WHITE PAPER

Passage of Juvenile and Adult Salmonids Past Columbia and Snake River Dams

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INTRODUCTION

Development of the Federal Columbia River Power System (FCRPS) on mainstem Snake and Columbia Rivers began with the completion of Bonneville Dam in 1938, and ended with the construction of Lower Granite Dam in 1975 (Fig. 1). Throughout the past six decades, many structural configurations and operational strategies have been tested to improve the survival of juvenile and adult salmonids (*Oncorhynchus* spp.) passing through the FCRPS. This report summarizes the information pertinent to the FCRPS as it is currently configured for each route of passage and life history, and discusses uncertainties associated with the existing database. The reader is referred to Mighetto and Ebel (1994) and Whitney et al. (1997) for historical reviews of studies conducted over the past decades to evaluate the causes of fish loss, various improvements tested, and programs implemented to improve fish condition and survival through the FCRPS.

Figure 1. Columbia River hydrosystem.

JUVENILE PASSAGE THROUGH SPILLWAYS

Description of Spillways

The spillways of all FCRPS dams consist of a forebay, spill gates, ogee, stilling basin, and tailrace. The forebay typically consists of about 1 km of reservoir immediately above the spillway gates. Most spillway gates are a radial design with a 60-ft radius and 50-ft width (COE 1996b). Two projects have vertically operated lift gates of similar width. Number of spillbay gates per spillway varies from 8 to 10 at lower Snake River dams to 18 to 23 at lower Columbia River dams. The ogee sections transition flow from below the gates to the stilling basin. Flow deflectors that help reduce dissolved gas production are located on the ogee sections at elevations designed for each project. Below the ogee, the spilled flow enters a stilling basin designed to dissipate turbulent energy in a confined, armored zone, thereby minimizing the threat to the spillway's structure. Beyond the stilling basin, the tailrace extends for about 1 km downstream. Spillway capacities are designed for the maximum probable flood and vary from 850,000 cubic feet per second (cfs) at lower Snake River dams to 2,290,000 cfs at lower Columbia River dams.

Spill Management

Background

Spill has long been considered one of the safest routes of passage for juvenile salmonids at Snake and Columbia River hydroelectric projects. In the l940s, the U.S. Fish and Wildlife Service conducted survival studies at the newly constructed Bonneville Dam. After 7 years of releases of juvenile chinook salmon and the subsequent recovery of adults, the agency reported that spillway survival was 97% using pooled data and 96% using weighted averages, and that these values were about 10% higher than turbine passage survival (Holmes 1952). Studies conducted since Holmes indicate a similar trend, where survival through spillways was generally better than through turbines (Whitney et al. 1997). Based on this information, regional fishery managers have long regarded spill as the safest passage route for juvenile salmonids.

Despite the fishery agency positions in favor of spill for fish passage, the majority of spill at hydroelectric projects prior to the 1980s was involuntarily caused by river flows that exceeded the hydraulic capacity of the powerhouses. Voluntary spill reduced power production and was provided only for short periods to address specific passage situations. Much of the conflict over using spill for fish passage was based primarily on the fact that dams were authorized and operated for power production, not fish passage.

On 5 December 1980, the Pacific Northwest Electric Power Planning and Conservation Act created the Northwest Power Planning Council (Council) and required the establishment of a fish and wildlife program consisting of measures "to protect, mitigate, and enhance fish and wildlife affected by the development, operation, and management" of the hydroelectric facilities located on the Columbia River and its tributaries. In 1982, the Council released the first version of this program now known as the Columbia Basin Fish and Wildlife Program (Program). This program and its amended versions contained measures that instructed the COE to “develop and implement a plan for spills which will achieve a level of smolt survival comparable to or better than that achievable by the best available bypass and screening systems” at several mainstem dams including John Day, Ice Harbor and Lower Monumental Dams (NPPC 1982). In the 1984 Program amendment, a similar requirement for interim spill was added for The Dalles and Bonneville Dams (NPPC 1984). The 1984 amendment also established a 90% survival goal for each project (except Bonneville Dam where the goal was 85%) and a goal of 85% fish passage efficiency (FPE), where 85% of the juvenile salmon were to pass through non-turbine routes.

The Program and its amendments did not define exactly how to implement spill at each dam to achieve the survival and FPE goals. In the ensuing years, numerous technical discussions occurred between COE and the fish management agencies and tribes about the implementation of spill at each dam. The fishery agencies and tribes discussed spill and other fish passage operations with COE prior to each fish passage season. These preseason discussions led to separate implementation plans, and the resultant in-season spill operation was a compromise between power production and fish passage, falling short of what the fishery agencies and tribes believed was necessary to meet the Program goals.

To end the dispute over spill required for passage, a 10-year Fish Spill Memorandum of Agreement (MOA) was signed on 10 April 1989 by the regional fishery agencies, Indian tribes, and the Bonneville Power Administration (BPA). This agreement was then adopted by the Council into the Program. The MOA provided a specific amount of spill at four mainstem Columbia River dams as “final and complete settlement of any claims regarding any obligation of the United States of America to provide spill as mitigation for mortality to anadromous fish attributable to turbine passage at all Federal Columbia River Hydroelectric Projects.” The four dams (The Dalles, John Day, Ice Harbor, and Lower Monumental) were included because they either did not have bypass systems or the existing bypass system was not performing to the expected standards. Implementation of this MOA was determined annually by the signatories and presented as the Fish Spill Implementation Plan in the Detailed Fishery Operating Plan published each year by the Columbia Basin Fish and Wildlife Authority. While not a signatory, the COE implemented the majority of the fishery agency spill requests at the dams included in the MOA. Bonneville Dam was not included in the MOA, and implementation of spill at this project required annual discussions.

In 1992, Snake River sockeye salmon (*O. nerka*) were listed by the National Marine Fisheries Service (NMFS) as endangered under the ESA. In the following 6 years, additional Columbia Basin salmon stocks were listed under ESA as either threatened or endangered. With listing came consultation between NMFS and the action agencies and eventually a series of Biological Opinions (BIOPs) which required specific spill scenarios at each FCRPS dam. Of particular importance were the 1995 and 1998 BIOPs, which established the most extensive fish spill programs yet implemented in the Columbia Basin (NMFS 1995a, 1998b).

Present Status

The 1995 FCRPS BIOP (NMFS 1995a) established a spill program that passed 80% of downstream migrants through non-turbine routes, or an FPE of 80%. This 80% FPE goal was to be achieved by spilling a specific percentage of total river flow at each FCRPS dam based on the performance of other fish passage devices already in place. For example, if a bypass system passed 50% of the daily fish passage, then spill was provided as necessary to pass an additional 30% of the fish. Specific spill hours and dates were prescribed for each dam along with spill limitations based on total dissolved gas generation and adult passage concerns.

In 1998, after new listings of steelhead stocks in the Columbia River Basin, the 1995 BIOP was supplemented with additional requirements to protect these stocks (NMFS 1998b). This 1998 Supplemental Opinion and its appendices required spill above the 80% FPE goal to aid system-wide juvenile fish passage by adding spill at projects where the 80% FPE goal could be exceeded without exceeding the dissolved gas limits, to make up for projects where spill was held below the 80% FPE goal by dissolved gas limits or other fish passage concerns.

Spill Efficiency and Effectiveness

Spill effectiveness is the proportion of fish approaching a project that pass via the spillway. Spill efficiency is spill effectiveness divided by the proportion of total river flow passing over the spillway at the same time. Recent reviews of spill efficiency and effectiveness include Steig (1994), Giorgi (1996), Whitney et al. (1997), and Marmorek and Peters (1998). Estimates of spill efficiency vary by project.

Most spill efficiency estimates are based on hydroacoustic methodologies which make estimates for the general population, not specific species or stocks. Radiotelemetry studies have been conducted at some dams, where yearling and subyearling chinook salmon and steelhead were marked, released upstream, and their behavior and route of dam passage noted. With sufficient receiving antennae and sample size, estimates of spill efficiency and effectiveness can be derived.

Steig (1994) reviewed studies at Snake and Columbia River dams published through 1992 and noted that there is considerable variability in daily and weekly spill effectiveness. However, he concluded that most of the results fall around a 1:1 relationship between the proportion of water spilled and the proportion of fish passed in spill (i.e., 1.0 spill efficiency). Giorgi (1996) reviewed estimates of spill efficiency published through 1993 and noted that efficiencies are poorly estimated for most species due to a combination of sparse observations, imprecise estimates, and the reliance of most estimates on hydroacoustic monitoring which is unable to distinguish among species. He cautioned that the assumption of a spill efficiency of 1.0 could not be justified in most cases and implied that a suite of estimates acquired with different methodologies should be considered when attempting to derive species-specific estimates at individual dams. Relying largely on Giorgi's (1996) review, the PATH Hydro Work Group (PATH 1997) concluded that a range of spill efficiencies from 1.0 to 2.0 should be considered and incorporated into sensitivity analyses of passage at dams in the Snake and Columbia Rivers.

The forebay and spillway stilling basin of The Dalles Dam are configured differently than other projects, with the spillway oriented at right angles to the natural course of the river and the powerhouse oriented nearly parallel to the course of the river. The Independent Scientific Group (ISG 1996) suggests it is not surprising that this project exhibits higher spill efficiency than many other projects, due to its unique configuration. Giorgi and Stevenson (1995) reviewed biological investigations that described smolt passage behavior at The Dalles Dam and discussed implications to future surface bypass research. They cited three investigations that indicated that spill efficiency was near 2.0 when about 20% of the flow passed over the spillway. These included Willis (1982), which describes a curvilinear relationship in which spill efficiency is equal to or greater than 2.0 at spill below approximately 30% of total river flow, declining to about 1.4 at 60% spill, and further declining to 1.0 at 100% spill. A recent radiotelemetry study at The Dalles by Holmberg et al. (1998) supports this general relationship. Spill efficiency for yearling chinook was 2.3 at 30% spill and 1.25 at 64% spill in 1996. NMFS suggests that a factor of 2.0 be applied at The Dalles Dam at spill levels up to 30%; when spill levels are above 30% spill, the relationship grades from 2.0 to 1.0 according to Equation (1). This relationship predicts a spill efficiency of 1.5 at 65% spill:

$$P_f = 2.0P_w \qquad 0 < P_w \leq 0.30 \qquad (1)$$
$$P_f = (2.43 - 1.43P_w)P_w \qquad P_w > 0.30$$

P_f is the proportion of fish passing over the spillway (the spill effectiveness)
P_w is the proportion of total river flow passing over the spillway
Spill efficiency is defined as $P_f \div P_w$.

Spill efficiency at Lower Granite, Little Goose, and Lower Monumental dams can be estimated based on radiotelemetry observations for yearling chinook salmon at Lower Granite Dam (Wilson et al. 1991), because of the similarity of the three projects. Combining the radiotelemetry observations with the assumptions that 0% of fish pass the spillway at 0% spill and 100% pass at 100% spill, the following relationship (Smith et al. 1993) can be applied:

$$P_f = 2.583P_w - 3.250P_w^{\ 2} + 1.667P_w^{\ 3} \qquad (2)$$

P_f is the proportion of fish passing over the spillway
P_w is the proportion of water passing over the spillway
Spill efficiency is defined as $P_f \div P_w$.

The shape of this relationship is highly uncertain outside of the range of observations (20 to 40% spill), even though P_f must logically go to 0 and 1.0 at the extremes (ISG 1996).

Hydroacoustic studies conducted in 1997 and 1998 at John Day Dam (BioSonics Inc. 1999a, b) indicated high spill efficiency, particularly for daytime spill. For example, in the spring of 1998, daytime and nighttime spill efficiency was as high as 3.4 and 2.0, respectively. Summer efficiency in 1997 averaged 5.1 and 3.0 for daytime and nighttime spill, respectively. Daytime spill efficiency tended to decrease as spill percentage increased, whereas nighttime spill showed no significant correlation with spill level.

Seasonal Spill Timing

Seasonal spill timing has historically been based on juvenile fish abundance in the river system. Early spill programs relied primarily on preseason planning dates and in-season estimates of cumulative fish passage as a trigger for the beginning and end of the spill season at each project. These programs were managed to provide spill for the middle 80% of the juvenile outmigration. These percentages were applied separately to the spring and summer migration periods and were based on actual fish sampling at each project via a smolt monitoring program (FPC 1995). Present spill programs are governed by planning dates stated in the NMFS FCRPS Biological Opinions. The dates may be adjusted in-season based on the abundance of marked listed fish in the system.

The NMFS 1998 BIOP proposed that the actual dates of spill be determined annually by the regional Technical Management Team and based primarily on in-season monitoring information on abundance of tagged fish and population indices at Lower Granite and McNary Dams. The Snake River spill planning dates are April 3 to June 20 and June 21 to August 31; lower Columbia River dates are April 20 to June 30 and July 1 to August 31 for spring and summer, respectively. Mid-Columbia River spill planning dates are April 10 to June 30.

One problem noted with this spill program schedule is that fish left in the river below Lower Granite Dam after August 31 do not receive the benefit of the spill program. Smolt travel times for subyearling chinook passing Lower Granite Dam indicate it takes approximately 3 weeks for these fish to reach Bonneville Dam under normal late-summer flow conditions (COE 1999e).

Daily Spill Timing

Daily spill timing in the early spill programs was based on hourly monitoring of smolt abundance at some projects where this information was available. Where this information was not available, daily spill hours were determined preseason by using the best available diel passage information, often applying information gained from dams other than the dam in question. At most dams, this information was derived from smolt monitoring or research activities conducted at the powerhouses rather than the spillway. More recently, passage timing through the spillways at some dams has been shown to be quite different from passage timing through the powerhouses. For example, at John Day and Lower Monumental Dams, smolt monitoring has indicated that 60 to 90% of the daily powerhouse passage occurs from 1800 to 0600 hours for spring and summer migrants (Ransom and McFadden 1987, Martinson et al. 1997). However, recent hydroacoustic studies conducted during years when involuntary daytime spill was occurring indicated that both day and night passage of juvenile migrants through the spillways at these two dams is high (Johnson et al. 1998, BioSonics Inc. 1999a, b). Observations at The Dalles and Bonneville Dams also indicate that spillway passage occurs at fairly constant rates, day and night, if daytime spill is provided (BioSonics Inc. 1997, Hensleigh et al. 1998). This recent information suggests that using powerhouse diel passage patterns to manage spill can cause juvenile migration delays as fish wait to pass the project after dark via either the powerhouse or spillway. Studies conducted at John Day Dam in years with little daytime spill found that fish often milled in front of the dam when they arrived during the day and passed the dam at night, most often through the powerhouse (Giorgi et al. 1985, Sheer et al. 1997). In contrast, one of these studies found that fish passing The Dalles Dam during 24-hour spill delayed very little and most (85%) passed through the spillway (Sheer et al. 1997). Also, recent radiotelemetry studies at John Day Dam during higher flow years with significant amounts of 24-hour spill indicated relatively low forebay residence times with high (50 to 75%) spillway passage rates for yearling and subyearling chinook salmon and steelhead (Hensleigh et al. 1999, Liedtke et al. 1999).

Forebay Predation

In studying predation in the John Day Reservoir, Beamesderfer and Rieman (1991) found that forebay populations of northern pikeminnow (*Ptychocheilus oregonensis*) and smallmouth bass (*Micropterus dolomieui*) were present in substantial numbers in the forebay of John Day Dam. Poe et al. (1991) reported that the diet of northern pikeminnow in the forebay of John Day Dam was 66% salmonid smolts. Based on this, any delay of outmigrants in the forebay could reduce survival due to increased predation, and project operations such as daytime spill that decrease forebay residence time could increase survival.

Tailrace Passage

Spillway tailrace residence time of outmigrating salmonids is likely influenced by spill volume and pattern. High volumes of spill help push water and presumably juvenile salmonids out of the immediate tailrace. This volume and associated water velocity also helps redistribute piscivorous predators such as the northern pikeminnow away from the immediate spillway tailrace, thereby reducing potential predation opportunities (Faler et al. 1988). Shively et al. (1996) found that ambient river flow velocities of at least 1 m/s were necessary to keep northern pikeminnows from holding in areas near bypass outfalls. Effectiveness of water velocity in eliminating northern pikeminnow holding was increased as distance from shore and depth of water increased. Hydraulic cover such as eddies and backwaters that included flow velocities below this threshold were found to be preferred northern pikeminnow feeding locations, particularly if these areas are near primary smolt outmigration paths (Hansel et al. 1993). Spill patterns that facilitate rapid juvenile egress from the spillway stilling basin and through the tailrace are likely to increase juvenile survival. Spill patterns are now developed with emphasis on minimizing hydraulic cover and maintaining high water-velocities near the spillway shorelines. These spill patterns are often employed during nighttime hours only, because it is thought that most juveniles pass the spillways at night, and these nighttime patterns will not interfere with daytime adult passage (COE, 1999d).

The concept of developing spill patterns at FCRPS dams specifically for fish passage was first addressed systematically in the 1960s to facilitate adult salmon passage into the adult fish collection systems. Junge (1967) observed improved adult salmonid passage under intermediate to large spill volumes if four or five gates at each end of the spillway were at low volume settings. At large dams this resulted in a tapered spill pattern near each end and a flat spill pattern across the central portion of the spillway. At smaller dams this produced a “crowned” pattern across the entire spillway tailrace, with the highest discharge in the middle bays. Junge evaluated adult salmon passage success by comparing ladder passage counts associated with various spill patterns. Junge’s spill pattens that appeared best for adult passage conflict with what is thought today to be best for juvenile passage (high shoreline velocities), since under Junge’s adult patterns near-shore velocities are purposefully kept low to allow adults to migrate and move into shoreline oriented entrances.

Spill patterns that attempt to satisfy both adult and juvenile passage criteria during the daytime have been developed for Bonneville and John Day Dams using scale hydraulic physical models at the COE Waterways Experiment Station (WES). The Bonneville and John Day Dam patterns have been implemented and juvenile and adult salmonid responses to these patterns are being evaluated through radiotelemetry studies. At John Day Dam, good juvenile egress through the spillway tailrace with spring and summer migrants was observed with the present spill patterns, and marked fish passed through the first 0.7 km of tailrace in 5 to 10 minutes (Liedtke et al. 1999). This study also indicated slower passage and higher predation on marked fish that passed through end spillbays with the improved spill patterns.

Dissolved Gas Standards

Recommended total dissolved gas standards for surface waterways were developed by the U.S. Environmental Protection Agency under the authority of the 1977 Clean Water Act amendment to the Federal Water Pollution Control Act of 1948. These standards were subsequently adopted by the state environmental quality agencies. Each of the Pacific Northwest states have slightly different statutes. However, in the case of the mainstem Snake and Columbia Rivers, a common standard of 110% total dissolved gas supersaturation (TDGS) was adopted. Each state has provisions for short-term modifications of the standard. In 1994, NMFS first applied for and was granted a special spill program from Washington and Oregon. These modifications allowed total dissolved gas levels up to 115% in the forebay and 120% in the tailrace of each FCRPS dam. The 1995 FCRPS BIOP included these modified standards in the spill program requirement. Since 1994, NMFS has requested and received annual water quality modifications from each state.

In 1997, the state of Washington replaced the dissolved gas standard annual modification with a “fish passage exemption” in the Water Quality Standards for Surface Waters of the State of Washington (Chapter 173-201A-060 (4)(b)), which mandates allowable dissolved gas limits identical to those in the NMFS BIOP, with the addition of a 1-hour maximum of 125%. This exemption specifically states that it is intended for “spillage for fish passage” and is “temporary...to be reviewed in the year 2003.” In qualifying for this exemption, NMFS has met specific annual reporting and monitoring requirements.

Table 1 presents the estimated 1999 spill volumes which result in approximately 120% total dissolved gas at the tailwater gas monitors. At Bonneville Dam, the spill levels are more often limited by the 115% dissolved gas limit established downstream from Bonneville Dam at the Camas-Washougal, Washington gas monitoring station. Spill volumes vary depending on forebay dissolved gas content, powerhouse flow volumes, and spillway tailwater elevations.

Table 1. Estimated spill caps[a].

Project	Spill Caps (kcfs)
Lower Granite	55-65
Little Goose	40-50
Lower Monumental	35-45
Ice Harbor	95-105
McNary	120-135
John Day	110-150
The Dalles	185-200
Bonneville	100-135

[a] Adapted from the COE of Engineers Fast-Track Gas Abatement Program (Rock Peters, COE, Portland District, Pers. commun., 11 May 1999).

Biological Effects of Dissolved Gas Supersaturation

Soon after Bonneville Dam was completed in 1938, dead adult salmon were observed downstream by fishermen (Merrell et al. 1971). Unreconciled losses of adult salmon continued through the 1950s. Gas bubble disease (GBD) was first documented on the Columbia River in the McNary Dam spawning channel by Westgard (1964). Dissolved gas supersaturation was documented and unequivocally associated with spill at mainstem Columbia River dams in the late 1960s by Ebel (1969). By inference, Merrell et al. (1971) attributed earlier observed adult salmon losses to supersaturation. In 1967, run-of-the-river adult and juvenile salmon were observed with GBD and holding tests linked high dissolved gas and increases in temperature with mortality of juveniles (Ebel 1969). Adult salmon mortality was documented in conjunction with high levels of supersaturation (125 to 135%) from Wells to Chief Joseph Dams from 1965 through 1969 (Meekin and Allen 1974). In 1968, when John Day Dam was completed but before turbines were in operation, dead adult chinook and sockeye salmon were found floating downstream and live fish with signs of GBD were captured (Beiningen and Ebel 1970). From 1968 to 1975, GBD in high-flow years contributed to high mortalities of juvenile salmonids migrating from the Snake River (Ebel et al. 1975).

