWG cooperatively developed a list of Issue Statements, Issue Determination Statements and Agreed-Upon Study Plans. An Issue Statement is an agreed-upon definition of a resource issue raised by a stakeholder. An Issue Determination Statement reflects the RWG’s efforts to review the existing project information and to determine whether an issue matches with FERC's seven criteria and would be useful in making future relicensing decisions. Agreed-Upon Study Plans are the finished products of the informal RWG process.

Based upon these meetings and discussions, the Aquatic RWG proposed to conduct a study to evaluate the effect of Project operations on compliance with temperature standards in the Wells Project (6.2.1.6). The need for this study was agreed to by all of the members of the Aquatic RWG, including Douglas PUD. This study will help to inform future relicensing decisions and will fill data gaps that have been identified by the Aquatic RWG.

The Issue Statement and Issue Determination Statement listed below were included in the PAD (section number included) filed with FERC on December 1, 2006:

4.1.1 Issue Statement (PAD Section 6.2.1.6)

Project operations may affect compliance with temperature standards in the Wells Project.

4.1.2 Issue Determination Statement (PAD Section 6.2.1.6)

The Wells Project can have an effect on compliance with the water temperature standard. The Aquatic Resource Work Group members agree that studies to address this issue are feasible and the results will be meaningful for the 401 Water Quality Certification Process. Douglas PUD is currently collecting temperature data throughout the Wells Project. Furthermore, Douglas PUD has established weather stations to collect meteorological data in key locations of the Wells Reservoir. These data sets will be utilized to develop a temperature model (i.e., CE-QUAL-W2) to assess the Wells Project's effect on water temperatures.

The Resource Work Group believes that a study to develop a temperature model is necessary to determine compliance with the state's water quality standards. The resource work group agrees that this study (development of specific water temperature models) should be implemented during the two-year ILP study period.

Toward this goal, Douglas PUD will continue to collect water temperature and meteorological data during 2006 and 2007 for use in the development of a temperature model to be used in 2008 and/or 2009. Data may continue to be collected in 2008 and 2009, if necessary.

4.2 Project Nexus

Ecology is responsible for the protection and restoration of the state's waters. Ecology has adopted standards that set water quality criteria for lakes, rivers, and marine waters in order to protect water quality and dependent uses. Ecology's current (2006) water quality standards classify fresh water by use, rather than by class, as was done in earlier standards. Those most pertinent to the Project are:

For the tributary reaches that are within the Wells Project boundary (Okanogan River from RM 0 to RM 15.5 and the Methow River from RM 0 to RM 1.5),

- Water temperature shall not exceed 17.5°C (63.5°F), where water temperature is measured by the 7-day average of the daily maximum temperatures (7-DADMax);
- When a water body's temperature is warmer than 17.5°C (or within 0.3°C (0.54°F) of 17.5°C) 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 natural condition of the water is cooler than 17.5°C, the incremental temperature increases resulting from the combined effect of all nonpoint source activities in the water body must not, at any time, exceed 2.8°C (5.04°F);

- The Methow River within the Project boundary (RM 0 to RM 1.5) has been identified by Ecology as a requiring special protection for salmon and trout spawning and incubation. From October 1st to June 15th, water temperature shall not exceed 13.0°C, as measured by the 7-DADMax.

For the mainstem Columbia River that is within the Wells Project boundary,

- Water temperature shall not exceed 17.5°C (64.4°F), where water temperature is measured by the 7-DADMax;
- When a water body's temperature is warmer than 17.5°C (or within 0.3°C (0.54°F) of 17.5°C) 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 natural condition of the water is cooler than 17.5°C, the incremental temperature increases resulting from the combined effect of all nonpoint source activities in the water body must not, at any time, exceed 2.8°C (5.04°F).

Water flowing into and through the Wells Reservoir typically begins warming in March and reaches peak annual temperatures in August through early September. During this time period, incoming water to the Wells Project can exceed both the tributary and mainstem 7-DADMax numeric criteria of 17.5°C. A portion of the mainstem Columbia River encompassing Wells Dam is on the 2004 303(d) list as an impaired waterbody for temperature.

Water temperature is one of many environmental factors that may affect salmonid populations in the mid-Columbia River basin. Increasing temperature levels above a given threshold can cause upstream migration delays, promote disease, and increase the probability of mortality for salmonids at all life history stages. Natural ambient water temperatures often exceed lethal tolerance levels for salmonids in the lower Okanogan River (NMFS, 2002). Yet, the Okanogan watershed currently supports healthy runs of summer and fall Chinook salmon, the largest run of sockeye salmon in the Columbia Basin, and steelhead (NMFS, 2002).

5.0 METHODOLOGY

The W2 model is widely used to support the establishment of TMDLs for Washington waters and is a generally accepted model for evaluating the effects of hydroelectric projects on various water quality parameters (EES Consulting, 2006).

The development of a W2 model consists of two major components: data collection for model input and model development/implementation. The data collection component in W2 model development includes site review and field reconnaissance, data gap analyses, preliminary data collection design and implementation of data collection programs. The model development/implementation component consists of model input data preparation, model development, hydrodynamic and temperature calibration, sensitivity analyses, and hypothesis testing.

5.1 Model Data

Data for the W2 model of the Wells Project included bathymetry, flows, inflow water temperatures, meteorology, and in-reservoir temperatures for model calibration. Douglas PUD collected significant temperature data in the reservoir and meteorological data during 2006 and 2007.

5.1.1 Bathymetry

Douglas PUD collected high-resolution bathymetric data for the Project. GeoEngineers (2008) recently used these data to develop a one-dimensional, steady-flow HEC-RAS model (HEC, 2005) of the system. The cross sections from the HEC-RAS model were used to develop the W2 geometry file, supplemented by some additional sections cut from the ARC/GIS geometry files.

5.1.2 Flows, Stage, and Water Temperature

Water flowing into the Wells Project originates from Chief Joseph Dam on the Columbia River, and from the Okanogan and Methow Rivers. Continuous hourly flow data from Chief Joseph Dam, located upstream of Wells Dam, are available from the Corps of Engineers' Columbia River Operational Hydromet Management System (CROHMS) database. A stream gauge station located near the town of Malott, WA, measures flow and temperature in the Okanogan River (USGS Gauge No. 12447200) 1.5 miles upstream of the location where the Okanogan River enters the Wells Project. A stream gauge located near Pateros measures flow in the Methow River (USGS Gauge No. 12449950) at the point where the river enters the Wells Project. All three of the boundary water monitoring stations provided Douglas PUD with hourly flow data. Water flowing out of the Wells Project must first pass through Wells Dam. Douglas PUD collects and records hourly flow data for the water passing through the turbines, spillways and adult fish ladders at Wells Dam. Additionally, there is a USGS gauging station downstream of Wells Dam that also collects river flow information and measures the total flow of water passing through Wells Dam.

Input data to the model included flows and water temperatures at all upstream boundaries of the W2 model (Figure 5.1-1). Flow was defined at the downstream end of the "with" and "without" project models, respectively, allowing the W2 models to compute outflow temperatures. The model data were assembled from the gauges shown in Figure 5.1-2.

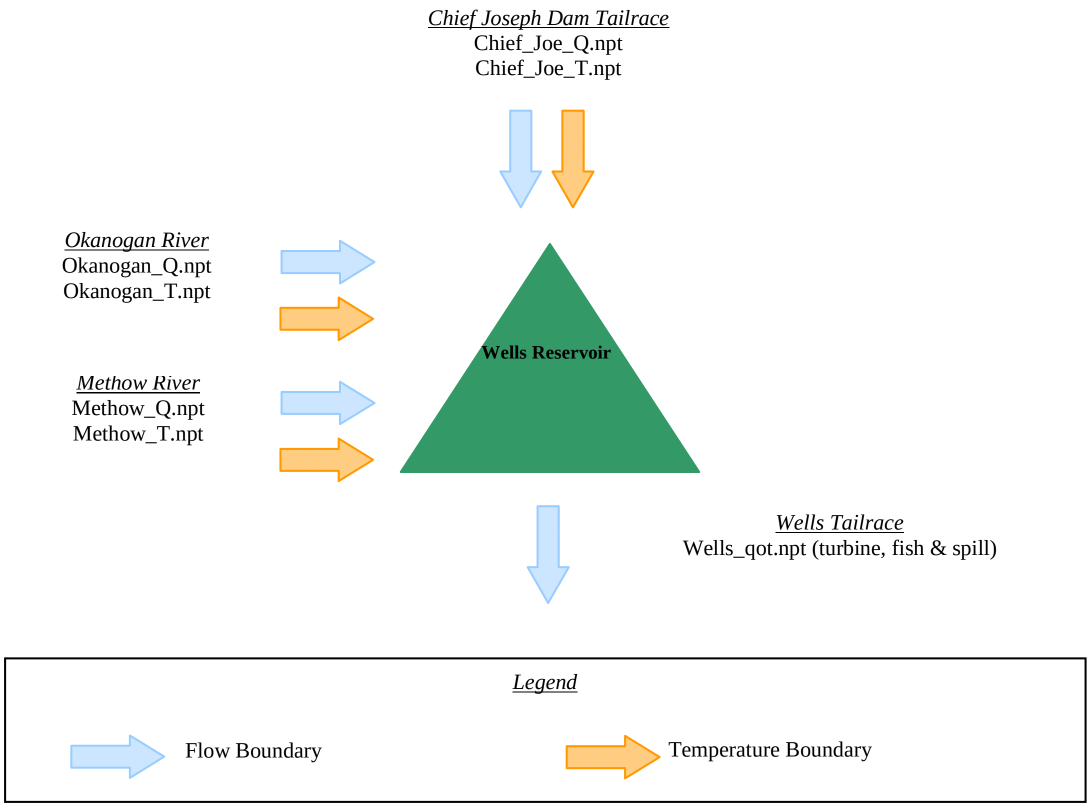

Figure 5.1-1 Schematic of W2 boundary conditions and file names.

Douglas PUD provided hourly flow data from the Chief Joseph Dam (Figure 5.1-3) and Wells Dam (Figure 5.1-4) for January 1, 2006 through December 31, 2007. Hourly streamflow data entering the Wells Project for the Okanogan River (Malott: USGS Gauge No. 12447200; Figure 5.1-5) and for the Methow River near Pateros (Pateros: USGS Gauge No. 12449950; Figure 5.1-6) were obtained from the USGS for January 1, 2006 through September 30, 2007. The flows in these figures are shown in "m^3/sec".

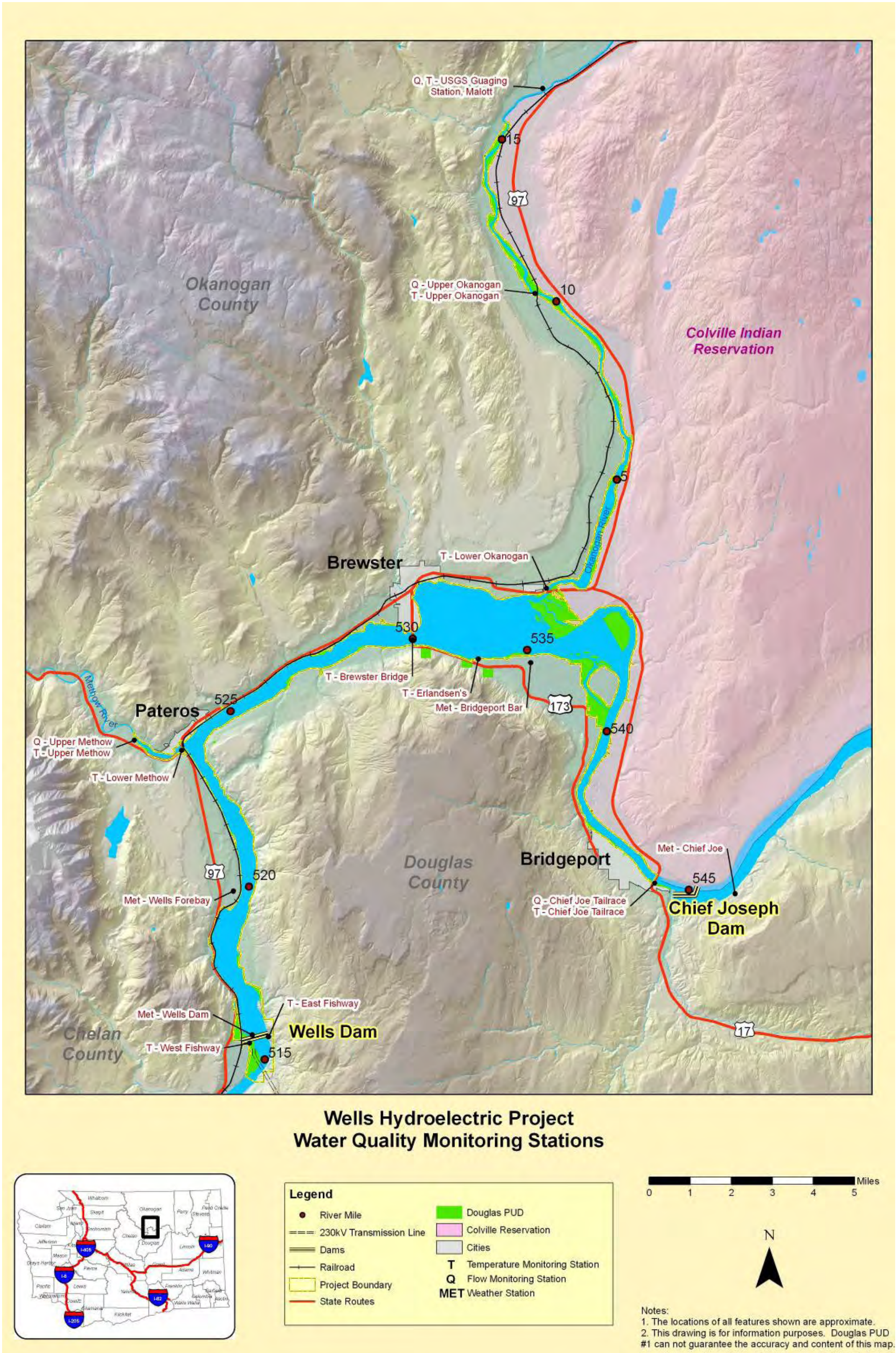

Figure 5.1-2 **Location of stream gauges.**

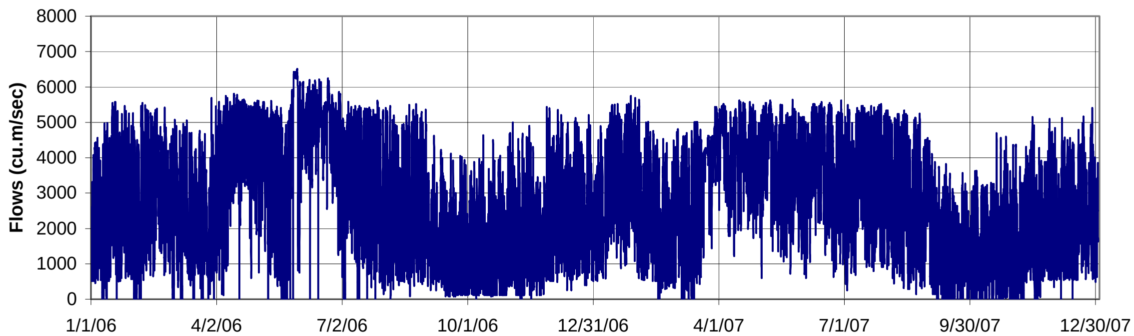

Figure 5.1-3 Chief Joseph Dam total hourly discharge.

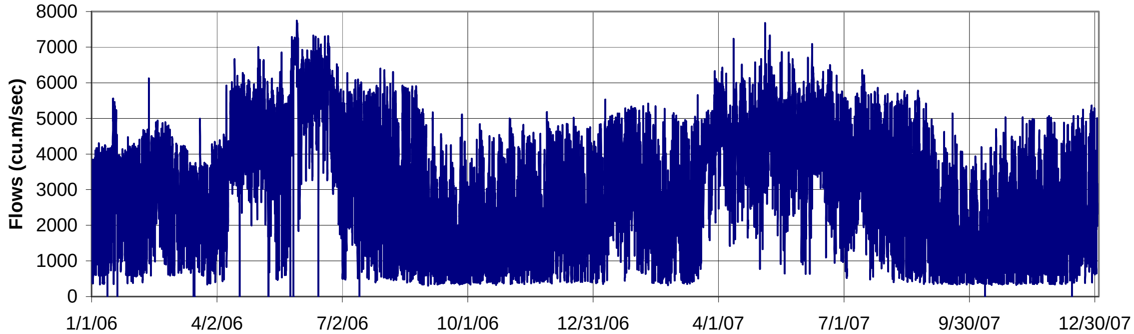

Figure 5.1-4 Wells Dam total hourly discharge.

Figure 5.1-5 Hourly Flows in Okanogan River at Malott.

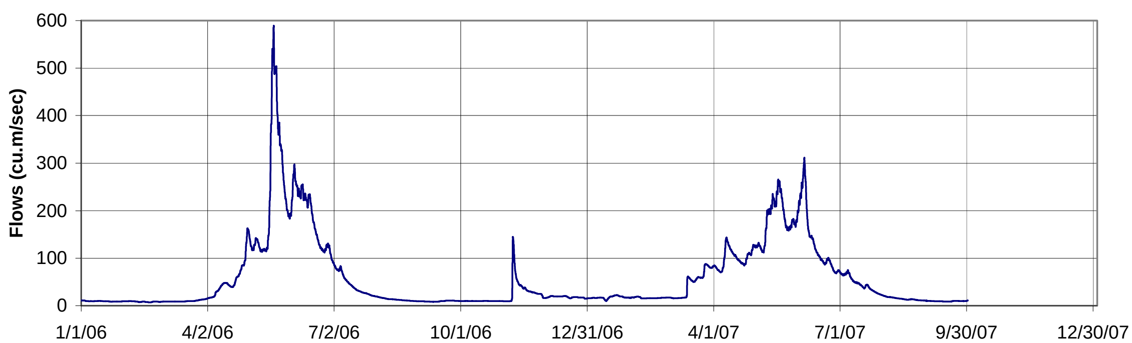

Figure 5.1-6 Hourly Flows in Methow River Near Pateros.

Reservoirs modeled using W2 generally use upstream inflows and downstream outflows. Therefore, it is important that these flows balance, otherwise the reservoir may rise or fall to unrealistic water surface elevations. Figure 5.1-7 shows the daily difference between the measured outflow from Wells Dam minus the measured total inflow to Wells Reservoir (Chief Joseph Dam, the Okanogan River, and the Methow River). This imbalance is not surprising. As with most flow measurements, the reported discharge values may have small measurement errors.

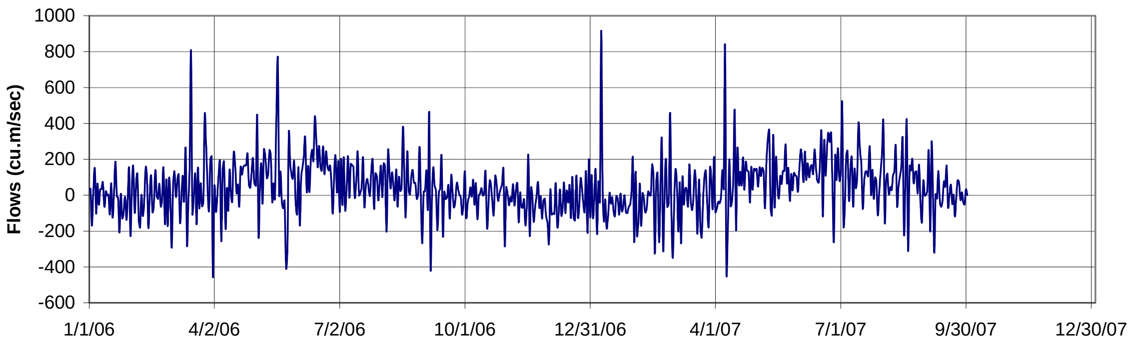

Figure 5.1-7 Difference between daily total outflow minus inflow.

Over the two-year period of model calibration data, the net imbalance, outflows minus inflows, is about 43 m^3/sec, or about one percent of average flows in the Columbia River. A "water balancing" approach was used to calculate the daily differences between outflows and inflows, including changes in reservoir storage, which were then added as a source distributed uniformly along the Columbia River. Figure 5.1-8 compares the observed stage in the Wells Forebay with the modeled stage. The agreement is reasonable given that the reservoir elevation changes little over the two-year period.

A review of the observed Wells forebay stage shows that the stage generally varies from 236.1 m (774.5 ft) to 238.1 m (781.0 ft), but the reservoir was lowered to 235.1 m (771.2 ft) during May 2006 in response to large inflows throughout the system. A stage of 237.4 m (778.8 ft) was exceeded 80% of the time; a stage of 237.7 m (779.8 ft) was exceeded 50% of the time; and a stage of 237.9 m (780.4 ft) was exceeded 20% of the time. These data demonstrate the extent to which the Wells Project maintains a near "run-of-the-river" condition with a steady water surface elevation.

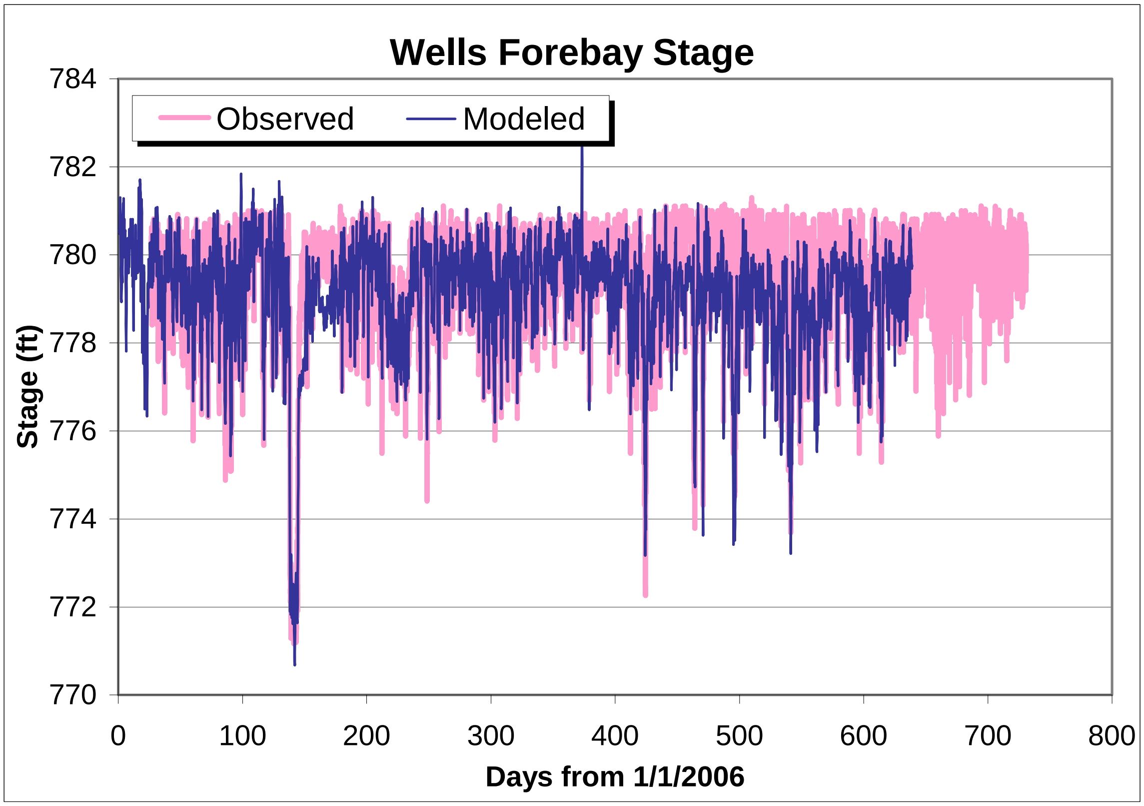

Figure 5.1-8 Wells forebay simulated and observed stage after water balancing.

5.1.2.1 Water Temperature Inflows

Water temperature data were input into the model for three inflow locations into the Wells Reservoir; Chief Joseph Dam outflow, the Okanogan River, and the Methow River. Douglas PUD provided hourly temperature data from the Chief Joseph Dam tailrace (Figure 5.1-9). Hourly temperature data for the Okanogan River near Malott (USGS Gauge No. 12447200) were obtained from the USGS for January 1, 2006 through September 30, 2007 (the end of Water Year 2007) (Figure 5.1-10). Douglas PUD measured hourly temperatures at the upstream and downstream ends of the Project reach on the Methow and Okanogan Rivers, and provided these data. There are no USGS temperature gauges on this reach of the Methow River.

The upstream gauge on the Methow River had large data gaps because it was difficult to retrieve the instrument when the river iced over, and significant amounts of data were lost. However, a comparison of data between the upper (above project boundary) and lower (Methow RM 0.0) gauges showed that the measurements were very similar (the reach is only 1.5 miles long), and data from the lower gauge were used to fill the data gaps retrieved from the upper gauge. The resulting inflow temperatures for the Methow River are shown in Figure 5.1-11. Raw data from Chief Joseph and the Okanogan River had very few missing values. The temperatures are shown in "degrees-C" in these figures. Inflow temperature data for the Methow River were also used to describe the temperatures of the "added" distributed sources.

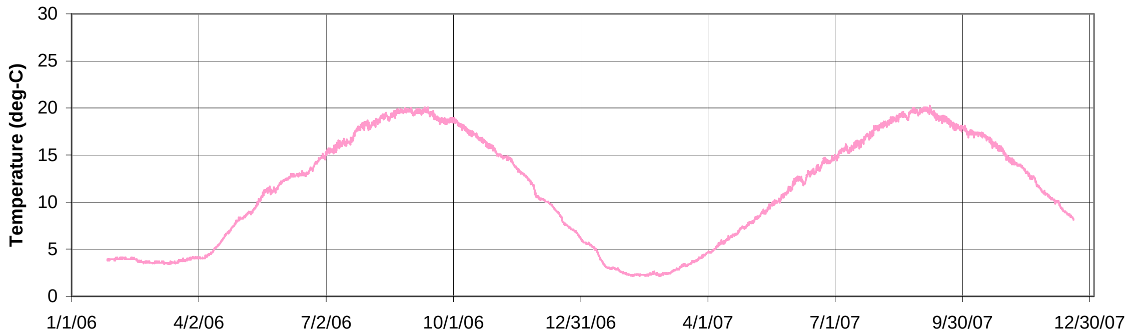

Figure 5.1-9 Hourly temperatures in the Chief Joseph Dam tailrace.

Figure 5.1-10 Hourly temperatures from USGS gauge on Okanogan River at Malott (at RM 17, approximately 1.5 miles upstream of the Wells Project boundary).

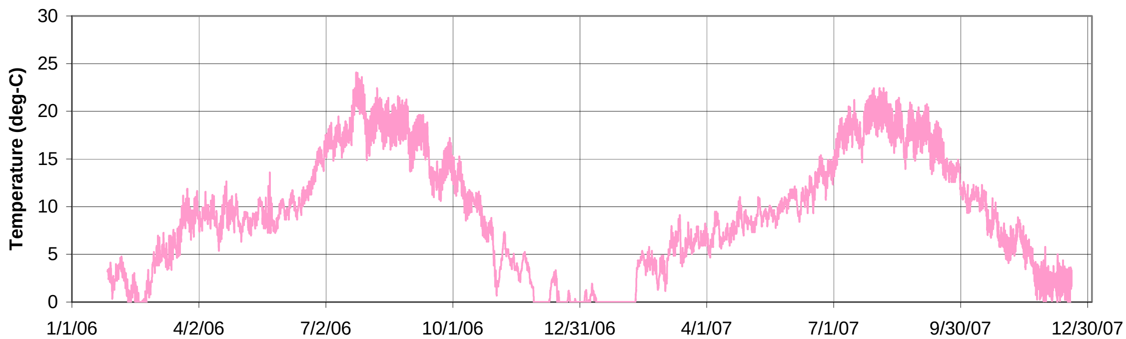

Figure 5.1-11 Hourly temperatures on Methow River near Pateros (RM 1.5).

5.1.3 Meteorology

Meteorological data are available at three stations in the vicinity of the Wells Reservoir (Figure 5.1-2). The U.S. Bureau of Reclamation maintains a station just upstream of the Chief Joseph Dam. Douglas PUD maintains a station at Bridgeport Bar, and another on Wells Dam, and collected wind speed and direction in the forebay about three miles upstream of the dam. In addition, there is a NOAA National Weather Service (NWS) station at Omak airport.

5.1.3.1 Air Temperature

Figure 5.1-12 shows the air temperature (in degrees-C) at the Wells, Bridgeport Bar and Chief Joseph meteorological stations. The data show little variability between the stations.

