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Anadromous fish
Regional fish

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Turbine-Related Fish Mortality: Review and Evaluation of Studies

Prepared by
Eicher Associates, Inc.
Portland, Oregon

REPORT SUMMARY

SUBJECT Hydroelectric systems

TOPICS
Fish protection
Fish mortality
Fish passage
Fish entrainment
Anadromous fish
Regional fish

AUDIENCE Generation managers / Environmental engineers, scientists, and analysts

Turbine-Related Fish Mortality: Review and Evaluation of Studies

Can the mortality rate of fish passing through hydroelectric turbines drop below 10% to reach increasingly stringent regulatory goals? Existing studies seem doubtful, yet this assessment can help utilities—particularly those involved in plant relicensing—understand the magnitude of the problem. Diversion of fish around turbines remains the most cost-effective approach.

BACKGROUND Unless protected by diversion systems, fish migrating downstream can suffer injury or death by passing through turbines at hydroelectric plants. For more than 50 years, laboratory and field studies of the effects of hydraulic turbine passage on fish have sought to establish the causes and mechanisms of damage. Many interesting facts have arisen; however, the industry is no closer to understanding the exact mechanisms for mortality than it was in the 1940s.

OBJECTIVES To determine if the industry can achieve fish mortality rates in turbines below 10%; to critically review past studies to avoid duplication of effort; and to establish the credibility of past data in an attempt to understand which damage mechanisms are important.

APPROACH A literature search produced 64 studies on fish passage through hydraulic turbines, which the project team cataloged as specific mortality studies, other directly related studies, and indirectly related studies. Researchers reviewed materials and rated them according to credibility in terms of design and execution of studies, completeness of work, and attention to details in planning, procedures, and reporting. The team then reviewed the data to draw further conclusions.

RESULTS Past studies show that fish mortality rates in turbines, even under the best of conditions, rarely drop below 10%. Evaluation of factors thought to be significant showed the following:

- A demonstrated correlation exists between peripheral turbine blade velocity and fish mortality for the Francis turbine design, but not for the Kaplan design.

- Hydraulic head did not appear to be a relevant factor for either turbine, based on tests conducted over a wide range—40–410 ft for the Francis turbine and 20–110 ft for the Kaplan turbine.

- Reduced pressures beneath turbine blades and lowered efficiency operation both tend to increase mortality.

- In general, it is impossible to identify the source of fish injury by injury type or character.

EPRI PERSPECTIVE This evaluation of fish mortality studies clearly reveals a poor understanding of the causes and magnitude of the problem. The findings further reveal that improved monitoring is critical to a better comprehension of the fish mortality issue. There was no evidence, however, to suggest that greater knowledge would lead to a solution. The assessment could not point to a single operational or design approach that would markedly decrease mortality rates to less than 10% on a consistent basis. Consequently, diverting fish around turbines is probably the most cost-effective method of meeting the low mortality levels required by fish agencies.

PROJECT RP2694-4
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Turbine-Related Fish Mortality: Review and Evaluation of Studies

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Research Project 2694-4

Final Report, November 1987

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NOTICE

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ABSTRACT

The purpose of this project is to collect, list and review past studies of turbine-related fish mortality and from the review qualify evaluation findings and their implications in fish passage improvement. Publications describing such studies were obtained from all known sources. Included were 64 reports of turbine passage investigations at specific sites. Thirty-six papers reviewing turbine mortality aspects in general, but not of individual plants, were also studied, as were 56 study reports of subjects related to turbine mortality, such as turbine design, cavitation, gas supersaturation, pressure, descaling and shear. Annotated bibliographies for these three groups are provided, as is a glossary of terms used in this work.

Hydraulic turbines are described with particular reference to routes of fish through them in relation to assumed zones of fish damage. Methods and purposes of assessing such damage as well as factors affecting accuracy are discussed.

Detailed critiques of the turbine passage studies examined include reasons for the studies, types of studies, methods, execution, and results. Factors which may have modified the studies are discussed.

Comparisons of turbine operational and design characteristics with mortalities in prototypes found few good cause-effect relationships. The only relatively clear linkage with mortality was that of peripheral runner speed in the case of Francis units. Turbine model studies indicate influences of tailwater level, cavitation, wicket gate opening, and speed at which fish strike turbine blades. Injury types do not provide clear evidence of their source. Conjecture can be made concerning several factors, but concrete evidence is limited, because fish movement through turbines cannot be visually observed.

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SUMMARY

The Review and Evaluation of Studies of Turbine-Related Mortality was sponsored by EPRI to update knowledge with respect to passage of fish through hydraulic turbines. All available test reports, reviews and studies of ancillary subjects were assembled for this purpose.

Test reports were obtained by literary research and contact with individuals in academic, governmental and consulting groups conversant with history and current status of such work. Reviews and ancillary study reports were also obtained from literature research.

The test reports were reviewed and rated for degree of adherence to scientific principles in design and prosecution of studies, completeness of work, and attention to details in planning, procedures, and reporting.

The majority of studies were found deficient in attention to environmental factors, and many lacked proper control strategies. Various accepted study systems may not be inherently equal in accuracy. Many variations in indicated mortalities at retested plants are not explainable.

As a byproduct of the study review, some effects of turbine design and operational characteristics on fish mortality were suggested. These include:

- Kaplan and Francis turbines present different areas of possible fish damage. In Kaplan units, the principal effect may be on fish caught between the blade tips and distributor ring. The dominant effect in Francis turbines seems to involve the entrance point of fish into the runner blade cage. Damage at that point may be

caused by the wicket gates, the shape of the runner, and the speed at which the runner periphery passes the trailing edge of the wicket gates. A significant correlation between peripheral runner velocity and mortality is indicated for Francis but not for Kaplan prototypes.

- Head does not appear to be a significant factor. Tests of Francis units under either 40 or 410 feet of head show essentially the same mortality levels. No relationship was found between fish mortality and head in 19 tests of operating Kaplan turbines between 20 and 110 feet of head.

- Subatmospheric pressures, including cavitation, are shown by exploratory turbine model tests to affect mortality.

- Efficiency is shown by turbine model and some exploratory operational turbine tests to parallel mortality levels. Efficiency is related to to negative pressure effects.

- Wicket gate openings have been related to mortality in Francis unit models and some prototypes, with greatest hazard at full gate.

- Elevation of the runner center line with respect to tailwater elevation has been shown by exploratory tests in prototypes and models to affect mortality levels of fish, presumably because of the resulting variation in subatmospheric pressures under the runner blades.

- Water shear, assumed by experts in the field to be a factor in turbine-caused mortality, is difficult to positively identify with respect to fish damage or location of occurrence within turbines.

- In at least one Kaplan model study it was found that velocity at which young salmon struck the blades was a factor determining mortality.

- Source of fish injury within turbines cannot generally be identified by injury type and character.
- The principal difficulty of studying injury of fish in turbines is the fact that happenings within such units cannot be observed.
- Evidence indicates that stress of fish in passing through turbines is discriminate, affecting only those individuals exposed to discrete damaging areas as opposed to indiscriminate stress that affects all fish in a test lot uniformly such as in pressure effects.

Systems and methods used in conducting tests to determine mortality of fish passing through turbines are described, as are factors affecting accuracy of such methods. Types of information that should be collected in the course of future tests to make the results more meaningful are also suggested. Suggestions are made for future studies to improve turbine design to protect fish or select turbine types with least damaging effects.

Three annotated bibliographies are included. One describes individual turbine mortality tests identified by a T after the reference date, the second covers reviews of turbine mortality subjects in general identified by an R after the date, and the third lists studies ancillary to turbine-related effects on fish identified by an A after the reference date.

A glossary of terms found in reports of studies of fish passae through turbines and related subjects is provided.

Section 1

INTRODUCTION

In December 1984, the Electric Power Research Institute (EPRI) sponsored an international workshop in Portland, Oregon on the subject of fish passage through hydraulic turbines. The 27 participants, including experts in the fields of turbine design, fish passage research, and turbine operation discussed history and other aspects of this subject but were unable to reach agreement with respect to exact mechanisms by which fish were injured or killed in passing through these machines or consequently how to redesign turbines to reduce damage. It was generally agreed that mechanical damage from collision with components of turbines, cavitation, and shearing action of water planes were probably the principal areas of concern. A questionnaire returned by the participants ranked eight possible avenues of future action. The first choice was that of a careful review and analysis of all studies that have been performed in the subject area.

The dominant reference on turbine passage has been the compendium of study reports assembled by Bell, DeLacy, Paulik and others in 1967 (Bell, et al, 1967R) and updated in 1981 by Bell, Bruya, and Scott for the U.S. Army Corps of Engineers (Bell et al 1981T). In this compendium, the assembled results were examined, and correlations of certain parameters with mortality were made separately for Kaplan and Francis types of turbines. All reports of studies in the compendium were taken at face value, and no attempt was made to review them for accuracy or degree of adherence to standard methods. Subsequently, errors have been found in some studies, and others included factors altering interpretations of findings. Many additional studies have been made in the interim. The Bell compendium of 1981 dealt with 26 prototype studies. This review covers 66 including the 26 of the

Bell Compendium.

The current review, also sponsored by EPRI, is intended to respond to the priority item suggested by the Workshop members: "Review existing data on the relationship of fish survival to characteristics of machines and various use conditions in light of new information." The approach has been to examine all known previous aspects of experimental turbine mortality studies. To obtain a complete list of known studies, all logical sources were canvassed. These works are fairly well known. The older ones are referred to in earlier review publications bearing on the subject of turbine-induced fish mortality such as Bell, et al (1967R), and Turbak, et al (1981R). Since all such studies in North America have involved state, provincial, or Federal regulatory agencies, appropriate individuals in these agencies were contacted. In addition, knowledgeable individuals in private enterprise and academia were contacted. We do not believe any known legitimate sources have been overlooked. Since completion of the search, two additional works were reported, but one turned out to be merely educated opinion; the other was a legitimate formal study, but it has not been completed or reported upon. Individuals who participated in identified studies were interviewed for additional data or opinons.

Three annotated bibliographies are involved in this study. The principal reference covers the specific individual study reports reviewed in Appendix A. It is contained in Section 7 and referred to in reference indices by a T following the date, as (1981T). The second bibliography references reviews of general subjects such as aspects of turbine mortality or factors bearing on it. It is contained in Section 8 and is referenced by an R following the date, as (1981R). The third bibliography includes studies ancillary to turbine passage such as those of gas supersaturation, marking methods, or descaling. It is Section 9 and referenced by an A following the date, as (1981A).

Studies show results in terms of percent mortality, or reciprocally, survival.

For consistency, this report generally uses the mortality designation as do most of the study reports.

Each report has been evaluated for quality of work. Criteria by which quality was judged included plant description, appropriateness of procedures described, recording of test data, and adequacy of attention to environmental aspects. Those found acceptable have been subjected to additional analysis to determine if information available since the study suggests additional or modified conclusions. Information analyzed includes turbine types, turbine operation during testing, design, mode of operation, fish species and size, acclimatization, type, magnitude of injury and environmental factors.

An important part of this review has been compilation of a glossary of terms used in studies of fish passage through turbines. Sources for this include Allis Chalmers Corporation, the U.S. Bureau of Reclamation Glossary of Environmental Terms, and knowledgeable individual engineers and biologists. This glossary is included as Appendix C.

Section 2

DESCRIPTION OF HYDRAULIC TURBINES

TURBINE TYPES BY PRINCIPLE

Hydraulic turbines fall into two general groupings: impulse types, which use the force of a high velocity jet at atmospheric pressure directed into cups at the circumference of a wheel; and the reaction type, which uses the force of water under pressure on submerged blades of a turbine wheel. Almost all turbine mortality tests have been concerned with reaction type turbines because impulse turbines are not normally sited where fish are a concern. General belief has also been that few fish would survive the violent conditions within impulse turbines. Reaction types are further divided into two groups: propeller and Francis.

TURBINE DESIGNS

Propeller

Most propeller turbines are of the Kaplan design in which the blades are adjustable during operation to provide best efficiencies under changing head and load conditions. Figure 2-1 shows a typical large Kaplan unit. Kaplan units normally consist of propeller blades in a runner attached to a vertical shaft and surrounded by a semi-spiral case, which is a water passage directing flow to the blades through stay vanes and wicket gates. Stay vanes are structural in nature, supporting the upper portion of the distributor. They also influence angle of flow. Wicket gates control the rate of flow and its direction or angle approaching the blades. Horizontal variations of the Kaplan turbine are bulb and tube types, in which the shafts are in tubular housings without spiral cases. Propeller turbines usually have four to six blades, with spaces between blades much greater than for Francis types. They are used most often for low heads up to 100 ft (30m).

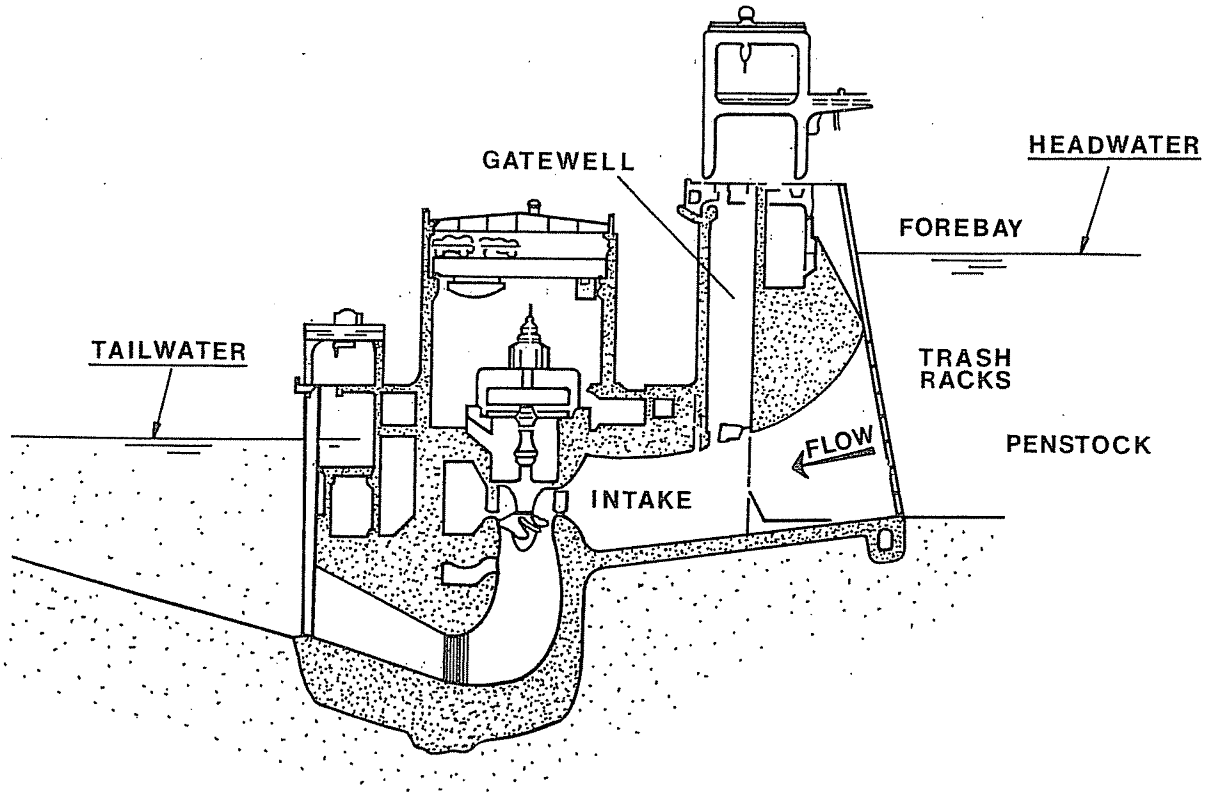


Figure 2-1 Cross-sectional view of typical large Kaplan turbine.
(Source -- Long and Marquette, 1967, redrawn)

Francis Turbines

Francis runner buckets are solid parts of the runner and vary in number from 14 at low heads to about 20 at high heads, with the minimum opening between buckets ranging from 2.5% of the discharge diameter for low heads to 4.5% for high heads. Francis units are normally used for heads between 100 and 1000 feet (30-305m) although many older installations and some new small plants use them for low heads also. Figures 2-2, 2-3 and 2-4 illustrate details of Francis turbine design.

TURBINE COMPONENTS

Hydraulic Flows Within Turbines

Turbine runner blades or buckets travel in the direction of flow at an average speed less than the velocity of incoming water. For a head of 600 feet (183m), water enters the turbine at a velocity of about 150 feet (46m) per second. At 100 feet (30m) of head, velocity is about 60 feet (18m) per second. For all heads, velocity leaving the turbine is 25 to 30 feet (7.6 to 9.0m) per second which is reduced to about 8 feet (2.4m) per second at the draft tube exit. Velocity in the spiral case prior to acceleration into the turbine varies from approximately 29 feet (8.8m) to 19 feet (5.8m) per second at 600 feet (183m) and 100 feet (30m) of head respectively (Cramer and Oligher 1964R). Water routes through turbines, penstocks, and draft tubes are usually as smooth as can be designed, in the interest of efficiency. Figure 2-3 shows the paths of water through Kaplan and Francis turbines and Figure 2-4 compares the two types of runners. Figure 2-5 shows the velocities of the water in passing through different turbine areas.

Guide Vanes and Wicket Gates

Guide or stay vanes direct the water into the wicket gates and are fixed in position. Wicket gates rotate to control the flow and direction of water and are essentially continuations of the guide vanes. Velocities are relatively low and pressures strongly positive in passages cqrrying water to a turbine. Velocity accelerates through the guide vanes and wicket gates, reaches a maximum at the

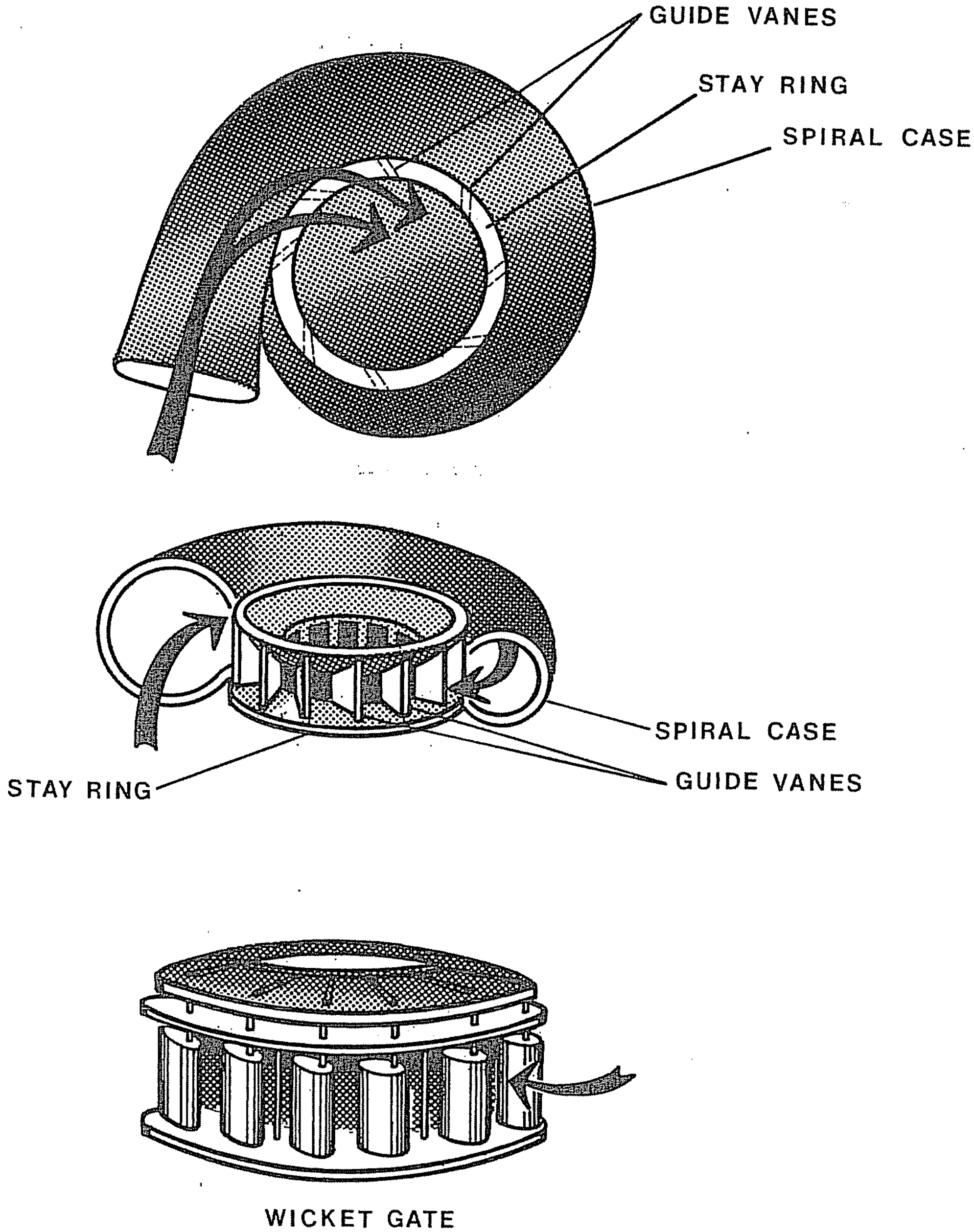


Figure 2-2 Details of Francis turbine showing flow paths.
(Source -- Montreal Engineering Co.)

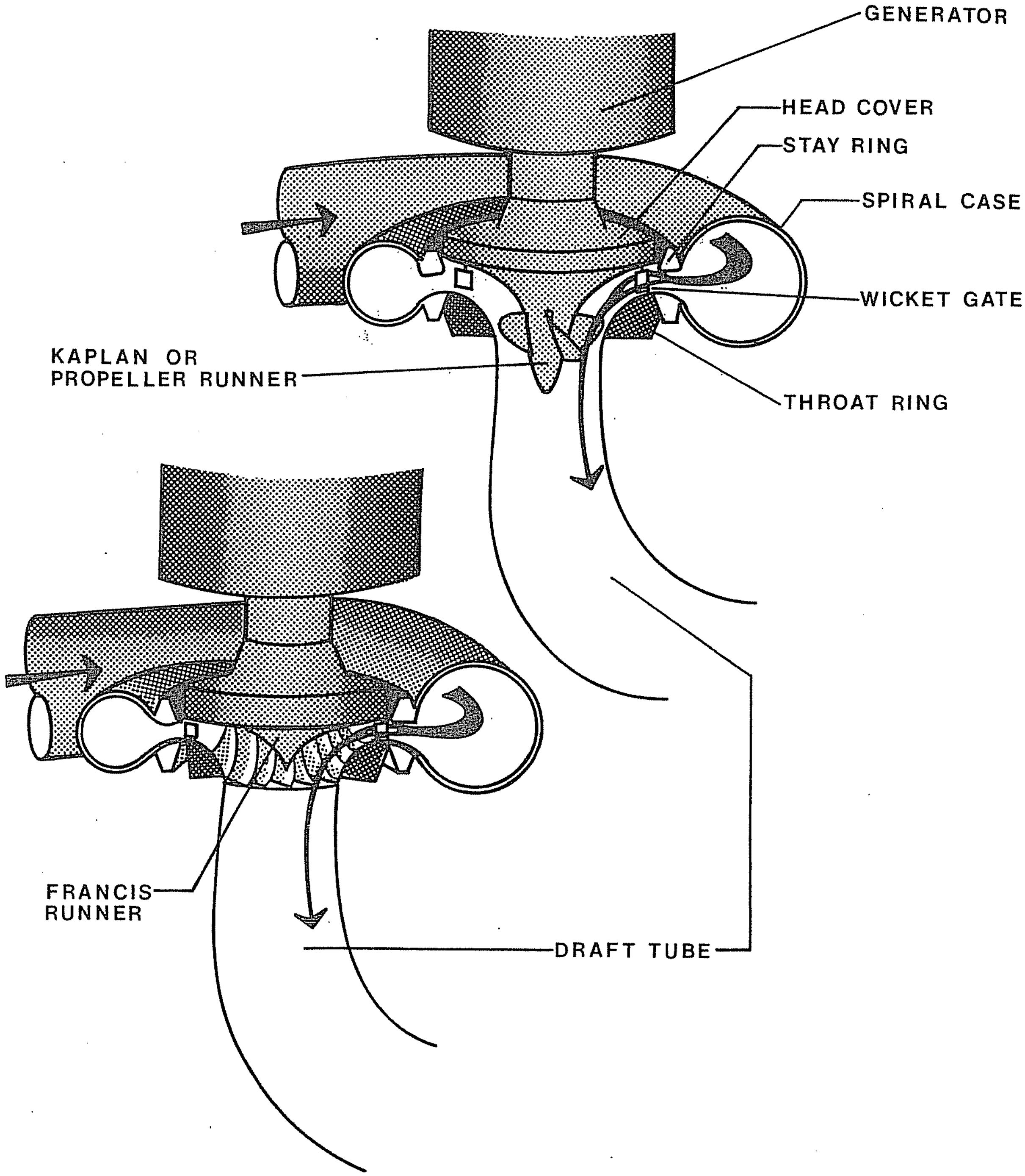
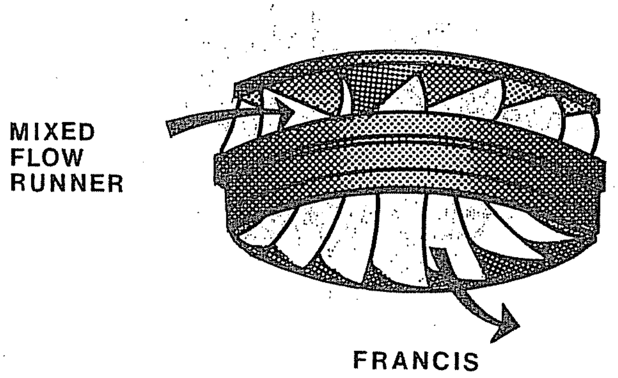


Figure 2-3 Details of typical Francis and Kaplan turbines showing flow paths.
(Source -- Montreal Engineering Company, 1980, redrawn)



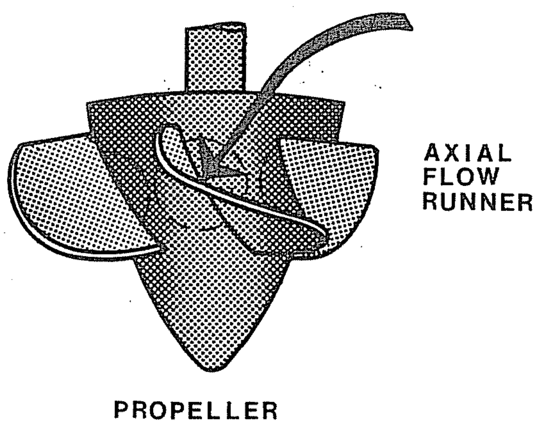


Figure 2-4 Francis and Kaplan (propeller) runners.
(Source -- Montreal Engineering Company, Inc., 1980, redrawn)

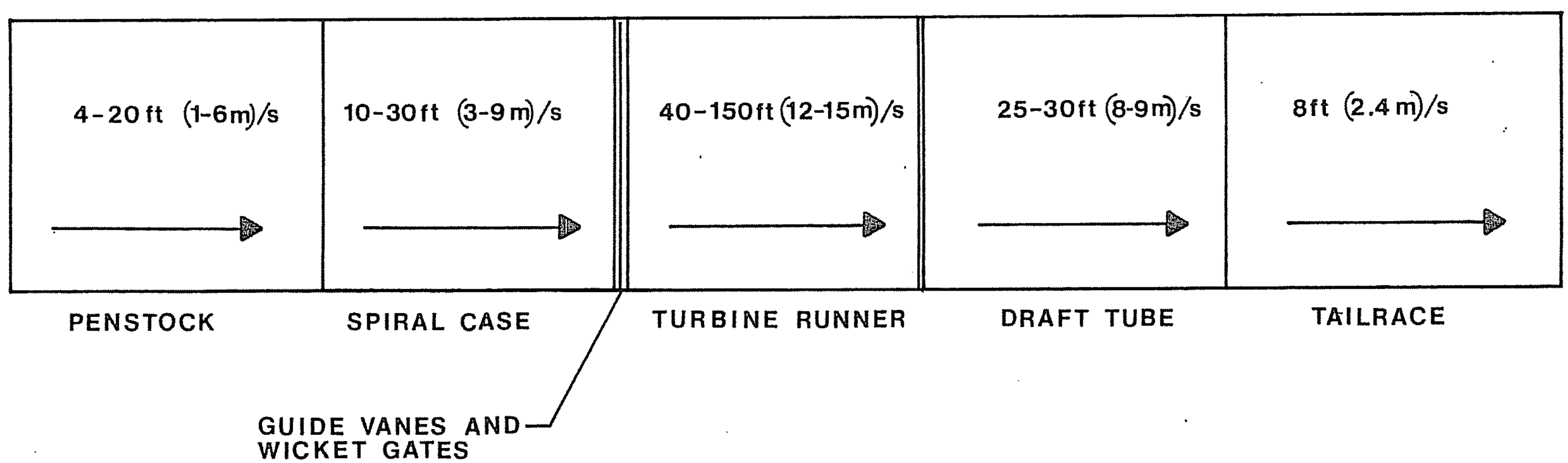


Figure 2-5 Diagrammatic depiction of flow velocities through turbine passages.

blade front and decelerates after passing through the blades.

Draft Tubes

All reaction turbines have draft tubes. In most Francis and Kaplan units, this is usually a simple tube taking water from the discharge side of the turbine runner changing flow direction from vertical to horizontal in an elbow shape and flaring to the discharge end so that velocity is reduced at that point. Axial flow turbines such as bulb and tube types tend toward straight but flared draft tubes. Water decelerates through the draft tube to about 8 feet (2.4 m) per second at the discharge (Cramer and Oligher, 1964T). Some of the newer small bulb and tube units use lower velocities.

TURBINE OPERATIONAL FEATURES

Turbine Siting Characteristics

Runners are normally set at an elevation calculated to avoid local subatmospheric pressures sufficient to cause cavitation resulting in blade erosion and loss of efficiency. Deeper settings incur greater construction costs for a given output rating. Francis turbines normally are sited with the runner higher relative to tailwater than is the case of Kaplan units, which tend to have the runner centerline below tailwater surface elevation.

Sigma

Sigma is a dimensionless parameter used to define the required depth of the turbine centerline in relation to tailwater level. Plant sigma differs from runner sigma in that it reflects barometric pressure at a site, as well as the safety margin. Runner sigma is usually numerically smaller. (See Glossary, Appendix C.) The deeper the relative turbine setting (high sigma), the lower is the potential for cavitation. In general, for given turbine types, higher head plants require greater submergence than those of lower heads in order to avoid cavitation. Sigma is not the only factor affecting cavitation potential (Ruggles and Collins 1981T).

Section 3

FACTORS AFFECTING FISH IN PASSAGE THROUGH TURBINES

INJURY ASPECTS

Categorical Evidence

Hydraulic turbines constitute closed passageways that do not ordinarily allow visual observation of fish passing through them. Fish recovered after passage through turbines have exhibited various manifestations that have been categorized as caused by mechanical, pressure or shear forces. It should be emphasized that such cause-effect appraisal cannot be accurate because it is not based on direct observation. Members of an EPRI workshop on turbine mortality (Eicher Associates 1985R) disagreed with respect to assignment of injury sources and whether pressure, mechanical or shear origin could be separated with certainty. Assignment of routes and impacts on fish within turbines can only be from conjecture based on inferential data.

Discriminate and Indiscriminate Stress

Brett (1958A) hypothesized that stress to downstream-migrant fish passing through turbines is probably indiscriminate; that is, the effects are uniform on all individuals. He described a 10% loss as catastrophic to a population going through a turbine because this meant that the uniform stress killed the weakest 10%, with the balance damaged sufficiently that further stress of natural conditions would soon kill them. He based this theory on the assumption that the principal turbine passage stress to fish was pressure change, which affects all fish uniformly. Brett conceded that the McNary Dam turbine passage studies (Schoeneman et al 1961T) suggested that mortalities at that site were discriminate because the 11% loss was estimated from stations several miles downstream, but felt that his leaning toward turbine stress as indiscriminate was correct. Many biologists have long sided with Brett, although the evidence of many tests through the years has pointed in the other direction. Ruggles and Collins (1981 T), at the Lequille power plant, took trout which had survived passage through a turbine once with a 50% mortality and recycled them through the same plant again. The loss in the second trip was again 50%, indicating that the stress was indeed discriminate and probably due to certain individuals encountering discrete damage sources which affected only them. The authors concluded that the survivors of the first test were as healthy after the passage as before, or a greater percentage would have perished in the second test.

TYPES OF INJURY

Mechanical Injury

The term mechanical injury infers damage to fish caused by their impact with solid objects within a turbine system. Such objects include conduits, wicket gates, guide vanes, turbine blades or other turbine components. Damage characteristic of mechanical impact includes bruises, lacerations, skeletal fractures, scraped or crushed heads, severed bodies, internal hemorrhaging or popped or missing eyes (Collins and Ruggles 1982T). Mechanical injury evidence is generally external. Mechanical injury may be particularly pronounced in turbines with small clearances in relation to fish size (Cramer and Oligher 1964T).

Pressure Effects

Subatmospheric pressure may cause internal injury, or mortality of fish; cavitation is the extreme case. Apparently, fish that have been acclimatized to pressures in deep reservoirs before exposure to negative pressures within turbines are particularly vulnerable (Lucas 1962R). The type of swim bladder found in various fish species is important to pressure effects. Those that possess a duct between swim bladder and esophagus (physostomous) are better adapted to pressure changes than physoclistic fishes, which do not not have such a duct. The duct allows air to evacuate from the bladder more quickly (Collins and Ruggles 1982T). Collins and Ruggles (1982T) concluded that fish can generally tolerate high positive pressures, and that the rate of change in pressure is more significant than absolute magnitude of change. Fish adapted to atmospheric pressure are not adversely affected by sudden pressure increases to three atmospheres followed by almost instantaneous release of pressure to atmospheric values (Holmes 1952A). This effect is species related; however, those species most often involved in turbine passage such as trout and salmon, are least affected (Faye and Scott 1965A). Evidence of pressure damage in fish includes air bladder deflation or rupture, popped eyes and embolism. Most pressure injury evidence is internal.

