IMPACTS OF HYDROELECTRIC PLANT TAILRACES ON FISH PASSAGE

A Report on Effects of Tailraces on Migratory Fish and Use of Barriers, Modified Project Operations, and Spills for Reducing Impacts

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Impacts of Hydroelectric Plant Tailraces on Fish Passage - A Report on Effects of Tailraces on Migratory Fish and Use of Barriers, Modified Project Operations, and Spills for Reducing Impacts

This report summarizes what is known about the impacts of tailrace barrier structures and operations at hydroelectric plants on injury, mortality, migration, and reproductive success of fish. Little scientific information exists about these topics. Important tailrace issues arise at some hydropower developments, however, particularly when tailraces appear to disrupt migratory behavior patterns of anadromous fish populations.

This report provides background perspective and technical guidance for FERC staff to use when reviewing hydropower license applications and evaluating resource agency recommendations about tailrace problems. The purpose of the report is to assist staff in establishing independent, objective, and sound licensing positions about tailrace barriers.

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EXECUTIVE SUMMARY

Fish injury, mortality, and migration delay are associated with some hydroelectric project tailraces. This report reviews the extent of these issues and identifies tailrace characteristics that may affect fish.

Little scientific information exists on these topics. To collect information for this report, we conducted a computerized literature search and a telephone survey of fisheries agencies, and we sent a survey questionnaire to hydroelectric projects where tailrace barriers are installed or proposed. We requested information on site conditions and cost and effectiveness of tailrace barriers. Based on survey results, we offer conclusions about tailrace effects on populations, causes of injury and delay, and use and effectiveness of tailrace barriers. Importantly, we also obtained sufficient information from the surveys to provide guidance for reviewing license applications and agency recommendations involving tailrace barriers.

None of the information collected quantified the effects of tailrace delays on migratory fish population levels. Migration delays can, however, limit the upstream extent of migration, and delays of as little as 3 days may have critical effects on the spawning success of a population. Delays can cause migrants to spawn in suboptimal habitat or to abandon spawning. Delays can cause mortality by reducing energy reserves of migrating fish.

Tailrace-related injury can be caused by both biological and physical conditions. Swimming speed of a fish influences its ability to enter dangerous areas of the tailrace. Turbine elevation, exit velocities, and turbine type influence susceptibility of fish to injury in the tailrace. Fish are injured when they contact the turbine runner, walls of tailrace structures, or hydraulic shear in the draft tube. Fish also can be injured from water quality related impacts of hydropower operation (e.g., nitrogen supersaturation). Secondary infection of injured fish can lead to delayed mortality and lowered reproductive success.

Upstream migrants can be delayed when stream scents and hydraulic conditions attract migrants to impassable tailrace flow discharges. Inadequate fishway entrance conditions also can delay fish passage.

Limited data are available on the effectiveness and use of tailrace barriers; our survey identified only 22 sites with useful information about bar racks, screens, netting, and other guidance devices for migrants.

Tailrace barriers can be used to repel migrants from undesirable passage routes and guide fish to ladders or preferred routes of migration. Horizontal diffuser barriers physically block migrants without inducing fish to jump. Vertical diffuser barriers with low differential head can be equally effective. Height and water velocity can be used to block or guide fish passage at barrier dams. Electric fields also have successfully been used to block upstream passage. Sound

and light behavioral barriers may provide alternative methods of blocking fish passage. However, fisheries resource agency acceptance of these methods has been limited. Modified project operation and spill release also have been used to limit delay and improve passage conditions.

This report provides guidance for reviewing tailrace barrier recommendations; guidance is a four-step evaluation of need, feasibility, effectiveness, and cost. A clearly identified need can eliminate some contentious issues and help identify the appropriate tailrace barrier. Biological or hydrological studies often can provide information needed for completing the four-step evaluation process for tailrace barriers at a project. Project generation and revenue also can be influenced by head loss associated with installing and operating barrier dams, bar racks, and screens.

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1.0 INTRODUCTION

A tailrace is an area of turbulent flow at the discharge of a hydroelectric facility turbine. Tailraces can have adverse effects on the upstream migration of fish that live in the sea but spawn in freshwater (anadromous) and fish that live in freshwater but spawn in the sea (catadromous). Other fish species spend their entire life in freshwater and make long migratory movements. We will refer to all these groups of fish as migratory in this report.

There are other areas associated with hydroelectric facilities that have hydraulic characteristics similar to turbine discharge tailraces. These areas, which may mimic tailrace effects, include:

1) spillway discharges;

2) trash sluices; and

3) fishway entrances.

The creation of impoundments at hydroelectric facilities alters the hydraulics of some river systems such that tailraces may be the only areas of flowing water. Migrating fish, particularly anadromous fish returning to their natal waters to spawn, are attracted to point discharges where flow quantities are relatively large or velocities are high. Water quality (e.g., desirable water temperatures) also may attract fish to these areas (NMFS 1993).

The artificial hydraulic conditions created by the layout of hydroelectric facilities may attract fish away from appropriate passage routes. Fish that are attracted to these areas may be either significantly delayed in their upstream passage or diverted away from fish passage facilities such as fish ladder entrances. Tailraces associated with turbine discharges also may attract migrants to draft tubes where they may be injured or killed by contact with physical structures and turbine runners or by exposure to hydrodynamic shear forces near the turbine runner.

All fish species may be affected by tailraces, but most research on tailrace attraction focuses on salmonids, and the majority of the literature is about anadromous species.

This report identifies tailrace characteristics that may affect migratory fish and summarizes impacts on these resources. Section 2 presents the methods used to gather the information for this report, and a technical summary of the results is provided in Section 3. Section 4 presents a discussion on guidelines and criteria for assessing the need for tailrace barriers, modified project operation, or spill regimes at project sites. Section 5 presents conclusions, and Appendix A contains an annotated bibliography. It also identifies potential solutions and mitigation measures for reducing impacts.

2.0 METHODS

A literature search and a survey questionnaire were used to gather data on tailraces. A thorough review of the open literature was conducted. Data were gathered on the nature of tailraces (e.g., physical hydraulic characteristics that attract fish) and direct and indirect effects they have on fish. Direct effects include diversion into areas where fish may be injured or killed, such as draft tubes and plunge pools (where they may be adversely affected by altered river temperatures or gas supersaturation). Indirect effects include decreased fitness leading to lowered reproductive success and less subsequent recruitment into the population.

Data also were collected on the types of tailrace barriers that are currently used to reduce injury to fish and/or delays in migration. Studies were reviewed and summarized to develop the database and to formulate guidelines and criteria for modifying project operation or spill regimes to mitigate impacts.

The literature search included: 1) a computer search of the open literature, and 2) a telephone survey of selected fishery agencies to identify pertinent reports and data not readily available through published literature. Agencies contacted include the National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (FWS), fishery agencies in those states where tailrace barriers are installed, the Canadian Department of Fisheries and Oceans (CDFO), and other fishery agencies identified through published literature.

A total of 55 studies were identified and reviewed for this report. Most available information on tailraces is included in literature on fish passage facilities. Tailraces generally have been studied as part of studies to determine the best location for fish ladders or bypass entrances. Much of the literature, therefore, considers tailraces as a secondary issue.

In addition to the literature search, data were gathered from a survey of hydroelectric projects with known tailrace problems or at which FERC or state agencies have required installation of tailrace barriers. Hydroelectric projects where tailrace barriers are installed and operating also were surveyed to determine barrier effectiveness and costs.

A preliminary list of projects was compiled and reviewed by FERC to verify addresses of contacts to determine if each project was currently licensed or being considered for relicensing or a new license. License applications for several projects identified during the telephone survey were dismissed before development of tailrace barrier plans. The contacts for the remaining projects received a tailrace barrier survey questionnaire, which requested information on:

1) site conditions;

2) effectiveness of existing tailrace barrier designs in reducing fish injury, mortality, or delay in migration; and

3) the cost of these devices.

After 29 survey questionnaires were mailed, follow-up telephone calls were made to those parties that failed to respond to the questionnaire. Information was received for a total of 24 sites. Data gathered from the literature review and survey were collated and summarized, and Section 3 presents the results.

3.0 TECHNICAL SUMMARY

The literature search and survey indicate that there is little pertinent information on tailrace effects on fishery resources. Most available data on tailraces are related to fish passage facilities. Further, there are few data on effectiveness (in terms of numbers of spawners or escapement) of tailrace barriers at existing hydroelectric facilities.

The literature focuses most commonly on Pacific salmonids. Most survey responses were from projects with anadromous salmonid runs. The following discussion focuses on anadromous salmonids with occasional reference to other anadromous, catadromous, and resident fish populations, as applicable.

3.1 Tailrace Effects on Injury, Mortality, and Migration Delay

The development of hydroelectric power has dammed many river systems that formerly supported large runs of migratory species. Impoundments associated with hydroelectric development change river hydraulics so that tailraces are the only areas of flowing water that mimic historic river hydraulics. Fish are attracted to tailraces by a number of hydraulically related factors.

When turbine discharges or spillway flows contain water from natal streams located upstream of a hydro project, migratory species detect the scent of their natal streams and often will be falsely attracted from fish ladder flows. Some turbine discharges or spillway flows compete with fishway entrance flows or mask the presence of natural stream channels. The greater volume of water and higher velocities associated with turbine discharges and/or spillway flows are key factors that falsely attract migrants from the best route of upstream passage.

Typically, there is more than one area of turbulent flow at a hydro site. As noted in Section 1, spillways, trash sluices, and entrances to fishways or bypasses may create tailrace-like conditions. Depending on the project size and layout of dam, powerhouse, and appurtenant structures, each of these areas may attract fish.

Water quality, particularly desirable water temperatures, also may attract fish. Habitat (e.g., for resting, holding, and feeding) is an important criterion of attraction, but habitat desirability depends more on water velocity. The high volumes of water and residual energy of tailrace flows can provide attractive habitat to some species. Areas of turbulence that generally attract fish also can become zones of exclusion if velocities in these areas are excessive. Each project is unique, however, and there is relatively little documentation about the extent of adverse effects at existing hydro sites. Consequently, there may be other physical characteristics beyond those noted in this report that may be identified through future research as important determinants of tailrace attraction.

Attraction of migrants to tailraces may result in injury, mortality, or a substantial delay in migration and subsequent late or non-arrival at spawning grounds.

3.1.1 Injury and Mortality

Migrants that are attracted to turbine discharges or other tailrace-like areas may be injured when they attempt to ascend draft tubes or other areas not intended for passage. Lacerations and abrasions from these attempts may result in direct or delayed mortality.

Physical and biological factors influence potential injury and mortality. Physical factors include draft tube velocity, turbine design, elevation relative to tailwater, proximity to concrete walls, presence of rocks or obstructions in the tailrace, and variable operating conditions. Biological factors include species, life stages, size, and swimming ability. Different species have different swimming capabilities (duration and speed of movement) that influence the potential for injury and mortality at a project. Project design and operation govern the physical factors that affect injury and mortality. The types of injury sustained are often related to a combination of the swimming ability of the species and the turbine design.

Swimming Ability

This factor has a species-specific impact. For example, where both species occur, salmonids, with their stronger swimming capabilities, are more likely than clupeids to ascend draft tubes during periods of high project flows. This increases the salmonids' risk of injury or mortality.

Fish swimming capabilities strongly influence potential injury and mortality in powerhouse draft tubes. Fish swimming speed and stamina, combined with draft tube length and minimum discharge flow velocity, determine the ability of a fish to ascend a draft tube. Some draft tubes may have water velocities that can be negotiated by fish, but, if the draft tube is too long, fish may not be able to sustain enough speed to reach the turbine runners. Fish also may expend a great deal of energy attempting to ascend these areas and then lose valuable energy reserves. Loss of these reserves then could result in death or poor condition before spawning.

At sites with high discharge velocities (such as typical draft tube discharges) fish use their maximum swimming effort (burst speed) when attempting to ascend these flows. Burst speeds, which cannot be maintained for more than a few seconds and cannot be repeated without a period of recovery, are directly related to fish length and species type (Hildebrand et al. 1980). Larger fish, therefore, are more likely to enter draft tubes than smaller fish and are more susceptible to injury and mortality. If discharge water velocities are low, however, fish could enter draft tubes with steady or sustained swimming speeds, depending on water temperature and oxygen levels (Hildebrand et al. 1980). Fish could also enter the draft tubes during unit shut-down if leakage water attracts fish.

At projects where there are adult salmonids, water velocities less than 16 feet per second (fps) may not exclude migrants from ascending a draft tube. Steelhead trout and chinook salmon are able to negotiate the entire length of an 85 foot channel at water velocities of 13.4 and 15.8 fps (Weaver 1963). Clupeids also may be able to swim upstream against velocities greater than 10 fps. Adult American shad are able to swim moderate distances (less than 75 feet) in water velocities up to 14 fps (Weaver 1963).

Swimming capabilities also may vary among individuals of the same species, depending on location in the river and how ready the fish is to spawn (gamete maturation stage). During a study conducted with Fraser and Thompson River pink salmon, gravid (ready to spawn) fish had greater swimming strength than spawning fish, and spawning fish had greater swimming strength than fish that had already spawned (Williams and Brett 1987). Williams and Brett also found that pink salmon that were collected lower in the Fraser River were stronger swimmers than those collected at upriver spawning sites. This suggests that lower basin projects may have more problems with fish entering draft tubes because fish are generally stronger swimmers at lower points in a river basin.

Project Design and Operation

Physical factors such as project design and operation influence potential injury or mortality. Physical factors that may affect powerhouse-related damage include: turbine type, draft tube design, tailwater elevation, and discharge flow and velocity.

Although type of turbine may affect fish injury and mortality, discharge velocities have more influence on whether or not fish are able to move into a draft tube and subsequently approach shear zones or turbine runners. Because turbine discharge velocities typically do not exceed the upper range of adult salmonid swimming speeds, there is potential for draft-tube-related injury and mortality at most hydroelectric sites where there are migratory salmonids.

Even if discharge water velocities at full load operation would prevent fish from ascending a draft tube, low velocities during partial operation may allow fish to enter. There may be partial load operation during prolonged shut-down or start-up, while a unit is on spinning reserve, or during low-flow periods. Fish also may enter draft tubes during non-generation periods and then be injured or killed during turbine start-up.

Water velocity in draft tubes can be highly variable in space and time. Draft tubes can have significant variability in distribution of high and low velocities. Low velocity areas may allow fish to enter a draft tube with a high average discharge velocity. During start-up and shut-down, velocity distributions vary with rapidly changing flows. These shifting velocity patterns may induce fish to swim at burst speed toward and into turbine runners. Fish injured in this manner generally drop to the tailrace and are undetected (NMFS 1993).

Many projects have draft tubes with a 90° elbow and multiple tailrace openings for a single unit. These multiple openings are created by splitter walls or flow training vanes. Projects with these types of draft tube structures can have complex hydraulics and may have high hydraulic shear zones that can injure fish. Some of the multiple draft tube openings may experience reverse flows; tailrace water enters one draft tube opening and exits via another. In these cases any downstream fish may be drawn into the draft tube and be injured by hydraulic shear.

Fish may be injured or killed by turbine contact at projects with vertical-shaft Francis units (Bengeyfield 1982), reaction turbines (Fedorenko 1989), and axial flow-tube turbines (Williams 1985). Fish may not be able to contact Pelton turbine runners since they usually are located above draft tube water levels (Schadt et al. 1985; Beak Consultants, Inc. 1993). Fish also may contact Kaplan turbine runner blades, and protective measures have been requested by resource agencies at some hydroelectric sites with this type of turbine.

Although fish may be able to physically ascend a draft tube, other factors may prevent them from reaching a station's turbines. At the Jackson Hydroelectric Project on the Sultan River in Washington, adult salmonids do not contact the two Pelton turbines because the runners are about 11.5 feet above the tailwater elevation during periods of average flows (actual distance depends on discharge flows and tailwater elevation; Schadt et al. 1985). In addition to unit location, high water velocities (actual measurements were not reported), considerable turbulence, air depression system noise, and lack of a tailrace pool prevented fish from contacting the turbine runners (Schadt et al. 1985).

Fish also may be injured or killed by contact with draft tube walls caused by high water velocities and turbulence. Fish ascending draft tubes can be thrown against concrete walls and/or contact turbine blades and runners. Injuries also have been attributed to hydraulic shear within a draft tube (Bengeyfield 1982). Fish also may be injured by attempting to "jump" at powerhouses. Injuries, which are usually sustained from striking rock or structural projections, often result in direct or delayed mortality (NMFS 1993).

Injury Type

The types of injury sustained by some fish entering draft tubes or contacting turbines vary from site to site, as do immediate and delayed mortality rates. Several studies, however, attribute injuries in migrating salmonids to powerhouse structures associated with tailrace areas (Department of Fisheries, Canada 1958; IPSFC 1976; Marshall 1973; Schadt et al. 1985; Williams 1985; PacifiCorp 1993).

At the Puntledge Hydroelectric Project, dead adult salmon recovered upstream from the powerhouse had severe head and dorsal injuries (Department of Fisheries, Canada 1958). Although there was no direct evidence, injuries were attributed to fish swimming into the draft tubes and subsequently striking concrete walls and/or turbine runners. Reports subsequent to the 1958 study also identify fish injury (particularly head injury) and mortality at the tailrace barrier and in the Puntledge bypass when flows were high (Department of Fisheries, Canada 1962; Marshall 1973). This barrier was deemed unsatisfactory, and design improvements were recommended in 1988.

Contact-type injury or mortality associated with powerhouse structures has been identified at a number of other sites where there are migratory salmonids. The discharge from the powerhouse at the Seton Hydroelectric Project on the Fraser River attracts migrants that enter the draft tube and are injured or killed (IPSFC 1976; Bengeyfield 1982). During high discharge flows at Seton (e.g., full load operation), fish are not able to ascend the full length of the draft tubes because of excessive velocities (greater than 20 fps immediately downstream of the turbine runners). However, at lower flows and during start-up following shut-down periods, fish are able to enter and travel upstream into the draft tubes.

Tailrace-related injuries sustained by adult chinook salmon and steelhead trout were reported at the Winchester Hydroelectric Project on the North Umpqua River, Oregon (Williams 1985). Turbine load and subsequent water flow rates induced migrants to enter the powerhouse draft tubes and contact turbine runners. Project flow distributions determined the passage route of migrants; when spillway flows were a greater proportion of the total flow, migrants typically bypassed the project's tailrace. The turbines at Winchester were often operated at lower generation levels to reduce downstream migrant mortality. The lower generation levels, however, resulted in lower discharge velocities and made it easier for migrants to ascend the draft tubes and contact the runners.

Injuries sustained in tailrace areas also can lead to latent mortality. Abrasions and lacerations that leave fish vulnerable to secondary disease such as fungus growth, when combined with other stresses, are possible sources of mortality.

Tailrace-related injury and mortality also have been reported for migratory freshwater fish species. At the Peshtigo Hydroelectric Project on the Peshtigo River in Wisconsin, mortality of lake sturgeon and adult salmonids was attributed to fish entering draft tubes and striking turbine runners (Krueger 1989). Specifically, the runners for one of the plant's two turbines are located at the normal tailwater elevation (the runner for the other turbine is about 3.5 feet above this elevation). Dead fish that were recovered immediately downstream of the project on several occasions exhibited injuries and marks indicating contact with mechanical structures. Plant operations were modified (the suspect unit was operated continuously) to try to prevent fish from entering the draft tube; however, injury and mortality persisted. A bar rack was then designed and installed at the draft tube exits to exclude entry of larger fish.

Another injury type associated with tailraces is fish stranding. Fish can become attracted to a tailrace by the hydraulics, water temperature, natal scent, or other features. When flows subside or cease, fish may become stranded in pools and stressed or killed by lack of water, high temperatures, or poor water quality.

Supersaturation of nitrogen in tailrace or spillway flow can cause noncontact injury or death for upstream migrants. On the Columbia River in the late 1960s, nitrogen concentration levels downstream of project spillways often exceeded safe threshold levels (greater than 120 percent saturation) for adult salmonids (Ebel 1969; Beiningen and Ebel 1970). In 1968, upstream migrant mortality below John Day Dam was attributed to nitrogen supersaturation that was produced by spill over the dam (Beiningen and Ebel 1970). The effects of nitrogen supersaturation (i.e., injury and mortality) were exacerbated by delays in fish passage at the dam. Spill deflectors that were installed at Columbia River dams reduced nitrogen concentration levels and related fishery impacts. Nitrogen supersaturation has not been an issue in the tailraces of Columbia River projects until this year (1994). The need for greater flow releases to improve fish passage has been challenged by those concerned about the impacts of nitrogen supersaturation.

Migrating Atlantic salmon and American eels were injured and killed as a result of gas supersaturation (nitrogen and oxygen) in the tailrace of the Mactaquac Hydroelectric Project on the Saint John River in New Brunswick (MacDonald and Hyatt 1973). An investigation of gas bubble disease injury and mortality downstream of the project found that gas supersaturation was produced from air vented into the turbines at low generating levels to reduce negative pressures. This study and the problems experienced at mainstem Columbia River projects, indicate that supersaturation of atmospheric gases downstream of a dam or powerhouse may adversely impact upstream migrants. However, structural or operational modifications (such as those implemented on the Columbia River) should alleviate such impacts.

3.1.2 <u>Migration Delays</u>

Migration may be delayed when tailrace flows successfully compete with river bypass reaches or fishways. Migration delays caused by tailrace effects may have a greater impact on fish populations than injury and mortality.