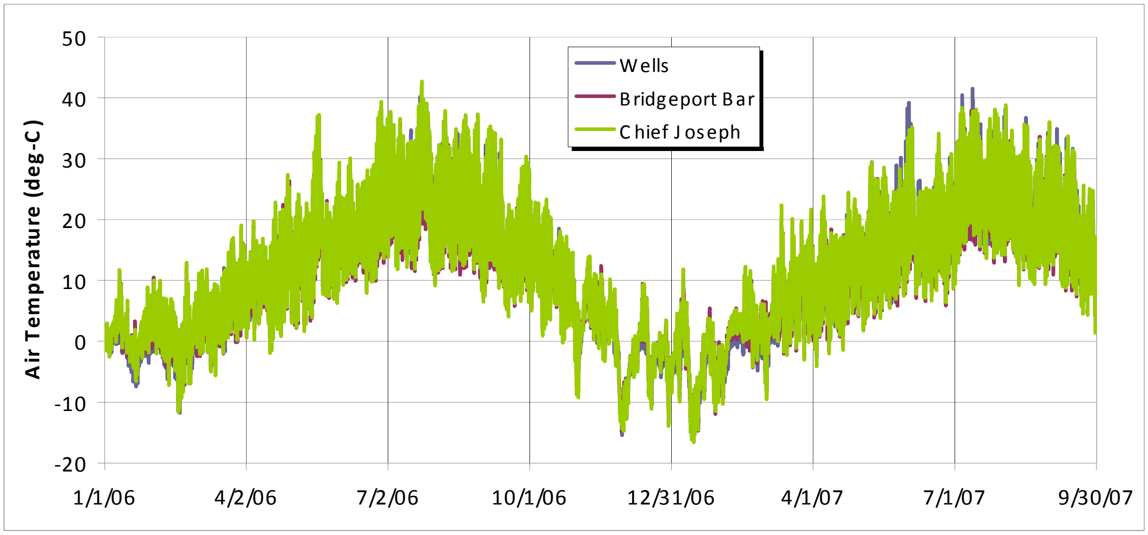

Figure 5.1-12 Air temperatures at meteorological stations.

5.1.3.2 Dew Point Temperature Data

Figure 5.1-13 shows the dew point temperature (in degrees-C) at the Wells, Bridgeport Bar and Chief Joseph meteorological stations. The data show little significant variability between the stations, except at the Wells station. The Wells data have a number of suspect values and were not considered further.

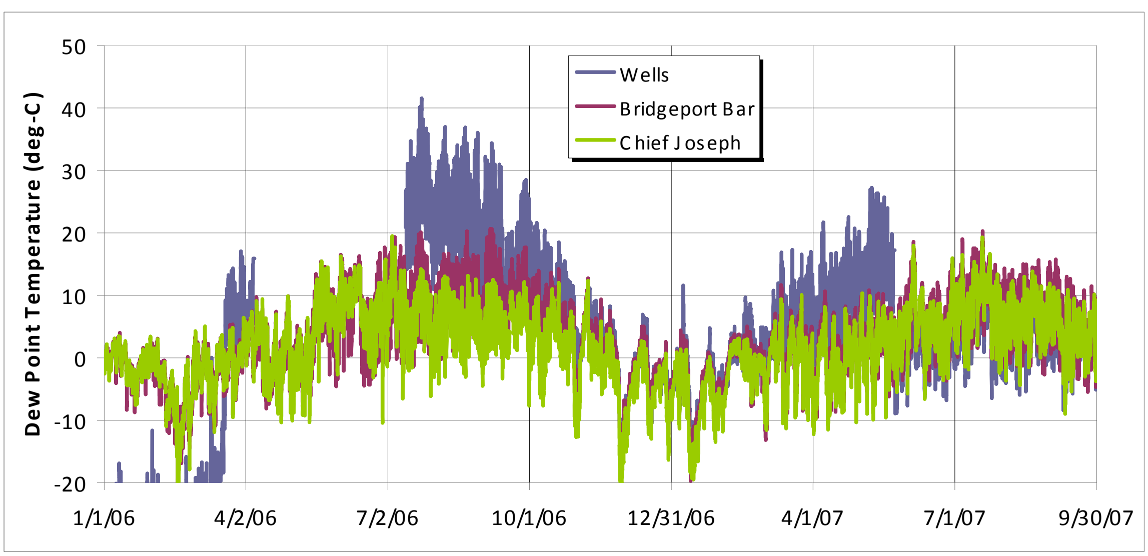

Figure 5.1-13 Dew point temperatures at meteorological stations.

5.1.3.3 Wind Speed and Direction, and Sheltering

There were three meteorological stations in the vicinity of the Wells Project that measured wind speed and direction: "Wells Forebay" (about three miles upstream of the dam), Bridgeport Bar, and near Chief Joseph Dam (Figure 5.1-2). Wind speed and direction are also measured at Omak Airport. Figure 5.1-14 shows the variation in wind speed. Analyzing wind speeds at the three gauges shows that, on average, the wind speeds measured at Chief Joseph are about 59 percent of those measured at Bridgeport Bar, and the wind speeds measured at the "Wells Forebay" are about 104 percent of those measured at Bridgeport Bar. These data reflect the similar valley conditions at Wells and Bridgeport Bar, compared to the topographic sheltering seen near Chief Joseph.

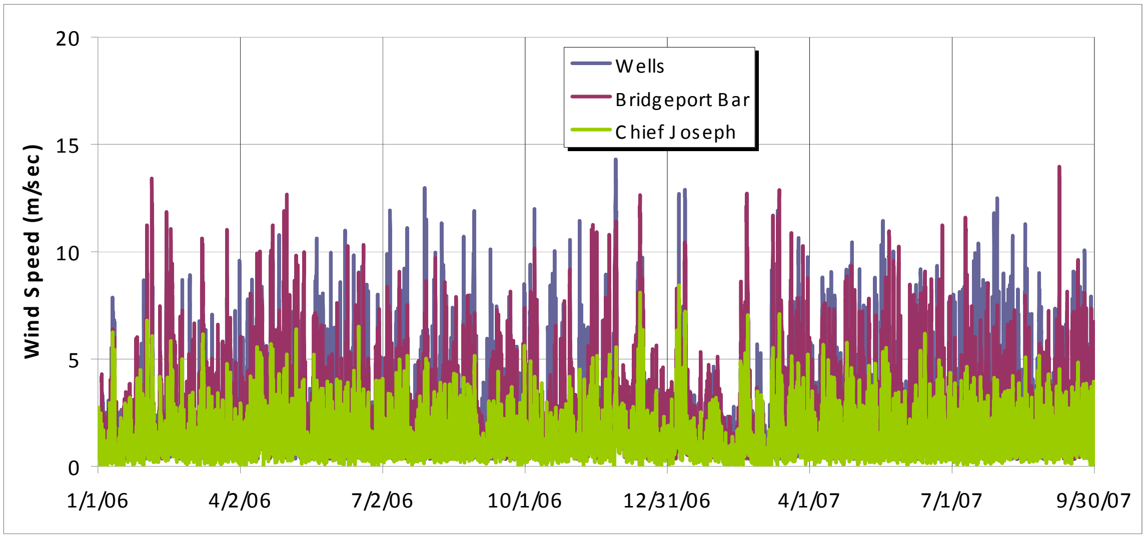

Figure 5.1-14 Wind speeds at meteorological stations.

Wind direction is more difficult to analyze because wind can blow from nearly every direction during a short period of time (e.g., one week), and there are clear differences between the stations. One way to view wind direction data is to plot wind speeds and directions in an excursion plot, and note the net direction of the long-term wind movement. Data from the three stations and Omak Airport are plotted for January 2006 in Figure 5.1-15. During this period, the winds are predominantly from the south (as seen at Omak Airport), but the responses at the three "project" stations differ. The winds at the "Wells Forebay" station appear to blow across the reservoir, while those at Bridgeport Bar and Chief Joseph seem more aligned with the reservoir axis. A closer review of the data indicates that there are periods when the wind appears to be "steered" by the terrain, and other times when it is not. This makes it difficult to decide the best way to use these data in the model. There are several possibilities. First, a single station could be selected (probably Bridgeport Bar) and wind speeds adjusted using the "wind sheltering" parameter in W2 to modify wind speed elsewhere. Second, the system could be broken into three "water bodies", and a different meteorological station applied to each. Third, the W2 code could be modified to use only one meteorological station (probably Bridgeport Bar) but force the wind direction to align with the local segment direction. Each of these alternatives has its "pros" and “cons”. While we prefer the first approach, to use only the data from Bridgeport Bar and adjust for “wind sheltering”, because of its simplicity, we decided to first conduct a sensitivity analysis to examine the effect of including the wind before making a final determination.

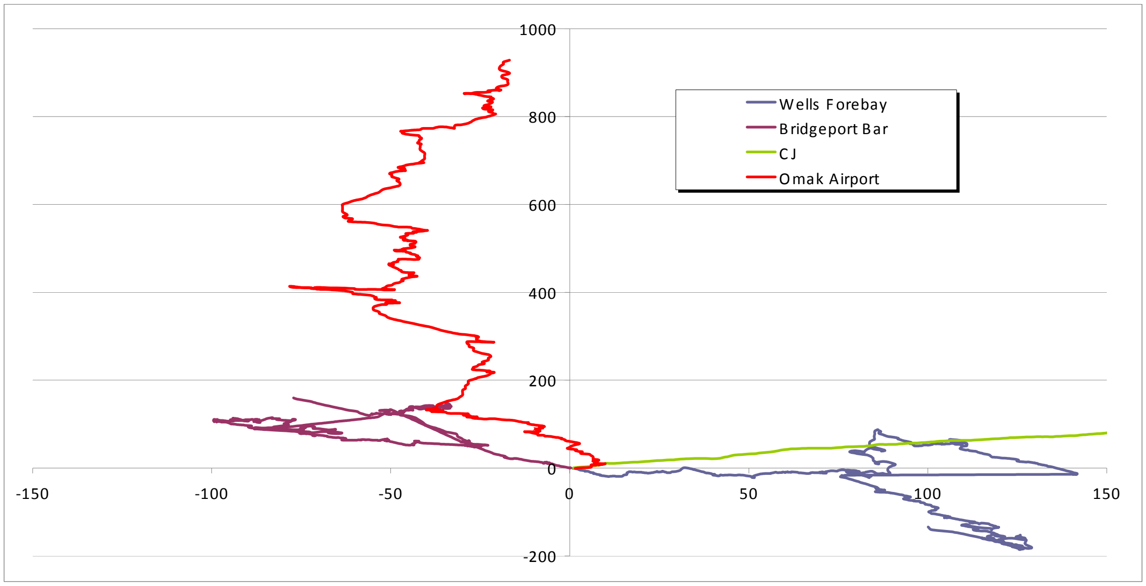

Figure 5.1-15 Wind excursion at meteorological stations during January 2006.

5.1.3.4 Cloud Cover Data

None of the meteorological stations along the reservoir measure cloud cover. However, there is a NWS station at Omak Airport that includes cloud cover (Figure 5.1-16). These data were used in the model.

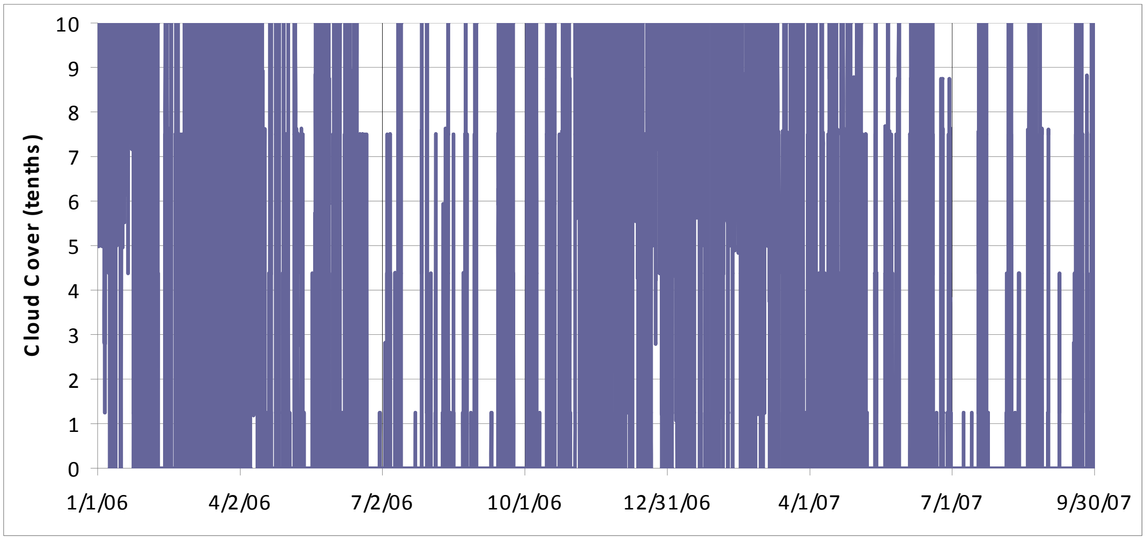

Figure 5.1-16 Cloud cover at Omak Airport.

5.1.3.5 Solar Radiation Data and Dynamic Shading

Figure 5.1-17 shows solar radiation (in Watts/m^2) at the Wells, Bridgeport Bar and Chief Joseph meteorological stations. The data show little significant variability between the stations. Figure 5.1-18 shows an arbitrary 10-day period to illustrate the similar values between stations.

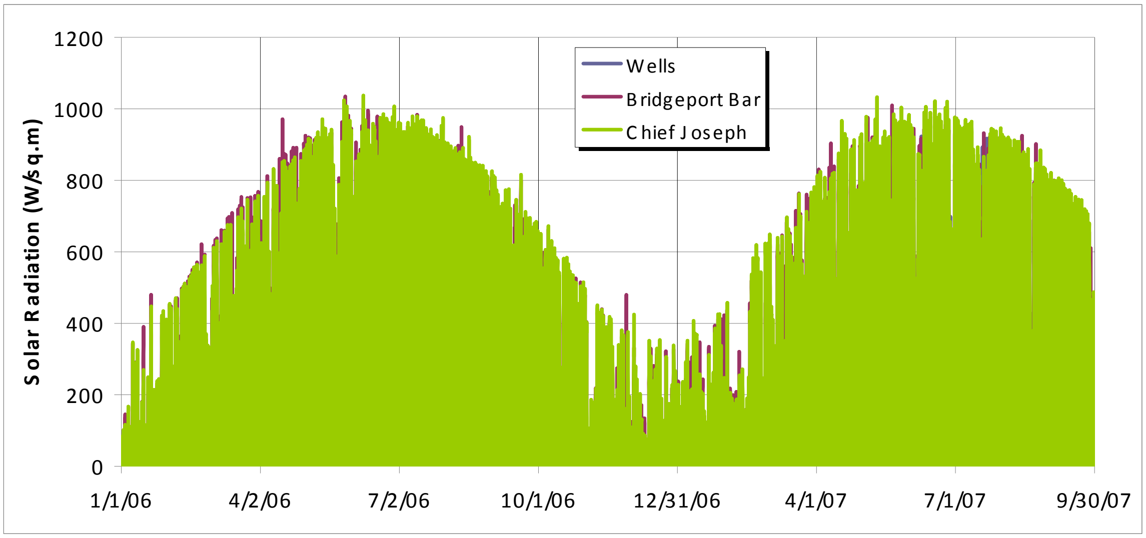

Figure 5.1-17 Solar radiation at meteorological stations.

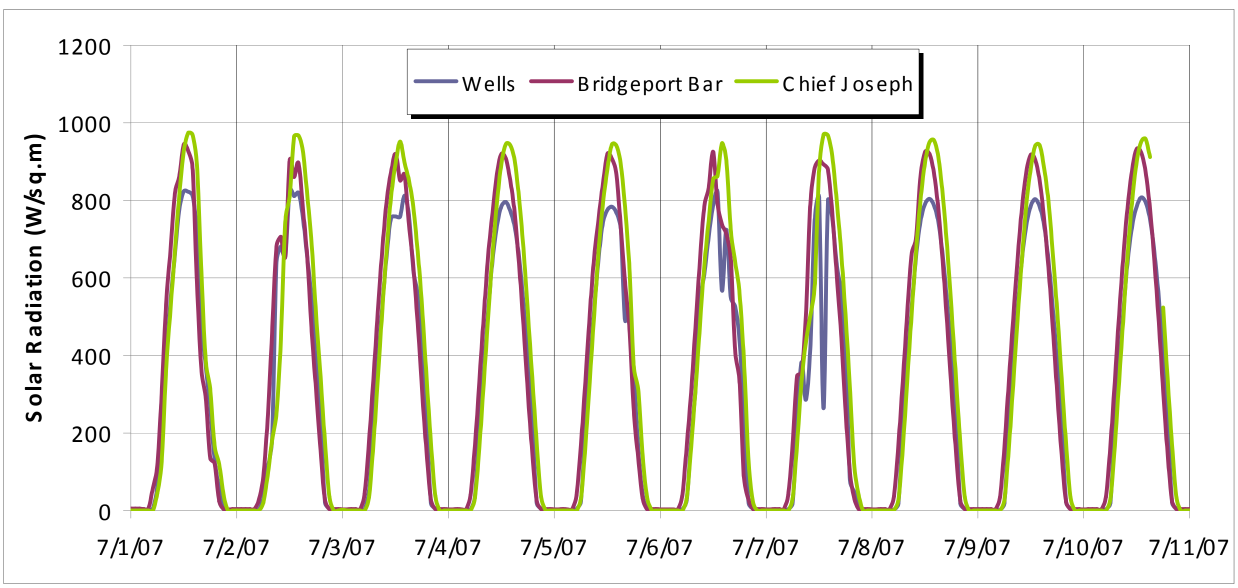

Figure 5.1-18 Solar radiation for an arbitrary 10-day period.

At low sun angles (early morning and late afternoon) it is possible that the sun may not shine directly on the water surface, especially if the river is deeply incised and/or is shaded by mountains. In W2, this effect can be introduced using the "dynamic shading" option. Starting from north (zero degrees), the limiting azimuth angle that the sun can strike the water surface is defined. W2 then uses the Julian day (from January 1), and the latitude and longitude of the project location to calculate the sun angle and azimuth, and compares it against the minimum azimuth for that direction. If the sun is below the horizon, the solar radiation is reduced to zero for that time step. Using the (x,y,z) coordinates of the centers of each model segment, we used a USGS 30 m Digital Elevation Model, freely available on the Internet, to compute the limiting azimuth angles. Dynamic solar shading data sets were created for the with-Project conditions using a normal reservoir elevation of 238 m (780.8 feet msl), and for without-Project conditions using water surface elevations determined from an HEC-RAS model of the system (GeoEngineers, 2008). Compared to the normal reservoir elevation of about 238 m (780.8 feet msl), typical flows in the system without the Project would results in water surface elevations of about 225.5 m (740 feet msl) at the confluence with the Okanogan River, about 221.5 m (727 feet msl) at the confluence with the Methow River, and about 214 m (702 feet msl) at the Wells Dam location. The water surface elevation at the dam would be approximately 24 m (80 feet) lower if the dam were not present.

5.1.4 Observed In-Reservoir Temperatures

Continuous water temperature was measured at the five interior locations in the Wells Reservoir during 2006 and 2007 (Figure 5.1-2). Several locations recorded temperature at multiple depths in the water column. The temperature gauges were anchored to the bed, and maintained at a fixed elevation above the bed. Table 5.1-1 summarizes the gauge locations and elevations.

Table 5.1-1 Summary of Water Temperature Recording Gauges.

Location	Date and time deployed	Depth below water surface (ft)	Forebay elevation at deployment (ft NGVD)	Estimated elevation of gauge (ft NGVD)
Erlandsen's (mid)	1/26/06 12:00	30	780.4	750
Erlandsen's (bottom)	1/26/06 12:00	50	780.4	730
Lower Okanogan R. (bottom)	1/26/06 14:00	32	780.2	748
Brewster Bridge (mid)	1/26/06 15:00	*25*	780.1	755
Brewster Bridge (bottom)	1/26/06 15:00	46	780.1	734
Lower Methow River (mid)	1/26/06 12:00	19	780.4	761
Wells Forebay (surface)	1/26/06 16:00	"surface"	780	<780
Wells Forebay (mid)	1/26/06 16:00	30	780	750
Wells Forebay (bottom)	1/26/06 16:00	50	780	730

5.2 Model Development and Calibration

5.2.1 Modeling Approach

We used the following approach in modeling the Project:

- Develop the geometry for the reservoir;

- Ensure that the model flows would "balance" water in the reservoir;
- Perform model sensitivity to determine the optimum set of model parameters;
- Calibrate the "with Project" model to observed, in-reservoir continuous temperature measurements ("time series") collected during 2006 and 2007;
- Modify the input files to develop a "without Project" model; and
- Run the "without Project" model for the same period, and compare the resulting temperatures.

The PUD collected large amounts of temperature data during 2006 and 2007. USGS flow data and temperatures were available through September 2007. Therefore, we decided to calibrate the W2 model of the Wells Project for the period 1/1/2006 to 9/30/2007. This period contains two high-temperature summer periods, which is the main period of interest for this study.

5.2.2 Description of the Numerical Model

W2 is a two-dimensional, laterally-averaged hydrodynamic and water quality model. Because the model assumes lateral homogeneity, it is best suited for relatively long and narrow water bodies exhibiting longitudinal and vertical water quality gradients. The model has been applied successfully to numerous rivers, lakes, reservoirs and estuaries.

The hydrodynamic routine of the model predicts water surface elevations, velocities and temperatures. Temperature is included in the hydrodynamic calculations because of its effect on water density. The water quality routines simulate any combination of constituents that can represent a range of simple-to-complex eutrophication kinetics and various trophic levels. The model includes algal dynamics driven by nitrogen, phosphorus and silicon, and carbon cycling. Both water column and interactions with sediment can be modeled as defined by the user. W2 uses an internally-calculated time step, to maximize computational efficiency and minimize model instability problems. The user can specify a minimum and maximum time step. For this study, we used W2 Version 3.5 (Cole and Wells 2007).

5.2.3 Development of the "Existing Conditions" Model

Detailed bathymetry data of the Wells reach, including Wells Reservoir, the lower 1.5 miles of the Methow River, and the lower 15.5 miles of the Okanogan River, were provided to the project team. Figure 5.2-1 shows the resulting reach bathymetry.

GeoEngineers, Inc. developed a geo-referenced HEC-RAS 1-D hydraulic model of the Wells Reach to develop backwater curves at various flows (GeoEngineers 2008). The geometry data for this W2 model were developed from the detailed bathymetric survey of the reservoir. We then processed the model geometry to develop stage-width curves at 0.5-m intervals at each cross section, and then averaged the data between cross sections to develop stage-width relationships corresponding to W2 "segments." Some smaller segments were merged, and some additional sections were cut through the GIS coverage, to create more resolution in some areas and to refine the detail in the Columbia River near the confluence with the Okanogan River.

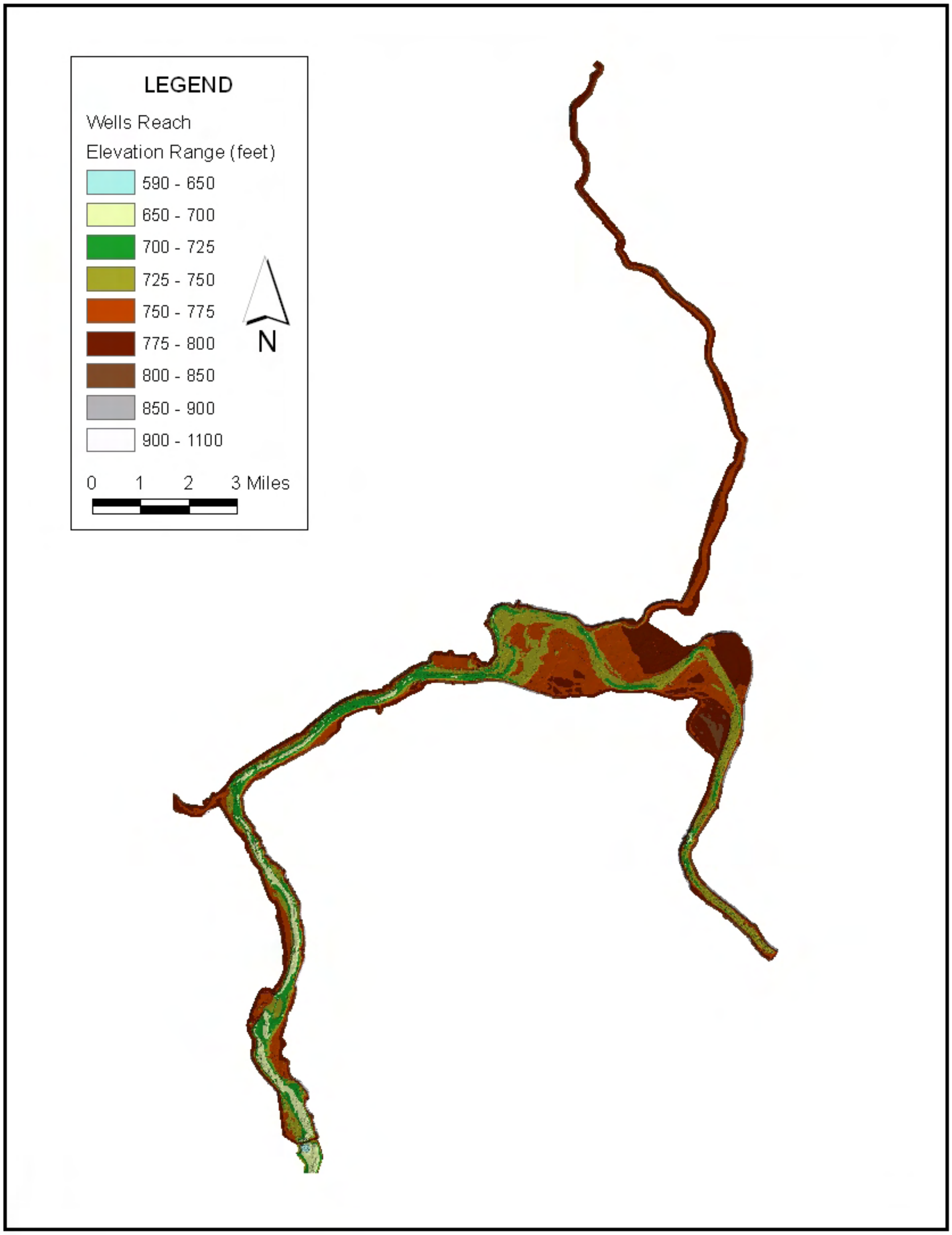

Figure 5.2-1 Wells Reach Bathymetric Data.

Figure 5.2-2 compares the resulting model geometry (stage-area and stage-volume) with data from the detailed bathymetric survey, and demonstrates that the model is a good representation of the physical geometry. The average horizontal resolution is approximately 470 m (1,550 ft). In the initial model, there were 90 segments along the Columbia River, 53 segments along the lower Okanogan River, and 8 segments along the lower Methow River. The geo-referenced HEC-RAS model was also used to develop segment lengths and orientations, and to specify Manning coefficient of roughness values.

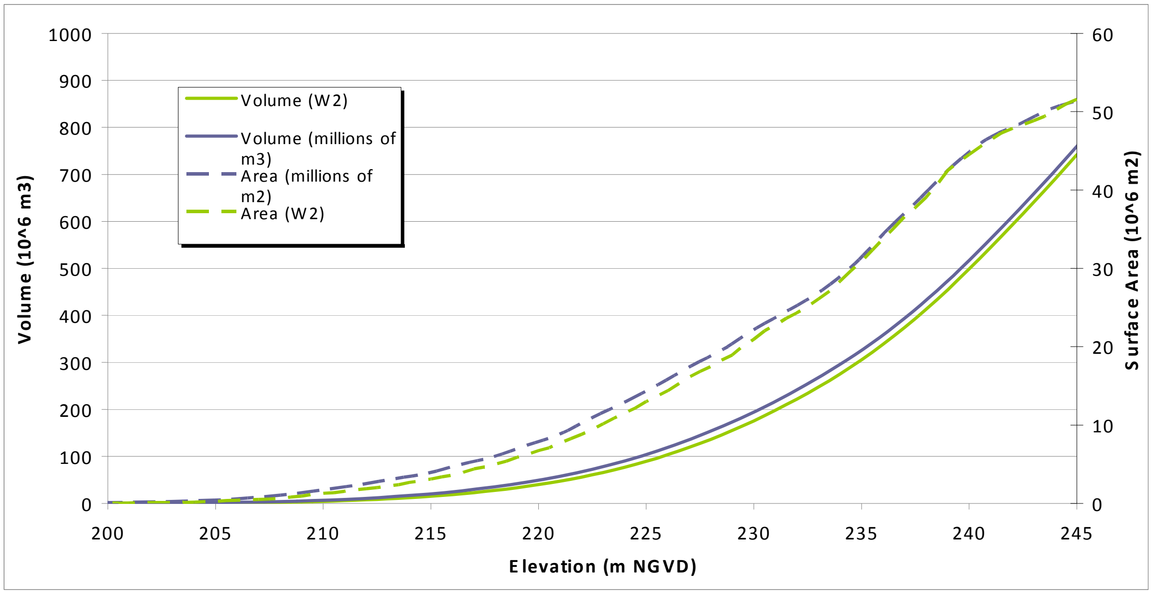

Figure 5.2-2 Comparison of model and survey geometries.