Shear Effects

Shear in this context is taken to mean the effect of two adjacent high-velocity water flows on fish situated in the boundary plane between the two flows.

The evidence of this factor in turbine mortality is unclear. It is difficult to pinpoint exactly where and how it happens, and resultant damage is hard to separate from that of other causes. Severing of fish is often thought to be due to shear effect, but can also be logically attributed to other sources. An experimental shearing study (Groves 1972A) showed principal consequences to be torn gill covers, popped eyeballs and decapitation. However, such effects have also been linked to mechanical damage.

Data indicate that shear damage is most likely to occur at velocities greater than 60 feet fps (18 m per second)(Theus, 1972A). It is not clear where such velocity difference may occur within turbines. Experimental work in this area (Groves, 1972A, and Theus, 1972A) has been confined to studies of high velocity jets carrying fish into static water rather than interaction between two flows. The conditions and effects may be different.

DESIGN AND OPERATIONAL EFFECTS

Types of Turbines

The type of turbine involved in fish passage has long been considered to be a determining factor in mortality although most differences in mortality rates seem more related to siting than to turbine design. Each has peculiarities that influence damage to fish in different ways. Francis units tend to be sited with the runner higher than do Kaplan types.

Head

Head is the difference in elevation between the surface of the forebay and that of tailwater. This translates into pounds per square inch (gms/cm^2) of force exerted against the turbine blades. Each foot of head equals 0.434 pounds per square inch (0.03kg/cm^2) pressure. Subatmospheric pressure may exist on the underside of the blades and in the draft tube. This component is known as "draft" head. Head indirectly affects fish mortality in turbines because it creates the velocity of water (and fish) entering the turbine chamber and moving through the blade spaces, as discussed on page 2-2.

Elevation of Runner Above Tailwater

This parameter is of considerable importance in turbine passage of fish because it is the major operational variable controlling levels of subatmospheric pressures and cavitation, both of which may be deleterious to fish, as explained earlier. Elevation of the runner above sea level is of lesser importance. It determines atmospheric pressure but is fixed at each site. Moreover, hydroelectric plants involving migratory fish do not significantly differ in elevation, tending to be below 1000 feet (305m) elevation.

Cavitation

Cavitation results from the violent collapse of vapor pockets when they emerge from an area of extreme vacuum to one of higher pressure. Such vapor pockets can occur along the blade edges as well as behind the blades where most blade damage is apparent. A type of cavitation peculiar to Francis turbines is that of core vortex occurring near the middle of the space under the runner where it may extend a distance below the blade cage in the form of a "rope" that is perhaps a tenth of the runner diameter in width. As is the case of most cavitation, it results from heads or loads that are below or above optimum (Fisher and Cybularz, no date A) and is not a normal occurrence. Kaplan units are prone to cavitation in areas of pressure leakage at the distal, and sometimes at the hub end of the blades because of the relatively large clearances at these points required for blade movement in pitch change (Figure 3-1). Some Kaplan types avoid the hub clearance, however. Unfortunately, these clearances are also locations through which fish probably pass. Since cavitation is a force sufficient to remove metal from the turbine blades, fish entering areas where it is in progress can be assumed to suffer damage.

Efficiency

The efficiency at which a turbine converts water under pressure into mechanical energy is an indicator of other factors bearing on the amount of mortality of fish passing through turbines rather than being a factor in itself. It was generally agreed by all experts involved at a workshop on turbine mortality in 1984 (Eicher Associates, 1985A) that maximum survival of fish coincides with greatest turbine efficiency. At greatest efficiency, cavitation and related pressures are least prevalent and flows are smoother (Bell et al, 1967R). Comparisons of efficiency and mortality curves are imprecise because the curves are relatively flat without clear relationships with each other (Figure 3-2). Efficiency is controlled by wicket gate opening and resulting flow quantities, and design head in relation to operating head. It usually increases from small gate openings and reaches a peak at from 60-80 percent of maximum flow (Cramer and Oligher 1961T). Efficiency falls off near maximum flows, which frequently occur during seasons when fish are

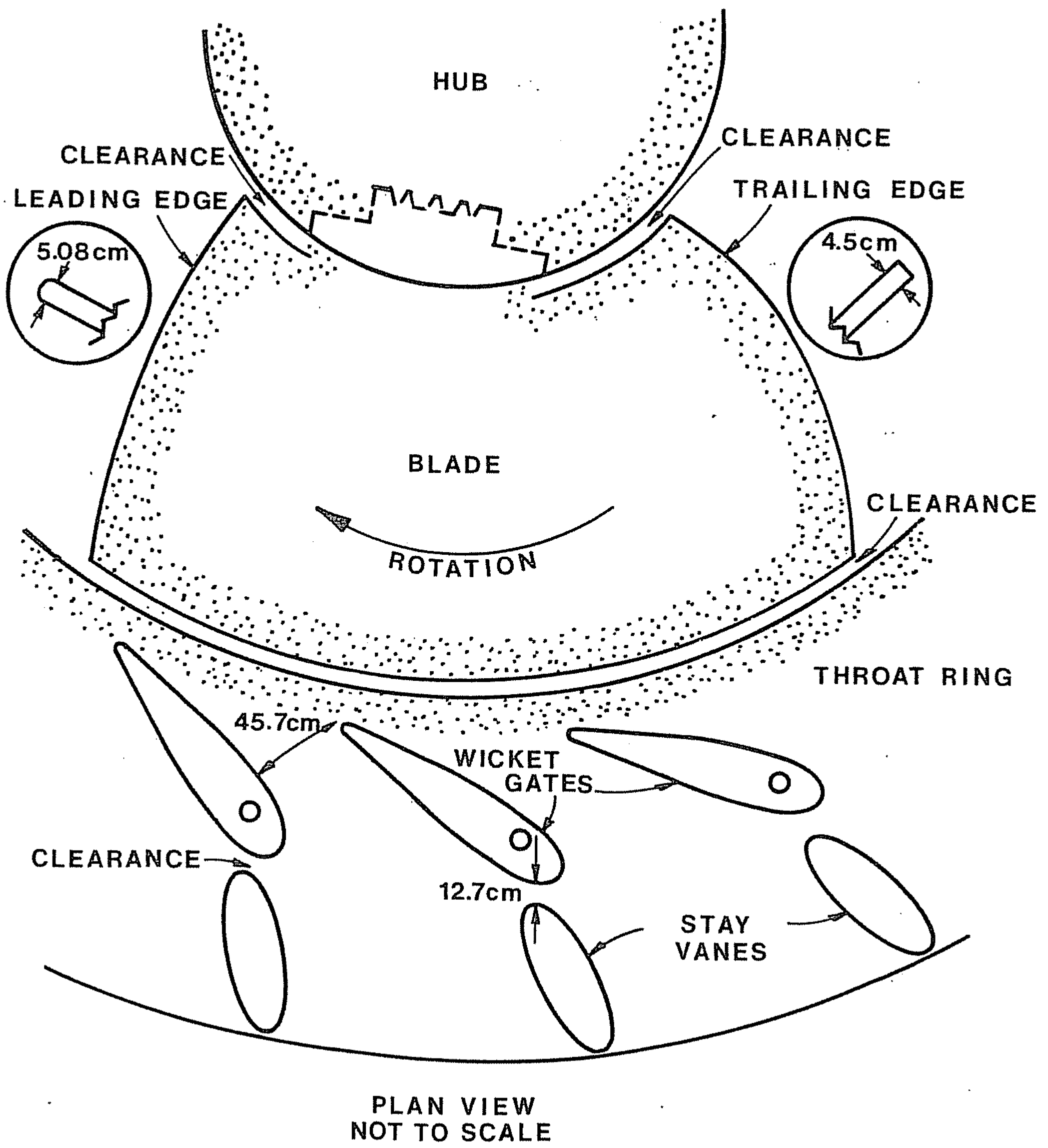


Figure 3-1 Top view of Kaplan runner blade showing clear openings between the hub and runner blade, the wicket gates and the blades, and the guide vanes and wicket gates. (Source -- Long and Marquette, 1967R)

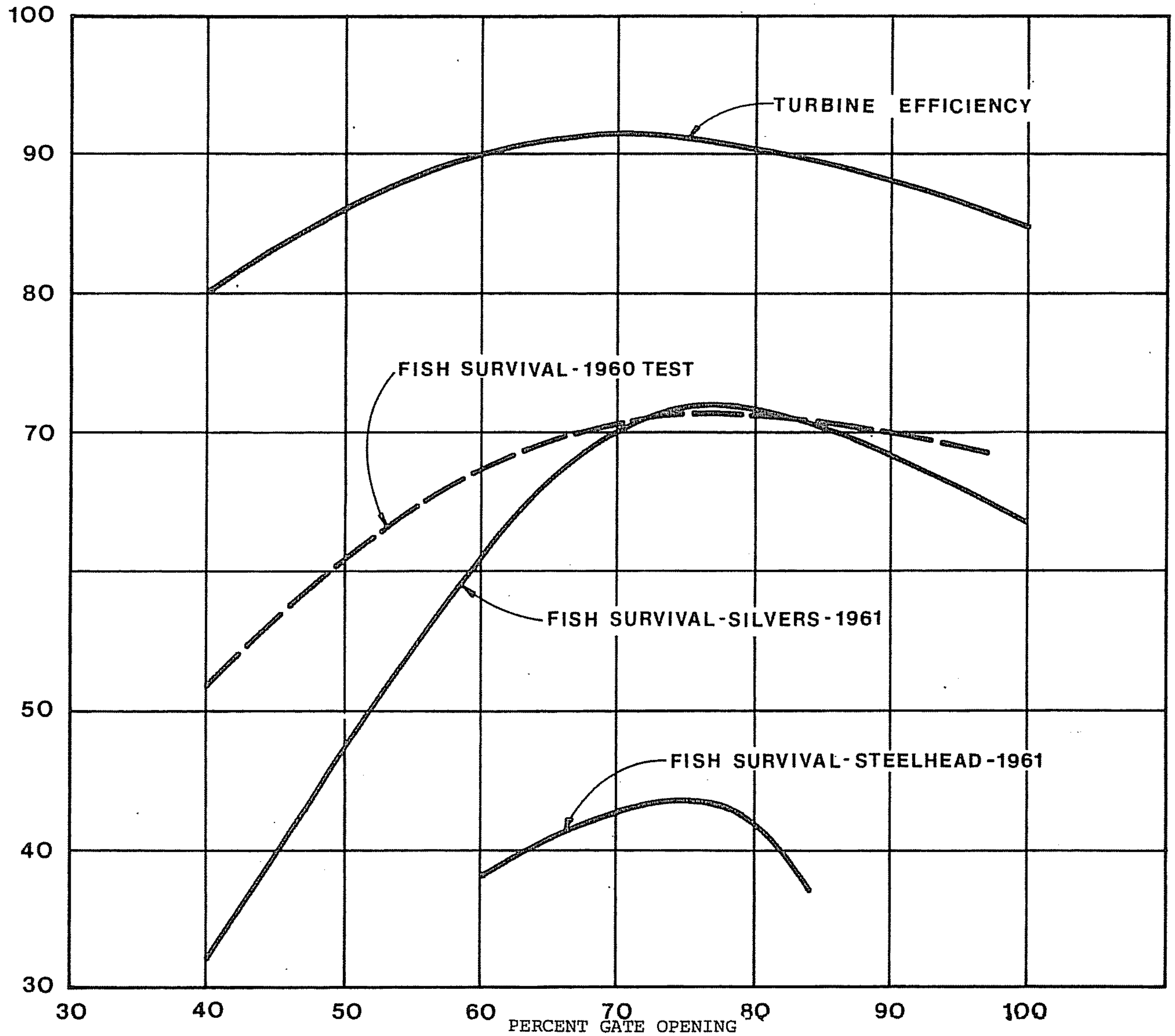


Figure 3-2 Percent efficiency of a turbine and survival rate of fish passed through it at various gate openings. (From Cramer and Oligher, 1961T)

migrating downstream.

Runner Speed at Shaft and Periphery

In some reviews of turbine mortality, peripheral runner velocity has not been seen as having a major effect on fish. The inference has been that shaft speed is the determining factor. However, it appears that peripheral velocity is actually the dominant factor. The relationship is most clear in the case of Francis units, because of the documented mortality of fish in the gap between the wicket gate trailing edge and the leading edge of the buckets (Cramer 1960T). Cramer and Oligher (1961T) found that decreasing the number of buckets of a model Francis runner lowered fish mortality. This substantiates that mortality is influenced by the number of times a bucket intersects the gap between vanes in a given period of time. The degree to which this happens is dependent upon the speed that the bucket edges pass the critical area rather than shaft speed.

As indicated on page 2-2, because water and fish usually approach turbine blades or buckets at a velocity slightly higher than that of the blades, fish tend to strike a turbine blade rather than the blade's leading edge striking the fish. Bell, et al (1967R) examined a formula devised by a German, Kurt Von Raben, in 1957 to predict the probability that fish will contact a given Kaplan or Francis blade or bucket in passing through such turbines, using the factors of blade numbers and cross-sectional areas, the angle of water (and fish) flow into the blade, the average flow and an arbitrary correction factor. The conclusion of Bell's examination was that, while agreement of Van Raben's theory with actual test data with fish was poor, the basic theory was probably consistent with hydraulic and mechanical mechanisms.

Wicket Gate Manipulations

The function of wicket gates differs slightly between Francis and Kaplan turbines. In both they control and/or stop flow. Their effect on fish in Kaplan units has been assumed to be negligible because they do not present problems of clearance or velocities. In Francis units, wicket gates have definite impacts on fish, because the trailing edge of the gate may, at full gate, close a narrow gap between it and the rapidly moving periphery of the turbine buckets. Fish in this gap may be subject to injury or mortality as the buckets pass the gate ends; fish size is a factor (Ruggles, 1980A; Cramer, 1960T).

Blade Tip Clearance

Runner rotation of Kaplan turbines tends to be slower than for Francis types. Runner size tends to be larger, however, so that blade tip speed may be equal. In the case of the majority of juvenile anadromous fish, which tend to pass through the upper levels of penstocks (Long 1975A), passage through Kaplan units tends to be near the hub where theoretically the least damage normally occurs (Bell, pers. comm. 1986A). Only a small percentage are believed to reach the tip area where greater damage potential exists in the gap between blade edge and distributor ring and where higher rotational velocities exist. In the case of horizontal propeller units such as bulb and tube turbines, the proclivity of fish to follow upper water levels in the penstock means that most tend to pass through the blades in the outer flow zone where danger is considered greatest, as noted above. Bulb and tube turbines, however, are usually constructed with quite small clearances between blade tip and distributor ring, thus preventing entrance of most fish into the gap. This may offset the hazard of larger proportions of fish at the runner periphery.

Backroll

In many hydroelectric plants, particularly those with larger Kaplan turbines such as on the Columbia and Snake Rivers, a phenomenon known as "backroll" occurs in the tailrace area, with varying degrees of prevalence, (Long, et al, 1968T). It is the result of the draft tube discharge creating a boil. The forward portion of this, the "frontroll", continues on downstream. The rear portion tends to reverse direction some distance downstream of the powerhouse and comes back upstream on the surface. This apparently results from a combination of forces, one being a surface drawdown caused by the flow emerging from the draft tube. It is augmented by head created by the boil, which is influenced by depth of draft tube submergence, upslope of tailrace bottom and quantity of discharge from a unit, (Bell, pers. comm. 1986A). Some fish are carried upstream by backroll into areas of heavy predation.

Section 4

STUDIES OF MORTALITY OF FISH IN PASSAGE THROUGH TURBINES

TYPES OF STUDIES

Studies of fish mortality in turbines have been of two general types categorized as informational and exploratory. Informational tests measure typical mortality levels at given plants. Exploratory studies attempt to find, define and measure influences on mortality by various turbine-related factors.

Informational

Most of the studies have been of the informational type, in which a turbine is tested for mortality and injury levels typically found under representative conditions at a site. In such tests, fish are usually of the size and species normally passing through the power plant tested. Recovery methods are those usually least costly to perform. These favor downstream recoveries (including adult returns), fyke net sampling or floating tags. Turbines are operated under conditions expected at the time of greatest fish exposure. Tests are typically of few or no replications. Such tests show mortality of a particular unit under expected conditions of load, wicket gate opening, and efficiency, or in the larger sense, the average impact of that turbine on downstream-migrant populations. The 1955-56 tests at McNary Dam, for example assessed turbine mortality of one species under one turbine condition (Schoeneman, et al, 1961T).

Exploratory

Exploratory tests are designed to explore the relative effect of various areas affecting mortality within turbines or how changing operating conditions influence mortality. This type of test is more rigorous and demands strict attention to details. Many "runs" are required, the actual number depending upon the number of parameters tested as well as the various conditions examined. Each parameter, such as wicket gate clearance, may require replications with varying sizes of several fish species. Because they are costly and of value to limited interests, only a few have been performed.

This type of test requires that enough test fish be recovered that nature and degree of injury and mortality can be accurately assessed. This necessitates direct methods of fish recovery and knowledge of the effects of these on fish survival.

The test goal is normally to measure individual sources of mortality as influenced by varying conditions. Changes in turbine design to reduce mortality may result. An example is the 1962 series of tests at Shasta Dam conducted by the U.S. Army Corps of Engineers on three species of fish under various conditions of tailwater levels and wicket gate openings (U.S. Army Corps of Engineers, 1963T). The purpose was to produce designs that could be used elsewhere in building new units of a similar type to produce least damage to fish.

DESIGN OF STUDIES TO ASSESS TURBINE RELATED MORTALITY OF FISH

DIRECT METHODS

Fyke Net Sampling. One of the earliest methods of assessing turbine mortality has employed medium-sized fyke nets (nominally 5 ft <1.5 m> square entrances) in the tailrace to capture live, dead, and/or injured fish emerging from the draft tube. These nets can be calibrated for capture rate by passing known numbers of marked fish through the turbine and recording the percentage captured in the nets. Because fish killed by the turbine are normally captured at a different rate than are live fish, groups of dead fish are usually also passed through the turbines and their rate of recovery by the nets recorded. If numbers of injured fish captured by fyke nets in the tailrace are an important consideration, a further refinement is advisable -- that of fishing similar fyke nets in the forebay to capture fish approaching the penstock entrances. This provides information on the status of fish moving downstream with respect to preexisting injury levels. Rivers (1951-1957T) used this method.

A variation of the above procedures for naturally migrating populations is the introduction of marked hatchery or wild fish directly into the turbine intakes. In order to assess the degree of error introduced by release and recovery gear, it is desirable to employ control lots of fish which experience every impact of the procedures affecting the test fish except for passage through the turbines. Control fish are normally entered into the fyke nets by the same equipment used to place them in the turbine intakes. Mortality and injury of the control fish are compared to that of the test animals and adjustments in mortality and injury estimates of the latter group made accordingly.

The principal advantage of the fyke net method is that it is relatively inexpensive, yet gives fairly representative results if sufficient numbers of migrating or introduced fish are available.

A disadvantage is that fairly large numbers of fish must be used to provide a representative net catch. An unavoidable source of error, as discussed later under "Parameters affecting accuracy of results" is that of test fish being exposed to hazards of both the turbine and recovery nets, neither of which may singly kill or injure, but additively can do so (Bell, et al, 1967R); whereas control fish experience only recapture impacts.

Large Net Straining Major Flow From a Turbine. This system has been used in several major turbine mortality studies. It involves a net of sufficient size to strain essentially all of the water issuing from a turbine draft tube. This net is fastened to a frame enclosing the draft tube discharge. Introduction and handling of test, control, and dead fish, are roughly the same as described above for fyke net sampling, except that virtually all of the test fish are captured. This system is seldom, if ever, used with naturally migrating populations. It is the only system that can logically be used in exploratory tests requiring recovery of all dead and injured fish for examination to assess type and probable sources of injuries and mortalities (Cramer and Oligher, 1960T).

A major disadvantage is expense. For relatively small turbines passing 500 cfs ($14 m^3/s$), a net can cost over $100,000. It takes expensive gear and many workers to install, adjust and remove it. If used as an informational method to assess the exact mortality of a given turbine, it suffers from the same unavoidable "double jeopardy" error described earlier for fyke nets. Because of this, the most effective use of the large net is to assess relative mortality levels, such as in replicative studies of operational elements.

Sampling Methods

Downstream Recoveries. These include a variety of different methods such as scoop nets (Schoeneman, et al, 1961T), fyke nets (Schoeneman and Junge 1954T), gatewell sampling at downstream dams (Olson and Kaczynski, 1980T) and downstream beach seining (Long et al, 1968T). Adult collections are a variation of these methods.

The downstream recovery principle involves passing marked test fish through turbines and simultaneously releasing marked control lots in the turbine discharge in a procedure closely resembling that used for test fish so that both lots experience the same impacts except for turbine passage.

This method is relatively inexpensive because recovery gear is normally not costly. It cancels considerations of such things as delayed mortality and predation.

Disadvantages include the requirement of good mixing of test and control fish. More time is required for this system than for draft tube straining. It is of little use for exploratory tests to define types or sources of injury or mortality, because dead and most injured fish do not usually reach the recovery stations (Schoeneman et al, 1954T). Relatively large numbers of test and control fish must be used to ensure statistically sound levels of recoveries.

Adult Recoveries. This method is an extension of the downstream recovery technique. The same systems of marking, passage through turbines and handling of controls are used. Recovery, however, is delayed by a matter of months or years and after the fish have grown. Marking of the fish must be by a method offering long-term permanence, such as fin excision or coded wire tags. In short-term downstream recoveries, temporary marks, such as tattoos, partial fin clipping, freeze branding or dye dips may be used since identification for only a few days or weeks is required (Wunderlich and Dilley, 1985T).

An advantage of this method is that it cancels or accounts for the effects of predation and delayed mortality of fish exposed to turbines almost to completion of their normal life span. It is probably the most reliable method providing the most believable results.

A disadvantage is that a long period of time is involved -- up to several years. Many developments can happen in this time such as loss of funds to complete the research. For this reason it may be desirable to use fast growing fish. In the salmon, the most likely species would be coho, since many of these return as "jacks" (sexually precocious males) in the year of downstream migration. Even larger numbers of test and control fish must be used than for shorter term down=stream recoveries to offset the increased time-related attrition. Methodology requirements are the same as for downstream recoveries insofar as the turbine passage and control release stage is concerned.

Miscellaneous Methods

Radio Tagging. This method requires that both test and control fish be fitted with internal radio tags as described by Knight and Kuzmeskus (1982T). Test fish are released into the turbine intake and controls into the tailrace with the same type of equipment and at the same time. Because these fish must be tracked individually by radio receivers, it is normally necessary to confine releases of test and control animals to a few individuals at a time. Work done thus far has included the criterion of survival to mean passage of test fish past a point several hundred yards downstream. Radio-tagged dead fish are also passed through the turbines to reveal movement or non-movement of mortalities (Stier, 1983T).

An unexplored area of this technique is the effect of the tags themselves on fish. In one test (Stier 1983T), fish with dummy tags were held in static water overnight without mortality. This leaves some unexplained items, however. In order to more thoroughly determine these, the following tests would be desirable.

- Compare turbine mortality indicated by radio-tagged fish with that of accepted methods using tattoos, clipped fins, freeze branding, etc., in direct or sampling programs at a given site and time.

- Test relative effects on fish of radio tags compared with those of dummy duplicates. Passage of radio waves through fish probably has no deleterious effect, but this should be established.

Until such research is completed, results from radio tagging will probably be regarded as tentative or qualified.

Balsa Box Enclosures. A few experimenters, Monten (1955T) and McGrath and Twomey (1959T), have enclosed fish in small balsa wood boxes which were then passed through turbines. Control fish in similar boxes were released in tailraces. The boxes were weighted to neutral buoyancy in water with lead shot attached by paper or soluble glue so that the shot fell off after a short exposure to water. The boxes would then float to the surface where they could be retrieved with dip nets from boats in the tailrace area.

This system offers quick pickup of individual fish and is relatively inexpensive if manpower to carve the boxes and fit the fish and weights to them is not too costly. The principal disadvantage is the time involved in preparing the boxes as well as the uncertainty of the degree of protection from turbine impacts that the boxes may give fish, thus affecting results. This method has not been used nor evaluated sufficiently to permit judgement on its relative worth.

Floating Tags. In some turbine tests, fish have been fitted with small styrofoam floats. After they have passed through the turbines, the colored floats raise the fish to the surface of the tailwater area, where they can be dipnetted from boats and examined for injuries (Daugherty, 1969T).

This system is inexpensive and can be quickly done for gross indications; however, it is an uncontrolled type of experiment that appears to give only crude and imprecise results.

The effect of the tags themselves on fish passing through turbines has apparently not been established. Such tags could exacerbate impacts. This could be tested by comparing survival of float-tagged fish with those marked by proven methods such as clipped fin marking, tattoos, branding, etc., in simultaneous passage through a turbine and downstream recovery.

Gossamer Bags. A few turbine studies have employed the gossamer bag method in which fish encased in bags of fabric such as cheesecloth are passed through turbines (McKernan, 1940T). They are floated to the surface of the tailrace by various methods such as a balloon that inflates after exposure to water. This system, after trials in the 1940's, has not been favored by researchers as is indicated by its sparcity of use. The bags themselves have been thought variously to either increase or reduce mortality.

FACTORS AFFECTING ACCURACY OF RESULTS IN TURBINE MORTALITY STUDIES

Fish Species

Species of fish vary greatly in frailty and susceptibility to damage in turbines. Tests have shown that salmonids, particularly rainbow trout, are among the most durable. Salmonids have also been the subject of more turbine tests than most other species, largely because they are most affected by hydroelectric plants in the paths of their migration. Tests in a Kaplan turbine on the Connecticut River found Atlantic salmon smolt mortality averaging about 10%; whereas juvenile clupeids averaged about 70% (Kynard, et al, 1982T). Gloss et al (1982T) found mortalities of Atlantic salmon and steelhead trout in two New York State Ossberger turbines averaging about 50%; whereas those of striped bass and American shad approached 100%. In tests of pressure effect exclusively of up to 300 psi in transparent holding tanks, Foye and Scott (1965A) found no mortality in Atlantic salmon, lake trout, and fallfish but deaths ranging from 20% to 100% in yellow perch, pickerel, and shiners. No evidence suggests that different salmonid species or races of the same size have different mortality rates. However, various species may move downstream at different depths in streams and reservoirs, which may affect relative susceptibility to turbine damage because of levels of travel vertically through the penstocks (Long 1968A).

Fish Size

In almost all turbine mortality tests in which size has been an observed parameter, it has been found that smaller fish survive at a higher rate than do larger ones (Ruggles, 1980A). The phenomenon seems related to discriminate mechanical contacts.

Condition

Fish condition can be a significant factor in mortality. In some tests, fish have been transported for hours in a truck tank to be put through turbines almost immediately. Such fish would be in poor condition to survive rigorous tests, being weakened by chemical factors such as ammonia, and possibly atmospheric gases entrained by the aeration system. Control fish mortalities under such conditions are normally so high as to render turbine test results suspect. To ensure the best possible condition, test fish should be acclimated to the water of the test area for at least 24 hours during which time they should not be fed. Recently-fed fish are more susceptible to stress (Horton, 1956A).

Gas
Dissolved atmospheric gases can be a prominent factor in fish mortality, particularly under severe conditions of subatmospheric pressure. Only test fish are affected by this factor. A small amount of gas in blood of test fish can be fatal at only small levels of vacuum which permits the gas to expand and stop heart action (Harvey, 1963A; Rucker, 1972A; Ruggles, 1980A).

Temperature
Temperature is a prominent factor, usually affecting both test and control fish. Some instances of heavy control mortality have probably resulted from high temperatures. Higher than normal temperatures add an additional and unmeasurable stress to test fish and, if control fish mortalities are large, test results become questionable (Ruggles, 1980A). Temperature can also affect predation by fish. At low temperatures, predation declines (Horton, 1956A).

Test Procedures
Procedures for handling test and control fish before and after tests are important. To eliminate or alleviate the effects of such things as dissolved gas, the fish should be held in test water for a sufficient period of days before testing to allow dissipation of the gas (Wedemeyer, 1972A). Fish should not be fed for at least one day before testing, and care should be exercised in use of anesthetics when test and control fish are examined following a test.

Controls
In all turbine mortality tests, proper use of control lots of fish can be critical. The theory of experimental design involving controls dictates that these fish be as similar to test animals as possible, preferably from the same batch divided into similarly-sized lots. Control fish should experience the exact circumstances, impacts, duration of exposure and other factors affecting test fish with the one exception of exposure to the turbine (Cox 1958A). This includes exposure to the

same pressures, turbulence and water chemistry in the forebay and tailrace, predatory birds, mammals and fish, temperature, handling, recapture stress, marking, transportation, and other procedures. It is usually deemed advisable to employ a third lot of fish other than basic test and control fish to use as a standard against impacts affecting those two groups. Such fish are held separately and subjected only to the holding experience in water identical to that of the test and controls. This permits assessment of non-test impacts. The point at which control mortality exceeds limits affecting test accuracy is sometimes difficult to judge. In some tests, control mortality has exceeded 75%.

Many early turbine mortality tests used no controls, and frequent arguments over test validity resulted. This is still a vulnerable point of many tests in which use of control lots has been inadequate.

In the case of large net recapture, an often-overlooked test-control lot phenomenon results. Test fish emerge from the draft tube directly into the net. Control fish are also introduced directly into the net entrance. The assumption is made frequently that the difference between test and control fish mortality adequately measures turbine survival. According to Bell, et al (1967R) it does not, because the test fish are subjected to additional stress beyond that of the turbine. The controls suffer a stress from the net that may be insufficient to cause mortality, and similarly the test fish may not experience turbine stress sufficient to cause mortality, but the additive impact from both sources could be sufficient to kill the test fish. Unfortunately, this source of error is impossible to quantify or compensate for and is a major shortcoming of this type of test. Bell et al (1967R) also indicate that in this method the control correction cannot accurately measure turbine loss by simply subtracting control from test losses. Such a process ignores the fact that some killed fish may not reach the recovery gear to be included in the total. Instead, the formula to adjust for overall survival of the test lot is:

$$\frac{S\ (\text{over-all})}{S\ (\text{control})} = S\ (\text{turbine effects only})$$

where S (over-all) is the fraction of live test fish recovered

S (control) is the fraction of live controls recovered

S (turbine effects only) is the fraction surviving without recovery losses.

In sampling studies involving downstream or delayed recapture of test and control fish (including adult returns), the degree to which control fish duplicate behavior of test animals is quite important. Validity is affected by the relative speed of travel, because if the two groups are not adequately mixed and are in different locations at given periods of time in their travels, they could encounter different environmental conditions (water quality, predation, food supply, etc.) affecting survival. Moreover, if one group moves substantially slower than the other, it could suffer greater natural loss because of longer exposure to lethal agents (Schoeneman and Junge, 1954T). Passage through areas of food production or predation can be affected by time of day, sunshine, turbidity, temperature, or movements by predators. Perfect mixing, unfortunately, is difficult to achieve.

Marking

Methods of marking the fish are important. Fin excision is critical in choice of combinations used which may variably affect swimming ability or health. Most turbine studies use temporary marks such as tattoos, partial fin removal, dyes or brands which are thought to be indiscriminate in effect (Schoeneman et al, 1961T). Long-term studies such as those involving adult recoveries, must use permanent identification such as coded wire tags or complete fin excision.

Disease

Disease normally is not thought to be an important factor unless it is present immediately prior to testing and leaves the fish in a vulnerable condition at the time of a test (Ruggles, 1980A).

Pressure Variables

Pressure and its effect on internal organs such as the swim bladder can be important in some instances. Some evidence indicates that fish acclimatized to high pressure of deeper reservoirs are more subject to damage from sudden exposure to subatmospheric pressures than are those suddenly taken to turbine depths from the water surface (Lucas, 1962R). Identification of this factor or adjustment for it in tests is difficult.

Predation

Predation by birds, fish, and mammals can affect the outcome of tests, particularly if the test fish are exposed differently than are controls (Ruggles, 1980A).

Delayed Mortality

Mortality occurring after completion of turbine mortality studies is of obvious importance because it determines the final magnitude of mortalities for a given study. It is important only in the case of direct large net and fyke net recoveries close to the plant. In downstream sampling recoveries, including adult returns, it is not a factor because the time and distance between turbine exposure and collection results in recovery of swimming fish only. Delayed mortality normally occurs on a rapidly descending scale. Cramer and Oligher (1961T) at Cushman, found 82.7% of the delayed mortality occurring the first day of holding, 10.5% the second and 6.8% the third. This pattern seems to fit most studies, not only of turbine-related mortality, but also of others involving injury to fish.

Injury Identification and Classification

A number of exploratory type turbine studies have classified injury by source. By the nature of such studies and the fact that it is impossible to view injury taking place, such classifications are the result of assumptions and educated guesswork. Aggravating this problem is the fact that frequently the same injury type is assigned to more than one source. Bulging and protruding eyes have been attributed to mechanical, pressure and shear effects. Torn operculi have been assigned to shear and mechanical sources. Internal hemorrhaging has been indicated as a handling, cavitation, pressure, mechanical and recovery net effect. Decapitation and body severance has been assigned to mechanical and shear sources. Clearly, better identification of injury by source is highly desirable.

Variability of Mortality Levels From Unidentified Sources

Examination of turbine mortality study results show a wide unexplained variability in results in exploratory types involving many replications at a single plant and under the same conditions. This variability has been prominent in the Corps of Engineers model studies and at Cushman, Shasta, and Foster Dams. The fact that such widely varying results are obtained when various component factors can be held constant casts doubt on the validity of many informational types of studies in which only one or two experiments are performed.

Study Bias

It seems clear that the type of study; that is, informational versus exploratory, tends to bias mortality figures. Other things being equal, exploratory designs normally show higher average mortality levels than do informational types. The reason is fundamental. Informational studies normally are conducted in a turbine or turbines at plants operating under conditions that fish management agencies feel are typical of times of downstream migrations. These include fairly full load, favorable wicket gate openings and efficiency, and relatively high tailwater levels, all of which favor low mortality.