Migration delays can expose upstream migrants to unfavorable environmental stresses (high temperatures and low flows) including predation and poaching. Migration delay may also increase potential for injury as fish attempt to move into the tailrace. There may be delay-related mortality before spawning because of accumulated stresses from lengthy migrations in an altered environment or from loss of energy reserves needed to reach spawning areas. Because spawning seasons are finite, delayed fish also may never reach spawning areas and may select suboptimal habitats for egg deposition and fertilization or may not spawn at all.

Migration delays are well documented for anadromous salmonids in the Pacific Northwest (Department of Fisheries, Canada 1958, 1962; IPSFC 1976; Haynes and Gray 1980; Rondorf et al. 1983; Schadt et al. 1985; Vogel et al. 1990;

Williams 1985; Brown 1991). There is little information, however, on migration delays for Atlantic salmon, clupeids, and other species that may undertake spawning migrations in rivers. Effects of delay may be extrapolated, however, from studies conducted with other species if differences in spawning parameters (e.g., time of year, duration of spawning period, length of migration) and biological characteristics (e.g., energy reserves, swimming capabilities) are considered.

Assuming that fish passage facilities are present at a project, migration delays can result from attraction to non-fishway flows or inadequate fishway entrances. The following discussion examines these two issues and the effects of migration delay on spawning success.

False Attraction

For migratory fish, false attraction occurs when upstream migrants are attracted to turbine discharge or spillway flows rather than to fishway flows. False attraction also occurs when upstream migrants detect the scent of their natal stream downstream of its natural outlet (Fretwell 1989). This happens when water from a natal stream is diverted through a canal or pipe to a hydroelectric project. In either instance, without proper project design or operation modifications, there may be extensive migratory delays.

The scent of natal waterbodies can be influenced by the upstream impoundment. At the Green Peter Dam on the Santiam River the reservoir is stratified. Returning adult fish are attracted to the juvenile outmigrant discharge structure which spills reservoir surface waters. Adults could not be attracted to the fishway which is served by a deep reservoir water supply because as juveniles they were not imprinted with the scent of the deep reservoir waters (Bates 1992).

When confronted with several flow alternatives, upstream migrants typically are attracted to the flow with the greatest velocity (Weaver 1963). Therefore, fish may not locate or enter the fishway if spillway or turbine discharge velocities are considerably greater than fishway entrance velocities.

At hydroelectric projects without river bypass reaches, fishway entrances usually are located adjacent to draft tube outlets and spillways. Migrants are attracted to turbine discharge and spillway flows when velocities and volumes are greater than fishway flows. Long spillway training walls can also become a barrier when periodic spill flows attract fish away from the powerhouse and fish passage channel. This can also lead to migration delay.

At sites where the spillway is not adjacent to the powerhouse (e.g., sites with upstream diversion dams and power canals or pipelines), fish may or may not use the bypassed reach of river for migration (Department of Fisheries, Canada 1958, 1962; IPSFC 1976; Schadt et al. 1985; PacifiCorp 1993). At the Sultan Project in Washington, a berm was used to concentrate bypass flows to the powerhouse side of the channel and attract fish from the tailrace into the bypass. Many projects with a long bypass provide fishway entrances both at the tailrace and at the head of the bypass reach. Depending on the site, migrants may be attracted to hydraulic conditions in the tailrace (Department of Fisheries, Canada 1958, 1962; Schadt et al. 1985; PacifiCorp 1993; IPSFC 1976). Bypass reach water temperatures may be unattractive to upstream migrants due to low flows and extremes in atmospheric conditions. Increases in bypass reach flows or decreases in powerhouse flows may reduce attraction of migrants to tailrace areas. This type of flow control may not be necessary at projects that have upstream fishway entrances at the powerhouse and spillway.

Some powerhouses are located a considerable distance from the river, and their design includes wasteways to spill unneeded water or to pass debris back to the river channel. These wasteway channels are dead ends to upstream fish passage. At the Roza and Leaburg/ Walterville projects, barriers were constructed at the confluence of the wasteway channel with the river to minimize this potential impact.

Inadequate Fishway Entrances

The ability of fish to locate or enter fishways depends on entrance design and location and the presence of competing flows. If fishway entrances do not provide adequate flow and velocity at the proper location, migrants may be reluctant to enter them, even in the absence of competing flows. It also is possible for a fishway to attract fish despite higher velocities at adjacent spillways or draft tubes if the fishway entrance is properly located with adequate entrance water velocities. The most effective fishway entrances are sited based on fish behavioral response to tailrace conditions. Multiple entrances may be required to cater to a range of flows.

To reduce false attraction, fishway attraction flow should be at least 3 percent of adjacent powerhouse or spillway discharges when a fishway is located along the shoreline (Hildebrand et al. 1980). For small hydroelectric projects, Hildebrand et al. (1980) recommend attraction flows that are 3 percent of the average annual river flow at the project. For a number of sites that pass Pacific salmonids, fishway flows are 4 to 10 percent of the total project flows (Bates 1992). Where possible, project operation and spillway flow distribution should alleviate false attraction and consequent migration delays.

A poorly designed or located fishway can inhibit fish passage at hydroelectric dams. Other factors that can influence fishway attraction include lighting, flow patterns, channel shape and size, and availability of holding areas. Although a fishway may be properly designed and sited for the behavioral and physical characteristics of targeted fish species and for local hydraulic conditions, migration still may be delayed if powerhouse or spillway flows mask fishway entrance attraction water. Such delays can be alleviated by manipulating generation levels and the amount or distribution of spill over a dam. The most efficient fishway entrances are located based on site-specific assessment of migrating fish aggregations in the tailrace.

Migration Timing and Spawning Success

Specific effects of spawning migration delays on fish population size are not well documented in the literature. As shown in the following discussion, however, there are many possible adverse effects of migration delay on fish.

Effects of delays on migration timing and spawning success depend primarily on the species of fish and environmental factors. For example, negative impacts may be considerably greater for populations of migratory fish that spawn once during their life span and die at the end of the spawning season whether they have spawned or not. If an entire age class of these fish is adversely impacted, the effect may be observed over many generations. Populations of species capable of spawning several times during their life span, including most clupeids, may not be similarly affected by migration delays but may see some proportional loss in reproductive potential.

Some species that spawn in multiple years also can be affected both by the need for adults to successfully pass downstream and by delay-related spawning failures. Some that spawn in more than one year of their lives spawn infrequently (e.g., sturgeons). Other species such as clupeids and Atlantic salmon suffer high mortality levels after spawning, and second time spawning frequency is low. Therefore, a single spawning migration for these species contributes more to their population than to the population for a species that spawns every year with little mortality (typical of most resident freshwater species).

All fish species have distinct spatial and temporal spawning requirements. Fixed spawning times in habitats with annual variations in productivity have evolved to ensure that larval fish hatch at a time when the physical environment (e.g., water temperature and flow) and food supply levels are conducive to survival (Bye 1984). Some species such as chinook salmon hold in the river for several months before initiating their final upriver migration and spawning. This provides for optimal spawning timing but requires adults to migrate in a weak physical condition.

Spawning habitats and time of spawning also are important for the survival of eggs. Without adequate temperature and oxygen regimes, hatching rates may be considerably reduced. Migration delays can reduce the survival of both eggs and larvae by causing adults to spawn in marginal habitats or at times when environmental factors are less than optimal.

Most migratory fish species have fixed spawning times. Photoperiod (length of day) is a major influence on salmonid reproductive cycles (de Vlaming 1972; Bye 1984). Photoperiod influences gamete maturation in anadromous fish even when spawning migrations are delayed. Females that ovulate before reaching spawning areas have lower spawning success. In a study that examined the viability of over-ripened ova from female rainbow trout, egg hatching rates decreased and alevin deformities increased with increased length of time between ovulation and fertilization (Sakai et al. 1975).

Fish may spawn in suboptimal habitats if they cannot reach preferred spawning areas because of migration delay. Adult salmonids at the Red Bluff Diversion Dam on the Sacramento River in California experienced migration delays that caused fish to spawn below the dam where summer water temperatures were too warm for egg survival (Vogel et al. 1990; Brown 1991). Delay also may prevent some fish from spawning even if they reach preferred spawning areas, because inappropriate environmental cues are present (Hoar 1953) (e.g., low water temperatures inhibit ovulation in some salmonid species) (Goryczko 1972 [cited in Bye 1984]). Species that spawn shortly after reaching spawning areas (e.g., most Pacific salmon and clupeids) may be more affected by delays than species that may not spawn for months after entering their natal river basin (e.g., Atlantic salmon, summer-run steelhead, spring chinook). However, inability of individuals of the latter group to reach suitable holding areas before spawning may cause prespawning mortality that would not otherwise occur.

Resident species delayed during annual migrations also may spawn in suboptimal habitats and suffer lower egg-hatching rates and larval survival. A study on the effect of spawning-run delays on Arctic grayling determined that delays caused fish to stop migrating before reaching their upstream goals (Fleming and Reynolds 1991). Migration rate was positively correlated to maturation level, and more mature females did not travel as far upstream as less mature females. Delays of 3 days were critical for females near the end of their spawning run. Study results indicate that delayed graylings may spawn in unsuitable habitats because they cannot reach upstream spawning areas due to biological (e.g., level of maturation) and physical (e.g., water temperature) constraints.

Delays also may kill migrants before spawning if energy reserves, which are used to reach breeding areas and for spawning, are completely depleted. This is especially true for migratory species that do not feed during migration. Energy depletion may be exacerbated by increased stress levels caused by migration blockages. Energy stores can be significantly reduced at a powerhouse or spillway if fish continually make attempts to ascend turbine discharge or spillway flows. Pre-spawning death from excessive delays has been cited at several projects on the Columbia River and in other river basins throughout North America (Burgner 1991; Heard 1991).

Effects of migration delays on spawning success are difficult to extrapolate to the recruitment of young to the spawning stock of a population. Depending on the species, recruitment depends on the number of spawners, environmental factors that influence survival, or a combination of number of spawners and environmental factors. Environmental factors may influence recruitment when resources (preferred habitats and food) are limited and fish densities are high. If recruitment is directly related to the number of spawners, fewer spawners will result in lower recruitment levels. Alternatively, if recruitment is related to environmental factors (i.e., survival of young after hatching and up to recruitment to the spawning population), a reduced number of spawners may not directly influence recruitment levels. If the number of spawners is low such that the maximum number of young produced would be far below the carrying capacity of the environment, however, then spawning stock size could strongly influence recruitment levels.

3.1.3 Summary of Tailrace Effects

Most hydroelectric sites have the potential to cause injury or mortality to migratory and resident fish that move into tailrace and draft tube areas. Tailrace-related injury and mortality are a particular concern for species with strong swimming capabilities or particular migratory behavior (i.e., the need to move to upstream areas for spawning, feeding, or rearing) and at sites with variable operating conditions. The extent of impact and the need for mitigation measures depend on biological factors and physical characteristics at each site.

Potential for adverse impact is greatest at sites with adult migratory species that are capable of negotiating high water velocities. Migrating salmonids are particularly susceptible to attraction to tailrace areas, and few projects have discharge velocities that would exceed the swimming speeds of adult salmonids at all operating loads. Clupeids, however, may be less susceptible than salmonids to draft tube and turbine runner injury and mortality. Unlike salmonids, they typically avoid highly turbulent areas such as turbine discharges and generally are unable to negotiate areas with high water velocities greater than 15 fps (Bell 1990).

There is also potential for tailrace effects to cause injury or death of any fish with strong swimming capabilities (e.g., freshwater basses, walleye, pike, catfishes, paddlefish, and sturgeons). Few data, however, document effects on these species.

Project layout, local hydraulic conditions, and operating schedules influence potential for injury and mortality in tailrace and draft tube areas. In tailraces where fish entry is unavoidable, fishway entrances should be appropriately located with optimum hydraulic conditions that minimize residence of migrants in spillway flows and turbine discharges. A spillway flow with hydraulic characteristics that are more attractive than the powerhouse flows should prevent migrants from entering most discharges and tailraces. Discharge velocities in excess of 20 fps across the entire draft tube opening should exclude the entry of any fish if the length of the high velocity channel is long enough for the target species.

To successfully identify or predict migrant injury and mortality related to a hydroelectric project, all relevant biological and hydraulic characteristics at a site must be understood. Hydraulic conditions are often complex and difficult to characterize. Even if fish are not being directly injured in tailrace and draft tube areas, there may be adverse impacts from migration delays.

Migration can be delayed at any hydroelectric project when migrants are falsely attracted to areas other than natural stream channels or fishway entrances. False attraction usually occurs at projects with considerable mainstem bypass reaches. Long bypasses with relatively low flow releases may not contain enough natal scent to attract fish from tailrace flows especially if the bypass reach contains inflow from other stream channels or tributaries. Migrants typically are attracted away from the main river channel and into a tailrace by the discharge from the powerhouse. False attraction also can occur in the vicinity of powerhouse and spillways if turbine discharge and spill produce hydraulic conditions that mask fishway attraction water.

Level of impact depends on fish species. Resident fish populations may not be affected by delays if spawning takes place over several months. Some resident fish species may have shorter spawning seasons, however, that depend on distinct environmental conditions (e.g., sturgeon).

Migratory fish may be most affected by migration delays because they travel long distances to reach spawning areas and typically spawn during distinct time periods. Lengthy delays may deplete energy reserves and lead to spawning failure.

For migratory fish populations, the loss of adult spawners due to delay, injury, or mortality may result in lower spawning success or recruitment. This is especially true if spawning populations are low. For catadromous species, there may be some injury and mortality of upstream migrating juveniles. Migration delays, however, do not have the same effects on catadromous juvenile upstream migrants; there may, however, be some effect on survival, growth, and maturation. It is important to identify sources of injury, mortality, and delay and to implement the appropriate protective measures to ensure effective passage of all age classes and species of migratory fish.

Many false attraction problems can be eliminated or reduced by improving fishway entrance location and hydraulics, or by modifying powerhouse operations or spillway flow amount and distributions, as discussed in the following section.

3.2 Description of Tailrace Barriers, Modified Project Operation, and Spill

Physical structures, behavioral barriers, and modifications in project operation and spill may alleviate powerhouse-associated injury and mortality or reduce migration delays. Tailrace barriers are used specifically to avoid injury to upstream migrants especially where the project is upstream of the terminus of fish migration. Effective physical and behavioral barriers can limit draft tube-related damage but may not reduce migration delays unless specifically designed to do so. Likewise, modified project operation and spill regimes can alleviate migration delays but cannot eliminate injury and mortality at a powerhouse. At sites where there are injury and mortality and migration delays, physical structures that guide fish to fishway entrances or a bypass reach may be necessary.

Regardless of the impact type, all site-specific biological, physical, and hydraulic parameters must be considered when formulating appropriate measures to reduce injury or migration delays.

Migration delays at many projects can be reduced through improved fishway entrance design, flow characteristics, or location. Fishway entrance design and location may be the most important aspects of successful fish passage at powerhouses and dams (Clay 1961). Although some delay in migration may be inevitable at hydroelectric projects, properly designed and constructed fish passage facilities minimize delays and subsequent impacts.

Before selecting appropriate mitigative measures to reduce or prevent negative impacts to fish passage at a hydroelectric project, specific issues must be identified. If injury, mortality, or migration delays result from tailrace attraction, then a barrier that blocks movements into tailraces and guides fish to fishway entrances or a bypass reach may be required. A barrier that completely blocks upstream movement may be sufficient, however, at projects where fish injury and mortality are the only concern. At sites with only migration delay problems, measures to guide fish to passage routes will be needed.

Appropriate mitigation for impacts on upstream migrants must consider a design that will not have an impact on downstream migrants. Downstream migrants may pass existing spillways or turbines with some success. Some tailrace barrier designs may lead to impingement or injury from plunging into a concrete sill or striking fixed structures on the tailrace barrier. Downstream migrating juvenile salmonids were observed to be impinged on the rectangular bar rack tailrace barrier at the Weber Dam on the Grand River in Lansing, Michigan (Whelan 1994).

Downstream migrants can also be affected by predators that populate tailrace habitats. Downstream migrants that successfully pass turbine or spillway flows are often prey for tailrace predators. Tailrace barriers for upstream migrants would not be expected to contribute to this effect.

After the problem is defined, mitigation (such as barriers) can be developed based on site-specific biological, physical, and hydraulic characteristics. Depending on the barrier type, biological characteristics such as swimming and leaping capabilities of the target species must be considered. Important physical characteristics at a project include length and width of a tailrace, location of fishways, spillway size and location, water velocities, and other physical structures associated with the powerhouse or tailrace. Important hydraulic conditions that can influence tailrace barrier design include powerhouse and spillway discharge volume and water velocity at all operating conditions and all headwater and tailwater elevations.

3.2.1 Tailrace Barriers

Tailrace barriers prevent entry of fish into tailrace areas or turbine draft tubes or guide migrants to a fishway or bypass reach. Tailrace barriers may be physical structures, behavioral barriers, or electrical barriers. Physical structures include various bar racks (or screens) and barrier dams that create hydraulic head or water velocities that fish cannot ascend. Behavioral barriers block fish movement by eliciting an avoidance response from them which causes them to retreat or seek an alternative route. Behavioral barriers have been extensively evaluated for blocking or guiding downstream migrants (EPRI 1986, 1993), but not as much for upstream migrants. Electrical barriers have been examined more than any other available device for upstream passage.

NMFS categorized tailrace barrier designs as diffuser or non-diffuser (NMFS 1993). Diffuser barriers distribute flow over a relatively large area and may reduce attraction of fish and physically prevent movement of fish into upstream areas. Diffuser barriers include vertical or inclined bar racks, horizontal bar racks, and floating weirs.

Non-diffuser barriers create impassable physical or hydraulic conditions or produce a stimulus that elicits an avoidance response from fish. Non-diffuser barriers include various types of barrier dams and behavioral barriers (e.g., electrical fields, lights, and sound).

Both types of tailrace barriers are designed to prevent upstream movement of fish. Any of these barriers can be operated seasonally. They can also be used in combinations to overcome unique conditions of any tailrace. If designed accordingly, barriers also can be used to guide fish to alternative passage routes.

Diffuser Barriers

Diffuser barriers (barrier screens or bar racks) prevent movement of fish into tailraces or draft tubes and are designed to guide migrants to a fishway entrance or bypass channel. Diffuser barriers include vertical, inclined, and horizontal screens. Despite design differences, each diffuser barrier produces a physical block to fish without inducing fish to swim or jump at the barrier in attempts to move upstream.

Although diffuser barriers may alleviate fish injury and mortality, they may not reduce migration delays unless they are specifically designed to do so. To facilitate upstream passage and to block movement into draft tubes, barrier screens and racks should be angled with the upstream terminus located at a fishway or bypass channel entrance. Regardless of purpose, a properly designed diffuser barrier should block upstream movement of fish in a selected water course without creating additional injury, mortality, or delay problems.

Important barrier screen characteristics include water velocities, static head levels, and location. The most important biological factors affecting barrier screen performance are water velocities and hydraulic head levels that do not induce fish to jump at a barrier. Between-bar spacing (i.e., clear opening) must be narrow enough to prevent the smallest upstream migrating fish of a target species from becoming wedged or gilled or from passing through the barrier. To reduce such problems, 1-inch clear bar spacing has been recommended for tailrace barrier screens (NMFS 1993). Bates (1992) recommends sizing the spacing narrow enough to prevent fish from injuring their eyes as they attempt to push their way through the clear spaces. To minimize jumping-related injury, it has been recommended that average water velocities should not exceed 1 fps and should be uniformly distributed across the entire area of a barrier screen structure (NMFS 1993). When water velocities are not uniform, there may be high-velocity zones that induce fish to jump at the barrier.

An important consideration for diffuser barrier design is provision for downstream migrants. To prevent downstream migrant impingement, removal of the barrier during outmigration may be necessary. Alternatively, a downstream fish protection/guidance device can be used to prevent downstream migrants from following the flows into the upstream side of the tailrace barrier.

Fish injury is less likely with horizontal diffusers (Figure 3-1). Unlike vertical or inclined barrier screens (Figure 3-2) that are set at or nearly perpendicular to the flow (i.e., upright position), horizontal diffusers are set parallel to the flow. This design directs turbine discharge upward, creating an upwelling effect. The hydraulic conditions created by horizontal diffusers minimize potential for injury because fish are less likely to jump at upwelling flows.

Variable-slope barriers (or weirs) are designed to adjust to varying flow levels and allow most debris to pass over the screen and continue downstream (see Figures 3-3, 3-4, and 3-5). NMFS describes three types of variable-slope weirs (floating, hydraulic, and pneumatic) for use as tailrace barriers at hydroelectric projects (NMFS 1993). All three types are inclined downstream at an angle that depends on water level. Most debris contacting these screens will push the screen downwards as the debris is carried downstream by the flow. Hydraulic and pneumatic screens also may need to be mechanically lowered to facilitate passage of debris.

Site-specific debris loads will affect the feasibility of vertical, inclined, or horizontal screens. Vertical or inclined screens designed for sites with heavy debris loads or with unscreened water diversions may need a cleaning system (e.g., a rake device). Because these structures are completely submerged, horizontal screens are not easily cleaned and are best suited for sites with light debris loads or screened intakes.