Wells Dam releases water through the turbine generators, through the spillway, and from the surface to fish ladders on either side of the dam. Table 5.2-1 summarizes these data, which were used to specify the elevations and widths for downstream flows in the W2 model "control" file.

Table 5.2-1 Reservoir and Dam technical specifications.

Feature	**Wells Reservoir and Dam**	
	Elev (ft) (NGVD)	**Elev (m) (NGVD)**
Low point in reservoir (for 0.5 m vertical resolution)	640	195
Normal Reservoir operating range	771-781	235-238
Normal maximum operating level	781	238
Spillway crest elevation	716	218.2
Spillway gates	11 46x65 gates	11 14x19.8
Intake elevation to generators	646-706	197-215.2
Intake width	10 25-ft	10 7.6-m
Fish ladder withdrawals	Surface	Surface

5.2.4 Initial and Boundary Conditions Data

The reservoir model requires initial and boundary conditions. These are:

- Initial reservoir stage;
- Initial reservoir temperatures;
- Inflows to the reservoir;
- Water temperatures of the reservoir inflows;
- Outflows from the reservoir through the various structures; and
- Meteorology.

The W2 model was run for the period 1/1/2006 to 9/30/2007, with a maximum time step of one hour. As the reservoir stage on 1/1/2006 was very close to its normal maximum operating level of 781 ft (238 m), the initial stages in the reservoir were set to 238 m (780.9 feet msl). The reservoir temperatures are cold at the beginning of each year. The initial reservoir temperature was set to a uniform value of 1^{o}C. Temperatures this low have been measured in the Okanogan and Methow rivers, and initial simulation showed that the model adjusts from this initial condition by the time the first in-reservoir temperatures are measured on 1/26/2006. Observed reservoir inflows and outflow, and inflow temperatures were specified from observations (see Figure 5.1-1). Meteorological data from the Brewster station were used in the model, with cloud cover data from Omak Airport.

5.2.5 Initial Model Runs

The initial model included the Columbia River from Wells Dam to Chief Joseph Dam, the lower 15.5 miles of the Okanogan River, and the lower 1.5 miles of the Methow River. When this initial model was run, however, it became numerically unstable in the upper reach of the Okanogan River at the upstream limit of the relatively flat backwater from the confluence. This upstream limit is influenced by the flow in the Okanogan River.

For much of the simulation, the model runs without numerical instabilities. However, instabilities were seen in mid- to late-May 2006 when two things happened: the reservoir was lowered from about 238 m (780.9 feet msl) to about 235.25.m (771.8 feet msl), and at the same time a significant flood occurred on the Methow and Okanogan rivers. As W2 generally uses horizontal layers to model reservoirs, and the surface elevation is constrained to be in the same vertical layer throughout a "waterbody", when the reservoir is lowered to 235.25 m (771.8 feet msl) the most upstream segments in the Okanogan River have top-layer thicknesses approaching 10 m, with underlying layers of only 0.5 m thick. This is a very unstable combination numerically, and the model fails.

Figure 5.2-3 shows three example profiles on the lower 15.5 miles of the Okanogan River developed from the HEC-RAS one-dimensional hydraulic model. The lowest profile ("PF1") specifies the stage in the reservoir forebay at 238 m (780.8 feet msl) and includes moderate reservoir inflows. The second profile ("PF2") again holds the reservoir stage at 238 m (780.9 feet msl), but includes flood flows on the three rivers. The third profile ("PF3") lowers the forebay reservoir stage to 235.25 m (771.8 feet msl), and includes the flood flows of late May 2006. The results show that the lower 6-7 miles of the Okanogan River are relatively unaffected, but that the water surface elevations rise sharply farther upstream in response to flood flows on the Okanogan River. In addition, Figure 5.2-4 compares the observed hourly temperatures at the USGS gauge at Malott (RM 17) with hourly observations at the PUD gauge at Wakefield Bridge (RM 10.5), for August and September 2006. The temperatures are generally similar, with those at the Wakefield Bridge gauge showing some "damping" (lowering of daily maximum temperatures and raising of daily minimum temperatures) due to the backwater effect from the Wells Project.

To overcome this numerical instability, a shorter reach of the Okanogan River was modeled to capture only the extent of the backwater at high flows in the Okanogan River combined with the simultaneous lowering of the Wells Reservoir, and to test the effect of this through sensitivity analyses. Therefore, three additional models were created: (1) a model of the Columbia River only (only the Okanogan and Methow River inflows and temperatures were added); (2) a "short Okanogan River" that included the lower 6 miles; and (3) a "longer Okanogan River" that included the lower 11.3 miles, which is the most upstream reach influenced by backwater effects from the Columbia River under Project conditions. In addition, a sensitivity analysis was performed to compare the use of temperatures from the Malott gauge with the use of temperatures from the Wakefield Bridge on results in the lower Okanogan River and in the Columbia River.

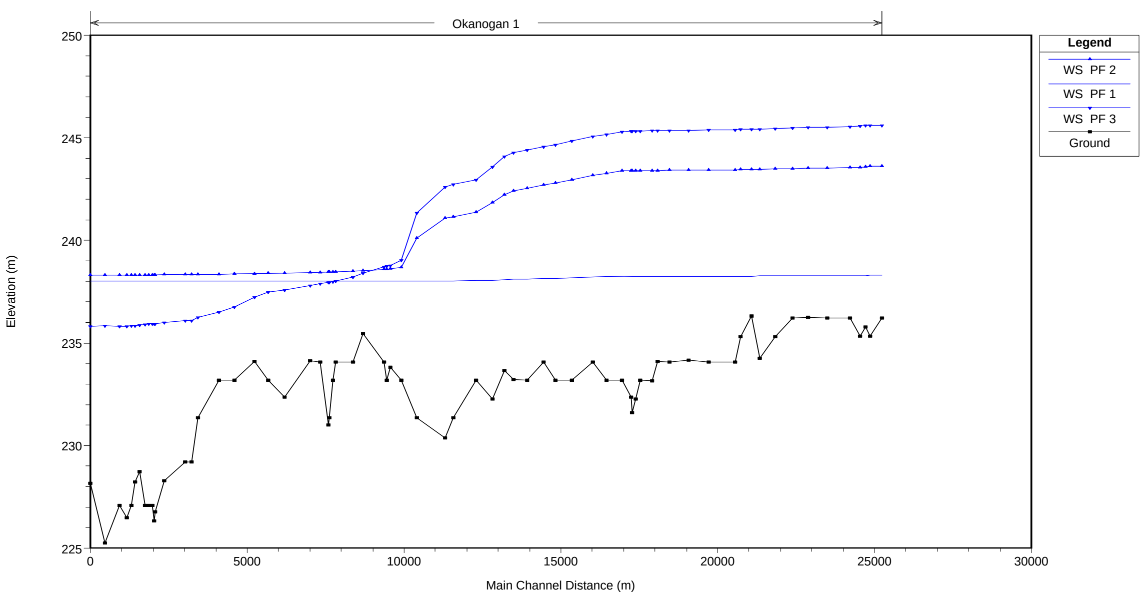

Figure 5.2-3 Flow profiles on lower Okanogan River.

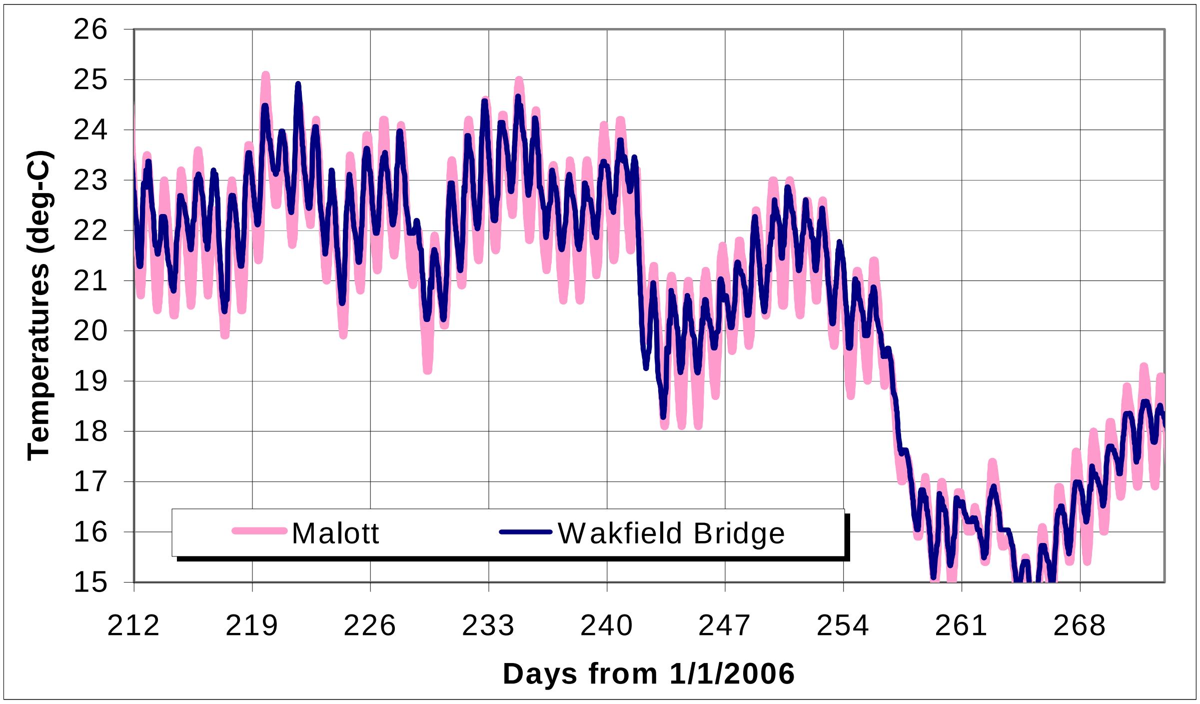

Figure 5.2-4 **Comparison of observed temperatures at Malott (RM 17) and Wakefield Bridge (RM 10.5) on Okanogan River.**

5.2.6 Hydrodynamic Calibration

The hydrodynamic (stage) calibration of the reservoir was achieved by using "additional" inflows, developed from a mass balance of observed inflows and outflows, to force a good agreement with observed reservoir stages (Figures 5.2-2 and 5.1-8).

5.2.7 Model Sensitivity and Calibration

The W2 model has relatively few calibration parameters. They include the grid resolution, Manning coefficient of roughness values, the choice of turbulent mixing scheme, the choice method used to model surface heat exchange processes, wind sheltering, and solar radiation shading. Other parameters were kept at the default values recommended by Cole and Wells (2007).

The model sensitivity analyses focused on:

1. The length of the Okanogan River included in the model ("Columbia River Only"; "short Okanogan River" of the lower 6 miles; and "longer Okanogan River" of the lower 11.3 miles).
2. The inclusion of wind mixing and thermal exchange ("no wind" and "no solar").
3. The method to compute the rate of thermal exchange with the atmosphere ("ET" is an equilibrium temperature approach, and "TERM" includes all the solar exchange terms).

4. The method to compute vertical turbulent mixing (“W2N”, “PARAB”, “NICK”, “RNG”, and “TKE” – these methods are fully described in Cole and Wells [2007]).
5. The effect of increasing the Manning coefficient of roughness values (base values; and 110% of base values).
6. The use of temperature data from the USGS gauge at Malott or the PUD gauge at Wakefield bridges as Okanogan River inflow temperatures.

The “base case” was taken to be the “longer Okanogan River” (the lower 11.3 miles), using the equilibrium temperature method (“ET”) to simulate thermal exchange, including the wind and solar radiation processes, and using the “W2N” method the compute vertical turbulent mixing. Several of the simulations became unstable under these conditions, with only one “parameter” changed (to test its sensitivity). In these cases, the “short Okanogan River” geometry was used. These instances are noted with a “*” in the following summary tables.

Following each simulation, a range of summary statistics was developed that compared the model results with observations at the monitoring stations (Figure 5.1-2). The statistics included mean error (ME), mean absolute error (MAE), root mean square error (RMSE) and the correlation coefficient (COR). Of these statistics, the mean errors were generally close to zero, and the correlation coefficients were generally very close to “1”, so little is illustrated by reporting their values. Instead, the mean absolute error (MAE; Table 5.2-2) and the root mean square errors (RMSE; Table 5.2-3) for the various sensitivity simulations were reported.

Based on these results, as shown in Tables 5.2-2 and 5.2-3, the following conclusions were drawn:

- The inclusion of the Okanogan River, or of the Methow River, has little effect on temperatures in the Wells Forebay.
- The use of the “W2N” method to compute turbulent mixing produces the best results.
- There is little difference between the equilibrium temperature (ET) and the term-by-term (TERM) methods for computing surface heat exchange. Cole and Wells (2006) note that while the term-by-term method has a stronger theoretical foundation, the equilibrium temperature method often gives better results with less computational effort.
- Including the wind terms has only a small effect. This is not surprising given the relatively short residence time (about one day at high flows, to 10-12 days at low flows) in Wells Reservoir.
- Inclusion of the surface heat exchange processes is perhaps the most significant process affecting model calibration.
- Modest variations in roughness (Manning coefficient of roughness) cause little difference in reservoir temperatures.
- The use of temperature data from the PUD gauge at Wakefield Bridge improved the results in the lower Okanogan River with no effect on the results in the Columbia River.

Figure 5.2-5 through Figure 5.2-7 illustrate some of the differences seen in the model sensitivity analyses. Figure 5.2-5 looks at the effect of including the lower Okanogan River in the model simulation. While the results show only small differences downstream of Brewster Bridge, some differences can be seen in the reservoir near the confluence of the Columbia River and the Okanogan River. We believe that the inclusion of at least some of the lower Okanogan River allows vertical mixing in the vicinity of the rise in the bed elevation of the Okanogan River located 3-6 miles upstream of the confluence (Figure 5.2-3). There does appear to be little difference, however, between including either 6 miles or 11.3 miles of the lower Okanogan River.

Table 5.2-2 Mean absolute errors for sensitivity analyses.

Condition	Forebay stage (m)	Temperature (°C)								
		Erlandsen's (mid)	Erlandsen's (bot)	Lower Okanogan	Brewster Bridge (mid)	Brewster Bridge (bot)	Lower Methow River (mid)	Wells Forebay (surface)	Wells Forebay (mid)	Wells Forebay (bot)
"longer Okanogan River"	0.15	0.24	0.25	0.83	0.16	0.15	0.71	0.16	0.13	0.13
"short Okanogan River"	0.15	0.23	0.24	0.88	0.16	0.15	0.74	0.16	0.12	0.13
Columbia River only	0.14	0.22	0.27		0.16	0.17		0.16	0.12	0.13
Term-by-term solar exchange ("TERM")	0.14	0.25	0.26	0.86	0.17	0.16	0.72	0.18	0.14	0.14
"PARAB" turbulent mixing*	0.09	0.25	0.43	1.30	0.16	0.22	1.02	0.76	0.13	0.19
"NICK" turbulent mixing*	0.09	0.25	0.44	1.28	0.16	0.22	1.04	0.77	0.13	0.19
"RNG" turbulent mixing*	0.09	0.25	0.43	1.30	0.16	0.22	1.02	0.76	0.13	0.19
"TKE" turbulent mixing*	0.09	0.24	0.27	0.77	0.15	0.16	0.70	0.17	0.12	0.13
No wind terms included	0.14	0.24	0.25	0.81	0.17	0.15	0.72	0.17	0.14	0.15
No solar radiation included	0.14	0.23	0.24	0.88	0.19	0.19	0.81	0.28	0.28	0.29
110% of Manning's *n**	0.16	0.23	0.24	0.89	0.16	0.15	0.75	0.16	0.13	0.13
Wakefield Bridge temperatures for Okanogan	0.14	0.12	0.13	0.82	0.16	0.15	0.72	0.16	0.13	0.13

Table 5.2-3 Root mean square errors for sensitivity analyses.

Condition	Forebay stage (m)	Temperature (°C)								
		Erlandsen's (mid)	Erlandsen's (bot)	Lower Okanogan	Brewster Bridge (mid)	Brewster Bridge (bot)	Lower Methow River (mid)	Wells Forebay (surface)	Wells Forebay (mid)	Wells Forebay (bot)
"longer Okanogan River"	0.20	0.38	0.47	1.48	0.20	0.20	1.08	0.20	0.16	0.17
"short Okanogan River"	0.20	0.37	0.46	1.49	0.20	0.20	1.13	0.21	0.16	0.17
Columbia River only	0.19	0.31	0.54		0.21	0.29		0.20	0.16	0.17
Term-by-term solar exchange ("TERM")	0.20	0.39	0.49	1.49	0.22	0.21	1.09	0.23	0.17	0.18
"PARAB" turbulent mixing*	0.12	0.42	0.78	2.00	0.21	0.29	1.46	1.03	0.17	0.24
"NICK" turbulent mixing*	0.12	0.42	0.79	1.99	0.21	0.29	1.47	1.04	0.17	0.24
"RNG" turbulent mixing*	0.12	0.42	0.78	2.01	0.21	0.30	1.45	1.02	0.17	0.24
"TKE" turbulent mixing*	0.12	0.41	0.57	1.24	0.20	0.22	1.07	0.22	0.16	0.17
No wind terms included	0.19	0.38	0.49	1.50	0.21	0.21	1.10	0.22	0.18	0.19
No solar radiation included	0.20	0.35	0.44	1.50	0.25	0.25	1.19	0.34	0.35	0.35
110% of Manning's *n**	0.22	0.36	0.46	1.52	0.20	0.20	1.14	0.20	0.16	0.17
Wakefield Bridge temperatures for Okanogan	0.20	0.17	0.24	1.47	0.20	0.21	1.09	0.20	0.16	0.17

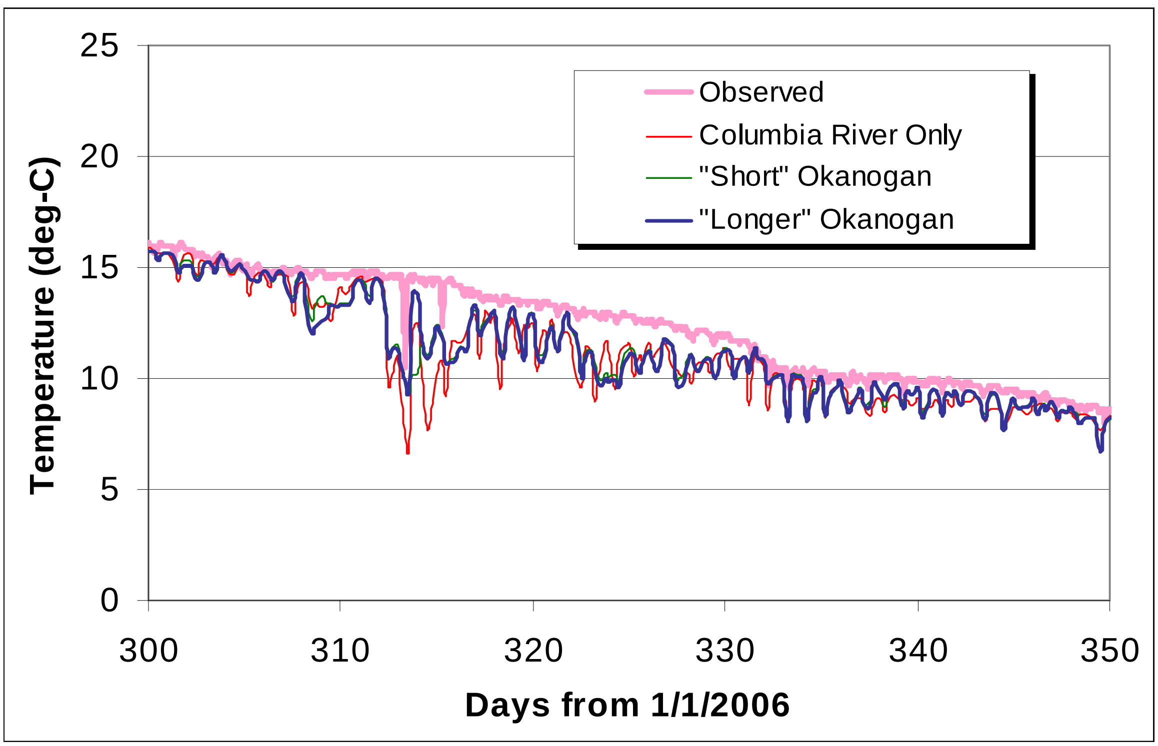

Figure 5.2-5 Effect of including the Okanogan River on the Columbia River at Erlandsen's (bot).

Figure 5.2-6 looks at the effect of including or not including surface heat exchange processes in the model. The effect is more pronounced on the cooling limb of the annual temperature series, as the model cools less quickly when this surface exchange processes are not included. However, the results also show that the diurnal range is relatively small, and that the system is perhaps most influenced by the temperature of the inflows from Chief Joseph.

Figure 5.2-7 looks at the effect of some of the different methods of modeling vertical turbulent mixing in W2. Cole and Wells (2007) recommend using the "W2N" method for relatively deep systems, such as Wells Reservoir, and this seems to be borne out by the model results. The "W2N" method includes more wind-induced mixing than many of the other methods, which are based more on velocity-induced mixing. The results show that the "PARAB" method (the "NICK" and "RNG' methods show similar effects) under-predicts the amount of vertical mixing, and allows the near-surface water to respond more dynamically to surface heat exchange than is seen in the observations. The "W2N" method not only better fits the trend of the observations but also better models the diurnal variations.

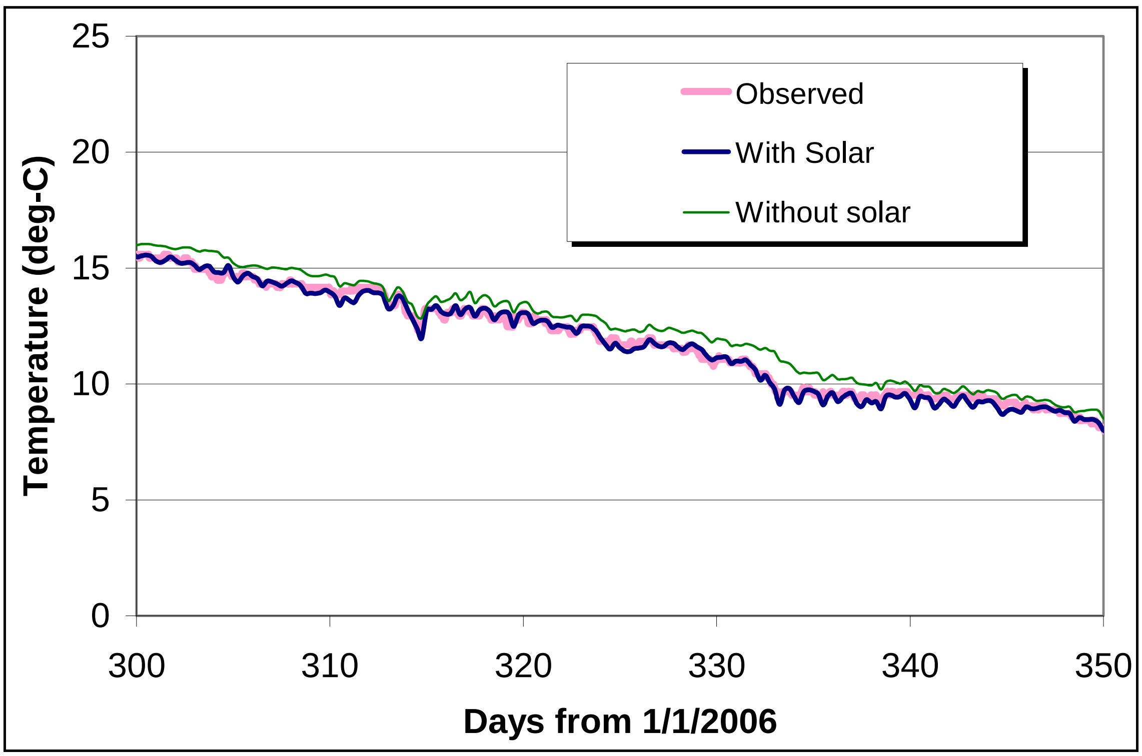

Figure 5.2-6 Effect of including surface heat exchange at Forebay (surface).

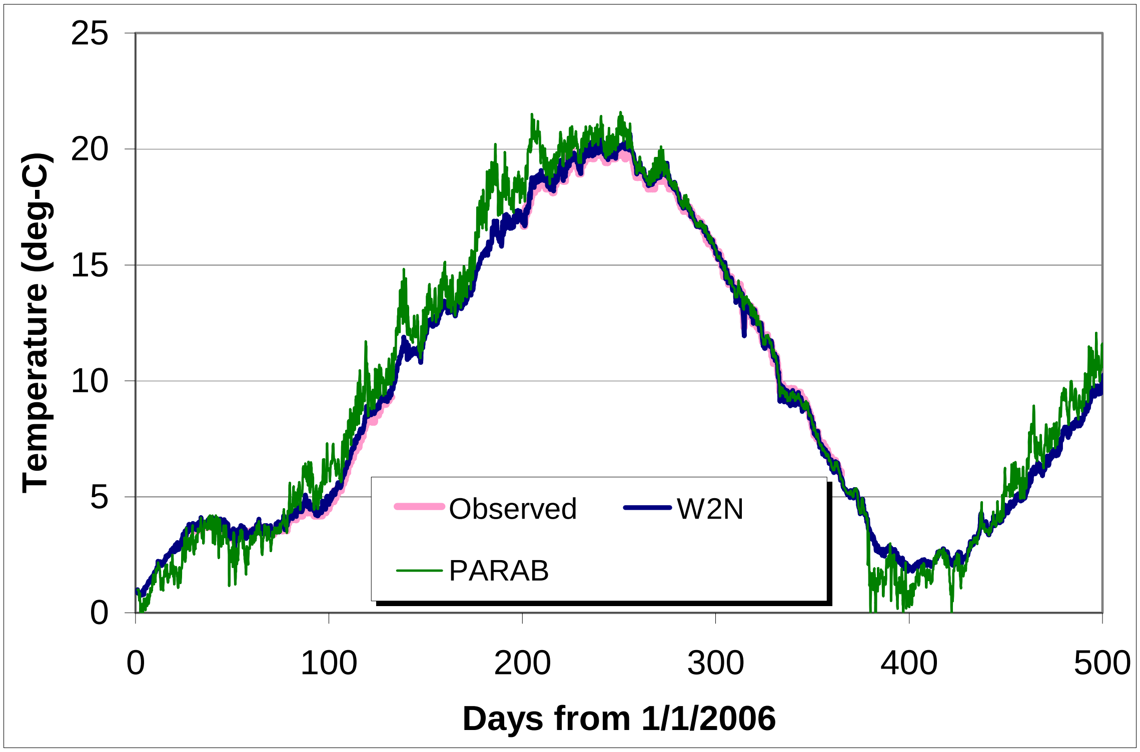

Figure 5.2-7 Effect of vertical mixing methods at Forebay (surface).

5.2.8 Temperature Calibration

From the model sensitivity analyses, it was concluded that temperatures for "existing conditions" are best modeled using the same bottom friction (Manning coefficient of roughness values) as in the HEC-RAS model, that surface heat exchange should be included, that the "W2N" method should be used to model vertical turbulent mixing, and that observations at the Wakefield Bridge gauge should be used to represent Okanogan River inflow temperatures (as this gauge at RM 10.5 is closer to the model upstream boundary at RM 11.3. It appears appropriate to use the wind speed and direction reported at the Bridgeport Bar meteorological station and to use the "wind sheltering" coefficient to modify the wind speed in other areas of the reservoir. The lower 11.3 miles of the Okanogan River was included in the model (1) because this model does run stably and (2) because it provided some temperature mixing in the lower Okanogan River prior to flowing into the Columbia River, which improves the results of the model at the Erlandsen's temperature monitoring site. The results of the "with Project" model calibration are shown in Figure 5.2-8.