Exploratory studies, on the other hand, aiming at discovery of reasons and factors influencing mortality, usually explore a range of conditions ranging from those expected to be least favorable to the best. The average results can thus be expected to show greater mortality than do results of informational tests. We have used the average result for the representative exploratory figure in comparisons, realizing that this indicates higher mortality levels than would be shown by informational studies of the same sites.

Design Peculiarities

Given the fact that all turbines of a type are not identical in design or manufacture, it should follow that differences can cause varying fish mortality rates for turbines otherwise the same with respect to head, flow, tailwater level in relation to runner elevation, runner speed or similar facets. Basically identical types frequently display differences in efficiency and power production. Some older Francis units had efficiencies of less than 80 percent. Those manufactured within the last 30 years are significantly improved in this respect. Different types of turbines, particularly Francis, have varying routes through which the water enters the turbine. This could affect injury incidence and severity. Design and operating variance places additional hazards on prediction of mortality levels from a given turbine type operating at given flows, heads, tailwater levels, and other constants.

DISCUSSION OF REPORTS REVIEWED

Turbine Mortality Research Reports

These publications describe studies made by various researchers of the effects of turbines on fish passed through them. Sixty-four studies involving about 30 plants have been reviewed and critiqued for methodology, adequacy of data, environmental factors, site and turbine characteristics and results. Some turbines have been the subject of a number of studies involving different species and time periods. Table 4-1 provides the principal data of interest to turbine passage for 14 Francis and 12 Kaplan units that have been used in discussions and data analysis. Table 4-2 is a matrix of types of information found in the studies examined. Descriptions of these studies are contained in Section 7 as an annotated bibliography. Table 4-3 provides a list of items that ideally should be recorded in conjunction with turbine mortality studies. Appendix A presents critiques and ratings of the 64 studies reviewed.

Table 4-1

DATA AVAILABLE ON FACTORS AFFECTING TURBINE MORTALITY FROM SPECIFIC SITES

FRANCIS UNITS

Plant	Head		RPM	Peripheral Velocity		Runner Diameter		Runner Elevation Above Tailwater		Average Percent Estimated Mortality
	Ft	Mtrs		Ft/s	Mtr/s	Ft	Mtrs	Ft	Mtrs	
Baker	250	76	300	80	24	5	1.5	- 5	-1.5	31
Cushman	450	137	300	108	33	6.9	2.1	11	3.4	41
Elwha	104	32	300	59	18	4.9	1.5	14	4.3	10
Faraday	120	37	360	62	19	3.3	1.0	10	4.0	4
Glines	194	59	225	86	26	7.7	2.3	7	2.1	36
Leaburg	89	27	225	88	27	7.5	2.3	11.9	3.6	17
Lequille	387	118	519	121	37	4.5	1.41	6.5	2	48
North Fork	136	41	139	82	25	9.7	2.95	5	1.5	26
Publishers	42	13	300	47	14	3	91	23	7.1	13
Puntledge	340	104	277	103	31	7.1	2.2	2	0.6	33
Ruskin	124	38	120	78	24	12.4	3.8	10	3	10
Seton Ck.	142	43	120	95	29	12	3.7	16	4.9	9
Shasta	410	125	138	111	34	13	4	3	0.9	39
Sullivan	42	13	240	64	20	6.2	1.9	23	7.0	20

KAPLAN UNITS

Plant	Head Ft	Head Mtrs	RPM	Peripheral Velocity Ft/s	Peripheral Velocity Mtr/s	Runner Diameter Ft	Runner Diameter Mtrs	Runner Elevation Above Tailwater Ft	Runner Elevation Above Tailwater Mtrs	Average Percent Estimated Mortality
Big Cliff	90	27	163	53	16	12	3.7			14
Bonneville	60	18	75			23	7.0			9
Foster	101	31	257	112	34	8.3	2.5	7	2.1	8
Gold Hill	20	6								8
Hadley Falls	51	16	129			14.2	4.3			18
Model UBC	50	16	2800	117	36	0.8	0.24	7	2.1	38
Sullivan	42	13	240					19	5.8	10
Tobique	75	23				8.7	2.7	-17	-5.2	18
Tusket	20	6				6	1.8	0	0	19
Walterville	56	17				10	3.8	0	0	9
Wells	65	20								16
Rock Island	40	12	86	103	31	23	7	-32	-9.8	5

Table 4-2

TURBINE TEST INFORMATION PROVIDED BY STUDIES

STUDY	Turbine size	Runner speed	Peripheral velocity	Turbine type	Horsepower	Flow quantity	Number of blades	Runner elevation above tailwater	Plant sigma	Head	Runner diameter	Efficiency	Space between blades	Blade tip clearance	Mortality	Injury types	Wicket gate opening	Environmental data
Ruskin	x	x		x	x			x		x	x		x		x			x
Hadley (Stier)	x	x		x	x	x				x	x	x			x		x	
Hadley (Anon)				x														
Foster	x	x	x	x	x	x	x		x	x	x	x			x		x	
Faraday (Clark)	x	x	x	x		x		x		x	x				x			
Lequille	x	x	x	x	x	x	x	x		x	x		x	x	x	x	x	
Hadley (Bell)	x				x	x				x					x			
Turners Falls															x			
Shasta	x	x	x	x	x	x		x		x	x				x	x	x	
Vernon (Daugherty)															x		x	
Faraday (Eicher)	x	x	x	x		x				x	x							
Colliersville	x			x	x	x				x			x	x	x			
North Fork	x	x	x	x	x	x		x		x	x				x			
Merrimack	x	x	x	x	x	x				x	x				x			
Hadley (Taylor)	x	x		x	x	x					x				x			
Crown Z. Willamette	x	x		x	x	x		x		x					x			x
Sullivan	x	x		x	x	x		x		x					x			x
Publishers	x	x		x	x	x		x		x	x				x			x
River Erne	x			x	x					x								
Dryden															x			
Leaburg	x			x	x	x				x					x		x	
Stayton	x	x		x	x	x		x		x					x			
Walterville	x	x		x	x	x				x					x		x	
Gold Ray	x			x	x	x				x					x		x	
Gold Hill	x			x	x	x				x					x			
Elwha	x	x	x	x	x	x		x		x				x	x			
McNary	x	x		x	x	x				x	x				x			
Tusket		x		x	x					x					x			
Bonneville (Weber)	x	x		x	x	x				x					x			
Wells	x			x	x				x	x					x			
Glines	x	x	x	x	x	x				x					x			
Cushman	x	x	x	x	x	x		x		x	x				x			
Rock Island	x	x	x	x	x	x		x		x	x				x			
Bonneville (Holmes)	x	x		x	x	x				x	x		x		x			
Seton Creek	x	x	x	x	x	x		x		x	x		x		x	x		x
Baker	x	x	x	x	x	x		x		x	x		x	x	x			
Montala	x	x		x						x	x				x			
Tobique	x							x		x	x				x			
UBC Model	x	x		x		x	x	x		x	x	x	x		x	x	x	

Table 4-3

TURBINE MORTALITY STUDY FACTORS*
RECORDED IN TESTING

Turbine Parameters	Biological Parameters
Name of plant	Test number
Turbine type	Date
Manufacturer	Time of day
Name plate horsepower	Water temperature
Number of blades	Turbidity
Rated head	Percent saturation of atmospheric gases
Turbine number (in plant)	Air temperature
Approximate Q at rated output	Cloud cover -- percent
Approximate Q during test	Recapture method
Design specific speed	Species of fish
Runner diameter	Source
Maximum	Age
Inlet	Condition
Outlet	Fork length
Clearance between blades	Average
Maximum	Minimum
Minimum	Maximum
Cavitation normal to plant	Number of test fish
Cavitation at time of test	Condition of test fish
Actual specific speed	Number recaptured
R.P.M.	Number of immediate mortalities
Peripheral runner velocity	Apparent causes of mortality
Critical sigma	Delayed mortalities
Plant sigma	Time held after test
Head during test	Number of injuries by type
Centerline runner elevation	Causes of injuries
Tailwater elevation during test	Number of control fish used
Percent wicket gate opening	Number of control mortalities
Percent efficiency	Release site of test fish
Load during test	Release site of controls
	Predatory animals noted

* It is normally found that many of these items are not available. If the investigators record as many as possible, however, future value of the study is enhanced.

Turbine Mortality Reviews

A large body of literature in the field of turbine-related fish mortality is contained in review-type papers. Typical of this is a paper presented at a conference. A paper may review much of what was known at the time of its writing on subjects such as cavitation damage to fish, the effects of dissolved gases on fish mortality in turbines or turbine-related fish mortality in general. Papers of this type usually review a number of studies bearing on the subject presented. They are frequently useful as sources of varied information on a single factor in turbine passage. These reviews are contained in an annotated bibliography as Section 8.

Ancillary Studies

Studies of an ancillary nature are of considerable value to the evaluation of studies of turbine-related fish mortality. These publications reference such things as descaling, gas embolism, design of experiments, and effects of pressure on fish. Referenced frequently in this report, these are included in the annotated bibliography of Section 9.

SUMMARY OF FINDINGS WITH RESPECT TO ACCURACY OF STUDIES

- Variability in study results is too great to permit precise estimates for any one study.
- Reasons for variable study results probably include unmeasurable factors such as test fish condition, environmental and operational subtleties and the general difficulty of coping with unknown conditions in the field.
- Even relatively closely controlled model experiments often produce unexplained variability.
- Almost all studies have suffered from major reporting deficiencies concerning variables affecting test accuracy. The greatest single

oversight is with respect to environmental data, followed by deficiencies in control techniques.

- The commonly accepted theory that direct and downstream sampling methods of testing produce comparable results may not be accurate. Sampling studies tend to indicate greater mortality than direct methods where both have been used at the same site. This could be due to predation and other delayed effects that are not adequately treated in direct methods.

- A major problem with studies of turbine effects on fish is the inability to view fish as they pass through units and thus learn their travel routes and interaction with various effectors of injury.

Section 5

RELATIVE IMPORTANCE OF FACTORS AFFECTING TURBINE PASSAGE OF FISH* AS SHOWN BY EXAMINATION OF TEST DATA

TURBINE TYPE

Most reviewers of turbine test data (Bell, et al 1967R; Cramer and Oligher 1960T; Ruggles 1980A; Eicher, 1970R; Eicher Associates 1985R; Loar 1982R; Gloss 1982R; Lucas 1962R; Turbak et al 1981R; and Von Gunten 1960R) agree that at similar heads, runner elevations above tailwater, and speed, essentially no difference in total mortality levels exists between Kaplan and Francis units in tests of the same species of fish. Because Kaplan units tend to be sited with the runner centerline lower with respect to tailwater, their indicated mortality level as a group tends to be lower. Much remains to be understood about this factor, however. Two tests (Olson and Kaczynski 1980T and Knight and Kuzmeskus 1982T) indicate that bulb turbines probably produce less mortality than do Francis or conventional Kaplan types. Gloss, et al (1982T) found mortalities in Ossberger turbines that were greater than averages for other types. Tube types have not been tested.

Until work cited in the Bell Compendium (Bell et al 1967R) became common knowledge, it was generally believed that Francis units were inherently more damaging than Kaplan types because mortality tests seemed to show this. Even as late as 1974, some biologists were ascribing heavy fish damage to some untested plants because Francis units were involved (Clark, et al, 1974T). Findings of researchers cited in the Compendium, and particularly model work by Cramer and Oligher (1960T) concluded that although Francis units did tend toward greater mortality incidence,

*Section 3 briefly describes these factors.

this was due to siting rather than turbine design. Examination of characteristics of various test sites shows that Francis units characteristically are designed and sited with high heads, fast runner speeds and runners high above tailwater. Kaplan turbines, on the other hand, tend toward low heads (under 100 feet <30 m>), low shaft speeds and with the runner low with respect to tailwater levels, all items bearing on fish survival. In studies which compared the two types under similar conditions (Cramer 1960R and Cramer and Oligher 1961T), Francis and Kaplan 12 inch (30 cm) runner models tested with fish at varying runner speeds of from 100 to 1400 rpm, heads from 5 feet (1.5 m) to 45 feet (14 m) and tailwater levels from runner centerline of plus 15 and 20 and minus 10 and 20 feet, mortality of test fish was essentially the same for both models. Prototype studies are less amenable to comparison because of differences in siting characteristics. Although it is possible to have the same conditions for Kaplan and Francis turbines at a given site, in practice, they are usually different.

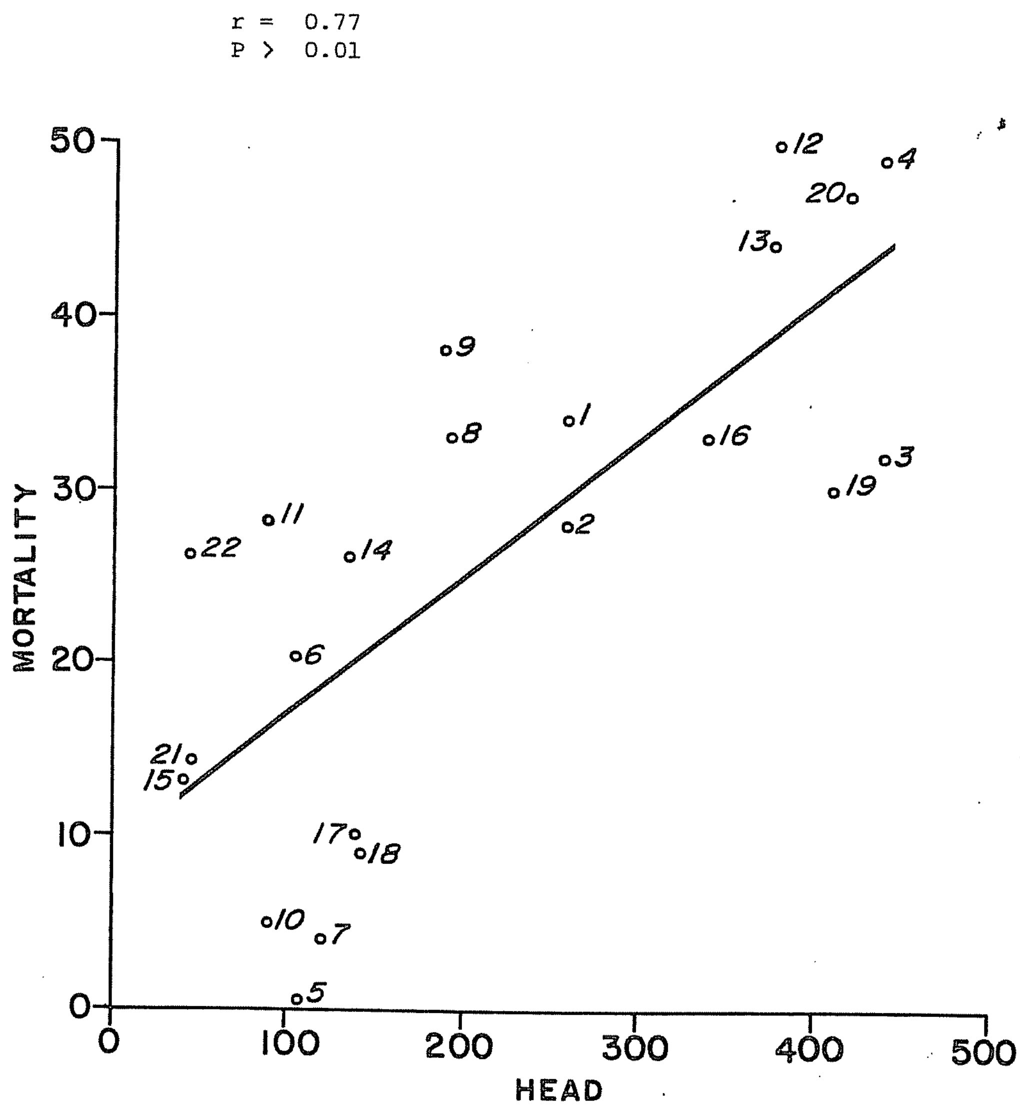
HEAD

Head does not seem to be a determining influence in turbine mortality. Cramer and Oligher (1961T) state that their work at Cushman No. 2 plant indicated that for heads of up to 470 feet (143 m) hydraulic head was not a significant factor; however, Cramer (1960T) shows in model tests progressive mortality in heads ranging from 5 feet (1.5 m) to 45 Feet (14 m). The mortality progression was from 4 to 66% in the Kaplan and from 7 to 52% in the Francis model. Unfortunately, the relationship is masked by shaft speed that was concurrently increased from an already high 500 to 1400 rpm in the Kaplan and from 313 to 939 rpm in the Francis. Negative pressures were also involved but not evaluated (Bell, pers. comm., 1986A).

In prototype, two well-tested sites can be compared. One is Willamette Falls on the Willamette River in Oregon where a number of Francis units were tested for mortality of steelhead trout and chinook salmon in 1960 and 1961 (Massey 1967R). Under nominal head of 41 feet (12.5 m) and optimum operating conditions, five tests yielded mean mortality rates for steelhead and chinook of 20.3% and 18.0% respectively. The range of steelhead mortality was from 12.1% to 30.4% and for chinook from 12.6% to 28.4%. Similar tests were pursued at Shasta Dam on the Sacramento River in 1962 also with Francis turbines but at heads of 408 and 430 feet (124-131 m) (U.S. Army Corps of Engineers 1963T). These included 38 tests with steelhead and 33 with chinook. The mean mortality rates for steelhead and chinook were 13.7% and 20.5%, respectively with a range in steelhead of 8.6% to 62% and for chinook, 9.7% to 50.5%. The range of mortalities is much less for Willamette Falls than for Shasta because those tests were performed under optimum conditions only, whereas the Shasta exploratory tests were conducted under conditions varying from worst case to optimum. Thus, the mortality levels were similar for the two plants with vastly different heads. U.S. Army Corps of Engineers data (Bell and Bruya 1981T) for Foster Dam studies, show an inverse relationship between head and mortality at two levels tested of 86 feet (26 m) and 110 feet (33.5 m), but it was felt by the authors that the difference was mostly the result of efficiency variations. At heads lower than the 101 foot, design optimum for that turbine, efficiency was sacrificed to produce the desired energy level.

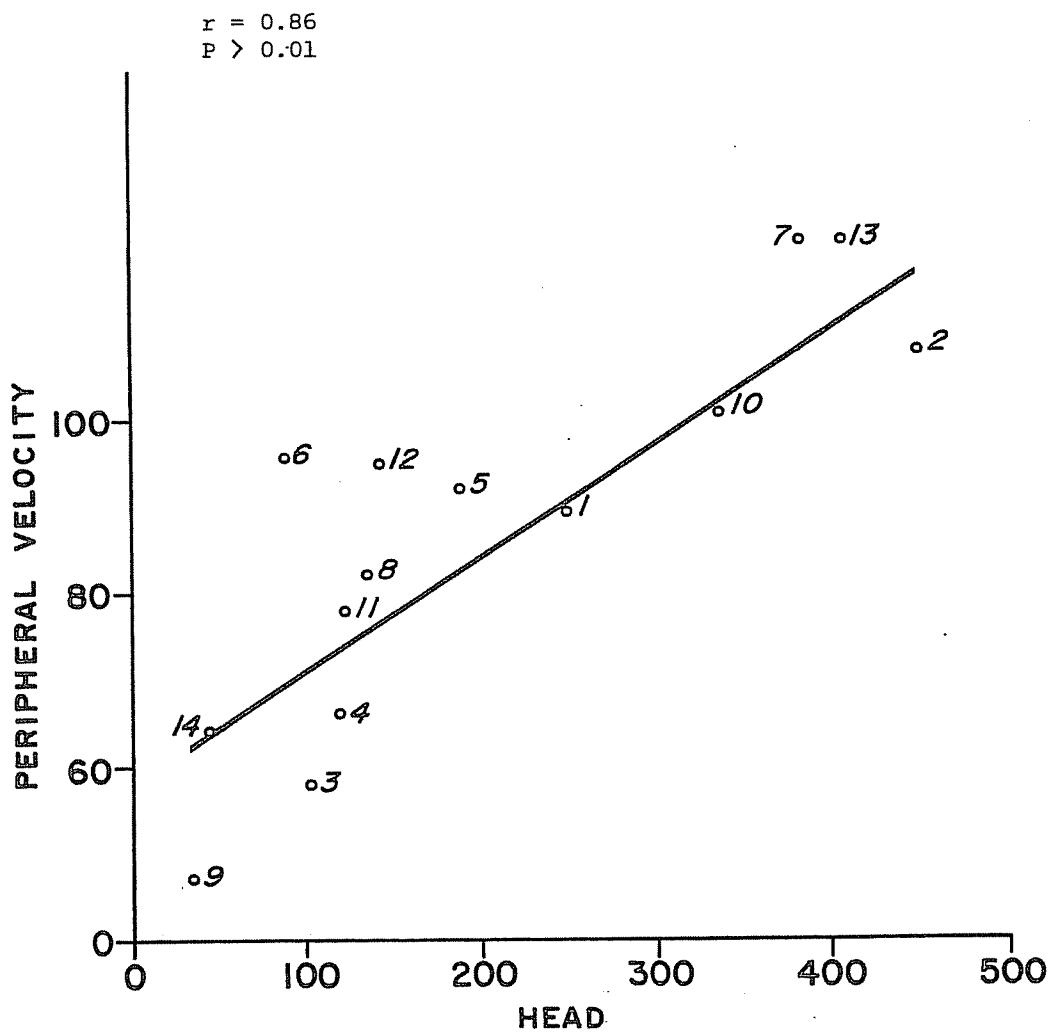
If head is plotted against mortality for Francis units a strong correlation is evidenced (Figure 5-1). It must be realized, however, that in this turbine type, peripheral runner velocity is also strongly influenced by head. Figure 5-2 plots head against peripheral velocity. This plot shows an even stronger correlation than for head versus mortality with a coefficient (r) of 0.86. It will be shown later that a similar correlation exists between mortality and peripheral velocity of Francis turbines. In design and siting of Francis turbines, head is important because it determines velocity of water against the runner blade which also influences design to take advantage of this. The usual result is faster moving runner peripheries at higher heads to match higher water velocities.

If head alone were a determining factor, the effect would be one of pressure, which would be the same for any turbine type. The fact that head in itself is not



1.	Baker	steelhead	9.	Glines	1983		17.	Ruskin	
2.	Baker	coho	10.	Leaburg	1954		18.	Seton Creek	
3.	Cushman	1960	11.	Leaburg	1980		19.	Shasta	January
4.	Cushman	1962	12.	Lequille	1980		20.	Shasta	November
5.	Elwha	1954	13.	Lequille	1982		21.	Sullivan	chinook
6.	Elwha	1985	14.	North Fork			22.	Sullivan	steelhead
7.	Faraday		15.	Publishers					
8.	Glines	1954	16.	Puntledge					

Figure 5-1 Relationship of head to mortality Francis units.



1. Baker
2. Cushman
3. Elwa
4. Faraday
5. Glines
6. Leaburg
7. Lequille
8. North Fork
9. Publishers
10. Puntledge
11. Ruskin
12. Seton Creek
13. Shasta
14. Sullivan

Figure 5-2 Relationship of head to peripheral velocity Francis units.

a determining factor in mortality is shown by Figure 5-3 which plots head against Kaplan turbine mortality. Obviously, no relationship exists. It seems clear that head per se is not a determining factor. It can be seen that in some cases of more than one test at a plant, the points on the plots for these are separated. Some of these differences can be explained; others not. Appendix B discusses discrepancies.

RUNNER ELEVATION ABOVE TAILWATER

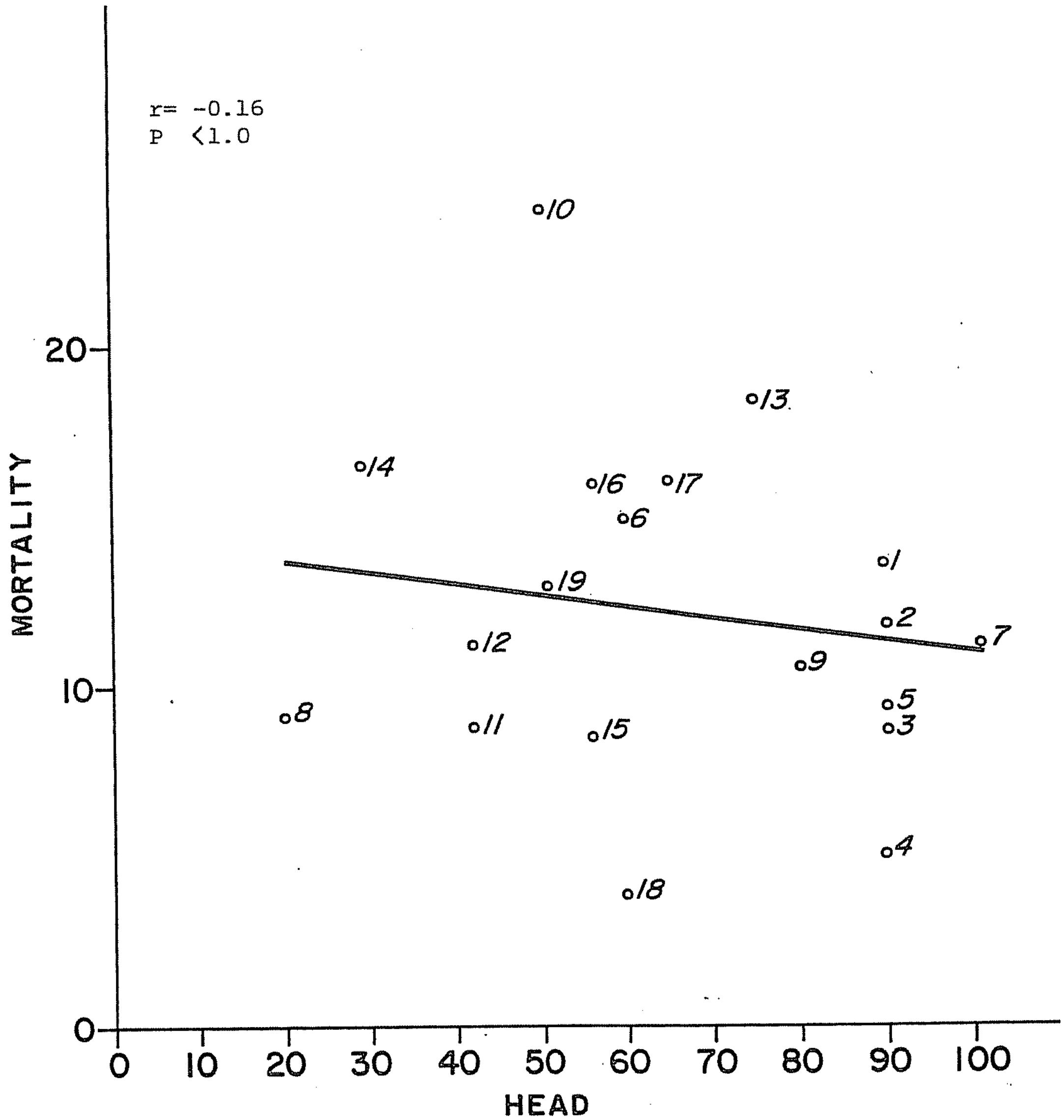
Elevation of the runner centerline in relation to tailwater surface has long been considered a determining factor in survival of fish passing through turbines. This parameter influences pressures under the turbine blades. Head for power is subtracted by the runner, sometimes resulting in pressure below atmospheric as the water leaves the runner and enters the draft tube. Subatmospheric pressure can cause cavitation. It is generally believed from turbine test indications (Bell et al., 1967R) that mortality can also result from subatmospheric pressure short of cavitation. Cramer and Oligher (1961T), in model studies, found that as tailwater was lowered in successive stages in relation to the runner centerline elevation, mortality of test fish occurred before the point of cavitation was reached.
In tests with one runner design and holding other factors constant, the following was found:

- Mortality increased 3% when tailwater level was reduced from plus 15.0 feet (4.6 m) to plus 2.0 feet (0.6 m)

- Mortality increased 6% when tailwater level was reduced from plus 2.0 feet (0.6 m) to minus 10.0 feet (3.0 m)

- Mortality increased 10% when tailwater level was reduced from minus 10.0 feet (3.0 m) to minus 20.0 feet (6.0 m)

The same investigators also found similar relationships between tailwater level and mortality in prototype studies at Cushman and Shasta, as did Ruggles and Collins (1981T) at Lequille.



1. Big Cliff 1957
2. Big Cliff 1964
3. Big Cliff 1966
4. Big Cliff 1967 CH
5. Big Cliff 1967 ST
6. Bonneville 1940
7. Foster
8. Gold Hill
9. McNary
10. Model UBC
11. Sullivan chinook
12. Sullivan steelhead
13. Tobique
14. Tusket
15. Walterville 1954
16. Walterville 1983
17. Wells
18. Bonneville 1954
19. Holyoke

Figure 5-3 Relationship of head to mortality Kaplan units.

CAVITATION

This effect has long been known to cause mortality to fish passing through turbines. Because of the drastic forces prevailing in cavitation areas, sufficient to remove metal from turbine blades and other metal areas, fish entering them are subject to damage. As reported under the section covering runner elevation, mortality also occurs at subatmospheric pressures short of cavitation levels. It has not been clearly established that appearances of affected fish are significantly singular to identify cavitation mortality by visual reference. Cavitation effect on a tested population is discriminate and selective to those individuals that by chance enter cavitation zones. Such zones are shown by model tests and damage evidence to occupy a limited proportion of a turbine interior. It is clear at least from the model studies showing mortality response to variation in this factor that cavitation damage can and does occur, but it is difficult, if not impossible, to quantify with evidence presently available.

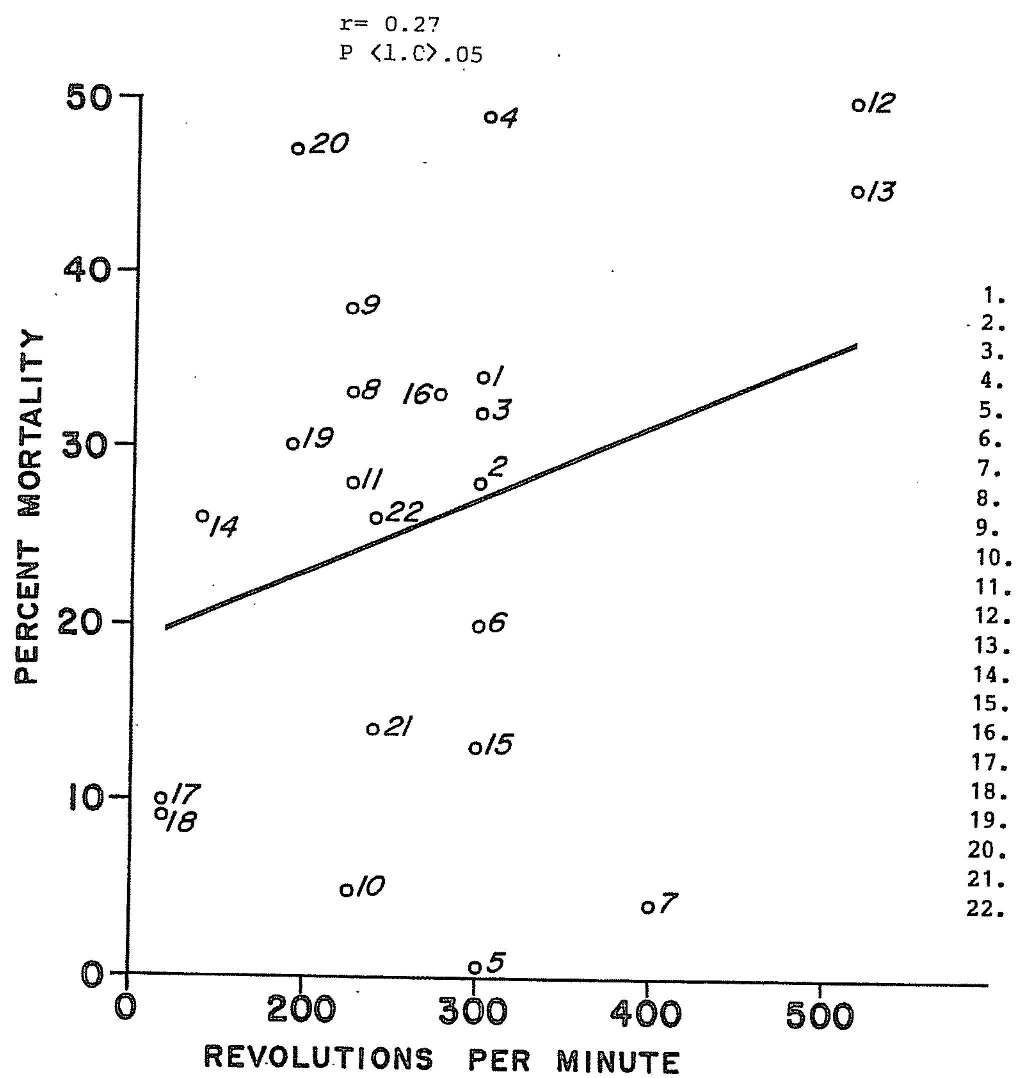
EFFICIENCY

Almost all investigators and reviewers in this field have concluded that least mortality occurs when turbines operate at best efficiency (Bell, et al, 1967R; Cramer and Oligher, 1960T; Ruggles, 1980A; Eicher, 1970R; Eicher Associates, 1985R; Gloss, 1982R; Lucas, 1962R; and Von Gunten, 1961R). No other facet seems to enjoy such a degree of unaninimity. Inferentially, this means that some other allied factors are equally important, because efficiency alone does not affect fish. Fisher and Cybularz (no dateA), in examining the effects of efficiency on cavitation of Kaplan runners, concluded that, under common design conditions resulting in best efficiency and least leakage past the blades, the least amount of cavitation occurs. Fisher and Donaldson (no dateA) in exploring cavitation of Francis turbines concluded that, under conditions of design head and load, best efficiency and least cavitation results. Since efficiency is strongly linked to both cavitation and fish mortality, the conclusion seems obvious that cavitation or subatmospheric pressure short of cavitation is the major source of mortality affected by efficiency. As noted previously, Cramer and Oligher (1961T) clearly show this in model studies (see page 5-7). The prototype studies we have examined unfortunately do not lend themselves to such comparisons because few include sufficient data involving efficiency or related items such as wicket gate openings over a range of studies. Only the Corps of Engineers studies and those by Ruggles and Collins (1981T) at Lequille explore this sufficiently to provide definitive results. The Corps of Engineers Shasta work (U.S. Army Corps of Engineers, 1963T), however, is quite productive.