Barrier screen location may affect power generation because, to some extent, screens reduce operating head. Generally, the closer the barrier is to the project tailrace, the more it will impact generation. The height and bar spacing of a screen also can affect tailwater elevations and subsequently reduce generation capacity. Generally, reductions in operating head from a diffuser barrier would be less than those from a barrier dam. Barrier screens and bar racks designed with an approach velocity of

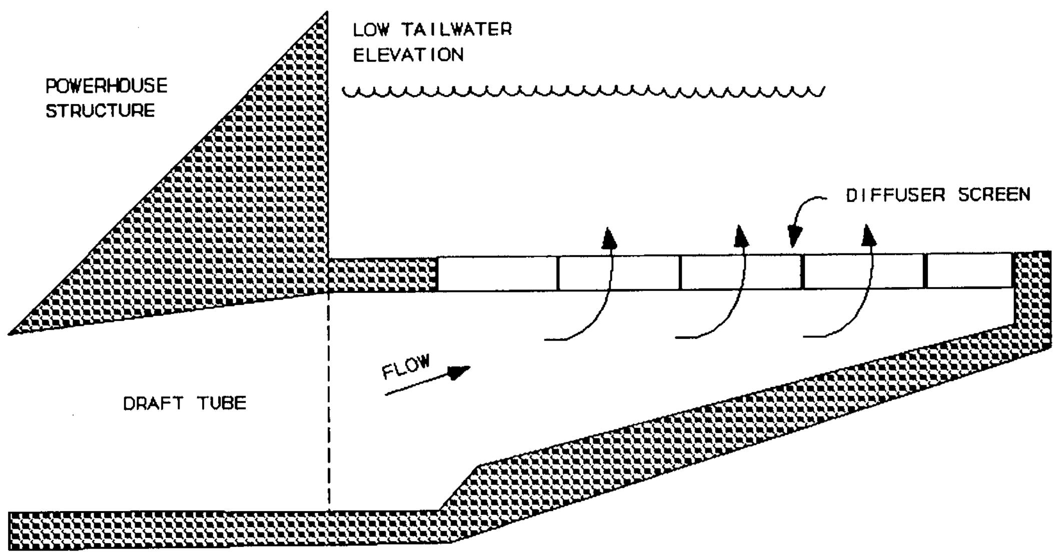

FIGURE 3-1
HORIZONTAL DIFFUSER
RACK

TAILRACE BARRIER STUDY

SOURCE: MODIFIED FROM NMFS 1993

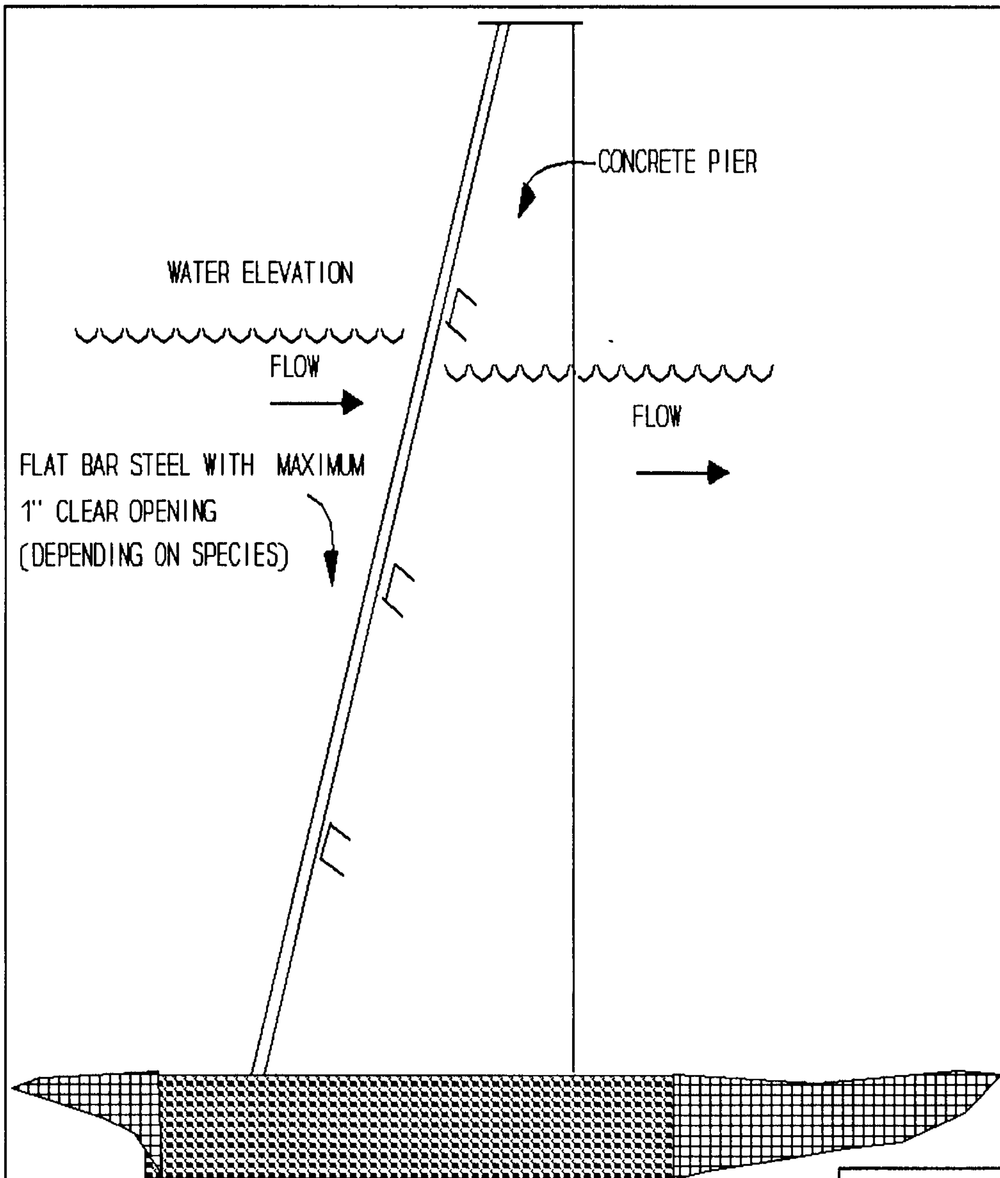

FIGURE 3-2

VERTICAL OR INCLINED DIFFUSER BARRIER

TAILRACE BARRIER STUDY

SOURCE: MODIFIED FROM NMFS 1993

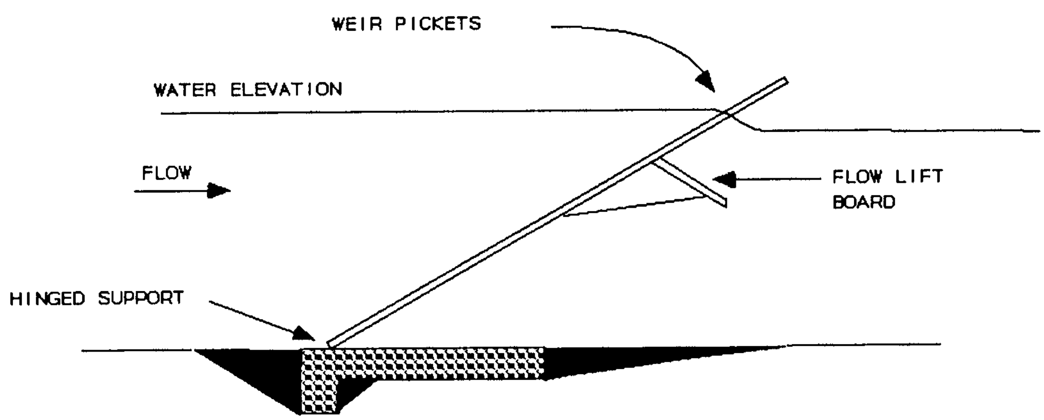

FIGURE 3-3

FLOATING WEIR

TAILRACE BARRIER STUDY

SOURCE: MODIFIED FROM NMFS 1993

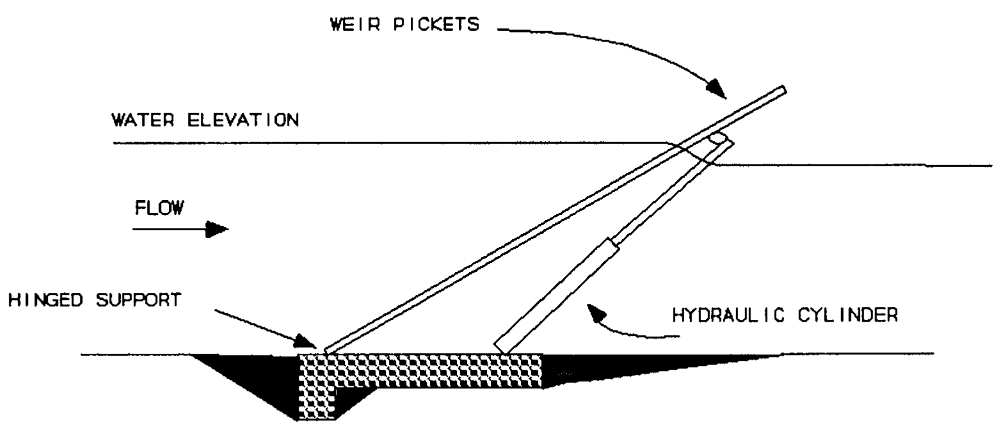

FIGURE 3-4

HYDRAULICALLY OPERATED WEIR

TAILRACE BARRIER STUDY

SOURCE: MODIFIED FROM NMFS 1993

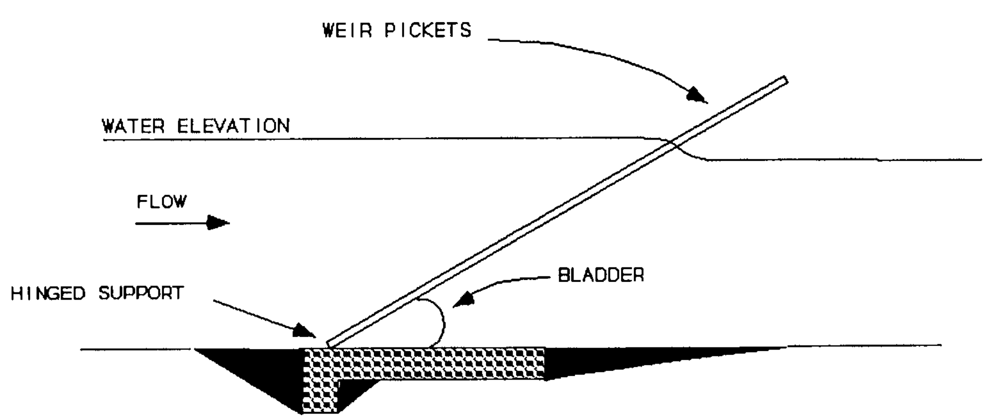

FIGURE 3-5

PNUEMATICALLY OPERATED WEIR

TAILRACE BARRIER STUDY

SOURCE: MODIFIED FROM NMFS 1993

1 fps equate to a head differential of less than 0.2 feet and should have a minor effect on power generation.

Jumping-related injuries and mortality have been observed at the Roza Hydroelectric Project on the Yakima River in Washington (NMFS 1993). Fish diverted from the mainstem river into the water wasteway are delayed because the wasteway is a dead end (i.e., there are no upstream fish passage facilities). To reduce false attraction to the wasteway, a bar rack diffuser barrier was constructed at the confluence of the wasteway and the river. The Roza barrier also was designed to inhibit fish jumping at the rack.

Barrier screens can be located downstream of debris sluices and tailraces or flush against powerhouse draft tube exits to reduce injuries. A barrier screen called a "fish guard gate" was installed at one of the turbine discharges at the Peshtigo Hydroelectric Project, Peshtigo River, Wisconsin (Krueger 1989). The fish guard gate was installed to prevent lake sturgeon and adult salmonids from entering the draft tube where they were being injured and killed. The barrier screen at Peshtigo has panels of steel bars set horizontally in a large frame and supported by larger vertical bars. The entire gate structure is set flush to the powerhouse at the turbine outfall. The panels can be rotated to a position parallel to the flow for maintenance. The spacing between horizontal bars is adequate for blocking the movement of the target species into the draft tube.

Non-Diffuser Barrier Dams

Barrier dams are a hydraulic barrier that uses height or velocity to block migration. Barrier dams are the most common non-diffuser barrier used to block fish entry into tailraces and draft tubes and to guide migrants to fishway entrances or a bypass channel. They should be designed to block movement of target species and to minimize potential injury and reductions in power generation.

Barrier dams are similar to barrier screens. They should be angled and designed to terminate upstream at a fishway or bypass channel entrance, which facilitates migration past a project by directing fish to locate upstream passage routes.

Barrier dams are usually one of the following types: (1) Ambersen or buttress; (2) velocity barrier; or (3) porous dams or dikes (e.g., rock dams or gabion diffusers). Buttress-type and velocity barriers are classified as hydraulic barriers because they create hydraulic conditions that cannot be ascended by fish. Hydraulic barriers usually are used at sites with upstream adult salmonid migrants because most salmonids can swim at high speeds and jump considerable heights. Porous dams allow water but not fish (depending on size class) to pass through the structure, physically preventing fish from moving upstream. Because porous dams usually are designed to function without spill, they are appropriate for blocking movement of most adult fish. Also, porous dams act as a diffuser (similar to barrier screens) creating low water velocities that are unattractive to migrants.

A porous dam is more suitable as a downstream reregulating dam or as a block to passage into the bypassed reach of river than as a draft tube barrier because head loss is generally high.

Buttress-type barrier dams (Figure 3-6) are designed to prevent movement of fish into bypassed reaches and spillways, while simultaneously providing flows that attract fish away from tailraces and towards fishway entrances.

Typically, this type of dam is constructed below a spillway to block upstream fish movement, but above a tailrace so not to reduce effective project head. Although a buttress-barrier does not directly block entry of fish into draft tubes, it can be used in conjunction with a fishway to make fishway entrance flows more attractive than tailrace flows to migrating fish.

A channel is constructed under the crest of the dam overflow and connected to a fishway entrance to facilitate upstream passage away from tailrace flows. Fish attempting to jump the barrier either fall or swim into the channel beneath the overflow crest; if the barrier is angled, a lower elevation at the downstream end will provide an attractive, direct flow through the channel for fish to follow to the fishway entrance.

Fishway entrance flows, combined with flow through the channel beneath the dam, provide a stronger attraction flow for fish than do tailrace flows.

Recommended hydraulic head levels for buttress-type barriers are not less than 10 feet for salmonids (Wagner 1967; NMFS 1993). To ensure effectiveness, this type of barrier must be designed to operate at all possible combinations of head- and tailwater levels when fish are migrating.

Velocity barriers (Figure 3-7) create either water velocities that are greater than the swimming speeds of a target species or a plunging flow where fish cannot turn to jump. Spill or tailrace discharges descend over a sill at shallow depths and most typically over a concrete apron. High velocity flow is produced across the apron. Generally, fish are unable to ascend the spilling water at the end of the apron (Wagner 1967). If fish do swim or jump on to a velocity barrier apron, the hydraulic conditions at the upstream portion of the apron are not suitable for fish to leap or swim over the sill (i.e., flow is too fast and shallow). Low tailwater levels may cause fish to jump at the dam and may lead to injury. Apron depth on a velocity barrier should not exceed 6 inches for salmonids (Wagner 1967; NMFS 1993). The water velocity necessary to block upstream fish movement depends on the swimming capabilities of all species that are targeted for protection or guidance at a site. Minimum water velocities of 18, 22, and 26 fps have been recommended for coho salmon, chinook salmon, and steelhead trout, respectively.

Wagner (1967) provides general criteria for salmonid velocity barriers. Criteria include maximum water depth of 6 inches with a minimum velocity of 16 fps on an apron at least 15 feet in horizontal length. A water velocity of 16 fps would

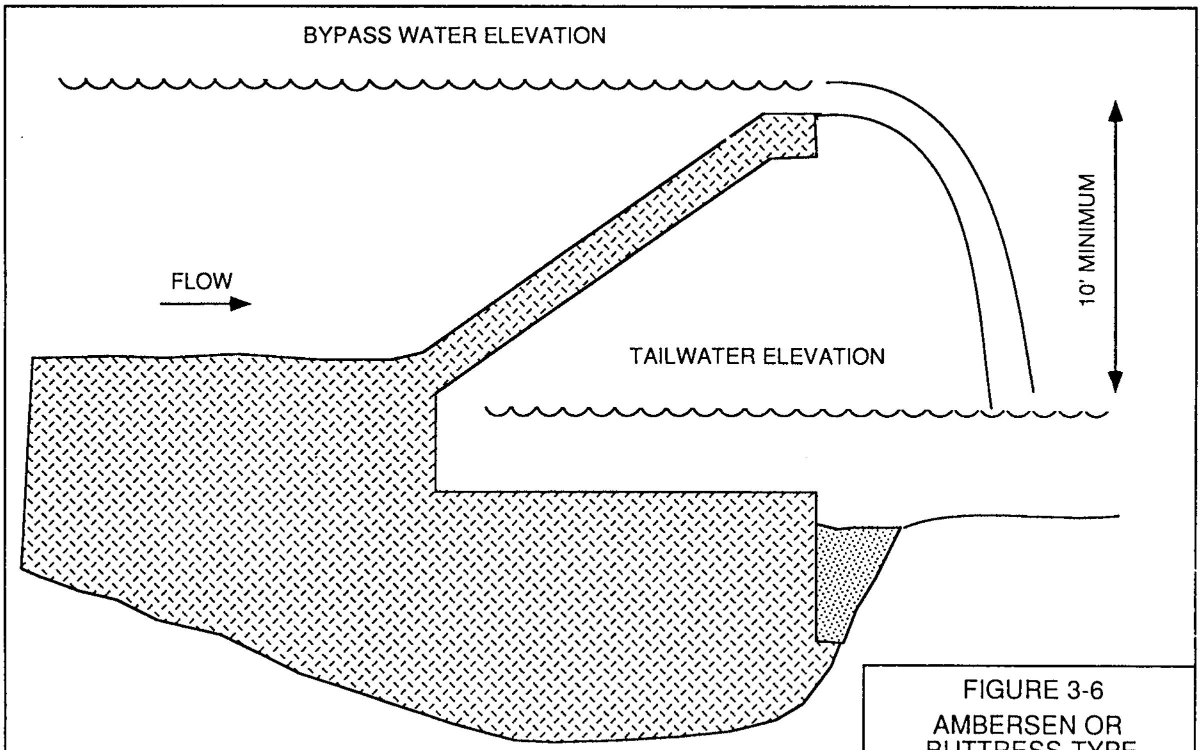

FIGURE 3-6
AMBERSEN OR BUTTRESS-TYPE BARRIER DAM

TAILRACE BARRIER STUDY

SOURCE: MODIFIED FROM NMFS 1993

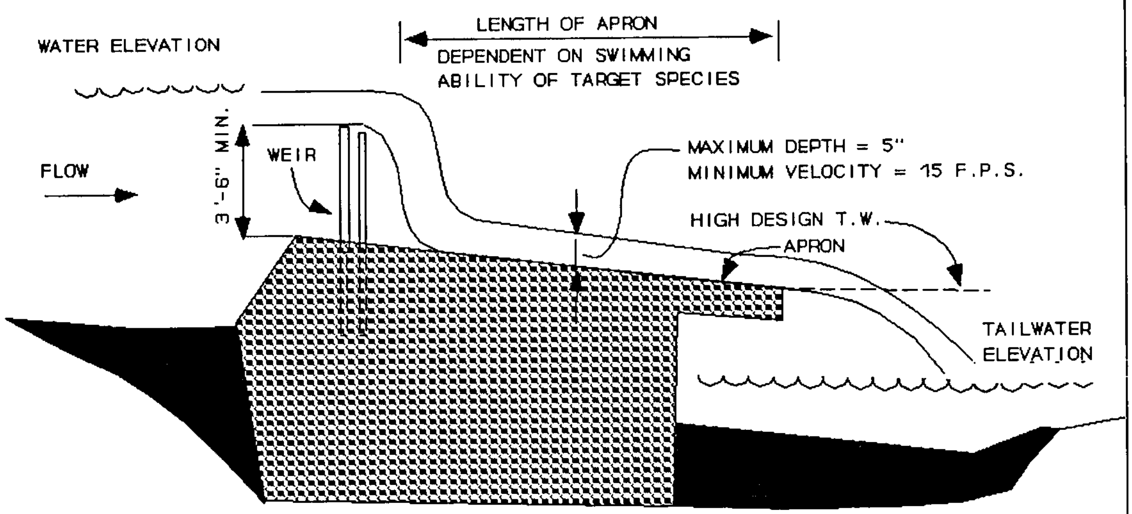

FIGURE 3-7

VELOCITY BARRIER

TAILRACE BARRIER STUDY

SOURCE: MODIFIED FROM NMFS 1993

require a minimum sill height of 3.5 feet (Wagner 1967). Velocity barriers may be ineffective if tailwater levels exceed the height of the downstream end of the apron. Similar to buttress-type barriers, velocity barriers are used to guide upstream migrants to a fishway entrance or bypass channel. If a velocity barrier is angled, a channel with directed flow can be placed beneath the crest of the apron overflow. The abutments of a barrier dam must be designed for a range of flows to prevent fish passage around the ends of the dam.

Porous dams are physical structures that block the upstream movement of fish too large to swim between gaps in the core material. River flow continues downstream by passing through the dam without overflow, except during high water periods. Porous dams effectively prevent upstream fish movement as long as there is no overflow. Because upstream migrations often occur during high water periods and tailwater elevations at hydroelectric projects can fluctuate considerably, porous dams most likely cannot be placed near spillways or powerhouses. Porous dams could be used at the downstream exit of a tailrace or bypass reach.