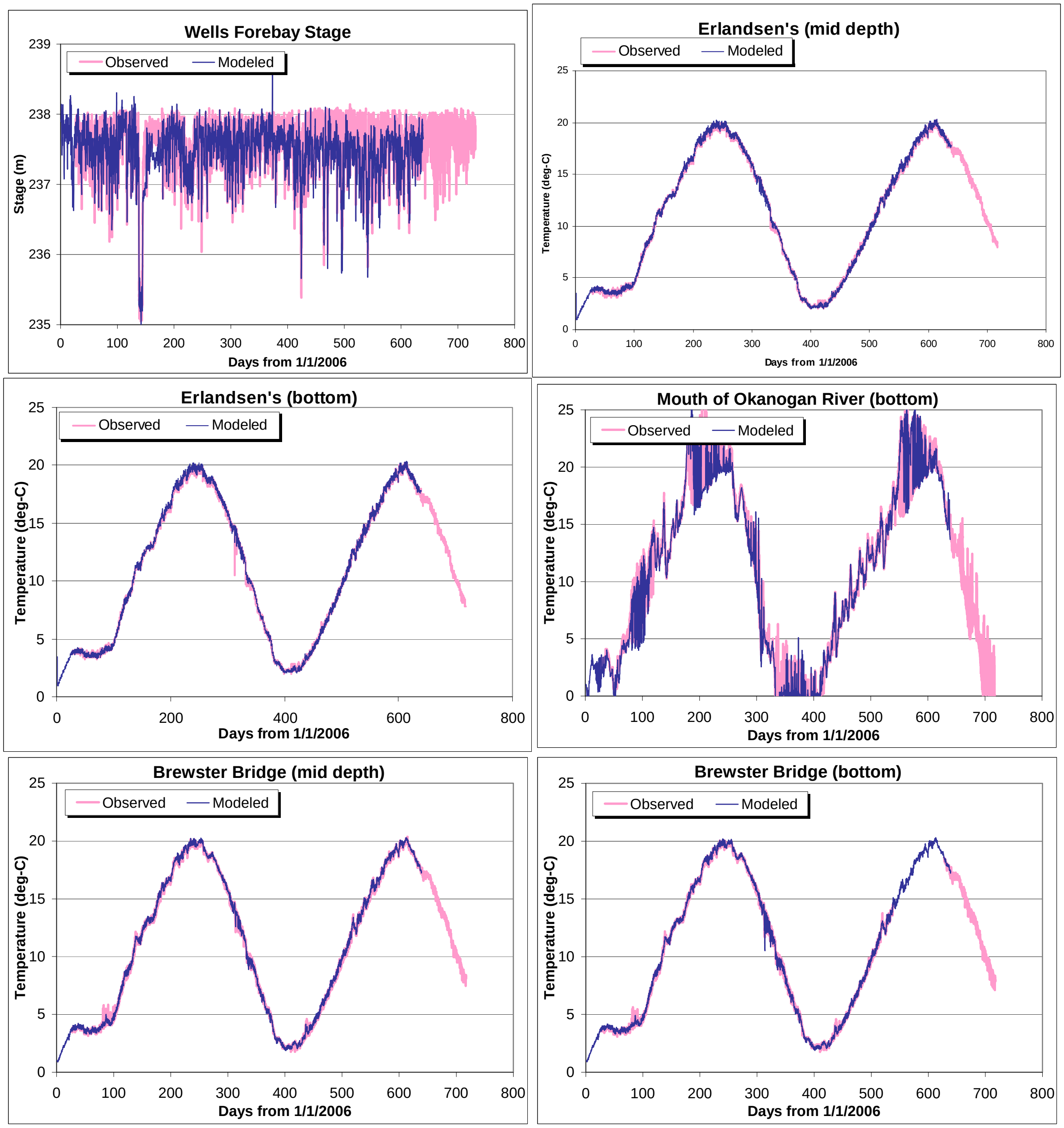

Figure 5.2-8. Calibration of state and temperatures at In-Reservoir stations.

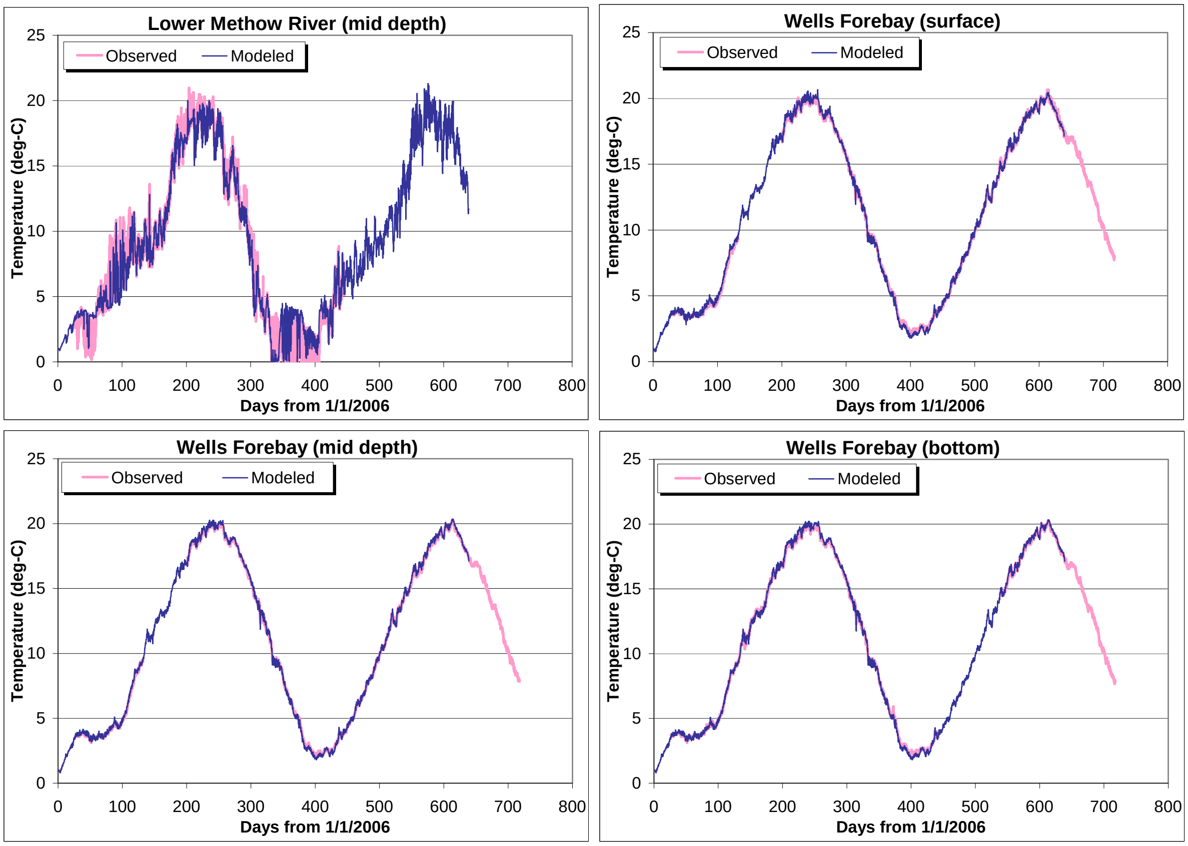

Figure 5.2-8 Calibration of stage and temperatures at In-Reservoir stations.

5.2.9 Development of "Without" Dam Model

The HEC-RAS model developed by GeoEngineers (2008) was used to guide the development of the "without-Project" W2 model. The HEC-RAS model was extended to include about four miles (7,000 m) downstream of Wells Dam, and a starting water surface slope was prescribed at the downstream extent of the model.

Using Figure 5.2-9 as a guide for "normal" and "flood" water surface profiles in the system, the W2 model for "without-Project" conditions:

- divided the Columbia River into two reaches – upstream and downstream of the "weir". In the "without Project" W2 model, a weir was used to hydraulically connect these two reaches;
- did not include a description of the lower Methow River, as the reach is short and very steep. Rather the same flows and temperatures were introduced directly into the Columbia River segment at the confluence with the Methow River;
- included the lower Okanogan River from about RM 5 (just upstream of the sharp grade break) to approximately river mile 11.3 (the upstream extent of the "with Project" model).

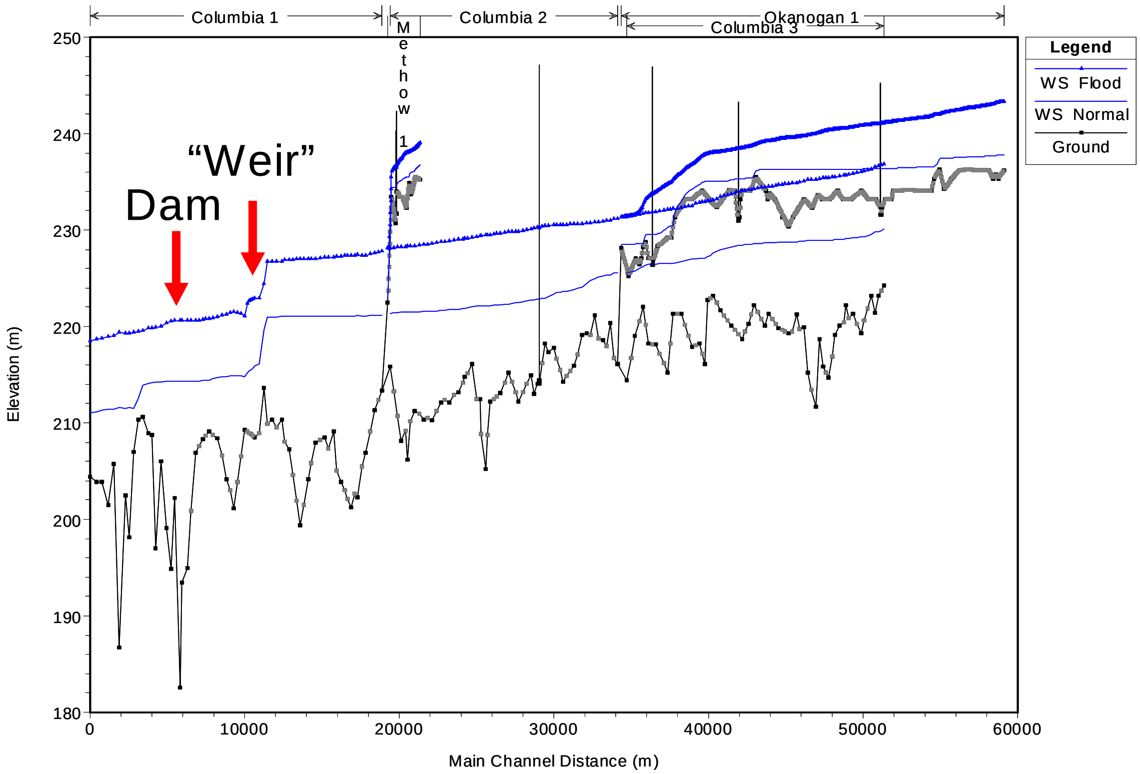

Figure 5.2-9 HEC-RAS Profiles of "Without-Project" Conditions.

Results from the HEC-RAS "without-Project" model (GeoEngineers, 2008) for flows in the Okanogan River on the order of 11 m^3/s (390 ft^3/s) indicate velocities in the lowest five miles of the Okanogan River on the order of 0.6 m/s (2 ft/s). This indicates that flows would take less than four hours to travel through this lowest five miles of the Okanogan River to reach the Columbia River. As the lowest five miles are relatively steep and generally shallow, they would be difficult to include in the larger "without Project" W2 model. As the travel time through this reach is relatively short, it was decided to not include it in the model for the results at RM 5 will be characteristic of conditions throughout the lowest five miles of the Okanogan River.

Aside from adjusting the values in the "dynamic shading" file to represent different angles for the sun to penetrate to the lowered "riverine" water surface elevations, all other input files remained the same as for the "with Project" model. The model was run for the same time period as the "with-Project" W2 model so that the results could be directly compared.

6.0 COMPARISON TO WATER QUALITY CRITERIA

The W2 models for “with Project” and “without Project” conditions were run for the nearly two years of simulation (1/1/2006 to 9/30/2007), and the results written each hour as depth-averaged temperatures. The results were saved at five “compliance point” locations (see Figure 6.1-1), and at other locations to evaluate system processes:

- Erlandsen’s
- Brewster Bridge
- Wells Forebay
- Wells tailrace
- Lower Okanogan (about RM 5)

The results were reported at RM 5 in the lower Okanogan River, because this is the downstream limit of the “without Project” model. It is located at the upstream end of the final steep section of the Okanogan River before it enters the Columbia River, and is representative of the reach not influenced directly by mixing between Okanogan River and Columbia River waters under “with Project” conditions.

The hourly results were post-processed to calculate daily maximum values. Then these maximum values were averaged over seven days (including the three days before and three days after) to calculate the 7-DADmax values at each location.

6.1 “Compliance Point” Comparisons

Figure 6.1-2 through Figure 6.1-6 show the “with Project” and “without Project” 7-DADMax values and their differences at the five locations in the Columbia River and Okanogan River (Figure 6.1-1). The maximum differences are summarized in Table 6.1-1. The results show that there are no “exceedances” of 0.3^{o}C at the four locations in the Columbia River. The results at RM 5 in the Okanogan River show a maximum difference of 1.1^{o}C, and exceedances of 0.3^{o}C occur on about five percent of the days. However, one significant problem when comparing “with Project” and “without Project” conditions is that the water moves through each system at different speeds. Therefore, if a pool of warm water is released from Chief Joseph Dam, it would reach Wells quicker if the dam were not there (i.e., under “natural river” conditions). This is especially true of the lower Okanogan River during the low-flow summer months, which is backwatered from Wells Dam. Thus, comparing the same time periods between “with Project” and “without Project” model results may not be an appropriate way to analyze Project effects on water temperature, due to differential flow velocities causing the same inflow waters to arrive at the compliance points at different times.

Another way to evaluate the results with regard to water quality temperature standards would be to compare the temperature exceedance distributions at each location, and evaluate their differences. Figure 6.1-7 through Figure 6.1-11 show the temperature exceedance distributions at each of the five locations in the Columbia River and Okanogan River, and the maximum differences are reported in Table 6.1-1. At each location, the maximum differences between the distributions did not exceed 0.15^{o}C, including at RM 5 in the lower Okanogan River. As depicted in Figure 6.1-6 and Figure 6.1-11, there is a balancing of heating and cooling in the lower Okanogan River that results in almost identical exceedance distributions. Figure 6.1-6 also shows the tendency for the temperatures "with Project" to be reduced as compared to "without Project" by about 0.5°C during the hottest summer months.

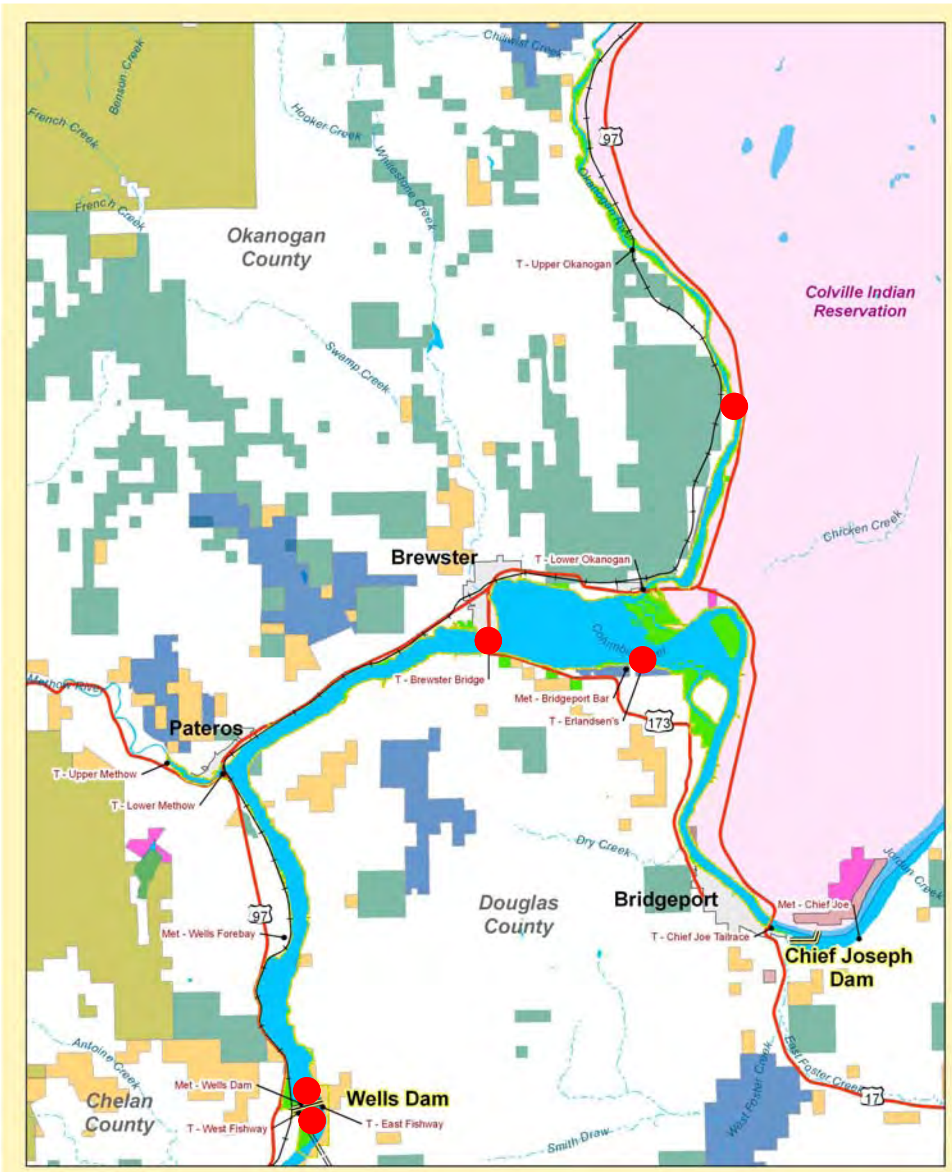

Figure 6.1-1 Water temperature model "Compliance Point" Locations.

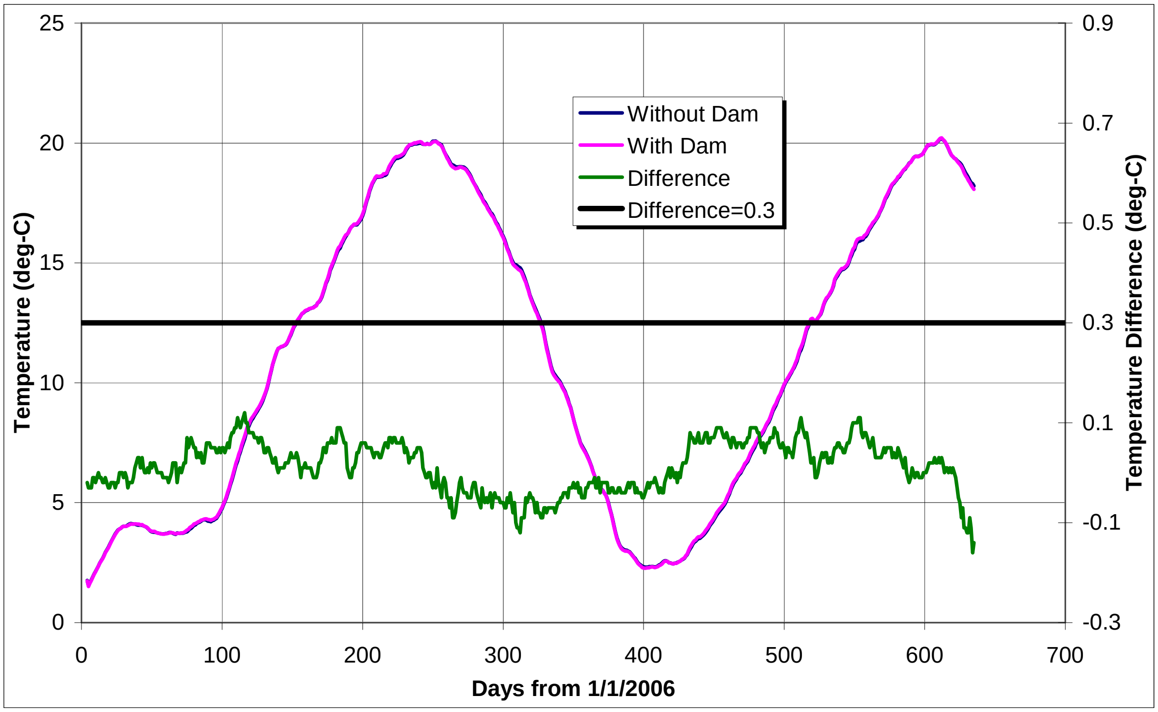

Figure 6.1-2 Comparison of 7-DADMax at Erlandsen's.

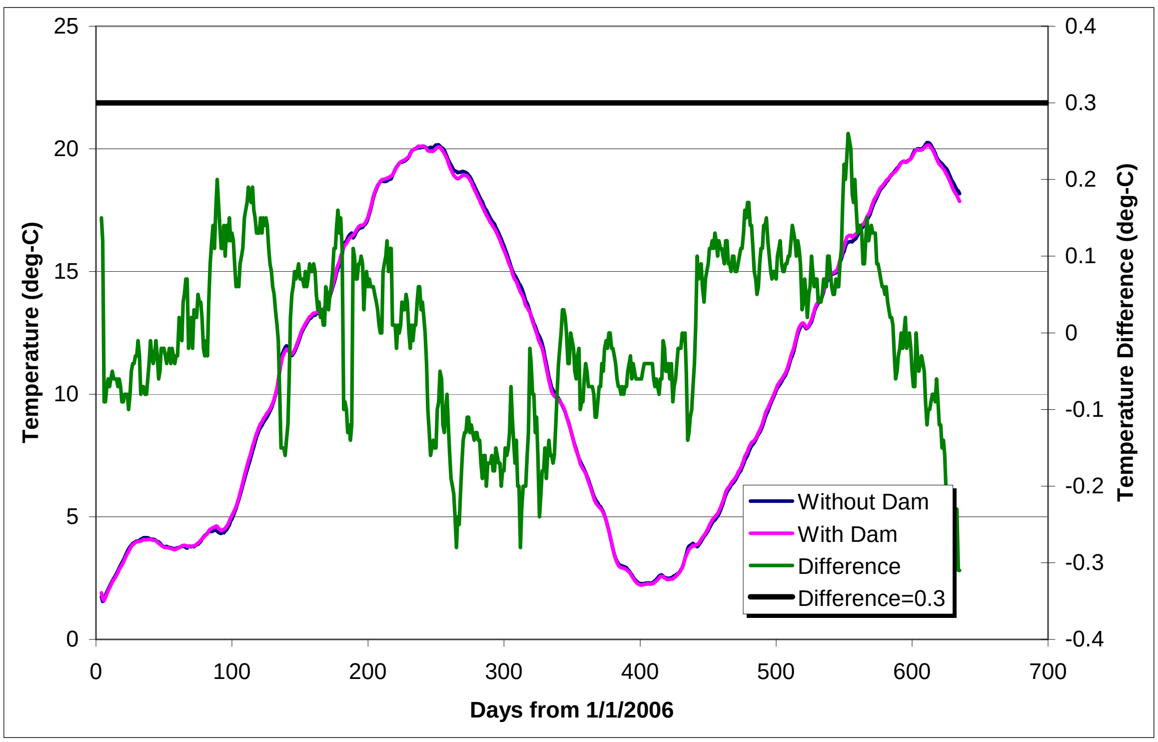

Figure 6.1-3 Comparison of 7-DADMax at Brewster Bridge.

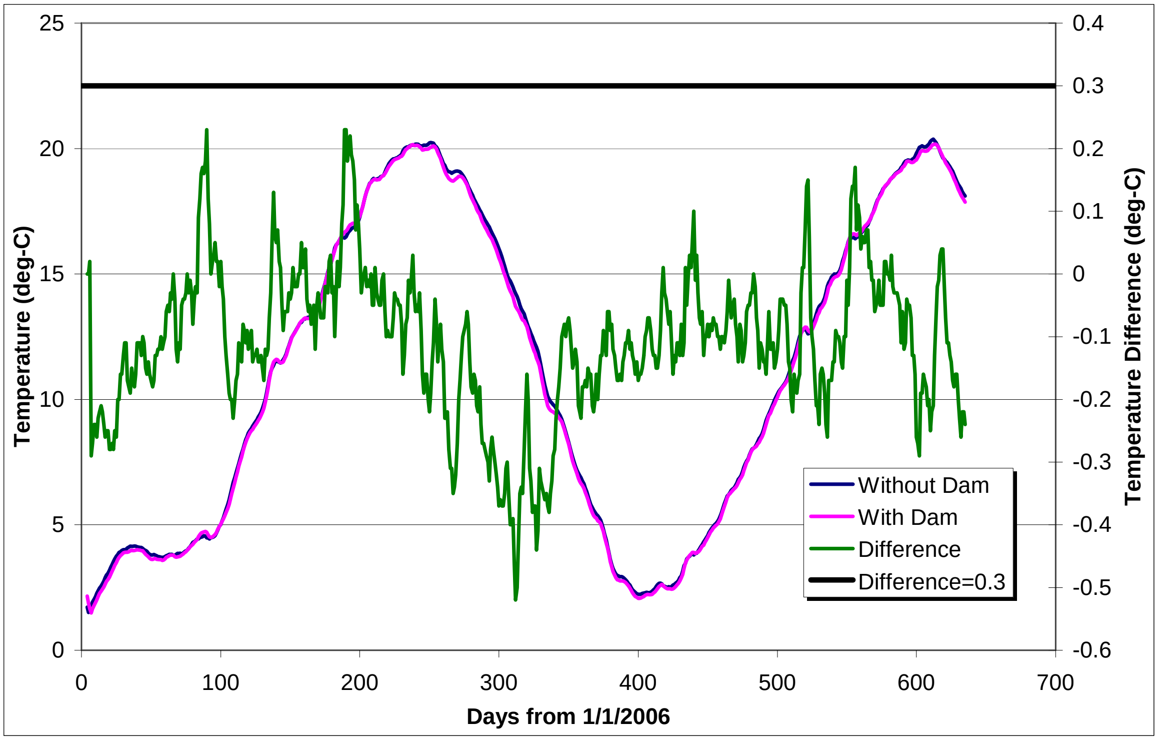

Figure 6.1-4 **Comparison of 7-DADMax at Wells Forebay.**

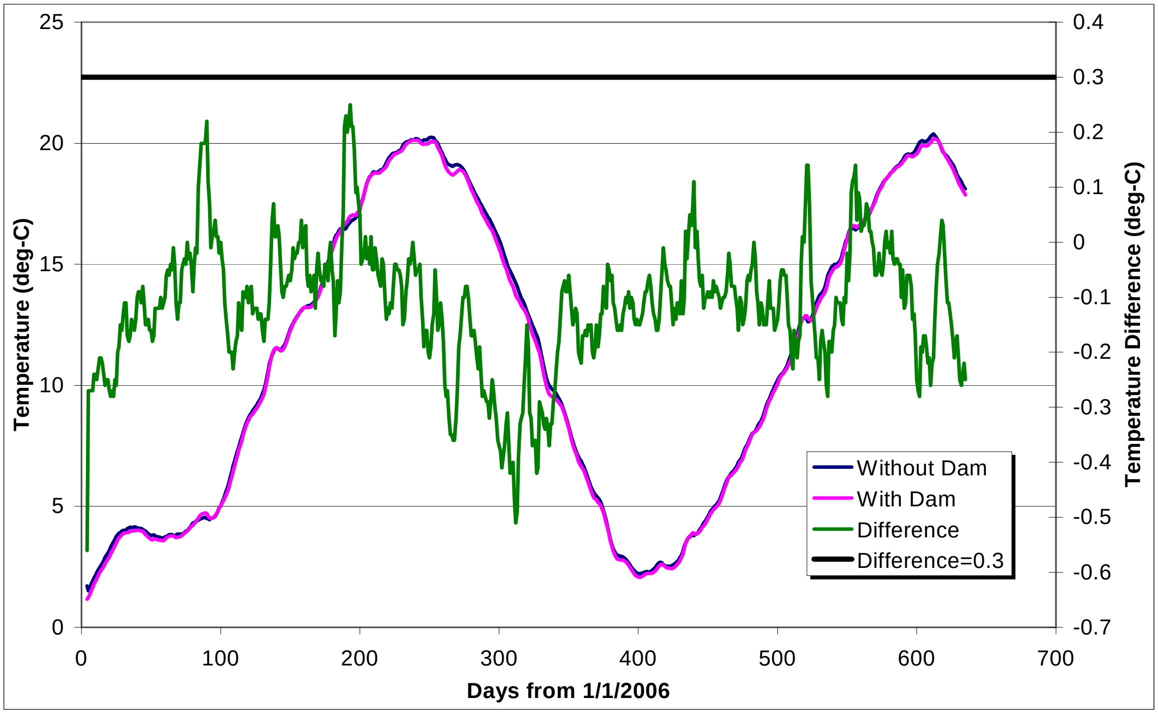

Figure 6.1-5 **Comparison of 7-DADMax at Wells Tailrace.**

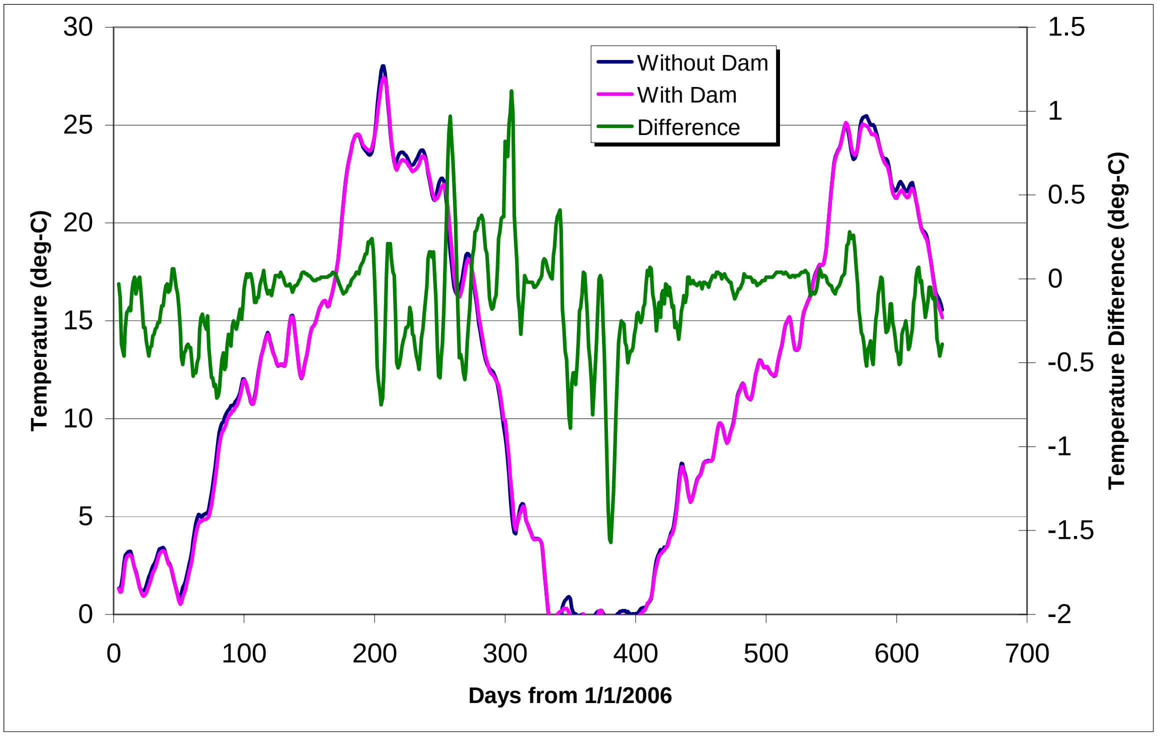

Figure 6.1-6 Comparison of 7-DADMax at Okanogan RM 5.