RUNNER SPEED AT SHAFT AND PERIPHERY

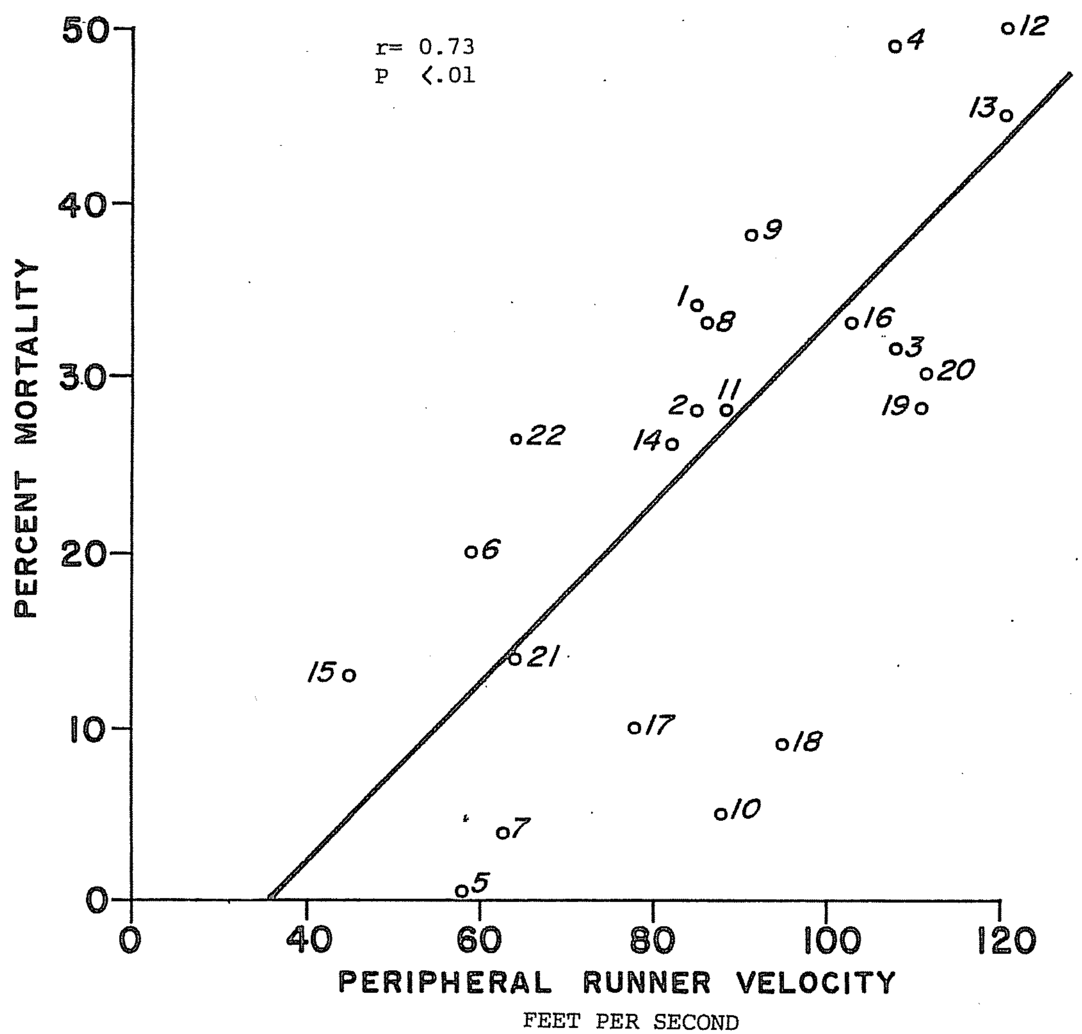
These two factors are closely related, particularly in the case of the same or similarly sized runners. Peripheral velocity is of major concern in the case of Francis units and seems to be the principal variable affecting mortality in this turbine type. It is of no demonstrated importance in Kaplan types. In a Francis turbine, initial contact of fish with the runner, if it occurs, is at the periphery because this is where they enter the unit. The wicket gates introduce them directly into the spaces between buckets of the runner. In Kaplan units, because downstream migrant fish tend to move downstream through the upper level of the intake passageway, they are believed to mostly descend in the turbine casing along the runner hub (Long and Marquette, 1967R) and contact the blades in that area as indicated by Figure 5-6.(page 5-16).

It is useful to compare the relative effects of peripheral velocity and shaft speed. Figure 5-4 is a scatter diagram showing the relationship between turbine mortality of salmonids in 22 studies of Francis units discussed in this report and revolutions per minute. As can be seen, although a slope does exist, the 0.27 coefficient of correlation is not significant at the 5 percent level. Figure 5-5 depicts the relationship in the same 22 turbine studies with peripheral velocity plotted against mortality of salmonids. This is obviously a significant relationship, as indicated by the regression line least squares fit. The r value of 0.73 betters the 1 percent level of significance. (The probability is 99 of 100 that



1. Baker -- sockeye
2. Baker -- coho
3. Cushman -- 1960
4. Cushman -- 1962
5. Elwha -- 1954
6. Elwha -- 1983
7. Faraday
8. Glines -- 1954
9. Glines -- 1983
10. Leaburg -- 1954
11. Leaburg -- 1980
12. Lequille -- 1980
13. Lequille -- 1981
14. North Fork
15. Publishers
16. Puntledge
17. Ruskin
18. Seton Creek
19. Shasta -- January
20. Shasta -- November
21. Sullivan -- chinook
22. Sullivan -- steelhead

Figure 5-4 Relationship of revolutions per minute to mortality Francis turbines.



Number Key

1. Baker -- sockeye
2. Baker -- coho
3. Cushman -- 1960
4. Cushman -- 1961
5. Elwha -- 1954
6. Elwha -- 1983
7. Faraday
8. Glines -- 1954
9. Glines -- 1983
10. Leaburg -- 1958
11. Leaburg -- 1983
12. Lequille -- 1980
13. Lequille -- 1981
14. North Fork
15. Publishers
16. Puntledge
17. Ruskin
18. Seton Creek
19. Shasta -- January
20. Shasta -- November
21. Sullivan -- chinook
22. Sullivan -- steelhead

Figure 5-5 Relationship of peripheral runner velocity to mortality Francis turbines.

the relationship is not due to chance.) Bell, et al (1967R) show a similar relationship in the Cramer and Oligher (1961T) Francis turbine model studies with an r value of 0.862 for mortality plotted against peripheral velocity in 146 tests.

WICKET GATE OPENING

The effect of wicket gate opening is different for Kaplan and Francis units. Wicket gate openings in Kaplan units are of importance only as they control unit efficiency through regulating volume of flow for a given load. In Francis units, however, wicket gates are more important. They not only control or stop flow, but also give direction to water entering the area between vanes. Additionally, they may directly influence fish mortality because in full open positions, the trailing ends of the gates may be close to the leading edges of the turbine buckets. If this clearance becomes small, it can be an important area of mortality, particularly with larger fish and higher peripheral runner speeds.

Unfortunately, in any analysis of mortality relationships concerning this factor, it is difficult to separate mortality possibly caused by wicket gate opening with such related factors as peripheral runner speed and cavitation. Wicket gate manipulation in certain exploratory studies of single operating units (Collins and Ruggles 1982T) and models (Cramer and Oligher 1961T) have demonstrated effects, but comparisons of prototype plants have not.

BLADE TIP CLEARANCE

The effect of fish exposure to openings between Kaplan turbine blades and adjacent structure can only be judged by conjecture based on knowledge of design and operation of turbine. Two clearance areas are important in Kaplan turbines. These are the gaps at both ends of the blades which are necessary if the blade is to rotate to change pitch as was shown in Figure 3-1. The degree to which this is a factor in mortality is unknown. In large Kaplan turbines in which the leading edge of the blade is 2 inches (5 cm) thick, and the radius of curvature 1 inch

(2.5 cm), the fish may be shunted aside by a static boundary layer without striking the blade. Other openings are large, leaving the gaps noted above at each blade as the only logical area for fish damage (Long and Marquette 1967R). Unfortunately, this gap is frequently of a size likely to permit entry of fish; that is, roughly the size of the fish encountered. In the case of the distal end of the blade, the potential for damage is seemingly great because not only are fish reaching this point likely to be drawn into the gap by the high velocity leakage, but the movement at that point insures that they will be ground between blade and wall. Additionally, the leakage encourages a discrete area of cavitation under the blade tips. It seems safe to assume that fish entering this gap are destroyed.

The potential for mortality occurring at the hub end of a Kaplan turbine blade is considerably less. Many Kaplan turbines do not have a gap at this point. Unlike the distal end of the blade, which has the potential to grind the fish between the blade tip and the surrounding ring, little interaction between components occurs here. The only movement involved is the occasional twisting of the blade to change angle. This is so slight and infrequent that it can be disregarded. Localized cavitation, if it occurs, on the underside of the blade adjacent to the gap is the only probable injury source.

As mentioned previously, tests have shown that a majority of downstream migrants descend through turbine intakes in the upper levels. Leman (1959A) found that if cooling water intake pipes were extended from the roof of the spiral case of the early Rock Island Dam units down about 2 feet (60 cm), few fish would be drawn into the pipes, indicating that most were immediately adjacent to the roof. Long (1968A) experimentally determined the vertical distribution of downstream migrant chinook, steelhead and sockeye in turbine intakes at the Dalles and McNary Dams on the Columbia River using fyke nets fished at various levels simultaneously. He found that, on the average, between 60% and 75% of the fish moved through the 50 foot (15.2 m) deep penstock between the roof level and 14.4 feet (4.4 m) deeper.

About 20% traveled through the levels between 14.4 feet and 30 feet (9 m). The balance of around 10% used the levels below this to the bottom. These properties were similar at the intake end, the middle, and the downstream end of the penstock in front of the spiral case entrance at both dams. Figure 5-6 shows flow paths at these three levels in the penstock and spiral case of such a turbine. Long and Marquette (1967R) state that these paths are generally consistent and predictable. From the above, it can be assumed that about 70% of the fish reach the turbine runner at a point adjacent to the hub. About 20% approach the mid-section of the blades, and the remaining 10% arrive near the perimeter. Various studies have found mortalities in large Kaplan turbines at between 4 and 15% (Schoeneman et al. 1961T; Holmes 1942T; Weber 1954T). This seems a logical percentage range of a population which might encounter the gap at the blade periphery as indicated by the above considerations.

WATER SHEAR

Two adjacent levels of water moving at different high velocities result in a shear plane wherein fish damage is thought to occur. It is perhaps the least understood and least identifiable of fish mortality agents in turbine passage. It cannot be seen, and the areas within turbines where it could occur have not been identified. Studies involving the introduction of fish entrained in high velocity jets into pools of static water (Groves, 1972A; Theus, 1972A) have identified specific injury types. These are the same that have been attributed to other sources (popped eyes, torn operculum, severed body). Thus far, no known studies using fish have involved shear planes involving intersecting or overtaking flows. Nor have any explored the prevalence or location of shear in turbines. A passing reference is made to this in Bell and Bruya (1981T) with respect to studies of draft tube velocities at Foster Dam. It cites the Groves and Theus reports and the fact that they both found little effect at shear velocities below 50 feet per second. Because areas in which velocities exceeding such figures are limited in most turbines at medium and low heads and nonexistent at many (see

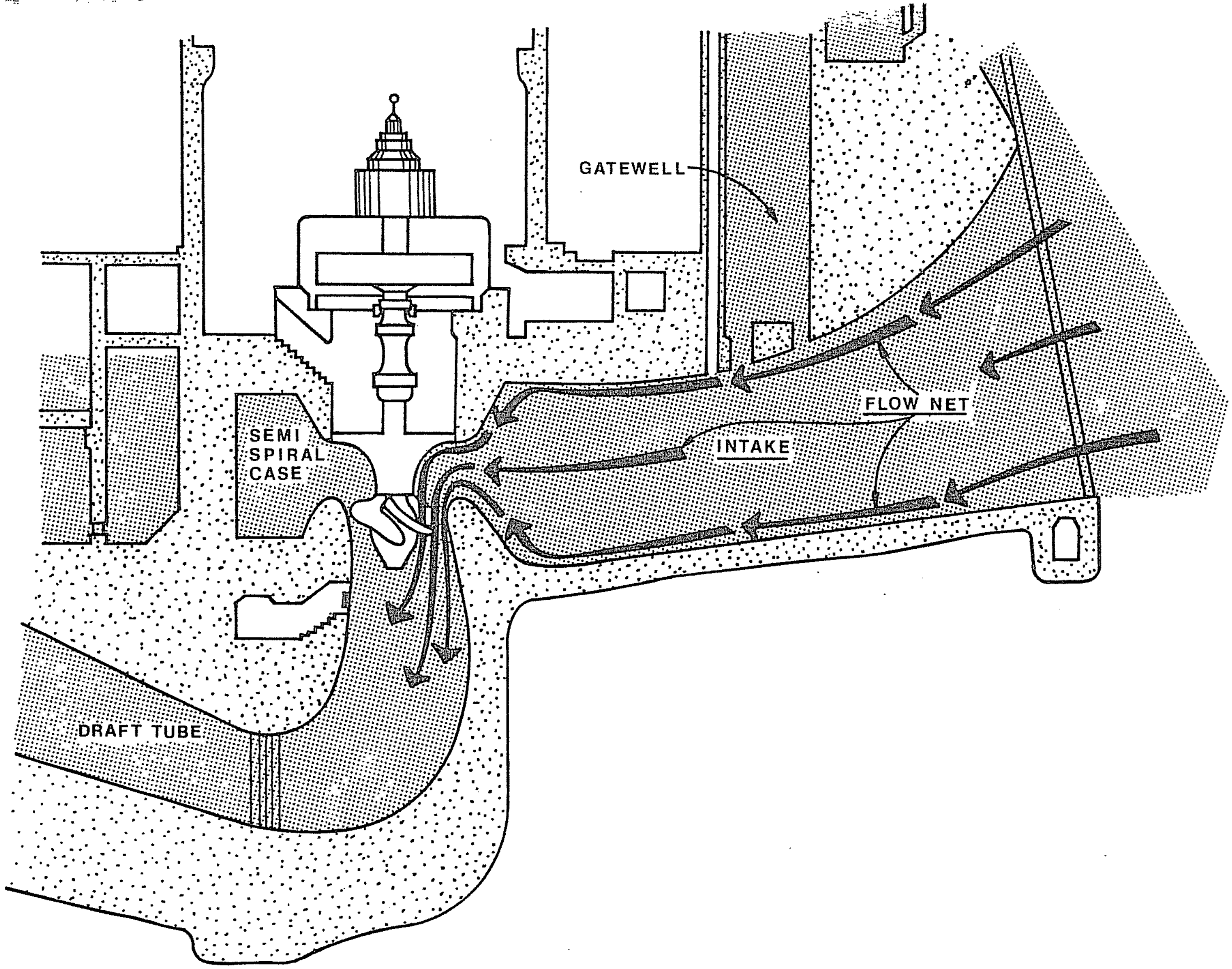


Figure 5-6 Section through large Kaplan turbine unit showing flow paths which are generally consistent and predictable. (From Long and Marquette, 1967R)

"hydraulic flows within turbines", page 2-2), this factor becomes even more difficult to quantify. The effects of blade and water entrance velocity have not been explored in experimental field work.

BACKROLL

Backroll in itself does not cause fish mortality, but fish emerging from the draft tubes and entrained in its volume are carried back upstream to a turbulent low velocity area inhabited by varying numbers of predatory fish and birds conditioned by experience to search this zone for downstream migrants concentrated there. Significant predation losses have been experimentally found in backrolls (Long, et al, 1968T). Apparently, the division of fish numbers continuing downstream in the frontroll compared to those trapped in the backroll is unpredictable and variable, as is the length of time of entrapment. Backroll results in indirect mortality in addition to that caused by turbines and makes assessment of turbine mortality at affected power plants less reliable.

FISH SIZE AS A VARIABLE AFFECTING TEST RESULTS

The size of fish used in turbine mortality tests has long been considered to be a major factor (Bell et al. 1968R). Ruggles and Collins (1981T) found in exploratory studies at the Lequille Francis unit that fish length was the most important variable affecting mortality; however, length relationships with mechanical and non-mechanical components differed. They were pronounced with respect to minimum clearances causing mechanical damage. Non-mechanical injuries, however, did not seem size related.

Wunderlich and Dilley (1985T) hypothesize that the mortality difference between zero and 20% obtained in tests at Lower Elwha Dam in 1954 and 1983 using almost identical methods results from the difference in fish size of 90 day fall chinooks and that of yearling coho. The former average about 2 inches (5.1 cm) in length and the latter 5-1/2 inches (14 cm).

Size is generally believed to influence mortality in turbine passage because smaller fish of a given species are normally less subject to damage. They are more supple and bend around protrusions that might injure larger fish. Because they are weak swimmers, they are swept passively through passages that might injure stronger swimmers able to maintain themselves in perilous surroundings longer. Perhaps most importantly, they are able to pass through narrow openings that might trap or damage larger fish.

Unfortunately, certain details combine to prevent good analysis of prototype relationships of this factor. Many of the prototype studies examined did not provide data on fish size. Where records were kept, the majority fell into two size groups of fairly narrow limits represented by fall chinook fingerling with a mean length of about 2 in. (5.1 cm) and smolt-sized migrants averaging about 5-1/2 inches (14 cm). Deviations from these means are not sufficient to affect comparisons. Thus a mathematical study with but two points results. Mortality differences by fish size are probably less in the case of large machines than in small ones. Size of fish seems logically related to mechanical damage, and of course large passageways through turbines are less likely to cause injuries than are small ones. Thus, comparison of fish size with turbine mortality in prototypes is probably obscured by differences in unit size. Insufficient studies are available to group plants by size.

This factor could be studied more effectively with one machine under a single set of conditions, but with several sizes of fish. Unfortunately this has not been effectively done thus far. Ruggles and Collins (1981T) come the closest to doing it.

FINDINGS IN ASSESSMENTS OF TURBINE EFFECT FACTORS

Injury Types

Examination of turbine mortality studies, reviews, and ancillary studies reveals that the assignment of injury sources through physical study of injured fish is less than exact. It would be helpful if injury types permitted instant identification of sources. This is not possible with available information. Injury sources attributed by investigators in the field are as follows:

Mechanical:	bruises, lacerations, skeletal fractures, scraped or cracked head, severed bodies, internal hemorrhaging, popped or missing eyes
Pressure:	ruptured swim bladder, popped eyes, internal hemorrhaging
Shear:	popped eyes, severing and decapitation, torn gill covers.

Note that some of these manifestations are common to more than one source. Some can also be attributed to other sources. Rivers (1951-57T) for instance, found that internal hemorrhaging resulted from stress in capture nets.

If injury types were more definitive in identification of sources, assigning the proper proportion of blame to each potential source would be less hazardous.

Analysis of Factors

The only plausible manner in which to deal with assignment of injury area is through analysis of factors for each turbine type in prototype studies. Kaplan turbine mortality areas are less clear than are those for Francis units. As noted earlier, in examination of 19 Kaplan turbine studies involving working units, no relationship of mortality to head could be found. In the 15 prototype units studied, only two explore the relationship between tailwater and and mortality. As noted previously, largely because of the phenomenon of only two sizes used in studies, no relationship can be shown for size of fish. No relationship between mortality and peripheral runner speed can be developed in the 12 Kaplan studies appropriate for this. Although individual studies show changes in mortality levels when efficiencies are manipulated, the total of six studies providing these data is too small for meaningful correlations. As shown earlier, although mortality can be linked to efficiency of Kaplan turbines, the efficiency and mortality curves are both so gradual and flat that discrete peaks are not apparent making the relationship vague. No effect of pressure is indicated by mortality comparisons with head and runner/tailwater levels except for individual unit manipulations.

The above virtually exhausts the list of recognized injury sources for Kaplan units, yet mortality does occur, leaving only mechanical injury and that resulting from such things as subatmospheric pressure including cavitation, and water shear. In spite of the confidence assumed by many researchers that certain injury can be assigned to water shear, it has yet to be demonstrated where and how this phenomenon occurs or that injuries assigned to it are not actually caused by other sources. As mentioned previously, few injury types can be exclusively or positively attributed to but one cause. The most plausible type of mechanical injury in Kaplan units is that occurring at the blade ends where a gap usually exists of a size and shape to draw fish into it to be ground between the blade and containment ring. It could quite logically account for the amount of mortality found in most Kaplans. No other logical source of mechanical injury is apparent in Kaplan turbines. It does not appear possible that many mortalities could occur to fish approaching or intersecting the blades of this runner type. As noted on page 5-14, the majority of fish probably contact the blades near the hub where the least damage potential exists. In a 24-foot (7.3 m) diameter runner turning 75 rpm, the blade, at a point close to the hub, is moving only about 15 feet (4.6 m) per second, hardly enough velocity to damage fish with the smooth rounded surface typical of the leading edge of this type of blade. If the exact routes taken by fish in passing over turbine blades could be discovered, a positive step would be made in correcting mortality in this type of turbine. Cavitation unquestionably occurs under some conditions in Kaplan units but does not appear to be severe under design operating conditions.

Francis units offer better insight into their forces affecting fish mortality. The relationship between peripheral runner velocity and mortality in examination of 22 prototype studies which accounts for over 50 percent of the variation in mortality in this type of unit, offers an attractive field for further research. Although significant correlation does not guarantee cause-effect relationship, in view of the fact that less mortality is associated with lower speeds, this seems to be a logical result. Other factors seeming to affect fish mortality in Francis turbines such as cavitation, wicket gate opening, runner/tailwater relationships, while producing noticeable effects in manipulation of individual units, do not exert enough force to produce demonstrated strong relationships in comparisons of the effects for several units. The case for peripheral velocity as a deciding factor is positive enough to indicate that at lowest speeds, few mortalities probably occur. This indicates possible paths to mortality reduction through design or operation modifications. While they have not been clearly identified, it seems probable that certain damage sources lie in the areas responsive to this factor; most likely they are impacts to fish occurring as they enter the peripheral area of the runner. This could involve the trailing edge of the wicket gates or the number and/or shape of the buckets at the entrance point of water and fish. Model studies have shown both of these to be a factor (Cramer and Oligher, 1960T). Since these areas have never been designed with fish as a consideration, it seems probable that improvements could be made to reduce mortality if fish were considered.

Section 6

STUDIES THAT COULD BE PURSUED TO AID REDUCTION OF MORTALITY IN TURBINES

MECHANICAL FACTORS

Peripheral Runner Velocity

Research on peripheral velocity may be productive in the design of Francis turbines. As mentioned in the report, indications are that at lower speeds, little mortality occurs. Model work could explore this facet. Models have shown surprising abilities to measure influences affecting fish mortality and to pass small fish successfully. Cramer and Oligher (1961T) had difficulty with fish too large for comparative results. The small bass they used were many times larger than the pink salmon fry used by Prempridi (1964T) who found no mortality of fish striking the blades of a Kaplan model at velocities of less than 29 feet (8.8 m) per second. A good model program using small fry could explore pertinent factors in a fairly short time using existing facilities such as at the Voith laboratory.

Kaplan Turbines

Large Kaplan units have few areas in which fish could be subject to mechanical injury. These include the gaps or clearance between the distal end of the blade and the containment ring and another less important gap sometimes occurring between the attached end of the blade and the hub. The amount of mortality in a group of fish passing through such a turbine seems logically related to the proportion that reach the gap at the other end of the blade because this is an area obviously hazardous to fish, and the proportions of fish expected to enter it match the mortality measured for these units. A study aimed at determining this can be pursued in two stages. First would be an examination of hydraulic and biological factors influencing the distribution of fish horizontally on top of the blade. Second, studies with transparent models would follow fish in passage through such areas to reveal routes of travel. Knowledge of these routes might permit intelligent and fruitful design modifications to protect fish. It is not productive to make changes blindly in an area that may not be frequented by fish. Cavitation, also a source of mortality in such turbines, seems to be largely controllable under normal operations.

Bulb and Tube Turbine Tests

Only two tests of bulb units are known to have been completed, one at Rock Island Dam on the Columbia River and the other at Essex Dam on the Merrimack River. In spite of a controversy (as reported in critiques on this project) with respect to Rock Island, obviously low mortality occurred, as it did at Essex. Further tests could be made at installations such as the Pelton regulating dam on the Deschutes River in Oregon. Tests of tube turbines can be accomplished at Winchester Dam and some other small units in the northwest. Winchester is particularly appealing because it employs a peripheral runner velocity of only 36 feet (1 m) per second. Peripheral velocity could logically be a prominent factor in axial flow units such as bulb and tube types because fish characteristically moving through penstocks near the roof tend to pass through such runners at the periphery. The characteristically small clearances of such units may negate this factor, however. To date, no tests with fish of tube turbines have been made.

BIOLOGICAL FACTORS

Injury Characteristics

One of the frustrating problems in evaluating study results has been the inability to key fish injury types to exact causes. It would be quite useful to be able to identify the cause of an injury by its characteristics. Studies with models or small prototypes in which operating conditions can be manipulated to cause specific types of injury which can then be the subject of pathological examination would be extremely helpful in making mortality studies more accurate. This might permit insight into design modifications to reduce mortality more than with any other factor.

Comparison of Turbine Passage with Other Fish Passage Methods

Passage of fish through turbines has long been a normal route of travel by fish past power projects. It would be useful to compare the relative value of turbine passage to that of diversionary systems such as screens, louvers, etc., in terms of cost and degree of protection afforded fish. This would involve reviews of various studies of turbine fish passage as well as those of diversionary methods. The best, worst and average results for both types of passage would be compared.

Section 7

ANNOTATED BIBLIOGRAPHY OF TURBINE MORTALITY STUDIES
(Identified by a "T" after date in references)

Andrew, F.J. and G.H. Geen
Sockeye and Pink Salmon Investigations at the Seton Creek Hydroelectric Installation. International Pacific Salmon Fisheries Commission, Progress Report, 1958, 4:74 p.

Mortality was estimated for fish passing through the Francis turbine. Tests were replicated four times. Tailwater level was higher than normal indicating a mortality estimate below normal. Mortality was 9.2%.

Anonymous
Turbine Mortality Studies, Connecticut River, 1968. Unpublished report (probably U.S. Fish and Wildlife Service). 1968.

Turbine mortality studies using smolt-sized salmonids fitted with styrofoam floats were conducted at Vernon, Turners Falls, Hadley and Boat Lock power plants on the Connecticut River in Massachusetts and Vermont-New Hampshire. Recoveries were by boats in the tailraces. Of 1307 fish released, 856 were recovered. Mortality, ranging from 3.3 to 19.5%, averaged 12.6%, with a cumulative mortality of 47.4% for all plants

Anonymous
Result of Mortality Study of Downstream Migrating American Shad in HWP Co Canal and Hadley Station, Holyoke MA, 1958.

A surface trawl was fished downstream of the two plants to capture fish and check mortality. Test lots and dead fish were put through turbines. Conclusion was of minimal mortality in the No. 2 station and inconclusive results at Hadley.

Anonymous
Mortality Test of Downstream Migrant Salmonids at the T.W. Sullivan Plant of Portland General Electric Company. In Massey, Julius B. Summary Report on Juvenile Downstream Migrant Fish Passage and Protection Studies at Willamette Falls, OR. Oregon State Game Commission, Portland OR. August 1967.

Unit no. 9, a Francis turbine in 1960, and Kaplan units 7 and 8 in 1961 were tested with chinook and steelhead yearlings. Runner elevations were about 25 ft (7.6 m) above tailwater and head averaged 42 ft (12.8 m), rpm was 240 for all units with flows of 260-400 cfs. Some environmental data are provided. Mortality in the Francis unit in 1960 was 25.9% for steelhead and 14.3 for chinook. Mortality of steelhead in the Kaplan in 1961 was 7.7 and 9.9% and of chinook 11.8 and 10.5%.

Anonymous
Mortality of Downstream Migrant Salmonids at West Linn Plant of Crown Zellerbach, Inc. In Massey, Julius B. Summary Report on Juvenile Downstream

Migrant Fish Pasage and Protection Studies at Willamette Falls, OR. Oregon State Game Commission, Portland OR. August 1967.

Francis turbines nos. 20 and 21 of the West Linn plant were tested in 1960 and 1961 with steelhead and chinook. RPM was 277 in no. 20 and Francis turbines nos. 20 and 21 of the West Linn plant were tested in 1960 and 1961 with steelhead and chinook. RPM was 277 in no. 20 and 255 in no. 21. Runners were 25 ft (7.6 m) above tailwater. Mortality of steelhead was 34.4% in no. 20 and 20.0% in no. 21 with chinook at 28.4 and 18.8 respectively in 1960. Although all test and turbine conditions were virtually identical in 1961, essentially 100% mortality of both species in both turbines occurred. It has been conjectured that nitrogen gas in the blood in presence of the unusually high draft tube vacuum at the plant was the cause. Some environmental data are provided.

Anonymous

Mortality of Downstream Migrant Salmonids at Publishers Paper plant at Willamette Falls. In Massey, Julius B. _Summary Report on Juvenile Downstream Migrant Fish Passage and Protection Studies at Willamette Falls, OR._ Oregon State Game Commission, Portland OR. August 1967.

Unit no. 2, a Francis turbine, was tested with chinook salmon and steelhead trout using a large net and control fish at a head of 43.5 feet (13.3 m) and at 300 rpm in January 1961. The runner elevation was 24 ft (7.3 m) above tailwater. Mortality of steelhead was 12.9 percent and of chinook 15.5 percent. Some environmental data are provided.

Bell, Charles Edward

Immediate Mortality of Adult American Shad (_Alosa Sapidissima_) Resulting from Passage through a Kaplan Turbine, Holyoke Dam, Holyoke, Massachusetts. Masters Thesis. University of Massachusetts, August 1982.

A 17 mw Kaplan turbine with 15.5 m nominal head was tested for immediate mortality suffered by small groups of American shad fitted with radio transmitters. Dead fish were also used, as were controls. In 1981, 20 test fish were employed and 36 in 1982. Control fish were used normally in 1981 but in 1982 were apparently only held in a tank and not subjected to non-turbine environmental factors faced by test fish. Mortality of 53% in test and 38% in controls was not considered statistically different. In 1982, mortality was 18.5% for test fish and 1.5% for "controls".

Bell, Milo C. and Kenneth J. Bruya

Updated compendium on the Success of Passage of Small Fish Through Turbines. Foster Dam Mortality Studies. Corp of Engineers. 1981.

Raymond C. Oligher, Corps of Engineers biologist directed this work in 1969. Explores draft tube effects, head and efficiency. Best survival was at 25% gate opening and less than best efficiency. Head of 110 feet is one of highest Kaplan plants. Average mortality in 43 runs was 11.2 percent.

Calderwood, W.L.

Passage of Fish Through Turbines. Experiments of a Powerhouse. _Salmon and Trout Magazine_, No. 115. 1125: 214-221. September 1945.

Thousands of smolts were passed through turbines at Tongland Dam in Scotland. One smolt was killed and nine stunned. Observation was from a boat. Note: Data are insufficient for critique.

Canada Department of Fisheries
The Fisheries Problems Associated With The Power Development of The Puntledge River, Vancouver Island, B.C. Canada Department of Fisheries, 1958.

A vertical-shaft Francis turbine, operating at 354 feet of head and five feet above tailwater, was tested by releasing 10 groups of 1500 live and 500 dead smolts and fry into pipeline in forebay. Recovery method was a floating trap net in the tailrace. Test fish were steelhead smolts, Kamloops fry and salmon ranging in size from 1.4 to 4.9 inches (3.6 to 12.4cm). Dead fish were released with each group of live fish to calculate recovery rate of killed fish. No visible injuries were apparent to 75% - 86% of killed fish. Mortality was greatest with smolt-size fish (41.9%) while fish of fry size exhibited mortality ranging from 27.5% to 32.6%.

Clark, Don, Stanley Katkansky, and George J. Eicher
Comments on the Fish Commission's Case as Presented to the Oregon Fish Commission at the Meeting of October 24, 1974. Unpublished report. October 1974.

Results of an impromptu turbine mortality test at the Faraday powerhouse on an old Francis unit showed approximately 4 percent mortality in 355 chinook and 492 coho passed through.

Collins, N.J. and C.P. Ruggles
Fish mortality in Francis turbines, Montreal Engineering Company, Ltd., Halifax, N.S. September 1982.

Exploratory research involving trout passage through a high speed Francis turbine was performed at the Lequille power station in Nova Scotia. It was found that turbine effects were discriminate. The effects of wicket gate opening were explored.

Cramer, F.K.
Fish Passage through Turbines, Model Turbine Experiments. U.S. Army Engineer District, Walla Walla, Corps of Engineers. Progress Report no. 1, September 1960, 9 p.

Presents results of testing 12" Francis and Kaplan model turbines with largemouth bass fingerling, fathead minnows and killifish. Found little mortality difference between Kaplan and Francis turbines at similar heads and normal operating conditions. Types of injury are discussed. Relation of runner setting to tail water level was important.

Cramer, F.K. and R.C. Oligher
Fish Passage through Turbines, Tests at Cushman no. 2 Hydroelectric Plant. U.S. Army Engineers, Walla Walla District, Corps of Engineers, Progress Report no. 2, September 1960, 26 p.

Tests were at Cushman No. 2 plant, with a high head Francis turbine. Chinook and silver (coho) salmon and steelhead trout were tested. Found that turbine characteristics are important to mortality, mechanical mortality is directly associated with physical features of turbine design and hydraulic head per se is not a significant factor.

Cramer, F.K. and R.C. Oligher
Fish Passage through Turbines. Further Model Turbine Experiments -- Francis Runners. U.S. Army Corps of Engineers, Walla Walla District, Progress Report No. 3, April 1961, 12 p.