A rock dam fish barrier constructed on a tributary to the Cordell Hull Reservoir in Tennessee successfully limited passage of undesirable species from moving upstream (Bulow et al. 1988). Although the barrier was effective, fish were able to move upstream during periods of high river discharge. The dam had a negative impact, however, in that river habitats upstream of the barrier experienced decreased quality because of increased sedimentation and siltation.

Behavioral and Electrical Barriers

Behavioral barriers have been extensively examined for downstream fish protection (EPRI 1986, 1993), but not for upstream migration.

Two behavioral devices have considerable potential for protecting juvenile downstream migrants (specifically juvenile clupeids and salmonids): strobe lights and transducer sound systems (Loeffelman et al. 1991; Klinect et al. 1992; EPRI 1992, 1993; Dunning et al. 1992; Nemeth and Anderson 1992; Ross et al. 1993; RMC and Sonalysts 1993). An underwater strobe light pulses bright, broad frequency light at rates of approximately 300 flashes/minute to repel fish. Strobe lights may have upstream applications, but further studies are needed to determine effectiveness for adult fish. A transducer system that uses low-frequency sounds has been shown to block the movement of steelhead trout ascending a fish ladder (Loeffelman et al. 1991). However, as with strobe lights, further studies are needed to refine sound systems before they can be considered a viable upstream fish barrier technology.

Electric fields are an effective upstream fish barrier. These devices elicit an immediate avoidance response from approaching fish. They may also temporarily impair a species' swimming ability, which allows them to be swept downstream. Electric barriers require a constant water velocity to sweep fish from the electric field.

Electric fields or fences have been used as fish barriers for many years, but persistent problems (e.g., fish injury and mortality, safety, and effectiveness at a wide range of flows and environmental conditions) have inhibited widespread acceptance and use (Clay 1961; NMFS 1993).

Recently, Smith-Root, Inc., developed and patented a Graduated Field Fish Barrier (GFFB) designed to block upstream fish movement. The GFFB produces a DC electrical current with electrodes placed across the channel bottom (e.g., stream or tailrace) perpendicular to the flow. The electrodes are mounted in an insulating medium (often a specific type of concrete), evenly spaced, and designed to produce a electrical field decreasing in strength from upstream to downstream. This design increases field strength as fish approach the barrier. Fish that do not initially retreat eventually are overcome by the electrical current and are involuntarily swept downstream.

Studies have been conducted to examine the GFFB's effectiveness while minimizing additional injury or mortality (Rozich 1989; Hilgert et al. 1992). Other studies focused solely on a GFFB's ability to repel fish or prevent upstream movement (Seelye 1989; Barwick and Miller 1990). A study at the Quilcene Hatchery on the Quilcene River in Washington demonstrated that a GFFB prevents upstream movement of adult salmonids without causing injury or mortality or damaging gametes of upstream migrants (Hilgert et al. 1992). However, the GFFB at Quilcene was ineffective when river flows were high. Two studies conducted on rivers in Michigan demonstrated that GFFBs could effectively block upstream migrations of sea lampreys (Rozich 1989; Seelye 1989). One study also showed no apparent injury or mortality sustained by downstream-migrating steelhead trout post-spawn adults and smolts exposed to the GFFB (Rozich 1989). The GFFB's also block migration of non-target species such as lake sturgeon and adult steelhead (Whelan 1994). In an experimental flume, a GFFB successfully inhibited movements by several species of resident freshwater fish (Barwick and Miller 1990). This study assessed the fish response to the GFFB during simulated non-generation, generation, and pumpback flow regimes.

Although electrical fields like the GFFB show promise as tailrace barriers, many state and federal resource agencies do not consider them a proven technology (NMFS 1993). Electrical barriers may not be completely effective at blocking fish under all conditions. High flows reduce the effective strength of an electrical field, and increased field strength to overcome high flows may increase injury or mortality. Also, temperature, conductivity, and fish size influence the effect of electrical currents on fish. Because the ability of an electrical current to immobilize fish depends on fish size, smaller fish may easily pass through electrical fields that are designed for larger fish. Safety to other animals and humans may be an operational concern. Monitoring for corrosion and reliable operation may be maintenance issues.

3.2.2 Modified Project Operation and Spill to Reduce Tailrace Impacts

Powerhouse operations often can be modified to reduce attraction of migrants to draft tube discharges. This may improve the ability of fish to locate a fishway entrance or bypass reach and eliminate potential injury and mortality at the powerhouse. Modification of spill regimes (e.g., amount of flow and distribution) also can help migrants find fishways or bypass reaches. Attractive upstream passage routes can reduce powerhouse-related injury and mortality by limiting the time fish spend in the tailrace.

Modified project operation can alleviate injury, mortality, and migration delays in several ways. Migrants often are most susceptible to powerhouse-related damage during turbine start-up and shut-down when draft tube discharge velocities are considerably lower than during full or partial load operations. Since many migratory species have diurnal (within a 24-hour cycle) movement patterns, injury and mortality may be reduced if start-ups and shut-downs are scheduled during low fish activity. Fish may still enter draft tubes and be injured or killed, however, when units are operating with partial loads. Adverse impacts may be reduced or eliminated if units are shut off or run at full load. Injury and mortality that occurs at full load operation may necessitate shut-down of problem units. Shut-downs during all or part of migration seasons have been somewhat successful at several projects (Department of Fisheries, Canada 1958; IPSFC 1976; Fedorenko 1989).

Alterations in powerhouse operations can eliminate migrant attraction to draft tubes. Clay (1961) described several scenarios for operating powerhouse units and for controlling spill distributions to improve upstream passage. At large powerhouses, a flume with multiple entrances leading to a fishway can be constructed across the face of the powerhouse above the draft tube exits. One solution for reducing fishway entrance problems associated with false attraction is to keep all units off line during the entire migration period or during peak movements each day.

Spill regimes also can be modified at some sites where fishway entrances compete with spillway flow (Clay 1961). At sites with fish ladders on both river banks, spill can be concentrated in the middle of the spillway. At sites with one fishway, spill should be greatest away from the fishway entrance and decrease closer to the fishway. This spill regime controls hydraulics to lead fish to the fishway entrance and assumes that high velocities near the spillway exceed the swimming capacity of fish. At many projects that do not have some type of adjustable spill gates, it may be impossible to control flow distribution across the spillway. At these sites, multiple fishways (located at both ends and in the middle of the spillway) may be the only means to reduce migration delays and false attraction. If the spill amount can be controlled, the ideal situation may be no spill at all. Without spill, fishway attraction water would be the only flow source available for migrants to follow. However, if spillway flows are required to maintain habitat quality downstream of the dam or to allow fish to move up the river, no spill would not be a viable solution.

Bell (1990) presents powerhouse and spillway modifications for improving upstream passage that are nearly the opposite of those proposed by Clay (1961), even though both authors would likely agree on project-specific fishway and spillway flows. Bell (1990) states that spillway flow and turbine discharges should be greatest near fishway entrances in order to *attract* fish to the vicinity of the entrance. These opposite conclusions are based on the opposite assumption each author makes on the effect of spillway flows. Clay assumes, from experience with large hydro projects, that spillway flows create velocity conditions that exclude fish. Bell assumes spillway flows attract fish in the high-flow conditions. Bell (1990) views spillway flows as supplementary attraction water and suggests that flows should increase in volume from the opposite end of a powerhouse or spillway to the end with the fishway entrance. Bell (1990) also suggests that flows at spillways with fishways at either end should be greatest near the fishway entrances and taper off towards the center of the spillway.

If natal stream scents are the source of false attraction, altering powerhouse operation and spill regimes may not alleviate injury and mortality or migration delays. At the Seton Hydroelectric Project on the Fraser River in British Columbia, the powerhouse was shut down during the upstream migration of sockeye and pink salmon runs to reduce attraction of fish to the draft tubes where they were being injured and killed (IPSFC 1976). Seton Creek is diverted into a power canal that leads to the Seton powerhouse which releases the water into the Fraser River downstream of its confluence with Seton Creek. Spill was increased at the Seton diversion dam to enhance mainstem river flows and, consequently, facilitate upstream migration. Because of wicket gate leakage, however, fish still ascended the draft tubes. Continued attraction of fish was attributed to the scent of Seton Creek water leaking through the gate. Fish that followed the leakage into the draft tubes were susceptible to injury and mortality during start-up periods. The leakage problem was reduced by injecting air into the turbines when they were not operating.

Spillway flows may need to be increased when the bypass reaches contain important spawning or rearing habitats (for resident and migratory species) which attract migrants despite low-flow levels. For tailraces leading to a powerhouse without passage facilities, increased bypass reach flows may keep fish from entering the tailrace. Artificial freshets may be used to stimulate fish movement in a river channel (Hayes 1953), thus allowing migrants to reach spillway fishways. Ramping rates may be necessary when altering flows to prevent safety hazards to humans and stranding of fish.

At most projects, powerhouse operation modifications will reduce generation revenues if one or more units cannot be operated at full load. However, if flow levels necessary for operating all powerhouse units at full capacity are not available, there may be no loss of revenues. Spill reductions to enhance fishway attraction flows may not affect generation capability, whereas an increase in spill levels would decrease generation potential.

For new hydroelectric developments or retrofits to existing projects, powerhouses and fishways can be designed to minimize modified operation and spill. At the Wilder Hydroelectric Project on the Connecticut River in Vermont, for example, a small hydro turbine was added to the existing powerhouse specifically to supply attraction water to a fishway collection area (Doret 1987). The new unit also passes minimum required flows when the larger units are not operating. This innovative approach increases the efficiency of the plant even when the fishway is operating. The technique is also in use at the Dalles North Shore fishway and is planned for installation at the McNary Dam.

Innovative solutions to upstream migration problems can be implemented but they depend on the site of the new installation or retrofit. Innovative designs always should be considered especially if construction costs would not be considerably greater than the cost of alternative scenarios (e.g., lost generation revenues because of modified powerhouse operation or spill). Innovative solutions are appropriate, however, only to the extent that there is compelling evidence that they work.

3.2.3 Costs

Depending on the selected barrier, costs are incurred for installation, operation, maintenance, and impacts on power generation. Costs are highly dependent on site characteristics, and literature sources do not provide meaningful values for the barriers discussed. However, cost of each barrier type and factors that contribute to overall expense can be compared among barriers. Factors influencing installation, maintenance, and operation costs of tailrace barriers include dimensions, materials, and location. Power generation impacts would depend on barrier type and location.

Screens are the most expensive type of barrier to install and maintain because of cleaning requirements. At sites with heavy debris loads, screens may require a special cleaning device (e.g., a rake system) or removal for cleaning. Tailrace screen cleaning is often unnecessary if debris is removed at the project intake. Barrier dams generally have lower installation and maintenance costs than screens, but greater impacts on power generation depending on proximity to the powerhouse. Of the three barrier types, behavioral barriers should be the least costly to install and maintain and should have the least impact on power generation. Operating costs for behavioral barriers, unless they are automated, however, may be greater than for other barrier types. Also, behavioral barriers generally are less reliable than physical barriers at blocking upstream fish movement.

Backfitting tailrace barriers to existing projects is more costly than designing barriers into a new project. Backfitted construction of this type in the wet is generally 30 to 50 percent more costly than new project construction (Taug 1994).

3.2.4 Summary

Tailrace barriers are designed to prevent target fish species from entering areas where they might be injured or delayed in their upstream passage. Tailrace barriers are often used with fish passage facilities, but some are also used solely to prevent injury. The biology of the target species, the physical and hydraulic conditions of the tailrace, and project operations all influence the effectiveness of tailrace barriers.

There are two major categories of tailrace barriers: diffuser and non-diffuser. Diffuser barriers are typically bar racks or barrier screens used to spread out the tailrace velocity distribution and physically block passage of fish. Diffuser barriers minimize high-velocity zones to reduce the potential of some species to jump at cascading or high velocity flows. The screens or bar racks are often angled to direct migrants to a fishway entrance or away from a location not suitable for passage. Although diffuser barriers can incrementally reduce operating head and thus energy production, typical designs should have little effect on head. Diffuser barriers also may require periodic cleaning to prevent debris build up, unless flow has already been screened upstream.

Non-diffuser barriers include barrier dams, electric fields, and behavioral devices that use sound or light to repel fish. Porous dams physically exclude upstream migrating fish but allow downstream passage of water. Buttress dams use differential head to block upstream passage. Buttress dams must be higher than the height that target fish species can jump. Velocity barriers are low dams that create long, high-velocity flows in the path of migrating fish. The water velocity and hydraulic jump must be higher than the swimming ability of the target species. In addition, the path that fish must swim at high velocity must be greater than the longitudinal distance the target species can jump.

Electric fields are a type of non-diffuser barrier. Electric barriers with graduated field strengths are designed to limit injury to target species. While effective at some sites, variable flows, conductivity, temperature, and fish size can alter the effectiveness and induce injury under some operating conditions.

Strobe lights and underwater sound transducers also have been used to repel fish, but additional studies are needed to determine their effectiveness for adult upstream migrants.

Modified project operation can influence fish injury and migration delay. Depending on site hydraulics, greater or lesser amounts of water in a bypassed reach of river may allow more suitable passage conditions.

Cycling operation or partial loading of a turbine may allow fish to enter the draft tube and contact rotating equipment. Preferential operation of units, or shut down of problematic units may reduce some fish injuries. At large powerhouses with multiple units, selectively operating units may attract upstream migrants to a fishway entrance.

Spillways with adjustable gates or those that can be fitted with non-overflow sections, can also be operated to attract fish to a fishway entrance. Spillway operation often can be used to improve fish passage in a bypassed reach of river.

Modified project operation can have negative impact on generation capacity and project revenue. But innovative project designs, as illustrated by experience at the Wilder Project where the addition of a small hydro turbine supplied fishway attraction water, can have positive economic benefits.

Little cost information is available for general comparison of barriers because site-specific conditions generally determine feasibility and costs of these devices. Physical barriers typically require extensive civil works, and tailrace civil conditions and costs vary greatly. Costs may also be incurred to provide passage of downstream migrants around the tailrace barrier. Generally, behavioral barriers are the least costly, while barrier screens would be the most costly alternative because of cleaning requirements. Barrier dams and some screen designs also may reduce usable head and thus reduce energy and revenue.

4.0 DISCUSSION

The level of mitigation required to minimize impacts to upstream fish migrations is determined by a project's biological, hydraulic, and physical characteristics. Some species suffer more from delays than others because they spawn under a narrow range of environmental conditions and within a short time period. Migration delays, injury, and mortality associated with powerhouse operation may have more adverse impacts to fish stocks and populations that are at very low levels.

To provide additional information for assessing the need for tailrace barriers and modified project operation and spill, a survey of existing projects was conducted (see Section 2). The information obtained through the literature search was used with survey information to develop criteria and guidelines for assessing the need for tailrace barriers and modified project operation and spill. Recommended studies that would provide additional information on the impacts of hydroelectric tailraces on upstream migration also are discussed.

4.1 Summary of Current and Potential Applications of Upstream Fish Migration Protection Technologies

As described in Section 2, a survey of hydroelectric projects where tailrace barriers are operating, are proposed, or have been requested by resource agencies was conducted.

Table 4-1 summarizes the information collected. Of the 24 identified projects, 8 currently have upstream migrant protection in the form of diffuser barriers such as bar racks, netting, screens, or guidance devices. There is very little information on effectiveness of these barriers. At Morse Creek, Washington, plastic netting effectively reduces injury and mortality to Pacific salmon. Screens at Peshtigo River, Wisconsin, also have been effective in protecting lake sturgeon and adult salmonids. A berm passageway was installed at Sultan, Sultan River, Washington, and is reported to be successful in reducing migration delay for Pacific salmon and steelhead trout. There are no reported data on the effectiveness of the bar racks in place.

Protection, primarily in the form of bar racks, is proposed at an additional five sites.

One site (North Fork, Clackamas River, Oregon) presently uses modified generation as mitigation for injury, mortality, and migration delay of Pacific salmon, steelhead, and resident trout. The modified generation schedule has reduced injury and mortality but also has reduced the operator flexibility in loading the units.

At eight sites, resource agencies have requested or required mitigation that consists of physical and velocity barriers such as floating weirs, upwelling systems, bar racks, and generation shut-down. At two sites, no mitigation is proposed or required at this time. At one of these two sites, Bull Run, Sandy River, Oregon, tailrace attraction is complicated by another diversion project. At the other site, Snoqualmie Falls, Washington, a 1993 study (Beak Consultants, Inc. 1993) showed that suspected tailrace mortality did not occur. Resource agencies still suspect that the geometry of the draft tubes and hydrology may injure fish.

Studies, which have been performed at only 5 of the 24 sites, include radio-tracking (2), biological evaluations (2), and one hydraulic study of the relationship between spill and passage. As previously noted, the majority of target species are Pacific salmonids.

4.2 Additional Studies

Site-specific injuries and migration delays identified in the literature survey indicate that additional studies may be needed to determine the most appropriate mitigation for a project. Some issues may be difficult to address even with additional study. This section identifies types of studies that may be useful in identifying tailrace-influenced injury and migration delay and in developing the most appropriate mitigation.

Both biological and hydraulic studies may be used to acquire the necessary information for target species and physical conditions in the tailrace. Biological studies can help determine migratory fish presence, incidence of injury, duration of delay, and population impacts. Hydraulics studies can provide data on tailrace velocity conditions and fishway and bypass passage conditions.

4.2.1 Biological Studies

The most important biological issue requiring more study is presence of migratory or resident fish and identification of delayed migration in the tailwaters. In some cases, the presence of these species may be poorly documented.

Table 4-1. Summary of tailrace barrier project information. Includes sites where tailrace barriers or modified operations (including spill) have been installed/implemented, proposed by project owners, or requested by resource agencies. The information in this table was obtained from (1) a preliminary telephone survey of resource agency and industry personnel; (2) a survey mailed to project contacts (projects selected based on information obtained during telephone survey); (3) a follow-up telephone survey of contacts that did not return the survey; and/or (4) reports and manuscripts gathered during a literature search. Abbreviations in the table represent the following: NP, information not provided; NA, not applicable; UNK, unknown. The migration impacts that are listed have not always been proven and generally are hypothesized based on general observations at a site. Injury and mortality listed under migration impacts refers to fish injury and mortality associated with powerhouse structures (e.g., turbines, draft tube walls, training walls).