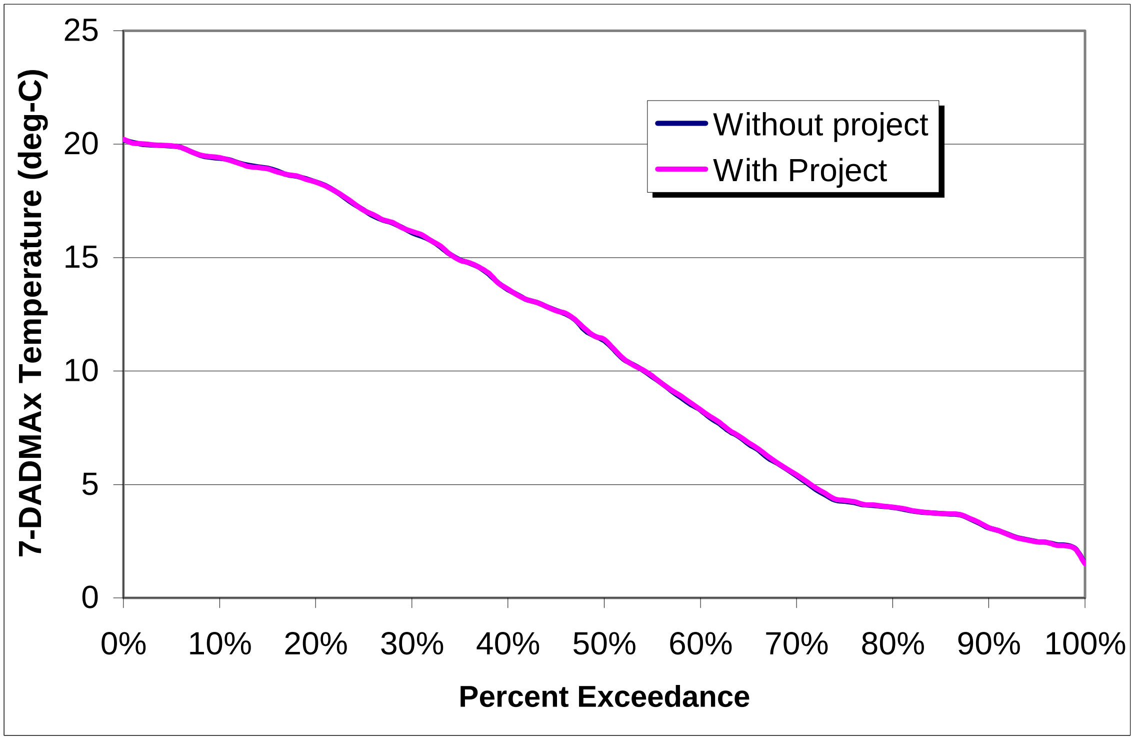

Figure 6.1-7 Comparison of Exceedance Frequencies at Erlandsen's.

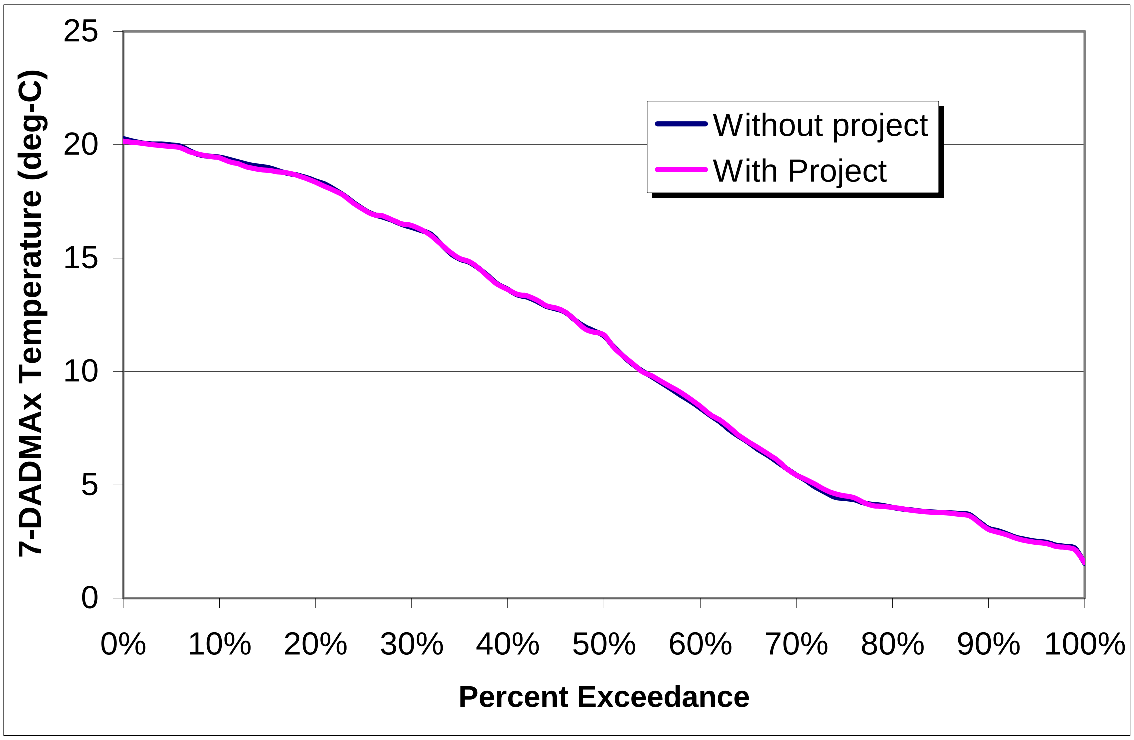

Figure 6.1-8 **Comparison of Exceedance Frequencies at Brewster Bridge.**

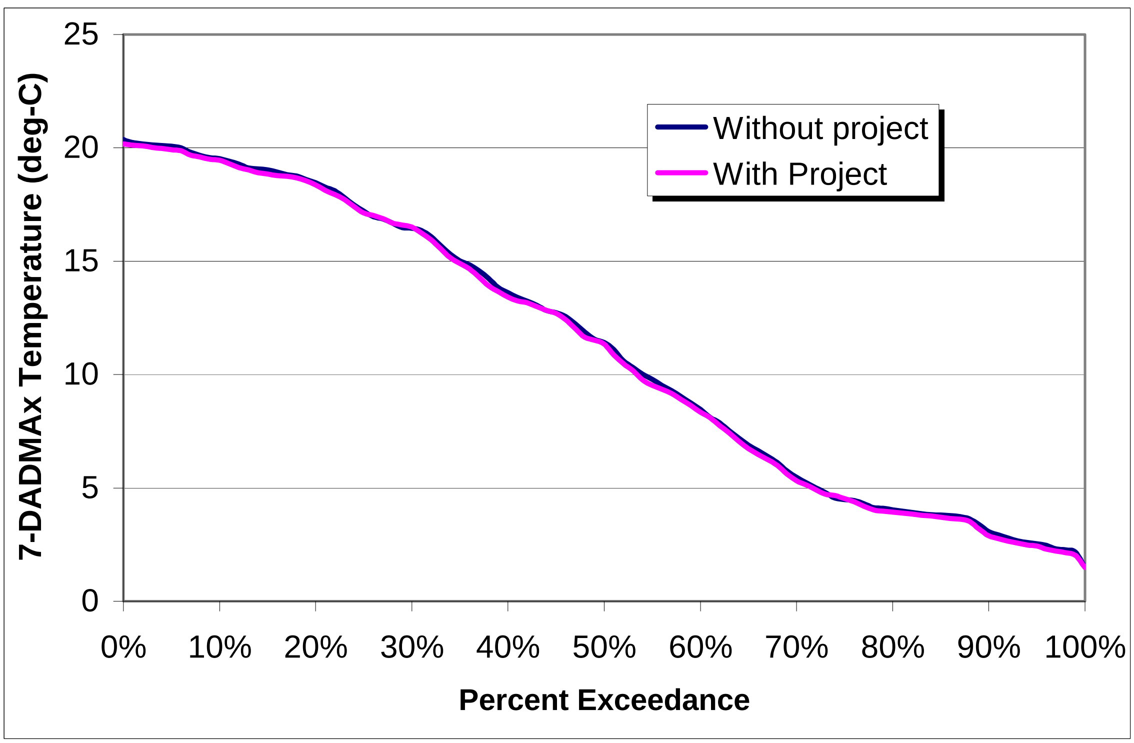

Figure 6.1-9 **Comparison of Exceedance Frequencies at Wells Forebay.**

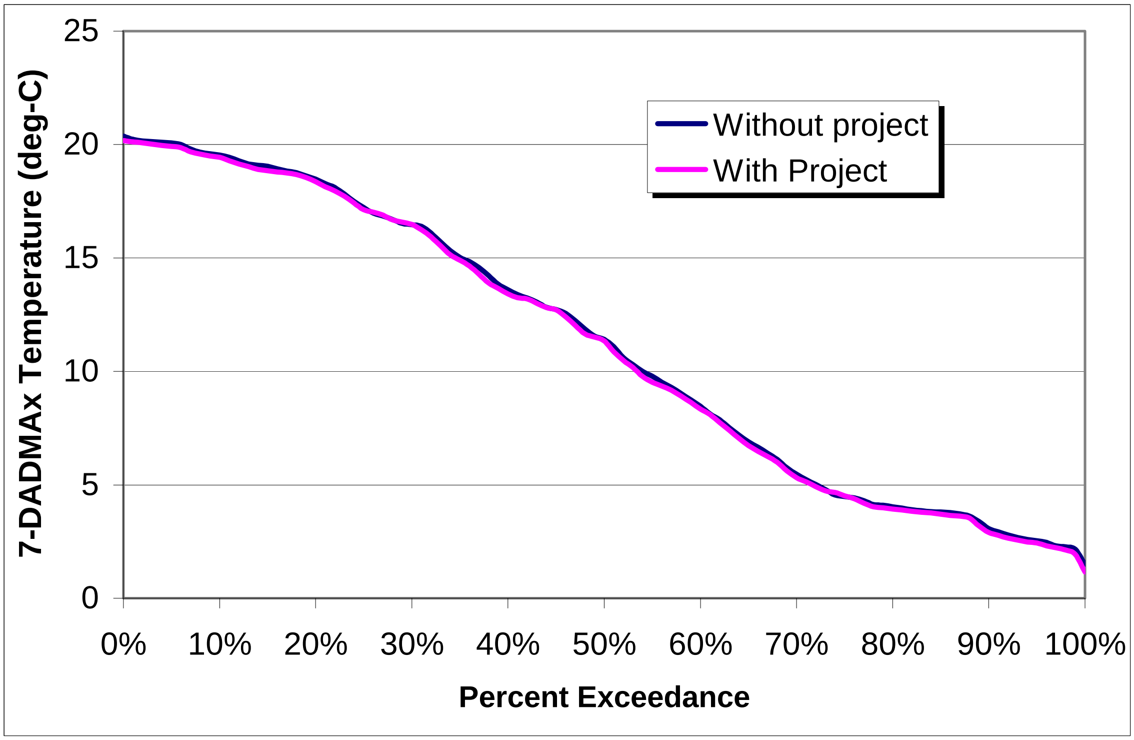

Figure 6.1-10 Comparison of Exceedance Frequencies at Wells Tailrace.

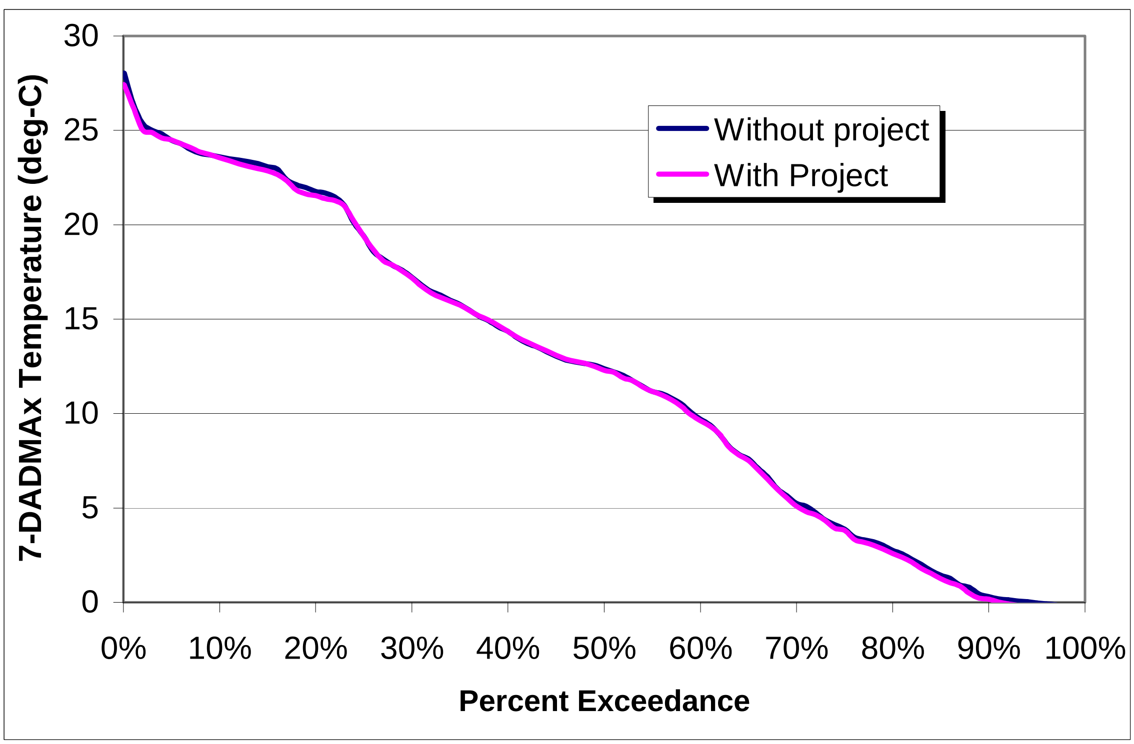

Figure 6.1-11 Comparison of Exceedance Frequencies at Okanogan RM 5.

Table 6.1-1 Comparison of Maximum Temperature Differences.

Location	Percent of days with difference exceeding 0.2(°C)	Maximum 7_DADmax difference (°C)	Maximum Exceedance difference (°C)
Erlandsen's	0	0.12	0.08
Brewster Bridge	0.9	0.26	0.15
Wells Forebay	0.8	0.23	0.11
Wells Tailrace	1.3	0.25	0.12
Okanogan River (RM 5)	(see text)	1.12	0.10

6.2 Mixing in the Lower Okanogan River

Figure 6.2-1 shows the "with Project" 7-DADMax temperatures at locations in the lower Okanogan River. Also shown are the temperatures released from Chief Joseph. In the lower Okanogan River, especially below the SR 97 Bridge, there is significant mixing with Columbia River water. During the very hot summer months, the releases from Chief Joseph are significantly cooler than the very warm temperatures upstream in the Okanogan River. During the winter months, the releases from Chief Joseph may be significantly warmer than the temperatures in the Okanogan River and serve to reduce ice formation. During the spring months, relatively little effect is seen, as this is a period of high snowmelt runoff in the Okanogan River. The most pronounced effect is during very short periods in the fall months when the Okanogan River cools more rapidly than the releases from Chief Joseph and the Okanogan River flows remain low.

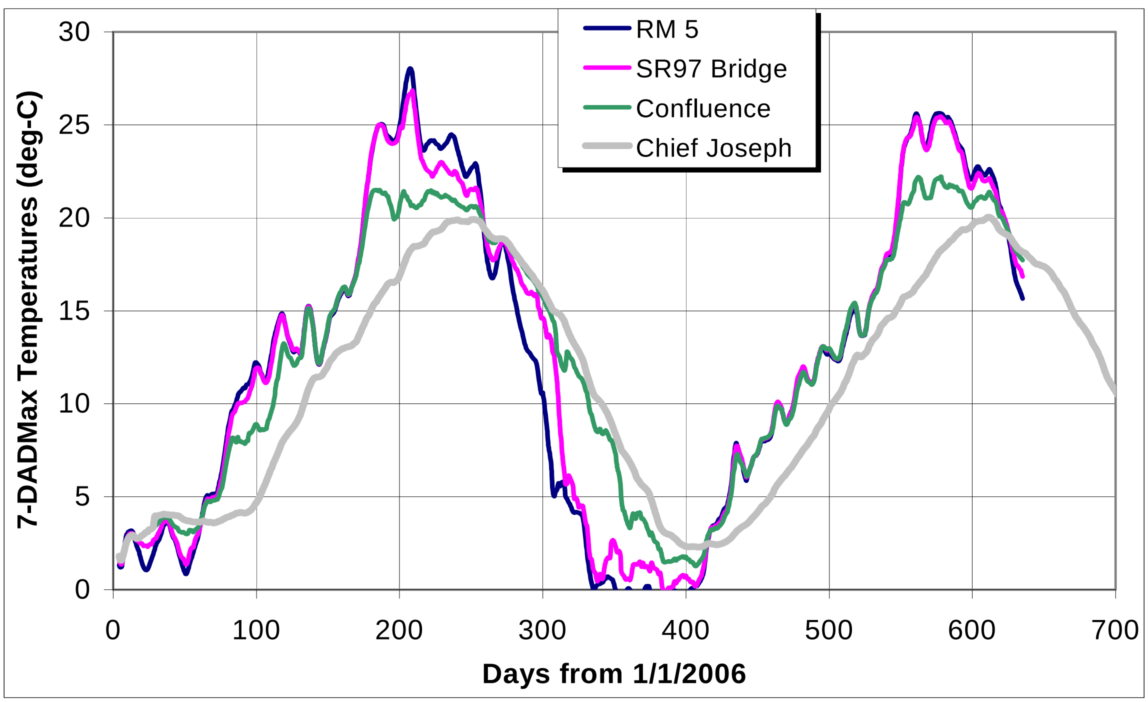

Figure 6.2-1 Comparison of 7-DADMax in Lower Okanogan River.

To examine these temperatures more closely, to determine whether they are influenced by (1) the backwatered flow moving slowly towards the Columbia River heating up more than 0.3°C due to thermal heating, or (2) whether this was simply mixing of the two water bodies at different temperatures, the data were processed to look for conditions with (1) Okanogan River ("without Project") temperatures exceeding 17.5°C, (3) downstream temperatures exceeding upstream temperatures by more than 0.3°C, and (4) the downstream water being warmer than temperatures in the Columbia River. 17.5°C was selected because it represents the threshold temperature for salmon rearing and migration (Ecology 2006). The analysis used the "without Project" modeled temperatures at RM 5 as ambient conditions, assuming that these temperatures would remain relatively uniform along the lower five miles of this steep section of the Okanogan River.

The analysis of the results for 2006-2007 showed only three days on which these conditions occurred, with the largest increase above Columbia River temperatures being 0.24°C. All of the differences occurred during late September when the flows in the Okanogan River were low and would have been caused by thermal heating in the lowest few miles of the Okanogan River. The analysis neglected any warming in the Columbia River between Chief Joseph and the Okanogan River confluence. Therefore, it is clear that whether the origin of the water is from the Okanogan River or from the Columbia River, thermal heating does not cause the ambient water temperature to increase more than 0.3°C.

6.3 Mixing in the Lower Methow River

Figure 6.3-1 shows time histories of the RM 1.5 observations, the results of the "with Project" model at the SR 97 Bridge, and the temperatures released from Chief Joseph. The results show processes very similar to those discussed in the lowest 1-2 miles of the Okanogan River. In the winter months, the very cold flows in the Methow River are moderated by warmer releases from Chief Joseph. In the hottest summer months, the high temperatures observed at RM 1.5 are moderated by cooler backwater from the Columbia River, and may cool the lower Methow River by 2-3°C. In the fall, backwater from the Columbia River may intrude into the lower Methow River and mix with the more-rapidly cooling but generally low flows in the Methow River.

The next step in the model including processing the data to look for conditions with (1) Methow River ("without Project") temperatures exceeding 17.5°C, (2) downstream temperatures exceeding upstream temperatures by more than 0.3°C, and (3) the downstream water being warmer than temperatures in the Columbia River. 17.5°C was selected because it represents the threshold temperature for salmon rearing and migration (Ecology 2006). The analysis of the results for 2006-2007 showed only seven days on which this thermal heating condition occurred, with the largest increase above Columbia River temperatures being 0.3°C. All of the differences occurred in July-September when the flows in the Methow River were relatively small. Again, the analysis neglected any warming in the Columbia River between Chief Joseph and the Methow River confluence. Whether the origin of the water is from the Methow River or from the Columbia River, thermal heating does not cause the ambient water temperature to increase more than 0.3°C.

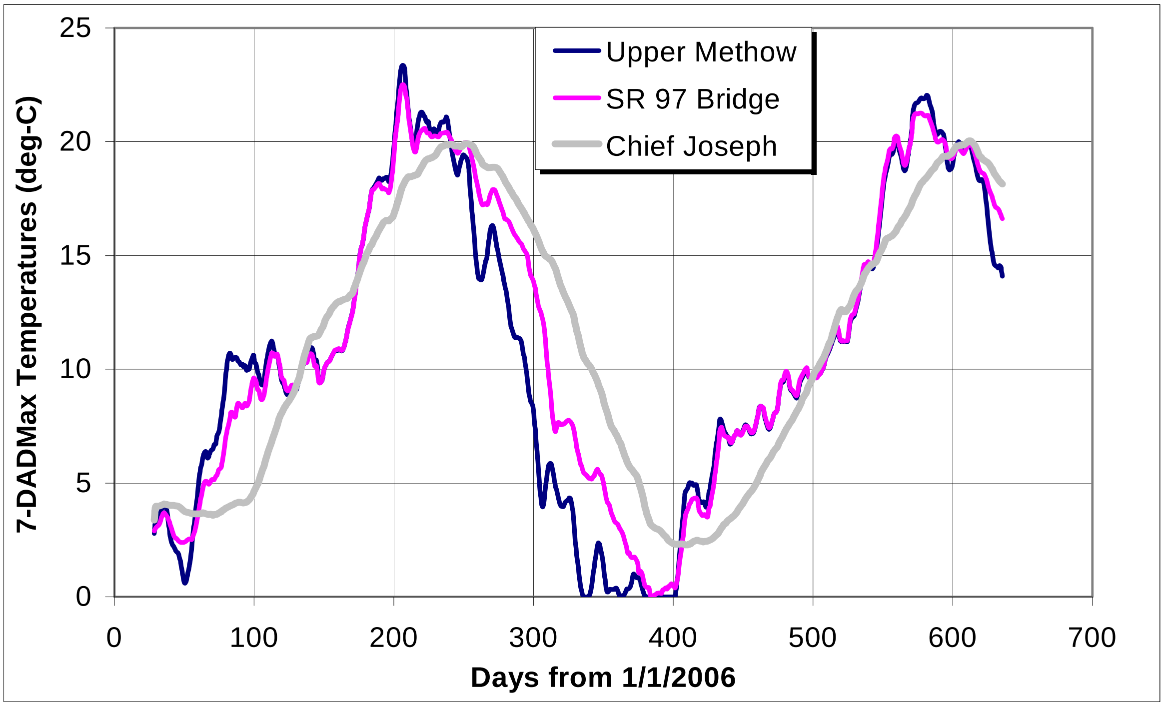

Figure 6.3-1 Comparison of 7-DADMax in Lower Methow River.

7.0 DISCUSSION AND CONCLUSION

Ecology must assess Wells Project compliance with State water temperature criteria, and determine whether the Project causes the 7-day average of maximum daily water temperatures (7-DADMax) to increase significantly compared to "without Project" conditions. When the waterbody's temperature is naturally greater than maximum values recommended for various classes of aquatic life (Ecology, 2006), or within 0.3°C of those values, then the Project should not cause the temperatures to increase by more than 0.3°C. This report presents the development and calibration of a "W2" model of the Wells Project ("with Project" model), and the development of a second W2 model of "without Project" conditions, to examine the change in temperatures within the Project's boundaries. The results of the model were processed to calculate the 7-DADMax for each day of the simulation period, 2006-2007. The results demonstrate that the Wells Project does not cause increases over "ambient" temperatures that exceed 0.3°C.

The simplest way to evaluate temperature changes within the Project is to analyze the model results and identify increases of more than 0.3°C over the ambient ("without Project") conditions. Time histories and exceedance distributions were compared at five "compliance" points. None of the four locations along the Columbia River had temperature increases that exceeded 0.3°C in either the time histories or the exceedance distributions. While the location at RM 5 in the lower Okanogan River had one occurrence of a maximum 7-DADMax temperature increase of 1.1°C, occurring under unique weather and flow conditions and when modeled "without Project" river temperatures were about 17.5°C, the maximum difference in the exceedance distributions was only 0.1°C. This shows that while there may be short-term differences in temperatures, where the occurrences of high temperatures may be influenced by the slower downstream movement of Okanogan River water due to the backwater from Wells Dam, the overall temperature regime at this location is essentially the same.

In the Okanogan River, upstream of approximately RM 5, the river is moderately influenced by backwater conditions from the Columbia River. A comparison of observed temperatures at Malott (RM 17) and Wakefield Bridge (RM 10.5) shows that, in general, backwater from Wells Dam creates a deeper pool that tends to reduce the very high upstream summer temperatures found farther upstream in the free flowing Okanogan River. The daily high temperatures within the inundated portions of the Okanogan River were often lowered relative to the daily high temperatures upstream of the Project during the hottest summer months.

The lowest 1-2 miles of the Okanogan River are influenced by the intrusion of Columbia River water. This too has the significant effect of reducing summer high temperatures by 2-6°C, and increasing winter temperatures 1-3°C, reducing the extent and length of freezing. In the fall months, as the Okanogan River temperatures drop more quickly than those in the Columbia River, the lowest 1-2 miles of the Okanogan River may see fall increases of about 1°C, as Columbia River water intrudes into the lower Okanogan River during a period when flows in the Okanogan River are quite small. However, additional analyses indicate that while backwater from the Columbia River does tend to slow the speed of the Okanogan River, the additional thermal "exposure" does not cause increases in temperatures of more than 0.3°C. Rather, the differences in the lower river temperatures are a result of Columbia River water intruding into the lower Okanogan River and not warming of Okanogan River water.