During the late 1960s and early 1970s, a regional task force defined the problem and developed possible remedies for excessive spill, methods to diminish supersaturation, and strategies to ameliorate impacts of dissolved gas supersaturation to salmonids. The methods investigated and implemented that decreased spill and supersaturation were 1) to increase headwater storage to control flow during the spring freshet, 2) to install additional hydroelectric turbines at many dams, and 3) to install flow deflectors ("flip-lips") on spillway ogees at selected dams to reduce plunging and air entrainment of spilled water (Smith 1974). Additionally, various fish releases were made to coincide with decreased flow through the hydro-power system, and river water used in fish holding areas was degassed. As a result of these remedial measures, there was little evidence of GBD in salmonids in the late 1970s and 1980s (Dawley 1986).

Many studies on GBD and its effect on salmonids were conducted in an attempt to define the threat in the mainstem Columbia and Snake Rivers. The severity of GBD was dependent upon species, life stage, body size, level of total dissolved gas, duration of exposure, water temperature, general physical condition of the fish, and swimming depth (Ebel et al. 1975). A thorough review of the literature on dissolved gas supersaturation and of recorded cases of GBD was compiled by Weitkamp and Katz (1980) and updated by Fidler and Miller (1993). Despite numerous studies, there were still questions regarding the total dissolved gas saturation (TDGS) that migrating salmonids can safely tolerate and how to evaluate impacts. In 1994, NMFS and BPA convened a panel of experts to review dissolved gas conditions on the river and assess impacts to salmonids from GBD resulting from voluntary spill (GBD Panel 1996). The panel concluded that not enough was known to accept the hypothesis that aquatic organisms in the Columbia and Snake Rivers were not impacted by dissolved gas from voluntary spill.

GBD Monitoring

Beginning in 1994, waivers for the state standards of 110% TDGS were granted for voluntary spill on the Columbia and Snake Rivers by Oregon Department of Environmental Quality and Washington Department of Ecology. The annual wavers were granted with the stipulations that proper monitoring would be conducted and results of research and monitoring would demonstrate minimal effects from GBD at temporarily increased levels of 115% in reservoirs and 120% in tailraces at dams. A formal plan was developed by NMFS to monitor TDGS and signs of GBD in the aquatic biota (NMFS 1997). Critical uncertainties of the monitoring program were identified (Biological Monitoring Inspection Team 1995), gas bubble disease research priorities were developed (NMFS 1996), and thresholds of 15% prevalence and 5% severe GBD signs were set for continued voluntary spill.

Through the 1990s, TDGS monitoring improved. By 1998, timely data distribution by COE included hourly dissolved gas levels and water temperatures from 41 monitoring sites in forebays and tailraces on the mainstem Columbia and Snake Rivers (COE 1998b). Quality assurance and control measures and improved gas measurement technology increased data precision and provided confidence that fisheries management decisions regarding the threat from TDGS were based on sound data. However, concerns still exist over whether the monitoring sites appropriately represent all conditions experienced by salmonids according to the Independent

Science Advisory Board (ISAB 1999). Additionally, intensive monitoring throughout reservoirs and in tailraces has allowed a series of models to be developed that relate tailwater TDGS to spill, total project release, and forebay TDG for all mainstem dams from Grand Coulee and Lower Granite to Bonneville Dams, as well as from Dworshak Dam (COE 1998a).

Through the 1990s, GBD monitoring of migrating juvenile and adult salmonids was also greatly improved. Numbers of fish, methods, locations, and times for sampling were adjusted to provide a representative network of samples. Quality assurance and control methods met regional requirements, thus providing confidence that fisheries management decisions were based on the best possible data given the present state of technology.

Uncertainties associated with the GBD monitoring are: 1) whether the relationship between smolt/adult mortality and gas bubbles in fins, gills, and lateral line is known, 2) whether clinical signs change during collection and examination, 3) whether signs in sampled fish represent the river site over the entire 24-hour period, 4) whether samples are taken at representative locations, including those of high risk from GBD, 5) whether sample size is statistically adequate for required confidence limits, 6) whether key signs of GBD and their relative significance are known, and 7) whether the 15% threshold level for GBD prevalence can be tolerated by the juvenile migrant population. Research conducted to address these uncertainties suggests:

The relationship between prevalence and severity of GBD signs and mortality of juvenile salmonids is unresolved. Research has produced an equivocal relationship except at consistent 130% TDGS (Mesa et al. in press).

1) Fish samples collected for GBD assessment of smolt monitoring facilities at Snake and Columbia River dams adequately represented fish passing through the smolt bypass systems (NMFS 1999b).

2) Smolt monitoring sites appeared to provide samples that were generally representative of upstream and downstream locations.

3) Evaluation of sample statistics by Maule et al. (1997) showed that numbers of sampled fish were generally sufficient to document a species-specific GBD prevalence when impacted migrants reached the NMFS threshold of 15% prevalence or 5% severe signs of GBD. An exception is at McNary Dam where migrants from the Snake River cannot be differentiated from Columbia River migrants. Here, a low prevalence in the total sample could be associated with a large prevalence within the Snake River subpopulation. However, at dissolved gas levels present during voluntary spill, this problem is insignificant.

4) The GBD signs utilized as a GBD index for smolt monitoring are externally visible

subcutaneous emphysema. Research to identify other indicators of GBD such as blood chemistry changes was not pursued. Acoustic assessment of internal gas emboli was determined too expensive and not suitable for use in field locations (Carlson 1995). Excision of gill lamella was investigated, but thought to be no better an index of GBD impacts than other less invasive methods.

5) Signs of GBD can only be utilized as a subjective tool. The GBD Panel (1996) stated that when GBD signs are observed in any fish, there should be regional concern about survival. Also, the greater the prevalence and severity of GBD signs the more concerned managers should be about fish survival.

Recent Impacts of GBD on Migrating Smolts

Results of GBD monitoring and research on juvenile salmonids in the 1990s show that incidents of high prevalence and severity of GBD signs and probable related mortality are associated with exceptionally high river flows and/or exceptional dam operation problems where powerhouse flows were limited. In 1990, a fire at John Day Dam caused 100% spill for an extended period, resulting in downstream TDGS levels greater than 130% and GBD prevalence up to 74% in steelhead and 38% in coho salmon. In 1993, turbine outages at Lower Granite Dam caused TDGS to increase, resulting in 18% prevalence of GBD in migrants at Little Goose Dam. In 1995 and 1996, turbine outages at Ice Harbor Dam coupled with high river flows caused TDGS exceeding 130% during the spring freshet. PIT-tag interrogation data collected at Snake and Columbia River dams suggested losses of juvenile chinook salmon coincident with the high levels of TDGS in the 67-km reach from Lower Monumental Dam to the Snake River mouth in 1995 (Cramer 1996a) and 1996 (Cramer 1996b, NMFS 1997). However, no losses of steelhead were measured in that same river reach for fish that prior to release at Little Goose Dam had been experimentally exposed to supersaturation sufficient to produce low-grade mortality (Monk et al. 1997a). Resident fish downstream from Ice Harbor Dam also showed high prevalence and severity of GBD signs in 1995 and 1996 (Schrank et al. 1997, 1998).

High river flows in 1996 and 1997 caused excessive spill at all mainstem dams, and TDGS exceeded 120% (the maximum allowed for voluntary spill) for extended periods throughout most of the lower Snake River and mid- and lower-Columbia River. Results of GBD monitoring showed that prevalence of subcutaneous emphysema in juvenile salmonids was minor when TDGS was 120 to 125%, but was generally 10% or greater when TDGS was higher than 125% (NMFS 1998a).

In the early 1990s, river flow was low and often within powerhouse hydraulic capacities. When there was sufficient market for power, voluntary spill for fish passage and TDGS at 120% in tailraces and 115% in forebays could be regulated. Effects of GBD under these conditions appeared benign, signs were minimal or non-existent, and there was no apparent GBD related mortality (Maule et al. 1997, ISAB 1999). Even during periods of involuntary spill, GBD impacts appeared to be minor, except when TDGS was over 120% (NMFS 1997, 1998a, 1999b).

Impacts of GBD as measured by visual external signs in river migrants are greater at higher temperatures, particularly when the ambient water temperature of supersaturated water increases (Ebel 1969, Ebel et al. 1971). Steelhead have a lower tolerance to TDGS than other species based on Smolt Monitoring Program data (NMFS 1997, 1998a, and 1999b) and laboratory tests (Fidler and Miller 1993).

Dissolved Gas Abatement

Starting in 1994, a COE Dissolved Gas Abatement Study developed concepts for decreasing TDGS at the eight Snake and Columbia River dams. The COE is pursuing numerous potential structural modifications to spillways and stilling basins for dissolved gas abatement alternatives. While some of these alternatives may be implemented in the future, only flow deflectors have been implemented to date to reduce gas production at the FCRPS projects. None of the gas reduction alternatives evaluated met biological, operational, and economic criteria, nor did they decrease gas levels to the 110% water quality standard for the 7-day 10-year discharge events. Whitney et al. (1997) found that under appropriate operating conditions, flow deflectors generally lowered dissolved gas levels downstream from the projects by 10 to 20% for a given spill flow. Deflectors installed recently at Ice Harbor and John Day Dams have provided gas abatement benefits in the upper portion of this range.

JUVENILE PASSAGE THROUGH MECHANICAL SCREEN BYPASS SYSTEMS

Description of Systems

Two submersible fish screen designs are used at Columbia River hydroelectric dams to guide fish away from turbine intakes and into juvenile bypass systems: a submersible traveling screen (STS) and an extended submersible bar screen (ESBS). On STSs a monofilament mesh screen rotates around two large rollers at the top and bottom of the screen. Flow passing through the screen flushes the mesh surface clean of debris. STSs are currently installed at Lower Monumental, Ice Harbor, John Day, and Bonneville Dams. The ESBSs are made of a fixed wedgewire screen material, and have a bar sweep that is turned on periodically to brush debris from the face of the screen. ESBSs are currently installed at Lower Granite, Little Goose, and McNary Dams. The Dalles Dam does not have a mechanical screen juvenile bypass system.

The STSs or ESBSs guide migrating juvenile salmonids from the turbine intake into gatewells. Fish exit the turbine intake gatewells through orifices and enter a collection channel that travels the length of the powerhouse. The collection channel conveys fish and orifice flow from all of the gatewells to dewatering facilities, which reduce channel flow to approximately 30 cfs. Transportation flumes transport fish and the 30 cfs flow to a tailrace bypass outfall, or transportation barge or truck. Smolt monitoring facilities installed at key bypass systems allow fish condition and species composition to be evaluated, and passage indices to be estimated. PIT-tagged fish can be detected at these facilities, time and date of passage noted, and the fish diverted for further evaluation, if required.

Mechanical screen bypass system design criteria are described in NMFS Juvenile Fish Screen Criteria (NMFS 1995b), COE bypass system design memorandums (COE 1995a, 1996a, 1999a), the COE Fish Passage Plan (COE 1999d), and an intake design guidelines manual (ASCE 1995). NMFS guidelines for locating and designing bypass outfalls are presented in NMFS 1995b. NMFS design criteria for smolt monitoring facilities are presented in Appendix B.

Fish Guidance Efficiency (FGE)

Fish guidance efficiency (FGE) is a measure of how efficiently turbine intake screens guide juvenile salmonids out of turbine intakes. FGE for each species is calculated as gatewell catch (guided fish) divided by the total number of fish (guided plus unguided) passing through the turbine intake during the test period (Brege et al. 1992). The most common method used to sample unguided juvenile salmonids uses fyke-net frames installed in the turbine intake. Gatewell dip-netting provides the number of guided fish (Swan et al. 1979). Gatewell dip-net recapture efficiency tests with yearling and subyearling chinook salmon have resulted in recapture efficiencies of 95 to 100% (McComas et al. 1994, Brege et al. 1997a,b, 1998).

Early FGE studies utilized fyke nets attached to a frame beneath the STS to collect unguided fish (Krcma et al. 1986). Beginning in 1993, a more streamlined fyke-net frame and newly designed nets were used to reduce the effects on flow through the test unit (Brege et al. 1994). Unlike the fyke-net frame used to tests STSs, this frame is placed in the downstream slot to estimate FGE with the ESBSs. The newly designed fyke nets and frame placement in the downstream slot minimize water resistance and possible effects on FGE. Tests by NMFS suggest that STS FGE may have been biased upward by the fyke-net position, which may have created a pressure field that enhanced yearling chinook salmon guidance into the gatewell when the fyke net was located beneath the STS (Williams et al. 1996).

PATH (1998) developed a correction factor to adjust STS FGE estimates for fyke-net position to improve the accuracy of the PATH retrospective model analysis for yearling chinook salmon. The correction factor was the ratio of FGEs derived at McNary Dam with the nets in the downstream slot compared to the upstream slot (i.e., directly beneath the STS). McNary Dam has a large, low velocity intake compared to most other powerhouse intakes. The application of the FGE correction factor for yearling chinook salmon at McNary Dam to all other intakes may or may not be a valid adjustment. Monk et al. (1999a) acknowledged the PATH FGE adjustment but chose not to apply it to the data for Bonneville Second Powerhouse. In their view, the intakes at McNary Dam and Bonneville Second Powerhouse are so hydraulically different that the correction factor was not considered applicable to ESBS FGE at Bonneville Second Powerhouse, nor would the correction have affected the conclusions of their analysis.

Guidance screens are deployed and operated from late March through late fall or early winter, depending on the project (COE 1999d). To obtain sufficient sample sizes, fyke-net FGE evaluations are designed to target specific species or life histories during the main portion of the outmigration period. They are conducted during the evening hours when passage rates are highest, typically from 2000 to 2200 hours, and therefore subsample the outmigration. Fyke-net FGE studies usually target yearling and subyearling chinook salmon, and steelhead. Incidental catches of sockeye and coho salmon are reported if numbers captured during the test are statistically meaningful. Also, they are average values for the population, which is a mixture of wild and hatchery fish.

More recently, FGE estimates have been obtained from the probability of detecting PIT-tagged fish (Smith 1997, Kransow 1998, Anderson et al. 1998), radiotelemetry, and hydroaoustics. Differences exist among the FGE estimates derived from these methodologies, and each method has associated sampling strengths, weaknesses, and critical assumptions. For example, when using the probability of detecting PIT-tagged fish to estimate FGE, the results are most reliable in cases where all groups of tagged fish pass during periods of near 0% spill. Where all groups pass during periods of relatively high spill, the method gives less reliable results, which are dependent on the questionable assumption that spill index and detection probability have the same linear relationship throughout the range of observed spill values (Smith 1997).

Describing a single point estimate of FGE for each dam and species is difficult due to the high degree of uncertainty associated with the FGE methods and estimates. FGE varies with location (dam, powerhouse, and unit), time (within and between years, day versus night), species, rearing type, and environmental factors (temperature, flow, turbidity). This spatial and temporal variability is likely related to complex interactions between biological and physical factors. Williams et al. (1996) attempted to clarify some of the mechanisms affecting FGE; however, the FGE database is generally limited to studies designed to compare FGE under different test (hydraulic) conditions, and little could be concluded. Factors such as water temperature, turbidity, flow, photoperiod, physiological development, and predation by northern pikeminnow may affect FGE (Gessel et al. 1991).

Nonetheless, single-point estimates of FGE are estimated and used. For example, Anderson et al. (1998) derive several correction factors for yearling chinook salmon, including fyke-net position, screen type (STS and ESBS), operating gate position, and wild versus hatchery fish, to develop retrospective FGE values for PATH passage modeling. Krasnow (1998) builds upon the Anderson et al. (1998) report and provides estimates of FGE for yearling and subyearling chinook salmon and steelhead for all FCRPS dams, by year, and provides two sensitivity analyses based on whether FGE with ESBSs is greater than with STSs. NMFS has developed a "SIMPAS" spreadsheet model that uses various passage input parameters such as FGE to evaluate benefits to fish survival associated with various FCRPS configuration and operations alternatives. The FGE values used in SIMPAS differ slightly from Krasnow (1998).

No single point estimates for FGE for each species and dam are universally accepted. The FGE values presented in Table 2 are the values commonly used by PATH (Anderson et al. 1998) for their retrospective analysis for yearling chinook salmon, and NMFS (Krasnow 1998). These estimates likely represent FGE values that exist for each species and project at some periods during the outmigration. However, due to differences in the sampling and derivation methods used, and the inherent variability in FGE due to the factors stated above, these point estimates may not represent precise or accurate estimates of actual FGE over the entire outmigration.

Despite the caveats discussed above regarding variability, some general trends in FGE have been observed. Side-by-side fyke-net estimates of FGE with STSs and ESBSs generally indicate that FGE is statistically significantly higher with ESBSs (McComas et al. 1993, Brege et al. 1994). FGE for yearling chinook salmon at Lower Granite Dam generally increases over time from the beginning to the end of the migration season (Swan et al. 1990). A correlation was found between increased FGE and the level of smolt development exhibited by the migrant population (Giorgi et al. 1988). With subyearling chinook salmon an opposite trend occurs; FGE generally decreases as the season progresses (Brege et al. 1988, Monk et al. 1999a). In the lower Columbia River, coho salmon FGE is generally high and similar to steelhead, and sockeye FGE is generally lower than that of yearling chinook salmon. In addition, increases in FGE have been produced by a variety of adaptations to the basic STS, including extending the length of the screen from 20 to 40 feet (STS versus ESBS), raising the operating gate, lowering fish screens to open the throat area, and the use of an inlet flow vane with ESBSs to straighten flow up the gatewells.

Table 2. Fish guidance efficiency (FGE) at Columbia and Snake River dams for 1999 configuration.[d]

Site (Screen type)	Species	PATH FGE (%)	NMFS FGE (%)[b]
Lower Granite Dam (ESBS)	Yearling chinook	78	78
	Subyearling chinook	-	53
	Steelhead	-	81
Little Goose Dam (ESBS)	Yearling chinook	82	82
	Subyearling chinook	-	45
	Steelhead	-	81
Lower Monumental Dam (STS)			
	Yearling chinook	61	61
	Subyearling chinook	-	49
	Steelhead	-	82
Ice Harbor Dam (STS)	Yearling chinook	71	71
	Subyearling chinook	-	46
	Steelhead	-	93
McNary Dam (ESBS)	Yearling chinook	95	95
	Subyearling chinook	-	62
	Steelhead	-	89
John Day Dam (STS)	Yearling chinook	67	64
	Subyearling chinook	-	34
	Steelhead	-	85
The Dalles Dam (None)[c]	Yearling chinook	46	46
	Subyearling chinook	-	46
	Steelhead	-	40
Bonneville Dam			
Powerhouse One (STS)			
	Yearling chinook	41	38
	Subyearling chinook	-	16
	Steelhead	-	41
Powerhouse Two (STS)			
	Yearling chinook	43	44
	Subyearling chinook	-	18
	Steelhead	-	48

a) Based on report to PATH from Anderson et al. (1998).
b) Based on NMFS sensitivity run #1 (assumes FGE_{ESBS}>FGE_{STS} for wild yearling chinook salmon).
c) FGE values for The Dalles are based on passage through the ice and trash sluiceway.
d) These estimates likely have range, but that range changes with a number of factors and is not easily estimated.

Orifice Passage Efficiency

Orifice passage efficiency (OPE) is the percentage of guided juvenile salmonids which exit the gatewell via the orifice in a given time period (usually 24 hours). The most recent estimates of OPE conducted at Lower Granite, Little Goose, McNary, and John Day Dams and at Bonneville First Powerhouse have been conducted by releasing either fin-clipped or PIT-tagged fish into the gatewell with the orifice open. With the fin-clipped fish, after 24 hours, any remaining fin-clipped fish are removed from the gatewell and counted. The percent that left the gatewell in 24 h is the percent OPE. With the PIT-tagged fish, the number exiting the gatewell is recorded by PIT-tag detectors in the bypass system.

The regional accepted minimum level for OPE with STSs installed is 70%. However, because of the increased flows and higher turbulence in the gatewell associated with ESBSs, OPE levels approaching 90% are probably more appropriate for gatewells with ESBSs. At Columbia and Snake River dams where OPE has been estimated, either with ESBSs or STSs in place, estimates have generally been greater than 70% for yearling and subyearling chinook salmon and steelhead, with the exception of McNary Dam which had lower OPE estimates with ESBSs with much greater variability (Brege et al. 1998) (Table 3). Evaluations of OPE for coho and sockeye have not been conducted.

Table 3. Most recent orifice passage efficiency (OPE) estimates for existing conditions (and prototype testing) at Snake and Columbia River Dams.

Project	Species	OPE[a] (%)	Reference
Lower Granite	Yr. Chinook	95	Monk et al. 1997b
ESBS, 25-cm orifice	Steelhead	97	
Little Goose	Yr. Chinook	97	Gessel et al. 1996
ESBS, 25-cm orifice			
Lower Monumental[a]	Yr. Chinook	88	Gessel et al. 1993
STS, 30-cm orifice	Steelhead	66	
Mc Nary	Yr. Chinook	69	Brege et al. 1998
ESBS, 30-cm orifice	Subyr. Chinook	79	
John Day	Yr. Chinook	81	Brege et al. 1997a
Existing STS, 35-cm orifice	Subyr. Chinook	98	
John Day	Yr. Chinook	99	Brege et al. 1997a
Prototype ESBS, 35-cm orifice	Subyr. Chinook	97	
Bonneville Dam 1st Powerhouse	Yr. Chinook	80	Monk et al. 1999b
Existing STS, 30-cm orifice	Subyr. Chinook	98	
Bonneville Dam 1st Powerhouse	Yr. Chinook	90	Monk et al. 1999b
Prototype ESBS, 30-cm orifice	Subyr. Chinook	97	
Bonneville Dam 2nd Powerhouse[a]	Subyr. Chinook	86	Krcma et al. 1984
Existing STS, 30-cm orifice			

[a] All estimates (except Lower Monumental) done with releases of fin-clipped fish; Lower Granite estimates are results of PIT-tagged and fin-clipped releases averaged together.
[b] Estimates made by comparing ratios of numbers of fish in adjacent gatewells with orifices closed and open.
[c] Estimates made using orifice trap.

Separator Efficiency

Separation of outmigrant juvenile salmonids by size is an integral part of the juvenile bypass programs at FCRPS dams. Separators sort fish using an array of suitably spaced bars oriented parallel to flow through a tank, allowing smaller fish to pass between the bars while excluding the larger fish. The strategy for using bars for separation falls into two categories, single- and two-stage, depending on the objective of the process. The Dalles Dam has no juvenile fish bypass system or separator.