Project and Location	Gen. Capacity (MW)	Normal Head (ft)	Max Flow (cfs)	Target Species	Migration Impacts	Studies Performed	Upstream Migrant Protection/Mitigation Measure	Protection/ Mitigation Status	Project Costs/Effects	Biological Effectiveness
Morse Creek Port Angeles, WA	0.5	442	19	Pacific salmon	injury and mortality	delay study	original plastic netting replaced with plastic coated steel barrier rack	installed	NP	effective, no change in spawner distribution
Cispus #4 Cispus River	NP	NP	1800	steelhead	migration delay	none	bar racks	proposed	NP	NA
West Springfield Westfield River W. Springfield, MA	1.2	31	622	Atlantic salmon American shad	migration delay	none	grates	proposed	maintenance	NA
Sultan Sultan River Sultan, WA	112	1100	1300	Pacific salmon steelhead trout	migration delay; injury and mortality	radio-tracking study conducted with adult migrants	berm passage-way	installed	NP	reduces migration delay
Peshtigo Peshtigo River Peshtigo, WI	0.6	13	740	lake sturgeon adult salmonids	injury and mortality	none	screens	installed	maintenance	effective
Condit White Salmon River White Salmon, WA	15	160	1200	Pacific salmon steelhead trout	migration delay; injury and mortality	none	bar rack	proposed	NP	NA
Barclay Creek Deschutes River Bend, OR	1.1	17	1200	resident salmonids	injury and mortality	none	bar racks and velocity barrier	proposed	NP	NA

Table 4-1. (continued)

Project and Location	Gen. Capacity (MW)	Normal Head (ft)	Max Flow (cfs)	Target Species	Migration Impacts	Studies Performed	Upstream Migrant Protection/Mitigation Measure	Protection/ Mitigation Status	Project Costs/Effects	Biological Effectiveness
Weber Dam	3.25	30	NP	chinook coho steelhead	delay	none	horizontal grate	installed	NP	greatly reduces migration delay
Winchester Dam North Umpqua River Winchester, OR	NP	NP	1100	chinook salmon steelhead	injury and mortality	visual surveys and carcass counts	grates	installed	NP	NA
Puntledge Project Puntledge River Vancouver Island, B.C.	NP	NP	1000	chinook salmon coho salmon pink salmon	injury mortality migration delay	counting fence carcass collections swim surveys	tailrace screens powerhouse shut-downs and bypass freshets bypass barrier racks	installed	NP	NA
Lower Mokelumne Mokelumne River Amador, CA	10.7	120	1200	chinook salmon	migration delay; injury and mortality	proposed	rock guidance fence	installed	maintenance	UNK
North Fork (Faraday) Clackamas River Estacada, OR	38.4	13	NP	Pacific salmon steelhead trout resident trout	migration delay; injury and mortality	relationship between spill and passage was examined; spill increases did not improve passage	modified generation schedule	implemented	lost generation revenues	reduces injury and mortality
Bull Run Sandy River Sandy, OR	21	320	800	Pacific salmon steelhead trout resident trout	migration delay	none	none	NA	NA	NA
Barrier Dam Cowlitz River Lewis Co., WA	9	16.5	8000	Pacific salmon steelhead trout resident trout	migration delay; injury and mortality	none	bar racks	proposed	maintenance; lower generating efficiency if considerable debris buildup	NA

Table 4-1. (continued)

Project and Location	Gen. Capacity (MW)	Normal Head (ft)	Max Flow (cfs)	Target Species	Migration Impacts	Studies Performed	Upstream Migrant Protection/Mitigation Measure	Protection/ Mitigation Status	Project Costs/Effects	Biological Effectiveness
Snoqualmie Falls WA	NP	NP	NP	Pacific salmon steelhead trout	injury and mortality	biological evaluation of potential for injury and mortality	none	NA	NA	NA
Cushman Skokomish River	NP	NP	NP	Pacific salmon	migration delay; injury and mortality	biological evaluation of fish behavior during shutdowns	powerhouse shutdowns or barrier rack	requested	lost generation revenues during project shutdowns; maintenance for bar racks	project shutdowns appeared to be ineffective
Seton Creek Fraser River Lillooet, B.C.	NP	NP	4500	sockeye salmon pink salmon	migration delay; injury and mortality	NP	operate units on full load only; draft tube air injection	installed	NP	migration delay continues; injury and mortality eliminated
Roza Yakima River, WA	NP	NP	2200	chinook salmon	migration delay	delay observations radio tagging	diversion-tailrace diffuser rack tailrace-diffuser rack	installed	NP	jumping eliminated, continued delay at diversion dam
Nisqually WA	NP	NP	NP	Pacific salmon	migration delay; injury and mortality	requested	hydraulic or physical barrier	requested	NP	NA
Blue River Lane Co., OR	14.6	NP	NP	chinook salmon	migration delay	required	velocity barrier	required	NP	NA
Woods Creek	NP	NP	NP	Pacific salmon	injury and mortality	none	bar racks	installed	NP	NP
Mill Creek	NP	NP	NP	steelhead trout	injury and mortality	none	bar racks	installed	UNK	UNK

Table 4-1. (continued)

Project and Location	Gen. Capacity (MW)	Normal Head (ft)	Max Flow (cfs)	Target Species	Migration Impacts	Studies Performed	Upstream Migrant Protection/Mitigation Measure	Protection/ Mitigation Status	Project Costs/Effects	Biological Effectiveness
Leaburg/ Walterville McKenzie River OR	16/9	89/55	2500 each	chinook	migration delay; injury and mortality	radio-tracking study conducted with adult chinook	floating weir being considered for Leaburg; bar racks currently at Walterville, with a velocity barrier being considered	new barriers proposed at each site	NP	NA for proposed barriers; NP for current barrier at Walterville, assumed to have problems
Yelm Centralia River WA	NP	NP	NP	NP	migration delay; injury and mortality	may be license requirement	physical barrier	requested	NA	NA
White River Wasco Co., OR	8.5	170	NP	chinook salmon steelhead trout	migration delay; injury and mortality	none	tailrace barrier (velocity barrier proposed)	required	NP	NA
Bend, OR Deschutes River	NP	NP	NP	bull trout brown trout rainbow trout	migration delay; injury and mortality	UNK	upwelling system	requested	NA	NA
Tieton Tieton River Yakima Co., WA	13.6	NP	NP	chinook salmon steelhead trout	injury and mortality	none	bar rack (horizontal diffuser screen was proposed)	required	NP	NA
Burnham Creek Pacific Co., WA	.03	NP	NP	Pacific salmon steelhead trout cutthroat trout	migration delay; injury and mortality	monitoring required	bar rack	installed	NP	NP

Table 4-1. (continued)

Project and Location	Gen. Capacity (MW)	Normal Head (ft)	Max Flow (cfs)	Target Species	Migration Impacts	Studies Performed	Upstream Migrant Protection/Mitigation Measure	Protection/ Mitigation Status	Project Costs/Effects	Biological Effectiveness
Desabla-Centerville Butte Creek Butte Co., CA	6.4	590	183	Pacific salmon resident trout non-salmonids	migration delay	required	the owner has proposed GFFB and hydraulic conditions that would inhibit fish entering the draft tubes; the resource agencies have requested a physical barrier or appropriate hydraulic conditions	GFFB and hydraulic conditions proposed; physical barrier or appropriate hydraulic conditions requested	NP	NA
Mayfield	NP	NP	NP	NP	NP	NP	barrier dam and electric barrier	installed	NP	NP
Baker	NP	NP	NP	NP	NP	NP	barrier dam	installed	NP	NP
Weeks Falls	NP	NP	NP	NP	NP	NP	tailrace rack	installed	NP	NP
McNary North Shore Hydro	NP	NP	NP	NP	NP	NP	tailrace rack	installed	NP	NP
Dalles Auxiliary Fishway Water Supply	NP	NP	NP	NP	NP	NP	tailrace rack	installed	NP	NP
Rocky Brook	NP	NP	NP	NP	NP	NP	height barrier	installed	NP	NP
South Fork Tolt	NP	NP	NP	NP	NP	NP	porous dam	installed	NP	NP
Taneum Chute	NP	NP	NP	NP	NP	NP	velocity barrier	installed	NP	NP
Skookum Creek	NP	NP	NP	NP	NP	NP	height barrier	installed	NP	NP
Skookumchuck	NP	NP	NP	NP	NP	NP	height barrier	installed	NP	NP
Nisqually Yelm	NP	NP	NP	NP	NP	NP	tailrace rack	requested	NP	NP

Table 4-1. (continued)

Project and Location	Gen. Capacity (MW)	Normal Head (ft)	Max Flow (cfs)	Target Species	Migration Impacts	Studies Performed	Upstream Migrant Protection/Mitigati on Measure	Protection/ Mitigation Status	Project Costs/Effects	Biological Effectiveness
Enloe Project	NP	NP	NP	NP	NP	NP	tailrace rack or electric barrier	requested	NP	NP
Clearwater Creek	NP	NP	NP	NP	NP	NP	velocity barrier	requested	NP	NP
Warm Creek	NP	NP	NP	NP	NP	NP	tailrace rack	proposed and requested	NP	NP
New Halem	NP	NP	NP	NP	NP	NP	velocity barrier	proposed	NP	NP
White River	NP	NP	NP	NP	NP	NP	ogee velocity barrier	proposed	NP	NP
Heislers Creek	NP	NP	NP	NP	NP	NP	horizontal tailrace rack	proposed	NP	NP
Cottrell	NP	NP	NP	NP	NP	NP	porous gabion dam	proposed	NP	NP

For example, small populations of sauger, sturgeon, or other species may be present or conjectured to be present. Radiotelemetry may be a useful technique to document this issue. Small populations may not be important unless the species is threatened or endangered, and documenting the presence of rare species is often difficult. Agencies often dictate that all sampling must be nondestructive. However, presence of a rare migratory species sometimes can be confirmed by trapping, electrofishing, or netting preferred habitats in the tailwaters at the appropriate season.

The second biological issue is whether or not fish can enter draft tubes during generation, thereby exposing themselves to risk of injury or death. One way to identify a species' capability to enter the draft tubes is through release and monitoring of radiotagged fish in the tailrace. If actively migrating fish are radiotagged and released into the tailwaters, movement into the draft tube may be identified by well-positioned receiver antennas.

Discharge hydraulics also can be studied. There is abundant literature on fish swimming capabilities, but little on draft tube hydraulic conditions. As a first measure of draft tube tailrace water velocities, the open area of the draft tube can be divided by unit flow to yield average exit velocities; additional sampling usually is required. Tailrace flow distributions are often skewed because the water rotates during passage through the generating unit. Average velocity estimates, therefore, may not accurately represent the velocities migrating fish would swim against in the tailrace. A velocity profile of the tailrace discharge can be collected with a flowmeter mounted on a downrigger or from a mounting rack positioned in draft tube dewatering slots (if available).

The third biological issue to study is whether or not migratory species that are capable of entry into the draft tubes are uninjured, or are injured in numbers that are a threat to population levels. The simplest way to document injury is to search the river banks and tailwater areas during migration. Dead and injured fish showing injury consistent with turbine blade strikes and abrasion from concrete can be assumed to be injured by the project. Injury may be difficult to document, however, because some dead or injured species may settle to the river bottom or be consumed by predators.

To demonstrate population effects, impacts must be assessed. Data on population size, age structure, reproductive capacity, numbers of fish killed or injured, and possibly compensatory survival are required. Population modeling also may be necessary. Available data may limit the effectiveness of the modeling especially if modeling of multiple species is undertaken.

A tagging study can provide valuable information on tailrace hydraulics and fishway entrance conditions. These biological studies should be done under a variety of operating conditions to identify conditions that may cause delay and injury. These studies can identify how fish respond behaviorally to modified project operation. Appropriate sampling methods are conventional marking, fin clipping, or acoustic and radiotagging. Actively migrating fish are collected, tagged, and released into the project tailwaters. The fish entering the fishway are trapped. The time between release and recapture is defined as the delay time. With radiotags and directional antennas, radiotagged fish movements can be monitored. Fish that are delayed due to hydraulics or fishway entrance conditions often can be identified from such a study.

4.2.2 Hydraulic Studies

Numerical or physical modeling studies may indicate that the draft tube can be extended or reshaped to increase velocities or redistribute flows more evenly, which could reduce fish injury. Specific numerical or physical modeling conducted would depend on the physical features of the draft tube or tailrace area. Physical modeling is also very useful in characterizing conditions under a variety of spill and operation conditions. Such studies also should model backwater affect of such changes since tailrace modifications could impact the effective head and energy of the project.

Hydraulic modeling also may help identify simple modifications to improve the hydraulics near fishway entrances. Studies may be able to identify how separator walls between the spillway and powerhouse could eliminate eddies that mask spillway attraction flows or otherwise misdirect migrating fish.

4.3 Guidelines for Evaluating Agency Requests for Tailrace Barriers

In evaluating requests for tailrace barriers, FERC staff should consider the need, feasibility, effectiveness, and cost of such devices. Although these four considerations are interrelated, staff should evaluate each of the four steps separately. Staff should also consider the professional opinion of the resource agencies.

4.3.1 Need

The need for tailrace barriers should be well documented before FERC staff pursues further steps. One source of documentation is a comprehensive fish management plan for the watershed. Tailrace barriers will have capital and operational costs that must be justified by a defined need. Cases that would pass the need step include:

1) an established migratory fish program that would be adversely affected by tailrace injury, mortality, or delay at a specific project;

2) a potential for a recurring, or large fish kill, high injury rate, or delay that is a result of project tailrace operations;

3) a watershed management plan or specific fish restoration plan that cannot be implemented until a tailrace barrier can be

incorporated at a specific project; or

4) physical or hydraulic tailrace conditions similar to other projects that have been shown to lead to injury, mortality, or migration delay to the same species of fish.

Poorly identified needs for tailrace barriers include:

1) a non-presence of a migratory fishery, or a proposed fishery that has a less than reasonable restoration plan even with installation of tailrace barriers;

2) a concern for undocumented or poorly documented injury or delay at a project tailrace; or

3) use of only hydraulic flow velocities to show that some resident fish species may be able to ascend the draft tubes of a project.

Poorly identified needs for tailrace barriers *must* be clarified before continuing the need evaluation. Additional studies (see Section 4.2) to identify need may be requested of the licensee or the agency requesting tailrace barriers. Poorly identified needs for tailrace barriers may come from watershed plans or migratory fish restoration plans. Insufficient data on need for a barrier will not justify the typical costs of a tailrace barrier. The need for barriers has been a contentious issue. If the plans do not contain enough information to demonstrate that the fish populations require tailrace barriers to sustain a viable population, then additional information must be obtained to define the need. Studies may demonstrate that such barriers are not necessary.

4.3.2 Feasibility

Feasibility of a tailrace barrier depends on the type of impact to be mitigated (injury or delay), the biological characteristics of the species, and the physical conditions of the tailrace. The relative importance of these issues, which is project specific, will determine the feasibility and selection of the most appropriate tailrace barrier.

Generally, a change in project operation should first be investigated to determine feasibility to prevent injury and delay. Changes in project operation are not as likely to require an irrevocable capital expense and can be tested to determine their effectiveness, before being implemented on a permanent basis.

If passage into a bypassed reach of river leads fish beyond a tailrace ladder entrance, a barrier dam should be considered. A barrier dam in the bypassed reach of river does not necessarily affect the conventional operation of the hydro facility.

If injury or delay due to draft tubes is a problem, bar racks or screens should be considered. Debris conditions should be factored into the feasibility assessment because the bar or screen spacing is likely to be smaller than the trash racks on the intake of the hydroelectric facility. Behavioral barriers may be a promising alternative to the bar racks or screens, but many behavioral barriers lack suitable documentation of effectiveness at this time. Underwater sound or lights may be effective at repelling fish from unsuitable passage locations. There should be enough data on the species-specific repellent efficacy of the device and the ambient tailrace sound or light levels to evaluate the feasibility of these devices for the site.

If migration delay is a problem, angled bar racks or diffuser dams that can alter the hydraulic characteristics and guide migrating fish to a ladder entrance should be considered. Also ladder entrance conditions and improvements to orientation or hydraulics that could further limit tailrace delays should be reviewed. These types of studies can be readily accomplished with radiotagging or hydraulic (physical or numerical) modeling.

A barrier dam or velocity barrier below the powerhouse tailrace should be considered for species which are not likely to jump (e.g., American shad) or for species with limited swimming ability (e.g., alewife and blueback herring). These devices could reduce available head, generation, and revenue for the project. This should be one of the last options considered for a turbine discharge during the feasibility analysis because barrier dams and velocity barriers are likely to create permanent operational costs to the project.

4.3.3 Effectiveness

The effectiveness of a feasible tailrace barrier must be evaluated against the fish restoration plan, watershed management plan, or professional opinion of the resource agencies that prompted the need for the tailrace barrier. If the plan specified that no more than 50 percent of the upstream migrants must be delayed for 3 days or less, then the expected effectiveness of the proposed device should satisfy this requirement. There should be sufficient data to determine the expected effectiveness, these data should be available from actual experience at similar sites or should be demonstrated with a less costly prototype at the site. Prototype testing may also be necessary for any innovative solutions that lack experience-based effectiveness data.

For methods that use modified project operation or spill as the proposed tailrace barrier, the recommended barrier should be accompanied with a requirement for the licensee to monitor the effectiveness of the system. Monitoring may identify minor changes to the proposed modified operation that may improve effectiveness. Monitoring is particularly useful for trimming overly conservative schedule requirements for operational spills. For example, a monitoring study may show that the migration season is more protracted than identified in original data used to establish a spill season for fish attraction. With additional monitoring information, mitigation probably will be less costly.

4.3.4 Cost

Cost of mitigation devices is always an important consideration in balancing feasibility with effectiveness. There is limited transferable experience with cost of tailrace barrier installation.

To determine costs for tailrace barriers, design data that is more detailed than that available at a conceptual level must be developed. Because there is little information on costs of tailrace barriers and site-specific conditions can be highly variable, capital costs will probably be identified from quantities of materials. Backfitted tailrace barriers are more costly than those installed with new project construction.

Operational costs should include effects of the tailrace barrier on power generation and maintenance. Maintenance may be a considerable factor if a device requires on-site maintenance personnel throughout the migration season, especially if the project typically operates in an unmanned mode.

5.0 CONCLUSIONS

Available literature was reviewed and a survey of sites with installed or proposed tailrace barriers was conducted. Data were collected and the following conclusions were made:

Population Effects

- No studies were identified on the specific effects of tailrace delays on migratory fish populations.
- Migration delays can limit the upstream extent of migration.

Spawning Success Effects

- Delays of as little as 3 days may have critical effects on the spawning success of a species.
- Delays may cause upstream migrants to spawn in suboptimal habitat or not spawn at all.
- Delays can cause mortality to migrating fish by reducing energy reserves.

Causes of Injury

- Swimming speed of target species influences their ability to enter dangerous areas of the tailrace.
- Turbine elevation, velocity conditions, and turbine type influence the susceptibility of fish to injury in the tailrace.
- Fish are injured in tailrace areas from contact with the turbine runners, abrasion on the walls of the tailrace structure, or from non-contact water-quality related impacts.

- Secondary infection of fish with contact-type injury can lead to delayed mortality and lowered reproductive success.

Causes of Delay

- Stream scents and hydraulic conditions can attract upstream migrants to impassable tailrace flow discharges.
- Inadequate fishway location, numbers, or entrance conditions also can delay passage.

Tailrace Barriers

- Few data are available on the effectiveness of tailrace barriers at existing hydroelectric facilities.
- A survey of sites with tailrace barriers shows 22 sites currently have bar racks, screens, netting, or other guidance devices for upstream migrants.
- Tailrace barriers can be used to repel migrants from undesirable passage routes and guide fish to ladders or other preferred routes of migration.
- Diffuser barriers provide a physical block to migrants without inducing fish to jump at the structure.
- Height and water velocity block or guide fish passage at barrier dams.
- Graduated electric fields have been successfully used to block upstream passage.
- Sound- or light-based behavior barriers have potential for providing alternative methods in blocking fish passage but generally require more documentation of effectiveness.
- Modified project operation and spill releases have been used to limit delay and improve passage conditions.

Guidance for Reviewing Tailrace Barrier Recommendations

- Guidance for tailrace barriers is a four step evaluation of need, feasibility, effectiveness, and cost.
- Biological or hydrological studies often can provide the information needed for completing the four-step evaluation for tailrace barriers at a project.

- Project generation and revenue can be influenced by the head loss associated with installation and operation of barrier dams, bar racks, and screens.

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KEYWORDS

UPSTREAM FISH PASSAGE
FISH LIFT
AMERICAN SHAD
ATTRACTION WATER

LOCATION OF STUDY:

Hadley Falls Hydroelectric Project, Connecticut River, Holyoke, Massachusetts

PROJECT CHARACTERISTICS:

The Hadley Falls Project comprises the Holyoke dam, a powerhouse, and a power canal system which provides water used by local industry for generation purposes. At the time of this study, the Hadley Falls powerhouse had one generating unit (a second unit has since been installed) with an additional unit located in the canal system. Fish passage is provided by two fish lifts, and both are attached to the powerhouse. One fish lift collects upstream migrants from the powerhouse tailrace and the other collects fish that move up the spillway. The entrance to the tailrace lift collection area is located next to the powerhouse discharge exits.

BIOLOGICAL CHARACTERISTICS:

Four species of anadromous fish that return to the Connecticut River to spawn are lifted at the Hadley Falls Project each spring. These species include blueback herring, American shad, sea lamprey, and Atlantic salmon. There also are Striped bass juveniles and shortnose sturgeon at the Hadley Falls Project during the spring, but they are not currently lifted upstream past the counting station to spawn. Atlantic salmon populations are being restored to the Connecticut River, and the number of returning adults is still at low levels. Generally, several hundred thousand blueback herring and American shad are lifted each spring at the Hadley Falls Project.

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE:

The Holyoke dam is an impediment to upstream migrants. The operation of the two fish lifts alleviates this problem and allows fish to reach historic spawning grounds upstream of the project. The purpose of this study was to determine if there were problems with American shad locating the entrance to the tailrace lift collection area.

TAILRACE BARRIER DESIGN: N/A

BIOLOGICAL EFFECTS OF TAILRACE BARRIER: N/A

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION: N/A

COMMENTS:

Based on the movements of radio-tagged fish, it was determined that fish were repelled by turbulence from the powerhouse discharge. Estimated delays of American shad at the Hadley Falls Project ranged from 2 to 7 days. Problems also were noted with the attraction of upstream migrants to the spillway lift. Attraction water for the spillway lift competes with dam spill during periods of high flow. High flows are the prevailing condition for upstream migrating shad and river herring. During low flows, all river water is diverted through the powerhouse and canal system which results in virtually all upstream migrants being attracted to the tailrace. To reduce delays in the tailrace, it was suggested that the entrance to the tailrace lift collection facilities be moved downstream so that the attraction flows did not compete with the turbine discharge. Also, it was noted that the future operation of a second unit probably would increase delay problems. Potential for fish entering the powerhouse draft tubes was not discussed.

Beak Consultants Incorporated. 1993. A study to determine the influence of the Snoqualmie Falls Project on the injury and mortality of adult salmonids. Prepared for Puget Sound Power & Light Company, Bellevue, WA.

KEYWORDS
PACIFIC SALMON INJURY AND MORTALITY

LOCATION OF STUDY:

Snoqualmie Falls Hydroelectric Project, Snoqualmie River, Washington.

PROJECT CHARACTERISTICS:

The Snoqualmie Falls Project is composed of two generating stations, Plants 1 and 2. Plant 1 is located at the base of Snoqualmie Falls and Plant 2 is about one-quarter mile downstream of the falls. Plant 1 has pelton turbines; the number of turbines was not reported. Plant 2 has two generating units. The type of turbines that are in Plant 2 was not reported. No specifics were provided with respect to flow levels or generating capacity.

BIOLOGICAL CHARACTERISTICS:

The Snoqualmie River supports Pacific salmon (chinook and coho salmon, others not reported but may occur) and steelhead trout populations.