Tests were run in the model with original and modified Francis turbines. Found that relatively small increase in blade clearance significantly decreased mortality; maximum reduction of mortality was about 300 percent; total mortality increased as tail water level dropped below runner centerline. Influential variables are rated.

Cramer, F.K. and R.C. Oligher
Fish Passage through Turbines, Further Tests at Cushman No. 2 Hydroelectric Plant. U.S. Army Corps of Engineers, Walla Walla District, Progress Report No. 4, July 1961, 18 p.

Tests at Cushman Hydroelectric Plant No. 2 with a high head Francis turbine 450 feet (137m) found that mortality was linked to turbine characteristics, but head and turbine design were not important. Mortality ranged from 22.7 to 55.4%.

Daugherty, William
Vernon Dam Mortality Study. U.S. Fish and Wildlife Service. Unpublished manuscript, Boston MA. October 1969.

Small-sized rainbow trout fitted with styrofoam tags were passed through turbines at Vernon Dam on the Connecticut River in five tests using 285 fish, of which 111 were recovered. Mortality was estimated at 24.3%.

Eicher, George J.
Clackamas Dams and Anadromous Fish. A History of Fish and Dams on the Clackamas River in Oregon. Portland General Electric Company, Portland, OR, July 1977.

Contains an account of a 1937 mortality test of No. 2 turbine at Faraday Power Plant involving 1700 sockeye fingerling. Testing involved a hard-hat diver observing fish emerging from draft tube who estimated 50% mortality. No controls were used and no environmental data were recorded. This was not a definitive test and is of only historical value.

Gloss, Steven P., James R. Wahl and Robert B. DuBois
Potential Effects of Ossberger Turbines on Atlantic Salmon Smolts, Striped Bass and American Shad. In <u>Potential Effects of Kaplan, Ossberger and Bulb Turbines on Anadromous Fish of the Northeast United States</u>. U.S. Fish and Wildlife Service, Newton Cornen, MA, September 1982.

Ossberger turbines of 656 and 850 mw were tested at Colliersville Dam, apparently in about 1981, using striped bass, juvenile American shad, Atlantic salmon and rainbow trout. A large net was used to capture fish emerging from draft tubes. Control fish were used. Mortality estimates were 50% for shad, 54% for striped bass and 24-62% for Atlantic salmon, depending on size.

Gunsolus, R.T. and G.J. Eicher
Evaluation of Fish Passage Facilities at the North Fork Project on the Clackamas River in Oregon. Oregon Fish Commission, Oregon Game Commission, U.S. Bureau of Commercial Fisheries, U.S. Bureau of Sport Fisheries and Wildlife, and Portland General Electric Company, 1970.

Turbine mortality test at North Fork Dam was incidental to evaluation of all fish passage facilities and routes. Hatchery coho were entered into turbine through vent shaft. Control and dead fish lots were entered into tailrace. Recovery was 2 miles downstream in fyke nets. Mortality was between 25.5 and 31.6 percent.

Hamilton, J.A.R. and F.J. Andrew
A Study of Mortality Rates of Sockeye Salmon Fingerlings in a Turbine at Ruskin Dam. International Pacific Salmon Fisheries Commission.1 Unpublished, 1954, 13 p.

Mortality was estimated at 10.5% from tailrace fyke net catches of measured proportions of the Francis turbine discharge. This was a surrogate test to forecast mortality from proposed Seton Creek project. It proved accurate.

Hamilton, J.A.R. and F.J. Andrew
An Investigation of the Effect of Baker Dam on Downstream-migrant Salmon. International Pacific Salmon Fisheries Commission, Bulletin 6, 1954, 73 p.

The effects of the 250-foot high Baker Dam on the downstream migration of sockeye and coho salmon were investigated in order to determine the pattern of migration from the reservoir. The effect of the spillway and the Francis-type turbines on survival and the causes of mortality were examined. The mortality rates in passing through the turbines were calculated to be 34 percent for native sockeye and 28 percent for native coho under full load conditions. These findings are supported by data showing that sockeye marked as downstream migrants and released over the spillway and through the turbines had, upon their return as adults, experienced a spillway mortality of 63 percent and a turbine mortality of 37 percent. Further confirmation of the effects of the structure is provided by the decline of 55 percent in the sockeye run since the dam was constructed.

Holmes, H.B.
Loss of Salmon Fingerlings in Passing Bonneville Dam as Determined by Marking Experiments. Manuscript with revisions and statement by J.A. Craig. U.S. Fish and Wildlife Service, Portland OR, 1952.

Small fish were released in the forebay and turbine intakes at Bonneville Dam, which has a high velocity discharge through the spillway and turbines. As dead salmon fingerlings sink to the bottom, it was deemed impracticable to make direct observations of mortality resulting from passage at the dam. The marking experiment was planned to indicate losses of fingerlings in passing the dam by recapture of returning adults. The results of a series of 15 such experiments conducted during the period 1938 to 1948 inclusive indicated a mortality of 11 to 15 percent. J. A. Craig critiqued the manuscript and cast doubt on some of the results.

Knight, Alexis E. and Daniel M. Kuzmeskus
Potential Effects of Bulb Turbines on Atlantic Salmon Smolts. In Potential Effects of Kaplan, Ossberger and Bulb Turbines on Anadromous Fish of the Northeast United States. U.S. Fish and Wildlife Service, Newton Corner, MA, September 1982.

Describes studies at Essex Dam on the Merrimack River at Lawrence. MA, where two bulb turbines of 7.8 mw each are operational. Radio transmitters inserted in fish stomachs were used to trace post-turbine activities. Fifty each of test and control fish were used, although controls tested only the effects of tagging and not environmental non-turbine impacts. A 2% mortality (1 of 48) was found.

Kynard, Boyd, Ralph Taylor, Charles Bell and David Stier
Potential Effects of Kaplan Turbines on Atlantic Salmon Smolts, American Shad and Blueback Herring. In Potential Effects of Kaplan, Ossberger and Bulb Turbines on Anadromous Fish of the Northeast United States. U.S. Fish and

Wildlife Service, Newton Corner, MA. September 1982.

Blueback herring were tested in passage through the 17 mw Kaplan turbine at Holyoke Dam on the Connecticut River in October 1981. Stained test, control, and dead fish were introduced into the turbine and tailrace. Recovery was in four trawls 300 m downstream of draft tube exit. 16.5, 12.0 and 5.5 mw power levels were tested, giving mortality levels of 63, 83 and 83 percent respectively. Shad were fitted with radio tags inserted in stomachs and traced by radio telemetry. Mortality in the lot of 20 test fish was 53% and of controls 38%, not considered to be a statistical difference. Atlantic salmon smolts were also studied by radio tagging, 61 test and 53 control fish. Adjusted mortality was 4.9%.

Liston, C.R.
Estimates of Salmonid Fish Mortalities Occurring at the Ludington Pumped Storage Power Facility During 1975-1976, and Related Studies. 1978 Annual Report, Ludington Project, Vol. I, No. 2. Department of Fisheries and Wildlife, Michigan State University, East Lansing MI, 1979, 100 p.

Weekly estimates were determined for the mortality of steelhead trout, brown trout, coho salmon, chinook salmon and lake trout resulting from pumped storage operation. Mortality estimates were directly related to abundance of salmonids in the reservoir. Losses of the five species accounted for between 1.2 to 9.2% of their respective angler harvest from tributaries and Lake Michigan in two local counties. Methods used to calculate mortality are described fully.

Liston, C.R., Dan Brazo, Rich O'Neal, Joe Bohn, Greg Peterson, and Rick Ligman
Assessment of Larval, Juvenile, and Adult Fish Losses at the Ludington Pumped Storage Power Plant on Lake Michigan. 1980 Annual Report. Deparmtent of Fisheries and Wildlife. Michigan State Universtiy, East Lansing, MI. February 1981.

Estimates were made of the total losses to the Lake Michigan fish biomass of 16 species of fish passing through the Ludington pumped storage plant in both directions and returning to the lake in various life stages from larvae to adults. Pumping was more damaging to fish than generation.

Long, C.W., Krcma, R.F., and F.J. Ossiander
Research on Fing-rling Mortality in Kaplan Turbines -- 1968. U.S. Bureau of Commercial Fisheries, Biological Laboratory, Seattle WA.

Results presented indicate an interrelationship between turbine losses and losses resulting from predation in discrete locations of the tailrace. Control and test fish entering the tailrace in the backroll suffered a loss up to 33% due to predation while those entering the frontroll did not. Turbine mortality was estimated at 10-19% and was assessed by capture of test and control fish using purse seines and beach seines (7 miles downstream) and gatewell dipnets (45 miles downstream).

Long, Clifford W., Frank J. Ossiander, Thomas E. Ruehle, and Gene W. Matthews
Survival of Coho Salmon Fingerlings Passing Through Operating Turbines With and Without Perforated Bulkheads and of Steelhead Trout Fingerlings Passing Through Spillways With and Without a Flow Deflector. National Marine Fisheries Service, Coastal Zone and Estuarine Studies, Northwest Fisheries Center, 2725 Montlake Boulevard East, Seattle, WA.. Final Report, 1975, 7 p.

Tests at Lower Monumental Dam on the Snake River using perforated bulkheads at turbines operating at 105-115% overload yielded 11 to 16.5% mortality of coho salmon as compared to 20% mortality with a standard turbine (no perforated bulkhead). Significant reduction of steelhead mortality was determined for the spillway examined which was equipped with flow deflectors (2.2%) as compared to standard spillways (27.5% mortality). Fish mortality at this spillway may not be comparable to that at other dams. Schoeneman et al (1961) reported significantly lower mortality of chinook salmon passing over the McNary Dam spillway (1-3%) without flow deflectors. Over 600,000 test and control fish were released in the turbine study with 40,000 recaptured downstream.

MacEachern, N.
Mortality tests at Tobique Narrows Dam, 1959 and 1960. Canada Department of Fisheries. Unpublished. 24 p. 1961.

Turbine mortality assessment was conducted in 1959-60. Results of 1960 tests on Atlantic Salmon fingerlings at rated generator load indicated mortality of 16.5% for 3-1/2 to 5-1/2 inch (8.9 to 14.0cm) fish and 23% for 5-1/2 to 8-1/2 inch (14.0 to 21.6cm) fish.

McGrath, C.J. and E. Twomey
Passage of Smolts through Turbines -- Experiments with Balsa-wood Boxes and Fish Shapes at River Erne Hydroelectric Station in May 1959. Irish Department of Sea and Inland Fisheries, 1959, Appendix No. 24. 44 p.

Atlantic salmon smolts in balsa boxes and fish shapes of balsa were passed through turbines at two power plants on the River Erne in Ireland. About 110 were recovered of which eight were "smashed". The conclusion was that damage to fish was light.

McKernan, Donald L.
A progressive report of experiments on downstream migrating chinook fingerlings at Dryden Ditch. Washington Department of Fisheries informal report, 1940.

An attempt was made to measure mortality in two turbines at Dryden Dam using cheesecloth bags to carry the fish. It was unsuccessful. Mortality was estimated at 10% from a large turbine and 16.7% in a small one. Figures were from visual observations of live and dead fish below the plant.

Monten, Erik
The Possibility of Salmon Smolt Passing Unharmed through Power Plant Turbines When Descending to the Sea. Translated from Swedish by the U.S. Joint Publication Service, for the Fish Passage Research Program, U.S. Bureau of Commercial Fisheries, Seattle WA, June 1963. (Original reference: Om utvandrande laxungars möjligheter att oskadda passera genom kraftverksturbiner (preliminärt meddelande). Laxforskningsinstitutet, Bankagatan 8, Sundsvall, Sweden, Vandringsfiskutredningen, Meddelande Nr. 13, Stockhldm, July 18, 1955, 24 p.

The writer felt that injuries were caused by blade strike or the recovery net. Injured fish show immediate signs or develop injuries in 2 days. Uninjured fish and controls have the same mortality rate after 2 days.

Monten, Erik
Studies on Fish Mortality Due to Passage through Turbines. Institute of Freshwater Research, Drottningholm, Preliminary Report No. 45:190-1955, 1964.

Fish were passed through the turbine of the Krangede plant in Sweden in 649 balsa wood boxes. Fish mortality ranged from 36% to 96%. Larger boxes had lighter mortality.

Oligher, Raymond C. and I.J. Donaldson
Fish Passage through Turbines. Tests at Big Cliff Hydroelectric Plant. U.S. Army Corps of Engineers, Walla Walla District. Progress Report No. 6, August 1966.

This study evaluated mortality of chinook salmon in 1964 and 1966 through a Kaplan turbine. In 1964 Mortality varied from 10.3 to 5.5%. In 1966, mortality was 10.2 to 7.8%. The study also compared turbine efficiency with survival.

Oligher, R.C. and I.J. Donaldson
Fingerling Mortality Versus Turbine Efficiency at Big Cliff Dam. U.S. Army Corps of Engineers , Walla Walla District, October 1965.

This report reviewed the turbine efficiency and mortality of fingerling chinook salmon in the 1964 studies.

Olson, F.W. and V.W. Kaczynski
Survival of Downstream Migrant Coho Salmon and Steelhead Trout through Bulb Turbines. Prepared for Public Utility District No. 1 of Chelan County by CH_2M-Hill, 1980, 45 p. plus app.

The study estimated mortality of juvenile coho salmon and steelhead trout passing through a horizontal-axis bulb turbine unit at Rock Island Dam. Marked fish were released into the intake, and differently marked control fish were simultaneously released immediately below the same unit. A total of 18.4 percent of the 685,292 marked fish were subsequently recovered. Estimated mortality rate of yearling coho salmon smolts was 7.0 percent, with a 95 percent confidence interval of 4.4 to 9.6 percent. Steelhead smolt mortality was estimated to be 3.1 percent with a 95 percent confidence interval of -5.9 to 12.0 percent.

Oregon Department of Fish and Wildlife
Studies of turbine mortalities at Leaburg and Walterville turbines of Eugene Water and Electric Board on the McKenzie River in Oregon. Unpublished report. 1984.

Tests with yearling chinook salmon were made in turbines of Walterville and Leaburg power stations by releasing test fish into power canals upstream of plants and controls into river. Recoveries were in a trap 180 miles downstream. Mortalities were estimated at 13% at Walterville and 28% at Leaburg, higher than 1958 tests with rainbow trout which gave 2.5 to 7.5% at Walterville and 4.8% at Leaburg. Reasons for difference are not discussed.

Oregon State Game Commission
Leaburg and Walterville Turbine Studies, McKenzie River. Eugene Water and Electric Board. Unpublished report. 1958.

Studies of turbine mortality in a Francis turbine under 89 feet of head at Leaburg plant yielded a mortality rate of 4.8%. Two runs at 54 and 84 percent load at Walterville Kaplan turbine at 55 feet head showed mortalities of 2.5 and 7.5 percent respectively. A large net was used for recovery. Control fish were used.

Oregon State Game Commission

Stayton Turbine Tests. Unpublished report. 1959.

Assessment of turbine mortality was made using steelhead trout and chinook salmon passed through turbine and collected in a large net straining all of discharge. Controls were used. Mortality of steelhead was 2.4% and that of chinook 9.1%.

Parametrix

Survival of Steelhead Smolts During Passage Through Wells Dam Turbines and Spillway. Parametrix, Inc., Seattle WA. April 1985.

In a turbine and spillway mortality test at Wells Dam on the Columbia River in Washington in 1980, 221,000 freeze-branded steelhead were passed through a turbine and spillway and survivors recovered at four downstream dams. Turbine mortality rate was 16%. No environmental data are shown.

Prempridi, Thamrong

Effect of Compressed Air on Mortality of Fish Passing Through a Model Turbine. M.S. Thesis, Department of Civil Engineering, University of British Columbia, Sepember 1964, 114 p.

This was a model study of a propeller turbine operating under 50 feet of hydraulic head with various draft tube pressures. Mortality of juvenile pink, chum, and coho salmon was reduced by addition of compressed air immediately downstream of turbine blades when operated at low speed and efficiency. No change in mortality occurs at high turbine speed and efficiency, however. Introduction of compressed air into the penstock and atmospheric air into the draft tube just downstream of the blades resulted in reduced fish mortality when turbine operated at high speed. Limited number of tests from which results were derived prohibited statistical evaluation of the causal relationships suggested.

Rivers, Cole

Unpublished reports, Oregon Game Department with additional information from Jack Hanel, Pacificorp biologist on Gold Hill Project. 1950-53

Describes turbine mortality studies in 1950, 1951, 1952 and 1953 at the Gold Hill hydroelectric plant of Ideal Cement Co. on the Rogue River in Oregon. Fyke nets were fished in the tailrace. Injuries, typified as mortalities ranged from 13.3 to 13.9% in the four years. Upstream fishing indicated 5.7% injury level in fish approaching the plant. An adjusted level of 8.1% caused by the plant was agreed upon.

Rivers, Cole

Unpublished monthly reports, Oregon Game Department and records of Jack Hanel, Pacificorp biologist with respect to Gold Ray plant on the Rogue River in Oregon.

Fyke nets below Gold Ray turbines were used to estimate mortality of fish passing through them in 1950, 1951 and 1957. Precise results were not obtained. Wild chinook mortalities were estimated at 2.5%, and steelhead at 22.9%. Internal hemhorrages were found to be caused by capture nets.

Robinson, J.B.

Effects of Passing Juvenile King Salmon through a Pump. The Progressive Fish-Culturist, October 1971, 33(4):219-223.

King (chinook) salmon fingerlings were passed through a volute pump to determine mortality and value of this method of moving young fish. Salmon from 1.8 to 4.9 inches were passed through the pump at 550, 650 and 900 rpm. Suction heads of 12 and 16 ft were employed. Control fish were used. A mortality of 2.7 percent, deemed acceptable, was obtained.

Ruggles, C.P. and N.H. Collins
Fish Mortality As a Function of the Hydraulic Properties of Turbines. Report for the Canadian Electrical Association by Montreal Engineering Company, January 1981.

A series of exploratory turbine mortality tests using Atlantic salmon and brook trout were performed in a Francis turbine with a head of 387 ft (118m). Parameters tested were fish length, gate opening and tailwater level. Secondary relationships between gate openings and types of impacts on fish were also examined. Mortalities generally exceeded 50% for both species. Correlations were weak.

Schoeneman, D.E., and C.O. Junge, Jr.
Investigations of Mortalities to Downstream Migrant Salmon at Two Dams on the Elwha River. Washington State Department of Fisheries. Research Bulletin No. 3, 1954, 51 p.

Study was of turbine and spillway mortalities of young salmon at Elwha and Glines Canyon Dams on the Elwha River. Also studied methods of assessing mortalities using downstream recoveries. Found 33% turbine mortality at Glines and zero at Elwha. Control fish were employed. No environmental data were collected.

Schoeneman, D.E., Meekin, T.K., and Junge, C.O., Jr.
Dam Mortality Studies Conducted on the Lewis, Big White Salmon and Chelan Rivers, 1954. Unpublished report, Washington Department of Fisheries, Olympia, WA, 1957.

Evaluates chinook fingerling mortality in July 1954 at Condit Dam (14 to 43%) on the Big White Salmon River. During August 1954, mortality of coho fingerlings was estimated at less than 30% to 100%.

Schoeneman, D.E., R.T. Pressey and C.O. Junge, Jr.
Mortality of Downstream Migrant Salmon at McNary Dam. Transactions American Fisheries Society, 1961, 90(1):58-72.

This report describes studies at McNary and Big Cliff dams to estimate the mortality of fingerling and yearling chinook salmon passing through Kaplan turbines at each facility. Mortality was estimated at 11% with a 95% confidence interval of from 9 to 13%. Estimated mortality of salmon passing over the spillway was 2% with a 95% confidence interval of 0 to 4%.

Seiler, Dave
Evaluation of downstream migrant passage at Condit Dam 1983 and 1984. Washington Department of Fisheries, Draft Report.

This study evaluated coho smolt mortality through a Kaplan turbine during April and May 1984. Mortality varied from 68.9 to 87.6% based on recapture of test and control fish.

Smith, K.E.H.
Mortality Tests - Young Salmon and Gaspereau. Tusket River Power Dam, Yarmouth County, Nova Scotia. Canadian Department of Fisheries, 1960.

Tests of mortality in three 1660 hp Kaplan turbines were made using Atlantic salmon and gaspereau (alewives). Recovery was with draft tube nets. Control fish were not used during testing but were employed in holding of lots for delayed mortality. Instantaneous mortality averaged 11.5% for salmon and 14.1% for gaspereau. Delayed mortalities for these species were 5 and 38.8% respectively.

Smith, K.E.H.
Mortality Tests, Yearling Gaspereau at Tusket River Power Dam, Yarmouth County, Nova Scotia. Canada Department of Fisheries. Unpublished manuscript, 1961.

Tests using only gaspereau were conducted similarly to those using both salmon and gaspereau in 1960. The 1961 tests centered on determining the proportion going through the turbines as opposed to the fishway. This was apparently determined by general observation which decided that most fish used the fishway because they stayed near the surface of the forebay. Controls were used only to test holding mortality. Turbine and holding mortality was estimated to be 50.3%.

Stier, D.J.
Immediate Mortality of Atlantic Salmon, Salmo salar, Smolts Resulting from Passage through a Kaplan Turbine at Holyoke Dam, Massachusetts. M.S. Thesis, University of Massachusetts, February 1983, 46 p.

Mortality of 108 2-year old Atlantic salmon smolts passed through a 17 mw Kaplan turbine at Holyoke Dam on the Connecticut River was estimated using radio tagging. Survival of test fish was estimated by comparing their downstream migration to that of 34 dead fish. Mortality was estimated at 11.8% in 1981 and 13.7% in 1982.

Taylor, Ralph Edmund
Immediate Mortality of Juvenile Clupeids at a Kaplan Turbine on the Connecticut River, Holyoke MA. Master's Thesis, University of Massachusetts, February 1983.

A 15 mw Kaplan turbine at Holyoke Dam was tested for immediate mortality of juvenile clupeids passed through it. Fish marked by staining, and dead and control fish were used. Recovery of fish was through use of passive trawls 984 feet (300m) downstream of the turbine discharge. Immediate mortality was calculated to be 62 percent at 16.5 mw generator, 82 percent at 12 mw and 82 percent at 5.5 mw.

U.S. Army Corps of Engineers
Fish Passage through Turbines. Further Tests at Cushman No. 2 Hydroelectric Plant. Progress Report No. 4, July 1961.

This report covers further tests at Cushman No. 2 plant. Silver (coho) salmon and steelhead were used. Different wicket gate settings were tested. Desirable characteristics for a Francis turbine are low runner speed, high efficiency, relatively deep setting of runner, adequate clearance between gates and blades and operation at relatively high sigma.

U.S. Army Corps of Engineers, Walla Walla District
Fish Passage through Turbines -- Tests at Shasta Hydroelectric Plant. Letter report covering tests conducted January 21-29, 1962. 12 p.

Presents effects of Shasta Francis turbine with greater blade clearances and slower shaft speed than those at Cushman. Recoveries of test and control fish were high. Mortality rates were 32.3% for chinook, 13.2 for steelhead, and 40.1 for rainbow.

U.S. Army Corps of Engineers, Walla Walla District
Fish Passage through Turbines, Tests at Shasta Hydroelectric Plant. Progress Report No. 5, May 1963.

Tests were conducted at Shasta where Francis runners had slower shaft speeds and greater clearances between adjacent blades than at the previously tested Cushman No. 2 plant. Average mortality varied from 29.7 to 45.2% for chinook, 10.1 to 24.6% for steelhead, and 28.8 to 47.9% for rainbow.

U.S. Army Corps of Engineers, Portland District
Fish Passage through Turbines: Tests at Big Cliff Dam. Research Summary. Fifth Progress Report on Fisheries Engineering Research Program, September 1979, p. 359-363.

Summarizes tests conducted in October 1967 using juvenile Chinook salmon and steelhead trout. Mortality varied from 7.5 to 24.1% for Chinook and 3.2 to 17.1% for steelhead.

Washington Department of Fisheries
Research Relating to Mortality of Downstream Migrant Salmon Passing McNary Dam. 1955. Final report submitted to U.S. Army Corps of Engineers, Contract No. DA-35-026-ENG-29893. In U.S. Army Corps of Engineers Progress Report 1956.

Tests were conducted to evaluate survival of chinook fingerlings. Mortality was 13% with a 95% confidence interval of 7 to 19%. Mortality of fish passing over the spillway was estimated at 2% with a 95% confidence interval of -8 to 11%.

Washington State Department of Fisheries
Research Relating to Mortality of Downstream Migrant Salmon Passing McNary Dam. In U.S. Army Corps of Engineers, North Pacific Division, Fishery Engineering Research Program, Progress Report, November 1956.

Summarized the 1955 and 1956 studies to estimate the effect of passage of fish through the McNary Dam spillway and turbines. No significant mortality was indicated at the spillway, but an 11% mortality was estimated for the turbines.

Washington State Department of Fisheries
Research Relating to Mortality of Downstream Migrant Salmon Passing Big Cliff Dam. Final Report submitted to U.S. Army Corps of Engineers, 1957, Contract DA-35-026-ENG-20893.

Reports mortalities of 9 to 21% for fall chinook 0+ and spring chinook yearlings passsing through a Kaplan turbine. Spillway mortality was 6% for fall chinook 0+ and 1% for spring chinook yearlings.

Wunderlich, Robert C.
A Preliminary Assessment of Juvenile Salmon Mortality through the Elwha River Dams. U.S. Fish and Wildlife Service, Olympia, WA, December 1983.

Essentially repeats Schoeneman and Junge (1954) study using same methods but larger juvenile salmon. Coho salmon smolts were tested in passage through the turbines and spillways of Glines Canyon and Elwha Dams on the Elwha River in

Washington. Collections of exposed test and control fish were in scoop traps 1.5 miles downstream from Elwha Dam. Mortalities to the trap site averaged 37.9% for those released above both projects and 36.6% for those released above the downstream Elwha Dam.

Section 8

REVIEWS OF TURBINE MORTALITY AND RELATED STUDIES
(Identified by an "R" after date in references)

Bell, M.C.
Fish Passage Through Turbines, Conduits and Spillway Gates. Pages 251-261. In L.D. Jensen, Edited Proceedings of the Second Workshop on Entrainment and Intake Screening. Palo Alto, CA: Report 15, Electric Power Research Institute, Palo Alto, CA, 1974.

Examines effects of passage of fish through turbines, conduits and spillway gates and evaluates the relative importance of several factors.

Bell, M.C. and K.J. Bruya
Updated Compendium on the Success of Passage of Small Fish Through Turbines. Research Summary. In Sixth Progress Report: Fish Passage Development and Evaluation Program 1979-1983. U.S. Army Corps of Engineers, North Pacific Division, Environmental Resources Branch, 1984, p. 127-134.

Updates 1967 Compendium through addition of a section covering turbine mortality studies at Big Cliff and Foster Dams by Raymond Oligher with an engineering analysis of turbine and draft tube characteristics at Foster Dam by C.T. Scott.

Bell, M.C., A.C. DeLacy and G.J. Paulik
A Compendium on the Success of Passage of Small Fish Through Turbines. U.S. Army Corps of Engineers, North Pacific Division, Portland, OR, 1967, 54 p. plus appendix.

Reviews a large number of turbine mortality studies for Francis and Kaplan model and prototype units. A number of analyses are made of causative factors which are compared by regression analysis to obtain relative value of each in model tests and Corps of Engineers exploratory studies at Cushman and Shasta projects.

Bell, M.C. and E.P. Richey
Report on the Feasibility of Turbine Passage of Downstream Migrants at Willamette Falls. Unpublished report for the Oregon Game Commission, April 4, 1963.

Reviews various means of passing fish past power plants with particular reference to turbine passage.

Bell, M.C. and E.P Richey
Special sections by J.J. Anderson, Z.E. Parkhurst, and C.T. Scott. Evaluation of Mechanisms for Fish Passage Around Dams, and Mortalities of Downstream Fish Passed Through Turbines. Unpublished data forming the basis of above report. Submitted to Oak Ridge National Laboratoy, Oak Ridge, TE, Subcontract No. 7678, 1979.

Evaluates various facilities used with experiments in passage of fish around dams. Gives mortality estimates for turbine types and installations.

Bell, M.C., E.P. Richey, J.J. Anderson and Z.E. Parkhurst
Design Consideration for Passing Fish Upstream Around Dams. In Analysis of Environmental Issues Related to Small Scale Hydroelectric Development. Edited by S.F. Hildebrand. Oak Ridge National Laboratory, Environmental Science Division, Publication No. 1567. Oak Ridge, TE, 1980.

Gives philosophy of planning fish passage and protection of fish in relation to small hydro projects.

Brett, J.R.
Salmon Research and Hydroelectric Power Development. Fisheries Research Board of Canada. Bulletin No. 114, 1957.

Examines the various factors affecting the survival of runs of anadromous fish when confronted with hydroelectric projects.

Burner, C.J.
Vertical Distribution of Downstream Migrating Chinook Salmon Fingerling in the Bonneville Forebay, with a Note Upon the Rate of Migration. U.S. Fish and Wildlife Service. Unpublished, 11 p., 1949.

Provides the results of a number of exploratory research efforts to establish the levels at which various species of Pacific salmon downstream migrants travel through the Bonneville pool.

Canada Department of Fisheries
The Fisheries Problems Associated with Power Development of the Puntledge River, Vancouver Island, B.C., October 1958.

Describes the Puntledge Project and makes estimates of its effect on anadromous fish of the Puntledge River.

Canada Department of Fisheries, Vancouver, B.C.
Summaries of Research on the Fish-Power Problem and Related Work by Fisheries Agencies in British Columbia. Prepared by Research Sub committee, Fisheries Development Council. December 1961. Revised August 1965.

Summarizes many research projects of bearing on the fish-power problem with particular reference to proposed projects on the Fraser River.

Cheney, W.O.
Discussion of Passage of Rainbow Trout Through Hydroelectric Conduits.Pacific Gas and Electric Company, Bureau of Tests and Inspection, Technical Data. Unpublished, July 28, 1953.

Reviews research results on passage of salmonids through high head conduits. Found little effect of pressure on fish.

Clemens, W.A.
The Fraser River Salmon in Relation to Potential Power Development. In The Investigation of Fish Power Problems; H.R. MacMillan Lectures in Fisheries. p. 3-10. A Symposium held at the University of British Columbia, April 19-20, 1957. Edited by P.A. Larkin, University of British Columbia, Vancouver, 1958.

Contains a series of papers by prominent scientists of the Pacific coast, speculating on the possible effects of dams on the Fraser on anadromous fish of that river. Papers on stream ecology, lake productivity, stress, energy stores and fish performance in fishways are included.

Cramer, F.K. and R.C. Oligher
Passing Fish through Hydraulic Turbines. Transactions of American Fisheries Society, July 1964, 93(3):243-259.

This report covers turbine model and actual plant tests (at the Cushman and Shasta plants) written for a professional fisheries journal. All tests conducted are described and results recorded and discussed. It is a compilation and summarization of the authors' work to date on the subject.

Cramer, F.K.
Fish Passage through Hydraulic Turbines. Corps of Engineers, Walla Walla District. Memorandum report, March 31, 1965.

Reviews turbine mortality testing results conducted by the Corps of Engineers prior to 1965. It discusses and summarizes the results of the model studies and the Shasta and Cushman No. 2 tests.

Eicher Associates, Inc.
Proceedings: Turbine Passage Workshop. Portland, OR, March 1985.

Covers three-day workshop attended by 27 international experts on turbine design, turbine mortality, and biological aspects.

Eicher, G.J.
Fish passage. In: N.G. Benson (ed), A Century of Fisheries in North America. American Fisheries Society, Special Publication No. 7:163-171, 1970.

Chapter covering fish passage at dams. Examines all aspects of both upstream and downstream movements.

Energy and Environmental Management, Inc.
An Assessment of Turbine-related Fish Mortality at Dam Number 4 on the Potomac River. Energy and Environmental Management, Inc., PO Box 71, Murrysville, PA 15668, December 1983, 32 p. plus app.

This is a literature search for information on the effect on fish of the adjacent waters of the Potomac River if a third turbine at Dam No.4 were built. No actual research field work is performed.

Gloss, Steven P.
A Review of Turbine Mortality and its Role in Small Scale/Low Head Hydroelectric Development. In Proceedings of 1982 Northeast Coldwater Workshop -- Hydropower Development and Fisheries Impacts and Opportunities, New York Chapter of American Fisheries Society and New York State Department of Environmental Conservation, Cornell University, Ithaca, NY, June 1982.

Provides characteristics, heads, and impacts on fish from examination of references on Francis, Kaplan, bulb, tube, Pelton and Ossberger turbines. Examines types of injuries and mortalities common to turbine types, such as mechanical, pressure, shearing and cavitation. Cites relative merits of model and prototype studies. Compares mortality of salmonids and clupeids.

Hoar, W.S.
Power Development and Fish Conservation on the Fraser River. The Fraser

River Hydro and Fisheries Research Project. Technical Report -- Biological. University of British Columbia, Vancouver, B.C., September 15, 1956.

Examines aspects of power development on the Fraser River and deleterious affects on anadromous fish, largely from a theoretical approach.

Hourston, W.R., C.H. Clay, L. Edgeworth, P.A. Larkin, E.H. Vernon, and R.G. McMynn
Planning Anadromous Fish Protection for Proposed Dams. North American Wildlife Conference, 20th Transaction, 1954, p. 440-445.

Discusses possible effects of proposed dams, principally on Fraser River runs of anadromous fish.

Knapp, W.E., B. Kynard and S.P. Gloss (eds.)
Potential effects of Kaplan, Ossberger and Bulb Turbines on Anadromous Fishes of the Northeast United States. Fish and Wildlife Service OBS-82/62.

Contains a series of papers describing actual research on turbine mortality with Kaplan, Ossberger and bulb turbines, as well as one on fish descaling.

Loar, James W.
Impacts of Hydropower on Downstream Fish Passage. In Proceedings of 1982 Northeast Coldwater Workshop -- Hydropower Development and Fisheries Impacts and Opportunities, New York Chapter of American Fisheries Society and New York State Department of Environmental Conservation, Cornell University, Ithaca, NY, June 1982.