Single-stage separators are used at Ice Harbor and John Day Dams and at both Bonneville Dam powerhouses, where the primary purpose of separation is to monitor the condition of juvenile salmon and steelhead passing through the project bypass system. These units remove adult salmonids and large incidental species using "dry" separation in which smaller fish (mostly salmonid smolts) simply fall between the bars along with incident flows, while large animals are carried across the bars for eventual return to the river. Smolts can then be sampled without concern for injury induced by larger animals in the sample holding area. At John Day Dam, the separation bars are wetted by small low-pressure jets along their upper surface to facilitate fish movement along the bars. Following separation and sampling, facilities using single-stage separators bypass fish to the river downstream from the dam.

Two-stage separators used at McNary, Lower Monumental, and Little Goose Dams are intended to separate smolts into large and small size-classes, as well as removing adult salmonids and large incidentals, prior to collection for transport using either barges or trucks. Size separation also allows selective bypass or transport of one or both smolt size-classes.

The separators at these three sites rely on 'wet' separation by keeping the fish submerged throughout the process. Each unit consists of three consecutive chambers (McComas et al. 1998). The first two chambers have separation-bar arrays with bars spaced approximately 19 mm (0.75 in) and 32 mm apart in the upstream and center chambers, respectively. Individual bars are 32-mm aluminum tubing. In both compartments, the arrays are submerged and have a slight positive slope, so that water depth over the array at the upstream end of each chamber is approximately 50 mm (2 in) deeper than at the downstream end. The most downstream chamber is a simple box with no separation-bar array.

Wet separators depend on sounding behavior, as an avoidance response to shallow conditions above the separation bars, to achieve separation (Gessel et al. 1985). All fish are introduced to the upstream compartment along with about 0.06 m^3/s flow from the bypass channel (Katz 1999). The smaller fish are filtered between bars in the upstream compartment, while larger smolts are removed in the second section. Large incidentals and adults pass through the unit to the third compartment for return to the river.

By keeping the animals submerged, wet separation is considered less stressful to fish. However, separation efficiency of operational wet separators is usually less than 70% for small fish, and varies considerably from year to year (Table 4). In addition, recent behavior and physiology studies have indicated that fish hold under the bars for extended periods rather than exit expeditiously from the wet separator unit (James L. Congleton, Idaho Cooperative Fish and Wildlife Research Unit, Department of Fish and Wildlife, University of Idaho, Moscow, Idaho 83844-1141, Pers. commun., 21 March 95). This suggests that many fish exit only after they are fatigued as a result of swimming to avoid hydraulic conditions within the unit.

Table 4. Annual separation efficiency (%) by species for outmigrant salmonid smolts using operational two-stage wet separators at hydroelectric dams on the Columbia and Lower Snake Rivers, 1994 - 1998.

Juvenile fish bypass facility	Species	Annual separation efficiency (%)					Reference
		1994	1995	1996	1997	1998	
McNary Dam	yearling chinook salmon	35.5	52.8	36.8	39.3	41.4	Hurson et al. 1999
	subyearling chinook salmon	48.7	58.1	46.3	56.9	49.8	
	steelhead, hatchery	96.1	84.6	88.1	75.5	84.1	
	steelhead, wild	80.3	55.1	67.0	59.1	62.8	
	sockeye salmon	27.4	35.1	22.7	34.5	26.7	
	coho salmon	24.3	20.6	25.6	38.1	22.9	
Lower Monumental Dam	yearling chinook salmon, hatchery	65.6	61.6	42.2	63.9	50.9	Spurgeon et al. 1998
	yearling chinook salmon, wild	57.5	56.1	38.7	49.5	39.2	
	subyearling chinook salmon	31.3	17.8	18.8	22.2	15.7	
	steelhead, hatchery	65.1	65.2	66.2	55.6	72.7	
	steelhead, wild	40.0	27.4	45.8	34.7	50.1	
	sockeye salmon, hatchery	- [a]	4.6	10.8	11.1	15.1	
	sockeye salmon, wild	24.4	19.4	21.9	24.9	7.1	
Little Goose Dam	yearling chinook salmon, hatchery	47.6	60.3	70.9	60.0	64.8	Baxter et al. 1999
	yearling chinook salmon, wild	44.1	57.0	74.6	59.8	64.5	
	subyearling chinook salmon, hatchery	- [b]	-	-	17.6	47.1	
	subyearling chinook salmon, wild	29.2	8.4	34.2	18.8	45.3	
	steelhead, hatchery	91.4	87.8	69.2	75.3	85.2	
	steelhead, wild	70.5	52.4	50.1	50.9	55.3	
	sockeye salmon, hatchery	- [a]	4.8	211	32.0	40.0	
	sockeye salmon, wild	16.0	30.0	44.2	60.0	21.8	

[a] Hatchery sockeye not present prior to 1995.

[b] Hatchery subyearling chinook salmon without PIT tags were not present until 1997.

The separator at Lower Granite Dam is unique, in that a single-stage wet separation process is employed to segregate large incidental and adult salmonids from smaller fish. Presently, smolts are not separated by size. This system is scheduled for modification when with the entire Lower Granite Dam juvenile fish bypass facility is upgraded after the year 2000.

A research program was initiated in 1996 to evaluate potential improvements to existing wet separators, and to develop new separator concepts (Katz 1999, McComas et al. 1998). Studies of separator bar length, slope, water velocity and bar spacing have produced improvements in separator efficiency and fish condition, as well as a high-velocity flume concept (Lynn McComas, NMFS, Pers. commun., September 1999). Work is ongoing to complete the development of these new design criteria and separation concepts.

Diel Passage and Timing

Starting in the late 1960s, sampling in gatewells at powerhouses of Columbia and Snake River dams has consistently shown that the majority of smolts pass through the powerhouses at night (Long 1968, Sims and Ossiander 1981, Brege et al. 1996). Since then, hydroacoustic investigations (Johnson and Dauble 1995; BioSonics Inc. 1996, 1998; Ploskey et al. 1998) and radiotelemetry data (Vendetti and Kraut 1999) at many dams confirmed this was a consistent pattern, and provided more detail regarding specific hours of peak passage. These studies have also shown that peak hours of passage change with different routes of passage. Passage at sluiceways at Bonneville and The Dalles Dams generally peaks in early morning hours. Diel passage information for spillways is more cursory and not as consistent, paralleling powerhouse patterns at some dams, but showing high daytime passage and morning peaks at others.

Lower Granite Dam

Since 1996, both radiotelemetry and hydroacoustic studies have been conducted in the forebay of Lower Granite Dam to assess fish behavior and efficiency of a surface bypass collector (SBC) in front of turbine Units 4, 5, and 6. Johnson et al. (1998) found that fish passage into the SBC and spillway was higher during day hours than night hours. However, passage at the powerhouse pier nose and inside the turbine intake was reversed (Fig. 2). In 1999, spill was on from 1800 to 0600 and highest peak spillway passage occurred at 2300 hours. However, the diel distributions of fish passage were similar for the SBC and turbines, with peak passage occurring between 0600 and 1700 hours (Anglea 1999) (Fig. 3).

Studies by Adams et al. (1997, 1998) have tracked radio-tagged spring chinook salmon as they approached the SBC. In 1998, 66 to 78% of all radio-tagged fish entered the fish bypass (via the turbine intakes) between 1900 and 0600 hours. With the exception of juvenile hatchery spring chinook salmon, most fish also entered the SBC during early evening and nighttime hours. Seventy-six percent of wild steelhead and wild fall chinook salmon, and 80% of hatchery steelhead entered the SBC between 1900 and 0600 hours.

INSERT FOR FIGS. 2 AND 3.

Little Goose Dam

In 3 years of research by Vendetti and Kraut (1999), passage of radio-tagged juvenile fall chinook through the powerhouse at Little Goose Dam showed a slightly different diel pattern for passage (Fig. 4). Peaks in the number of detections were observed between 0500 and 0600 hours, and again in the evening between 1800 and 2000 hours, with the evening peak being the larger and longer of the two.

Lower Monumental Dam

To assess the downstream migrational patterns of smolts passing the dam and to estimate the effectiveness of spill in passing migrants, hydroacoustic investigations were conducted at Lower Monumental Dam from 1986 to 1989 (Wright et al. 1986, Ransom and McFaden 1987, McFaden 1988, Ransom and Sullivan 1989). As at other dams, turbine passage rates were highest during nighttime, with a peak at 2300 hours. During the 4 years of study, nighttime project passage (powerhouse and spill) ranged from 70 to 84%.

Spillway operation varied over the 4 years of tests. In 1986, spill varied from just nighttime spill (1800 to 0600 hours) to a constant 24-hour spill. Examination of diel passage during these different flow regimes suggested that both fish behavior and dam operations influenced the timing of spillway passage. During a period when spill was relatively constant throughout the day, a pronounced peak in passage occurred at 2200 hours. However, this evening peak was enhanced during periods when spill was off during daylight hours and started at 1800 hours. In studies from 1987 to 1989, the spillway was only operated from 1800 to 0600 hours and highest passage rates occurred at 2300 hours and declined steadily from 2300 to 0600 hours.

Ice Harbor Dam

Three years of hydroacoustic investigations at Ice Harbor Dam revealed diel passage patterns similar to other Columbia and Snake River dams (Johnson et al. 1983, Ransom and Ouellette 1988). Most migrants passed the dam at 2300 hours. Sluiceway diel passage rates were highest from 0600 to1300 hours. Turbine passage rates were highest from 2100 to 0600 hours.

During all 3 years of study, hourly passage rates through the spillway were more variable than through the turbine units or sluiceway. Generally, passage rates were low in the early morning and then increased steadily to a peak at 1200 hours. The rate then declined rapidly, reaching a low point at 1700 hours, followed by a secondary peak at 2100 hours (only slightly lower than the 1200 hour peak).

John Day Dam

As part of a smolt program, NMFS has reported diel passage patterns of juvenile salmonids passing John Day Dam since the 1970s. This sampling, done mainly in gatewell Slots 3A and 3B, has shown that all species of juvenile salmonids tend to pass through the John Day powerhouse during hours of darkness (Brege et al. 1996). In more recent years, further observations by the Smolt Monitoring Program have confirmed predominant passage from 1800 to 0600 hours (Martinson et al. 1998) (Table 5).

INSERT FIG 4.

Table 5. Percent night passage (1800-0600 hours) for each season at John Day Dam, 1985 to 1997 (Martinson et al. 1998).

Year	Yearling chinook	Subyearling chinook	Wild steelhead	Hatchery steelhead	Coho	Sockeye
1985	83.2	83.7	N/A	N/A	91.0	86.8
1986	75.5	80.1	N/A	N/A	95.9	81.9
1987	84.5	85.4	93.6	85.6	95.0	94.9
1988	80.0	80.7	80.8	70.3	83.9	87.1
1989	86.4	86.2	73.6	79.4	93.0	79.0
1990	79.7	84.4	76.3	94.8	95.6	85.0
1991	89.9	77.0	91.0	92.3	96.2	83.6
1992	82.8	78.7	95.3	91.5	96.0	94.9
1993	83.3	87.8	83.4	80.7	95.1	86.5
1994	80.9	68.1	91.6	81.4	92.2	94.5
1995	80.7	79.7	87.9	75.8	91.5	79.5
1996	68.6	70.0	81.6	74.7	80.2	65.6
1997	62.6	73.1	67.0	70.6	73.7	59.6
AVERAGE	79.8	79.6	83.8	81.5	90.7	83.0
MIN	62.6	68.1	67.0	70.3	73.7	59.6
MAX	89.9	87.8	95.3	94.8	96.2	94.9

Giorgi and Stevenson (1995) reviewed all gatewell sampling, hydroacoustic, and radiotelemetry data from 1980 to 1989 and concluded that, even though none of the reviewed reports offered robust estimates of the diel passage estimates, the consistent agreement among all evaluation tools and across so many years indicated that smolts at John Day Dam exhibit a strong tendency to sound and pass through deep passage entrances during nighttime hours. Both the hydroacoustic and radiotelemetry data corroborated the gatewell sampling and also showed that timing of spillway passage through the deep spill intakes (47 to 58 ft below normal operating pool) paralleled powerhouse passage.

The Dalles Dam

Diel passage through the powerhouse at The Dalles Dam is similar to the pattern seen at other Columbia and Snake River dams. Both gatewell dipping (Long 1968) and hydroacoustics (Magne et al. 1983, Steig and Johnson 1986, Johnson et al. 1987, BioSonics Inc. 1996) documented that the majority of all salmonids entered gatewells between 1900 and 0700 hours. In studies conducted by BioSonics Inc. (1996), both spring and summer migrants exhibited peak passage during hours of darkness (Figs. 5 and 6).

As with Bonneville Dam, diel passage through the sluiceway does not seem to follow the nighttime passage patterns. Early studies by Nichols (1979) and Nichols and Ransom (1980, 1981) reported that sluiceway passage peaked during daylight hours, typically around mid-day. More recent hydroacoustic studies have also found that average daylight passage through the sluiceway was the predominant pattern at The Dalles in the spring (Fig. 5). During the summer period, passage rates through the sluiceway also showed low night passage, but the peak was during the afternoon rather than morning (Fig. 6). After reviewing all available literature, Giorgi and Stevenson (1995) concluded that regardless of the sampling approach employed, during the spring, juvenile salmonids pass via the sluiceway at The Dalles Dam through most of the 24 hour period with peak passage during daylight hours.

There are few measures of diel passage at The Dalles Dam spillway, because in most of the studies conducted there, spill was only provided at night and did not span a 24-hour period. However, in studies conducted in 1996 by BioSonics Inc. (1996), spill levels were maintained for 24-hour periods and slightly higher morning passage rates via spill were found during the spring (Fig. 5). This morning peak was even more pronounced during the summer migration (Fig. 6).

Bonneville Dam

Passage patterns at Bonneville Dam are more complex, because there are three separate structures, two powerhouses, and an unattached spillway. There are also two passage routes at each powerhouse; the turbines and ice/trash sluiceway. For this reason, the available information is provided separately for each powerhouse and the spillway.

First Powerhouse--From 1992 to 1995, the Smolt Monitoring Program sampled juvenile migrants moving through the downstream migrant channel on a 24-hour basis (Martinson et al. 1999). During this time, passage for all species increased at dusk, at about 2000 hours, and peaked at 2200 hours (Table 6). Since 1995, the Smolt Monitoring Program has sampled for 8 hours per day only (from 1600 to 2400 hours) and has reported the typical dusk peak in turbine passage observed at Snake River and lower Columbia River dams (Martinson et al. 1996, 1997, 1998).

FIG 5

FIG 6

Table 6. Percent night passage (1800-0600 hours) for 1992 to 1995 at Bonneville Dam First Powerhouse (Martinson et al. 1999).

Year	Yearling chinook	Subyearling chinook	Wild steelhead	Hatchery steelhead	Coho	Sockeye
1995	52.8	65.8	68.3	62.9	70.7	56.2
1994	49.6	52.4	52.2	53.1	66.7	74.6
1993	43.2	56.2	67.1	62.4	68.1	63.6
1992	52.0	44.0	62.3	61.3	60.0	69.0
MEDIAN	50.8	54.3	64.7	61.9	67.4	66.3
MIN	43.2	44.0	52.2	53.1	60.0	56.2
MAX	52.8	65.8	68.3	62.9	70.7	74.6

In 1998, Martinson et al. (1999) observed that the 8-hour passage patterns of tule and bright stocks of subyearling chinook salmon followed the same general pattern as spring migrants with only slight differences (Figs. 7 and 8). Increases in tule passage began earlier, at about 1800 hours, had a smaller peak at 2200 hours, then averaged a lower percent of total passage for the remaining hours. Upriver bright passage resembled the spring migrants, with a larger, more abrupt increase at 2200 hours and a gradual decline in passage thereafter.

Hydroacoustic data from Ploskey et al. (1998) also showed that mean hourly smolt passage into turbines at the First Powerhouse was higher during night hours than during day hours in 1996 and 1997. The data were more variable in spring than in summer. Ploskey et al. (1998) also observed that diel passage through the sluiceway at the First Powerhouse varied from turbine passage. During both the spring and summer smolt migrations, the majority of passage through the sluiceway occurred during the early morning hours with a peak at approximately 0300 hours. Passage was reduced during daytime hours, with a secondary peak shortly after sunset.

Second Powerhouse--The patterns of diel variation in fish passage rates during the spring migration, seen at the First Powerhouse, do not seem to be as strong or consistent at the Second Powerhouse . Studies by BioSonics Inc.(1998) showed little diel variation at Unit 11A (both guided and nonguided) with no peak at dusk. Spring studies by Ploskey et al. (1998) showed a nighttime peak for a couple of treatment days, but the majority of days had highly variable data, with no consistent pattern.

During summer migration studies by BioSonics Inc. (1998), subyearling chinook salmon exhibited a minor diel variation in Unit 11A with highest fish passage between 2100 and 2200 hours. However, Ploskey et al. (1998) observed a pronounced nighttime peak from 2200 to 2300 during summer smolt passage through the turbines at the Second Powerhouse.

Similar to the First Powerhouse, spring time fish passage through the sluice chute at the Second Powerhouse occurred during early daytime, between 0600 and 1300 hours (BioSonics Inc. 1998). A second smaller increase in passage rates was observed between 1800 and 2100 hours. During the summer migration, the peak passage rates through the sluice chute occurred between 0600 and 1800 hours. The hours of lowest passage through the sluice chute were from 2100 to 2200 hours, coinciding with the hours of highest fish passage of guided fish into Unit 11A.

Spillway--A limited amount of hydroacoustic data is available pertaining to diel timing of juvenile salmonids through the spillway. BioSonics Inc. (1998) found that fish passage rates were higher during nighttime at the spillway in the spring. These results were not adjusted for changes in spill levels; however, because of high river flows, spillway discharges showed little variation during the spring. During the summer, fish passage rates were also highest at night at the spillway; however, this was in part due to spillway operations, when Spillbay 5 (with transducer) was typically closed between 0500 to 2200 hours.

fig 7&8

Water Temperature Effects

The state water quality standard for water temperatures on the Snake and Columbia Rivers calls for temperature to not exceed 68°F. The upper incipient lethal water temperature for salmonids is defined as 77°F (Coutant 1999). Water temperature data are collected daily at mainstem Columbia and Snake River dams where Smolt Monitoring Program activities occur, from April to October at lower Snake River dams and into December at McNary Dam. Temperatures are taken at the juvenile fish bypass system sampling facility at 0700 hours, which corresponds to the beginning/end of the daily sample period. Since the data are collected early in the morning, reported temperatures do not represent the diurnal temperature cycle, and likely underestimate daily maximums. In addition to the daily data collection at the juvenile fish bypass sampling facility, at McNary Dam during July and August, detailed water temperature data are collected by thermistors by on-site fishery agency biologists under contract to COE. At the powerhouse, thermistors record data from northern, middle, and southern locations in the juvenile fish collection gallery and turbine intake gatewells. At the juvenile fish bypass facility, thermistors record temperature data from a representative raceway, the wet separator, and the barge-loading dock. These data show that horizontal, vertical, and diurnal temperature gradients occur between these sampling locations.

Water temperature issues are most prominent and of concern during July and August when ambient air temperatures can exceed 90°F. Acute fish mortality problems have been observed during times of high water temperatures. In 1994, the water temperature at the McNary Dam juvenile fish facility reached 68°F in mid-July. A few days later, the facility experienced a massive fish mortality, most likely related to inriver water temperatures exceeding 70°F. Prior to 16 July 1994, thermal profile data showed elevated water temperatures but not the large thermal gradients between operating and non-operating turbine units associated with fish mortality observed in previous years (Hurson et al. 1996). The NMFS 1995 BIOP required the action agencies to take measures to reduce the potential for reoccurrence of the 1994 incident (NMFS 1995a). At McNary Dam from 10 to 12 July 1998, daily facility mortality was 3 to 8% (34,900 of 831,700 fish collected), which was coincident with water temperatures above 70^0 F. Also in 1994, daily average river temperatures in the lower Columbia River migration corridor reached 74°F during late-July. Coutant (1999) suggested that the cause of these acute mortalities observed at McNary Dam was a cumulative thermal dose of exposure to high-temperature water, received over a period of several days.

Elevated water temperatures likely contribute to juvenile fish facility loss during summer months. In July 1998, facility mortality of wild subyearling fall chinook salmon collected at lower Snake River collector dams ranged from 1.5 to 3.8% for Lower Monumental and Little Goose Dams, respectively. In 1997, it ranged from 2.1 to 7.7% for Lower Monumental and Little Goose Dams, respectively. High water-temperatures and outbreaks of disease later in the season likely contribute to increased facility mortality. Total juvenile fish facility mortality during the summer at McNary Dam was 2.2% during 1997 and 1998 (Hurson et al. 1999).

To address these temperature issues, a regional Water Quality Team has been formed, which is co-chaired by the Environmental Protection Agency and NMFS. The Team is working on a plan to address alternative operations during warm water periods at McNary Dam, with the goal of developing an approved plan by 2000.

Effects of Bypass Systems on Smolt Condition

During the 1990s, two existing juvenile fish collection and bypass facilities at dams on the Snake and Columbia Rivers were replaced with new facilities (Little Goose Dam (1990) and McNary Dam (1994)), and new juvenile fish collection and bypass facilities were built at Lower Monumental Dam (1993), Ice Harbor Dam (1996), John Day Dam (1998), and Bonneville Second Powerhouse (1999). Each of these new facilities were tested to locate and correct any areas within the structures, flumes, and pipes that might cause descaling, injuries, or mortalities to juvenile fish passing through the facilities. In addition, the region's state and federal fishery agencies monitor daily samples of the fish for descaling, injury, and mortality to ensure that these facilities are operated in a safe manner.

Because the 1993 smolt outmigration through the Snake River was the first where all hatchery spring/summer chinook salmon were adipose-fin clipped, that year is used as a starting point for looking at fish condition (descaling and mortality) at each of the Snake River dams. Fish condition at the Snake River dams and at McNary Dam is reported in Hurson et al. (1994) and Hurson et al. (1998).