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE:

There is potential injury and mortality of upstream migrants that can enter the draft tubes of Plant 2 under certain generating conditions. Fish injury and mortality to upstream migrants is not a concern at Plant 1 because there is a 15-foot drop from the turbines to the tailwater elevation. However, there was no mention whether fish could be injured or killed from contacts with walls and structures in the Plant 1 draft tubes. It was concluded as a result of tailrace survey studies that upstream migrants were not being injured or killed in the draft tubes of the Snoqualmie Falls Project Plant 2.

TAILRACE BARRIER DESIGN: N/A

BIOLOGICAL EFFECTS OF TAILRACE BARRIER: N/A

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION: N/A

COMMENTS:

The purpose of this study was to determine if upstream migrants were being injured or killed in the draft tubes of Plant 2 of the Snoqualmie Falls Project. Shoreline, underwater, and angler surveys were used to assess the presence of dead or injured adult salmonids in the area downstream of Plant 2. Surveys were conducted from August 1991 through February 1993. Survey data indicated that upstream migrants were not being injured or killed in the Plant 2 draft tubes. Because fish could not ascend the draft tubes when the station was operating at full load, any potential injury and mortality probably would occur during low generation periods (e.g., start up and power down or low flow conditions). To evaluate the potential for fish to enter the draft tubes during these times, underwater surveys also were scheduled during worst case generation scenarios. However, after two surveys with no observations of live or dead fish, this portion of the study was canceled. Based on the evidence presented in this report, it is likely that there is not considerable potential for upstream migrants to be injured or killed in the Plant 2 draft tubes at the Snoqualmie Falls Project. Additional survey data from worst case scenarios when fish are also known to be in the tailrace area would be useful to either support this conclusion or to warrant the use of a tailrace barrier.

Beiningen, K.T., and W.J. Ebel. 1970. Effect of John Day Dam on dissolved nitrogen concentrations and salmon in the Columbia River, 1968. Transactions of the American Fisheries Society. 1970. No. 4. pp 664-671.

KEYWORDS
SUPERSATURATION PACIFIC SALMON STEELHEAD TROUT MIGRATION DELAYS

LOCATION OF STUDY:

John Day Dam, Columbia River, Washington.

PROJECT CHARACTERISTICS:

There was no specific information describing the John Day Project. Construction of the dam was completed just before initiation of the study, however, the powerhouse was not operating at this time.

BIOLOGICAL CHARACTERISTICS:

The Columbia River supports populations of five Pacific salmon species, steelhead trout, white and green sturgeon, lamprey, and American shad, all of which migrate annually upstream to spawning areas.

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE:

Columbia River hydroelectric projects are impediments to upstream migrants. Consequently, upstream fish passage facilities have been installed at most of the projects. This paper describes the effects of gas supersaturation on the Columbia River salmonid populations. Secondary problems (e.g., migration delays) also are discussed.

TAILRACE BARRIER DESIGN: N/A

BIOLOGICAL EFFECTS OF TAILRACE BARRIER: N/A

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION: N/A

COMMENTS:

This study examined dissolved nitrogen concentration below hydroelectric projects on the Columbia River mainstem (lower 640 km) and assessed the effects of the dissolved nitrogen levels on upstream migrants. Due to heavy spills, the nitrogen concentrations immediately downstream of the dam were high (exceeded 120 percent). Gas supersaturation-related mortality (i.e., gas bubble disease) of adult salmonids was observed below the John Day Dam; specifically, during delays in migration that were caused by inadequate fishway attraction flows. Also, many fish that did pass through the fishways exhibited external injuries characteristic of gas bubble disease. Based on the results of this study, it was concluded that high nitrogen concentrations (in excess of 125 percent saturation) were partially responsible for mortalities of adult upstream migrants downstream of the John Day Dam. Additionally, it was determined that delays caused by sub-optimal fishway attraction flows contributed to the mortality associated with gas supersaturation. The results of this paper demonstrate secondary negative impacts that may occur to upstream migrants when they are delayed at a hydropower project. When fish are delayed at hydroelectric projects, they may be exposed to changing environmental conditions (gas concentrations and temperature regimes). These conditions may lead to increased stress levels that result in mortality or reduced spawning success due to poor physical condition.

Bengeyfield, B. 1982. Review of fisheries enhancement programs in Seton Lake - Cayoosh Creek area. Prepared for British Columbia Hydro and Power Authority, Reservoir Land Management Department, Properties Division, Vancouver, B.C. Prepared by Environmental Sciences Ltd. Vancouver, B.C.

KEYWORDS
FALSE ATTRACTION SOCKEYE/PINK SALMON MIGRATION DELAY DRAFT TUBE INJURY

LOCATION OF STUDY:

Seton Hydroelectric Project, Seton Creek, Lillooet, British Columbia.

PROJECT CHARACTERISTICS:

The Seton Project consists of a dam on Seton Creek, a power canal, and a powerhouse that is located on the Fraser River downstream of the Seton Creek confluence. The dam diverts water from Seton Creek through the power canal which carries it to the powerhouse. At the powerhouse, water is discharged into the Fraser River. (Note: no information on flow volumes or powerhouse design was provided.)

BIOLOGICAL CHARACTERISTICS:

The Fraser River system supports runs of sockeye, pink, coho, and chinook salmon. The sockeye population is the most important salmonid that returns annually to Seton Creek to spawn. Sockeye spawn above and below the Seton Dam. Pink salmon also return to Seton Creek each year, but in lower numbers than sockeye.

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE:

Upstream migrants returning to Seton Creek have been delayed at the Seton powerhouse because it discharges large volumes of Seton Creek water into the Fraser River downstream of the natural confluence. The natural outlet discharges less water than the powerhouse. Upstream migrants detect the water from their natal stream at the powerhouse and consequently attempt to ascend the tailrace. Greater water velocities coming from the powerhouse also induce false attraction for adult salmon. Also, fish that did migrate past the powerhouse often had difficulty detecting the natural channel of Seton Creek because the concentration of water from another stream that discharged into it below the dam was much greater due to lower Seton Creek flows that resulted from power generation. Fish that did enter the powerhouse tailrace were able to enter the draft tubes and were injured or killed from striking concrete walls or contact with the turbine runner blades. Documented internal injuries were attributed to hydraulic shear within the draft tubes.

TAILRACE BARRIER DESIGN:

No physical tailrace barriers were installed or proposed at the Seton powerhouse to direct fish away from the tailrace or to prevent fish from entering the draft tubes. However, to reduce injury and mortality associated with the draft tubes, the turbines were only operated at full load. The discharge flow velocities physically prevented fish from entering the draft tube. Pressurized air was injected into the draft tubes during start-up and shut-down of turbines to prevent fish entry during these times. Although full power generation reduced the potential for fish injury and mortality at the powerhouse, fish continued to be attracted to the discharge and delayed in their migration.

BIOLOGICAL EFFECTS OF TAILRACE BARRIER:

Fish injury and mortality were reduced by operating the station at full generating capacity during the spawning migration, but false attraction was not reduced.

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION:

Lost generation and revenues could be expected during the upstream fish migrations if flows dropped below levels that prevented the station from operating at full load.

COMMENTS:

This paper reviewed the history of fisheries-related problems associated with hydropower development in the Seton area of the Fraser River, specifically focusing on the problems related to the operation and design of the Seton hydroelectric facilities. Evidence was provided that adult sockeye and pink salmon were being delayed at the Seton powerhouse and injured or killed in the draft tubes. Negative impacts from migration delays could not be documented; however, there were indications that delays could reduce the number of fish that survive to spawning time.

Bulow, F.J., W. D. Crumby, S. S. Quisenberry, M. A. Webb. 1988. Effectiveness of a fish barrier dam in limiting movement of rough fishes from a reservoir into a tributary stream. North American Journal of Fisheries Management. Vol. 8 pp 273-275.

KEYWORDS
ROUGH FISH FISH BARRIER DAM

LOCATION OF STUDY:

Roaring River, tributary to Cordell Hull Reservoir on the Cumberland River, Tennessee.

PROJECT CHARACTERISTICS: N/A

BIOLOGICAL CHARACTERISTICS: N/A

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE: N/A

TAILRACE BARRIER DESIGN:

A fish barrier dam was constructed on the Roaring River near where it empties into the Cordell Hull Reservoir. The fish barrier was constructed of steel, filled with stones, and reinforced with a concrete cap (after it was damaged by storm waters). The barrier is 69.2 meters in length and extends across the entire width of the river. The barrier crest is 3.45 meters above the downstream minimum pool elevation (152 meters).

BIOLOGICAL EFFECTS OF TAILRACE BARRIER:

The fish barrier dam was constructed across the Roaring River to prevent rough fish in the reservoir from moving upstream into the river. An evaluation of the barrier found it to be highly effective at excluding seven species of rough fish. River flow alterations caused by the barrier have produced silted areas extending about 3 kilometers upstream. The observed siltation could negatively affect resident fish populations located upstream of the barrier.

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION: N/A

COMMENTS:

This paper describes the design and biological effectiveness of a fish barrier that was constructed solely for preventing the movement of undesirable fish species into a tributary of a reservoir. Although the barrier was not used for a hydroelectric application, it does appear that this type of barrier could effectively exclude fish from entering a tailrace area at a powerhouse. The feasibility of this type of fish barrier for hydroelectric applications most likely would be site-specific. It appears the barrier has the potential to effectively exclude a wide range of fish species based on its ability to prevent seven species of rough fish from upstream areas during the study conducted on the Roaring River. No information was provided with respect to the size of fish that were excluded by the barrier; however, fish that may be small enough to pass through this type of barrier typically would not be a concern at powerhouse tailraces.

Clay, C.H. 1991. Upstream Atlantic salmon (Salmo salar) passage. In: Proceedings of the Workshop on Fish Passage at Hydroelectric Developments, March 26-28, 1991, St. Johns, Newfoundland. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1905.

KEYWORDS
ATLANTIC SALMON FISHWAY ENTRANCES FALSE ATTRACTION

LOCATION OF STUDY: N/A

PROJECT CHARACTERISTICS: N/A

BIOLOGICAL CHARACTERISTICS: N/A

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE: N/A

TAILRACE BARRIER DESIGN: N/A

BIOLOGICAL EFFECTS OF TAILRACE BARRIER: N/A

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION: N/A

COMMENTS:

In a general discussion of upstream Atlantic salmon passage, the author briefly discusses fishway entrance positions and possible techniques for improving a fish's ability to locate an entrance. It was concluded that fishway entrances should be placed at the furthest point upstream to which fish can swim before being impeded by obstacles (e.g., a dam or natural falls). Also, increased attraction flows or tailrace barriers (barred screens, barrier dams, electrical fields) were cited as ways to improve upstream fish passage where fishway attraction flows compete with tailrace discharges.

Clay, C. H. 1961. Design of fishways and other fish facilities. Department of Fisheries of Canada, Queen's Printer, Ottawa. 301 pages.

KEYWORDS
FISH LADDER DESIGN BARRIER DAMS FISHWAY ENTRANCES

LOCATION OF STUDY: N/A

PROJECT CHARACTERISTICS: N/A

BIOLOGICAL CHARACTERISTICS: N/A

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE: N/A

TAILRACE BARRIER DESIGN: N/A

BIOLOGICAL EFFECTS OF TAILRACE BARRIER: N/A

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION: N/A

COMMENTS:

This book provides comprehensive information on the design and application of fishways. The author discusses the biological and engineering aspects of fish ladders, locks, elevators, fences and barrier dams, screens, and artificial spawning channels. Two sections from this book are particularly relevant to the effects of tailraces and associated structures on upstream fish passage. The first relevant section discusses fishway entrances and the second provides information on fish barriers. The author cites fishway entrance locations as the most important aspect of a fish ladder because improper placement may lead to considerable migration delays or complete cessation of upstream movement, if fish cannot locate the entrance or are unwilling to enter it due to local hydraulic conditions. Additionally, it was stated that the physical changes in a fishes environment, other than blocked migration, that are produced by dams contribute to stress levels beyond the effects of delayed migration. These physical changes may include alterations in temperature and flow regimes (velocity and volume).

The author concludes that if a fishway is to be effective, there should be no delay in passage. To reduce potential delays at fishways located adjacent to spillways (i.e., at either end of the spillway), it was recommended that spill gates be opened from the center of the dam first with decreasing flow from the center of the spillway to the fishway. Obviously, at dams that do not have spill gates, controlling the flow in this manner would not be possible. Fishway attraction problems are not always related to spill; proper entrance configurations and water volume and velocity ultimately determine the ability of a fish ladder to pass fish. The location of an entrance for fishways adjacent to a powerhouse also is extremely important. It was stated that the farther downstream an entrance is from the powerhouse, the more difficult it will be for fish to find. Entrances that are located too far downstream from a powerhouse could lead to false attraction of upstream migrants to turbine discharge. Large powerhouses with many units may have fishway attraction problems because fish can be attracted to the middle of a powerhouse. This situation often can be alleviated by constructing a flume along the length of the powerhouse that has multiple entrances and leads to a fishway.

Several types of barrier dams are discussed as means to alleviate false attraction of fish to spillways and tailraces and to guide fish towards fishway entrances. The author provides descriptions and examples of buttress-type dam, a hydraulic barrier, and a concrete addition to a rock outcrop. Important design characteristics for all three of these barriers included that the hydraulic head should be equivalent to 10 feet and that fish did not sustain injuries as a result of jumping at the barriers. By design, the buttress-type barrier has a channel underneath the crest that fish either swim or fall into. The channel can have directional flow that leads fish to a fishway entrance. The hydraulic barrier is a concrete structure that produces high velocities and turbulence in the hydraulic jump that are sufficient to prevent fish from passing upstream. This barrier type can be angled towards a fishway to guide upstream migrants to the entrance. The last barrier that was described was a concrete addition to an natural rock outcrop downstream of the spillway. A minimum of 10 feet of head was achieved preventing fish from reaching the spillway.

This book is an excellent general reference for reviewing upstream fish passage concepts. The discussions are not filled with technical jargon and detailed figures make each concept easy to understand.

Department of Fisheries, Canada. 1958. The fisheries problems associated with the power development of the Puntledge River, Vancouver Island, B.C. 40 pages and 9 appendices.

KEYWORDS

PACIFIC SALMON
DRAFT TUBE INJURIES
MIGRATION DELAY
MODIFIED OPERATION
TAILRACE SCREENS

LOCATION OF STUDY:

Puntledge Hydroelectric Project, Puntledge River, Vancouver Island, British Columbia.

PROJECT CHARACTERISTICS:

At the time of this study (1955-1958) the Puntledge Project consisted of a dam at the outlet of Comax Lake (about 9 miles upstream from the river mouth), a diversion dam 2.5 miles downstream from the lake, and an intake and transport pipe carrying water 0.5 mile downstream to a powerhouse.

BIOLOGICAL CHARACTERISTICS:

Adult Pacific salmon (chinook, coho, pink, chum, and sockeye) and steelhead trout migrate upstream in the Puntledge River from May through December. Timing of spawning migrations varies among the six species; chinook salmon are the first to enter the river each year (late May) and sockeye salmon the last (late October).

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE:

This study concludes that adult salmon were delayed, injured, and killed at the Puntledge powerhouse tailrace. Fifty percent of adult migrants, recovered dead and unspawned after passing through a counting fence upstream of the powerhouse, had severe head and dorsal injuries. The injuries were attributed to fish striking concrete in or near draft tube exits. Large numbers of upstream migrants were attracted to the tailrace and attempted to swim up the draft tubes.

TAILRACE BARRIER DESIGN:

Two methods were evaluated for reducing the number of fish approaching the powerhouse and entering the draft tubes. In 1955, experiments were conducted with modified powerhouse operations and diversion dam releases that included shutdowns and artificial freshets.

A tentative modification in the project operations during the spring migration consisted of 100 to 200 cfs released downstream of the project diversion dam in conjunction with powerhouse shut-downs and an artificial freshet of 400 cfs produced once a week for 6 hours. Screens were installed in 1956 at the tailrace outlets and were designed to reduce draft tube injuries, not to minimize migration delays. (Note: no information was provided with respect to screen dimensions or design.) After the evaluations of the modified project operations and the tailrace screens were completed, a third approach to reducing migration delays and fish injury and mortality was recommended. The third approach consisted of a barrier dam and fish collection facility located immediately downstream of the powerhouse. Fish captured at the collection facility would be transported upstream to designated release points.

BIOLOGICAL EFFECTS OF TAILRACE BARRIER:

The modified project operations (i.e., timed diversion dam releases and powerhouse shut-downs) were successful in diverting some upstream migrants away from the powerhouse. However, it was noted that many fish were still delayed and injured at the tailrace and powerhouse. The tailrace outlet screens were considered ineffective because large numbers of seriously injured fish were still being observed after the screens were installed. There was no indication from this study that either the modified project operations or the tailrace screens were producing additional migration delays or injuries.

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION:

There was no discussion of how modified flows or tailrace screens and barriers affected project operation. It was noted, however, that the project owners would not be receptive to a permanent schedule of powerhouse shut-downs and increased water releases, which most likely would result in lost generation revenues. Also, there would be annual costs associated with the use of screens or a tailrace barrier. It was suggested that a flow release plan could be developed that minimized effects on adult salmon migrations and spawning and maximized power generation from available flows.

COMMENTS:

This study presents reasonable evidence that tailrace flows were resulting in migration delays and fish injury at the Puntledge powerhouse. The observed injuries, however, cannot be conclusively linked to contact of draft tube walls because fish were recovered upstream of the powerhouse not in the tailrace. Also, this study was not designed to specifically assess injury and mortality to upstream migrants entering the draft tubes. A discussion of other sources for fish injury or a more detailed study may have provided additional support for the conclusion that fish were being injured in the powerhouse draft tubes. This study does demonstrate that tailrace flows can delay spawning migrations and that modified project operations may alleviate these delays.

Doret, S. C. 1987. A fishway that generates power. Hydro Review, October.

Additional Literature:

Millette, A.J. 1989. Wilder fish ladder with a hydroturbine as a fish-attracting water system. American Fisheries Society Symposium 10:551.

KEYWORDS
ATTRACTION WATER ATLANTIC SALMON

LOCATION OF STUDY:

Wilder Hydroelectric Project, Connecticut River, Vermont.

PROJECT CHARACTERISTICS:

The Wilder Hydroelectric Project was constructed in 1950 with two 17 MW Kaplan turbines and provisions for a third unit and fish passage facilities. The third unit eventually was installed and consisted of a 3.2 MW Francis turbine. After the Anadromous Fish Conservation Act was passed in 1965, a restoration program for Atlantic salmon was developed for the Connecticut River Basin and subsequently a fish ladder was installed at the Wilder Project. The design of the third unit allows the Wilder Station to uniquely meet the needs of fishway attraction water, minimum flow, and power generation simultaneously. The attraction water for the fishway is provided from exit flows of the third unit which generates power at the same time. Minimum flow is passed both during fishway operation and when the other two units are shut-down. A bypass system has been incorporated in the event of a unit outage during the fish migration season. Construction costs were $7.54 million for the fish ladder and $6.5 million for Unit 3.

BIOLOGICAL CHARACTERISTICS:

Atlantic salmon are currently being restored to the Connecticut River. Very few fish have been passed upstream at the Wilder Project because only 10 percent of upstream migrants are allowed to pass the first dam they encounter after entering the river in the spring (the remaining 90 percent of adult returns are held for broodstock purposes). Also, the restoration program relies entirely on smolt and fry stocking for producing adult returns. The large majority of fish that are stocked are released downstream of the Wilder Project.

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE: N/A

<u>**TAILRACE BARRIER DESIGN**</u>: N/A

<u>**BIOLOGICAL EFFECTS OF TAILRACE BARRIER**</u>: N/A

<u>**TAILRACE BARRIER EFFECTS ON PROJECT OPERATION**</u>: N/A

<u>**COMMENTS**</u>:

Although no fish barriers have been installed at Wilder and no fish have been reported to be delayed or injured in the project's tailrace or draft tubes, the unique design of the third unit and its ability to provide attraction water to the fish ladder at all river flows may alleviate any potential problems.

Fleming, D. F., and J. B. Reynolds. 1991. Effects of spawning-run delay on spawning migration of Arctic grayling. American Fisheries Society Symposium 10:299-305.

KEYWORDS
MIGRATION DELAY ARCTIC GRAYLING GAMETE MATURATION HABITAT SELECTION RECRUITMENT EFFECTS

<u>LOCATION OF STUDY</u>:

Fish Creek, a tributary of the Jack River, Cantwell, Alaska.

<u>PROJECT CHARACTERISTICS</u>: N/A

<u>BIOLOGICAL CHARACTERISTICS</u>: N/A

<u>PROJECT EFFECTS ON UPSTREAM FISH PASSAGE</u>: N/A

<u>TAILRACE BARRIER DESIGN</u>: N/A

<u>BIOLOGICAL EFFECTS OF TAILRACE BARRIER</u>: N/A

<u>TAILRACE BARRIER EFFECTS ON PROJECT OPERATION</u>: N/A

<u>COMMENTS</u>:

This study examined the effects of delaying the spawning migration of Arctic grayling by collecting fish at a weir and holding them for 3, 6, or 12 days before tagging and releasing them. Tagged fish were recaptured at upstream traps and assessed for gamete maturation. Based on the data from recaptured fish, migration rates and gamete maturation were determined for each delay period. Of the fish initially captured, most males and about half of the females were classified as ripe (ready to spawn). During the holding periods more than half the females advanced in maturation level and the proportion of ripe males did not change considerably. From these observations, it was concluded that migration timing is more important for female spawners than for males.