A compilation of observations on studies and histories of various aspects of hydropower bearing on downstream migrant fish, including mortalities cited for various types of turbines, guidance by louvers, lights and others, screening, dissolved gases, predation, cumulative impacts and transportation of fish around dams. Gives guidelines for mitigation and compensation.

Long, C.W. and W.M. Marquette
Research on Fingerling Mortality in Kaplan Turbines. Bureau of Commercial Fisheries, Seattle, WA, October, 1967.

Discusses aspects of passage of fingerling salmon through large Kaplan turbines on the Columbia and Snake Rivers. Proposes research into postulated areas of mortality. Describes equipment to accomplish this.

Lucas, K.C.
The Mortality to Fish Passing through Hydraulic Turbines as Related to Cavitation and Performance Characteristics, Pressure Change, Negative Pressure and Other Factors. A paper to be presented on September 5, 1962, to the Symposium on Cavitation and Hydraulic Machinery, Sendai, Japan, held under the auspices of the International Association for Hydraulic Research, Canada Department of Fisheries, Vancouver. April 19, 1962.

Discusses various aspects of damage to small fish in passage through turbines with particular reference to cavitation effects.

Massey, Julius B.
Summary Report on Juvenile Downstream Migrant Fish Passage and Protection Studies at Willamette Falls, Oregon. Final Report. Columbia River Fishery Development Program, Project 912.4-SCR-1, Control No. 14-17-0001-456. Oregon Game Commission, Portland OR, August 1967.

Summarizes several studies of turbine mortalities at Willamette Falls in the turbines of Crown Zellerbach, Publishers Paper and Portland General Electric Company. Also summarizes studies made to provide alternative turbine and screening systems and estimates their costs.

Mathur, D and P.E Heisy
Monitoring of Fish in Pumped Storage Systems. In Biological Monitoring of Fish, C.H. Hocutt and J.R. Stauffer, Jr., Editors. D.C. Heath and Company, Lexington, MA, 1980.

Reviews common gear and methods to monitor various life stages of fish at nine operating pumped storage projects. Sampling problems associated with substantial daily water level fluctuations and relatively high velocites in intake and discharge areas are discussed. Extensive sampling at the Ludington pumped storage station in Michigan yielded a mortality of 57% in 20-50 cm fish during pumping and 45% during generation. Delayed mortalities were significant.

McIlquham, W.S.
Discussion on Proceedings Paper 1947 - Passage of Young Fish through Turbines. J. Power Division, Proceedings American Society of Civil Engineers, 1959, 85(PO5): 153-154.

Discusses engineering aspects of passage of fish through turbines.

Menzies, W.J.M, and F.T.K. Pentelow
Fisheries and the Development of Hydroelectric Power in Scotland. ICES. Salmon and Trout Committee. C.M., 1965, No. 2. 8 p.

Reviews the various provisons for upstream and downstream passage of fish past hydraulic stations with some reference to turbine mortality estimates.

Mills, D.H.
Observations on the Effects of Hydroelectric Development on Salmon Migration in a River System. I.C.E.S./C.M. No. 32, 1965, 5 p.

Discusses methods used to measure effects of hydroelectric development on a river in Scotland.

Monten, Erik
The Possibility of Salmon Passing Unharmed Through Power Plant Turbines When Descending to the Sea. Salmon Research Institute. 1955.

The report gives a synopsis of early experimental work on pressure and fish length as related to fish injury, beginning as early as 1927. This work was conducted by Alm, Carlin, Swenader, Björnemark and Lindroth. It noted that damage to sticks representing various lengths of salmon was less in large Kaplan turbines than in Francis turbines. One experiment examined the return of adult fish and use of balsa boxes.

Muir, J.F.
Passage of Young Fish through Turbines. Journal of the American Society of Civil Engineers, Power Division, February 1959, 85(PO1): 23-46.

Discusses areas of injury and mortality of fish in passing through hydroelectric turbines, including cavitation, strike and negative pressures.

Munro, W.R.
Effects of Passage through Hydro-electric Turbines on Salmonids. International

Council for the Exploration of the Sea, Salmon and Trout Committee. Committee Minutes No. 57, 1965, 5 p.

Reviews proceedings of a symposium covering passage of fish through turbines.

Oligher, R.C.
Juvenile Fish Passage through Turbines. U.S. Army Corps of Engineers, North Pacific Division. Fisheries-Engineering Research program. Third Progress Report, March 1966, p. 23-28.

This report is a summary of the studies conducted on a Francis turbine at Cushman No. 2, Shasta prototypes, and Francis model tests using various runner modifications. Tests at Big Cliff (on a Kaplan turbine) were also discussed.

Pretious, E.S., L.R. Kersey, and G.P. Contractor
Fish Protection and Power Development on the Fraser River. The Fraser River Hydro Fisheries Research Project. University of British Columbia, Vancouver B.C., February 1957.

Discusses relation of proposed hydroelectric development on the Fraser River with respect to anadromous fish impacts. Speculates on various new ways to attack fish-power problems.

Raymond, H.L.
Effects of Dams and Impoundments on Migrations of Juvenile Chinook Salmon and Steelhead from the Snake River, 1966 to 1975. Transactions American Fisheries Society, 1979, 108(6):505-529.

Discusses effects of dams on the Snake River on anadromous fish between 1966 and 1975. Attributes delayed migration and various types of mortality to the dams, as well as general decline in numbers of fish.

Rideout, S.G.
Connecticut River Mortality Studies at various Connecticut River power plants. Unpublished letter tranmitting results of several studies on the Connecticut River.

Letter from Rideout to Armand J. Millette of New England Power transmits results of tubine mortality studies at five hydroelectric plants on the Connecticut River. These are Bellows Falls, Vernon, Turner's Falls, Hadley and Boatlock Canal. Smolt-sized trout with attached styrofoam floats were passed through turbines. Mortalities ranged from 3.3 to 19.5 percent and averaged 12.6%.

Robbins, T.W., and D. Mathur
The Muddy Run Pumped Storage Project: A Case History. Transactions American Fisheries Society, 1976, 105(1):165-172.

Ecology of Conowingo Pond, the lower element of the Muddy Run pumped storage project, was studied for effects of the pumping and generating plant. Fluctuation in water levels limit fish reproduction, but mortality of fish passing through the unit appears negligible. No turbine or pump mortality estimates were made.

Turbak, S.C., D.R. Reichle, and C.R. Shriner
Analysis of Environmental Issues Related to Small-scale Hydroelectric Development IV: Fish Mortality Resulting from Turbine Passage. Environmental

Sciences Division Publication No. 1597, ORNL/TM-7521, Oak Ridge National Laboratory, Oak Ridge, TN, 1981.

A compilation of references and discussions of the various aspects of hydroelectric projects on fish with particular reference to turbine passage.

U.S. Army Corps of Engineers, North Pacific Division
Effect of Structures at Main Columbia River and Certain Other Dams on Downstream Migration of Fingerling Salmon. Research Report, Fisheries Engineering Research Program, Portland District October 1956.

Summarizes early studies that described and used gossamer bags and other methods in turbine and spillway tests at Bonneville Dam, Elwha River Dam and McKenzie River Dam.

U.S. Army Corps of Engineers, North Pacific Division
Effect of Structures at Main Columbia River Dams on Downstream Migration of Fingerlings. Progress Report, Fisheries Engineering Research Program, July 1960.

Summarizes several studies including experiments on passage, fishways, turbine guidance, and pressure changes. In addition, Bonneville Dam prototype turbine experiments of 1954 and 1956 and spillway tests of 1954 and 1956. McNary Dam turbine and spillway tests of 1955 were described. Balloon tests conducted at Elwha River Dam, McKenzie River dams and Bonneville Dam were discussed.

U.S. Army Corps of Engineers, North Pacific Division
Fish Passage Through Turbines. Progress Report, Fisheries Engineering Research Program, Walla Walla District, July 1960.

Summarizes the Francis model and the Cushman No. 2 prototype studies conducted in 1959 and 1960.

U.S. Fish and Wildlife Service
Connecticut River Mortality Studies (Bellows Falls, Vernon, Turners Falls, Hadley Station, and Boat Lock Canal at Holyoke). Includes cover letter by S.G. Rideout, Coordinator of Connecticut River Anadromous Fish Program, Hadley MA, July 1980.

A letter report listing a number of turbine mortality studies made at various hydroelectric projects on the Connecticut River. Cover letter by S.G. Rideout, Coordinator of Connecticut River Anadromous Fish Program, Hadley MA, July 1980.

Von Gunten, G.H.
Effects of Cavitation and Negative Pressures on the Passage of Fish in Hydraulic Turbines. Paper for the American Society of Civil Engineers, Hydraulic Division Conference, Seattle. U.S. Army Corps of Engineers, Walla Walla District, August 1960.

Reviews the basic concepts of fish passage through turbines and their significance. Procedures and results of model and prototype studies by the Corps of Engineers are presented.

Section 9

ANCILLARY STUDIES OF SUBJECTS WITH INDIRECT INFLUENCE ON TURBINE MORTALITY
(Identified by an "A" after date in references)

Allis-Chalmers
"Hydraulic Turbines and Auxiliaries." Commercial Publication, 1967.

A general treatise describing hydraulic turbines and their operational characteristics.

Beiningen, K.T. and W.J. Ebel
Effect of John Day Dam on Dissolved Nitrogen Concentrations and Salmon in the Columbia River, 1968. Transactions American Fisheries Society, 1970, 99(41): 664-671.

Documents nitrogen supersaturation of Columbia River water of 123-140% in 1978 below John Day Dam. Contains observations of gas bubble disease symptoms and mortality in juvenile and adult salmon caused by high flows over John Day spillway. Effects on fish are discussed. Passage of water through turbines does not increase concentrations of dissolved n_2.

Bell, M.C.
Handbook of Engineering Requirements and Biological Criteria. U.S. Army Corps of Engineers, Fisheries Engineering Research Program, Portland, OR, 1973. Contract no. DACW 57-68-C-0086.

Provides data on a great number of engineering requirements and biological criteria dealing with such things as turbine passage and screening of young salmonids.

Bell, M.C.
Personal communication to G.J. Eicher, March 1986, on turbine aspects.

Bell, M.C. and A.C. DeLacy
A Compendium on the Survival of Fish Passing through Spillways and Conduits. U.S. Army Corps of Engineers, North Pacific Division, Fisheries Engineering Research Program, Contract No. DACW 57-67-C-0105, Portland, OR, 1972.

Examines a large number of research reports covering passage of fish through conduits, spillways and similar passageways. Describes tests with fish dropped from helicopters. Gives characteristics of several types of spillway stilling basins.

Bell, M.C., Z.E. Parkhurst, R.G. Porter, and M. Stevens
Effects of Power Peaking on Survival of Juvenile Fish at Lower Columbia and Snake River Dams. Prepared for U.S. Army Corps of Engineers, North Pacific Division, Portland, OR, April 1976. Contract No. DACW 57-75-C-0173.

Provides history and criteria for management of power peaking procedures at hydroelectric plants on the Columbia and Snake Rivers.

Bjornn, T.C.
Trout and Salmon Movements in Two Idaho Streams as Related to Temperature, Food, Stream Flow, Cover and Population Density. Transactions American Fisheries Society, 1971, 100(3):423-438.

Discusses various ecological factors affecting juvenile salmonids in streams.

Bouck, G.R. and D.A. Johnson
Medication Inhibits Tolerance to Sea Water in Coho Salmon Smolts. Transactions American Fisheries Society, 1979, 108(1):63-33.

Indicates no mortality from medication in fresh water for most days tested, but high mortality in salt water. Additional recovery time from some treatments is necessary prior to exposure to salt water.

Bouck, G.R. and S. Smith
Mortality of Experimentally Descaled Coho Salmon (Oncorhynchus kisutch) in Fresh and Salt Water. Transactions American Fisheries Society, 1979, 198(1): 67-69.

Removal of scales from 25% of body of coho smolts caused no mortality in fresh water, but 75% mortality within 10 days in seawater. 90% of the fish regained salt water tolerance within 1 day in fresh water.

Brett, J.R.
Implications and Assessments of Environmental Stress. In: "The Investigations of Fish Power Problems", H.R. MacMillan Lectures in Fisheries, p. 69-83. A symposium held at the University of British Columbia, April 29-30, 1957. Edited by P.A. Larkin, University of British Columbia, Vancouver, B.C., 1958.

Discusses stress in fish particularly with respect to hydroelectric projects and passage of fish through turbines. Postulates that turbine-related stress is indiscriminate, affecting all fish equally.

Burner, C.J.
Vertical Distribution of Downstream Migrating Chinook Salmon Fingerlings in the Bonneville Forebay, with a Note upon the Rate of Migration. U.S. Fish and Wildlife Service. Unpublished, 1949, 11 p.

This study found that chinook fingerlings were as abundant at lower depths (45 and 55 feet) as they are at the surface (0 to 6 feet) in the forebay.

Calderwood, W.L.
"Passage of Smolts through Turbines. Effect of high pressures." Salmon and Trout Magazine, no. 115, September 1945, p. 214-221.

Smolt-sized brown trout were subjected to pressure of 10-45 psi, which was reduced to zero in one second. No distress or injury to three fish tested was noted.

CH_2M-Hill
Vertical Distribution of Juvenile Salmonids Entering the Turbine Intakes at Wanapum Dam. CH_2M-Hill report to Grant County Public Utilities District, 1984, 39 p., plus app.

This study was conducted to design efficient bypass systems. The study evaluated percentages of each species of fish (by depth) in the turbine and determined the fish pattern both vertically and horizontally at the powerhouse. Species evaluated included chinook, coho, sockeye, and steelhead.

Cox, David A.
Planning of Experiments. Book, Wiley and Sons, 1958.

Discusses the various aspects from a statistical standpoint of planning biological experiments.

Craddock, D.R.
An Improved Trap for the Capture and Safe Retention of Salmon Smolts. Progressive Fish-Culturist, 1961, 23(4):190-192.

Describes an improved floating trap for capturing and holding downstream migrant salmonids.

Cramer, F.K. and I.J. Donaldson
Evolution of Recovery Nets Used in Tests on Fish Passage through Hydraulic Turbines. U.S. Army Engineers, Walla Walla District. Progressive Fish-Culturist, 1964, 26:36-41.

Reviews the reason that recovery nets were developed, the use of gossamer bags and the evaluation of the nets used to recapture fish between the early 1950's and 1960's.

Dawley, E., T. Blahm, G. Snyder, and Ebel
Final Report: Studies on Effects of Supersaturation of Dissolved Gases on Fish. National Marine Fisheries Service, Northwest Fisheries Center, Seattle, WA, 1975.

Describes the effects on salmonid fish of dissolved atmospheric gases, principally nitrogen, in northwest rivers, namely the Columbia River.

Dawson, J., A. Murphy, P. Nealson, P. Tappa and C. van Zee.
Hydroacoustic Assessment of Downstream Migrating Juvenile Salmonids at Wanapum and Priest Rapids Dams in 1983. Report to Grant County Public Utility District. 23 p., plus app.

Discusses methods of hydroacoustic monitoring of fish in reservoirs behind certain Columbia River dams.

Ebel, W.J., H.L. Raymond, G.E. Monan, W.E. Farr, and G.K. Tononaka
Effect of Atmospheric Gas Supersaturation Caused by Dams on Salmon and Steelhead Trout on the Snake and Columbia Rivers. A review of the problem and the progress toward a solution, 1974. National Oceanic Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Center, Seattle, WA. Progress Report, 1975, 76 p., 3 app.

Discusses the various effects of gases dissolved in water on fish of the Columbia and Snake Rivers and possible methods of alleviating its prevalence and effects.

Elson, P.F.
Predator-prey Relationships between Fish-eating Birds and Atlantic Salmon. Fisheries Research Board of Canada. Bulletin 113, 1962, 87 p.

Discusses the relationship of fish-eating birds to Atlantic salmon, extent of problem and possible means of alleviating it.

Fisher, Richard K and Joseph M. Cybularz
Characteristics of Axial Flow Turbines Operating in Cavitating Regimes. Allis Chalmers Fluid Products Co., York, PA.

Discusses reasons for cavitation, how to avoid it and possible effects on turbines.

Fisher, Richard K. and R.K. Donaldson
Characteristics of Francis Turbines Operating in Cavitation Regimes. Allis Chalmers Fluid Products Co., York, PA.

Describes how cavitation develops in Francis turbines, unusual effects, such as core vortices and effects on turbines. How to avoid.

Foye, R.E. and M. Scott
Effects of Pressure on Survival of Six Species of Fish. Transactions of the American Fisheries Society, 1965, 94(1):88-91.

Chain pickerel, yellow perch, fallfish, common shiners, lake trout and Atlantic salmon were tested for the effects of high pressure in a steel tank 12 inches wide by 3 feet long with plexiglas viewing windows in Maine. Pressure was reduced from 300 psi to atmospheric in 10 minutes. High pressure caused extreme erratic activity in fish for a few seconds, after which fish sank to the bottom. Salmon, lake trout and fallfish had no mortality in 7 days after testing. Perch, pickerel and shiners had mortalities of more than 60 percent.

Giorgi, A.E. and Stuehrenberg, L.C.
Smolt Passage Behavior and Flow-net Relationships in the Forebay of John Day Dam. NOAA, National Marine Fisheries Service, Northwest and Alaska Fisheries Center, Coastal Zone and Estuarine Studies Division. 2725 Montlake Blvd., Seattle WA. Annual report of research for Bonneville Power Administration, 1984. Agreement DE-A179-83BP39644. 37 p. plus 3 app.

This is a continuation of work conducted and reported by Stuehrenberg and Liscom (1983). Distribution of fish in forebay, determined by purse seining and radio tracking is described. A potential avoidance reaction of chinook smolts to cooler, turbid water from John Day River (upstream of dam) is indicated; whereas, no similar behavior was observed for steelhead smolts. Fish entering the forebay near the dam at night tended to move through the dam with little delay while those entering the same area during daylight hours awaited darkness before proceding downstream. This observation is not conclusive and may be related to undetermined factors.

Groves, A.G.
Effects of Hydraulic Shearing Actions on Juvenile Salmon. Summary Report. National Oceanic and Atmospheric Administration, Northwest Fisheries Center, National Marine Fisheries Service, Seattle WA. November 1972.

Describes an experiment in which juvenile salmon were propelled by velocities up to 70 fps in jets of water into static pools -- effects on fish of various velocities.

Harvey, H.H.
Pressure in the Early Life History of Sockeye Salmon. PhD. Thesis. University of British Columbia, Vancouver. August 1963, 267 p.

A comprehensive discussion on the effect of pressure on fish. Relationship between pressure and regulatory mechanisms of the sockeye swim bladder are described in detail. Also described are tolerance to odd behavior resulting from pressure and pressure changes; relationship of dissolved gases to decompression, equilibration of fish with ambient dissolved nitrogen concentrations, as well as other related subjects. A review of related literature and appendices is also included.

Hays, L.
Determination of the Depth Distribution of Juvenile Salmonids in the Turbine Intakes at Rocky Reach and Rock Island Dams. Chelan County Public Utility District No. 1, 1984, 67 p., plus 6 app.

Salmon and steelhead juveniles pass mainly through the upper 50-60% of the turbine intakes at Rocky Reach and Rock Island Dams. All species studied had diel patterns with more fish in the upper part of intake during daylight than in darkness.

Hogan, J.
The Effects of High Vacuum on Fish. Transactions of the American Fisheries Society, 1941, 70:469-474.

Describes early research on subjection of small fish to intermittant and continuous vacuum.

Holmes, H.B.
Reaction of Salmon Fingerlings to Pressure Changes. Unpublished report. U.S. Fish and Wildlife Service, Portland OR, March 24, 1952, 6 p.

Fish become uneasy but not injured when under considerable pressure, which compresses the body increasing their specific gravity and causing them to sink or swim with head elevated. If air is present at surface, fish gulp it to adjust body gas content. Fish accommodated to high pressure, which is suddenly released, causes gas in the body to expand causing mortality. The same response to vacuum also occurs. Fish accommodated to three atmospheres and reduced to one react the same as in a reduction of one atmosphere to one third. Reduction from high to low pressure must be in a fraction of a second to cause fatalities. In nature, young salmonids have become accommodated to pressures existing 50 to 100 feet below the surface. In cases wherein fish pass from high pressure above a turbine runner to a vacuum below, mortality would be expected.

Holmes, H.B. and I.J. Donaldson
A Study of the Effect of Pressure Changes Upon Salmon Fingerlings as Applied to Passage through Spillway at Mayfield Dam, Cowlitz River, WA. Laboratory research report conducted for the City of Tacoma, Department of Public Utilities, U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries, 1961.

Studies examined the effect of taking small salmonids to high pressures, then changing in a fraction of a second to pressures below atmospheric Some mortality occurred.

Horton, H.F.
An Evaluation of Some Physical and Mechanical Factors Important in Reducing Delayed Mortality of Hatchery-reared Rainbow Trout. Progressive Fish-Culturist, 1956, 18(1):13-14.

Studies of post-planting mortalities of rainbow trout found that a transport temperature of 40° F controlled delayed mortalities from handling. Sodium amytal was ineffective. Loading and unloading technique variations were inconsequential. Venturi aeration reduced delayed mortalities.

Institute of Environmental Medicine
The Effects of Changes in Hydrostatic Pressure on Some Hudson River Biota. New York University Medical Center, New York. Progress report for Consolidated Edison Company of New York, Inc., 1975.

An in-depth review of the effect of pressure on fish and other biota is presented in a literature review which precedes the discussion of simulation studies designed to evaluate pressure effects of the Cornwall pumped-storage hydroelectric plant. Variations in pressure which occur in prototype installations at an instantaneous point in time could not be simulated in the laboratory. Considerable discussion is presented regarding effects of pressure changes on various life stages of striped bass. Results indicate rapid decompression from either an acclimated depth or to subatmospheric pressures (encountered during turbine passage) are the critical pressure changes affecting survival during entrainment.

Jensen, A.L. and C.W. Long
A System for Determining Cavitation Production by Acoustic Monitoring in Turbines. Progress Report No. 47, Fish-Passage Research Program, Bureau of Commercial Fisheries, 1964, p. 1-5.

Describes a system to auditorially monitor cavitation production in turbines so that its location could be traced.

Jensen, A.L., W. Marquette, C.W. Long, and R.W. Duncan
Evaluation of Equipment for Recovering Fish Passed through Kaplan Turbines. Progress Report No. 52, Fish-Passage Research program, BCF, 1964, p. 1-11.

Discusses facilities for recapturing fish without causing injury after passage through turbines.

Johnson, F.A.
A Device for Fish Recovery During Turbine-passage Mortality Studies. The Progressive Fish-Culturist, October 1970, 32(4):236-239.

Describes a styrofoam 1.5 x 1.0" float and fish hook device to aid recovery of test and control fish in turbine mortality experiments. Fish were recovered by dip net teams in boats. The size of the stream was not given. The system would seem to have drawbacks for large waters. The float could influence the path of passage through the turbine, particularly for small fish.

Kostecki, Paul and Boyd Kynard
Potential Effects of Scale Loss on Mortality of Atlantic Salmon and Juvenile Clupeids. In <u>Potential effects of Kaplan, Ossberger, and Bulb Turbines on Anadromous Fish of the Northeast United States</u>. U.S. Fish and Wildlife Service, Newton Corner, MA, September 1982.

Describes experiments to explore the effect of scale loss as a result of turbine passage, handling and as an artificially induced impact. Found that scale loss as an effect in many experiments could not be separated from those caused by blows causing internal injuries. Artificially descaled Atlantic salmon smolts did not exhibit mortalities in fresh water unless more than 20% of scales were removed. Scales were found to be lost more easily from tail and dorsal areas. Loss in the stomach area was most damaging but also much

lower in occurrence. Blueback herring were much more fragile and suffered mortalities with only 10% scale loss.

Leman, B.D.
Rock Island Project - Alleviation of Mortality to Downstream Migrant Salmonids on Cooling Water Screens. Public Utility District No. 1 of Chelan County, WA. Undated. (Covers testing in 1958 and 1959.)

Cooling water is taken from the ceiling of the scroll cases of the turbine units via a screened outlet. Downstream migrant salmonids were impinged on screen cleaning the water before entering the heat exchangers. Hoods were devised which extended from the screens in the ceiling about 20 inches down into the scroll case. Loss of fish in this area was almost eliminated. The work is evidence that downstream migrant salmon are most prevalent in the upper water layers of the penstocks and passages of the power plant.

Long, C.W.
Diel Movement and Vertical Distribution of Juvenile Anadromous Fish in Turbine Intakes. U.S. Fish and Wildlife Service, Fishery Bulletin 66(3):599-609. Washington, D.C., September 1968.

Finding is that most chinook salmon and steelhead trout were caught at night as compared to daytime sampling. Salmonids were mostly in the upper 30% of water (within 4.6 meters of the ceiling) in the intakes at McNary and The Dalles Dams.

Long, Clifford W., J.R. McComas, and B.H. Monk
Use of Salt (NaCl) Water to Reduce Mortality of Chinook Salmon (Oncorhynchus tshawytscha) During Handling and Hauling. Mar. Fish. Rev., 1977.

A small scale study in 1975 at Bonneville Dam showed that adding NaCl to water used in handling and hauling juvenile chinook salmon increased their survival and protected them from Saprolegnia spp. fungus.

Long, C.W.
Final Report on Vertical Distribution of Fingerling Salmonids in Turbine Intakes of the Bonneville First Powerhouse. Report to U.S. Army Corps of Engineers, 1975, Contract No. DACW 57-75-F-0569, 10 p.

Measured behavior of juvenile samonids in turbine intakes at The Dalles and McNary Dams to aid in studies of mortality reduction. Findings were that most chinook salmon, steelhead trout and lamprey moved at night, and most salmonids were in the uppermost 30% of depth but lampreys were deeper. The upper level of approach into the turbine causes fish to concentrate and pass by the turbine hub.

Meekin, T.K. and R.L. Allen
Summer chinook and sockeye salmon mortality in the upper Columbia River and its Relationship to Nitrogen Supersaturation. Washington Department of Fisheries Technical Report 12 (Nitrogen supersaturation investigations in the mid-Columbia River), 1974, p. 127-153.

Discusses relation of nitrogen supersatuation in the upper Columbia River to mortality of juvenile salmonids, its relation to dams and possible corrective measures.

Munro, W.R.
Observation on the Migration of Salmonids in the River Tummel (Perthshire, Scotland). ICES. Salmon and Trout Committee. C.M., 1965.

Discusses migrations of young salmonids downstream in the River Tummel in Scotland, the influences of dams, and turbine mortality implications.

Pfau, A.
Hydraulic Turbine Handbook. Third Edition. Hydraulic Turbine Department, Allis-Chalmers Manufacturing Co., 1948.

Describes design and operation of hydraulic turbines.

Pinder, L.J. and J.G. Eales
Seasonal Buoyancy Changes in Atlantic Salmon (Salmo salar) Parr and Smolt. Journal Fisheries Research Board of Canada, 1969, 26:2093-2100.

Tells why Atlantic salmon are more flexible in response to water level changes during warmer periods.

Prentice, E.F., C.W. Sims, and D.L. Park
A Study to Determine the Biological Feasibility of a New Fish Tagging System. National Oceanic Atmospheric Administration, National Marine Fisheries Service, Northwest and Alaska Fisheries Center, Coastal Zone and Estuarine Studies Division, 2725 Montlake Blvd. E., Seattle, WA. Annual Report for Bonneville Power Administration, U.S. Department of Energy, May 1985, Contract DE-A179-84BP11982, Project 83-319. 36 p. plus app.

Evaluation of a Passive Integrated Transponder (Pit) tag indicated successful injection of the radio tag into the body cavity of juvenile steelhead based on survial, tag retention and tissue response. This tag, combined with related detector system, may prove useful in the detection and recording of juvenile salmonid smolt travel time, migration timing, and survival through monitoring of fingerling collectors at dams on the Snake and Columbia Rivers. A prototype detection system proved accurate and reliable in an oval-flume test facility. Implementation of a tagging/monitoring system such as this would diminish the need for use of large quantities of fish in various passage studies as well as making the handling of untagged fish and exhaustive fish recovery methods unnecessary. Cost is a problem.

Raemhild, G.A., B. Ransom, B. Ross, B. and M. Dimmitt
Hydroacoustic Assessment of Downstream Migrating Salmon and Steelhead at Rock Island Dam in 1983. BioSonics, Inc. report to Chelan County Public Utility District, 1983, 33 p., plus app.

Explores depths of downstream migrant salmon in the pool above Rock Island dam as found by hydroacoustic sensing and monitoring.

Raemhild, G.A., S. Kuehl, and A. Murphy
Hydroacoustic Assessment of Downstream Migrating Juvenile Salmonids at Priest Rapids Dam in Summer 1983. BioSonics report to Grant County Public Utility District, 1984.

Describes monitoring results by hydroacoustic work of juvenile salmonoids in the reservoir of Priest Rapids dam.

Rees, W.J.
The Vertical and Horizontal Distribution of Seaward Migrant Salmon in the Forebay of Baker Dam. Washington Department of Fisheries, Fisheries Research Paper, 1957, 2(1):5-17.

Variable mesh gill nets were used to determine the vertical and horizontal distribution of downstream migrant salmonoids in the forebays of Baker Dam.

A definite preference by all species for the surface levels was found.

Regenthal, A.F., and W.H. Rees
The Passage of Fish through Mud Mountain Dam, 1957. Unpublished. Washington Department of Fisheries, Olympia, WA, 1957.

This study found that nearly 100% of both coho and chinook salmon would leave the reservoir via the only exit which is at the bottom at forebay levels of 118 feet or less; 75 percent of coho and 55 percent of chinook would leave at a level of 133 feet; 60 and 48 percent respectively at 146 feet; and 8 percent or less of each species at 160 feet or more. The report provides further evidence of preference for the higher water levels.

Rowley, W.E, Jr.
Hydrostatic Pressure Tests on Rainbow Trout. California Fish and Game, July 1955, 41(3):243-244.

Describes pressure tests to find mortality levels of rainbow trout. Pressures of over 300 psi were withstood.

Rucker, R.R.
Gas-bubble Disease of Salmonids. A Critical Review. Bureau Sport Fisheries Wildlife Technical Paper 58, 1972, 11 p.

Reviews the history of nitrogen gas supersaturation and its effect of fish.

Ruggles, C.P.
A Review of the Downstream Migration of Atlantic Salmon. Freshwater and Anadromous Division, Resource Branch, Department of Fisheries and Oceans. Halifax, Nova Scotia, July 1980.

Reviews published and unpublished information on downstream salmonid migrations, with particular reference to species similar in life history to Atlantic salmon. Describes mechanisms, hazards and mortalities experienced with particular reference to hydroelectric development.

Stuehrenberg, L.C., and K. Liscom
Radio Tracking of Juvenile Salmonids in John Day Reservoir, 1982. National Oceanic Atmospheric Administration, National Marine Fisheries Service, Northwest and Alaska Fisheries Center, Seattle, WA. Final report for U.S. Army Corps of Engineers, March 1983, Contract DACW 57-82-F-0373. 21 p., plus app.

Radio tags were implanted in steelhead and chinook salmon smolts to determine effects of various spill and powerhouse operational modes on fish behavior in the forebay and in passage time through John Day Dam. Various spill patterns and volumes are related to passage through the spillway versus turbines. Equal proportions of smolts passed through spillway and powerhouse. Results indicate smolts hold up in the forebay by day and pass through the dam at night. Trends indicated are based on rather small sample sizes.

Stuehrenberg, L.C., K.L. Liscom and D. Faurot
Migration Patterns of Salmonid Smolts in the John Day Dam Forebay, 1980-82. In <u>Fish Passage Development and Evaluation Program 1979-83</u>. Sixth Progress Report, U.S. Army Corps of Engineers, North Pacific Division, Environmental Resources Branch, 1984, p. 85-94.

Tracks the migration of salmon and steelhead smolts in the John Day pool. Gives timing and rates of movement as well as levels of travel within the pool.

Theus, H.P.
Fingerling Fish Research. High-velocity Flow through 4-inch Nozzle. Letter report, U.S. Army Corps of Engineers, North Pacific Division, 1972.

Fingerling salmonids were jetted from a 4 inch nozzle into static water. A velocity of 57.5 fps produced no mortality. 2.4 percent occurred at 67 fps, 7.2 percent at 77.5 and 31 percent at 92 fps. Only a few fish showed injuries including popped eyeballs, broken backs, torn gill covers and decapitation.

Thompson, Richard B.
A Study of Localized Predation on Marked Chinook Salmon Fingerlings Released at McNary Dam. Washington State Department of Fisheries, Fisheries Research Papers, April 1959, 2(2):82-83.

The results of this study indicated that predation was too slight to bias dam mortality test results.

Trefethen, P.S.
1955. Observation on the vertical distribution of fingerlings in the forebay of Baker Dam. Technical Progress Report No. 8. Pacific Salmon Investigations U.S. Fish and Wildlife Service, Seattle, Washington, July 1955.

This was a progress report describing incidence of schools of fingerlings from the surface to 60 feet in 10 foot intervals during May 1955. 65% of the schools were in the upper 30 feet of water.

Vanderwalker, J.G.
Responses of Fingerling Coho and Chinook Salmon to Modified Flows in a Simulated Turbine Intake. Transactions American Fisheries Society, 1970, 99(3):532-539.

Normal smooth and two modified penstock ceiling surfaces were tested to learn if more downstream fish could be induced to enter gate well slots. The roughened surfaces induced slightly more coho and substantially more chinook migrants to move into the gatewells. The tests were conducted on a model conduit with two types of current modifying surfaces.

Wedemeyer, G.
Some physiological consequences of handling stress in the juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). Journal Fisheries Research Board of Canada, 1972, 29:1780-1783.

Gear was tested to determine distribution of downstream migrant salmonids in dam forebays. Variable mesh gill nets, centrifugal pumps and echo sounding gear were evaluated. Evaluates stress of handling juvenile salmon and steelhead trout in soft water compared to water enhanced with NaCl and calcium which alleviates hypoglycemia and hypochloremia inducing reduction in handling stress.