The Lower Granite Dam juvenile fish facility was not replaced during the 1990s. Descaling rates from 1993 to 1998 averaged 3.8% for hatchery spring/summer chinook salmon, 2.5% for wild spring/summer chinook salmon, 6.2% for subyearling chinook salmon, 6.1% for hatchery steelhead, 1.8% for wild steelhead, 13.7% for sockeye salmon, and 2.5% for coho (declared extinct in the Snake River in the early 1980s, but coho were re-introduced for the 1996 outmigration). Mortality rates from 1993 to 1998 averaged 0.5% for hatchery spring/summer chinook salmon, 0.5% for wild spring/summer chinook salmon, 1.6% for subyearling chinook salmon, less than 0.1% for hatchery steelhead, less than 0.1% for wild steelhead, 1.4% for sockeye salmon, and 0.2% for coho.

Descaling rates at Little Goose Dam from 1993 to 1998 averaged 6.3% for hatchery spring/summer chinook salmon, 4.9% for wild spring/summer chinook salmon, 4.6% for subyearling chinook salmon, 6.2% for hatchery steelhead, 2.8% for wild steelhead, 9.6% for sockeye salmon, and 7.3% for coho. Mortality rates from 1993 to 1998 averaged 0.8% for hatchery spring/summer chinook salmon, 1.0% for wild spring/summer chinook salmon, 4.9% for subyearling chinook salmon, 0.2% for hatchery steelhead, 0.2% for wild steelhead, 5.2% for sockeye salmon, and 3.9% for coho.

Descaling rates at Lower Monumental Dam from 1993 to 1998 averaged 5.3% for hatchery spring/summer chinook salmon, 4.5% for wild spring/summer chinook salmon, 3.3% for subyearling chinook salmon, 6.9% for hatchery steelhead, 2.6% for wild steelhead, 10.9% for sockeye salmon, and 3.0% for coho. Mortality rates from 1993 to 1998 averaged 0.2% for hatchery spring/summer chinook salmon, 0.3% for wild spring/summer chinook salmon, 1.8% for subyearling chinook salmon, 0.2% for hatchery steelhead, 0.1% for wild steelhead, 1.8% for sockeye salmon, and 0.1% for coho.

The juvenile bypass system for Ice Harbor Dam was completed and evaluated in 1996. Hatchery steelhead and yearling chinook salmon released at two locations in the collection channel were recaptured and evaluated. Mortality and descaling for both species were less than 0.2% (Gessel et al. 1997).

The new juvenile fish facility at McNary Dam, the first Columbia River dam encountered by fish exiting the Snake River, became operational in 1994. The hatcheries in the Columbia River do not adipose-fin clip all of their spring/summer chinook salmon; therefore, the juvenile fish facilities at Columbia River dams cannot distinguish between hatchery and wild fish. Descaling rates at McNary Dam from 1994 to 1998 averaged 7.5% for spring/summer chinook salmon, 3.6% for subyearling chinook salmon, 6.5% for hatchery steelhead, 2.7% for wild steelhead, 10.5% for sockeye salmon, and 5.9% for coho. Mortality rates from 1994 to 1998 averaged 0.4% for spring/summer chinook salmon, 1.3% for subyearling chinook salmon, 0.2% for hatchery steelhead, 0.2% for wild steelhead, 0.5% for sockeye salmon, and 0.1% for coho.

Measures of bypass system survival at John Day Dam comprised of observations of mortality at the sampling facility (Martinson et al. 1998) and to data gathered during a recent bypass system evaluation (Absolon et al. in prep.). Mortality rates reported by Martinson et al. (1998) at the John Day Dam sampling facility averaged 2.4% for yearling chinook salmon, 3.0% for subyearling chinook salmon, 0.8% for wild steelhead, 1.7% for hatchery steelhead, 0.9% for coho salmon, and 1.3% for sockeye salmon.

The latest modifications to the juvenile bypass system at John Day Dam were completed in April 1998. Post-construction evaluation of the system was conducted by NMFS (Absolon et al. in prep.). As part of this evaluation, hatchery chinook salmon yearlings and steelhead were released into various points within the system. Direct mortality during passage from the collection channel to the evaluation facility ranged from 0 to 1.5% for yearling chinook salmon. Direct mortality for three collection channel releases of steelhead ranged from 0 to 1.5%.

At Bonneville Dam, mortalities at the First and Second Powerhouse sampling facilities were noted by Martinson et al. (1998). First Powerhouse mortalities from 1988 to 1997 averaged 0.1% for yearling chinook salmon, 0.4% for subyearling chinook salmon, 0.1% for wild steelhead, 0.1% for hatchery steelhead, 0.1% for coho salmon, and 0.4% for sockeye salmon. Mortalities observed at the Second Powerhouse averaged 1.5% for yearling chinook salmon, 1.4% for subyearling chinook salmon, 1.1% for wild steelhead, 0.9% for hatchery steelhead, 0.9% for coho salmon, and 7.9% for sockeye salmon. Although these estimates give some measure of the upper limit of direct, immediate bypass system passage mortality, they cannot reflect mortality through the entire system since sampling locations are typically some distance upstream from the outfall.

Also, some mortalities observed within a system may have resulted from prior injuries and conversely, some live fish observed in samples may die of passage effects at a later time.

Passage survival studies conducted by NMFS at Bonneville Dam from 1987 through 1990 and in 1992 involved releases of differentially marked subyearling chinook salmon into various passage routes at Bonneville Dam, including the Second Powerhouse bypass system (1987 to 1990) and the First Powerhouse bypass system (1992). These studies used fish identified with freeze brands and marked with coded-wire tags. Relative short-term survival for treatment groups was based on data from recapture of juvenile test fish at Jones Beach (RKm 74) during seaward migration. Relative long-term survival for test fish using the various passage routes was to have been based on recoveries of coded-wire tags from fisheries, hatcheries, and surveys of spawning areas. Results from the NMFS relative survival studies at Bonneville Dam were reported in Dawley et al. (1988, 1989), Ledgerwood et al. (1990, 1991, 1994), and Gilbreath et al. (1993). Results from Second Powerhouse tests conducted by NMFS from 1987 to 1990 indicated that relative survival of bypass-released groups averaged 8.3% less than reference groups released downstream from the dam and, surprisingly, 7.6% less than turbine releases (Dawley et al. 1996). Using similar methodology, NMFS released subyearling chinook salmon at the Bonneville Dam first powerhouse in 1992 (Ledgerwood et al. 1994). Results indicated that relative survival of bypass-released groups was 11.8% less than turbine-released groups and 28.3% less than groups released at the downstream reference location.

Due to the unforseen low relative survival of bypass-released groups, NMFS conducted a separate evaluation at the Bonneville Second Powerhouse bypass system from 1990 to 1992 (Dawley et al. 1998a). In these studies, referred to as direct assessments of passage survival, a trap-net attached to the submerged outfall was used to capture fish immediately upon exit from the bypass system. Results indicated that the bypass system was not responsible for the considerable survival differences noted in the previous paragraph, although descaling, injury, and stress among release groups did increase as the distance traveled through the bypass system increased. It was hypothesized that increased stress and fatigue of fish traveling through the bypass system, in combination with a poor outfall location, resulted in high predation rates on juvenile salmonids exiting the bypass system.

Effects of Bypass Systems on Blood Chemistry

Stress, generated by external and internal stimuli, induces quantifiable biochemical responses in fish (Hane et al. 1966, Grant and Mehrle 1973). Clinical evaluation of blood plasma has associated stress with changes in concentrations of cortisol and adrenaline, which influence levels of secondary indicators including lactate, glucose, liver glycogen, leucocyte count, free fatty acids, and the balance of various electrolytes (Mazeaud et al. 1977).

Several stressors related to passage through fish bypass facilities at hydroelectric dams have been shown to alter indicator concentrations in juvenile salmonids under experimental conditions. For example, elevated plasma cortisol and glucose levels have been associated with crowding and handling (Wedemeyer 1976, Congleton et al. 1984), descaling (Gadomski et al. 1994), acclimation temperature (Barton and Schreck 1987a), and confinement (Strange et al. 1978). Under field conditions, Maule et al. (1988) demonstrated that juvenile chinook salmon plasma cortisol and glucose concentrations could increase cumulatively as the fish passed successive points in the bypass system, corroborating similar results from laboratory work with sequential handling (Barton et al. 1986, Congleton et al. 1999). However, Congleton et al. (1999) found that, generally, peak plasma cortisol level in fish following handling experiments did not appear to be affected by repeated stressful experiences. They point out it is possible that fish in the multiple stress groups experienced some form of chronic, low-level stress, that was masked by the elevated pre-stress plasma cortisol levels in these groups.

Lactate, also used as a stress index, has been shown to increase in response to stress stimulus (Mesa and Schreck 1989, Gadomski et al. 1994). As with glucose and cortisol, blood plasma concentrations of lactate can rise dramatically with exposure to a stressor, returning to pre-exposure levels after several hours following suspension of, or acclimation to, the stimulus.

Blood plasma indicators have been used routinely as stress indices during the fish bypass system evaluation process for upgraded facilities constructed at FCRPS projects since 1990. At each dam, blood samples were collected from chinook salmon and steelhead smolts at successive points within the bypass system. Since blood plasma indicator levels in fish captured from the gatewell are similar to levels found in hatchery reared (naive) smolts (Congleton et al. 1984), results were compared to samples taken from smolts collected concurrently from gatewells. This process was replicated several times through the outmigration to accommodate timing differences. In all cases, blood plasma concentrations of cortisol, glucose, and lactate were measured as indices of stress resulting from passage through the facility. Mean levels of indicators (averaged across the entire outmigration) are included in Table 7 by facility for each species evaluated.

Results from these studies vary by site. For yearling chinook salmon, there were significant increases in cortisol and glucose concentrations at Little Goose (Monk et al. 1992), Lower Monumental (Marsh et al. 1995) and John Day (Absolon et al. in prep.) Dams as fish passed from the gatewells through the sample tanks, while no significant differences were reported for any indicator levels from Ice Harbor (Gessel et al. 1997) and McNary (Marsh et al. 1996) Dams. Lactate levels increased significantly only at Little Goose Dam. Subyearling chinook salmon, evaluated only at McNary Dam, showed a real change only for mean lactate values, which declined significantly before returning to gatewell levels in raceways.

Steelhead cortisol concentrations increased significantly through all bypass systems except at McNary Dam, and significantly elevated levels of plasma glucose were recorded at Little Goose, Lower Monumental, and McNary Dams. Mean lactate concentrations in steelhead plasma showed significant increases only at Little Goose and Lower Monumental Dams.

In general, blood plasma index responses through current bypass systems are within the normal range of expected values, given the stimuli. In cases where levels were measured following the bypass process (e.g., from raceways), plasma indicator concentrations returned to near gatewell levels within a few hours in non-stressed fish. Results to date suggest that physiological effects of passage through fish bypass facilities on juvenile chinook salmon and steelhead are nominal, as measured by blood plasma stress indices, and follow a typical sequence for fish subjected to a stressor followed by acclimation to or removal of the stress (Wedemeyer

Table 7. Most recent juvenile chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) mean blood plasma stress indicator concentrations by juvenile fish facility sample location for COE operated hydroelectric projects on the Columbia and Lower Snake Rivers.

Hydroelectric Project	Evaluation year	Authority	Species	Sample location	Blood plasma indicator concentration: Cortisol (ng/ml)	Glucose (mg/dl)	Lactate (mg/dl)
John Day	1998	Absolon et al. (in prep.)	yearling chinook salmon	gatewell	103.2	63.2	91.2
				pre-separator	151.6	76.2	82.6
				pre-sample tank	160.1	73.2	85.7
			steelhead	gatewell	98.8	88.2	98.6
				pre-separator	192.7	81.4	89.3
				pre-sample tank	179.0	107.5	105.5
McNary	1994	Marsh et al. 1996	yearling chinook salmon	gatewell	92.5	93.9	62.1
				post-dewaterer	97.5	97.1	74.8
				separator	102.4	91.6	65.3
				raceway (0-hour)	89.5	87.7	66.9
				raceway (2-hour)	98.4	93.1	61.5
				raceway (4-hour)	84.7	86.2	57.1
				raceway (6-hour)	79.8	88.3	52.3
				raceway (10-hour)	92.3	103.2	61.7
			steelhead	gatewell	83.2	153.3	59.3
				post-dewaterer	84.4	108.2	49.9
				separator	90.5	109.7	59.9
				raceway (0-hour)	101.2	132.7	72.4
				raceway (2-hour)	108.0	137.3	62.4
				raceway (4-hour)	86.9	132.7	59.6
				raceway (6-hour)	75.8	131.2	53.4
				raceway (10-hour)	100.9	161.5	62.6

Table 7. Continued.

Hydroelectric Project	Evaluation year	Authority	Species	Sample location	Blood plasma indicator concentration		
					Cortisol (ng/ml)	Glucose (mg/dl)	Lactate (mg/dl)
McNary	1994	Marsh et.al 1996	subyearling chinook salmon	gatewell	57.2	92.7	122.8
				post-dewaterer	82.6	85.1	75.5
				separator	75.9	88.2	77.7
				raceway (0-hour)	84.4	73.1	114.2
				raceway (2-hour)	70.8	82.0	82.0
McNary	1994	Marsh et al. 1996	subyearling chinook salmon	raceway (4-hour)	75.6	80.9	78.4
				raceway (6-hour)	68.1	87.0	77.3
				raceway (10-hour)	88.3	89.2	87.0
Ice Harbor	1995	Gessel et al. 1997	yearling chinook salmon	gatewell	140.3	105.9	53.7
				pre-separator	140.7	95.2	59.2
				pre-sample tank	135.9	97.2	60.2
			steelhead	gatewell	101.0	131.4	51.4
				pre-separator	165.5	117.7	71.1
				pre-sample tank	188.8	112.9	65.2
Lower Monumental	1993	Marsh et al. 1995	yearling chinook salmon	gatewell	115.7	62.5	114.5
				post-dewaterer	144.6	68.9	73.4
				pre-separator	144.7	81.5	66.8
				raceway (0-hour)	152.3	103.1	57.9
				raceway (2-hour)	127.2	110.4	49.0
				raceway (4-hour)	121.4	111.7	50.4
				raceway (6-hour)	110.3	108.3	55.9
				raceway (10-hour)	166.6	104.3	57.5
			steelhead	gatewell	84.4	119.8	54.6
				post-dewaterer	154.2	116.3	60.6
				pre-separator	184.0	127.0	72.7
				raceway (0-hour)	138.6	147.0	52.1

Table 7. Continued.

Hydroelectric Project	Evaluation year	Authority	Species	Sample location	Blood plasma indicator concentration Cortisol (ng/ml)	Glucose (mg/dl)	Lactate (mg/dl)
				raceway (2-hour)	173.1	147.2	44.9
				raceway (4-hour)	69.3	149.7	55.7
				raceway (6-hour)	103.2	138.0	54.8
				raceway (10-hour)	174.1	142.8	59.8
Little Goose	1990	Monk et al. 1992	yearling chinook salmon	gatewell	75.7	96.5	56.4
				post-dewaterer	77.3	87.5	75.1
				pre-separator	112.0	86.7	72.6
				raceway (0-hour)	140.7	107.8	71.0
Little Goose	1990	Monk et al. 1992	yearling chinook salmon	raceway (2-hour)	160.5	164.9	59.5
				raceway (4-hour)	129.4	155.6	55.7
				raceway (6-hour)	85.5	154.2	58.2
				raceway (10-hour)	81.7	160.4	72.2
				pre-barge	79.4	109.2	55.6
			steelhead	gatewell	42.2	133.0	36.6
				post-dewaterer	114.5	126.3	67.5
				pre-separator	142.3	119.5	74.8
				raceway (0-hour)	125.1	109.9	68.7
				raceway (2-hour)	91.2	150.1	44.7
				raceway (4-hour)	61.0	142.1	46.8
				raceway (6-hour)	65.3	129.1	46.3
				raceway (10-hour)	103.5	147.0	53.2
				pre-barge	125.4	140.8	51.4

1976, Mazeaud et al. 1977). Several researchers have reported that effects of stress as measured by hepatic plasma indicators diminish within 24 hours following removal of the stressor in a protected environment (Sharpe et al. 1988, Gadomski et al. 1994, Schreck and Knoebl 1997). For example, transported fish showed an initial increase in plasma cortisol levels immediately after loading onto a barge, but the effect abated after three hours to pre-loading levels (Maule et al. 1988).

The relationships between physiological indicators of bypass-induced stress and in-river survival are not as well documented. There is evidence that short-term survival may be directly impaired as a result of stress in poor quality chinook salmon smolts. Under controlled conditions, Barton et al. (1986) demonstrated that multiple acute disturbances, similar to those encountered during the bypass process, resulted in cumulative physiological responses. Plasma indicator levels of healthy animals returned to control levels within 30 hours with no mortality after 3 stress events, while analogous treatment for unhealthy fish resulted in 50% mortality within 3 to 6 hours after the third event. Indirectly, bypass stress may also contribute to reduced ability to respond successfully to in-river conditions. Barton and Schreck (1987b) found a positive relationship between metabolic rate and the plasma cortisol level in stressed fish. They concluded that even relatively minor events can reduce available energy stores in fish by as much as one quarter, leaving the animal with substantially fewer reserves to cope with environmental challenges such as temperature adaptation, disease, and demands on swimming stamina. There is evidence that weaker fish may be targeted differentially for predation as a result of predator selection or prey vulnerability. For example, Congleton et al. (1984) demonstrated a significant positive correlation between impaired predator avoidance and crowding stress resulting in plasma cortisol levels of 75 - 150 ng/ml. In another study, Gadomski et al. (1994) could not find a significant relationship between juvenile salmonid descaling and predation by northern squawfish, but noted there was evidence of increased predation of descaled fish compared to controls at higher descaling rates. The authors suggested that under field conditions, the stress related to descaling may be more serious than the injury itself, resulting in decreased performance and greater susceptibility to predation.

JUVENILE PASSAGE THROUGH SURFACE BYPASS SYSTEMS AND SLUICEWAYS

Introduction

Prototype and permanent surface bypass and collection systems are under assessment at numerous federal and public mainstem Columbia and Snake River hydroelectric dams. This passage concept is based on successful development of a permanent surface collection/bypass system at Wells Dam between 1981 and 1989 (Johnson et al. 1992), and three additional years of evaluation to substantiate spring and summer juvenile migrant passage performance. Bypass efficiency (ratio of fish passing surface bypass to total passage at test units) was 89% during that period (Dauble et al. 1999). The concept was developed based on the working premise, discussed below, that if smolts had the opportunity to discover a near-surface passage route, they would prefer this to sounding to pass through turbine intakes. The previous indications that surface routes would pass surface-oriented juveniles were the evaluations of passage through ice and trash sluiceways at The Dalles, Ice Harbor, and Bonneville Dams (Christensen and Wielick 1995). Based on the successful adaptation of the ice and trash sluiceway surface bypass principles into a surface bypass system at Wells Dam, prototype surface bypass/collectors have been tested at a number of locations in the Pacific Northwest since 1994, especially at lower Snake and Columbia River dams. The goal of the prototype testing at these sites has been to determine whether use of bioengineering principles observed at the Wells Dam surface bypass system can be successfully applied at dams with appreciably different and more typical powerhouse/spillway project configurations.

Wells Dam Surface Bypass System

Wells Dam is configured differently than all other run-of-the-river dams on the Snake and Columbia Rivers. It has deep powerhouse turbine intakes with 11 spillway gates located over and between the ten turbines. This unique structure is referred to as a hydrocombine. Turbine intake ceilings are 21.3 m (70 ft) deep. Each of five turbine pairs now has one surface bypass entrance 4.88 m (16 ft) wide and 22.25 m (73 ft) deep. The surface bypass entrance velocity is approximately 0.61 m/s (2 ft/s), and each surface bypass slot passes up to 62.3 m^3/s (2,200 cfs). The surface entrances are part of the surface-oriented bulkheads installed directly above turbine intakes and in front of each pair of spillbays. Bypassed fish and flow pass through the surface entrances into an afterbay between the slotted entrance and the spill gates, and are discharged to tailwater through the spillway lift gates. Spill gates are the controls that dictate surface entrance flow and velocity. Surface bypass flow is 5 to 7% of hydraulic capacity for each turbine pair (Johnson 1996).

Bypass entrance slot guidance efficiency (ratio of fish passing into bypass slot relative to fish passing both slot and turbine pair) has been approximately 90% (Johnson et al. 1992), ranging from 84.3 to 95.0% for spring migrants and 76.5 to 97.0% for summer migrants (Skalski et al. 1996).

Surface Bypass Premises

Based largely on what was learned about juvenile behavior in the Wells Dam forebay, biological premises that established testable hypotheses were developed (Dauble et al. 1999) that provide a conceptual framework for the application of surface bypass concepts to prototype facilities at other locations:

1) Smolts follow the bulk flow as they approach a dam.
Forebay hydraulic conditions are influenced by river discharge, bathymetry, and turbine/spill operations These variables affect fish approach patterns and influence relative numbers of smolts available for spill and other passage routes. Juvenile radiotelemetry and hydroacoustic studies show that smolt densities are usually higher in the main channel than shoreline areas. Thus, most smolts follow the bulk flow in the thalweg (Johnson et al. 1999).

2) Smolts can discover a surface bypass flow net.
The horizontal and vertical distribution of smolts must be considered when locating surface bypass entrances to maximize the smolts' "opportunity for discovery" of the attraction flow net provided by the surface bypass entrance. For a partial powerhouse prototype, both the vertical and horizontal components of smolt distribution must be considered in the design of prototype surface bypass systems. For a full powerhouse design, like Wells Dam where the surface bypass system covers the entire powerhouse, only the vertical component needs to be satisfied to be successful. The design features of entrance size and number must work together to increase the opportunity for smolts to discover and use entrance flow fields projecting upstream into the forebay (Rainey 1997).