The processes in the lowest 1.5 miles of the Methow River are similar to those in the lower Okanogan River. While the summer high temperatures in the Methow River (they can reach 24°C) are not as high as those upstream in the Okanogan River, backwater from the Columbia River still reduces the summer high temperatures by about 1°C and increases the winter temperatures by 2-3°C, reducing the extent and length of freezing. In the fall months, as the Methow River temperatures drop more quickly than those in the Columbia River, the lowest 1.5 miles of the Methow River may see fall increases of about 2-3°C, as Columbia River water intrudes into the lower Methow River during a period when flows in the Methow River are quite small. Again, additional analyses indicate that while backwater from the Columbia River does tend to slow the speed of the Methow River, the additional thermal "exposure" does not cause increases in temperatures of more than 0.3°C. Rather, the differences in the lower river are attributed to the mixing of Columbia River and Methow River waters within the geographic confines of the lower Methow River.

8.0 STUDY VARIANCE

There were no variances from the FERC approved study plan for the Water Temperature Study.

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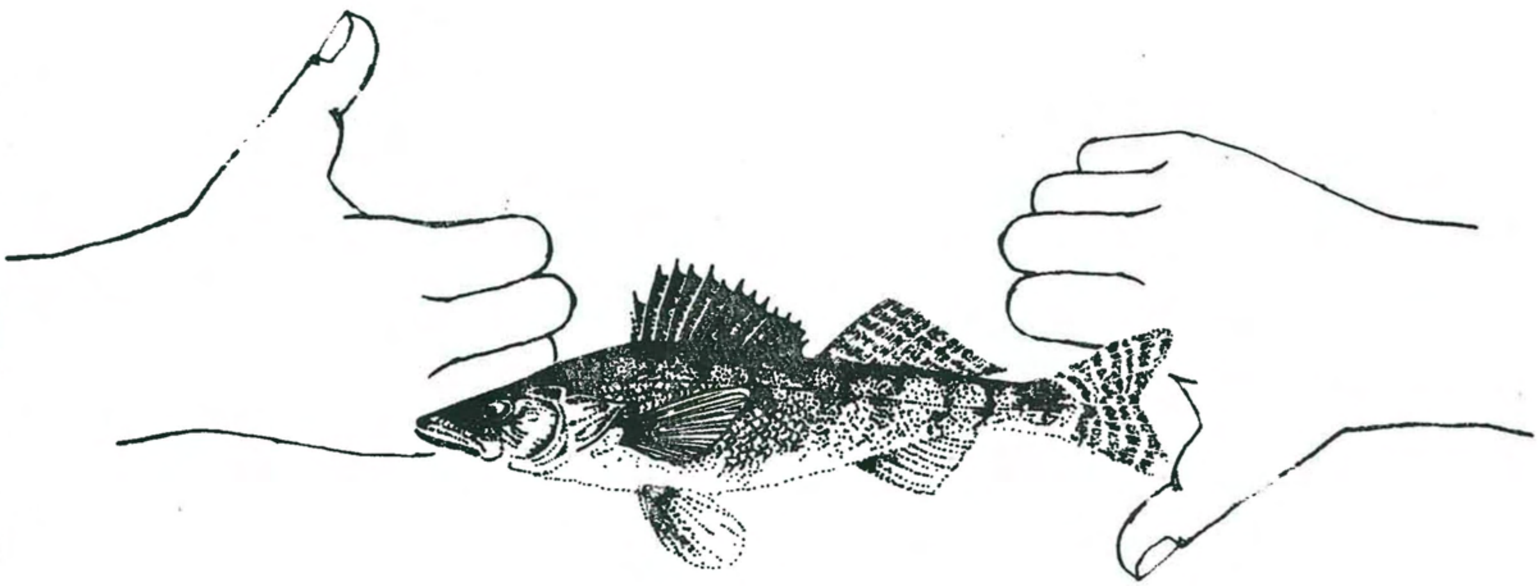
RESIDENT FISHERIES OF WELLS POOL

(A Review)



Prepared By

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FOR:

Public Utility District #1 of Douglas County

1151 Valley Mall Parkway

East Wenatchee, Washington 98801

August, 1983

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INTRODUCTION

The role played by resident fish in management of Columbia River reservoirs is an important issue that has been consciously avoided until very recently; not because biologists and managers have failed to recognize the importance of resident fish, but because consideration of resident fish and their impacts on overall management dramatically increases the complexity of an already nearly overwhelmingly complex management system. The anxiety and apprehension with which most biologists view the matter of resident fish is understandable, as is their eagerness to solve important problems affecting anadromous fish stocks. There is no question that anadromous fish problems deserve the high priority given them. However, resident and anadromous fish management are not mutually exclusive and any management plan developed for the Columbia River must consider interaction between all fisheries along with environmental, economic and a host of other factors that together determine abundance, distribution and survival of Columbia River fishery resources.

Essential to understanding Columbia River fish management is a knowledge of all fish species present, their relative abundance, factors influencing their populations, trends in abundance, distribution and growth, survival, and interaction between species. While a great deal of information has been collected for anadromous species; particularly with regard to their interaction with hydroelectric development, little is known about "the other" fish populations of the Columbia River, commonly referred to as resident fish. While many of these species are of little economic importance in themselves, their impact on anadromous fisheries can be significant and has not been adequately examined. The lack of information on resident species and their importance to anadromous salmonoids is only now beginning to get attention from fisheries managers. A number of resident fish investigations have recently been initiated on the Lower Columbia and Snake Rivers. But little information is available on the Mid-Columbia, and the need for comprehensive, coordinated resident fisheries work on Mid-Columbia reservoirs has prompted this review.

Nothing has served to focus attention to the issue of resident fish more than the establishment and expansion of walleye in the Columbia River. And nothing more clearly demonstrates our avoidance of resident fishes than the fact that even though walleye have become firmly established throughout the Mid and Lower Columbia and have been around for nearly 20 years, not one of the dozen or more entities involved in Columbia River fish management has developed a management policy for walleye; not even a statement of direction indicating management for or against walleye. The typical agency position is that taken by the Washington State Game Department in their regional fish management plan for Columbia River reservoirs (Zook et al., 1982); objectives "maintain current warm water (resident) game fish populations, while determining degree of compatibility with anadromous salmonoids." The reason for lack of direction and policy on management of resident fish populations in Columbia River reservoirs is the lack of information on species interaction. It is imperative that we finally begin to move forward toward understanding interaction between resident and anadromous species so managers can begin to exercise their options with resident game fish species.

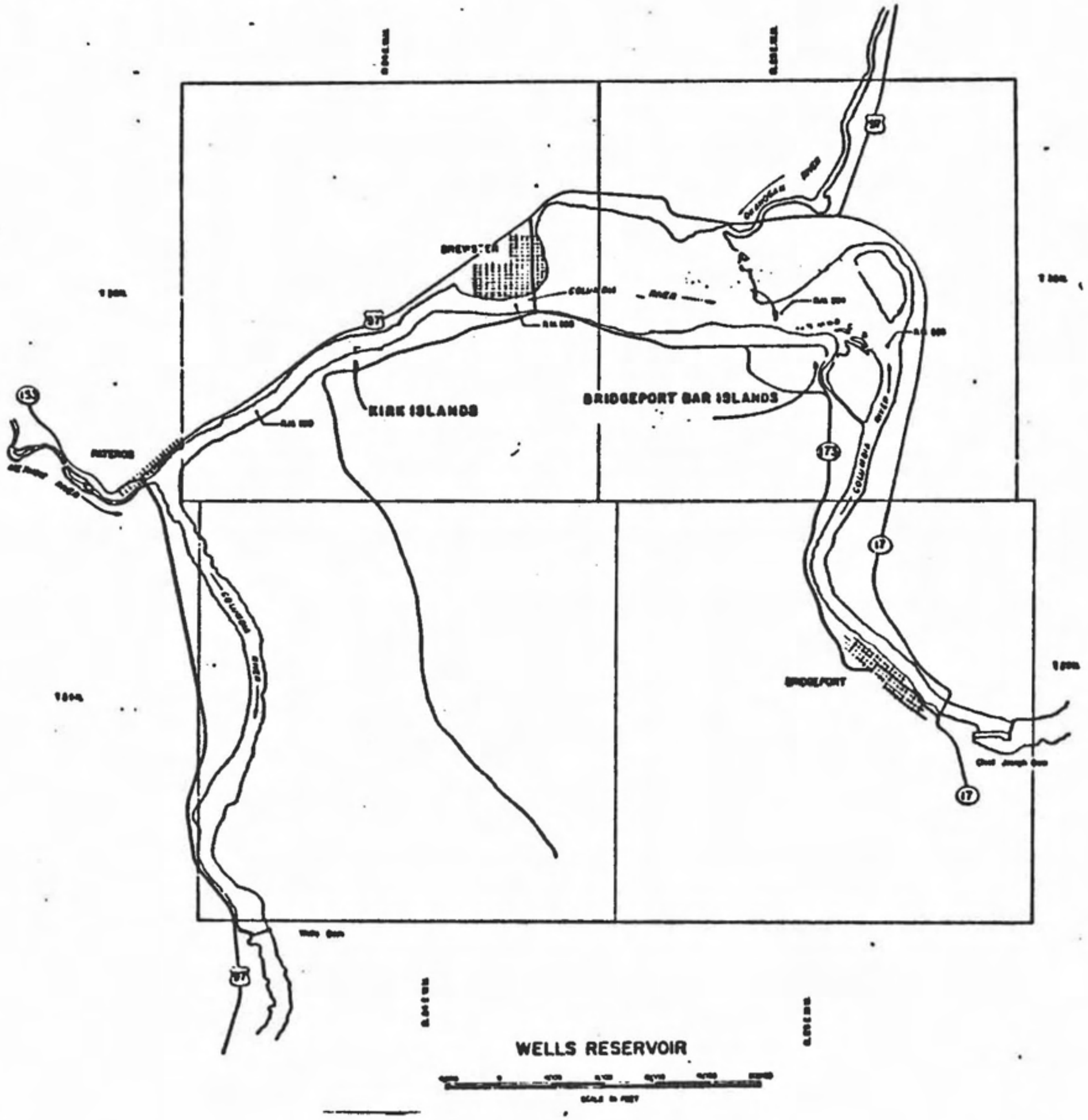
The intent of this report is to review, summarize, and evaluate all the information currently available on resident fisheries in Wells Reservoir, and to present information from resident fish studies from other Columbia River reservoirs, and, where possible, apply the findings to Wells Pool. This report will also identify and prioritize important information needs and suggest a systematic sampling program in order to collate the information needed to make important determinations about resident fish and their impacts on anadromous fish resources.

BACKGROUND

Wells Reservoir was formed in 1967 with the completion of Wells Dam, 516 miles upstream from the mouth of the Columbia River. The dam was built and is operated for power generation by the Douglas County Public Utility District. At normal pool elevation of 779 ft. ms., the reservoir covers an area of 10,280 surface acres and extends for a distance of nearly 30 miles upstream to Chief Joseph Dam at River mile 545 (Figure 1). The reservoir has an average depth of 34 feet, maximum depth of over 100 feet, and a total volume of approximately 350,000 acre feet (the fourth largest of six Mid-Columbia reservoirs) (Table 1). With nearly 100 miles of shoreline, it ranks number 1 of the Mid-Columbia reservoirs in ratio of shoreline to length due to a number of islands and two inundated tributary mouths. Wells Dam has a mean average annual discharge of 109,217 cfs, ranging from a low of approximately 25,000 cfs in late winter to well over 200,000 cfs in late spring. Water retention (exchange) time ranges from 0.6 days (14 hrs) during spring run-off (June) to 4.6 days in February (Table 2). The reservoir is fluctuated for power production and a maximum fluctuation of 8 feet occurs during the winter months, when demand for power is greatest. Water temperatures range from freezing to a high in the mid-60's, and the reservoir does not thermally stratify.

The shoreline of Wells Reservoir is lightly developed, primarily in orchard tracts. Two moderate sized communities,

Figure 1. Map of Wells Reservoir.



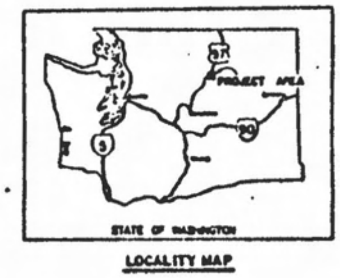


Table 1. Reservoir statistics, Mid-Columbia River.

Project	River in Miles	In-Service Date	Surface Area in Acres	Length in Miles	Miles of Shoreline	Volume (AC/ft)	Annual Flow (Median) c.f.s.	Retention Time Range (Days)	Normal Pool Elevation	Fluctuation Range Draw Down	Temp. Range
Chief Joseph Bureau of Rec.	545	1955	7,800	51.0	108.0	518,000	105,280	Feb. 7.2 June 0.9	-930.0- -946.0	16.0	33-65
Wells Douglas Co. PUD	515	1967	10,280	28.5	99.8	349,375	109,217	Feb. 4.6 June 0.6	-771.0- -779.0	8.0	33-66
Rocky Reach Chelan Co. PUD	474	1961	9,800	42.1	93.0	431,500	111,294	Feb. 5.5 June 0.7	-703.0- -710.0	7.0	33-66
Rock Island Chelan Co. PUD	453	1932	3,488	21.0	43.0	125,989	114,989	Feb. 1.6 June 0.2	-602.9- -606.9	4.0	33-68
Wanapum Grant Co. PUD	416	1963	14,550	38.4	94.0	727,000	114,714	[illegible] [illegible]	-560.0- -571.5	11.5	33-67
Priest Rapids Grant Co. PUD	397	1959	7,670	18.8	57.5	193,000	114,782	Feb. 2.3 June 0.3	-481.5- -488.0	6.5	33-67
McNary Corps of Eng.	292	1953	38,800	62.0	237.2				-335.0- -340.0	5.0	33-72

Table 2. Monthly median flows in cfs (40 year average), Columbia River dams.

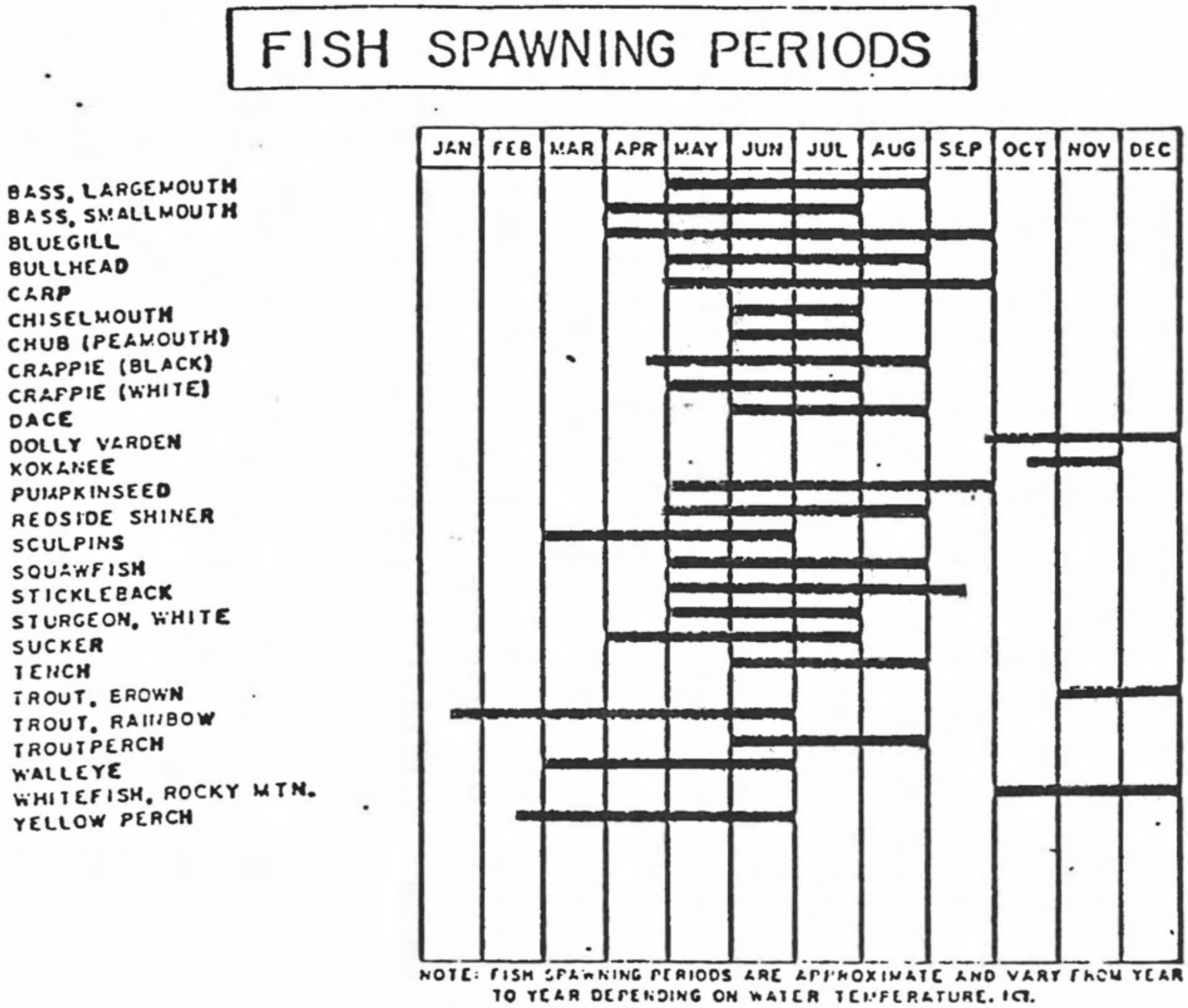
Project	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Average
Chief Joseph	36,245	36,390	49,650	113,650	250,050	304,150	182,300	99,840	62,115	47,900	41,670	39,405	105,280
Wells	37,805	38,575	51,545	116,200	261,700	316,650	187,150	102,650	64,120	49,775	43,670	40,765	109,217
Rocky Reach	37,465	39,370	52,145	117,600	266,900	324,250	190,500	105,100	65,280	50,645	44,930	41,340	111,294
Rocky Island	39,290	40,505	54,140	120,300	273,300	334,600	194,750	107,100	66,600	52,685	48,425	43,545	114,603
Wanapum	39,345	40,565	54,180	120,200	273,300	334,600	195,850	107,050	66,625	52,750	48,500	43,595	114,714
Priest Rapids	39,570	42,690	55,290	119,950	271,750	333,100	195,550	106,950	67,340	52,400	47,245	45,545	114,782
Mid-Columbia Averages	38,287	39,682	52,827	117,983	266,167	324,558	191,067	104,782	65,347	51,026	45,740	42,366	111,648

Bridgeport and Brewster, are located directly below Chief Joseph Dam and near the mouth of the Okanogan River respectively. The small settlement of Peteros is located at the mouth of the Methow River. More than half of the shoreline is undeveloped.

The productivity of Wells Reservoir is severely limited by rapid water exchange, cold water temperatures and precipitous shoreline. Plankton production is limited principally by short water retention time, but submergent aquatic plants are abundant, utilizing many of the available nutrients and further inhibiting usable food production for resident fish. Non-game fish species, principally suckers, chubs, squawfish and shiners make up the majority of resident fish populations. Resident game fish include walleye, largemouth and smallmouth bass, yellow perch, black crappie, bullhead catfish, mountain whitefish, rainbow trout, white sturgeon, burbot and dolly varden trout (Figure 2). Anadromous salmonoids include sockeye and chinook salmon and steelhead trout (Dell et al., 1975).

A fish hatchery at Wells Dam, jointly operated by the Washington State Departments of Game and Fisheries and funded by Douglas County Public Utility District, annually releases 75,000 lbs (500,000) of summer steelhead smolts into the Methow and Okanogan Rivers, and 60,000 (2.5 mil) pounds of summer chinook below Wells Dam. In addition, a federal mitigation hatchery located on the Methow River at Winthrop, annually releases 1 million spring chinook into the Methow River. An estimated 8,000 man days of angling is expended annually on the Lower Methow/Wells

Figure 2. Spawning time of Columbia River fishes.



Taken from Seasonality of River Use, Columbia and Lower Snake Rivers
Pacific Northwest River Basins Commission December, 1975.

Reservoir steelhead sport fishery, in addition to an estimated 500 man days on resident salmonoids, and 1,500 man days on resident warm water species, principally walleye.

DISCUSSION

ANADROMOUS FISHERIES

Wells Reservoir is an important transportation area for both adult and juvenile anadromous salmonoids. The importance of Wells Pool for transportation is heightened by the fact that it now is the upper limit of anadromous fish passage on the Columbia River. Three important anadromous stocks are currently maintained above Wells Dam. These include summer steelhead, chinook, and sockeye salmon. Historically, the area also provided for a run of coho salmon, but coho numbers are now insignificant. Steelhead and chinook stocks are currently maintained primarily through hatchery production on the Methow River while sockeye and chinook runs in the Okanogan River are maintained solely through natural production. The ten year average (1973-82) run size measured as passage over Wells Dam for anadromous species is: chinook - 10,193; steelhead - 3,726; sockeye - 23,289 (see Table 3). Chinook and sockeye populations show a declining trend while steelhead abundance appears to be increasing.

Prior to construction of Wills Dam, steelhead and chinook production were maintained primarily by mainstem production (Mullen, 1982). Since nearly all mainstem spawning and rearing habitat was inundated by Wells Dam, natural production for these species has been limited to the two major tributaries, the Okanogan and Methow Rivers. The anadromous fishery in the Okanogan

Table 3. Wells Dam salmon and steelhead counts, 1967-1982.

YEAR	SPRING CHINOOK	SUMMER CHINOOK	FALL CHINOOK	CHINOOK TRAPPED	TOTAL CHINOOK	TOTAL COHO	TOTAL SOCKEYE	STEELHEAD	STEELHEAD TRAPPED	TOTAL STEELHEAD	TOTAL SALMONOIDS	PERIOD OF COUNT INCLUSIVE
1967	960	12,266	2,735	2,004	17,966	261	110,038	1,410	171	1,581	129,846	May 21 - Nov. 19
1968	4,932	8,918	2,623	2,277	18,750	221	81,405	2,125	413	2,538	102,914	May 1 - Nov. 15
1969	3,713	6,854	2,972	2,873	16,412	30	17,289	1,464	530	1,994	35,725	May 1 - Nov. 15
1970	2,627	8,041	4,354	1,745	16,767	61	50,276	1,588	399	1,987	69,091	May 1 - Nov. 15
1971	3,172	6,007	2,027	1,793	12,999	134	48,258	3,777	358	4,135	65,526	Apr. 30 - Nov. 15
1972	3,617	4,058	2,414	1,694	11,783	678	33,102	1,876	354	2,230	47,793	Apr. 30 - Nov. 15
1973	3,006	5,089	2,649	2,088	12,832	317	37,129	1,832	627	2,459	52,737	Apr. 31 - Oct. 31
1974	3,413	4,572	1,116	2,893	11,994	101	16,647	479	260	739	29,481	May 1 - Oct. 31
1975	2,221	8,532	3,774	3,253	17,781	60	22,213	516	227	742	40,796	May 1 - Oct. 31
1976	2,778	7,889	3,834	2,518	17,019	98	27,628	4,643	337	4,980	49,725	May 1 - Nov. 15
1977	4,212	7,526	3,250	2,628	17,105	70	22,026	5,324	355	5,685	45,391	May 1 - Nov. 15
1978	3,616	6,422	1,338	2,259	13,635	73	7,259	1,580	356	1,580	22,547	May 1 - Oct. 31
1979	1,088	9,506	1,659	2,095	14,348	63	26,723	3,641	367	4,008	45,142	May 1 - Nov. 16
1980	1,177	5,520	724	1,827	9,248	77	26,525	3,426	372	3,800	39,648	May 1 - Nov. 22
1981	1,736	3,142	397	1,533	6,808	19	28,005	4,097	650	4,747	39,579	May 1 - Nov. 22
1982	2,257	2,218	847	700	6,022	337	18,737	7,929	590	8,519	33,615	May 1 - Nov. 22

River is still maintained by natural production except for occasional hatchery steelhead releases. It supports a small run of chinook (estimated at 500 fish) and less than 100 steelhead annually. By far the most important anadromous fishery remaining in the Okanogan River is sockeye. The Okanogan is one of only two remaining sockeye production areas still accessible in the Columbia River, which historically produced runs of over 1 million sockeye annually (Mullen, 1982). Okanogan River sockeye spawn in the Canadian portion of the River between Vaseux Lake and Lake Osoyoos, with fry dropping into Lake Osoyoos for rearing before migrating as 3-5" yearlings in late April through May (McGee et al., 1982; Weitkamp et al., 1981). Very small numbers of Age 0 chinook (3-4") and an occasional steelhead smolt (5-10") also migrate through the Okanogan River and Wells Pool during the April-May period. The Washington State Game Department has recently announced plans to release hatchery-reared steelhead smolts into the Similkamian River (a tributary of the Okanogan) beginning in the spring of 1983. These plants are part of a steelhead enhancement plan agreed on by the Washington State Game Department and the U.S. Bureau of Reclamation in conjunction with the Oroville-Tonasket Irrigation Rehabilitation Project.

The Methow River is intensively managed for both steelhead and chinook. A federal hatchery at Winthrop annually releases approximately 1 million spring chinook, and a Washington Game Department operated facility at Wells Dam releases 400-500,000 steelhead smolts into the Methow River annually. In addition, there is some natural steelhead and chinook production in the

Methow system. An estimated 2-300 naturally produced steelhead adults passed over Wells Dam in 1982 (Ken Williams, WDG, pers. comm., 1983), most of which were destined for the Methow River. Small numbers of natural steelhead and chinook migrants were collected in fyke net sampling on the Methow in 1981 (Weitkamp et al., 1981).

The estimated total number of anadromous migrants passing through Wells Reservoir annually is 3.1 million (Table 4). This number of course varies from year to year, depending on hatchery production levels and fluctuations in natural production conditions. Average migration time for chinook, steelhead, and sockeye differed slightly between two study years, 1981 and 1982, but appears to be rapid. Chinook released at Winthrop, 58 miles upstream from the mouth of the Methow, migrated to the Wells Dam forbay (65 mi) in 2 days in 1981 and 7 days in 1982. Steelhead released approximately 15 miles upstream from the mouth of the Methow migrated to the Wells forbay (21 mi) in 2 days in 1981 and in 3 days in 1982; sockeye from the Lower Okanogan River (30 mi) in 1 day in 1981 and 2 days in 1982 (McGee, Wietkamp). It appears that although migration of individuals may vary, movement through Wells Reservoir for most downstream migrants is rapid (averaging 1 or 2 days for all species). Time spent in the reservoir by migrant salmonoids is an important consideration in assessing potential impacts of predation by resident species.

In order to protect existing anadromous fisheries and take full advantage of the Columbia River's remaining capabilities for

Table 4. Estimated number of anadromous salmonoid migrants passing through Wells Pool annually and their average size.

Spring	Number	Size
Chinook		
Hatchery	1,000,000	3"-6"
Natural Production	500,000	3"-4"
Steelhead		
Hatchery	500,000	6"-10"
Natural Production	55,000	5"-8"
Sockeye		
Natural Production	1,500,000	3"-5"
TOTAL	3,055,000	

anadromous fish production, The Northwest Power Planning Council, created out of The Pacific Northwest Electric Power Planning and Conservation Act of 1980 (PL 96-501) has determined in its fish and wildlife plan that operational and management changes will be made to accommodate anadromous fish. Many of these changes will have direct impacts on resident fish species and the interaction of resident and anadromous fisheries will be a vital element of plans to increase anadromous fish production above Wells Dam. Changes include increased hatchery production, changes in spring reservoir operation to aid juvenile fish passage, and development of a juvenile bypass system. The future of anadromous fish management cannot be adequately considered without discussion of resident fisheries and questions such as predation and competition.

RESIDENT FISHERIES

Salmonoids

Since 1967 and change from a riverine to reservoir habitat, the resident population of salmonoid fishes in Wells Pool has declined. Historically, mountain whitefish (Prosopium williamsoni), rainbow trout (Salmo gairdneri) and dolly varden char (Salvelinus malma) were abundant in the Columbia River in the area now inundated by Wells Pool (Mullen, 1980). Resident fish sampling in Wells Reservoir in September and October of 1979 indicated very few resident salmonoids now inhabit the reservoir. From a sample of 2,431 resident fish examined in 1979, only 8 rainbow trout and 7 whitefish (less than 1% of the total) were collected (McGee, 1979). The Washington State Game Department (Ken Williams, WDG, pers. comm., 1982) reports that a small number of dolly varden char are caught in the Methow River sport fishery, and it can be assumed that dolly varden are at least seasonal residents of Wells Reservoir. One dolly varden was collected in purse seining operations during spring smolt migration in the Wells Dam forbay in 1981 (Wietkamp et al., 1981). This evidence and the low level catches of resident salmonoids in the reservoir sport fishery indicate that remaining populations are very small. However, counts of miscellaneous fish species from Wells Dam fish viewing facilities indicate significant populations of rainbow trout and whitefish exist somewhere in the reservoir or immediately downstream (Table 5).