Appendix A

CRITIQUES OF TURBINE INDUCED FISH MORTALITY STUDIES

These studies are quite variable in test design and quality, and the amount of data presented to aid in their understanding and evaluation. The greatest single area of deficiency is that concerning environmental influences. In some studies, such as those using models, aside from temperature, this is less important. In others, many environmental variables such as water quality, meteorology and activity of predatory species could be decisive. Ratings given these studies are indicators of value only to this review and do not indicate worth for the purpose originally intended.

Ratings are subjectively based on the degree to which four aspects are addressed, including:

Plant description

This involves a general description of the site including head, elevation, river flow, geographic locations and construction data; and the power house, including number and type of turbines and details of the individual units tested.

Procedures

This includes the design of the study and attention given to details and potential problem areas.

Test Data Reporting

The rating for this facet reflects the attention given to adequately and clearly describing the test operations and presenting results.

Environmental Data Adequacy

The degree to which the study records and describes environmental data of logical bearing on the test and the way in which such data influence results are reflected in this rating.

Each aspect is rated from zero to four. The lowest rating is zero because this is the amount of attention given some of the factors by some studies. The study rating is derived from the total of all aspect ratings divided by the maximum possible of 16 and is expressed as a percentage of a perfect score.

AUTHOR: Andrew, F.J. and G.H. Geen
TITLE: Sockeye and Pink Salmon Investigations at the Seton Creek -- Hydroelectric Installation
YEAR: 1958
PUBLISHED BY: International Pacific Salmon Fisheries Commission
REPORT TYPE: Informational

STUDY DATE: 1957
RIVER: Seton Creek
STATE/PROVINCE: British Columbia
RECOVERY METHOD: Fyke net in tailrace area
SPECIES: Sockeye
FISH SIZE: 3-3/8in (8.6cm)
SOURCE OF FISH: Chilko Lake
TEST FISH INTRODUCTION METHOD: Forebay
MORTALITY: 9.2%

NAME OF PLANT: Seton Creek Hydro-electric Installation
DATE INSTALLED: 1956
PLANT UNIT NO.: 1
TURBINE TYPE: Vertical Francis
TURBINE SIZE: 58,500hp
RUNNER DIAMETER: 144in (366cm)
NUMBER OF BLADES:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES: 6in (15.2cm)
RUNNER SPEED: 120rpm
MAXIMUM PERIPHERAL VELOCITY: 75ft/sec (23m/s)
RUNNER ELEVATION ABOVE TAILWATER: 16ft (4.9m) during test
UNIT EFFICIENCY:
HEAD: 150ft (45.7m)
TURBINE FLOW: 4500cfs (127m^3/s)

* Information supplied by reviewer

VARIABLES DISCUSSED: Injury, recovery gear, controls, cavitation, runner diameter, capture efficiency, tailwater elevation and pressure

CRITIQUE: An excellent study, using both live and dead fish and recording net losses. Velocity was recorded for recovery area. Head was held at 142ft and the gage pressure difference was 64lbs (from +62 to -2). Fish were acclimatized in net pens before tests. Tests were replicated four times for live fish and twice for dead. Recovery rate was good It was postulated that measured mortality was less than would be found with more normal tailwater levels than the unusually high flows encountered. Needs a better description of physical conditions within turbines. No environmental data were provided. Although title includes pink salmon, only sockeye were tested.

RATINGS

Plant description	3
Procedures	4
Test data recording	4
Environmental data adequacy	0
Study rating	69%

AUTHOR: Anonymous
TITLE: Results of Mortality Study of Downstream Migrating Juvenile American Shad, Alosa sapidissima, in H.W.P. Co. Canal and Hadley Station, Holyoke, Massachusetts, 1958.
YEAR: 1958
PUBLISHED BY: Unpublished Manuscript
REPORT TYPE: Informational
STUDY DATE: 1958
RIVER: Connecticut
STATE/PROVINCE: Massachusetts
RECOVERY METHOD: Trawl nets
SPECIES: Shad
FISH SIZE: Juvenile
SOURCE OF FISH: River
TEST FISH INTRODUCTION METHOD: Penstock
MORTALITY: Minimal

NAME OF PLANT: Hadley FAlls
DATE INSTALLED:
PLANT UNIT NO.:
TURBINE TYPE: Kaplan-Francis
TURBINE SIZE:
RUNNER DIAMETER:
NUMBER OF BLADES:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED:
MAXIMUM PERIPHERAL VELOCITY:
RUNNER ELEVATION ABOVE TAILWATER:
UNIT EFFICIENCY:
HEAD:
TURBINE FLOW:

VARIABLES DISCUSSED: Temperature

CRITIQUE: This was a study to determine the effects of various plants at Hadley Falls on the Connecticut River on American shad. Test and dead fish were passed through the turbines and recaptured in trawl nets downstream. Only some of the turbines were tested. The trawl at Hadley #2 plant strained about 4% of the flow and recaptured 3.65% of dead fish and 3.7% of test fish. The conclusion was minimal impact. A similar test was peformed at Hadley Falls Station. Results were inconclusive. These tests were not very intensive or extensive.

RATINGS

Plant description	1
Procedures	3
Test data recording	3
Environmental data adequacy	0
Study rating	44%

AUTHOR: Bell, Charles Edward
TITLE: Immediate Mortality of Adult American Shad (*Alosa sappidissima*) Resulting from Passage Through a Kaplan Turbine at Holyoke Dam, Massachusetts
YEAR: 1982
PUBLISHED BY: University of Massachusetts
REPORT TYPE: Informational
STUDY DATE: 1981-83
RIVER: Connecticut
STATE/PROVINCE: Massachusetts
RECOVERY METHOD: Radio telemetry
SPECIES: American shad
FISH SIZE:
SOURCE OF FISH:
TEST FISH INTRODUCTION
METHOD: Penstock entrance
MORTALITY: 0-17%

NAME OF PLANT: Hadley Falls
DATE INSTALLED: 1951
PLANT UNIT NO.: 1
TURBINE TYPE: Kaplan
TURBINE SIZE: 12,000hp
RUNNER DIAMETER: 170in (432cm)
NUMBER OF BLADES: 5
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES: 8.9ft (2.71m)
RUNNER SPEED: 129rpm
MAXIMUM PERIPHERAL VELOCITY:
RUNNER ELEVATION ABOVE TAILWATER:
UNIT EFFICIENCY:
HEAD: 51ft (15.5m)
TURBINE FLOW: 3500cfs (99.1m^3/s)

VARIABLES DISCUSSED: Controls, travel time

CRITIQUE: A 17mw Kaplan turbine with nominal head of 51 feet (15.5m) was tested for immediate mortality of groups of adult American shad numbering 20 in 1981 and 36 in 1982. In 1981, control fish were used in a normal manner, subjected to all of the non-turbine environmental factors, but in 1982 they were held in a tank in the project area. This would appear to control only the factor of holding fish with radio tags in static water. Mortality levels of 53% for test fish and 38% for controls were obtained in 1981 and 18.5% for test fish in 1982. No turbine data pertinent to fish passage such as runner elevation with respect to tailwater are given. No environmental data are presented.

RATINGS

Plant description	2
Procedures	2
Test data recording	3
Environmental data adequacy	0
Study rating	50%

AUTHOR: Bell, Milo and Kenneth J. Bruya
TITLE: Updated Compendium on the Success of Passage of Small Fish Through Turbines -- Foster Dam
YEAR: 1981
PUBLISHED BY: U.S. Army Corps of Engineers, North Pacific Division

REPORT TYPE: Exploratory
STUDY DATE: 1969
RIVER: South Santiam
STATE/PROVINCE: Oregon
RECOVERY METHOD: Large net
SPECIES: Chinook salmon
FISH SIZE: 4-1/2 - 5in (12cm)
SOURCE OF FISH: Hatchery
TEST FISH INTRODUCTION METHOD:
MORTALITY: 11.2% average

NAME OF PLANT: Foster
DATE INSTALLED:
PLANT UNIT NO.: 1-2
TURBINE TYPE: Kaplan
TURBINE SIZE: 13,800hp
RUNNER DIAMETER: 100in (254cm)
NUMBER OF BLADES: 6
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED: 257rpm
MAXIMUM PERIPHERAL VELOCITY: 112ft/sec (34m/s)
RUNNER ELEVATION ABOVE TAILWATER:
UNIT EFFICIENCY:
HEAD: 101ft (30.8m)
TURBINE FLOW: 800cfs (22.7m^3/s)
PLANT SIGMA: .430-.540

VARIABLES DISCUSSED: Wicket gate openings, turbine efficiency, shear effect, injury, recovery gear, predation, controls, gases, fish length, number of fish, runner sigma and pressure

CRITIQUE: Foster Dam fish mortality study performed in 1969 by Raymond Oligher of the Corps of Engineers, is reported on in section II of this publication, which is difficult to follow because it treats a number of other subjects and only intermittently returns to this one. Foster Dam is notable as one of the highest head, if not the most so, Kaplan installations existent, at up to 110 feet (33.5 m). During the test it was noted that large resident fish came through the turbines, but their condition is not noted. Adjusted turbine survival was tested against draft tube velocity, but no correlation was found. Velocities in these draft tubes were apparently considered higher than normal (in excess of 17 fps <5.2 ms>). This appears to be a good test series, with a total of 43 runs giving strong substance. Insufficient data are provided to adequately assess it, however. No environmental data are provided. Parameters explored are draft tube effects, head and efficiency. Of five percentage gate openings tested (0-25-50-75-100), 50 percent proved most efficient with a mean of 87.8 percent, ± 3.1. Greatest survival of fish, however, occurred at 25 percent gate opening and a mean efficiency of 85.7 ± 5.2 which is a departure from the norm of highest efficiency producing best survival. Average mortality was 11.2 percent.

RATINGS

Plant description	3
Procedures	4
Test data recording	3
Environental data adequacy	0
Study rating	63%

AUTHOR: Canada Department of Fisheries
TITLE: The Fisheries Problems Associated With The Power Development Of The Puntledge River, Vancouver Island, B.C.
YEAR: 1958
PUBLISHED BY: Canada Department of Fisheries

REPORT TYPE: Informational
STUDY DATE: 1955
RIVER: Puntledge
STATE/PROVINCE: British Columbia
RECOVERY METHOD: Floating trap net in tailrace
SPECIES: Steelhead, Kamloops trout, salmon fry
FISH SIZE: Fry & smolts
SOURCE OF FISH:
TEST FISH INTRODUCTION METHOD: In to Pipeline at the Forebay
MORTALITY: 4.9in steelhead (41.9%)
2.7in Kamloops (27.5%)
1.8in Kamloops (28.8%)
1.4in salmon fry(32.6)

NAME OF PLANT: Puntledge
DATE INSTALLED:
PLANT UNIT NO.:
TURBINE TYPE: Vert Shaft Francis
TURBINE SIZE:
RUNNER DIAMETER:
NUMBER OF BLADES:
BLADE TIP CLEARANCE
SPACE BETWEEN BLADES:
RUNNER SPEED: 277rpm
MAXIMUM PERIPHERAL VELOCITY: 103f/s (31.4m/s)
RUNNER ELEVATION ABOVE TAILWATER: 5ft (1.5m) above min. tailwater
UNIT EFFICIENCY:
HEAD: 340 ft (104m)
TURBINE FLOW:

VARIABLES DISCUSSED: Capture efficiency, injury, recovery gear, controls, fish length, number of fish

CRITIQUE: Ten tests, each comprised of 1500 live and 500 dead fish, were conducted. Effectiveness of recovery gear in tailrace was determined by recapture of dead fish released in pipeline at the forebay. No visible injuries occurred to 75% to 86% of fish killed during passage through the turbine.

SIZE GROUP	SPECIES	PERCENT LIVE RECOVERIES	PERCENT DEAD RECOVERIES	FINAL CALCULATED MORTALITY PERCENT RATE
4.9 in	Steelhead	3.5	3.9	41.9
2.7 in	Kamloops	3.4	3.4	27.5
1.8 in	Kamloops	4.9	4.2	28.8
1.4 in	Salmon Fry	2.5	3.2	36.6

RATINGS

Plant description	2
Procedures	3
Test data recording	3
Environmental data adequacy	0
Study rating	50%

AUTHOR: Coordinator, Technical Committee, Connecticut River
TITLE: Mortality to Fish Passing through Turbines at Holyoke Dam
YEAR: 1969
PUBLISHED BY: Unpublished
REPORT TYPE: Informational
STUDY DATE: 1969
RIVER: Connecticut
STATE/PROVINCE: Massachusettes
RECOVERY METHOD: Dip net from boat
SPECIES: trout
FISH SIZE: Smolt-sized
SOURCE OF FISH: Hatchery
TEST FISH INTRODUCTION: Forebay
MORTALITY: 24%

NAME OF PLANT: Hadley Falls
DATE INSTALLED:
PLANT UNIT NO.:
TURBINE TYPE: Kaplan
TURBINE SIZE: 24,000hp
RUNNER DIAMETER:
NUMBER OF BLADES:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED:
MAXIMUM PERIPHERAL VELOCITY:
RUNNER ELEVATION ABOVETAILWATER:
UNIT EFFICIENCY:
HEAD: 51ft (15.5m)*
TURBINE FLOW: 3500cfs (99cm^3/s)

VARIABLES DISCUSSED: Injury and capture efficiency

* Item supplied by reviewer

CRITIQUE: Smolt-sized fish fitted with colored styrofoam tags were passed through a Kaplan turbine at Holyoke Dam. The tags floated them to the surface of the tailwater where they were dipnetted from boats for examination. Control fish were subjected to tagging stress only and held in tanks. No environmental data are given. A mortality of 24.0% was obtained, which compares with 19.5% of 1968 test. This was not intended as a final test, and is somewhat superficial.

RATINGS

Plant description	1
Procedures	2
Test data recording	2
Environmental data adequacy	0
Study rating	32%

AUTHOR: Coordinator Connecticut River Technical Committee
TITLE: Mortality to Fish Passing Though Turbines at Turners Falls
YEAR: 1969
PUBLISHED BY: U.S. Fish and Wildlife Service, Unpublished report

REPORT TYPE: Informational
STUDY DATE: 1969
RIVER: Connecticut
STATE/PROVINCE: Massachusetts
RECOVERY METHOD: Styrofoam float
SPECIES: Trout
FISH SIZE: Smolt-sized
SOURCE OF FISH: Hatchery
TEST FISH INTRODUCTION
METHOD: Forebay
MORTALITY: 9.8%

NAME OF PLANT: Turners Falls
DATE INSTALLED:
PLANT UNIT NO.:
TURBINE TYPE:
TURBINE SIZE:
RUNNER DIAMETER:
NUMBER OF BLADES:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED:
MAXIMUM PERIPHERAL VELOCITY:
RUNNER ELEVATION ABOVE
TAILWATER:
UNIT EFFICIENCY:
HEAD:
TURBINE FLOW:

VARIABLES DISCUSSED: Controls

CRITIQUE: Smolt-sized rainbow trout fitted with colored styrofoam tags were passed through a turbine at Turner Falls. The tags provided sufficient buoyancy to bring the fish to the surface where they could be captured by dip net from a boat in the tailrace. Controls were untagged fish, fish formerly tagged but with tag removed, and tagged fish held in a live box but not subjected to the non-turbine stresses of test fish. They suffered no mortality. Test fish mortality was 9.8%. A similar test in 1968 found 3.3%. This was a somewhat superficial test and not too well controlled. It was not intended to give more than preliminary indices.

RATINGS	
Plant description	0
Procedures	2
Test data recording	2
Environmental data adequacy	0
Study rating	25%

AUTHOR: Cramer, Frederick K. and Raymond C. Oligher
TITLE: Passing Fish Through Turbines, Model Turbine Experiments
YEAR: 1960
PUBLISHED BY: U.S. Army Corps of Engineers, Walla Walla District, Progress Report No. 1, September 1960

REPORT TYPE: Exploratory
STUDY DATE: 1959
RIVER:
STATE/PROVINCE: Pennsylvania
RECOVERY METHOD:
SPECIES: Largemouth bass
FISH SIZE: 1.5-2.4in (3.8-6.1cm)
SOURCE OF FISH: Hatchery
TEST FISH INTRODUCTION METHOD:
MORTALITY: 4 - 94%

NAME OF PLANT: Allis Chalmers Turbine Laboratory
DATE INSTALLED:
PLANT UNIT NO.: Model
TURBINE TYPE: Kaplan
TURBINE SIZE:
RUNNER DIAMETER: 12in (30cm)
NUMBER OF BLADES:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED: 100-1400rpm
MAXIMUM PERIPHERAL VELOCITY:
RUNNER ELEVATION ABOVE TAILWATER:
UNIT EFFICIENCY:
HEAD: 5-45ft (1.5-13.7m)
TURBINE FLOW:

VARIABLES DISCUSSED: Tailwater levels, wicket gates, blade

CRITIQUE: The model (McNary prototype) studies showed that survival decreased with runner speed and that tailwater elevation could affect survival. Test fish and controls were used. Controls were not subjected to the turbine but were held. All fish were returned to the hatchery for observation. Mortality increased with runner speed (less than 100 to 1400 rpm). Survival was less at a tailwater elevation below as compared to above the runner (centerline elevation) but probably no significant difference was due to variation. Normal speed of unit was 500 rpm (at 45 feet of head). At 500 rpm, mortality was from two to four times greater with tailwater above than below runner centerline. Survival varied from 6 to 96% and was quite variable. Study results should be carefully examined and weighed before use.

RATINGS

Plant description	4
Procedures	3
Test data recording	3
Environmental data adequacy	3
Study rating	81%

AUTHOR: Cramer, Frederick K. and Raymond C. Oligher
TITLE: Fish Passage Through Turbines, Further Model Turbine Experiments -- Francis Runers
YEAR: 1961
PUBLISHED BY: U.S. Army Corps of Engineers, Walla Walla District, Progress Report No. 3, April 1961

REPORT TYPE: Exploratory
STUDY DATE: September-October 1960
RIVER:
STATE/PROVINCE: Pennsylvania
RECOVERY METHOD:
SPECIES: Largemouth bass
FISH SIZE: 3-1/2, 2-1/4 & 1-1/2in
SOURCE OF FISH: Hatchery
TEST FISH INTRODUCTION METHOD:
MORTALITY:

NAME OF PLANT: Allis Chalmers Turbine Laboratory
DATE INSTALLED:
PLANT UNIT NO.: Model
TURBINE TYPE: Francis
TURBINE SIZE:
RUNNER DIAMETER: 12in (30cm)
NUMBER OF BLADES: 8-17
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED: Less than 250rpm--more than 850
MAXIMUM PERIPHERAL VELOCITY:
RUNNER ELEVATION ABOVE TAILWATER:
UNIT EFFICIENCY: 84.67 - 92.75
HEAD: 5-45ft (81.5-13.7m)
TURBINE FLOW:

VARIABLES DISCUSSED: Space between blades and runner speed

CRITIQUE: Objective was to determine the relationship between runner speed and clearance in a model turbine. The Francis models used in previous tests (1959) were modified for this test by removing several wicket gates, portions of the intake edge of the blade, and runner blades. The results of tests indicated that small changes in clearance between intake edge of blade and wicket gates resulted in a significant decrease in mortality; increased runner speed resulted in increased mortality.

RATINGS	
Plant description	4
Procedures	3
Test data recording	3
Environmental data adequacy	3
Study rating	81%

AUTHOR: Cramer, Frederick K. and Raymond C. Oligher
TITLE: Fish Passage Through Turbines, Tests at Cushman No. 2 Hydroelectric Plant
YEAR: 1960
PUBLISHED BY: U.S Army Corps of Engineers, Walla Walla District, Progress Report No.3, September 1960

REPORT TYPE: Exploratory
STUDY DATE: 1960
RIVER: North Fork, Skokomish River
STATE/PROVINCE: Washington
RECOVERY METHOD: Large net
SPECIES: Chinook, coho, rainbow, steelhead
FISH SIZE:
SOURCE OF FISH: Hatchery
TEST FISH INTRODUCTION METHOD: Penstock injection
MORTALITY: 22.7 - 55.4%

NAME OF PLANT: Cushman No. 2
DATE INSTALLED:
PLANT UNIT NO.: 1
TURBINE TYPE: Francis
TURBINE SIZE: 37,500hp
RUNNER DIAMETER: 83in (211cm)
NUMBER OF BLADES:
BLADE TIP CLEARANCE: 3-3 1/2in (7.6-8.9cm)
SPACE BETWEEN BLADES
RUNNER SPEED* 300rpm
MAXIMUM PERIPHERAL VELOCITY: 108ft/sec (33m/s)
RUNNER ELEVATION ABOVE TAILWATER: 11.25-5.5ft (3.4-1.7m)
UNIT EFFICIENCY:
HEAD: 450ft (137m)
TURBINE FLOW: 800cfs (22.7m^3/s)

VARIABLES DISCUSSED: Wicket gate openings, injury, controls, fish length, turbine efficiency, capture efficiency, tailwater elevation and pressure

CRITIQUE: The study evaluated survival of several species under 12 separate combinations of operating conditions in 46 tests. All species were combined to estimate survival which varied from 44.6 to 77.3%. Tailwater elevation and wicket gate variables did not appear to affect survival except at 40% gate. Size of fish were reported as large, medium, and small. Control and test fish were held three days to assess delayed mortality which was on a descending scale with 82.7% of the total on the first day, 10.5% on the second day, and 6.8% the third day for test fish. Comparable control fish mortality was 76.3%, 13.2% and 10.5% respectively. Average delayed mortality was low at 3.9% for test fish and 1.9% for controls. Controls were placed into tailrace. Dead fish were placed into the turbine and recovered -- 90.2%. Live fish releases in the tests resulted in 90% recovery. Dye tests were run to estimate time of passage -- 2 to 4 minutes, depending on gate opening. This was a carefully conducted test.

RATINGS	
Plant description	3
Procedures	4
Test data recording	4
Environmental data adequacy	1
Study rating	75%

AUTHOR: Cramer, Frederick K. and Raymond C. Oligher
TITLE: Fish Passage Through Turbines, Further Tests at Cushman No. 2 Hydroelectric Plant
YEAR: 1961
PUBLISHED BY: U.S. Army Engineers, Walla Walla District, Progress Report No. 4. July 1961

REPORT TYPE: Exploratory
STUDY DATE: April 1961
RIVER: Skokomish
STATE/PROVINCE: Washington
RECOVERY METHOD: Large net
SPECIES & SIZE: Coho - 3in (7.6cm)
Steelhead - 6in (15.2cm)
SOURCE OF FISH: Hatchery
TEST FISH INTRODUCTION
METHOD: Fish lock in penstock
MORTALITY: 28 - 66.2%

NAME OF PLANT: Cushman No. 2
DATE INSTALLED: 1933
PLANT UNIT NO.: 33
TURBINE TYPE: Francis
TURBINE SIZE: 37,500hp
RUNNER DIAMETER: 83in (211cm)
NUMBER OF BLADES:
BLADE TIP CLEARANCE: 4.9-8.1in (12.4-20.6cm)
SPACE BETWEEN BLADES:
RUNNER SPEED: 300rpm
MAXIMUM PERIPHERAL VELOCITY: 109ft/sec (33.2m/s)
RUNNER ELEVATION ABOVE
TAILWATER: 5.5 -7.7ft (1.7-2.3m)
UNIT EFFICIENCY:
HEAD: 450ft (137m)
TURBINE FLOW: 800cfs (22.7m^3/s)

VARIABLES DISCUSSED: Wicket gate openings, recovery gear, controls, capture efficiency and tailwater elevation

CRITIQUE: Tests were conducted at four gate openings. Tailwater elevation varied from +5.5 to +7.7 feet msl. Dead coho and steelhead were introduced into penstock and all were recovered; thus fish not captured were probably live which means that survival of test fish may be a minimal estimate. Control fish were put into the large net in the tailrace. Type of injury was categorized as either mechanical or pressure. Steelhead had higher mortalities than coho which was probably due to size of fish used. It was noted that the clearance between the trailing edge of the wicket gates and the edge of the runner blades appeared to be beyond the critical size for 3-inch coho but not for 6-inch steelhead. A separate group of control fish, held but not subjected to rigors of testing or handling as were normal test and control lots, had a less than 1% mortality. Average survival varied from 34.5 to 72.0% for coho and 33.8 to 51.9% for steelhead. Relationship of survival to gate opening and tailwater elevation was noted but not pronounced.

RATINGS

Plant description	3
Procedures	4
Test data recording	4
Environmental data adequacy	1
Study rating	75%

AUTHOR: Cramer, Frederick K. and Raymond C. Oligher
TITLE: Passing Fish Through Hydraulic Turbines -- Tests at Shasta Hydraulic Plant
YEAR: 1964
PUBLISHED BY: Corps of Engineers, Walla Walla District, Progress Report No. 5, May 1963

REPORT TYPE: Exploratory
STUDY DATE: January & November 1962
RIVER: Sacramento
STATE/PROVINCE: California
RECOVERY METHOD: Draft tube net
FISH SPECIES & SIZE:
chinook 4in (10cm)
steelhead 6in (15cm)
rainbow 10in (25cm)
FISH SIZE: (above)
SOURCE OF FISH: Hatchery
TEST FISH INTRODUCTION
METHOD: Penstock fish lock
MORTALITY: 9.5 to 60.4%

NAME OF PLANT: Shasta
DATE INSTALLED: 1942
PLANT UNIT NO.: U-1
TURBINE TYPE: Francis
TURBINE SIZE: 103,000hp
RUNNER DIAMETER: 156-183in (396-465cm)
NUMBER OF BLADES: 15
BLADE TIP CLEARANCE: 11in (28cm)
SPACE BETWEEN BLADES: 6in (15cm)
RUNNER SPEED: 138.5rpm
MAXIMUM PERIPHERAL VELOCITY: 111ft (33.8m)
RUNNER ELEVATION ABOVE TAILWATER: 2-3ft (0.6-0.9m)
UNIT EFFICIENCY:
HEAD: 410ft (125m)
430ft (131m)
TURBINE FLOW: 3200cfs (90.6m^3/s)

VARIABLES DISCUSSED: Wicket gate openings, turbine efficiency, tailwater elevation, capture efficiency, injury, controls, fish length and pressure

CRITIQUE: Tests were conducted to compare survival at slower runner speeds and larger openings than at Cushman No. 2, but the comparisons were not convincing. Parameters explored were head, tailwater level, wicket gate openings and fish species. Survival was 57.6 to 84.5% for chinook, 50.5 to 89.3% for steelhead, and 39.6 to 90.5% for rainbow. Fish survival and turbine efficiency were correlated but data from all tests were not used. Light delayed mortalities occurred in test and control fish. Chinook were in poor condition in the January tests. In two tests the location where fish entered the penstock flow was varied to "roof" versus "center of flow". Dead fish were put into penstock to test efficiency of draft tube collection net. This appeared to be a comprehensive test.

RATINGS

Plant description	4
Procedures	3
Test data recording	3
Environmental data adequacy	1
Study rating	69%

AUTHOR: Daugherty, William
TITLE: 1969 Turbine Mortality Studies -- Vernon Dam
YEAR: 1969
PUBLISHED BY: Unpublished
REPORT TYPE: Informational
STUDY DATE: September 9, 1969
RIVER: Connecticut
STATE/PROVINCE: Vermont
RECOVERY METHOD: Floats
SPECIES: Trout
FISH SIZE: Small
SOURCE OF FISH: Hatchery
TEST FISH INTRODUCTION
METHOD: Penstock
MORTALITY: 24.3%

NAME OF PLANT: Vernon
DATE INSTALLED:
PLANT UNIT NO.: All
TURBINE TYPE:
TURBINE SIZE:
RUNNER DIAMETER:
NUMBER OF BLADES:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED:
MAXIMUM PERIPHERAL VELOCITY:
RUNNER ELEVATION ABOVE TAILWATER:
UNIT EFFICIENCY: Normal
HEAD:
TURBINE FLOW:

VARIABLES DISCUSSED: Injury, recovery gear and capture efficiency

CRITIQUE: Small-sized rainbow trout fitted with styrofoam tags were put through several turbines (unspecified type) at the Vernon plant. Recovery of fish was by boat in the tailrace. Gate openings ranged from 60 to 100%. Mortality was estimated at 24.3%. The coordinator did not feel that the stated number of 285 turbine-introduced fish was correct. This was intended as a preliminary test. No environmental data were provided. It appears to be somewhat superficial and inconclusive.

RATINGS

Plant description	0
Procedures	2
Test data recording	2
Environmental data adequacy	0
Study rating	25%

AUTHOR: Eicher, George J.
TITLE: Clackamas Dams and Anadromous Fish: A History of Fish and Dams on the Clackamas River in Oregon
YEAR: 1937
PUBLISHED BY: Portland General Electric Company
REPORT TYPE: Informational
STUDY DATE: August 1937
RIVER: Clackamas
STATE/PROVINCE: Oregon
RECOVERY METHOD:
SPECIES: Sockeye
FISH SIZE:
SOURCE OF FISH: Hatchery
TEST FISH INTRODUCTION METHOD:
Paper bags
MORTALITY: 50%

NAME OF PLANT: Faraday
DATE INSTALLED:
PLANT UNIT NO.: 2
TURBINE TYPE: Francis
TURBINE SIZE: 360hp
RUNNER DIAMETER: 40in (102cm)
NUMBER OF BLADES:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED: 360rpm(19m)
MAXIMUM PERIPHERAL VELOCITY: 66fps (20.1m/s)
RUNNER ELEVATION ABOVE TAILWATER:
UNIT EFFICIENCY:
HEAD: 120ft (37m)
TURBINE FLOW: 500cfs

VARIABLES DISCUSSED: Recovery gear and fish length

CRITIQUE: This was a crude test of fish passage through the no. 2 unit of the Faraday Powerhouse in August 1937. About 1700 hatchery sockeye salmon fingerlings were entered through a vent shaft in paraffined paper bags A biologist in a hard hat diving outfit lay on the bottom of the tailrace and observed fish going by from the draft tube. He saw no evidence of injury, but estimated that about 50 percent of the fish were stunned or dead. No control fish were employed and no environmental data were recorded. In view of the probable high temperature, the distance that the fish were transported, the lack of acclimatization and the fact that no controls were used, this "study" is of no apparent value, other than as an example of early testing.

AUTHOR: Gloss, Steven B., James R. Wahl and Robert DuBois
TITLE: Potential Effects of Ossberger Turbines on Atlantic Salmon Smolts, Striped Bass and American Shad. In: Potential Effects of Kaplan, Ossberger and Bulb Turbines on Anadromous Fishes of the Northwest United States.
YEAR: 1982
PUBLISHED BY: U.S. Fish and Wildlife Service, Newton Corner, Massachusetts

REPORT TYPE: Informational
STUDY DATE: Probably 1981
RIVER: Susquehanna
STATE/PROVINCE: New York
RECOVERY METHOD: Large net
SPECIES: American shad, Atlantic salmon and steelhead
FISH SIZE:
SOURCE OF FISH: Hatchery
TEST FISH INTRODUCTION: Penstock
MORTALITY: shad - 50%
striped bass - 54%
Atlantic salmon - 24-62%

NAME OF PLANT: Colliersville
DATE INSTALLED: 1970's
PLANT UNIT NO.: 1-2
TURBINE TYPE: Ossberger
TURBINE SIZE: 850hp; 1150hp
RUNNER DIAMETER: 39in (1.0m); 49in (1.25m)
NUMBER OF BLADES:
BLADE TIP CLEARANCE: 0.1in (3mm)
SPACE BETWEEN BLADES: 1.2in (35mm)
RUNNER SPEED: 135rpm; 104rpm
MAXIMUM PERIPHERAL VELOCITY:
RUNNER ELEVATION ABOVE TAILWATER:
UNIT EFFICIENCY:
HEAD: 32ft (9.75m)
TURBINE FLOW: 706cfs ($20m^3/s$)

VARIABLES DISCUSSED: Handling

CRITIQUE: Atlantic salmon, striped bass and American shad were tested in two Ossberger turbines at the Colliersville plant. Steelhead and rainbow trout were found acceptable surrogate species for Atlantic salmon. Fish were entered into the penstock and several in a large net straining the discharge. Mortalities were measured for turbine impact, net impingement, handling, holding and introduction. Control fish were employed. Mortality estimates included 50% for shad, 54% for striped bass and 24-62% for Atlantic salmon, depending on size. Good correlation resulted between mortality and power output. This was a generally good study, although little environmental data were recorded and no reference to year or month of the work.

RATINGS

Plant description	4
Procedures	3
Test data recording	4
Environmental data adequacy	1
Study rating	75%

AUTHOR: Gunsolus, Robert T. and George J. Eicher
TITLE: Evaluation of Fish Passage Facilities at the North Fork Project on the Clackamas River in Oregon
YEAR: 1970
PUBLISHED BY: Fish Commission of Oregon, Oregon Game Commission, U.S. Bureau of Commercial Fisheries, U.S. Bureau of Sport Fisheries and Wildife, and Portland General Electric Company

REPORT TYPE: Informational
STUDY DATE: November 11, 1964
RIVER: Clackamas
STATE/PROVINCE: Oregon
RECOVERY METHOD: Downstream sampling
SPECIES: Coho salmon
FISH SIZE:
SOURCE OF FISH:
TEST FISH INTRODUCTION METHOD:
MORTALITY: 25.5 - 31.6%

NAME OF PLANT: North Fork
DATE INSTALLED: 1958
PLANT UNIT NO.: 1
TURBINE TYPE: Francis
TURBINE SIZE: 34,500hp
RUNNER DIAMETER: 116in (295cm)
NUMBER OF BLADES:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED: 138.5rpm
MAXIMUM PERIPHERAL VELOCITY: 82fps* (25m/s)
RUNNER ELEVATION ABOVE TAILWATER: 5ft (1.5m)
UNIT EFFICIENCY:
HEAD: 134ft (41m)
TURBINE FLOW: 2500cfs* (70.7m^3/s)

VARIABLES DISCUSSED: Recovery gear

* Item supplied by reviewer

CRITIQUE: On November 11, 1964, 4,076 marked hatchery coho were released directly into one of two identical penstocks and through the turbine operating at 80% load. Release was in groups of fish in bags lowered through the vent shaft. This procedure was tested for efficiency and found satisfactory. A lot of 5,158 live control fish and 393 dead fish was released into the tailrace. 742 test and 1,192 live control fish were captured in fyke nets in a power canal about 2 miles (3.2 km) downstream. Because one lot of 350-400 test fish was accidently released into the vent shaft, its passage was questionable, resulting in maximum and minimum test results of 31.6 and 25.5% mortality. Operating and environmental conditions were not recorded.