3) Surface bypass entrance conditions should not elicit an avoidance response.
Milling behavior, lateral movement, and upstream movement of smolts has been observed in evaluations of prototype surface bypass systems (Johnson et al. 1998) . Hydraulic conditions that enhance use of entrances are thought to include no abruptly decelerating velocity or "null zones," weak downward currents, or localized, intense water-particle acceleration fields. Brett and Alderdice (1958) found that improved bypass efficiency resulted from uniform acceleration of water velocities and minimization of visual and turbulence cues within the bypass entrance.

The relative importance of light and sound to surface bypass entrance conditions and how these variables influence fish behavior is unknown. However, the ability of fish to respond to local turbulence and velocity components of flow fields is well documented. For example, recent studies at Columbia River dams indicate that smolts detect and respond to near-field flow characteristics associated with different bypass screen designs (Nestler and Davidson 1995). Haro et al. (1998) suggested that bypass entrances need to be large enough to accommodate large schools of fish in order to be effective. This indicates that flow nets may have a threshold size, below which smolt passage is reduced.

4) Smolts stay in and pass through the conveyance structure safely.
Limited data support the premise that a powerhouse surface bypass with a high volume channel connected to a spillway can quickly and safely deposit smolts at a spillbay outfall (Adams et al. 1998).

5) Smolts safely enter the tailrace and quickly migrate downstream.
The benefits of efficient collection and safe conveyance is negated if survival rates upon egress are low. Indirect data from radio-tagged juveniles, and direct data from radio-tagged predators (northern pikeminnow) indicate that smolts safely entered the tailrace and quickly migrated downstream at Lower Granite Dam (Piaskowski et al. 1998).

Surface Bypass Designations

During the mid- and late-1990s, evaluations of prototype surface bypass systems have occurred or will occur in the future at Bonneville (both powerhouses), The Dalles, John Day, Ice Harbor, Lower Granite, Wanapum, Rocky Reach, and Wells Dams. Based on these prototypes, five basic surface bypass designations characterize the surface bypass systems tested to date:

1) Powerhouse Surface Flow Attraction Channel (SFAC).
2) Powerhouse End Collector (PEC).
3) Surface Bypass Spill/Sluice.
4) Occlusion.
5) Hybrid.

Some prototypes fall into more than one designation, and are cross-referenced.

Powerhouse Surface Flow Attraction Channel (SFAC)

This designation applies to a surface bypass channel with one or more entrances on the upstream face of a powerhouse. This emulates the successful permanent facilities at Wells Dam. Three prototypes fit this category: Lower Granite Dam, Bonneville First Powerhouse, and Wanapum Dam. The plan for each was to first determine whether adequate numbers of fish could be collected from the forebay, and then determine how to safely route flow either to the tailrace, or to dewatering and transportation facilities.

Lower Granite SFAC--Tests of the SFAC were conducted in 1998 to 1999 in combination with a behavioral guidance structure (BGS) and simulated Wells Dam intake (SWI) to control horizontal and vertical distribution, respectively, with the goal of increasing SFAC collection. The BGS and SWI are also discussed below in the occlusion section. Lower Granite Dam has a six-turbine powerhouse located immediately to the south of eight spill bays. The 1998-1999 prototype SFAC configuration included a surface bypass collector (SBC) immediately upstream from and partially occluding, turbine Units 4 to 6. Attraction flow passes into one or more of four adjustable test entrances, then is conveyed to the adjacent spillbay through a longitudinal channel. The spillbay Tainter gate provides the flow-control for the prototype. Deep, wide entrance configurations (similar to Wells) were tested in 1996-1998, but in 1999 the emphasis was on surface-oriented entrances with greater entrance velocities (Anglea 1999).

In 1998, based on hydroacoustic estimates (Johnson et al. 1998), the SBC collected 36% of all outmigrants that approached the dam. Of those that passed through either the SBC or below the SBC and through turbine intakes at Units 4 to 6, 51% entered the SBC. In 1998, based on radiotelemetry estimates (Adams et al. 1998), 28, 29, and 49% of the wild steelhead, hatchery chinook, and hatchery steelhead, respectively, entered the SBC, of those fish that either entered the SBC or passed through Units 4 to 6. In 1999, based on hydroacoustic estimates (Anglea 1999), of those that passed through either the SBC or below the SBC and through turbine intakes at Units 4 to 6, 57.8% entered the SBC. Radiotelemetry evaluations were not conducted in 1999. The disparity between the hydroacoustic and radiotelemetry estimates may be due to the abundance of hatchery steelhead observed in the hydroacoustic samples, which are not species specific. For summer migrants in 1998, based on radiotelemetry estimates (Adams et al. 1998), 54% of the tagged subyearling fall chinook salmon approaching the powerhouse utilized the SBC.

Future efforts will attempt to further increase SBC entrance efficiency, and integrate the physical and biological data by simultaneously conducting three-dimensional tracking of fish (using sonic tags) and numerical modeling of the hydraulic flow fields. This would allow a greater understanding of the behavioral response to flow velocity and acceleration, and have broad application to many surface bypass systems at various dams.

Bonneville First Powerhouse SFAC--The Bonneville First Powerhouse consists of ten turbines and is separated from the spillway by Bradford Island. A prototype surface collector (PSC) in front of turbine Units 3 to 6 was installed in 1998 and evaluated to determine whether occluding the upper intake with the PSC and passing high flows through a deep SFAC slot of variable width would successfully attract fish. The bottom of the PSC is approximately 36 to 42 ft deep. Both 5- and 20-ft slot widths were tested (passing approximately 1,000 cfs and 3,000 cfs, respectively). Flow and fish passing each slot are routed into the upper turbine intake in the prototype.

Hydroacoustic evaluations showed an efficiency of 89 to 90% for both spring and summer migrants and both slot widths, with efficiency defined as the ratio of fish passing the PSC compared to total passage at the operating PSC test unit (Ploskey et al. 1999). This efficiency is based on committed fish that have passed into or under the PSC.

In radio-tracking studies by Hensleigh et al. (1998), approximately 45 and 40% of the tagged juvenile steelhead and yearling chinook salmon, respectively, that were contacted upstream from the Bonneville First Powerhouse were contacted at the PSC. A total of 67% of the tagged fish that contacted the PSC did not enter, and instead moved south along the PSC face and initially held upstream from turbines Units 1 to 2.

Tests in 2000 will include expanding the PSC to include turbine Units 1 to 2, to address the question of whether fish that moved laterally in 1998 will ultimately pass the PSC. The permanent SFAC would tentatively have one entrance slot for each of the ten turbines, and total bypass flow could be 30,000 cfs. A decision to proceed with further SFAC development will tentatively be made in 2000 to 2001, once the feasibility of passing juveniles at higher outfall volumes directly to the Bonneville First Powerhouse tailrace has been determined. Uncertainties associated with mortalities, both direct (from turbulent shear and strike) and indirect (from juvenile disorientation and predation), remain to be addressed. The option of a hybrid surface bypass collector, which utilizes an ice and trash sluiceway with an acceptable bypass outfall location along with ESBSs, has been discussed.

Wanapum SFAC--In 1995, Grant County Public Utility District installed and tested a 55-ft deep prototype SFAC at Wanapum Dam immediately upstream from turbine Units 7 to 10. A single 16-ft wide by 50-ft deep slot entrance was installed above Unit 8, with a hydraulic capacity of 1,400 cfs (Sverdrup Corporation 1995). The prototype was extended to occlude Units 4 to 6 for testing in 1996, and extended again to occlude Units 1 to 3 in 1997.

Mean collector efficiency (the ratio of fish entering collector vs. fish into and under collector) for the single unit with an entrance (Unit 8) was 30% in 1995 (Ransom et al. 1995). However, this number decreased when Units 7, 9, and 10 were included. Since fish collection in the SFAC did not increase to target collection levels with extension of the SFAC in 1996-1997, further SFAC testing was dropped after the 1997 passage season. No additional surface bypass evaluations are scheduled for Wanapum Dam.

Powerhouse End Collector (PEC)

Powerhouse end surface bypass collectors apply where juvenile outmigrants can be collected upstream from the powerhouse, but not passed into a new surface collector conveyance channel that has entrances extending the full width of the powerhouse. Examples include the Bonneville Second Powerhouse sluice chute, The Dalles Dam ice and trash sluiceway, and Rocky Reach Dam. These sites are unique since large numbers of juvenile outmigrants either pass or accumulate near the respective PEC. Each is characterized by a strong component of surface-oriented lateral flow. PEC entrances are placed where fish are known to congregate or pass in large numbers, taking advantage of fish behavior.

Bonneville Second Powerhouse Sluice Chute PEC--The sluice chute is located immediately south of Unit 11, the southern-most turbine at the powerhouse. The unique, excavated forebay bathymetry results in hydraulic conditions at the upstream powerhouse face that include strong lateral flows toward the north and south end of the powerhouse (Monk et al. 1999a), which concentrate juvenile fish at these locations.

In 1998, with the six southern-most turbine intake extensions removed, radiotelemetry studies detected 52% of steelhead and 36% of yearling chinook salmon moving through the sluice chute when in the open position. Additionally, 21% of the steelhead and 14% of the yearling chinook salmon were detected in the juvenile bypass system. With the chute closed, 50% of the steelhead and 30% of the tagged yearling chinook were detected in the bypass system (Hensleigh et al. 1998). Hydroacoustic studies found the combined efficiency of the sluice chute and turbine units 11-13 at 90% during spring and summer, while units 11-13 STS FGE alone when the chute was closed was only 55% in the spring and 30% in the summer. The efficiency of sluice chute relative to total passage at units 11-13 plus passage at the sluice chute averaged 83% in spring and 81% in summer. Effectiveness was high; about five times more fish passed through the sluice chute than would be expected from the proportion of water passing the chute. The researchers concluded the sluice chute has great potential as a corner collector (Ploskey et al. 1999).

The Dalles Dam PEC (Ice and Trash Sluiceway)--The Dalles Dam powerhouse is oriented parallel to the forebay river channel centerline. There is a surface-oriented, westerly lateral flow along the face of the powerhouse. The ice and trash sluiceway is located along the entire length of the 22-turbine-unit powerhouse. The ice and trash sluiceway is operated to pass up to 5,000 cfs (the hydraulic capacity of the sluiceway) through three or more chain gates. The priority chain gate operation is above turbine Unit 1 at the west end of powerhouse. During periods of no spill, sluiceway passage was estimated at 40 to 55% (Giorgi and Stevenson 1995). In 1998, hydroacoustic estimates of spring passage were 40.7 and 25.8%, for 30 and 64% spill, respectively; summer passage was estimated to be 35.2 and 26.2%, for 30 and 64% spill, respectively (BioSonics Inc. 1999c) Preliminary results from hydroacoustic studies in 1999 indicate sluiceway passage during the spring was 13 and 15%, for 30 and 64% spill, respectively (Ploskey et al. 1999). In 1997, Hensleigh et al. (1999) found that the greatest number of observations of radio-tagged wild and hatchery steelhead and yearling and subyearling chinook salmon was at the west end of the powerhouse.

Rocky Reach Dam PEC--Rocky Reach Dam has a high degree of surface-oriented lateral flow, similar to Bonneville Second Powerhouse and The Dalles Dam. The Rocky Reach powerhouse is oriented parallel to the river channel centerline while the spillway is upstream and perpendicular to the forebay channel. Fish accumulate at the downstream half of the powerhouse (Dauble et al. 1999), which was the basis for selecting a PEC configuration. In 1998, a PEC with double entrances above turbine Units 1 and 3 was tested. The Unit-1 entrance was tested with 7- and 15-ft wide by 56-ft deep slot entrances, which passed 2,275 and 3,000 cfs, respectively. Bypassed flow is routed to a dewatering screen and tailrace outfall. The Unit-3 entrance routes approximately 2,400 cfs into turbine Unit 2, where intake screens guide fish from the Unit 3 surface bypass slot upward into gatewells, which lead to a bypass system and tailrace outfall. Entrance flow from both of the surface bypass slots passes through an intake venturi that for turbine Unit 1 is an occlusion device. Intake guidance screens in turbine Units 1 and 2 also route some fish passing under the PEC facilities into collector gatewells, and all fish are ultimately routed into the common bypass and monitoring facility and outfall (Mosey et al. 1999).

In 1998, 27% of the PIT-tagged steelhead and yearling chinook salmon passed through the unit 1 and 3 surface bypass entrances, and 12 and 33% of the sockeye and subyearling chinook salmon, respectively, used the entrances (Mosey et al. 1999)

Chelan County Public Utility District plans to continue development of and ultimately build a permanent PEC system at Rocky Reach Dam, which will use a combination of slotted surface-oriented entrances and turbine intake screens to collect and bypass fish.

Surface Bypass Spill/Sluice

Surface bypass spill/sluice facilities route juvenile fish directly to tailwater, rather than into bypass systems with dewatering and sampling or transportation loading facilities. Examples include the proposed skeleton bay and raised spillbay crest concepts at John Day Dam, a Wanapum Dam sluice chute, and a Lower Granite raised spillbay crest. Sluiceways currently exist at The Dalles Dam and the Bonneville Second Powerhouse (chute). Present developmental efforts are focused on increasing the percentage and safety of fish bypassing these routes, including improving the outfall locations to minimize tailrace predation.

John Day skeleton bay surface bypass--John Day Dam has 20 spillbays and 16 operating turbines. To the immediate south of the spillway are turbine skeleton Bays 17 to 20, built for possible future turbine installations. The COE has developed a preliminary design of a single skeleton bay surface-oriented sluiceway that will pass approximately 18,000 cfs through three, 20-ft-wide ogee chutes with crests at elevation 243 feet msl (normal forebay elevation is 264 feet msl). Each chute would transition to a 20-ft horizontal apron at the downstream end of the ogee curve-to-tangent location. Control gates would operate either fully open or closed.

This concept has proceeded to the design memorandum completion point, but has not been constructed or prototype-tested. The basis for the design is the hypothesis that a strong, surface-oriented flow field projecting upstream into the forebay will provide an opportunity for juvenile salmon to discover and use this surface bypass route. Radiotelemetry studies show that as many as 75% of juveniles pass the skeleton bay within 100 m of the proposed location (COE 1998d).

John Day spillbay raised-crest surface bypass--A spillbay raised-crest option is being considered as a less costly but potentially equally effective alternative to the skeleton bay concept, discussed above. Scoping investigations suggest raising the crest of Spillbay 20 will enable a surface spill of 14,000 cfs. The Tainter gate would be operated fully open or closed. The hypothesis is similar to that of the skeleton bay, but the flow-field projected into the forebay.

Lower Granite spillbay raised-crest surface bypass--This option is similar to the John Day Dam spillbay raised-crest surface bypass, and a removable raised-crest prototype is scheduled for testing in 2001 at Lower Granite Spillbay 1. It is estimated that 6,000 cfs would be passed over the raised-crest. Also, the SFAC prototype would be partially removed, but the simulated Wells intake (SWI) would remain to occlude the upper intakes of Units 4 to 6. Since a strong lateral flow from the north occurs during zero or low spill periods, and based on efficient passage of fish at other sluiceway passage sites, the hypothesis is that juvenile migrants will pass near the strong surface-oriented flow field of Spillbay 1, discover it, and be spilled directly to tailwater.

Wanapum surface sluice chute--A surface sluice chute was investigated at Wanapum from 1986 through 1996. It is located adjacent to Spillbay 12, consists of a 20-ft-wide by 10-ft-deep gated notch in the non-overflow wall, and has a hydraulic capacity of 2,000 cfs. Mean chute passage was 6.5% of the total outmigration from 1986 to 1996, in 1.6% of the total flow (Ransom 1997).

Occlusion

An important goal of surface bypass systems is to reduce fish entrainment into turbine intakes. The SFAC does this by occluding the upper portions of the turbine intake. The BGS is a deep, long curtain and is considered an occlusion device. Occlusion devices increase the turbine flow-field intensity near the channel bottom, while reducing the flow-field intensity at mid-depth. This allows additional volitional movement and the opportunity for mid-depth fish to discover a surface bypass system entrance, potentially reducing the turbine entrainment rate.

Bonneville First Powerhouse occlusion is described above under SFAC prototype. With the 36- to 42-ft-deep SFAC prototype in place, fish either pass into the SFAC entrance slot, pass under the SFAC, or move laterally. The high effectiveness observed in 1998, and discussed above, indicates the SFAC provided attractive entrance conditions and discouraged fish movement under the SFAC and into the turbine.

The Dalles Dam blocked trashracks--The Dalles Dam turbine intake ceilings are at elevation 145 ft msl, relative to a normal operating pool elevation of 160 feet msl. Hydraulic-model studies were conducted to assess whether blocking the upper 45 ft of intake trash racks at the west end of the powerhouse down to elevation 100 ft msl would reduce turbine entrainment and increase ice and trash sluiceway passage. In 1996, hydroacoustic studies showed no effect from the blocked trashrack (BioSonics Inc. 1997). However, tests of a similar structure at Bonneville First Powerhouse in 1996 showed positive results (Ploskey et al. 1998). Tests at Lower Granite Dam in 1998 showed that higher surface bypass guidance could be achieved through use of the SWI, which is hydraulically less efficient than the single-leaf occlusion tested at The Dalles Dam in 1996. By occluding the upper turbine intake with a blockage that extends 20 ft upstream, the SWI causes the turbine to draw more flow from the lower forebay depths, reducing the intensity of downward water velocity at mid-depth. This may allow more mid-depth fish to discover surface bypass entrances, and should be considered at The Dalles Dam.

Lower Granite behavioral guidance structure (BGS) and simulated Wells Dam intake (SWI)--The BGS and SWI at Lower Granite Dam worked in tandem in 1998 to reduce the number of fish approaching turbine Units 1 to 3 (horizontal occlusion) and reduce entrainment into turbine Units 4 to 6 (vertical occlusion). Since only the three southernmost turbines (Units 1 to 3) were occluded, flow-BGS deflection angles were small. This was considered an important criterion by the design team, which was concerned that greater deflection angles would result in greater curtain tilt from vertical inclination, and potentially reduce BGS effectiveness.

Dauble et al. (1999) found that 80% of the fish approaching the BGS and turbine Units 1 to 3 passed elsewhere, and concluded that fish did not approach and guide along the BGS, but tended to stay away from it. Fish milling behavior was reduced from the entire powerhouse near-forebay to the near-forebay zone upstream from the SFAC. This suggests that a BGS may also improve spillway effectiveness and efficiency. The SWI performance was not assessed independently of the BGS, since it could not be moved to allow a blocked, randomized test sequence. The combination of BGS and SWI resulted in nearly a ten-fold increase in detections of radio-tagged fish near the dam, relative to tests conducted in 1996-1997 without the BGS and SWI, and fish meandered more before passing (Adams and Rondorf 1999). This meandering could mean fish have more opportunities to discover surface bypass entrances prior to sounding into turbine intakes. The COE plans to test a 6,000 cfs surface discharge over a raised spillbay crest with a BGS and /or SWI in 2001.

Wanapum SFAC occlusion--This configuration is discussed above under SFAC. In 1995, the horizontal distribution of passage through turbines was skewed toward turbine units not covered by the occlusion device, as compared to previous years before the occlusion was installed (Ransom et al. 1995). In addition to a shift in horizontal distribution, spillway efficiency was also higher from 1995 through 1997 (43%) than in previous years (30%) (Kumagai et al. 1996).

Rocky Reach SFAC occlusion--This configuration is discussed above under SFAC. While this occlusion device was not evaluated separately, it reduced turbine intake velocities near the intake ceiling and increased deeper turbine intake velocities. In 1996, an upstream-projecting floor-like shelf at the entrance invert elevation was also installed at turbine Units 1 to 2 in an effort to reduce fish sounding and turbine entrainment. However, it was concluded that many fish still sounded upstream from the shelf (Steig and Adeniyi 1997).

Hybrid

The surface bypass prototypes discussed above have not been as successful as the Wells Dam surface bypass system. Surface bypass alternatives continue to be developed in combination with existing project facilities such as spillways, sluiceways, and mechanical screen bypass systems to improve non-turbine passage. Examples of hybrid systems under development include the Bonneville First Powerhouse SFAC with ESBSs; The Dalles Dam turbine intake occlusion blocks with the ice and trash sluiceway; Lower Granite Dam SFAC with SWI, BGS, and ESBSs; Lower Granite Dam spillbay raised-crest surface bypass and BGS; and the Rocky Reach Dam surface bypass slots with occlusion and turbine intake screens.

JUVENILE PASSAGE THROUGH TURBINES

Background

Fish passage survival past FCRPS dams varies depending on the route of passage. As a result of reported high mortality for fish passage through turbines (Holmes 1952, Schoeneman et al. 1961, Long et al. 1968), regional efforts have focused on providing non-turbine passage routes for juvenile fish as a means to improve fish survival. Nevertheless, substantial numbers of juvenile fish will continue to pass through turbines, and minimizing turbine-related mortality is a priority of the fishery agencies and tribes. This can be accomplished through modified operations, and possibly by installing minimum gap runner (MGR) turbines or developing improved turbine designs that pass fish safely.

Operation of Existing Turbines

Turbine efficiency is considered to have a relatively direct effect on fish passage survival. Inefficient turbine operation is a result of a poor blade-to-wicket gate relationship, where efficiency drops due to turbulence and vortex shedding as a result of the rotating machinery (hub and blades) being misaligned with the hydraulic flow field coming off the stationary, but adjustable, wicket gates. Based on Oligher and Donaldson (1966), who evaluated direct fish survival under various turbine operating conditions, the relationship between survival of juvenile fish passing through Kaplan turbines is thought to be positively correlated with unit efficiency. This is based on a visual interpretation of the figures provided by Oligher and Donaldson (1966). However, a statistical evaluation of the same data sets would likely produce a low correlation between unit efficiency and fish survival, due to the variability in the data. Bell et al. (1981) reviewed all the information available, and recommended making every effort to operate turbines at peak efficiency at a given head during periods of peak fish passage to minimize fish mortality.