The response of fish to delays was exhibited in subsequent migration rates and appeared more closely related to maturation status at time of release than to length of delay. Migration rate of females increased with the level of maturation regardless of the number of days fish were held. Despite faster migration rates, females with greater levels of maturation did not travel as far upstream as females with lower levels of maturation.

From the data obtained during this study and evidence from two independent studies (Bry, 1981; Sakai et al., 1975) conducted with rainbow trout (controlled laboratory experiments), the authors concluded that spawning-run delays of Arctic grayling may reduce egg viability and result in decreased hatching rates of eggs and increased deformity rates of alevins. Also, delayed migration may lead to fish spawning in unsuitable habitats because they were unable to reach upstream spawning areas within time periods constrained by biological (e.g., level of maturation) and physical (e.g., water temperature) parameters. Based on these factors, it was concluded that spawning-run delays would reduce recruitment to the population.

Haynes, J. M., and R. H. Gray. 1980. Influence of Little Goose Dam on upstream movements of adult chinook salmon, *Oncorhynchus tshawytscha*. Fishery Bulletin 78(1):185-190.

KEYWORDS
CHINOOK SALMON FALSE ATTRACTION MIGRATION DELAY

LOCATION OF STUDY:

Little Goose Dam, lower Snake River, Washington.

PROJECT CHARACTERISTICS:

No information was provided with respect to the design and operation of the hydroelectric facilities at the Little Goose Dam.

BIOLOGICAL CHARACTERISTICS:

Adult chinook salmon migrate annually to spawning areas upstream of the Little Goose Dam.

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE:

The Little Goose Dam is an impediment to upstream migrants, consequently, fish ladders have been installed to allow fish to pass upstream.

TAILRACE BARRIER DESIGN: N/A

BIOLOGICAL EFFECTS OF TAILRACE BARRIER: N/A

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION: N/A

COMMENTS:

This study examined migration delays of adult chinook salmon encountering the Little Goose Dam. The average passage delay for radio-tagged and control fish combined was 216 hours in 1976 and 90 hours in 1977. At the Lower Granite Dam, which is upstream of the Little Goose Dam, passage delays of the same fish were less than 50 hours in 1976 and 58 hours in 1977. The passage delays recorded for chinook salmon in 1976 were significantly less ($p < 0.05$) than delays observed at other Columbia and Snake River dams. (Note: Brown, 1994 says more recent studies show average delays are approximately 20-30 hours.) Several factors were identified that may have been contributing to the observed migration delays at Little Goose, including dam spill, turbine discharge, and trapping operations. Dropbacks and milling were common in the spill area and turbine operation reduced salmon passage through the fish ladder (i.e., false attraction). Multi-dam passage delays were cited as a possible factor in declines of fall-run chinook salmon because the delays may reduce spawning success.

International Pacific Salmon Fisheries Commission. 1976. Tailrace delay and loss of adult sockeye salmon at the Seton Creek Hydroelectric Plant. Report No. 648. New Westminster, B.C., Canada. 74 pages.

KEYWORDS
FALSE ATTRACTION SOCKEYE/PINK SALMON MIGRATION DELAY

LOCATION OF STUDY:

Seton Creek hydroelectric project, the Fraser River, Lillooet, British Columbia, Canada.

PROJECT CHARACTERISTICS:

The Seton Creek project is composed of a concrete diversion dam on Seton Creek, a 12,500 foot power canal, and a powerhouse that is located on the Fraser River 4,000 feet downstream from its junction with Seton Creek.

BIOLOGICAL CHARACTERISTICS:

Adult sockeye migrate upstream each year to spawning grounds located above the Seton diversion dam. Two distinct sockeye populations migrate biannually into Seton Creek; once in the summer, and again in the fall. The majority of pink salmon spawn in river reaches below the diversion dam, less than 10 percent spawn above the diversion dam.

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE:

This study concluded that salmon populations were being depleted due to migration delay, injury, and mortality associated with the project's tailrace. Injuries resulted from turbines, draft tube entry, and attraction to leakage flows through the wicket gates, which fish follow into the turbines. During periods of large discharge flows, sockeye are prevented from reaching the turbines, eliminating the possibility of turbine runner contact.

TAILRACE BARRIER DESIGN:

Although no physical tailrace barrier was installed at this site, several methods were assessed to reduce fish injury and mortality in the tailrace. Plant shut-downs were implemented to reduce false attraction; however, leakage into the tailrace through the plant wicket gates continued to attract some sockeye. An increased discharge of 1,000 cfs through the spillway was evaluated as a means to reduce sockeye injury, mortality, and migration delay in the tailrace. Draft tube air injection also was assessed as a means to counter the leakage flow into the tailrace, as well as to prevent draft tube related injury and mortality.

BIOLOGICAL EFFECTS OF TAILRACE BARRIER:

Migration delays due to false attraction and injury and mortality from turbine runner contact have been acknowledged as the major contributors to sockeye losses in Seton Creek. Migration delays were observed even when the spill at the diversion dam was increased to 4,000 cfs. Based on observations of 4,000 cfs flows, it was concluded that 1,000 cfs would not adequately counteract the attraction of fish to the tailrace and would not alleviate the fish injury problem.

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION: N/A

COMMENTS:

This study evaluated migration delay mitigation measures and concluded the problem was reduced with the measures implemented (i.e., plant shut-downs). Impacts to the sockeye fishery were identified, and attempts were made to alleviate spawning migration delays, injury, and mortality. However, migration impacts were not completely eliminated, and other concepts were suggested. Alternative methods for reducing sockeye population losses included artificial scent attraction, implementation of a physical or electrical barrier, utilizing a trap and transport system, re-routing the water, and eliminating the tailrace by extending the draft tube.

National Marine Fisheries Service. 1993. Environmental & Technical Services Division, Portland, OR. Delay and injury associated with hydroelectric project powerhouses, draft position paper.

KEYWORDS

MIGRATION DELAY
INJURY AND MORTALITY
BARRIERS
OPERATION MODIFICATIONS

LOCATION OF STUDY: N/A

PROJECT CHARACTERISTICS: N/A

BIOLOGICAL CHARACTERISTICS: N/A

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE: N/A

TAILRACE BARRIER DESIGN:

The paper examined several exclusion methods developed to prevent adult upstream migrants from entering tailrace areas at hydroelectric projects. For each exclusion method, the discussion included the general purpose of the method (i.e., to block or guide fish), a basic structural description of physical barriers, and an explanation of how the method functions to achieve the desired effect. Exclusion method descriptions also included site applicability information and addressed barrier maintenance and operation issues. Exclusion methods that were discussed included diffuser barriers, hydraulic barriers, electrical barriers, operational changes, and modifications to stream channels. The following discussion summarizes the information that was provided for each method.

Diffuser barriers are designed to minimize attraction of fish to tailrace areas by reducing discharge water velocities. Diffuser barriers reduce water velocities by distributing flow over a relatively large area. It was recommended that average diffuser velocities not exceed 1 fps. Absence of backwater effects was cited as an advantage to diffuser barriers. Several types of diffuser barriers have been designed, including vertical (or inclined) and horizontal barriers, and variable slope weirs. Vertical diffusers, which are the most common, consist of a barrier rack with a maximum 1 inch clear spacing between bars. The bar racks are inclined in the downstream direction and should create even flow distributions with an average flow-through velocity of 1 fps. Horizontal diffusers are used to redirect the turbine flow from its horizontal direction upward through a flat bar barrier. This creates an upwelling flow at which fish are less likely to jump. A horizontal diffuser is entirely submerged even at low tailwater elevations.

The paper describes several types of variable-slope weirs that are designed to exclude fish whereas floating debris can pass through. Variable-slope weirs typically comprise smaller diffuser panels compared to vertical or horizontal barrier racks. The panels are placed side by side across the entire stream width and are connected by hinges to concrete sills or apron structures located on the river bottom. The entire diffuser inclines downstream. The hinges allow variable-slope diffusers to adjust to flow levels and to pass large debris. Floating, hydraulic diffuser, and pneumatic weirs are three types of variable-slope designs. Floating weirs have planer boards on the downstream side of the panels to provide uplift. As debris loads increase, the uplift is overcome and debris passes downstream. Hydraulic diffuser weirs use hydraulic cylinders to control the position of weir sections. Pneumatic weirs incorporate an air filled bladder downstream of the panels at the base of the structure. The inflation level of the bladder determines the angle of the weir.

Non-diffuser barriers include hydraulic and behavioral barriers. Hydraulic barriers are designed to impede fish passage by creating impassable static head or water velocities. Hydraulic barriers typically are concrete structures that either create static head in excess of 10 feet or high water velocities over a sloped apron. Behavioral barriers (e.g., electrical, sound, or light systems) are used to elicit an avoidance response from fish. Electrical barriers have been developed for tailrace applications and rely on fish to avoid the electrical field or become temporarily impaired causing the fish to be swept downstream. The electrical field is designed to decrease in strength from the upstream to downstream direction; this results in fish becoming more paralyzed by the electrical current as they attempt to swim upstream. Although extensive research has been conducted with alternative behavioral devices, such as various types of sound and lights, for fish protection, most of this work focuses on downstream migrants.

Operational changes can be implemented to alleviate migration delays and prevent turbine-related injuries and mortality. Partial or full plant shut down for designated time periods may inhibit fish from entering a tailrace or cause fish already present to leave and seek alternative passageways (e.g., fish ladders). Full load operation may exclude fish from draft tubes by creating impassable water velocities reducing related injuries and mortality. The manner in which turbines are brought on and off line also may influence occurrences of fish injury and mortality. Sudden increases or decreases in flow may trigger fish to enter draft tubes; lower water velocities prior to full generation or turbine stoppage will allow fish to enter draft tubes. Spill modifications also can influence the passage route chosen by approaching upstream migrants. Increased spill may draw fish away from tailrace entrances and towards spillway fishways.

BIOLOGICAL EFFECTS OF TAILRACE BARRIER:

The intention of the tailrace barriers that were discussed is to reduce tailrace migration delay and alleviate injuries and mortality caused by draft tubes and turbine contact. Diffuser barriers minimize false attraction flows that lead to migration delay and also can be used to guide fish to a bypass canal. Hydraulic and electrical barriers prevent fish from entering draft tubes and also can reduce migration delay. Operational changes may alleviate migration delays and injury and mortality associated with tailrace areas. If tailrace barriers are installed and operated properly, there should not be any additional delay, injury, or mortality associated with their use.

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION:

Aside from installation costs and the loss of power associated with screens that require maintenance, economic loss due to tailrace barriers is not expected. There would be economic loss to the extent that screens reduce effective head for the project. Economic losses can also be expected from implementing operational changes that may reduce the flow passing through the turbines resulting in lost power production or a complete plant shut down.

COMMENTS:

This document was a working paper prepared by the National Marine Fisheries Service. The paper provided information on different barrier types designed to prevent adult fish from entering draft tubes and turbines. Fish injury, mortality, and spawning migration delays are concerns at many hydroelectric sites and technology, and measures that can be applied for reducing these problems were discussed. The paper discussed the effectiveness of several barrier types and recommended why and when fish barriers or exclusion methods should be implemented at powerhouse wasteways, tailraces, and tunnel outfalls. Discussions of each barrier type included site-specific requirements for application and assessed the effectiveness of a barrier for reducing negative impacts of upstream migrants from hydroelectric project.

Northeast Utilities Service Company. 1985. The movements and behavior of migratory American shad (*Alosa sapidissima*) in the Turners Falls Project Power Canal, Turners Falls, Massachusetts. Northeast Utilities Service Company, Hartford, CT. 29 pages and figures and appendix.

KEYWORDS
AMERICAN SHAD FISHWAY ENTRANCE MIGRATION DELAY

LOCATION OF STUDY:

Turners Falls Hydroelectric Station, Connecticut River, Turners Falls, Massachusetts.

PROJECT CHARACTERISTICS:

The Turners Falls Project consists of a dam and gatehouse at the upstream end of a power canal (2.2 miles in length) and powerhouse at the downstream end of the canal. There are three fish ladders at the project. The first fish ladder encountered by upstream migrants is an Ice Harbor type pool and weir ladder located at the powerhouse and allows fish to move upstream into the canal. Another Ice Harbor type ladder is located at the base of the dam adjacent to the power canal and gatehouse. Fish ascending this ladder enter directly into the project impoundment. The third ladder is a vertical slot fish ladder and is located at the gatehouse on the opposite side of the canal from where the spillway ladder is located. The gatehouse fish ladder allows fish that entered the canal through the powerhouse ladder to continue upstream into the project impoundment. During low water level periods nearly all the river flow will be diverted into the canal so most fish will ascend the powerhouse ladder into the canal.

BIOLOGICAL CHARACTERISTICS:

Adults of four anadromous fish species migrate to spawning areas located upstream of the Turners Falls Project. Species include Atlantic salmon, American shad, blueback herring, and sea lamprey. Because American shad passage at Turners Falls was the focus of this report, the passage and population characteristics of the other three species are not described. American shad are a target species included in the Connecticut River anadromous fish restoration program. One purpose of the Turners Falls fish passage facilities, which began operating in 1980, is to allow American shad to reach historic spawning areas upstream of the project.

<u>PROJECT EFFECTS ON UPSTREAM FISH PASSAGE</u>:

The Turners Falls Project is an impediment to upstream migrants; however, the installation of three fish ladders has alleviated the inability of fish to reach upstream spawning grounds. This study examined the delay of adult shad in the power canal. Apparently, adult shad that entered the power canal through the powerhouse ladder were having difficulty finding the entrance to the gatehouse ladder and subsequently continuing their upstream migration.

<u>TAILRACE BARRIER DESIGN</u>: N/A

<u>BIOLOGICAL EFFECTS OF TAILRACE BARRIER</u>: N/A

<u>TAILRACE BARRIER EFFECTS ON PROJECT OPERATION</u>: N/A

<u>COMMENTS</u>:

The purpose of this study was to examine the movements of upstream-migrating adult American shad in the power canal of the Turners Falls Project. Shad upstream migrants were having difficulty locating the gatehouse fish ladder and were remaining in the canal rather than continuing their migration to upstream spawning areas. The Turners Falls study comprised two parts. First, radio-telemetry techniques were used to determine shad movements through the power canal, and second, hydroacoustics were used to locate areas in the canal where fish may have been accumulating rather than proceeding upstream.

During the radio-telemetry study, nine of ten tagged shad migrated from the powerhouse fish ladder exit to the head of the canal. Of these nine fish, only one passed through the gatehouse fish ladder and into the impoundment. Fish that did not enter the gatehouse fish ladder maintained position downstream of the gatehouse ladder entrance gallery. An eddy was observed immediately downstream of the entrance and was cited as potentially inhibiting shad passage. The hydroacoustic study determined that adult shad were congregating along the canal edges. It was concluded from the results of both studies that shad were able to ascend the canal but were reluctant to enter the gatehouse fish ladder due to inadequate attraction flows or entrance configuration.

This study clearly demonstrated the inability or unwillingness of upstream migrants to enter the fish ladder. The inefficiency of the Turners Falls gatehouse fish ladder delayed upstream migrants. Effects of the delay on spawning success cannot be determined from this study; however, it is likely that many adults would not reach upstream spawning areas before environmental conditions (specifically temperature) would prevent any further upstream movement and spawning would commence. Because fishery agency management goals included spawning of American shad throughout their entire range, the delay at Turners Falls was hampering restoration efforts.

Rondorf, D. W., G. A. Gray, and W. R. Nelson. 1983. Effects of hydropower development on Columbia River salmonids. In: Waterpower '83: International Conference on Hydropower. Volume III: Environmental Impacts; Research and Development; Dam Safety; General Sessions.

KEYWORDS

PACIFIC SALMON
MODIFIED OPERATIONS
MIGRATION DELAY
FALSE ATTRACTION

LOCATION OF STUDY:

Columbia River Basin.

PROJECT CHARACTERISTICS: N/A

BIOLOGICAL CHARACTERISTICS:

The Columbia River supports populations of five Pacific salmon species and steelhead trout.

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE:

Hydropower development has impacted all anadromous salmonid populations of the Columbia River Basin by delaying migrations and contributing to mortality and injury of upstream and downstream migrants. Depending on the project, impacts may include injury and mortality of upstream migrants from gas supersaturation, draft tubes, or turbine runners. Also, migration delays may result from false attraction of fish to spillway areas and tailraces and alterations in temperature regimes upstream of a project (typically in impoundments).

TAILRACE BARRIER DESIGN:

Physical tailrace barriers are not discussed and modifications to spill and turbine operation and improved fish ladder designs are briefly mentioned as means that have been employed to reduce upstream migration delays and injury and mortality.

BIOLOGICAL EFFECTS OF TAILRACE BARRIER:

Spill modifications may reduce migration delays by allowing upstream migrants to more readily locate fish ladder entrances. Modifications to turbine operations also would facilitate migrants finding fish ladder entrances and would reduce draft tube or turbine runner related injury and mortality (depending on the type of operating modification employed). Improved fish ladder designs would provide the proper hydraulic conditions that are necessary for attracting migrants to entrances.

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION:

Modifications to spill and turbine operations may effect generating capabilities, and revenues may be lost. Improved fish ladder designs would not impact project operation unless the improvements involved increasing attraction water flows or the ladder used greater volumes of water.

COMMENTS:

This paper provides a brief overview of impacts of hydropower development on the Columbia River on the anadromous fish population. Hydropower projects were cited as sources of fish mortality and migration delays. Mortality at some dams was positively correlated with flows. One possible source of mortality at dams was abrasion injuries (specifically observed for chinook salmon). Modified flow regimes throughout the river basin were believed to contribute to delays in migration. Delays may have been more significant during high flow periods because increased spill and turbine discharge can mask fishway attraction flows. In the Snake River, a thermal block was thought to delay upstream migrants and may have contributed to mortality of adult chinook salmon and steelhead trout.

Rozich, T. J. 1989. Evaluation of the Pere Marquette River electrical lamprey barrier. Fisheries Division, Michigan Department of Natural Resources.

KEYWORDS
SEA LAMPREY STEELHEAD TROUT ELECTRICAL BARRIER

LOCATION OF STUDY:

Pere Marquette River, Mason County, Michigan.

PROJECT CHARACTERISTICS: N/A

BIOLOGICAL CHARACTERISTICS:

Adult sea lamprey migrate upstream in the Pere Marquette River each spring to spawn. Lampreys are parasites that feed on the blood of fish. It is believed that they have contributed to observed declines in many Great Lakes salmonid populations. Adult steelhead trout also spawn in the Pere Marquette River each spring.

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE: N/A

TAILRACE BARRIER DESIGN:

The electrical barrier was oriented perpendicular to the flow and was supported by five wooden platforms (20 ft by 20 ft). Twelve Smith-Root Model GFFB 1.4U pulsators provided the pulsed energy. Seven 1-inch wide by 1-inch thick steel bands were used as electrodes and were imbedded in and hung from the wooden platforms. The pulsators (6 on each side of the river) were connected to the steel bands. The river was narrowed at the site of the barrier with plastic sheet piling and the bottom was raised with limestone rock to create a minimum water velocity of 5 fps across the barrier. During the latter stages of the study, the voltage gradient typically increased from about 0.5 V/cm at the downstream end of the platforms to 1.2 V/cm in the middle, after which it decreased to about 0.3 V/cm at the upstream end (voltage was measured between the bands). Voltage was slightly higher near the river bottom than near the surface (stream depth over the wooden platforms ranged from 2 to 5.5 feet).

BIOLOGICAL EFFECTS OF TAILRACE BARRIER:

As part of a lamprey eradication program, the barrier was evaluated for its ability to prevent sea lamprey from reaching upstream spawning areas without harming spent steelhead trout passing downstream. With the voltage gradient described above, the electrical barrier successfully blocked all upstream migrants and passed downstream-migrating steelhead trout without injury or mortality. Also, it was determined that no injury or mortality occurred to steelhead trout smolts that migrate downstream at the same time as adult lamprey and steelhead migrate upstream.

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION: N/A

COMMENTS:

The electrical barrier evaluated on the Pere Marquette River blocked upstream movements of adult sea lamprey. The barrier achieved the objective of blocking lamprey movements to upstream spawning areas without harming steelhead trout adults and smolts. These results show that electric barriers may effectively be used in hydroelectric applications as tailrace barriers.

Sakai, K., M. Nomura, F. Takashima, and H. Oto. 1975. The over-ripening phenomenon of rainbow trout -- II. Changes in the percentage of eyed eggs, hatching rate and incidence of abnormal alevins during the process of over-ripening. Bulletin of the Japanese Society of Scientific Fisheries 41:885-860.

KEYWORDS
RAINBOW TROUT GAMETE MATURATION MIGRATION DELAY

LOCATION OF STUDY: N/A

PROJECT CHARACTERISTICS: N/A

BIOLOGICAL CHARACTERISTICS: N/A

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE: N/A

TAILRACE BARRIER DESIGN: N/A

BIOLOGICAL EFFECTS OF TAILRACE BARRIER: N/A

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION: N/A

COMMENTS:

This study examined the viability of over-ripened ova of female rainbow trout. Eggs were stripped at 5-day intervals beginning immediately after ovulation and then artificially fertilized. Percent eyed, hatching rate, and alevin deformity rate were recorded for each egg group. The percentage of eggs eyed and the hatching rate exceeded 70 percent for eggs that were stripped within 10 days of ovulation. These values decreased to 0 percent for eggs stripped 1 month after ovulation. The percentage of deformed alevins increased with the time of stripping. The results of this study have significant implications for spawning migration delays experienced by salmonids. If upstream-migrating females have ovulated, migration delays could result in decreased egg viability and hatching rates and increased rates of alevin deformity. Consequently, considerable recruitment losses could be experienced for the affected population.