It is unclear in the case of whitefish if counts averaging around 20,000 annually represent a remnant spawning run or whether they represent random movement of a population that has taken up residence in and around the passage facilities. It appears that whitefish move over Wells Dam in the fall from downstream locations to spawn in the Methow River, but what remains of adults after spawning is unknown. Adults do not appear to remain in the reservoir and probably return to the Wells Dam tailrace (Table 6) (Figure 3). In the case of rainbow trout it is likely that a population has taken up residence in and around the stream-like passage facilities. The rainbow population is probably not self-sustaining, but a product of Methow River Hatchery steelhead and

Table 5. Number of resident fish species passing through Wells Dam fish ladders May 1-October 31, 1975-1982.

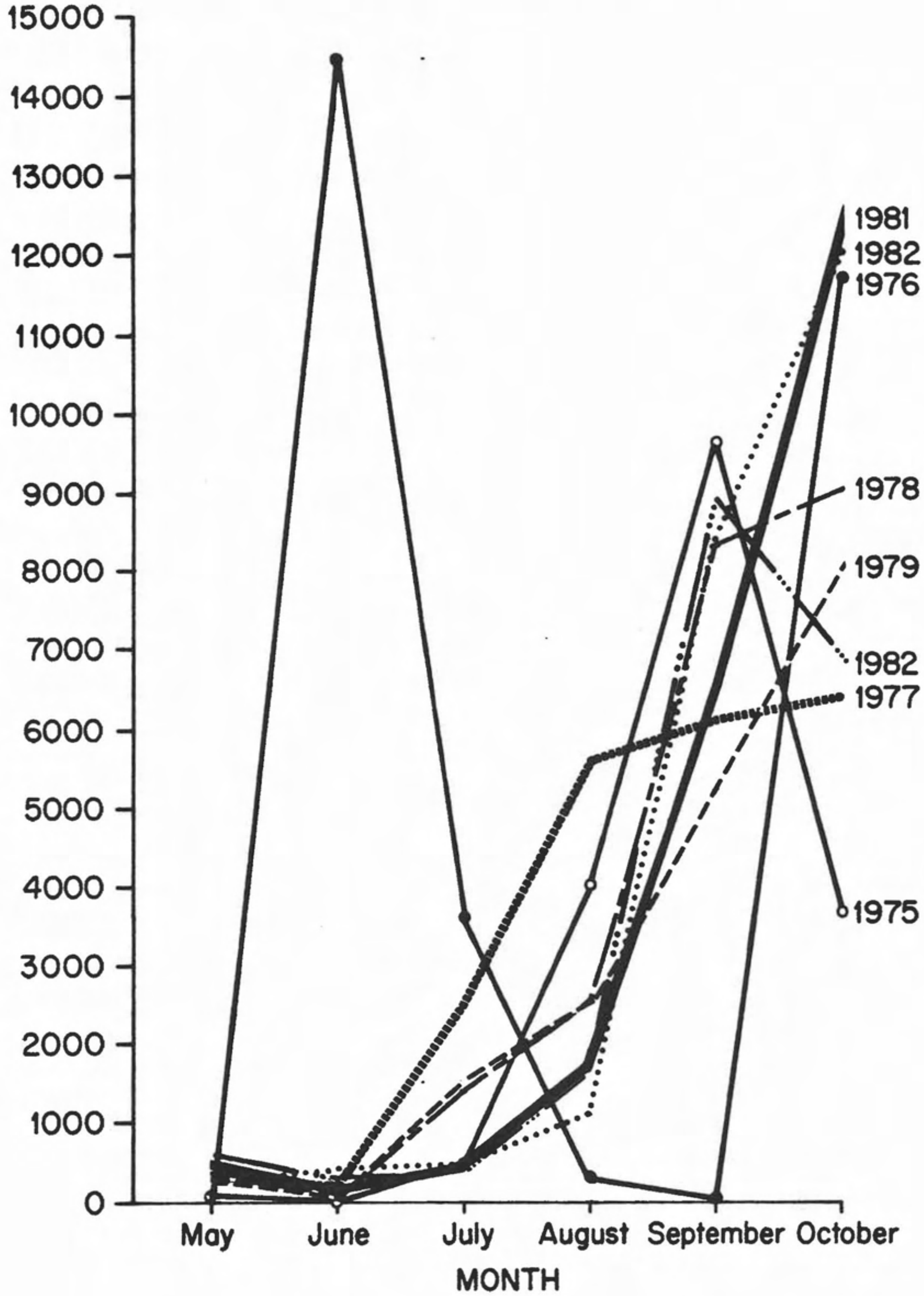
Year	Mt. Whitefish	Trout	Squawfish
1975	18,011	112	Not counted
1976	30,340	85	Not counted
1977	21,164	1,595	Not counted
1978	21,712	14,538	Not counted
1979	17,874	8,567	12,531[1]
1980	22,972	9,977	5,182
1981	21,961	9,477	2,469
1982	18,919	1,981	2,319

[1]Not counted from May 1-June 8.

Table 6. Monthly whitefish counts from Wells Dam, 1975-1982.

	Year							
Month	1975	1976	1977	1978	1979	1980	1981	1982
May	117	104	387	339	240	325	526	623
June	10	14,524	202	92	140	481	283	291
July	474	3,615	2,409	1,419	1,581	484	470	374
Aug.	4,041	342	5,623	2,530	2,568	1,089	1,718	1,890
Sept.	9,645	48	6,118	8,383	5,276	8,449	6,606	8,767
Oct.	3,724	11,707	6,425	9,009	8,069	12,094	12,358	6,979
TOTAL	18,011	30,340	21,164	21,772	17,874	22,972	21,961	18,919

Figure 3. Timing of mountain whitefish migrations over Wells Dam.



rainbow trout production programs. The timing of rainbow movement through Wells Dam does not suggest a spawning run (Table 7).

The Washington State Game Department (WDG) in their regional management plan for Wells Reservoir has the objective of maintaining resident salmonoid populations at current levels (Zook et al., 1982). They point out that the major considerations in maintaining any truly wild rainbow stocks that might remain in Wells Pool is the effect of residualism of hatchery-reared steelhead released into the Methow River. The incidence of residualism and its impact on resident fisheries may be greater than previously thought (Ken Williams, WDG, pers. comm., 1983). He observed in reading otoliths from steelhead broodstock collected at Wells Dam that a relatively high percentage of fish examined showed two years of fresh water growth. These fish had previously been classified as wild or naturally produced, but upon closer observation he concluded that many of these fish were actually hatchery-reared steelhead that did not migrate and spent an additional year rearing in Wells Reservoir. That would appear to explain the extreme fluctuation in rainbow trout numbers from Wells Dam counts between 1975-1982 (Table 5). In the future these counts may be useful in establishing an index of residualism as an additional factor in evaluating the Wells Hatchery steelhead program. Native Wells rainbow are probably at minimal levels and confined to the upper portions of the reservoir, in the tailrace of Chief Joseph Dam.

Unlike Chief Joseph Reservoir, where moderate populations of kokanee (Oncorhynchus nerka) and rainbow trout are self-sustaining

Table 7. Monthly rainbow trout counts from Wells Dam, 1975-1982.

	Year							
Month	1975	1976	1977	1978	1979	1980	1981	1982
May	20	32	68	1,373	841	1,060	1,046	356
June	25	6	17	735	846	1,206	864	301
July	23	9	52	3,280	1,358	2,118	2,348	226
Aug.	11	15	220	3,816	2,217	1,860	2,020	359
Sept.	11	21	325	3,343	1,832	1,915	1,458	231
Oct.	22	2	913	1,991	1,473	1,818	1,032	361
TOTAL	112	85	1,595	14,538	8,567	9,977	9,477	1,981

at levels capable of supporting modest sport fisheries (Erickson et al., 1975), Wells Reservoir does not have adequate spawning area to be self-sustaining, nor is it suitable for hatchery supplementation. Plants of hatchery-reared kamloops stock rainbow trout released in Priest Rapids and Wanapum reservoirs in the 1960's, proved to be futile in providing fishable populations (WDG unpublished file reports), and it is not feasible to consider hatchery trout plants in Wells Reservoir. Self-sustaining populations of rainbow, cutthroat, and eastern brook trout and mountain whitefish are being maintained in the Methow and Okanogan Rivers and their tributaries.

Burbot

A very small number of burbot (Lota lota) have been reported from Wells Reservoir since impoundment. Palmer and Osoyoos Lakes, both in the Okanogan River drainage, and several upper Columbia River reservoirs have self-sustaining burbot populations. Burbot found in Wells Pool are most likely individuals recruited from one of these waters, as it is unlikely that burbot successfully reproduce in Wells Reservoir as evidenced by the extremely low population levels observed over the 15-year life of the reservoir.

White Sturgeon

White sturgeon (Acipenser transmontanus), an anadromous species, has been landlocked by construction of dams on the Mid-Columbia. White sturgeon once moved freely between spawning areas in the Mid-Columbia and feeding areas in the Lower Columbia River and estuary. Hydroelectric development has probably had more impact on sturgeon than on any other species because it has so dramatically altered their life history. Because sturgeon do not migrate over fish ladders constructed for anadromous salmonoids, their very survival has been dependent on the ability to adapt to a completely new environment and as could be expected, sturgeon have not been able to cope with such radical changes. As a result of hydroelectric development white sturgeon populations in the Mid-Columbia and Snake Rivers have declined drastically, while lower river populations have flourished.

It is a very real possibility that white sturgeon will disappear completely from the Mid-Columbia by the end of the century. Only a few large individuals now remain in Wells Reservoir. An individual measuring 7 feet was observed dead and floating in Wells Reservoir in the summer of 1982 (Vern Marr, WDG, pers. comm., 1982). There have also been a few reported sitings of sturgeon "jumping" in recent years, but the sport fishery that once existed in this stretch of the Columbia has long since disappeared. It seems certain that reproduction was completely eliminated with construction of Mid-Columbia dams and the resulting inundation and blockage. Sturgeon are long lived, capable of living up to 100 years or more. The few sturgeon remaining in Wells and other Mid-Columbia reservoirs are remnants of pre-dam populations and once they are gone white sturgeon will become extinct in Wells Pool unless some enhancement efforts are made.

As part of the native fish community of the Columbia River (with a proven compatibility with anadromous salmonoids and indigenous resident fisheries), the sturgeon is one species that can be enhanced without controversy. Although there is evidence that white sturgeon do occasionally prey on small salmon and steelhead, they are not a factor historically or currently in predation. The capability to enhance sturgeon populations now exists. Recently hatchery propagation techniques have been developed, opening up the possibility of maintaining sturgeon populations through artificial propagation. Perhaps the easiest and most rapid way of beginning restoration of sturgeon populations in Wells and other Mid-Columbia reservoirs is through transplantation. Small sturgeon are so numerous in some portions of the Lower Columbia as to be a nuisance to commercial salmon gill net fisheries (Hugh Fiscus, WDF, pers. comm., 1983). Large numbers of 2 to 3 feet white sturgeon could be collected from the Lower Columbia periodically for transportation to Wells Reservoir. Transplantation was successfully employed recently by the Washington State Dept. of Fisheries to bolster sturgeon populations in the Chehalis River.

Although the Northwest Power Planning Council's Fish and Wildlife Plan does not emphasize the plight of white sturgeon, reestablishment of sturgeon in Wells and other Mid-Columbia reservoirs deserves serious consideration. The need for prompt action of some sort is due primarily to the fact that the white sturgeon is a native species facing eventual elimination in over 50% of its present range in the Columbia River Basin as a direct result of hydroelectric development and to its compatibility with other species targeted for enhancement.

Warm Water Species

A variety of introduced game fish species are found in Wells Reservoir. These species in aggregate are now commonly referred to as warm water game fish, and representatives in Wells Pool include: Smallmouth bass (Micropterus dolomieui); Largemouth bass (Micropterus salmoides); Black crappie (Promoxis nigromaculatus); Bluegill sunfish (Lepomis macrochirus); Pumpkinseed sunfish (Lepomis gibbosus); Yellow perch (Perca flavescens); Walleye (Stizostedion vitreum); Black bullhead (Ictalurus melas); and Brown bullhead (Ictalurus nebulosus). Most of these species were first introduced into the Columbia River Drainage between 1890-1930 (Lampman). Walleye were not reported from the Columbia River until the early 1960's.

Pond Fish

The term "pond fish" is applied to those warm water game fish generally associated with ponds and small lakes and reservoirs. It includes largemouth bass, crappie, sunfish, perch and bullhead catfish. All of these species are very strongly associated with the littoral zone and with productive, static waters.

Although Wells Reservoir has nearly 100 miles of shoreline, most of it is precipitous and the littoral area of the reservoir is quite small in comparison to its size. Rapid water exchange and a relatively featureless shoreline severely limit usable areas for pond fish species. By far, the area of the reservoir with the greatest abundance of pond fish habitat is the slough and backwater area around the mouth of the Okanogan River. Here summer water temperatures often exceed those of the main reservoir by 10^{o}F or more, and water exchange is minimized by low flows and irregular shoreline. These conditions promote reproduction, rearing and food production.

The relative abundance of pond fishes in Wells Reservoir is low except for the area mentioned. In a population inventory completed in 1974 (Dell et al., 1975) pond fish species made up only 2.0% of a sample of over 4,000 fish collected with trap nets, beach seining and angling (Table 8). In 1979, in a similar survey of resident fish populations, pond fish made up 15.8% of the sample (McGee, 1980) (Table 9). In the 1979 survey pumpkinseed sunfish comprised 13.4% of the sample.

To increase populations of warm water pond fish species in Wells Reservoir significantly would require creation of sub-impoundment habitats. Sub-impoundments, isolating portions of the reservoir from water exchange, have the effect of raising water temperature and increasing food production, as well as allowing control of species. The Washburn Island steelhead rearing pond is an excellent example of a sub-impoundment. It has excellent potential for intensive warm water fish management and could produce good populations of warm water game fish and provide substantial sport fishing opportunity if managed in that manner. However, as will be discussed later in this report, its greatest

Table 8. Species composition and relative abundance of resident fish species collected[1] from Wells Pool July-August, 1974 (Dell et al., 1975).

Species	Number	Percentage
Suckers (sp)	1,594	37.89
No squawfish	974	23.1
Redside shiner	604	14.3
Chiselmouth	416	9.9
Sculpin (sp)	234	5.5
Peamouth chub	172	4.1
Mountain whitefish	113	2.7
Yellow perch	36	0.9
Black crappie	16	0.4
Carp	13	0.3
Pumpkinseed sunfish	10	0.2
Tench	9	0.2
Black bullhead	7	0.2
Largemouth bass	7	0.2
Walleye	7	0.2
Dace (sp)	6	0.1
Bluegill	2	$>$0.1
Dolly varden	1	$>$0.1
TOTAL	4,221	

[1]Collected with trap nets, beach seines & angling.

Table 9. Comparison of the relative abundance of resident fish populations from Wells Pool, 1974 and 1979.

Species	1974[1]	1979[2]
Suckers (sp)	37.8	13.0
No squawfish	21.1	8.1
Redside shiner	14.3	13.1
Chiselmouth	9.9	43.5
Sculpin (sp)	5.5	0.8
Peamouth chub	4.1	3.0
Mountain whitefish	2.7	0.3
Yellow perch	0.9	0.1
Black crappie	0.4	1.0
Rainbow trout	---	0.3
Carp	0.3	0.6
Pumpkinseed sunfish	0.2	13.4
Tench	0.2	0.5
Largemouth bass	0.2	---
Smallmouth bass	---	0.5
Bullhead (sp)	0.2	1.3
Walleye	0.2	---
Dace (sp)	0.1	0.4
Bluegill	0.1	---
Dolly varden	0.1	---

[1]Dell et al., 1975. N=4,221 Trap nets, beach seine, angling

[2]McGee, 1980. N=1,994 Trap nets, beach seine, angling

potential may be as a rearing facility for walleye or smallmouth bass. There are two other island locations within Wells Reservoir that have some isolation potential as small sub-impoundments. One is located at RM 525 and another at RM 528.5, both on the Douglas County side of the river. Additionally, portions of the Bridgeport bar (RM 537-539) appear to have sub-impoundment possibilities. Relative inaccessibility and high cost of the two island sites may render them unfeasible because of their small size and limited ability to provide a sport fishery.

Smallmouth Bass

Smallmouth bass, unlike the pond fish species, have some potential for enhancement in Wells Reservoir Proper because they are better adapted to precipitous shoreline, low productivity, flowing water habitats. In its native range, smallmouth inhabit clear, almost oligotrophic lakes, rivers and streams, as well as traditional pond fish type habitat (Coble, 1975). An expanding smallmouth population has taken hold and is now firmly established throughout the Okanogan River, from Lake Osoyoos to the mouth. Their numbers in Wells Reservoir, however appear to be small and it is unlikely that successful reproduction is occurring in the reservoir. Ideal spawning temperatures for smallmouth bass range from 60-65°F (Calhoun et al., 1966; Coble, 1979). And although temperatures in that range occur in Wells Pool, it normally doesn't occur on a consistent basis until late summer. Once temperatures reach the acceptable spawning range, smallmouth begin spawning rapidly and as often happens throughout the Mid-Columbia, high run-off can occur and quickly depress temperatures 5-10°F. Rapid temperature drops usually cause nest abandonment and loss of spawn. The Hanford reach (undammed portion of the Columbia River downstream from Priest Rapids Dam) is the only mainstream area of the Mid-Columbia where smallmouth reproduction is known to occur. Here spawning occurs in a series of sloughs where water temperatures are elevated and protected from rapid change. But even in the Hanford reach, extremely high run-off and the resulting temperature reduction have been responsible for total loss of several year classes of smallmouth bass during the early 1970's (Montgomery et al., 1978; Zook, 1979). In Wells Pool, the absence of backwater warming areas for spawning and rapid water temperature changes during May/June, make it unlikely that successful reproduction is occurring. However, there is a small population of smallmouth bass in the preferred habitat areas throughout the reservoir, presumably recruited from the Okanogan River. The abundance of rocky and rip-rap shoreline areas and ample supply of forage species indicate that smallmouth bass might do reasonably well in Wells Reservoir if the reproduction problem could somehow be circumvented. The Washburn Island rearing facility offers a unique opportunity for artificial propagation of smallmouth fingerlings. An estimated 50,000 to 100,000 3-4" fingerlings bass could be reared annually for release into Wells Reservoir with only minor modifications to the existing pond. An attempt to rear 10,000 smallmouth bass for release into Rocky Reach Reservoir will be made by the Washington State Department of Game in 1983, utilizing a rearing pond at the Turtle Rock Hatchery.

The concept of smallmouth bass enhancement anywhere in the Mid-Columbia raises the question of potential impact on other fisheries, particularly the anadromous salmonoid fishery. It might be helpful in considering the potential impacts to look at the results of smallmouth bass introductions in other anadromous salmonoid river systems in the Pacific Northwest. Smallmouth were illegally introduced into the Lower Umpqua River of Southwest Oregon in the early 1970's and have since become firmly established. The Oregon Department of Fish and Wildlife has concluded that chinook and coho salmon and steelhead stocks have not been adversely affected by this development (Ray Temple, ODFW, pers. comm., 1978). The John Day river, a tributary to the Lower Columbia, was stocked with smallmouth by ODFW biologists in the mid-1970's resulting in the establishment of an excellent bass population in the lower reaches of the John Day with no apparent impact on salmon and steelhead resources in that river system (Larry Bisbee, ODFW, pers. comm., 1978). Closer to home the Okanogan River and lake system has had an established smallmouth population for at least a decade without noticeable impacts on chinook, sockeye or steelhead fisheries. A predator known to eat salmonoids, the smallmouth is apparently able to coexist with anadromous salmonoids because of spacial separation. Smallmouth bass prefer water temperatures and current velocities, not generally inhabited by rearing salmonoids during the summer months. During peak migration of juvenile salmonoids, corresponding with spring snow run-off, water temperatures are normally cooler than 50°F. Below

50°F, smallmouth are almost totally inactive and although they may feed occasionally, their feeding rate and movement is very restricted (Coble, 1975). In addition, rapid downstream migration of juvenile salmonoids, as we saw earlier, reduces vulnerability substantially.

Walleye

Walleye have resided in Wells Reservoir probably since its formation in 1967. The origin of walleye in Washington and the Columbia River drainage has not been conclusively determined, but it appears certain that the first introduction occurred in the Mid-Columbia most likely in the late 1950's. There are at least four possible explanations for walleye introductions currently being purported by various agencies and individuals. Mullen reported that walleye fry were introduced into the Clark Fork River in Montana in the 1940's (Mullen, 1980). He also reports that fry plants were made into Lake Roosevelt in the late 1950's by the U.S. Fish and Wildlife Service. Fletcher believes that walleye were present in Devils Lake, by a previous apparently illegal introduction, when the lake was inundated by Banks Lake in the early 1960's. He reports that walleye were transplanted to Lake Roosevelt before Devils Lake was flooded (Fletcher, 1981). Spence believed that walleye originated in Lake Roosevelt (from unknown sources) and reached Banks Lake via pumped irrigation water from FDR (Spence, 1972). Whatever the origin, it seems certain that they first became established in fishable numbers in Lake Roosevelt, Banks Lake and to a lesser degree in downstream reservoirs at least to the Wells Dam area in the early 1960's.

In the first extensive fisheries survey of Lake Roosevelt undertaken by the Washington Department of Game in 1966, no walleye were recorded after intensive sampling (Earnest et al., 1966). The first confirmed catches of walleye in the state were reported from Banks Lake, where walleye to 10 lbs were recorded (Spence, 1972). A longtime area fisherman, who now operates a walleye fishing guide service out of Peteros, reports catching walleye in the Wells Pool area (mouth of Okanogan River) in good numbers, and up to 5 lbs in the mid-1960's (Cliff Foster, pers. comm., 1983). The evidence suggests that the first significant year class of walleye produced in the Columbia River, most likely in Lake Roosevelt, occurred around 1958-1960. The evidence also indicates that FDR was the only source of walleye production in the Columbia Basin until the early 1970's, when populations were large enough for successful production in the Lower Columbia. The oldest age recorded from scale analysis of 131 sport caught walleye in the Mid-Columbia between 1978-1982 was from the 1965 brood (Brown et al., 1983). The oldest walleye aged from a sample of 893 collected from Lake Roosevelt in 1981 was from the 1969 brood (Nigro et al., 1982). In his age analysis of sport caught walleye from FDR in 1973, the oldest walleye Neilsen found originated from the 1965 brood (Neilson, 1974).

Current evidence strongly suggests that walleye are not successfully reproducing (and never have) in the Mid-Columbia downstream from Lake Roosevelt. First of all, young of the year and yearling walleye are essentially non-existent in any of the Mid-Columbia reservoirs from Grand Coulee to Priest Rapids. Furthermore, walleye caught in the sport fishery downstream from Grand Coulee are progressively fewer and larger (older) the farther downstream from FDR. In areas where reproduction is confirmed, Lake Roosevelt and John Day/McNary Reservoirs, juvenile walleye are easily observable through the summer months and Age I and II walleye are often caught in the sport fishery (Berge, 1981; Harper et al., 1981; Nigro et al., 1982). In their native range, young of the year walleye are also easily detectable in their first summer (Eschmeyer, 1948). Despite considerable effort to find juvenile walleye in Wells Pool and other Mid-Columbia reservoirs, Age 0+ walleye have only been observed on two occasions, both in Wells Reservoir. Two small, 3-4 inch, walleye fry were collected during intensive purse seining in the Wells Dam forbay; one in the spring of 1982, and the other in the spring of 1983 (Dan Yednick, DCPUD, pers. comm., 1983). The pattern of distribution, moderately good walleye numbers dominated by Age II and III in Chief Joseph Reservoir downstream to Wanapum and Priest Rapids Pool where the populations are too low to attract a sport fishery, suggests the following scenario:

Successful reproduction in FDR (Spokane River).

Entrainment of Age II and III walleye through (or over) Grand Coulee Dam with spring run-off.

Progressively smaller numbers of Age II and older walleye passing downstream over successive dams.

No reproduction in any Mid-Columbia reservoir.

After a period of 10 years or more, enough adult walleye accumulated in McNary and/or John Day Pool for successful reproduction to occur.

This scenario is supported by some additional evidence. Movement of walleye downstream over Grand Coulee Dam was demonstrated in 1980 and 1981 tagging studies. In both years, walleye tagged in the Spokane River (FDR) during the spring spawning period were later recovered in the Chief Joseph Reservoir sport fishery during the same summer (Harper et al., 1981; Nigro et al., 1982). This same recruitment pattern can also be applied to waters of the Columbia Basin Irrigation Project, except that it appears walleye are recruited through pumping at Age 0 (Zook, 1978). In his study of walleye life history in John Day Reservoir, the oldest walleye Maule found were produced in the early 1970's (Maule, 1982). At the present time, it seems certain that walleye are successfully reproducing in only two locations in the state, Lake Roosevelt and John Day/McNary Reservoirs.

Walleye have rather broad and unspecific spawning requirements. They are capable of successfully spawning in flowing and static water systems; on gravel, sand, silt, rock and mud bottoms, although they prefer rocky spawning areas (Eschmeyer, 1948). Wells Reservoir appears to have suitable walleye spawning habitat, especially in the upper portion, above the mouth of the Okanogan River. The Okanogan River itself also appears to be suitable for walleye spawning. Preferred spawning temperature is 45-50^{o}F, which occur in Wells Reservoir from April through May, and should be nearly ideal for walleye. Sexually mature male and gravid female walleye are abundant in the sport catch during late winter/ early spring and spent (spawned out) walleye are caught from mid-April on. Spawning is undoubtedly occurring in Wells Pool in April-early May, but spawning does not result in successful recruitment.

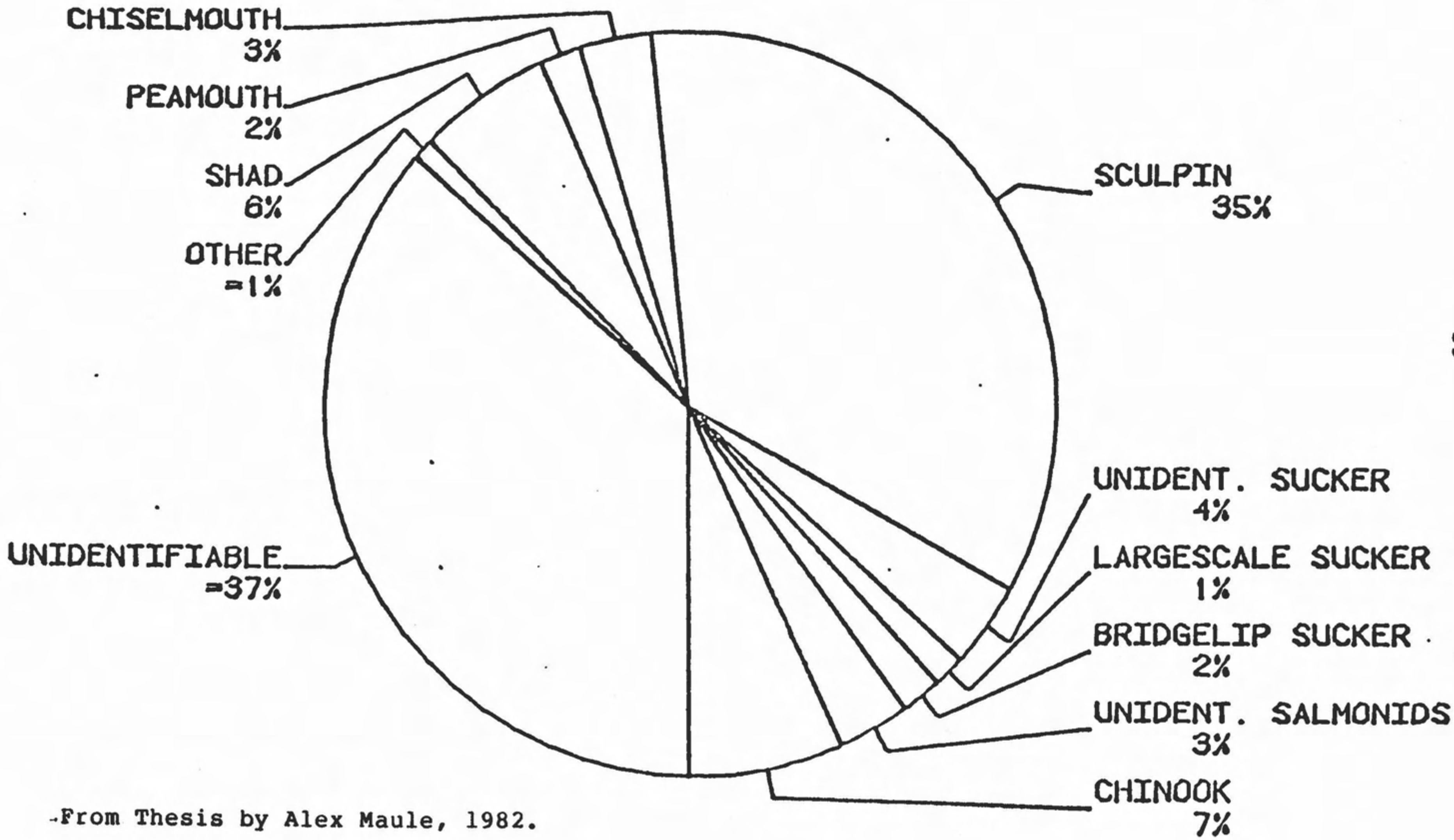
We can conclude then that losses are occurring either during incubation or early rearing. Water temperatures and fluctuations during this early spring period are fairly stable and there doesn't appear to be any reason to suspect widespread incubation problems. The reproductive failure can probably be attributed to lack of suitable rearing habitat. Walleye fry hatch in 10-20 days at an extremely immature stage of development and small size, so small in fact that they are difficult to see with the naked eye. Early survival is dependent on a static and highly productive environment. In river spawning walleye populations, fry drop immediately into a lake or reservoir to begin the rearing process. In lake and reservoir spawning populations, early rearing occurs in protected coves and bays. In Lake Roosevelt walleye fry leave the Spokane River immediately after hatching and are found through the summer months in the numerous sheltered embayments (Harper et al., 1981; Nigro et al., 1982). In John Day Reservoir, walleye fry were found in backwater and slough areas (Li et al., 1982). The key elements of early fry survival are quiet water and plenty of primary production, because walleye fry need to begin feeding immediately after hatching. In pond culture of walleye, the most important ingredient is careful fertilization and production of a good plankton bloom; without it it's not unusual to see total failure.