All mainstem FCRPS turbines are vertical-axis Kaplans, and all have six blades, except for Bonneville Dam turbines, which have five blades due to the lower head. The Kaplan design allows the blade angle to be adjusted (the blade rotated) up or down to best fit the incoming flow field, which varies with degree of wicket gate opening. Wicket gates are adjusted to control flow through the machine, and thus power output for a given head. For any given head, Kaplan turbines can operate over a wide range of power outputs and flow, and thus maintain a high level of efficiency over a broad range of operating conditions (head and load). Curves relating efficiency to unit performance (power output or flow) are developed for each head, and since head varies with forebay and tailwater elevation, a three-dimensional “hill” diagram of unit efficiency can be developed.

The 1995 BIOP (NMFS 1995a) requires that FCRPS turbines be operated within 1% of peak efficiency during the juvenile fish passage season. The COE provides the turbine operating points necessary to meet the BIOP requirement in their annual Fish Passage Plan, and any updates are coordinated with BPA, and the COE's Fish Facility Operation and Maintenance Committee.

Minimum Gap Runners (MGR)

A minimum gap runner (MGR) is a runner/hub design which minimizes the clear openings between the blade tip and the stationary discharge ring, and between the blade and the hub. The concept is to reduce the clearance openings in the runner to levels which are technically reasonable without causing mechanical interference between moving parts, while maintaining reasonable performance. MGRs reduce the opportunity for fish to be entrained in high velocity discharges through these narrow gaps, which is potentially harmful to fish (Eicher Associates Inc. 1987, COE 1995b). Another benefit of the MGR is that it usually results in increased peak turbine efficiency (Rod Wittinger, Portland District, COE, Pers. commun, August 1999).

To minimize the gaps near the hub, the shape of the runner hub must be modified to conform to the turbine blades in both the open and closed position. The simplest solution is to use a spherical hub to maintain a nearly uniform gap throughout the normal range of blade movement. Combined with the spherical hub is a specially shaped runner cone which allows the water passing the blades to exit with a constant velocity and without excessive turbulence. Closing the gaps at the hub reduces leakage and increases turbine efficiency, but the shape change of the hub and cone decrease efficiency if the blades move very far from the design conditions (Rod Wittinger, Portland District, COE, Pers. commun, August 1999).

Minimizing the blade-tip gap throughout the blade range poses a different design challenge. For a standard machine, the blade periphery is cut in a spherical shape corresponding to a discharge ring. The discharge ring is spherical below the axis of rotation of the turbine blades and conical above, allowing the turbine runner to be removed from above for maintenance. In the MGR, the spherical portion of the discharge ring extends upward above the axis of rotation of the runner and encompasses a greater portion, if not all, of the runner tip. This is accomplished by installing a spherical-shaped discharge ring which conforms to the shape of the runner tip after the turbine runner has been installed.

MGRs have been designed and are being installed in all ten units of the Bonneville First Powerhouse. Peak unit efficiency has been increased with the MGR to 95% from the former units which were 88% efficient. The efficiency curves of an MGR design are steeper, more a "peak" than the broad "hill" seen with standard Kaplan designs. These steeper curves mean that if the machines are operated within 1% of peak efficiency for fish passage, the operating range will be narrower than for the present machines, and the "capacity" of the powerhouse will be reduced. Fish survival through the new MGR turbines at Bonneville First Powerhouse will be tested starting in fall 1999.

COE Turbine Passage Survival Program (TSP)

The Turbine Passage Survival Program (TSP) was developed to investigate means to improve the survival of juvenile salmon as they pass through Kaplan turbines at Columbia and Snake River dams. The TSP is one part of the COE Columbia River Fish Mitigation Program (COE 1998c). The TSP utilizes hydraulic models of the turbine passage environment, located at the COE WES, to observe the behavior of beads and dye and to identify where fish mortality may be occurring within the turbine. These sources of mortality are then evaluated through point-specific releases of balloon-tagged fish through the areas in question.

At McNary Dam in 1999, balloon-tagged fish were released through rigid release pipes installed at location to allow survival probabilities to be estimated for fish passing through four areas of the turbine: mid-blade, blade hub, blade tip, and upstream of the stay vanes/wicket gates. The mid-blade area of the runner is considered the most benign, and the other three releases targeted areas of passage concern, based on hydraulic model studies at the COE WES. The relative survival probabilities for the three releases relative to the mid-blade release exceeded 0.97, and all survival probabilities were not significantly different ($P>0.10$) from each other or from the hypothesized ration of 1.0 (Normandeau et al. 1999).

JUVENILE SURVIVAL

Spill Survival

Whitney et al. (1997) reviewed 13 estimates of spill mortality for salmonids (3 steelhead and 10 salmon) published through 1995 and concluded that 0 to 2% is the most likely mortality range for standard spillbays. They also pointed out that local conditions, such as back eddies or other situations that may favor the presence of predators, may lead to higher spill mortality.

Some point estimates for mortality in spillbays with spill deflectors are higher than estimates for spillbays without deflectors. For example, the highest estimates of survival for yearling chinook salmon and steelhead were obtained from spillbays without flow deflectors, ranging from 98.4 to 100% (Muir et al. 1995b, 1996, 1998). Although lower survival estimates were obtained from spillbays with flow defectors (ranging from 92.7 to 100%) (Iwamoto et al. 1994; Muir et al. 1995b, 1998), differences in survival between the two types of spillbays compared pairwise were not significant at Little Goose (steelhead), or Lower Monumental Dams (yearling chinook salmon).

A number of methodologies have been used to estimate spillway survival at lower Columbia River dams, including identification of test fish by fin clips (Holmes 1952), freeze brands (Johnsen and Dawley 1974, Raymond and Sims 1980), coded-wire tags and freeze brands (Ledgerwood et al. 1990), balloon tags (Normandeau Associates Inc. et al. 1996a, b), and PIT tags (Dawley et al. 1998b, 1999).

At Bonneville Dam, Homes (1952) estimated that subyearling chinook salmon survival through the spillway was 96 to 97%, depending on how the data were analyzed. Johnsen and Dawley (1974) compared the survival of subyearling chinook salmon passing through spillbays with and without flow deflectors, and found that relative survival was 87 and 96%, respectively, and that these differences were not statistically different. Ledgerwood et al. (1990) found that survival of subyearling chinook through spillbay 5 was not significantly different than for fish released downstream. Based on the balloon-tag methodology, the calculated survival probabilities for deflector and non-deflector spillways were both 1.0 at Bonneville Dam, however, fish passing through a spillbay without a spill deflector displayed a slightly higher injury rate (Normandeau et al. 1996a).

At The Dalles Dam, Dawley et al. (1998b) released PIT tagged subyearling chinook and coho salmon in 1997, and estimated spillway survival of 87 and 92%, respectively, with 64% spill. Results from a 1998 study (Dawley et al. 1999) show that relative survival rates during 64% spill were 88% for coho salmon and 76% for subyearling chinook salmon, while during 30% spill, survival was 96 and 92% for coho and subyearling chinook salmon, respectively. Preliminary analysis of data from 1999 show that relative survival rates during 64% spill were 94% for coho salmon and 96% for subyearling chinook salmon, while during 30% spill, survival was 93 and 99% for coho and subyearling chinook salmon, respectively (Earl Dawley, NMFS, Pers. commun., September 1999).

Estimates of spillway passage survival at John Day Dam are limited to a single study conducted in 1979 by Raymond and Sims (1980), who found that spillway mortality relative to the tailrace was not different from 0. PIT-tag estimates of spillway survival are presented in Table

8.

Table 8. Test conditions, number of replicates, number of PIT-tagged fish released, and survival estimates (standard error) through various routes of passage for turbine, bypass and spillway releases at Lower Granite (LGR), Little Goose (LGO), and Lower Monumental (LMO) Dams, 1993 to 1997.

Release location	Dam	Year	Species	Locations/ conditions	No. of replicates	No. of fish released (treatment/control)	Survival (s.e.)	Reference
Spillway	LGR	1996	Steelhead	Bay 1, 3.9 kcfs	5	7,491/7,468	1.010 (0.019)	Smith et al. 1998
(no deflector)	LGO	1997	Steelhead	Bay 1, 4.9 to 10 kcfs	14	6,736/6,953	1.004 (0.015)	Muir et al. 1998
	LMO	1994	Yearling chinook	Bay 8, 4.4 to 4.8 kcfs	3	4,157/4,243	0.984 (0.033)	Muir et al. 1995b
Spillway	LGO	1993	Yearling chinook	Bay 3, 3.8 kcfs	3	2,328/2,201	1.021 (0.026)	Iwamoto et al. 1994
(with deflector)	LGO	1997	Steelhead	Bay 3, 4.9 to 10 kcfs	15	7,494/7,453	0.972 (0.015)	Muir et al. 1998
	LMO	1994	Yearling chinook	Bay 7, 4.4 to 4.8 kcfs	3	4,206/4,243	0.927 (0.023)	Muir et al. 1995b
Bypass	LGR	1994	Yearling chinook	Unit 6A, Col. chan.	3	3,896/2,194	0.994 (0.030)	Muir et al. 1995a
	LGR	1995	Yearling chinook	Unit 6A, Col. chan.	4	3,130/3,021	0.976 (0.036)	Muir et al. 1996
	LGR	1995	Steelhead	Unit 6A, Col. chan.	5	3,747/3,763	0.983 (0.019)	Muir et al. 1996
	LGO	1994	Yearling chinook	Unit 6C, Col. chan.	3	3,407/2,225	0.994 (0.023)	Muir et al. 1995a

Table 8.–Continued

Release location	Dam	Year	Species	Locations/ conditions	No. of replicates	No. of fish released (treatment/control)	Survival (s.e.)	Reference
Bypass	LGO	1995	Steelhead	Unit 6C, Col. chan.	5	3,097/3,653	0.979 (0.031)	Muir et al. 1996
	LGO	1997	Steelhead	Unit 6B, Trashrack.	12	6,847/5,953	0.953 (0.016)	Muir et al. 1998
	LMO	1995	Yearling chinook	Unit 6C, Col. chan.	5	4,197/3,783	0.954 (0.034)	Muir et al. 1996
	LMO	1995	Steelhead	Unit 6C, Col. chan.	5	4,120/3,746	0.929 (0.060)	Muir et al. 1996
Turbine	LGR	1995	Yearling chinook	Unit 4B, 135 MW	2	3,236/1,581	0.927 (0.027)	Muir et al. 1996
	LGO	1993	Yearling chinook	Unit 6B, 135 MW	3	2,236/2,201	0.920 (0.025)	Iwamoto et al. 1994
	LGO	1997	Steelhead	Unit 6B, 135 MW	13	6,215/6,505	0.934 (0.016)	Muir et al. 1998
	LMO	1994	Yearling chinook	Unit 6B, 135 MW	2	2,838/2,841	0.865 (0.018)	Muir et al. 1995a

Bypass Survival

Estimated survival through bypass systems based on PIT-tagged fish ranged from 95.4 to 99.4% for yearling chinook salmon and from 92.9 to 98.3% for steelhead for groups released into the collection channel (Table 8) (Muir et al. 1995a, 1996, 1998). Estimated survival was 95.3% for steelhead that passed through the entire bypass system at Little Goose Dam in 1997 (Muir et al. 1998).

Ledgerwood et al. (1994) evaluated survival through the Bonneville First Powerhouse juvenile bypass system. They found that recoveries of marked subyearling chinook salmon in the estuary were significantly reduced for fish released into the bypass system, compared to fish released 2.5 km downstream. Recovery percentages for bypassed fish were 28.2% lower than for the fish released downstream.

Turbine Survival

Iwamoto and Williams (1993) reviewed the research conducted through 1992 on fish survival through Columbia River turbines. They concluded that turbine survival, taken as a whole, averaged approximately 90% per dam. They expressed a number of weaknesses in the data base, including the use of various methodologies and that many tests were conducted under conditions which no longer exist. They also concluded that the fundamental relationships between physical variables in the turbine environment and biological variables as they relate to turbine passage and survival, had not been established. A more recent review (COE 1995b) similarly concluded that most turbine passage studies provided estimates of survival but not the causes of mortality. The COE is attempting to understand the causal mechanisms of mortality through the Turbine Survival Program.

PIT tags have recently been used to measure total (direct and indirect) survival. NMFS conducted survival studies through turbines at Snake River dams using PIT-tagged fish and found that estimated turbine survival ranged from 86.5 to 92.7% for yearling chinook salmon and was 93.4% for steelhead at Little Goose Dam in 1997 (Table 8) (Iwamoto et al. 1994, Muir et al. 1995a, 1996, 1998). At Lower Monumental Dam estimated turbine survival for yearling chinook was 86.5% (Muir et al. in prep).

Since the Iwamoto and Williams (1993) review, additional estimates of survival through turbines have been made using an inflatable balloon tag, which provides a measure of direct turbine mortality from point of release to the point of recapture in the immediate tailrace. Several studies with balloon tags evaluated survival at different release locations and unit operating conditions, and survival was generally in the mid-90% range (Normandeau Associates Inc.et al. 1995, Mathur et al. 1996). Normandeau Associates Inc. et al. (1996c) found a significant difference in survival probability with depth of release at Wanapum Dam, and 30 ft depth had a higher survival probability than 10 ft depth. They found no significant difference ($P>0.05$) between survival and turbine discharge for either depth. They noted a relationship between survival and theoretical turbine avoidable losses, where the highest survival coincided with the lowest avoidable losses. The theoretical turbine avoidable losses (in turbine efficiency) are lowest at the operating point of 15,000 cfs discharge, where hydraulic inefficiency due to turbulence in minimal. They suggest the relationship was negative and stronger for 10 than 30 ft depth. Although they state a relationship exists, no statistical analyses are presented, and the relationship appears to be a trend based on limited data. Franke et al. (1997) considered these results when developing a hypothesis that fish survival should not decline at turbine operations above peak efficiency. They suggested that efficiency losses at high gate-settings are due to physical losses from friction, when more water is forced through a fixed turbine structure and area, and not from hydraulic losses that are normally thought to be a cause of fish mortality. The relationship between survival and operating beyond peak efficiency has been theorized, but not rigorously established to date.

Project Survival

At Little Goose Dam in 1997, where survival through all passage routes was evaluated simultaneously, estimated survival was highest for PIT-tagged hatchery steelhead released into the spillbay without a flow deflector, followed by a spillbay with a flow deflector, the bypass, and the turbine (Table 8). ANOVA showed significant differences among means ($F = 3.79$, $P = 0.016$) with survival for fish released into the spillbay without a flow deflector significantly higher than for those released in the bypass and turbine locations. No other contrasts of means were significant. These estimates of survival, which include both direct and indirect effects of passage, are generally higher than past estimates (Whitney et al. 1997, FPC 1995), but similar to other recent estimates using modern techniques under present dam configurations and operating conditions (Normandeau Associates et al. 1995, 1997).

Survival was estimated for PIT-tagged juvenile chinook salmon and steelhead that migrated through Snake River dams and reservoirs from 1993 through 1998 (Iwamoto et al. 1994; Muir et al. 1995a, 1996; Smith et al. 1998; Hockersmith et al. 1999). The Single-Release Model (a multiple-recapture model) was used to estimate survival based on detections of PIT-tagged fish at downstream dams. The length of river over which survival estimates were made varied between years and was dependant on the number of dams with the capability to detect and re-release PIT-tagged fish back to the river, the total number of fish marked, and the efficiency of detection of PIT-tagged fish at each dam. Precision of survival estimates varied with the number of fish PIT-tagged and released, and the amount of spill at dams with PIT-tag detectors. When spill levels were high, detection probabilities were lower and precision was decreased. Mortality at bypass outfall sites (an important model assumption) was insignificant at all of the Snake River dams investigated. Per project (a combination of reservoir and dam passage) survivals averaged from 86 to 94% for yearling chinook salmon and from 88 to 92% for hatchery steelhead each year. Per project survivals were higher for both species in years when spill was used to pass fish through non-turbine routes. The per project survival estimates over the same stretches of river from 1970 through 1975, under similar flow conditions, averaged from 57 to 71% for yearling chinook salmon and 77 to 89% for steelhead each year (per project survival calculated from reach survival estimates presented by Raymond (1979).

For 1997, the survival of hatchery steelhead passing through Little Goose Dam was estimated at 96% and was nearly equal to the estimated reach survival from Lower Granite Dam tailrace to Little Goose Dam tailrace of 95.4%, resulting in less than 1.0% estimated reservoir mortality during that year in that reach (Hockersmith et al. 1999). Similar reach survival estimates through other reaches of the Snake River and during other years indicated that most juvenile salmonid mortality during the spring migration is associated with dam passage.

Reach Survival

Raymond (1979) provided survival estimates from the mid-1960s through 1975 for juvenile migrant spring/summer chinook salmon and steelhead that migrated downstream through the majority of the hydropower system. Additional estimates for the years 1976 through 1980 were made by NMFS researchers (unpublished data). These estimates clearly showed the substantial decrease in downstream migrant survival that occurred with the completion of the hydropower system. The estimates did not account for decreased survival for fish that passed through either John Day or The Dalles Dam (downstream dam where research was conducted was not the same in all years) and in all cases did not include passage through the Bonneville reservoir and dam. Nonetheless, the low measured survival rates were the onus to make changes to dams to increase fish survival. Much of these efforts related to installing or improving juvenile bypass systems and increasing passage through spill (discussed in the previous sections) with the expectation that they would increase survival of downstream migrant fish.

Beginning in 1993, NMFS researchers began to re-evaluate survival of downstream migrant fish through the hydropower system. The studies used PIT-tagged fish and newly installed PIT-tag facilities at dams. The first years of study covered only a short stretch of the hydropower system. As new facilities were installed, recoveries at sites downstream of Bonneville Dam became possible, and larger numbers of fish were PIT tagged, the reaches over which survival estimates were made increased. By 1999, direct estimates of survival were possible for downstream migrant steelhead and spring/summer chinook salmon from the tailrace of Lower Granite Dam to the tailrace of Bonneville Dam (Table 9 from Williams et al. unpublished manuscript in review).

Williams et al. (unpublished manuscript in review) expanded the 1960s and 1970s survival estimates to estimate survival of yearling salmonid migrants from the head of the upstream reservoir (Ice Harbor Dam through 1968, Lower Monumental in 1969, Little Goose Dam from 1970 to 1974, and Lower Granite Dam since 1975) to the tailrace of Bonneville Dam to compare with expanded estimates from 1993 through 1999. Results indicate that direct survival of yearling migrant fish through the hydropower system in recent years under good flow conditions and as a result of changes to the FCRPS based on the NMFS 1995 BiOp is now as high or higher than it was after completion of the mainstem hydropower system (Tables 10 and 11). Efforts to improve direct survival through the FCRPS have worked.

Table 9. Reach survival estimates from PIT-tag data, 1993-1999. Abbreviations: res-Lower Granite Dam reservoir; lgr-Lower Granite Dam; lgo-Little Goose Dam; lmo-Lower Monumental Dam; mcn-McNary Dam.

	Survival through Lower Granite Reservoir and Dam		X	Survival from Lower Granite Dam tailrace to tailrace of lower dam			=	Survival from Lower Granite Reservoir to tailrace of lower dam		
Year	Chinook salmon	Steelhead		Reach (no. projects)	Chinook salmon	Steelhead		Reach (no. projects)	Chinook salmon	Steelhead
1993	0.89	—		lgr-lgo (1)	0.84	—		res-lgo (2)	0.75	—
1994	0.92	0.90		lgr-lmo (2)	0.70	0.77		res-lmo (3)	0.64	0.69
1995	0.92	0.91		lgr-mcn (4)	0.72	0.74		res-mcn (5)	0.66	0.67
1996	—	0.94		lgr-mcn (4)	0.65	0.69		res-mcn (5)	—	0.65
1997	—	—		lgr-mcn (4)	0.65	0.73		lgr-bon (7)	—	0.47
				mcn-bon (3)	—	0.65				
1998	—	—		lgr-mcn (4)	0.77	0.65		lgr-bon (7)	—	0.50
				mcn-bon (3)	—	0.77				
1999	—	—		lgr-mcn (4)	0.79	0.69		lgr-bon (7)	0.56	0.50
				mcn-bon (3)	0.72	0.72				

Table 10. System survival estimates for 1966-1980 from the upper reservoir on the Snake River (Ice Harbor Dam 1966-68, Lower Monumental Dam 1969, Little Goose Dam 1970-74, and Lower Granite Dam 1975-80) to the tailrace of Bonneville Dam. Abbreviations: lgr-Lower Granite Dam; lgo-Little Goose Dam; lmo-Lower Monumental Dam; ihr-Ice Harbor Dam; mcn-McNary Dam; jda-John Day Dam; tda-The Dalles Dam; bon-Bonneville Dam.

	Survival from upper Snake River dam to lower river dam		X	Extrapolated survival outside research reach		=	Overall system survival		
Year	Reach (no. projects)	Chinook salmon	Steelhead	No. projects	Chinook salmon	Steelhead	Reach (no. projects)	Chinook salmon	Steelhead
	After Raymond (1979) (See Table 1)								
1966	ihr-tda (2)	0.63	0.75	2	0.63	0.75	ihr-bon (4)	0.40	0.56
1967	ihr-tda (2)	0.64	0.57	2	0.64	0.57	ihr-bon (4)	0.41	0.32
1968	ihr-tda (3)	0.62	0.60	2	0.73	0.71	ihr-bon (5)	0.45	0.43
1969	lmo-tda (4)	0.47	0.36	2	0.73	0.56	lmo-bon (6)	0.34	0.20
1970	lgo-tda (5)	0.22	0.38	2	0.77	0.61	lgo-bon (7)	0.17	0.24
1971	lgo-tda (5)	0.28	0.32	2	0.71	0.54	lgo-bon (7)	0.20	0.17
1972	lgo-tda (5)	0.16	0.20	2	0.56	0.48	lgo-bon (7)	0.09	0.09
1973	lgo-tda (5)	0.05	0.04	2	0.56	0.28	lgo-bon (7)	0.03	0.01
1974	lgo-tda (5)	0.36	0.20	2	0.80	0.40	lgo-bon (7)	0.28	0.08
1975	lgr-tda (6)	0.25	0.41	2	0.78	0.67	lgr-bon (8)	0.19	0.27
	From unpublished USNMFS data								
1976	lgr-jda (5)	0.30	0.36	3	0.33	0.35	lgr-bon (8)	0.10	0.13
1977	lgr-jda (5)	0.03	0.02	3	0.12	0.10	lgr-bon (8)	0.04	0.02
1978	lgr-jda (5)	0.47	0.33	3	0.51	0.27	lgr-bon (8)	0.24	0.09
1979	lgr-jda (5)	0.34	0.10	3	0.61	0.31	lgr-bon (8)	0.21	0.03
1980	lgr-jda (5)	0.36	0.21	3	0.41	0.13	lgr-bon (8)	0.15	0.03

Table 11. System survival estimates for 1993-1999 from Lower Granite Dam reservoir to the tailrace of Bonneville Dam. Abbreviations: res-Lower Granite Dam reservoir; lgr-Lower Granite Dam; lgo-Little Goose Dam; lmo-Lower Monumental Dam; mcn-McNary Dam; bon-Bonneville Dam.