Schadt, T. H., R. G. Metzgar, R. E. Carman, and J. H. Neuner. 1985. Background and assessment of a berm/fish passageway designed to facilitate upstream migration past a tailrace area. In: Symposium on Small Hydropower and Fisheries May 1-3, 1982-Aurora, Colorado, pp 409-415. The American Fisheries Society. Bethesda, MD. 497 pages.

KEYWORDS
PACIFIC SALMONIDS MIGRATION DELAY UPSTREAM FISH PASSAGE BERM/FISH PASSAGEWAY SCREENS

LOCATION OF STUDY:

Jackson Hydroelectric Project, Sultan River, northwestern Washington.

PROJECT CHARACTERISTICS:

The Jackson Project has four turbines with a combined generating capacity of 112 MW. Eight miles of tunnel and pipeline bring water from an upstream reservoir (Spada Lake) to the powerhouse. Only two (Pelton turbines) of the four turbines discharge water directly into the Sultan River and have a combined operating capacity of 1,300 cfs with a maximum discharge velocity of 4.8 fps (average velocity is about 2.6 fps). Discharge from the other two units (Francis turbines) moves through a pipeline that terminates upstream at a second lake (Lake Chaplain). Spada Lake is impounded by Culmback Dam and the lake provides water for the City of Everett. Because the Everett water supply and instream flow requirements have precedence over power production at the Jackson Project, water is rerouted back upstream to Lake Chaplain during periods of low flow. To meet instream flow requirements, water is returned to the Sultan River through another pipeline. The hydraulic head provided by Spada Lake is sufficient to transport water through the entire system.

BIOLOGICAL CHARACTERISTICS:

Anadromous species that utilize the Sultan River Basin for spawning and rearing purposes include chum, pink, coho, and chinook salmon; steelhead and sea-run cutthroat trout; and Dolly Varden. The primary species of concern that spawn above the Jackson Project are fall-run chinook and summer- and winter-run steelhead trout.

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE:

At certain flow regimes (dependent on total river flow and discharge levels from the powerhouse), powerhouse discharges during generation periods because of false attraction of fish to the tailrace flow can inhibit upstream salmonid migration. There also is potential for injury and mortality of fish that enter the powerhouse discharge canals and strike walls or the turbine runners.

TAILRACE BARRIER DESIGN:

To reduce the false attraction of fish to the powerhouse discharge canals, a hydraulic attraction to the project bypass was created by constructing a fish berm (lowhead dam) at the upstream end of the powerhouse. The berm extends across most of the river (perpendicular to the flow) from the bank opposite the powerhouse. A plume, with water velocities approaching 7 fps (depending on discharge), is created from the constriction of the river flow. The accelerated flows created by the berm make the main river channel more distinguishable to upstream migrants as they approach the Jackson powerhouse during periods of power generation. The installation of screens at the powerhouse also was considered for preventing fish from entering the discharge canal. Although screens may reduce any fish injury or mortality from canal wall and turbine contacts, they would not alleviate the problems associated with false attraction.

BIOLOGICAL EFFECTS OF TAILRACE BARRIER:

At the time this paper was presented, a field evaluation of the fish berm had not been completed. Based on the berm design, however, upstream migration delays and fish injury and mortality from fish entering the discharge canals should be reduced. Tailrace associated injury and mortality may be further reduced if screens are installed and the berm remains in place. If the screens are installed and the berm is removed, migration delays most likely would still occur and there may be injury and mortality from fish striking the screens in attempts to enter the discharge canals.

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION:

No lost generation should occur due to the fish berm because it is located on the main river channel near the tailrace area of the powerhouse. There may be maintenance costs associated with the berm, as well as with screens.

COMMENTS:

Based on its design, the fish berm installed at the Jackson Project should facilitate fish migration past the project's powerhouse during periods of generation. Without screens, fish can still enter the powerhouse discharge canals, but would be less likely to do so because of the high velocity plume created by the berm. Should fish enter the discharge canals, it was considered unlikely that they would contact the turbine runners because of the location and design of the two Pelton units. The distance of the turbines from the water surface, high water velocities, turbulent water, air depression system noise, and lack of a plunge pool inside the discharge canals are all factors that would prevent fish from leaping and striking the turbine runners. However, fish striking the canal walls could still be a source of fish injury and mortality.

Sloane, R. D. 1984. Upstream migration by young pigmented freshwater eels (Anguila australis australis Richardson) in Tasmania. Australian Journal of Marine and Freshwater Research 35:61-73.

KEYWORDS

FRESHWATER EELS
MIGRATION CUES

LOCATION OF STUDY:

Trevallyn and Meadowbank Hydroelectric Projects, the island of Tasmania off the southeast coast of Australia. Sampling also was conducted on smaller stream barriers throughout Tasmania.

PROJECT CHARACTERISTICS: N/A

BIOLOGICAL CHARACTERISTICS:

Juvenile freshwater eels (elvers) annually migrate upstream to rearing habitats throughout the river systems of Tasmania.

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE:

The Trevallyn and Meadowbank projects were an impediment to upstream movements of elvers. No upstream passage facilities exist at either project or at any of the smaller barriers that were examined. However, because eels can climb over land and up certain structures during rain periods, the blockage of elver migrations was not 100 percent at any of the study sites. At the Trevallyn Project it was determined that turbine output, not environmental factors, exerted the greatest influence on elver catches. When turbine output was high it prevented elvers from entering the trap areas in the tailrace because the elvers could not swim against the flow.

TAILRACE BARRIER DESIGN:

Tailrace barriers were not discussed in this paper. Juvenile eels do not have the swimming capabilities that are generally required for ascending draft tubes. Because fish were not trying to reach spawning areas and there were no upstream passage facilities, delayed migration was not an issue. Elvers remaining in the tailrace incur long-term physiological costs and population loss if elvers are not able to reach upstream feeding grounds. Trapping and transport was conducted, however, to stock upstream areas with elvers to improve the overall eel production of Tasmania's rivers.

BIOLOGICAL EFFECTS OF TAILRACE BARRIER: N/A

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION: N/A

COMMENTS:

This study demonstrates the effects that a hydropower project can have on the upstream migration of a juvenile life stage. The Trevallyn Station blocked upstream movements of elvers at all generating levels and prevented trapping of upstream migrants at high turbine outputs because elvers were unable to negotiate the high flow velocities.

Vande Sande, T. 1982. Potential impacts of hydropower development on upstream fish passage. In: 1982 Northeast Coldwater Workshop June 15-17, 1982-Ithaca New York; Hydropower Development and Fisheries Impacts and Opportunities. pp 37-44. New York State Department of Conservation. 127 pages.

KEYWORDS
UPSTREAM FISH PASSAGE MIGRATION DELAY HYDROPOWER IMPACTS FISHWAY DESIGN

<u>LOCATION OF STUDY</u>: N/A

<u>PROJECT CHARACTERISTICS</u>: N/A

<u>BIOLOGICAL CHARACTERISTICS</u>: N/A

<u>PROJECT EFFECTS ON UPSTREAM FISH PASSAGE</u>: N/A

<u>TAILRACE BARRIER DESIGN</u>: N/A

<u>BIOLOGICAL EFFECTS OF TAILRACE BARRIER</u>: N/A

<u>TAILRACE BARRIER EFFECTS ON PROJECT OPERATION</u>: N/A

<u>COMMENTS</u>:

The impacts of hydropower on upstream fish passage are summarized and several important factors that influence migration delays and spawning success are discussed. The study states that passage success in controlled flow conditions (e.g., hydropower projects) should reach 100%. The author suggested that to determine passage delays and its effects, the following information should be obtained: 1) total number of days fish could not pass (i.e., unfavorable flow conditions); 2) consecutive number of days fish could not pass; 3) number of days fish were present for passage; and 4) the effect of delay on spawning success. Also, available flow data should be incorporated into evaluations of passage delays. The author recommended the use of fish barriers (e.g., barrier dams, picketed fences, and electric fences) when more water is discharged from a powerhouse than from fishway channels or entrances. It was noted that power plants that operate under peaking schedules may cause additional delays for upstream migrants, and high discharge flows during power generation periods can mask fishway attraction flows. Major fluctuations in flow levels from peaking operations can interrupt migrations throughout a river reach below a powerhouse. Reduced oxygen levels due to organic waste assimilation at low water levels also may impede upstream fish movement. At projects with reservoirs, there may be more potential for low oxygen levels downstream of the plant. Reservoir discharges with high water temperatures were implicated in pre-spawning mortality and reduced spawning success of fall run salmon in some California rivers.

Spill over a dam also was cited as a source of passage delay. To allow fishway attraction water to be detected by upstream migrants, it was suggested that the majority of spill at a dam be released as far away from fishway entrances as possible to allow the fishway attraction water to be detected by upstream migrants. If there are fishways on both river banks, the spill should be concentrated at the center of the dam. Also, large volumes of water spilled over a dam can produce supersaturation of atmospheric gases, which can lead to fish mortalities at levels greater than 120 percent saturation.

Vogel, C. A., K. R. Marine, and J. G. Smith. 1990. A summary of evaluations of upstream and downstream anadromous salmonid passage at Red Bluff Diversion Dam on the Sacramento River, California, U.S.A. In: Proceedings of the International Symposium on Fishways 1990 in Gifu, Japan. October 8-10, 1990.

Additional Literature:

Brown, R. L. 1991. Bioengineering problems in river systems of the Central Valley, California. American Fisheries Society Symposium 10:19-31.

KEYWORDS
PACIFIC SALMON MIGRATION DELAY FLOW MODIFICATIONS FISH LADDER DESIGN

LOCATION OF STUDY:

Red Bluff Diversion Dam, Sacramento River (river mile 243), California.

PROJECT CHARACTERISTICS:

The Red Bluff Dam has diverted water for irrigation purposes since 1966. Minimum river flow at Red Bluff ranges from about 3,000 to 4,000 cfs, and normal flows range from 10,000 to 20,000 cfs depending on the season. The dam has 11 weir-controlled, fixed-wheel overflow gates (each 60 feet wide) that raise the river level 13 to 15 feet depending on the time of year. Upstream migrants pass upstream of Red Bluff by ascending one of two fish ladders that are located at either end of the dam. The entrance flow capacity of each fish ladder is 88 cfs with additional attraction flows of about 250 cfs.

BIOLOGICAL CHARACTERISTICS:

Chinook salmon and steelhead trout migrate to spawning grounds upstream of the Red Bluff Diversion Dam each year. There are several seasonal runs (e.g., winter run; summer run) of chinook salmon that result in adult salmon migrating upstream during all 12 months of the year.

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE:

Because the Red Bluff is a diversion dam, not a hydroelectric project, there is no injury or mortality associated with draft tubes or turbine blades. Studies conducted in the 1970s and

1980s, however, concluded that the diversion dam was a major impediment to the upstream migration of salmonids, contributing to considerable migration delays and blockage.

TAILRACE BARRIER DESIGN: N/A

BIOLOGICAL EFFECTS OF TAILRACE BARRIER: N/A

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION: N/A

COMMENTS:

This paper did not examine the use of tailrace barriers, but it did summarize studies that have been conducted at the Red Bluff Diversion Dam that have identified considerable migration delays at the dam's two fishways. Biological effects of migration delays that were identified included increased pre-spawning mortality, reduced egg viability, and fish spawning below the dam where high water temperatures may be lethal to eggs. During experiments conducted at Red Bluff, spillway crest gates were manipulated to produce various flow conditions in attempts to attract fish to the two fish ladders. It was concluded from these experiments that the fish ladders had insufficient flows and inadequate entrance configurations. Based on these results, replacement or modification of the fish ladders was recommended to provide increased flows at the entrances. Placement of entrances at a depth that would increase the probability of upstream migrants locating them also was recommended.

Wagner, C. H. 1967. Fish barrier dams. Fish Facilities Section, Columbia Fisheries Program Office, Bureau of Commercial Fisheries. Portland, OR. 9 pages.

KEYWORDS

FISH BARRIER DAMS
PACIFIC SALMON
AMBERSEN-TYPE

<u>LOCATION OF STUDY</u>: N/A

<u>PROJECT CHARACTERISTICS</u>: N/A

<u>BIOLOGICAL CHARACTERISTICS</u>: N/A

<u>PROJECT EFFECTS ON UPSTREAM FISH PASSAGE</u>: N/A

<u>TAILRACE BARRIER DESIGN</u>:

This paper discussed two fish barriers designed to guide fish. One design, an Ambursen-type dam, is based on a water level drop that is sufficient for preventing upstream movement of fish at all flow levels. The other design prevents fish passing upstream by producing shallow depths with high flow velocities on an apron structure that has a flow direction change at the upper end. Proper placement of the barriers and fishway entrances and modification of river channels (where necessary) were considered important to the fish guidance effectiveness of both barrier designs.

The Ambursen-type barrier is a structure that is angled upward in the downstream direction. A channel is produced behind turbine discharge water that falls over the barrier. Depending on the site, the channel can be connected to a side entrance of a fishway. Upstream migrants either swim or fall into the channel as they try to jump over the barrier. Directional flow through the channel can be produced from a side entrance of a fishway or if one end of the channel is set at lower tailwater level than the other end. A minimum of 10 feet of head was considered necessary; however, 8 feet of head may be sufficient for some anadromous salmonid species (i.e., barrier effectiveness depends on a species' swimming speed and jumping capabilities). Barriers of this type have been constructed at the Klamath River Fishway, Baker River Project, Mayfield Dam, and Cowlitz River salmon hatchery. Adjustable weirs and electric barriers have been used at sites where hydraulic conditions reduced the effectiveness of a Ambursen-type barrier dam.

The second type of barrier requires high water velocities (minimum of 16 fps) to prevent fish from ascending the apron of the barrier. Also, the water depth along the apron must be shallow (maximum of 6 inches). The water velocity and depth requirements are based on the swimming capabilities of Pacific salmonids and are subject to change depending on species of concern. Should a fish be able to swim up a barrier apron, the shallow apron depth eliminates the necessary hydraulic conditions that allow fish to jump over impediments. To attain proper hydraulic conditions a sill height of 3.5 feet and an apron length of 15 feet were recommended. The water velocities, depths, and barrier dimensions reported in this paper were considered general criteria; site-specific deviations were acknowledged.

BIOLOGICAL EFFECTS OF TAILRACE BARRIER:

The main purpose of these two barrier designs was to allow upstream migrants to find entrances to fishways located at dams or hatcheries. Therefore, the two types of barrier dams should reduce migration delays by facilitating fish passage. Also, these barriers, by design, would prevent fish from swimming into draft tubes and contacting walls and turbine runners. Proper placement of the barrier dams and fishway entrances was considered important for reducing attempts by fish to pass the barriers, subsequently reducing chances for injury.

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION:

The effects of either of these fish barriers on project operations was not discussed. Negative impacts on power generation may result from increased tailwater levels if sited in proximity to the tailrace discharge.

COMMENTS:

This paper provides important design criteria, both physical and biological, for two fish barrier designs. Several sites where these barriers have been successfully installed were used as examples to demonstrate modifications that may be necessary to prevent fish from passing upstream and effectively guiding them to a fishway entrance.

Weaver, C. R. 1963. Influence of water velocity upon orientation and performance of adult migrating salmonids. Fishery Bulletin 63(1):97-121.

KEYWORDS

COHO SALMON
CHINOOK SALMON
STEELHEAD TROUT
SWIMMING SPEED
ATTRACTION FLOWS

LOCATION OF STUDY:

Fisheries Engineering Research Laboratory at the Bonneville Dam, Columbia River, Washington.

PROJECT CHARACTERISTICS: N/A

BIOLOGICAL CHARACTERISTICS: N/A

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE: N/A

TAILRACE BARRIER DESIGN: N/A

BIOLOGICAL EFFECTS OF TAILRACE BARRIER: N/A

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION: N/A

COMMENTS:

This study examined the swimming capabilities of chinook and coho salmon and steelhead trout in a laboratory setting. The results support the false attraction phenomenon observed at many hydroelectric projects and provide a basis for fish ladder design and siting. The purpose of the study was to determine (1) how adult salmonids respond to differences in water velocities, (2) adult salmonid swimming capabilities in two relatively high-velocity flows, and (3) how flow velocity influences rate of movement. When presented with two different flow velocities in parallel channels, fish of each species typically selected the faster water velocity. Steelhead trout and chinook salmon swimming performance were assessed at water velocities of 13.4 and 15.8 fps in an 85-ft channel. During these tests, steelhead trout demonstrated an ability to swim greater distances against both flow velocities, and larger fish of both species typically swam greater distances than smaller fish. Both species negotiated the lower velocity (13.4 fps) more readily than the higher velocity (15.8 fps).

Rates of fish movement were evaluated at water velocities of 2 to 15.8 fps and over a distance of 30 feet. Steelhead trout and coho salmon increased their rate of movement as water velocities increased from 2 to 8 fps, whereas chinook salmon rates of movement decreased with increases in velocity. There was no indication that the distance fish were able to swim influenced their rate of movement at water velocities of 13.4 and 15.8 fps.

The results of this study are extremely important to the design of fishways, specifically for consideration of attraction flows. Upstream-migrating salmonids appear to select faster water velocities when confronted with two flow magnitudes. The author concluded that upstream migrants may not locate fishway entrances if there are adjacent flows with greater velocities. Specifically, the author cited spillway and turbine discharge at Columbia River low-head dams as competing flows that may prevent fish from locating fishway entrances. It also was noted that flow volume could have influenced water velocity selection, as it was greater in the channel with the faster velocity. Furthermore, because this was a controlled study that manipulated water velocities only, the influence of other factors such as turbulence, turbidity, temperature, and light intensity could not be determined. These parameters may vary considerably among fishway locations and could have a significant effect on the migration routes chosen by adult salmonids at hydroelectric sites. Variations in the swimming capabilities among the three species also demonstrate the need to assess upstream migration problems at a hydropower project on a species by species basis.

Williams, R. 1985. Report on the loss of salmonid fish at the Winchester Hydroelectric Project in 1984. Oregon Department of Fish and Wildlife, Research and Development Station.

KEYWORDS
CHINOOK SALMON STEELHEAD TROUT INJURY DRAFT TUBE

LOCATION OF STUDY:

The Winchester Hydroelectric Project, North Umpqua River, Winchester, Oregon.

PROJECT CHARACTERISTICS:

The Winchester Project consists of a powerhouse and dam with a bedrock outcrop separating the tailrace and spillway areas. A fishway is located adjacent to the powerhouse, and entrances have been placed in both the tailrace and spillway areas. A detailed description of the Winchester Project was not provided (i.e., number and types of units, discharge flow volumes, river flow levels).

[Note: This project was shut down per FERC order on remand rescinding the project's Exemption from Licensing. Issued December 17, 1985 - 33 FERC paragraph 61,387.]

BIOLOGICAL CHARACTERISTICS:

Adult chinook salmon and steelhead trout annually migrate to spawning areas upstream of the Winchester Project.

PROJECT EFFECTS ON UPSTREAM FISH PASSAGE:

Because the original Winchester Dam was an impediment to upstream fish passage, the existing fish ladder was upgraded when the powerhouse was installed. Injury and mortality associated with fish entering the station draft tubes were identified during the study. Injuries included broken vertebrae and internal bleeding immediately posterior to the head. Migration delays were not discussed; however, attraction to the tailrace discharge indicates delays may exist. It was assumed that the greater the flow going through the powerhouse the greater the attraction of upstream migrants to the tailrace. This was most evident at higher flow levels when the proportion of the total river flow diverted through the powerhouse was greatest.

TAILRACE BARRIER DESIGN:

Grates were installed at the powerhouse discharges in response to the reported losses of adult upstream migrants at the Winchester Project. The grates were set flush with the draft tube exit and had 1-inch bar spacing. The grates were installed in pairs at each turbine outfall to allow cleaning during power generation.

BIOLOGICAL EFFECTS OF TAILRACE BARRIER:

Because the draft tube grates were installed based on the findings of this study, no biological evaluation had been conducted; however, monitoring was proposed to determine the effectiveness of the grates. Although injury to downstream migrants was identified from effects of the upstream bypass facility, the report did not identify impacts on downstream migrants from impingement on the tailrace grates.

TAILRACE BARRIER EFFECTS ON PROJECT OPERATION:

Because the grates were installed at the draft tube opening, it is possible that they could influence power generation. There also would be general maintenance and operational costs.

COMMENTS:

This study was conducted during the first year of operation of the Winchester Project, and initially, injury and mortality were not a concern. However, cursory surveys were conducted to monitor the effect of the project on upstream fish migrations. Presence of dead adults downstream of the project prompted more detailed surveys and assessment of the project's impact on upstream migrants. Relative flow volume appeared to be a major factor in determining the migration path of adult salmonids as they approached the project. At higher flow levels more fish were attracted to the tailrace than to the spillway because a greater proportion of the total flow passed through the powerhouse than did at lower flow levels. During underwater surveys fish were observed entering the draft tubes while the plant was generating. Based on observations of mortality, injury, and fish movements in the tailrace, the study concluded that tailrace and discharge areas caused loss of 1.7 percent and 0.2 percent of the returning Chinook and Steelhead at Winchester Dam. Although it was not discussed, migration delays also may have occurred at the Winchester Project because fish were attracted to the draft tubes at higher flow levels.

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