Mid-Columbia reservoirs are of course seriously lacking in static areas where waters are warmed and where sufficient plankton production can occur. Rapid water exchange, low productivity and precipitous, featureless shoreline all contribute to walleye fry mortality. Lake Roosevelt is over 150 miles long with a total water volume of over 9½ million acre feet and a slow water exchange rate. But the key to successful reproduction still seems to be the presence of embayments with warming, static waters and early plankton production. Both John Day and McNary Pools are larger than any of the Mid-Columbia reservoirs, but again the key to their success appears to be the presence of slough type habitats where plankton production can develop.

Wells Reservoir walleye have displayed exceptional growth and condition. Although there is no quantitative data available on walleye food habits in Wells Reservoir, gross examination of stomachs from angler caught walleye indicate that sculpin, chiselmouth, suckers and other cyprinids are the major food items. Food habit studies in John Day Reservoir indicate that non-game species made up approximately 80% of walleye diet during 1980 and 1981 (Maule, 1982).

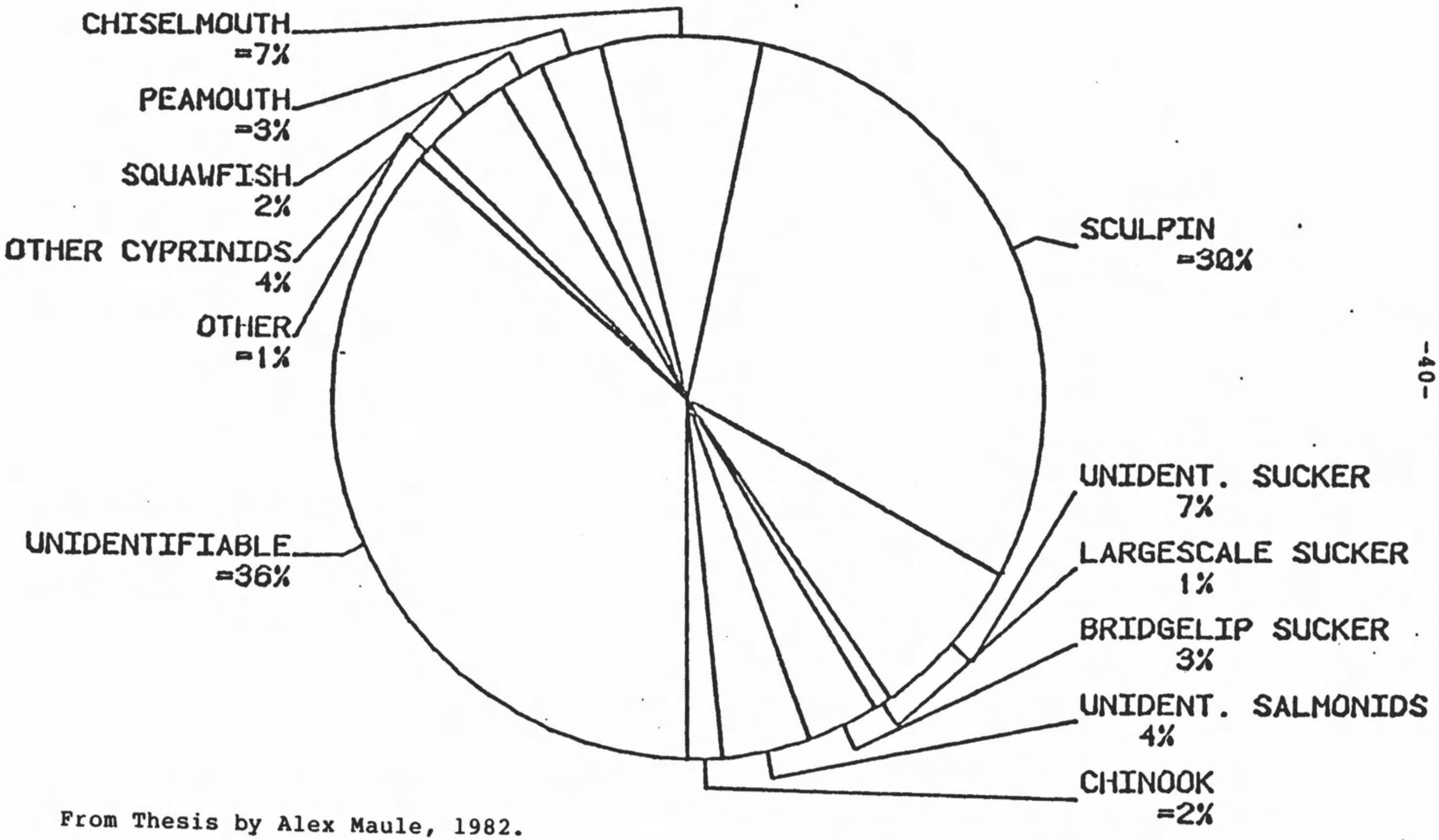
Salmonoids comprised 10 and 6 percent respectively of walleye diets. Maule contends that salmonoids are not a major food item for walleye because of spacial separation. Walleye are nocturnal

Figure 4. Proportion of prey items in walleye stomachs, 1980.



-From Thesis by Alex Maule, 1982.

Figure 5. Proportion of prey items in walleye stomachs, 1981.



From Thesis by Alex Maule, 1982.

feeders foraging near the bottom, while migrating salmonoids are found near the surface in the pelagic zone at night. It is however probable that walleye do feed to some extent on juvenile salmonoids in Wells Pool and in the tailrace of Wells Dam.

The average growth rate of Walleye sampled from Mid-Columbia reservoirs by Brown and Williams between 1978-1982 are comparable to those found by Neilsen (1974) and Harper (1980) in Lake Roosevelt. They are significantly faster than for walleye in other northern states, but somewhat lower than those for southern reservoirs (Table 10).

The sport fishery for walleye has become extremely popular, particularly in the last decade. It has become one of the most sought after game fish in the state. A number of walleye fishing clubs have been formed and well-attended seminars are being held throughout the state. The Washington Department of Game regional office in Ephrata reports that interest in the Columbia River walleye fishery has generated more calls, letters and requests for information than any other sport fishery over the past two years. Increased fishing pressure on this resource, dependent on recruitment from FDR has been of increasing concern to Washington Department of Game management biologists, who are proposing a major reduction in the walleye catch limit for the Mid-Columbia for the 1984 season (Ken Williams, WDG, pers. comm., 1983). The proposal would reduce the limit for walleye from the current 15, not more than 5 over 20", to 5, not more than 2 over 20". It has also increased public pressure on the State Game Department to do

Table 10. Mean back calculated total lengths (inches) of walleye in the Mid-Columbia River and other waters.

Location		Age 1	2	3	4	5	6	7	8	9	10	Source
Clear Lake, IA		7.0	11.3	14.7	17.1	18.9	20.7	22.0	23.8	25.3	27.0	Wydoski & Whitney, 1979
Lake Roosevelt, WA		8.4	13.5	17.0	20.2	22.4	23.8	—	—	—	—	Nielson, 1974[1]
Lake Roosevelt, WA		8.1	13.5	16.6	18.7	20.6	22.1	23.9	25.2	27.4	—	Harper et al., 1980[1]
Minnesota Lakes		4.6	8.6	12.0	15.0	18.1	20.4	22.9	25.2	26.7	—	Wydoski & Whitney, 1979
Lake Erie (1973)		4.7	8.3	11.1	13.6	15.6	17.6	19.4	21.1	22.6	24.1	Wydoski & Whitney, 1979
Lake of the Woods, Ontario		5.6	8.0	10.0	11.6	12.8	14.4	15.8	17.2	—	—	Carlander, 1943[1]
Lake Gogebic, MI		4.6	9.3	12.1	14.2	15.8	17.2	18.0	18.8	—	—	Eschmeyer, 1950[1]
N. Green Bay, WI	M	6.6	10.1	12.8	15.1	17.2	18.6	19.7	24.8	25.8	26.8	Wydoski & Whitney, 1979
	F	6.7	10.2	12.9	15.7	18.1	19.8	21.1	26.8	27.9	—	
Clayton Lake, VA		9.9	15.2	19.8	23.2	26.1	27.6	29.9	32.2	—	—	Wydoski & Whitney, 1979
Mid-Columbia River, WA	M	7.0	11.3	15.8	18.7	20.7	21.9	22.4	24.4	24.1	29.0	Brown & Williams, 1983
	F	7.4	12.3	17.2	20.1	22.6	24.0	25.8	27.7	29.0	30.9	
Utah Lake, UT		6.7	11.6	13.4	15.2	16.6	17.0	—	—	—	—	Wydoski & Whitney, 1979
Center Hills Res., TN		10.0	17.5	20.1	21.5	23.2	26.2	26.9	28.2	—	—	Muench, 1966[1]
Norris Res., TN		10.3	16.4	18.7	19.9	20.8	21.0	22.1	24.9	—	—	Wydoski & Whitney, 1979

[1]From Harper et al., 1980.

something to enhance walleye fishing in the Columbia River. Concern for the possible adverse impacts on anadromous stocks is growing dim because salmon management problems have nearly eliminated harvest opportunities on the Mid-Columbia.

Walleye have more potential for development of improved recreational fishing opportunities in the Mid-Columbia than any other resident species. They are well adapted to the reservoir environment and are capable of foraging on plentiful supplies of non-game prey species. Reproductive failure need not be a limiting factor. Juvenile survival problems can be circumvented by artificial propagation. The 150 acre Washburn Island rearing pond could be adapted for short term rearing of walleye in much the same manner described earlier for smallmouth bass. Walleye fry are easily obtainable from one of several U.S. Fish and Wildlife service hatcheries in the midwest. The pond, properly fertilized, should be capable of rearing 1 to 2 million walleye fry for late June release at 2-3". Walleye rearing could be done annually or on an every other year basis, alternating with rearing of smallmouth bass, depending on reservoir needs.

RESIDENT NON-GAME SPECIES

Resident non-game fish species make up the bulk of the standing crop of fish in Wells and other Mid-Columbia reservoirs. In 1974, they made up 93%, and in 1979, 83% of the total number of fish examined in Wells Reservoir (Table 9). In a similar survey of resident fish in Chief Joseph Reservoir in 1975, non-game species made up 81% of that population (Erickson et al., 1975).

The same general percentages hold true for Lake Roosevelt, Rocky Reach, Rock Island, Wanapum and Priest Rapid Reservoirs (Dell et al., 1975). The creation of Mid-Columbia reservoirs was followed by a sudden and dramatic increase in the population of non-game fish species. This initial "explosion" was followed by a reduction and eventually a leveling-off over the last decade, as indicated by resident fish counts from Priest Rapids Dam, 1960-1982 (Table 11).

In order of speculated abundance, the most frequently occurring non-game species in Wells Pool are: Chiselmouth (Arcocheilus alutaceus), Suckers (Catostomus sp.), Redside shiner (Richardsonius baiteatus), Northern squawfish (Ptychocheilus oregonensis), Carp (Cyprinus carpio), Tench (Tinca tinca), Speckled dace (Rhinichthys osculus), and Sculpins (Cottus sp.). The role of these non-game species, both collectively and individually, in the "big picture" of management of Wells Reservoir is not clearly understood. It is clear, however, that they play an important part in determining the ultimate success or failure of game fish populations as predators, competitors, and prey.

The species attracting the most attention over the years has been northern squawfish because of its role as predator on important game fish species. The squawfish is a native predator which evolved in association with anadromous salmonoids in a riverine habitat, and like other native species, it has been forced to adapt to significant habitat changes since the construction of dams on the Columbia River. Squawfish, like many of the other

Table 11. Miscellaneous fish species counts, Priest Rapids Dam, 1960-1982.

FISH SPECIES OTHER THAN SALMON AND STEELHEAD TROUT
AT PRIEST RAPIDS-UPSTREAM COUNTS ONLY 1/

Year	Kamloops	Trout	Whitefish	Shad	Suckers	Carp	Squawfish	Misc 2/	Fingerlings 3/	Total	Remarks:
1960	-	14	45,963	-	131,661	-	21,387	23,729	3,182	219,572	Misc. includes Carp
1961	-	30	23,190	-	78,113	-	10,017	36,201	2,579	144,972	Misc. includes Carp
1962	412	33	33,038	830	90,111	-	9,436	20,991	72	154,779	Misc. includes Carp
1963	42	1,461	23,458	523	73,211	18,690	13,292	6,620	131	137,166	
1964	71	819	35,503	513	43,333	15,455	11,479	3,023	95	110,101	
1965	39	672	26,093	752	50,131	10,949	19,229	8,511	2,175	114,123	3 Sturgeon
1966	515	571	29,293	716	33,816	9,057	16,754	6,748	1,019	96,451	8 Sturgeon
1967	108	278	9,489	239	20,185	24,486	18,338	3,659	1,912	74,870	5 (2½-3') Sturgeon
1968	70	256	16,528	300	28,037	9,600	16,990	4,020	10	75,651	
1969	31	174	13,193	3,440	23,566	14,147	17,310	4,937	68	76,668	
1970	49	204	10,751	6,751	35,967	9,558	18,419	3,702	-	85,401	
1971	1	136	8,793	1,360	10,523	11,095	13,296	9,705	-	54,907	
1972	-	191	10,068	2,322	8,972	11,382	8,964	15,281	-	57,180	
1973	-	422	10,489	12,598	46,690	11,390	11,035	13,070	-	105,694	4/ (4') Sturgeon
1974	-	123	6,535	8,338	8,374	10,792	5,525	9,656	-	49,343	4/
1975	-	640	6,156	6,939	26,763	4,220	5,245	6,448	-	56,411	5/
1976	-	515	7,201	6,423	21,895	2,509	6,370	9,721	-	56,634	5/
1977	-	181	2,347	26,510	23,689	3,119	4,435	14,334	-	74,615	5/ (2-3') Sturgeon
1978	-	196	1,546	23,761	24,461	2,609	2,838	18,196	-	73,607	5/ 3 (3-4') Sturgeon
1979	-	89	2,792	20,195	26,570	3,867	3,257	22,593	-	79,363	5/ 1 (2½') Sturgeon
1980	-	33	6,812	23,896	18,010	3,801	2,027	8,233	-	62,812	5/
1981	-	10	9,077	20,854	17,184	2,078	1,999	4,962	-	56,164	5/
1982	-	168	14,522	17,971	21,651	2,610	1,706	7,426	-	66,054	5/ (4½-5') Sturgeon

1/ Negative counts (downstream past station) are subtracted from totals
2/ Misc. fish include Lamprey (largest %) Chub, Shingers, Stickleback, Tench, Chiselmouth, Bass
3/ Fingerlings 1970 on with Misc.
4/ Factored (1.2 x actual) count + night factor
5/ Factored (1.2 x actual) without night factor

resident species, adapted to the reservoir environment much better than anadromous species, which were essentially displaced to the tributary systems. There is little doubt that squawfish are more abundant now than they were in pre-impoundment days. However, there is evidence that after an initial "boom" in abundance following impoundment, the number of squawfish in Mid-Columbia reservoirs has declined. The most demonstrative evidence of the decline is found in individual dam counts of miscellaneous fish species compiled by Mullen (Jim Mullen, USFWS, pers. comm., 1983) (See Table 11). Mullen's figures for all five Mid-Columbia "fish passage" dams shows a significant decline in the number of squawfish passing through fish viewing facilities. Table 12 shows the count of squawfish through Wells Dam from 1979 to 1982, the only years available.

The introduction and expansion of walleye into the Mid-Columbia has been forwarded by some as an explanation for the decline in squawfish abundance. Although there is considerable evidence that walleye have impacted squawfish, and that this relationship has resulted in declining squawfish abundance in other areas of the west, walleye can't be given all the credit in the Mid-Columbia. The best and clearest local example of declining squawfish populations can be seen in Lake Roosevelt. In 1949 (8 years after impoundment) squawfish made up an estimated 69.4% of the total fish population (Fulton et al., 1966). In 1966, the percentage had dropped to 25.5% (Earnest et al., 1967). By 1980, squawfish made up only 14.2% of the population and walleye comprised 30.1% (Harper et al., 1981). On the surface, looking at

Table 12. Monthly squawfish counts from Wells Dam, 1979-82.

	Year			
Month	1979	1980	1981	1982
May	0	201	122	7
June	2,864	1,895	1,067	1,019
July	7,832	2,555	914	796
Aug.	1,354	394	250	221
Sept.	325	116	66	56
Oct.	156	21	50	220
TOTAL	12,531	5,142	2,469	2,619

the last two figures only (the ones most often used), it appears to show a classic case of population shift, walleye replacing and displacing squawfish. However, it should be noted that even though walleye were probably present in Lake Roosevelt in 1966, none were found. They were not abundant enough to be collected in an intensive sampling effort, and certainly could not have been established long enough to be responsible for the drastic decline in the relative abundance of the long-lived squawfish. The decline, instead, reflects another commonly occurring phenomenon; that of expanding populations occurring in newly created reservoirs.

It is normal for a new reservoir to experience a rapid increase in all resident fish species, in reaction to expanded habitat and increased food availability, and later a readjustment to those species best suited for the new habitat, and a general decline in total numbers as initial productivity declines and stabilizes. This is what appears to have happened in the case of squawfish in Lake Roosevelt. Although it may have been accelerated by competition with walleye, a decline in squawfish abundance was occurring prior to walleye introduction. As evidence that this theory can be applied to other Mid-Columbia reservoirs, it should be noted that squawfish abundance in Rock Island, Wanapum and Priest Rapids Reservoirs has also declined while walleye populations have remained insignificant.

Other non-game fish species that appear from the limited data available, to be declining or stabilized at lower than initial levels in Mid-Columbia River reservoirs are redside shiner, sculpin and suckers. Those that appear to be increasing are peamouth club, and in Wells Reservoir, chiselmouth. Chiselmouth appear to be much more abundant in Wells Reservoir than in other Mid-Columbia impoundments. Since they are highly developed and specialized plant eaters (Carl et al., 1959), their success is probably due in great part to the abundance of submergent aquatics in the reservoir.

PREDATION

The issue of predation is a key one to the future management of Mid-Columbia reservoirs in general, and Wells Pool in particular. The importance of maintaining, and hopefully restoring the once considerably larger anadromous runs of spring and summer chinook, sockeye, and summer steelhead, certainly must be given top priority in management decisions concerning the Mid-Columbia region. The recently completed Northwest Power Planning Council Fish and Wildlife Plan for the Columbia Basin strengthens the commitment of all users to restoring anadromous fisheries to pre-impoundment levels. Anything that aggravates that already difficult task should not be tolerated at this particularly critical time. This commitment to anadromous fishery resources however should not be an obstacle to development of compatible resources, including resident sport fisheries that add to the quality of life.

The important issue remains, "Can selected resident fishery resources be enhanced without adversely impacting anadromous salmonoid fisheries?" Since Mid-Columbia reservoirs are not important rearing areas for juvenile salmonoids, competition for food and space should not be an issue. The real issue is predation. However, there is little information available to date on predation by important game fish predators like walleye and smallmouth bass. Do they prey on juvenile salmonoids to a significant degree, and is their predation additive or are they likely to displace non-game predators like squawfish? It is even conceivable that enhancement of walleye and/or smallmouth bass may result in decreased actual predation rates in anadromous stocks.

There are several on-going studies addressing the question of predation on the Lower Columbia River. But to date no studies designed to answer important questions concerning predation have been planned for the Mid-Columbia. The lack of information continues to hold up resident fish enhancement efforts. Preliminary results from the Lower Columbia seem to indicate that anadromous salmonoids are not an important component of the walleye diet. The speed and timing of salmonoid migration through Wells Reservoir also indicates that predation is not likely to be a significant problem. The risks to anadromous fish stocks are important enough, however, to warrant a good predation study before initiating any large scale walleye enhancement program in the Mid-Columbia, but it appears certain that smallmouth bass can be safely enhanced.

CONCLUSIONS

1. The role of resident fish in management of Columbia River water resources has not been adequately addressed. Without a better understanding of the interaction between resident and anadromous fisheries and how that relationship is affected by water management practices, managers will be handicapped in efforts to maximize public benefits.

2. Several resident game fish species (walleye, smallmouth bass, and white sturgeon) have potential for enhancement in Wells Reservoir. Enhancement efforts for some species are being held up by concern over potential adverse impacts on anadromous fisheries.

3. The productivity of Wells Reservoir for resident fish species is limited by rapid water exchange (.5 to 4.5 days), cold water temperatures (32-66^{o}F) and precipitous, featureless shoreline (small littoral zone).

4. The change from riverine to reservoir ecology in the Wells Pool area resulted in dramatic changes for anadromous fish populations. Mainstream chinook and steelhead spawning and rearing areas were eliminated, and losses were mitigated with artificial propagation at Wells Hatchery.

5. Wells Reservoir represents the upper range of anadromous salmonoids in the Columbia River, and remains an important

transportation area for three anadromous species. The 10-year average run size of adults passing above Wells Dam through the Wells Reservoir is 10,193 chinook; 23,289 sockeye; and, 3,726 steelhead. An estimated 3.1 million juvenile salmonoids migrate through the reservoir on their way to the ocean.

6. Average migration time for juvenile salmonoids through Wells Reservoir is 1 to 2 days.

7. Resident salmonoid populations have declined since impoundment and now represent less than 1% of total reservoir fish population.

8. Mountain whitefish appear to use Wells Reservoir principally as a migration route between spawning areas in the Methow River and the Wells Dam tailrace. An average of 20,000 whitefish pass through Wells Dam viewing facilities each fall.

9. Resident rainbow trout populations are primarily a product of residualism of hatchery-produced steelhead. The reservoir population measured by Wells Dam fish counts shows dramatic fluctuations most likely linked to smolt readiness of corresponding steelhead releases into the Methow River. True resident rainbow are rare and confined to Chief Joseph tailrace area.

10. White sturgeon populations in the Mid-Columbia have been

landlocked by hydroelectric dams. Sturgeon are not reproducing in Wells Reservoir, and will eventually disappear without assistance. Restoration may be possible with transplantation from the Lower Columbia or through artificial propagation.

11. Traditional warm water pond fish species are limited by the low productivity of Wells Reservoir. Populations can be enhanced only through construction of sub-impoundments.

12. Smallmouth bass are suited for some areas of Wells Reservoir. Their number and distribution is currently limited by lack of successful reproduction in the reservoir. Predation by smallmouth bass is not a threat to anadromous salmonoid stocks. Populations can be enhanced through artificial propagation utilizing the Washburn Island rearing pond.

13. Walleye do not successfully reproduce in Wells Reservoir. The existing population is recruited from Lake Roosevelt. Reproductive failure is due to lack of suitable rearing areas.

14. Walleye recruited from upstream locations have demonstrated exceptional growth and condition in Wells Reservoir, exceeding that of other northern states. They feed primarily on resident non-game species (80%), and although quantitative data on food habits in Wells Reservoir is not available, it is unlikely that salmonoids are a significant dietary component.

15. The sport fishery for walleye has become one of the most popular in the state. Of all resident game fish species in Wells Reservoir, walleye have the most potential for enhancement because reproduction problems can be circumvented through artificial propagation utilizing the Washburn Island rearing pond.

16. The Washburn Island steelhead rearing facility can be adapted for use as a summer rearing area for walleye or smallmouth bass fingerling.

17. Resident non-game fish species make up nearly 90% of the total fish population of Wells Reservoir.

18. Non-game fish populations benefited substantially from impoundment and their numbers have increased dramatically.

19. Populations of northern squawfish have declined in Mid-Columbia reservoirs after the initial population explosion following impoundment. Although that decline has been attributed by some to the expansion of walleye populations there is evidence to suggest that it actually reflects changing reservoir conditions.

20. The question of predation on anadromous salmonoids is the key issue in management of resident fish in the Mid-Columbia. That issue is delaying enhancement of resident game fish, and needs to be addressed immediately.

RECOMMENDATIONS

Baseline Data

Begin as soon as possible to establish baseline information on resident fish species in Wells Reservoir. Good baseline data should provide a measure (index) of current populations that can be used to demonstrate trends and impacts of any future operational or environmental change.

1. Start by conducting a comprehensive fisheries survey of Wells Reservoir in 1984.

   This survey should involve periodic intensive fisheries sampling of at least a dozen sites, representing all major habitat types and geographic locations. Fish sampling methods should include boat-mounted electro-fishing, vertical and horizontal gill netting, trap netting and beach seining. All sites should be sampled at least once every two weeks from March through October, and once a month during the remainder of the year. The objectives of the survey should be to determine species composition and relative abundance, spacial and seasonal distribution, age and growth, reproduction and food habits. Length, weight, age, sexual maturity and stomach content data should be collected. A year round creel census should be conducted in conjunction with the survey to provide additional biological data and measure one of the major influences on the fish population. An additional objective of this survey would be to develop some important "indexes" that can be evaluated periodically, to determine change in reservoir fish populations.

2. Follow up initial survey with annual sampling of important index areas and times.

3. Continue counts of miscellaneous fish species at Wells Dam and expand counts to include all species. Provide necessary training in fish identification of resident species to fish counters.

Enhancement

1. Cooperate with the Washington Department of Game (and Colville Tribe) in rearing of smallmouth bass at the Washburn Island rearing pond for release into Wells Reservoir in 1984.

    The Department of Game has expressed an interest in modifying the Washburn Island pond to rear smallmouth bass. Additional smallmouth in Wells Reservoir will not increase predation on salmonoids, and may significantly improve sport fishing opportunities. The pond should be drawn down and chemically rehabilitated by Washington Department of Game in March, 1984. Arrangements should be made as soon as possible to obtain 100,000 to 200,000 smallmouth bass fry for delivery in June. Following rehabilitation, the pond should be filled in mid-May and be fertilized at the rate of 50 lbs of 20-20-5 soluble fertilizer per acre per month. Fry should be reared in the pond from June through October 1, when the pond should be drawn down as far as possible, and as many 3-4" smallmouth fingerings, as can be, should be collected and transported to suitable sites in Wells Reservoir.

2. Make the necessary arrangements with the Washington Department of Fisheries to transplant 5,000 white sturgeon from the Lower Columbia to Wells Reservoir in 1984.

Other Recommendations

1. Conduct a predation study during at least two successive juvenile salmonoid migration seasons (April 1-June 15).

   Collect and evaluate stomach contents of resident predators (squawfish, walleye, smallmouth bass) from throughout Wells Reservoir, Lower Okanogan River and Wells Dam tailrace.

2. Determine the extent of steelhead residualism in Wells Reservoir.

3. Determine to what extent mountain whitefish utilize Wells Reservoir.

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