	Research reach (no. projects)		Survival through research reach		X	Extrapolated survival outside research reach			=	Overall system survival	
Year	Chinook salmon	Steelhead	Chinook salmon	Steelhead		Reach (no. projects)	Chinook salmon	Steelhead		Chinook salmon	Steelhead
1993	res-lgo (2)	—	0.75	—		lgo-bon (6)	0.43	—		0.32	—
1994	res-lmo (3)	res-lmo (3)	0.64	0.69		lmo-bon (5)	0.48	0.54		0.31	0.38
1995	res-mcn (5)	res-mcn (5)	0.66	0.67		mcn-bon (3)	0.78	0.79		0.51	0.53
1996	lgr-mcn (4)	res-mcn (5)	0.65	0.65		res-lgr (1) mcn-bon (3)	0.90 0.72	— 0.77		0.42	0.50
1997	lgr-mcn (4)	lgr-bon (7)	0.65	0.47		res-lgr (1) mcn-bon (4)	0.90 0.72	0.92 —		0.43	0.44
1998	lgr-mcn (4)	lgr-bon (7)	0.77	0.50		res-lgr (1) mcn-bon (4)	0.94 0.82	0.90 —		0.59	0.45
1999	lgr-bon (7)	lgr-bon (7)	0.56	0.50		res-lgr (1)	0.94	0.91		0.53	0.45

KEY UNCERTAINTIES ASSOCIATED WITH JUVENILE PASSAGE

In recent years, the regional process known as the Plan for Analyzing and Testing Hypotheses (PATH), and the Independent Scientific Advisory Board (ISAB) for the Northwest Power Planning Council and the National Marine Fisheries Service, have reviewed numerous data sets associated with dam passage on the Columbia and Snake Rivers. These reviews have identified a number of uncertainties that exist with respect to the data.

Potential Effects of Passage Through Juvenile Bypass Systems

Passive integrated transponder (PIT) tags have recently been developed (Prentice et al. 1990a, b, c). The tags are a uniquely-coded computer chip that allow each tagged animal to be individually identified. Systems to recover these tags were developed and installed within many mainstem dam juvenile bypass systems. The systems detect and record the PIT-tag codes as juvenile fish migrate downstream. Data from these detections are used to estimate collection efficiency, survival probability, migrational timing to and between dams, and in subsequent detection as adults, smolt-to-adult return percentages (SARs) (Sandford and Smith in prep.).

The PIT-tag methodology enables estimates of juvenile survival to be made for both dams and river reaches. For example, Muir et al. (in prep.) found that yearling chinook salmon survival was highest through spillbays without flow deflectors (98.4-100%), followed by spillbays with flow deflectors (92.7-100%), bypass systems (95.3-99.4%), and turbines (86.5-93.4%). These measures of juvenile survival are important for making decisions on how to operate and configure the FCRPS. However, SARs are perhaps a more complete measure of stock performance through the hydrosystem, since SARs incorporate both direct and indirect effects of dam and hydrosystem passage. Sandford and Smith (in prep.) developed statistical methods to obtain SARs for juvenile hatchery and wild spring/summer chinook salmon and steelhead PIT tagged at and above Lower Granite Dam from 1990 through 1995. They found that SARs estimated from Lower Granite Dam tailrace to the Lower Granite Dam adult detector were generally less than 1.0%, and many estimates were smaller than 0.5%. Adult returns from 1990 to 1994 juvenile releases were low, making inferences from these data sets tenuous at best. The estimated 95% confidence intervals were wide, representing significant variability due to the estimation process and small numbers of adult returns.

Major exceptions were for PIT-tagged hatchery and wild spring/summer chinook salmon smolts released at Lower Granite Dam in 1995, which produced relatively large numbers of returning adults. Adult returns from the 1995 outmigration were sufficient to provide reliable information for fish that were marked above Lower Granite Dam and had subsequently passed downstream through zero, one, two, or three juvenile bypass system PIT-tag detection facilities (Sandford and Smith, in prep.). Hatchery spring/summer chinook salmon SARs were 0.53, 0.42, 0.24 and 0.18% for fish that passed through the bypass systems at Lower Granite, Little Goose, Lower Monumental, and McNary Dams, respectively. Fish that passed through more than one bypass system had an average return rate of 0.25%, while fish that were never detected (assumed to have never passed through a bypass system and thus passed through turbines or spill) had a 0.39% return rate. Wild spring/summer chinook salmon returns were lower than the hatchery returns, but in general, displayed similar trends.

The information in this single study suggested that survival rates differed depending on which, and how many bypass systems PIT-tagged juveniles passed through. In general, SARs were higher if the fish passed the through Lower Granite or Little Goose Dam juvenile bypass facilities, and lower if they passed through the Lower Monumental and McNary Dam bypass facilities. Also, in general, SARs were lower as bypass frequency increased.

Preliminary, unpublished data on SARs from the 1996 and 1997 juvenile outmigrations are now available through the PITAGIS database maintained by the Pacific States Marine Fisheries Commission. Numbers of adults returning from the 1996 outmigration were too few to provide meaningful comparisons. However, hatchery spring/summer chinook salmon returns from the 1997 outmigration were sufficient to provide preliminary conclusions. SARs for 1997 were 0.50, 0.51, 0.59, and 0.53% for fish that passed through Lower Granite, Little Goose, Lower Monumental, and McNary Dam bypass systems, respectively. In contrast to 1995, these data indicated little difference between individual bypass systems. SARs for fish never detected, bypassed once, and bypassed more than once showed a somewhat decreasing trend, and ranged from 0.57 to 0.44%, respectively.

The cause of this apparent reduction in SARs for fish that has passed through multiple bypass systems, and the differences in SARs between individual dam bypass systems and between years (1995 and 1997), is unknown. SAR differences may have resulted from poor read rates on a batch of PIT tags used in 1995 (Bill Muir, NMFS, Pers. commun., August 1999), poor bypass outfall survival at specific dams, or problems associated with passing through specific components of the bypass systems at certain dams, such as the PIT-tag diversion systems. In 1999, NMFS estimated survival through the Lower Monumental Dam juvenile bypass system to evaluate whether passing through the smolt monitoring component of the bypass system reduced survival. PIT-tagged hatchery spring/summer chinook salmon were released downstream from the primary dewatering facility. The treatment fish were either bypassed directly to the outfall and river or passed through the smolt monitoring facility and then bypassed to the outfall and river. Preliminary analysis of these data indicated no significant differences between the treatments, and that relative survivals (treatment compared to tailrace releases) for both releases were near 100% (Eric Hockersmith, NMFS, Pers. commun., 30 August 1999).

The relationship between lower SARs and increased smolt bypass frequency suggested by the 1995 data could also be a result of an effect that has not yet been recognized in direct measurements of juvenile survival. Flows and turbidity were considerably higher in 1997 than 1995, which may have reduced predation at bypass outfalls, at least partially explaining the differences in SARs observed between 1995 and 1997.

Additional data on passage through multiple bypass systems collected over a longer time frame are needed to account for variation in environmental (freshwater and ocean) conditions. Additionally, ongoing studies of individual and multiple bypass passages and the relationship between blood chemistry indicators and fish survival will need to be completed, before the uncertainty associated with the potential effects of passage through juvenile bypass systems can be resolved.

Limitations in Performance Measures

The ISAB suggested that there is a need for a "common currency" of stock-specific performance when measuring the results of hydrosystem improvements (Bisson et al. 1999). They pointed out that management goals for population size are set at the individual stock or spawning population levels, whereas passage measures at dams are evaluated across the entire outmigration for a species or life history type. The performance data collected depends on the methods used. For example, fyke-net estimates of FGE are species-specific or life history specific, but hydroacoustic estimates of FGE generate a value for all targets observed, including non-salmonids. Further, fyke-net estimates are generated during 2-hour evening sampling periods from the main portion of the outmigration, to capture sufficient numbers of fish to estimate performance. Hydroacoustic estimates are benign, and can be collected for 24 hours per day over the entire migration season. Each passage research methodology has strengths and weaknesses, and many are used together to form a more complete data set. Only the PIT tag can be used to assess stock-specific performance, but it too has limitations, usually the number of fish that can be marked and detected. Until new sampling technologies are developed and the abundances of individual populations increase, the ISAB's comment on performance measures remains valid.

Selective Forces

The ISAB asserts that dams have acted as selective forces and reduce biodiversity (Bisson et al. 1999). They believe there is ample evidence to support this statement, based on observed variance in juvenile bypass system collection efficiencies for species and life histories. However, no direct measures of biodiversity are presented or cited to support their statement. The long-term effects that juvenile passage routes such as spill and surface bypass systems may have on all salmonid stocks and non-salmonid anadromous species are unknown. Therefore, uncertainty exists as to whether dam passage systems act as a selective pressure on populations that reduces biodiversity.

Extra Mortality

Time series of adult returns for salmon and steelhead indicate that many stocks declined throughout the Pacific Northwest in the late 1970s (NRC 1996). However, stocks from the Snake River appeared to decline more than mid-Columbia stocks. PATH has conducted extensive modeling on the effects of the hydrosystem on salmonid populations and recovery. PATH accounted for juvenile salmonid losses that occurred during their downstream migration through all or part of the FCRPS. However, additional losses must have occurred to have produced the low SARs observed for many of the spring/summer chinook salmon index stocks. The unexplained mortality associated with the Snake River stocks is called "extra mortality" (NMFS 1999a). PATH developed three hypotheses to explain the sources of the extra mortality: hydrosystem, ocean regime shift, and stock viability degradation (Marmorek and Peters 1998). Hydrosystem extra mortality includes any effect of the hydrosystem on salmonid survival that is not measured during the juvenile or adult migration through the hydrosystem corridor.

Conceptually, differential delayed mortality from transportation is a special category of “extra mortality” experienced only by transported fish, but it is not standardly referred to as a form of extra mortality (since it has its “own label”). An example of how the hydrosystem could produce extra mortality is the effect that hydro-regulation may have on flow timing, and thus ocean entry timing and subsequent survival. The ocean regime shift hypothesis attributes the recent low survival of salmonids to cyclical changes in ocean conditions. The stock viability degradation hypothesis represents the potential negative effects of many factors, including the effects of hatcheries on wild stocks, effects of diseases, bird predation associated with man-made dredge disposal islands in the estuary, inbreeding depression, etc. Therefore, uncertainty exists over whether the source of the extra mortality is caused by the hydrosystem or other factors. Additional studies will be required to clarify the true cause(s) of any uncertainty associated with this observed extra mortality.

ADULT PASSAGE

Background

Available information on adult migrations through the Snake River was synthesized by Bjornn and Peery (1992). They provided a thorough compilation of published and unpublished information on adult steelhead and chinook salmon migrational behavior through 1991. This review also included information on sockeye and coho salmon from sites outside the Snake River. We utilize the Bjornn and Peery (1992) synthesis, and add information collected from studies since 1991.

Adult Passage Criteria

All eight mainstem dams from Bonneville through Lower Granite Dams provide upstream passage for adult salmon and steelhead through one or more fish ladders. The ladder systems are operated according to criteria developed by the COE, NMFS, and state and tribal fishery co-managers. Each criterion is based on the results of biological testing to determine the hydraulic conditions that maximize fish attraction and minimize delay.

The COE annually coordinates with salmon managers and publishes the Fish Passage Plan (FPP), which provides detailed operating procedures and criteria for spill; turbine operation; juvenile fish collection, holding, and transportation; and adult fish passage facilities (COE 1999d). The FPP prescribes the required hydraulic operating criteria for all aspects of the adult passage facilities, including the depth and head on the entrance gates, powerhouse collection channels, floating orifices, ladder flow, counting windows, and ladder exits (COE 1999d).

Adult Passage System Issues

There is a significant backlog of unfunded maintenance and repair projects on entrance gates and gate lifting machinery at Snake and Columbia River dams. Also, the AWS systems on the Snake River projects cannot supply sufficient water to meet the required minimum of 1.0-ft differential on some the entrance gates, while the downstream projects are operating at MOP during periods of low river flow.

At Lower Monumental, Little Goose, and Lower Granite Dams, all ladder entrances are served by a single AWS pump station. Ladder entrances located on the opposite side of the spillway from the pump station cannot satisfy the established flow criteria. During high flow conditions, the submergence and head differential criteria for south entrances at Lower Monumental and the north entrances at Little Goose and Lower Granite Dams have been reduced.

The 1995 BIOP (NMFS 1995a) requires the COE to provide an emergency AWS source at each project that will satisfy fishway criteria if the main system fails. Engineering studies have been completed for all projects except Little Goose and Lower Granite Dams. The Walla Walla District has selected a contractor to complete the design studies for these projects. John Day and McNary Dams were able to meet the BIOP requirement with existing facilities. Engineering alternatives for meeting emergency AWS capability at The Dalles Dam and Bonneville Second Powerhouse are being evaluated.

Jumping in and from fish ladders (mainly steelhead at John Day Dam) has been associated with the transition from overflow weirs to vertical slot weirs, and with diffuser flow at the top of ladders (Dresser 1998).

Migration Behavior

The Oregon Fish Commission conducted the earliest study of migration rates in the Snake River prior to impoundment. From 1954 to 1957, chinook salmon averaged 17.7 to 24.1 km/day. Steelhead migration rates varied with the season; spring rates averaged 11.3 to 16.0 km/day, whereas fall rates averaged 8.0 to 9.7 km/day. Sockeye averaged 19.3 km/day to a weir at Redfish Lake, more than 600 km upstream. In a separate study, steelhead tagged at McNary Dam in January, February, and April migrated at an average rate of 3.2, 3.9, and 12.2 km/day, respectively. The effect of season and water temperature on steelhead migration rates was also seen in studies conducted from 1969 to 1971, where steelhead had summer migration rates of 10.7 to 16.7 km/day, and as low as 0.5 km/day during the late fall. The earlier studies were supported by Bjornn and Peery (1992) who concluded, from migration rates in free flowing stretches of river, that in the Snake River prior to impoundment, salmon migrated from 18 to 24 km/day, and steelhead migration rates varied with season and water temperature, and ranged from 11 to 17 km/day during the spring and summer to as low as 0.5 km/day during the late fall.

As salmonids move up the Columbia and Snake Rivers and through the reservoirs today with the FCRPS impoundments, there is a tendency to stay near the shore. This seems to hold true for all species. This trend is documented by arrival locations at dams and by tracking individual radio-tagged fish. Data from individual fish tracks indicate crossing between sides of the river or reservoir occurs at what appear to be random locations.

Natural migration behavior is a concern when designing fishway entrances and exits. Locating large fishway entrances on shorelines produces high net entrance rates (number of fish entering orifices minus number of fish leaving), and high fishway entrance efficiency (entrances that produce passages). Locating fishway exits on shorelines increases the probability that fish will continue upstream after exiting the fish ladders and reduces the chance of falling back downstream through the spillway. At Bonneville Dam the left bank (south shore) fish ladder exits upstream at an island (Bradford Island). Shoreline migrants moving upstream from the exit arrive at the spillway, shoreline migrants moving downstream from the exit arrive at the powerhouse. When only fallbacks within 24 hours of passage are considered, 92 to 97% of all fish that fell back at Bonneville Dam between 1996 and 1998 had used the Bradford Island fishway (Bjornn et al. 1998a).

First approach locations at the dam change as the portion of river discharge changes from the powerhouses to the spillway. In general, with no spill most fish approach the dam on the shoreline adjacent to the powerhouse and as spill starts, a portion of those fish move to the shoreline adjacent to the spillway. At moderate spillway rates, more fish approach the dam at the junction of the powerhouse and the spillway. At the highest spill rates (usually associated with high river discharge), very few fish enter the fishways.

Once at the dam, fish search across the downstream face looking for passage routes. Entrance preferences are for deep/wide openings with significant attraction flow. Shallower/smaller openings tend to have low numbers of entrances and negative net entrance rates. Median times for chinook salmon to first enter fishways were 1.9 to 2.6 hours at Ice Harbor and Lower Granite Dams in 1993 and 1994 (98.7 and 98.9% entered in less than 5 days). At Lower Monumental and Little Goose Dams, 98.5 and 98.2% entered in less than 5 days, and median times to first entries were 4.6 and 3.9 hours, respectively (Bjornn 1998b). Preliminary first entry time data from ongoing studies in the lower Columbia River are comparable to those at the three lower Snake River dams. At Bonneville Dam, chinook salmon median first entry times were 2.0 and 2.2 hours in 1996 and 1997; steelhead median first entry times were 1.9 and 0.3 hours in 1996 and 1997, respectively. First entry times ranged from 0 (when the first at-dam record was in the collection channel) to 20 days for chinook salmon and 17.8 days for steelhead.

Spring/summer chinook salmon migration rates through the Snake River reservoirs in 1991 to 1993 ranged from 31 to 65 km/day while migration rates through free flowing river sections above Lower Granite Dam ranged from 10 to 30 km/day (Bjornn 1998c). Fish marked at Bonneville Dam from 1996 to 1998 had median migration rates of 14.3 to 19.6 km/day and median travel times of 8.1 to 11.0 days for the reach from Ice Harbor to Lower Granite Dams. The migration rates ranged from 2.2 to 50.2 km/day and travel times ranged from 3.1 to 72.9 days for individual fish.

The median steelhead migration rate through the Snake River reservoirs in 1993 was 30 km/day while migration rates through free flowing river sections were generally less than 11 km/day (Bjornn 1998c). Based on the passage times at the dam and faster passage in the reservoirs than in free flowing rivers, Bjornn et al. (1999) estimated that median time for salmon to pass the four dams and reservoirs in the lower Snake River in 1993 was the same or less with dams as without the dams.

In addition to the radiotelemetry data presented above, in 1998, 41 steelhead of known Snake River origin (based on PIT tags) were detected at both Bonneville and Lower Granite Dams. Of these fish (1 wild and 40 hatchery fish), the median time for passage between the two dams was 33 days, or 13.9 km/day (ranged from to 2.2 to 41.8 km/day for the 460 km reach). Also in 1998, 27 spring/summer chinook salmon of known Snake River origin (based on PIT tags) were detected at both Bonneville and Lower Granite Dams. Of these fish (8 wild and 19 hatchery fish), the median time for passage between the two dams (a total of 460 km) was 17.0 days, or 27.0 km/day (ranged from to 12.4 to 46.0 km/day). Also in 1998, 38 fall chinook salmon of known Snake River origin (based on PIT tags) were detected at both Bonneville and Lower Granite Dams. Of these fish (1 wild and 37 hatchery fish), the median time for passage between the two dams (a total of 460 km) was 12.0 days, or 38.3 km/day (ranged from to 13.9 to 51.1 km/day) (Lowell Stuehrenberg, NMFS, Pers. commun., September 1999). This suggests that the 1998 migration rate of steelhead through the FCRPS falls within the range observed in the Snake River prior to construction of dams, and the spring/summer chinook salmon migration rate slightly exceeds the range reported by Bjornn and Peery (1992) for chinook salmon (run-type was not specified).

In their 1998 turbine priority report, Bjornn et al. (1998d) concluded that, when powerhouses are not at full load, changing the end of the powerhouse where turbines were operating had little, if any, influence on the time for steelhead to approach, enter, or pass fishways at Snake River dams. He saw a slight change in first approach sites, but that did not change first entrance locations. In a 1997 test of whether the first turbine unit's discharge near the large south shore entrance of John Day Dam affected chinook and sockeye salmon, and steelhead entrance locations or passage times, Bjornn et al. (1998e) concluded that the larger turbine boil created at 150 MW (vs-100 MW) did not. Information on whether increasing spills near the large spillway entrances decreases entrance rates at mainstem dams will be available once data from ongoing studies are analyzed.

Fishway fences installed adjacent to the north powerhouse entrances at Little Goose and Lower Granite Dams in 1991 to reduce exits as fish moved upstream in the collection channel were not effective (Bjornn et al. 1995). Funneling the down-channel moving fish away from the entrances (exits) at the downstream end of the collection channels at Little Goose in 1994 improved the net entrance rate at those entrances (Bjornn et al. 1998b).

A high rejection rate of the transition area between the collection channels or entry areas (where there is no collection channel) has been documented for spring and summer chinook and steelhead (Stuehrenberg et al. 1995, Bjornn et al. 1998b). For steelhead the rejection rates range from 46 to 71% on their first approach to the transition area at Snake River dams.

In 1994, the University of Idaho Cooperative Fish and Wildlife Research Unit (ICFWRU) installed radiotelemetry antennas in the transition pools of the four lower Snake River projects and tracked the progress of 220 to 246 steelhead at each project. From 36 to 61% of the fish turned around in the transition pools, moved downstream, and exited the fishway at least once (Bjornn et al. 1998f). An additional 8 to 27% moved downstream in the fishway but did not exit. Bjornn found similar behavior during radiotelemetry studies at McNary and Bonneville Dams, however the reports of those studies have yet to be published.