RATINGS

Plant description	4
Procedures	3
Test data recording	3
Environmental data adequacy	0
Study rating	63%

AUTHOR: Hamilton, J.A.R. and F.J. Andrew
TITLE: An Investigation of the Effect of Baker Dam on Downstream Migrant Salmon
YEAR: 1954
PUBLISHED BY: International Pacific Salmion Fisheries Commission

REPORT TYPE: Informational
STUDY DATE: 1951 & 1952
RIVER: Baker
STATE/PROVINCE: Washington
RECOVERY METHOD: Fyke net and survival box in tail race
SPECIES: Sockeye & coho
FISH SIZE: smolt
SOURCE OF FISH: Baker River, Cultus Lake and Marblemount Hatchery
TEST FISH INTRODUCTION:
METHOD: Fin-marked and released in tunnel 85ft (26m) below surface (live and dead)
MORTALITY: 34% -- sockeye
28% -- coho

NAME OF PLANT: Baker Dam
DATE INSTALLED: 1925-26
PLANT UNIT NO.: 1, 2, 3 & 4
TURBINE TYPE: Francis horizontal
TURBINE SIZE: 27,000hp each
RUNNER DIAMETER: 60in (1.5m)
NUMBER OF BLADES: 19
BLADE TIP CLEARANCE: 2in (5cm)
SPACE BETWEEN BLADES:
RUNNER SPEED: 300 rpm
MAXIMUM PERIPHERAL VELOCITY: 80ft/sec (24ms)
RUNNER ELEVATION ABOVE TAILWATER: -5 ft (-5.1m) below tailwater level. In second year of testing, difference was extended to 8ft (2.4m) because of river elevation.
UNIT EFFICIENCY:
HEAD: 250ft (76m)
TURBINE FLOW: 550cfs (15.6m^3/s) each

VARIABLES DISCUSSED: Injury, recovery gear, descaling, temperature, space betwen blades, controls, cavitation, diameter of runner, capture efficiency, tailwater elevation, and pressure

CRITIQUE: One variable was the survival rates of fish released through the turbines and those released through the spillway. The turbines were operated only at full load. During the two years of testing a 3-ft variation in tail water level occurred. Comparison was made with past records of many years of returning adults with the computed number of live downstream migrants, and a correlation was found. The investigators concluded that decreased tail water level increased cavitation and decreased survival. No environmental data were provided.

RATINGS

Plant description	4
Procedures	4
Test data recording	3
Environmental data adequacy	0
Study rating	69%

AUTHOR: Hamilton, J.A.R. and Fred Andrew
TITLE: A Study of Mortality Rates in a Turbine at Ruskin Dam
YEAR: 1954
PUBLISHED BY: Unpublished report by International Pacific Salmon Commission, New Westminster, B.C.

REPORT TYPE: Informational
STUDY DATE:
RIVER: Stave
STATE/PROVINCE: British Columbia
RECOVERY METHOD: Fyke nets downstream
SPECIES: Sockeye
FISH SIZE: 3.4in (8.6cm)
SOURCE OF FISH: Marblemount (Washington) Hatchery
TEST FISH INTRODUCTION METHOD: Air vent into penstock
MORTALITY: 10.5%

NAME OF PLANT: Ruskin
DATE INSTALLED:
PLANT UNIT NO.: 3
TURBINE TYPE: Francis
TURBINE SIZE: 47,000hp
RUNNER DIAMETER: 149in (378cm)
NUMBER OF BLADES:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED: 120rpm
MAXIMUM PERIPHERAL VELOCITY: 78ft/sec (23.8m/s)
RUNNER ELEVATION ABOVE TAILWATER: 10ft (3m)
UNIT EFFICIENCY:
HEAD: 130ft (40m)
TURBINE FLOW: 4000cfs (113m^3/s)

VARIABLES DISCUSSED: Tailwater elevation, capture efficiency, injury, recovery gear, controls, fish length and number of fish

CRITIQUE: Ruskin Dam was chosen for this study as a surrogate for the Seton Creek plant, which was proposed for construction at the time of the study and which would have similar turbines. It was felt that Ruskin would provide an accurate index of Seton Creek mortalities, and it did. The Ruskin mortality rate was found to be 10.5%. Later work at Seton Creek when it was constructed, found a mortality of 9.0%. Ruskin employed a vertical shaft Francis turbine with a fairly low peripheral runner speed at a head of 130 feet (40 m). Fyke nets, 5 feet (1.5 m) square, were fished about 3/4 mile (1.2 km) downstream. Hatchery sockeye salmon fingerling numbering 12,125 test and 12,159 controls were used. Only the controls were marked because no resident sockeye population existed. Dead fish were released and captured but not used in mortality computations. The turbine was operated at "full load". This appears to be a straightforward, well designed and executed test.

RATINGS

Plant description	3
Procedures	4
Test data recording	3
Environmental data adequacy	0
Study rating	69%

AUTHOR: Holmes, Harlan B.
TITLE: Loss of Salmon Fingerlings in Passing Bonneville Dam as Determined by Marking Experiments
YEAR: 1952
PUBLISHED BY: Unpublished
REPORT TYPE:
STUDY DATE: 1938-45
RIVER: Columbia
STATE/PROVINCE: Oregon
RECOVERY METHOD: Adult returns
SPECIES: Fall chinook
FISH SIZE: 2-3in (8-12cm)
SOURCE OF FISH: Herman, Tanner, Little White Salmon & Spring Creeks Hatcheries
TEST FISH INTRODUCTION METHOD: Forebay
MORTALITY: 11-15%

NAME OF PLANT: Bonneville Dam
DATE INSTALLED: 1938
PLANT UNIT NO.: 1-10
TURBINE TYPE: Kaplan
TURBINE SIZE: 74,000hp
RUNNER DIAMETER: 300in (7.6m)
NUMBER OF BLADES:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED: 75rpm
MAXIMUM PERIPHERAL VELOCITY:
RUNNER ELEVATION ABOVE TAILWATER: Variable
UNIT EFFICIENCY:
HEAD: 40-60ft
TURBINE FLOW: 13,000cfs
PLANT SIGMA: 1.63

VARIABLES DISCUSSED: Introduction gear, introduction points

CRITIQUE: This was the first major experiment conducted to determine the effects on salmon of passage through turbines. The fin marked test fish were released at various locations. Spillway gate openings were given for certain experiments. Recoveries of marked adult fish were in the commercial fisheries through the payment of rewards for marks. This was augmented by a biologist in continuous contact with the canning industry of the Columbia River. Fish that returned to hatcheries were also examined for marks. This manuscript, for many obscure reasons, was never published, although it has been reviewed, critiqued and discussed by many through the years. Various problems in introduction techniques and lack of knowledge at the time of certain factors affecting mortality of test and control fish such as dissolved gas probably affected the accuracy of some results. Because of the sheer volume of replicates, however, the average results are probably representative.

RATINGS

Plant description	4
Procedures	3
Test data recording	3
Environmental data adequacy	0
Study rating	69%

11-A-20

AUTHOR: Knight, Alexis E. and Daniel M. Kuzmeskus
TITLE: Potential Effects of Bulb Turbines on Atlantic Salmon Smolts. In: Potential Effects of Kaplan, Ossberger, and Bulb Turbines on Anadromous Fishes of the Northwest United States
YEAR: 1982
PUBLISHED BY: U.S. Fish and Wildlife Service, Newton Corners, Massachusetts

REPORT TYPE: Informational
STUDY DATE: 1981
RIVER: Merrimack
STATE/PROVINCE: Massachusetts
RECOVERY METHOD: Radio telemetry
SPECIES: Atlantic salmon
FISH SIZE:
SOURCE OF FISH: Hatchery
TEST FISH INTRODUCTION METHOD: Release into forebay
MORTALITY: 2.0%

NAME OF PLANT: Essex
DATE INSTALLED: 1981
PLANT UNIT NO.: 1-2
TURBINE TYPE: Bulb
TURBINE SIZE: 9750hp
RUNNER DIAMETER: 144in (3.7m)
NUMBER OF BLADES:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED: 128.6rpm
MAXIMUM PERIPHERAL VELOCITY: 81ft/sec ($25m^3/s$)*
RUNNER ELEVATION ABOVE TAILWATER:
UNIT EFFICIENCY:
HEAD: 29ft (8.84m)
TURBINE FLOW: 4400cfs ($127.4m^3/s$)

* Information supplied by reviewer

VARIABLES DISCUSSED: Recovery gear, controls, capture efficiency and river flow

CRITIQUE: This test utilized radio transmitters in the stomachs of 50 fish. Dummy tags were inserted in 25 "control" fish which were held in a forebay live box, thus testing the effects of tags in static water. Two radio tags became inoperative. All but one of the tagged fish survived for a mortality rate of 2.0%. A mention is made of a seagull eating a test fish, assumed to have been injured by a turbine, but no reason for the assumption is given or that if this is the single mortality listed or is in addition to it. Had it not been observed being eaten it would have been classified a turbine mortality. This appears to be a sound test except for the lack of controls to test environmental and other factors except tagging. No mention is made of significance in relation to the small number of test fish. No environmental data provided.

RATINGS

Plant description	3
Procedures	2
Test data recording	3
Environmental data adequacy	0
Study rating	50%

AUTHOR: Kynard, Boyd, Ralph Taylor, Charles Bell, and David Stier

TITLE: Potential Effects of Kaplan Turbines on Atlantic Salmon Smolts, American Shad and Blueback Herring. In: Potential Effects of Kaplan, Ossberger and Bulb Turbines on Anadromous Fishes of the Northwest United States

YEAR: 1982

PUBLISHED BY: U.S. Fish and Wildlife Service, Newton Corner, Massachusetts

REPORT TYPE: Informational

STUDY DATE: 1981

RIVER: Connecticut

STATE/PROVINCE: Massachusetts

RECOVERY METHOD: Clupeids -- Trawls; Atlantic salmon and shad -- Radio telemetry

SPECIES & SOURCE:
- Atlantic salmon - Hatchery
- American shad - River
- Blueback herring - River

FISH SIZE:

SOURCE OF FISH:

TEST FISH INTRODUCTION METHOD: Penstock

MORTALITY: Atlantic salmon - 4.9%
- Shad - Not significant
- Herring - 63 and 83%

NAME OF PLANT: Hadley Falls

DATE INSTALLED: 1951

PLANT UNIT NO.: 1

TURBINE TYPE: Kaplan

TURBINE SIZE: 12,000hp

RUNNER DIAMETER: 170in (432cm)

NUMBER OF BLADES:

BLADE TIP CLEARANCE:

SPACE BETWEEN BLADES:

RUNNER SPEED: 129rpm

MAXIMUM PERIPHERAL VELOCITY:

RUNER ELEVATION ABOVE TAILWATER:

UNIT EFFICIENCY:

HEAD: 51ft (15.5m)

TURBINE FLOW: 1552cfs ($44m^3/s$)

VARIABLES DISCUSSED: Capture efficiency, recovery gear and controls

CRITIQUE: Dye-stained blueback herring were passed through a 17 mw Kaplan unit at Holyoke Dam on the Connecticut River in 1981. Control fish were entered into the tailrace. Dead fish were also passed through the turbine. Recovery was in four trawls 980 ft (300 m) downstream. Testing was at 16.5, 12.0 and 5.5 mw of power generation. Shad and Atlantic salmon were fitted with radio transmitters in stomachs and traced by radio telemetry downstream of the plant. Mortality of shad test fish was 53% and of controls 38%, not considered statistically different. Atlantic salmon suffered 8 mortalities of 61 test fish and 4 dead controls from a lot of 53, giving mortalities of 13.1 and 78.6 respectively. Adjusted mortality was 4.9%. These appeared to be good studies with valid results. Environmental data are not shown.

RATINGS

Plant description	3
Procedures	3
Test data recording	4
Environmental data adequacy	0
Study rating	63%

AUTHOR: Long, C.W., R.F. Krcma and F.J. Ossiander
TITLE: Research on Fingerling Mortality in Kaplan Turbines -- 1968
YEAR: 1968
PUBLISHED BY: U.S. Bureau of Commercial Fisheries, Biological Laboratory, Seattle WA.

REPORT TYPE: Exploratory
STUDY DATE: Spring 1968
RIVER: Snake
STATE/PROVINCE: Washington
RECOVERY METHOD: Downstream
SPECIES: Coho (1+)
FISH SIZE:
SOURCE OF FISH: Leavenworth Hatchery
TEST FISH INTRODUCTION
METHOD: 10ft below ceiling (Intake B)
MORTALITY: 10-19% (Turbine) up to additional 33% (Predation)

NAME OF PLANT: Ice Harbor Dam
DATE INSTALLED:
PLANT UNIT NO.: 2 (Intake B)
TURBINE TYPE: Kaplan
TURBINE SIZE:
RUNNER DIAMETER:
NUMBER OF BLADES:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED:
MAXIMUM PERIPHERAL VELOCITY:
RUNNER ELEVATION ABOVE TAILWATER:
UNIT EFFICIENCY: 115%
HEAD:
TURBINE FLOW:

VARIABLES DISCUSSED: Turbine efficiency, capture efficiency, recovery gear, predation, controls and number of fish

CRITIQUE: Results presented indicate significant mortality may occur to fish after passing through hydraulic turbines depending on their location when entering the tailrace. This is in addition to mortality associated with the turbine itself. Fish entering the backroll of the tailrace experience up to 33% mortality due to predation while those entering the frontroll did not. Since fish were released into a discrete portion of the intake flow in this study, their arrival in the tailrace may not be representative of naturally distributed fish and therefore predation may also be different. Additionally, predation to naturally distributed fish passing through a turbine is also affected by light and would seem to indicate lower mortality at night. The relationship between various locations of fish released in the intake to their destination in the tailrace (i.e. back or front roll) would have assisted the ability to predict expected predation in the tailrace in this study. Mortality due to turbine passage was estimated at 10-19% and was assessed by capture of test and control fish using beach and purse seines 7 miles (11.3km) downstream and gatewell dip-nets 45 miles (72.4km) downstream. The value of control fish in turbine mortality studies is especially apparent from this study.

RATINGS

Plant description	1
Procedures	3
Test data recording	3
Environmental data adequacy	0
Study rating	44%

AUTHOR: Liston, Charles, R.
TITLE: Estimates of salmonid fish mortalities occurring at the Ludington pumped storage power facility during 1975-1978, and related studies
YEAR: 1979
PUBLISHED BY: Department of Fisheries and Wildlife, Michigan State University

REPORT TYPE: Informational
STUDY DATE: 1975-1979
RIVER: Lake Michigan
STATE/PROVINCE: Michigan
RECOVERY METHOD: Net sampling
SPECIES: Coho and chinook salmon -- steelhead brown, and lake trout
FISH SIZE:
SOURCE OF FISH: Wild
TEST FISH INTRODUCTION METHOD: Paper bags
MORTALITY: Pumping -- 56.9%
Generating -- 44.9%

NAME OF PLANT: Ludington
DATE INSTALLED: 1973
PLANT UNIT NO.:
TURBINE TYPE: Francis
TURBINE SIZE:
RUNNER DIAMETER: 27ft (8.2m)
NUMBER OF BLADES:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED: 112rpm
MAXIMUM PERIPHERAL VELOCITY: 159fps (49mps)
RUNNER ELEVATION ABOVE TAILWATER: -25ft (7.6m)
UNIT EFFICIENCY:
HEAD: 295-362ft (90-110m)
TURBINE FLOW: 12,660cfs (358.5m^3/s) generation
11,100cfs (314m^3/s) pumping

VARIABLES DISCUSSED: Net efficiency, residence periods, mortality rates

CRITIQUE: Fish numbers were estimated by gill net sampling in the reservoir above the plant. Actual turbine-pump mortality was estimated from passage of rainbow trout through the system. These mortalities were then related to numbers of other salmonids estimated to be present in the reservoir to produce total mortality figures annually. Visual observations of turbine-related injuries were made from the shore. Systematic surveys were made in transects on the reservoir surface to give direct observation of killed fish. This was a long-term, carefully planned, comprehensive study.

RATINGS:

Plant description	3
Procedure	4
Test data recording	4
Environmental data adequacy	2
Study rating	81%

AUTHOR: Liston, Charles, Dan Brazo, Rich O'Neal, Joe Bohr, Greg Peterson, and Rick Ligmans

TITLE: Assessment of larval, juvenile and adult fish losses at the Ludington pumped storage power plant on Lake Michigan

YEAR: 1981

PUBLISHED BY: Michigan State University

REPORT TYPE: Informational

STUDY DATE: 1980

RIVER: Lake Michigan

STATE/PROVINCE: Michigan

RECOVERY METHOD: Fyke nets

SPECIES: Several

FISH SIZE: Larvae to adults

SOURCE OF FISH: Wild

TEST FISH INTRODUCTION METHOD: Penstocks

MORTALITY: High and variable
Pumping mode universally more damaging than generating
No mortality rates given.

NAME OF PLANT: Ludington

DATE INSTALLED: 1973

PLANT UNIT NO.:

TURBINE TYPE: Francis

TURBINE SIZE:

RUNNER DIAMETER: 27ft (8.2m)

NUMBER OF BLADES:

BLADE TIP CLEARANCE:

SPACE BETWEEN BLADES:

RUNNER SPEED: 112rpm

MAXIMUM PERIPHERAL VELOCITY: 159fps (49mps)

TAILWATER: 25ft (7.6m)

UNIT EFFICIENCY:

HEAD: 295-362ft (90-110m)

TURBINE FLOW: 12,660cfs (358.5m^3/s) generating
11,100cfs (314m^3/s) pumping

VARIABLES DISCUSSED: Pumping versus generation

CRITIQUE: Study dealt with estimations of losses of fish from plant operations in terms of total adult fish prevented from entering the Lake Michigan fishery. Direct passage mortality studies of fish through the turbine-pump were not performed. Samples of fish were taken from Lake Michigan in front of the plant and from the reservoir above. Fish of a great number of species in various stages from larvae to adults were sampled. Comparison of estimates of numbers entrained from the lake entering the plant with those extrained (leaving the system after experiencing both pummping nd generating passage) gave the basis for total losses. Attention was given to environmental factors affeced by seasons of the year. This appears to be a comprehensive study.

RATINGS:

Plant description	2
Procedures	4
Test data recording	3
Environmental data adequacy	3
Study rating	75%

AUTHOR: MacEachern, N.
TITLE: Mortality Tests at Tobique Narrows Dam, 1959 and 1960
YEAR: 1961
PUBLISHED BY: Canada Department of Fisheries
REPORT TYPE: Informational
STUDY DATE: 1959, 1960
RIVER: Tobique (Trib to St.John R.)
STATE/PROVINCE: New Brunswick
RECOVERY METHOD:
SPECIES: Atlantic Salmon
FISH SIZE: 3 1/2-5 1/2 & 5 1/2-8 1/2
SOURCE OF FISH:
TEST FISH INTRODUCTION
METHOD:
MORTALITY: (1960 results)
16.5% (3 1/2-5 1/2" fish)
23% (5 1/2-8 1/2" fish)

NAME OF PLANT: Tobique Narrows Dam
DATE INSTALLED:
PLANT UNIT NO.:
TURBINE TYPE: Kaplan
TURBINE SIZE: 13,500hp
RUNNER DIAMETER: 104in (264cm)
NUMBER OF BLADES:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED:
MAXIMUM PERIPHERAL VELOCITY:
RUNNER ELEVATION ABOVE TAILWATER:
-17.0ft (-5.2m)
UNIT EFFICIENCY: Rated Load
HEAD: 75 ft (22.9m)
TURBINE FLOW:

VARIABLES DISCUSSED: Fish length

CRITIQUE: Detailed information not provided, as data presented above was obtained in summary form entitled "Summaries of Research on the Fish-Power Problem and Related Work by Fisheries Agencies in British Columbia", prepared by Research Sub-Committee, Fisheries Development Council. Department of Fisheries, Canada. Vancouver, B.C. Revised August, 1965.

RATINGS	
Plant description	2
Procedures	2
Test data recording	2
Environmental data adequacy	0
Study rating	38%

AUTHOR: Massey, Julius B.
TITLE: Crown Zellerbach Turbines 20 and 21. In: Summary Report on Juvenile Downstream Migrant Fish Passage and Protection Studies at Willamette Falls, Oregon
YEAR: 1967
PUBLISHED BY: Oregon Game Commission
REPORT TYPE: Informational
STUDY DATE: 1960-61
RIVER: Willamette
STATE/PROVINCE: Oregon
RECOVERY METHOD: Large net
SPECIES: Steelhead and chinook
FISH SIZE:
SOURCE OF FISH: Bonneville Hatchery
TEST FISH INTRODUCTION METHOD: Penstock

MORTALITY: 1960
- #20 - steelhead - 30.4%
  - chinook - 28.4%
- #21 - steelhead - 20.0%
  - chinook - 18.8%

1961
- #20 - steelhead - 99.6%
  - chinook - 99.8%
- #21 - steelhead - 100%
  - chinook - 99.8%

NAME OF PLANT: West Linn
DATE INSTALLED: 1925
PLANT UNIT NO.: 20-21
TURBINE TYPE: Francis
TURBINE SIZE: 1600hp; 2500hp
RUNNER DIAMETER: 39in (15cm), 36in (14cm)
NUMBER OF BLADES:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED: 240rpm
MAXIMUM PERIPHERAL VELOCITY: 40.8ft (14.6m) per second
RUNNER ELEVATION ABOVE TAILWATER: 20.9ft (6m); 27.2ft (8.2m)
UNIT EFFICIENCY:
HEAD: 40ft (12m)
TURBINE FLOW: 410cfs ($12m^3/s$)
519cfs ($15m^3/s$)
519cfs ($15m^3/s$)

VARIABLES DISCUSSED: Tailwater elevation, capture efficiency, injury, recovery gear, temperature, controls and fish length

CRITIQUE: These studies were performed in 1960 and 1961 by William Pitney who had previously performed a single study of unit 20 in 1959. A large net was used to recapture test and dead fish entered into the penstock. Controls were entered into the mouth of the large net. Runners were unusually high above tailwater (21 and 27.2 ft) (6.4 and 8.2 m). Wicket gate openings were 100% on #20 and 90% on #21. An unusual result is the fairly normal mortality rates of 18.8 to 30.4% in 1960 contrasted with the 100% losses in 1961 in both units. In spite of high temperatures and control mortalities of 58%, in 1959 test mortalities were also a more normal 34 to 40%. It was later discovered that the hatchery producing the test fish was prone to nitrogen gas saturation, which seems the probable explanation for this aberration. Only a slight amount of gas in the blood would cause instant embolism mortality in passage through the unusually high vacuum of these penstocks.

RATINGS

Plant description	3
Procedures	3
Test data recording	3
Environmental data adequacy	2
Study rating	69%

AUTHOR: Massey, Julius B.
TITLE: Publishers Paper Plant. <u>In:</u> Summary Report on Juvenile Downstream Migrant Fish Passage and Protection Studies at Willamette Falls, Oregon
YEAR: 1967
PUBLISHED BY: Oregon State Game Commission
REPORT TYPE: Informational
STUDY DATE: 1960-61
RIVER: Willamette
STATE/PROVINCE: Oregon
RECOVERY METHOD: Large net
SPECIES: Steelhead and chinook
FISH SIZE:
SOURCE OF FISH: Hatchery
TEST FISH INTRODUCTION METHOD: Penstock
MORTALITY: 1960: 12.1% - steelhead
12.6% - chinook
1961: 12.9% - steelhead
15.5% - chinook

NAME OF PLANT: Willamette Falls
DATE INSTALLED: About 1928
PLANT UNIT NO.: 2
TURBINE TYPE: Francis
TURBINE SIZE: 622hp
RUNNER DIAMETER: 36in (91cm)
NUMBER OF BLADES:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED: 255rpm
MAXIMUM PERIPHERAL VELOCITY: 47ft (14.3m) per second
RUNNER ELEVATION ABOVE TAILWATER: 23.3ft
UNIT EFFICIENCY: 80%
HEAD: 40ft (12m)
TURBINE FLOW: 275cfs ($8m^3/s$)

VARIABLES DISCUSSED: Wicket gate opening, injury, controls, recovery gear, tailwater elevation, fish length and temperature

CRITIQUE: This study was performed by William Pitney in 1960 and 1961 using the large net method with controls and dead fish. The runners in the plant are unusually high above tailwater (23 ft <7 m>). These were well controlled and executed studies. Water temperature was fairly low (47 F - 8.3 C). Experiments in both years were identical, with test and dead fish entered into the turbine penstock. Controls were entered into the entrance of the large net. Test and control lots were held for three days in hatchery troughs for delayed mortality assessment.

RATINGS

Plant description	3
Procedures	4
Test data recording	3
Environmental data adequacy	2
Study rating	75%

AUTHOR: Massey, Julius B.
TITLE: Portland General Electric Company Plant. In: Summary Report on Juvenile Downstream Migrant Fish Passage and Protection Studies at Willamette Falls, Oregon
YEAR: 1967
PUBLISHED BY: Oregon Game Commission
REPORT TYPE: Informational
STUDY DATE: 1961
RIVER: Willamette
STATE/PROVINCE: Oregon
RECOVERY METHOD: Large net
SPECIES: Steelhead and chinook salmon
FISH SIZE:
SOURCE OF FISH: Hatchery
TEST FISH INTRODUCTION METHOD: Penstock
MORTALITY:

Kaplan #7
7.7% - steelhead
11.8% - chinook

Kaplan #8
9.9% - steelhead
10.5% - chinook

NAME OF PLANT: T. W. Sullivan
DATE INSTALLED: 1952
PLANT UNIT NO.: 7-8
TURBINE TYPE: Kaplan
TURBINE SIZE: 1740hp
RUNNER DIAMETER:
NUMBER OF BLADE:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED: 240rpm
MAXIMUM PERIPHERAL VELOCITY:
RUNNER ELEVATION ABOVE: TAILWATER: 20.7; 21.7
UNIT EFFICIENCY:
HEAD: 41ft (12.5m)
TURBINE FLOW: 390cfs (11m^3/s
260cfs (7m^3/s)

VARIABLES DISCUSSED: Wicket gate openings, injury, controls, recovery gear, tailwater elevation, capture efficiency, temperature and fish length

CRITIQUE: This plant has the runners unusually high above tailwater (21 ft <6.4 m>). Water temperatures averaged about 40°F (4.4°C). Tests were in January and used dead fish entered into the penstocks with test fish. Controls were entered into the mouth of the large net. Fish were held for three days after the test in hatchery troughs for delayed mortality assessment. These were well conceived and executed studies. In spite of the high elevation of runners above tailwater, the owner reported little blade cavitation and attributed this to the fact that the turbines were oversized for the generators used, resulting in light loading.

RATINGS

Plant description	3
Procedures	4
Test data recording	4
Environmental data adequacy	2
Study rating	81%

AUTHOR: Massey, Julius B.
TITLE: Portland General Electric Company Plant. In: Summary Report on Juvenile Downstream Migrant Fish Passage and Protection Studies at Willamette Falls, Oregon
YEAR: 1967
PUBLISHED BY: Oregon Game Commission
REPORT TYPE: Informational
STUDY DATE: 1960
RIVER: Willamette
STATE/PROVINCE: Oregon
RECOVERY METHOD: Large net
FISH SIZE:
SOURCE OF FISH: Hatchery
TEST FISH INTRODUCTION METHOD: Penstock
MORTALITY: 25.9% - steelhead
14.3% - chinook

NAME OF PLANT: T. W. Sullivan
DATE INSTALLED: 1920
PLANT UNIT NO.: 9
TURBINE TYPE: Francis
TURBINE SIZE: 1470hp
NUMBER OF BLADES:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED: 242rpm
MAXIMUM PERIPHERAL VELOCITY:
RUNNER ELEVATION ABOVE TAILWATER: 20.7ft.(6.3m)
UNIT EFFICIENCY
HEAD: 41ft (12.5m)
TURBINE FLOW: 260cfs (7m^3/s)

VARIABLES DISCUSSED: Wicket gate opening, injury, controls, recovery gear, tailwater elevation, capture efficiency, temperature and fish length

CRITIQUE: This plant has the runners unusually high above tailwater (21ft <6.4m>). Water temperatures averaged about 40°F (4.4°C). Controls were entered into the mouth of the large net. Fish were held for three days after the tests in troughs in a hatchery on the Sandy River. This was a well conceived and executed study.

RATINGS	
Plant description	3
Procedures	4
Test data recording	4
Environmental data adequacy	2
Study rating	81%

AUTHOR: McGrath, C.J. and Twomey, E.
TITLE: Passage of Smolt Through Turbines -- Experiments with Balsa Wood Boxes and Fish Shapes at River Erne Hydro-Electric Station in May 1959
YEAR: 1959
PUBLISHED BY: Irish Department of Sea and Inland Fisheries, Appendix No. 29

REPORT TYPE: Exploratory
STUDY DATE: May 1959
RIVER: Erne
STATE/PROVINCE: Ireland
RECOVERY METHOD:
SPECIES: Atlantic salmon
FISH SIZE:
SOURCE OF FISH:
TEST FISH INTRODUCTION METHOD:
MORTALITY: Not estimated

NAME OF PLANT: Cliff and Cathleens Falls
DATE INSTALLED:
PLANT UNIT NO.:
TURBINE TYPE: Kaplan
TURBINE SIZE: 12,500-28,000hp
RUNNER DIAMETER:
NUMBER OF BLADES:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED:
MAXIMUM PERIPHERAL VELOCITY:
RUNNER ELEVATION ABOVE TAILWATER:
UNIT EFFICIENCY:
HEAD: 42ft (12.7m); 96ft (29m)
TURBINE FLOW:

VARIABLES DISCUSSED: Turbine loads

CRITIQUE: Atlantic salmon smolts were put through four Kaplan turbines at two plants on the River Erne in Ireland in balsa wood boxes. The boxes were weighted with lead shot to neutral bouyancy. The shot was held in place with paper which disintegrated in water after passing through the turbines, so that the boxes came to the surface. Fish shapes were also made of balsa and similarly weighted. Turbine tests were at low, medium and full load. The numbers of boxes and fish shapes used is not stated, but 113 were recovered of which eight were classified as "smashed". Surviving fish were held for 48 hours, as were control fish. It was concluded that danger for fish was essentially only at low loads. The reason for this is not given. The small number of fish used and lack of data generally results in the tests being not too meaningful.

RATINGS	
Plant description	2
Procedures	2
Test data recording	3
Environmental data adequacy	0
Study rating	44%

AUTHOR: McKernan, Donald L.
TITLE: A Progressive Report of Experiments on the Downstream Migrating Chinook Fingerlings
YEAR: 1940
PUBLISHED BY: Unpublished report, Washington Department of Fisheries

REPORT TYPE: Informational
STUDY DATE: 1940
RIVER: Wenatchee
STATE/PROVINCE: Washington
RECOVERY METHOD:
SPECIES: Chinook
FISH SIZE:
SOURCE OF FISH:
TEST FISH INTRODUCTION METHOD:
MORTALITY: 10-17%

NAME OF PLANT: Dryden Ditch Screens
DATE INSTALLED:
PLANT UNIT NO.:
TURBINE TYPE:
TURBINE SIZE:
RUNNER DIAMETER:
NUMBER OF BLADES:
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED:
MAXIMUM PERIPHERAL VELOCITY:
RUNNER ELEVATION ABOVE TAILWATER:
UNIT EFFICIENCY:
HEAD:
TURBINE FLOW:

VARIABLES DISCUSSED: Recovery gear and temperature

CRITIQUE: First known record of attempted recovery of test fish by enclosing them in cheese cloth (gossamer) bags. Unsuccessful. Both live and fresh killed fish were put through two turbines and observed in tailrace. Squaw fish mortality occurred. Delayed mortality not determined. No turbine or environmental information was given. Mortality was estimated at 16.7% for small turbine and 10% for large. Figures were calculated from observation of dead and live fish below the plant as no satisfactory recovery methods were devised. System was not very sophisticated. Study of minimal value.

RATINGS

Plant description	0
Procedures	2
Test data recording	2
Environmental data adequacy	1
Study rating	31%

AUTHOR: Monten, Erik
TITLE: The Possibility of Salmon Passing Unharmed Through Power Plant Turbines When Descending to the Sea
YEAR: 1955
PUBLISHED BY: Salmon Research Institute
REPORT TYPE: Exploratory and Informational
STUDY DATE: 1954
RIVER: Lake Våttern
STATE/PROVINCE: Sundsvall, Sweden
RECOVERY METHOD: Net
SPECIES: Atlantic salmon
FISH SIZE: 1 summer old
SOURCE OF FISH:
TEST FISH INTRODUCTION METHOD:
MORTALITY: See Critique below

NAME OF PLANT: Grånna
DATE INSTALLED:
PLANT UNIT NO:
TURBINE TYPE: Francis
TURBINE SIZE:
RUNNER DIAMETER: 29in '740mm)
NUMBER OF BLADES: 15
BLADE TIP CLEARANCE:
SPACE BETWEEN BLADES:
RUNNER SPEED:
MAXIMUM PERIPHERAL VELOCITY: 95ft/sec (29m)
RUNNER ELEVATION ABOVE TAILWATER:
UNIT EFFICIENCY:
HEAD: 354ft (108m)
TURBINE FLOW:

VARIABLES DISCUSSED: Injury, recovery gear, fish length and diameter of runner

CRITIQUE: Of 100 balsa wood boxes 4in (10cm) long, released in turbine intake, 5 boxes recovered with 4 fish uninjured and 1 dead from compression of rubber band.

RATINGS

Plant description	2
Procedures	3
Test data recording	3
Environmental data adequacy	0
Study rating	50%