Several hypotheses have been offered to explain this transition and junction pool behavior: a) velocities are too low and unsteady, b) inadequate flow rates and velocity to attract fish to the submerged section of the ladders and through the orifices at the base of the submerged ladder weirs, c) seasonal and intermittent temperature gradients between the ladder flow and the diffuser flow, d) high flow rates through large floor diffuser areas obscure attraction flow at the base of the ladders, and e) fish may be wary and reluctant to move into confined ladder pools.

The COE (COE 1994) measured the velocities in the collection channel and transition pools at Little Goose and Lower Granite Dams. Velocities were found to be lower than the minimum criterion of 1.5 fps; in addition velocities were non-uniform and unsteady. The COE is planning to test the first two hypotheses (above) by installing baffles in the transition pool at Little Goose Dam in 2000 and monitoring fish fallback using radiotelemetry.

Radiotelemetry studies in 1993 and 1994 have shown that adult fish both enter and exit the floating orifices in the powerhouse collection channels of Snake River dams. The net entry rate indicated that, of the fish that entered the collection channel via the orifices, more fish left via the orifices than stayed in the collection channel (Bjornn et al. 1998b). The COE's Fish Passage Operations and Maintenance (FPOM) committee concluded that closing the floating orifices at Snake River dams would improve the operation of the adult fishways because more water would be available for the large fishway entrances, and maintenance would be improved because the bulkhead could be sealed and the collection channels dewatered on a more frequent basis.

The correlation between the number of collection channel exits per fish and migration time through the lower Snake River dams was very low. From this, it was concluded that the number of collection channel exits a fish makes is not a significant factor in the Ice Harbor to Lower Granite Dam travel time (Bjornn et al. 1998f).

Passage through fish ladders is relatively fast (in relation to total passage time). With the exception of sockeye, most species will not exit the fish ladder after dark. Long ladder passage times are usually associated with holding in the ladder over night while waiting for daylight to exit.

A substantial percentage of adult salmon and steelhead passing dams have been observed to fall back through spillways at certain dams under certain conditions (Bjornn and Peery 1992). High fallback rates are usually associated with high river flows and spill, as well as the location of fishways exits relative to the spillways. In studies in which both adult chinook salmon and steelhead were radio-tagged, fallback rates are generally similar for both species (Table 12). Fallback rates ranged from 0 to 38.9% and 0 to 50% (n = 4 for the 50% estimate) for chinook salmon and steelhead, respectively. Liscom et al. (1979) concluded from several fallback studies that fallback rates can be high at times, but few fish are injured or die as a direct result of fallback. Migration times are increased if the fish must reascend the dam.

The Bradford Island ladder exit at Bonneville Dam has been associated with the highest fallback rates on the Columbia River. Bjornn et al. (1998a) found that overall fallback percentages for chinook and sockeye salmon at Bonneville Dam ranged from 11.5 to 15.2%, and were less than 6% for steelhead. They found passage rates and percentages were 2.5 to 3.7 times higher for chinook salmon that passed via the Bradford Island ladder than the Washington-shore ladder, and 16 to 20 times higher for sockeye salmon. In 1996, almost all steelhead that fell back passed via the Bradford Island ladder.

In addition to the fish that fall back within 24 hours of exiting the fish ladder, a large number of fallbacks occur after fish have migrated significant distances upstream. Dam operating procedures or environmental conditions at individual dams are unlikely to affect fallback associated with this behavior. The cause of this wandering behavior has not been determined, but potential causes include natural survival adaptation, the use of hatchery broodstock not native to the drainage, and some level of homing impairment from having been transported. Mendel (1995) attributed much of the fallback that he recorded to poor entrance conditions at the Lyons Ferry Hatchery and to extensive wandering up and down the Snake River and into tributaries.

Estimating mortality associated with fallback is difficult because some of the fish may have over-shot lower-river tributaries and are returning to them after falling back. If sockeye salmon (a species that has no spawning below Bonneville Dam) are used, the observed fallback mortality of 8% (Bjornn 1998a) can be estimated for fish that likely fell back through spillways. For fall chinook salmon in the Snake River, Mendel (1995) estimated fallback mortality of 26 and 14% in 1993 and 1994, respectively. This higher mortality for fall chinook occurred during periods of no spill, when the fallback was assumed to have been through turbines.

Table 12. Radiotelemetry estimates of adult steelhead and chinook salmon fallback past Snake and Columbia River dams.

Project	Reference	Chinook fallback rate	Number tagged	Steelhead fallback rate	Number tagged	Difference (SH - CH)
Bonneville	Monan and Liscom (1975)	0.389 (Summer)	18	0.500	4	0.111
	Liscom et al. (1979) in Bjornn and Peery (1992)	0.022 (Spring)	90	0.0	35	-0.022
	Ross (1983)	0.150 (Summer/Fall)	20	0.050	20	-0.100
	Ross (1983)	0.0 (Fall)	12	0.0	14	0.0
Lower Monumental *	Liscom et al. (1985) in Bjornn and Perry (1992)	0.094 (Summer/ Fall)	32	0.202	258	0.108
Little Goose*	Liscom et al. (1985) in Bjornn and Peery (1992)	0.077 (Summer/Fall)	13	0.038	157	-0.039

* Steelhead and chinook salmon in this study were released 1,300 ft upstream of Lower Monumental Dam.

Survival

Losses between dams have been defined as the difference between fish counted at consecutive dams minus those accounted for between those dams (harvest and tributary turn off). The largest portion of the over-counts at the dams is due to multiple counts of fallback fish. In 1995, based on radio telemetry, Mendel estimated that due to fallback at Lower Granite Dam the number of fall chinook salmon available to spawn above Lower Granite Dam was over-estimated by 39% in 1993 and by 54% in 1992.

Survival of spring/summer chinook salmon from Ice Harbor Dam to spawning grounds or hatcheries was estimated at 77% in 1993, 73% in 1992, and 54% in 1991 from fish that were tagged at John Day Dam in 1993, and Ice Harbor Dam in 1992 and 1991 (Bjornn et al. 1995). This compares to an estimated 55% survival to spawning for spring/summer chinook salmon that were counted at Ice Harbor Dam during 1962-1968 when only one dam was present, and 46% for the 1975-1988 period when all four dams were in place (estimated by relating counts at Ice Harbor Dam with redd counts in Snake River tributaries)(Bjornn et al. 1998c).

For spring/summer chinook salmon radio-tagged at Ice Harbor Dam, survival from Ice Harbor Dam to Lower Granite Dam was 80.8 and 74.4% in 1991 and 1992, respectively. For spring/summer chinook salmon radio-tagged at John Day Dam in 1993 and Bonneville Dam in 1996, survival from Ice Harbor Dam to Lower Granite Dam was 85.9 and 93.2%, respectively (Bjornn et al. 1999). These differences in survival from Ice Harbor Dam to Lower Granite Dam include differences between years (environmental conditions), and tagging sites. Future analyses of similar data collected in 1997 and 1998 from fish tagged at Bonneville Dam will provide additional estimates of reach survival and year-to-year variation.

Estimates of reach survival through the lower Snake River that are based on tagging conducted at Ice Harbor Dam include any effects trapping, tagging, and release. Estimates of survival through the reach that are based on tagging conducted at John Day and Bonneville Dams may be more accurate than estimates based on fish marked at Ice Harbor Dam, since any effects from trapping, tagging, and release are likely to have occurred prior to entering the lower Snake River reach. If this is the case, these data from Bjornn et al. (1999) suggest that the difference between the average survival through the lower Snake River reach for fish marked in the lower Columbia River (89.6% for 1993 and 1996), and those marked at Ice Harbor Dam (77.6% for 1991 and 1992), indicates that effects on survival from trapping at Ice Harbor Dam may average 12%.

Zero Flow Operations

Taking the dams to near zero river discharge (the fishway flow is operational) during hours of darkness is a technique used to preserve water for periods of higher power demand. Tests of the effects of the procedure on the migration of adult steelhead were conducted between

1991 and 1993. There is no clear evidence that reducing flows to near zero flow at night affected migration rate, proportion of fish passing dams, proportion of fish captured in the fishery, or proportion of fish returning to hatcheries (Bjornn et al. 1998g). A consistent pattern of slower migration in the early and late portions of the runs was found, which was associated with very warm water early and cold water late in the runs.

Temperature

Summer water temperatures in the Snake and Columbia Rivers often exceed 21°C (70°F), and water temperatures in ladders can be even higher than ambient river temperatures. The 1995 BIOP (NMFS 1995a) requires the COE to provide water temperature control in fish ladders. The ICFWRU began monitoring temperatures in the forebays and adult fishways at Ice Harbor and Lower Granite Dams in 1995. Temperature changes along the length of the fish ladder were found to be slight: less than 0.5°C with differential increases to 2°C found on a few occasions (Keniry and Bjornn 1998). Temperature differences upstream and downstream from diffusers were also found to be slight. COE also monitors water temperatures in the ladders at John Day Dam. Reports of radiotelemetry studies in these ladders are in preparation.

High water temperatures can cause migrating salmonids to stop their migrations or seek cooler water that may not be in the direct migration route to their spawning site. Of 71 radio-tagged sockeye salmon that held in the Columbia River until the Okanogan River cooled in 1992, only 24 (33.8%) survived to the spawning grounds (Swan 1994). Snake River fall chinook salmon and steelhead often slow their migration through the Columbia River and delay entering the Snake River when water temperatures are high (Stuehrenberg et al. 1978). The fish resume their migrations when water temperatures decline in the fall. In 1967 an estimated 2,000 steelhead were delayed in the McNary pool (Stuehrenberg et al. 1978). These delays are likely to affect steelhead, which spawn the following spring. Delay caused by high water temperatures could impact fall chinook reproductive success, however, no data exist on this relationship.

Since 1992, Dworshak Dam has been operated to provide cold water for lower Snake River temperature control to benefit outmigrating juvenile fall chinook salmon. Up to 1.2 Maf of water at temperatures from 5.6°C to 13.3°C (typically 8.9°C to 11.1°C) have been used to augment flows and reduce high water temperatures. These releases are managed by regional salmon and reservoir managers to improve migration conditions for migrating smolts, and are typically made during July and August. In 1994, 1995, and 1996, releases from Dworshak Dam reduced temperatures by 3.1 to 5.3°C for 18 to 32 days at Lower Granite Dam, and by 2.4 to 3.1°C for 14 to 43 days at Ice Harbor Dam (Karr et al. 1998). Flow management that reduces mainstem water temperatures to below 21°C would reduce risk to populations of migrating adult salmon (Dauble and Mueller 1993). Thus, flow augmentation can provide cooler water temperatures beneficial to migrating juveniles and adult summer and fall chinook salmon and steelhead in the lower Snake River during the months of July, August and September.

Biological Effects of Dissolved Gas Supersaturation Caused by Spill

Mortality of adult salmon from GBD has occurred in the Columbia River intermittently since the first dams were constructed (see the section on Historical Background of GBD impacts on juvenile salmon). However, effects of GBD on adult salmonids are less understood than effects on juveniles. Relationships between TDGS exposure, GBD signs, and mortality are not defined. Depth distributions of upstream migrants are poorly documented, thus, the mitigative effects of hydrostatic compensation at ambient TDGS is unknown. Also, there are no research data sufficient for determining a threshold TDGS level for ensuring successful spawning of upstream migrant adult salmonids (NMFS 1997).

Monitoring for GBD

Following implementation of voluntary spill to enhance dam passage for juvenile salmonids, monitoring was initiated to examine upstream migrating adult salmonids for GBD signs. Beginning in 1994, adult fish were examined annually at Bonneville and Lower Granite Dams and intermittently at Ice Harbor and Priest Rapids Dams. Also, monitoring was done at Three Mile Dam on the Umatilla River, Oregon. However, these facilities to capture and examine adult salmonids are limited, and inadequate to obtain representative samples at locations where the greatest impacts may occur, for example, downstream from the spillways at Bonneville and McNary Dams. Also, spawning success in relation to TDGS was not consistently monitored. In conclusion, under voluntary spill conditions where reservoir and tailrace TDGS is limited to 115 and 120%, respectively, signs of GBD were not seen and effects were assumed to be benign.

The only period in the 1990s when GBD signs were observed that suggested a problem for adult salmonids was the spring freshet in 1997 (NMFS 1998a). However, GBD signs were documented only at a few sites and no estimates of impact could be made. During that period, TDGS downstream from Bonneville Dam exceeded 135% for 16 days and 130% for 24 days. TDGS exceeded 125% for extended periods at other river reaches. At Bonneville Dam Second Powerhouse, daily prevalence of GBD was high for sockeye salmon (14 to 100% for more than 3 weeks) and steelhead (6 to 50% for 2 weeks). Chinook salmon during the same period showed relatively few signs, with 0 to 6.5% prevalence. No samples were collected from fish traversing the Bonneville Dam spillway tailrace, where TDGS was highest. No GBD signs were observed at Lower Granite Dam; however, fish were not examined until they had spent several hours in low TDGS conditions of the fish ladder, and GBD signs may have disappeared during ladder passage. At Priest Rapids Dam, sampling took place after TDGS decreased to moderate levels of 113 to 124%.

Head burns (skin deterioration at the top or sides of the head) of adult salmonids was observed in the Snake River during many periods of high spill and was commonly thought to be a sign of GBD. Clinical evaluation of fish with typical head burns from Lower Granite Dam suggested the head burns were caused by mechanical abrasion and laceration rather than necrosis associated with subcutaneous emphysema from GBD (Elston 1996). In 1993, 66 radio-tagged chinook salmon were noted as having head scrapes or injuries, and 38% of these did not migrate to known spawning areas and were classified as possible prespawning moralities (Bjornn et al. 1995).

Marine Mammal Marks

Marine mammal predation on adult salmonids has been documented by markings observed on adult salmon that have escaped these predators. Harmon et al. (1994) estimated annual injury rates of 14 to 19.2% of the spring and summer chinook and 5.4 to 14.2% of the steelhead that arrived at Lower Granite Dam between 1990 and 1993. Based on the size of the teeth marks it is believed that harbor seals created the marks observed. A NMFS Report to Congress (NMFS 1999c) under the Marine Mammals Protection Act evaluated the impacts of California sea lion (*Zalophus californianus*) and Pacific harbor seal (*Phoca vitulina*) predation on salmonids and to coastal ecosystems. It was concluded that pinniped populations are abundant, increasing, and widely distributed along the western United States coastline. Highly precise information on pinniped food habits is lacking. However, there are a number of sites along the West Coast where there is a high potential for pinniped impacts on salmonid populations. A series of recommendations are presented along with public comments received on a draft of the report.

KEY UNCERTAINTIES ASSOCIATED WITH ADULT PASSAGE

Starting in the early 1990s, the use of individually coded adult radiotelemetry tags greatly increased the precision associated with studies of adult migration behavior and survival past dams and through the mainstem corridor. Individual fish have been uniquely tagged and their behaviors of approach and passage over dams and through reservoirs monitored and their run histories reconstructed. A large amount of information has been gathered, and those data sets that have been analyzed are reported in this document. However, a number of uncertainties associated with dam and hydrosystem passage remain.

Fallback From Bonneville Dam

While the rate of adult fallback at Bonneville Dam has been documented, the cause has not been determined. A high proportion of the fish falling back are fish that use the Bradford Island exit. A substantial number of fish pass the dam only to fall back from several miles upstream. Mobile radiotelemetry studies of fish behavior in the immediate forebay have been conducted, and will be evaluated in conjunction with physical model studies of the hydraulic conditions the fish experienced while falling back, to determine whether the cause is, in part, related to localized hydraulic conditions at the dam.

Fallback Not Associated with Dam Operations

As discussed above for Bonneville Dam, many fallbacks originate with fish that are above the influence of dam operations. For example, fallback over Ice Harbor Dam of fish destined to the upper Columbia River appears to have less to do with dam operations than a behavioral response to searching for the appropriate tributary. Fallbacks at dams are counted, but the true cause remains unknown unless the total migration behavior and history is documented.

Adults Passing Lower Granite That Fail to Reach the Spawning Grounds

Survival of spring and summer chinook salmon from Ice Harbor Dam to spawning grounds or hatcheries varied between years, and was estimated to be no more than 77% and as low as 54% from 1993 and 1991, respectively. Further studies will be required to resolve the accuracy and cause of these preliminary observations.

Effect of Hydrosystem Passage on Reproductive Success

Another adult passage uncertainty is whether migrating through a series of reservoirs and dams imparts a burden on adults that is manifested in reduced reproductive success. Reproductive success requires a migration of both sexes to the spawning grounds, appropriate reproductive behavior (nest building and spawning), high gamete quality, proper embryonic development, and survival of offspring for the downstream migration. Delays in migrations, excessive energy consumption during the migration, and exposure to higher water temperatures during the migration are factors that could lead to reduced reproductive system function, disease, and low quality and quantity of gametes. The impacts of the hydrosystem on reproductive success are unknown. Studies and possibly experimental designs that address these topics will have to be developed to answer the question of whether the hydrosystem affects the reproductive success of salmonids and other anadromous species.

Lamprey Passage

One of the uncertainties associated with salmonid ESA issues is the potential impact an adult fish passage environment, designed specifically for salmonids, has on non-salmonid species. Concurrent with the decline of salmonid populations, the Columbia River Pacific lamprey (*Lampetra tridentata*) populations have also declined. As an anadromous species, lamprey must pass through the same hydrosystem as salmonids but without the same physical capabilities or migration behaviors. Ongoing studies are addressing whether parts of the hydrosystem are impacting lamprey biology, including the swimming abilities of lamprey in relation to fishways at dams, strength of the homing instinct, problems adult lamprey face as prey, and lamprey life histories that might explain observed migration behavior.

Inter-Dam Losses

Radiotelemetry researchers now tag adult fish from the entire population crossing a given dam, without knowing the source, origin, or evolutionary significant unit (ESU) of the animals tagged. This is inherently a problem when trying to use radio-tagged fish to determine inter-dam losses. When tagged fish arrive at upstream sites, only information on those fish surviving to the upstream sampling site is known. What is not known is the origin of the fish lost between the release site and the upstream sites, or how many other fish should have arrived at the upstream sites. As the number of returning PIT-tagged adults in the system increases and adult PIT-tag detection systems are developed and installed at key locations, estimates of survival between PIT-tag detectors for known-source fish will be more readily available. Combining PIT-tag detections at various locations during the upstream migration, with the fate of PIT-tagged fish lost between the downstream and upstream detectors as determined through radiotelemetry, will provide more precise estimates of inter-dam losses.

Adult Count Accuracy

Adult counting occurs at all mainstem dams to ensure that fish passage facilities are operating properly. Partial hourly counts are expanded, and little counting occurs during hours of darkness. Counts include all adults passing each dam, and are upwardly biased by any fish that fall back and reascend. The present counting schedule and systems meet their intended purpose of ensuring that the adult passage facilities are functioning properly. However, the ISAB (Bisson et al. 1999) noted a number of problems associated with the precision and accuracy of adult counts at mainstem dams, especially if the data are used to make management decisions.

Deschutes River Straying

Straying of steelhead into the Deschutes River, Oregon has been observed during recent unpublished radiotelemetry studies. The natal origin of these fish was unknown. The behavior was observed during periods when the water of the Columbia River was warmer than the Deschutes River. Possible causes for this behavior include fish seeking the cooler water, straying behavior associated with transportation, and an evolutionary adaptation that enhances survival. Additional studies of known-source fish will be required to better understand the cause of this observed behavior.

CONCLUSIONS

Juvenile Passage

1) Direct survival of yearling migrants through the FCRPS in recent years under good flow conditions and with the measures implemented in the NMFS 1995 and 1998 BiOps is now as high or higher than it was in the 1960s and 1970s.

2) In general, juvenile migrant survival is highest through spillbays, followed by mechanical screen bypass systems, and turbines.

3) Spill survival is typically 98 to 100%. An exception to this range is The Dalles Dam where relative spill survival has ranged from 76 to 99% since 1997, depending on the spill volume, season, and year.

4) In general, screen bypass systems guide a high percentage of juvenile migrants away from turbine intakes, and pass them to tailrace outfalls or transportation facilities with comparatively low levels of injury. These systems are neither perfect nor benign, but they afford fish a higher level of protection than turbines. Survival through mechanical screen bypass systems is higher than through turbines, except at Bonneville Dam (tested with subyearling chinook salmon only).

5) Blood plasma stress indicators can rise dramatically during, or after passage through bypass systems, but generally return to pre-exposure levels within several hours. This response does not always occur, and has been observed to vary by species, rearing history, and dam. The response is typical for a fish subjected to a stressor. The relationship between elevated physiological stress indicators and survival is not well documented. Some evidence suggests bypass induced stress may contribute to reduced ability to respond to in-river conditions, the presence of predators, and environmental conditions. Acute debris events can result in high levels of descaling associated with passage through mechanical screen bypass systems; however, the relationship between descaling and survival is not well documented. Acute temperature events at the McNary Dam bypass facilities can cause elevated mortality levels in summer migrants.

6) Although survival through mechanical screen bypass systems is higher than turbines, the potentially negative factors associated with bypass systems (as measured by blood chemistry, descaling, and mortality of smolts) suggest that attention should continue to focus on incremental ways to improve mechanical bypass systems, and the day-to-day diligent operation of these facilities. This includes better ways to guide fish, dewater flow, separate fish, place outfalls, and reduce stress associated with bypass passage.

7) A number of prototype surface bypass systems have been tested since the mid-1990s. The Wanapum Dam surface bypass concept has been dropped due to poor performance. Prototypes tested at Rocky Reach and Lower Granite Dams have shown moderate levels of performance.

Prototypes at Bonneville First and Second Powerhouses have shown moderate to high levels of performance, depending on the evaluation methodology. However, complete surface bypass prototypes have not been tested at Bonneville Dam. Further testing of surface bypass prototypes will be required (including surface bypass through modified spillways), and routing to tailrace issues resolved, before comparisons of survival between surface bypass systems and other routes of passage can be made.

8) Survival through turbines ranges from the mid-1980s to mid-1990s. The highest estimates were obtained by recent balloon-tag estimates of direct survival, although 3 of 4 estimates with PIT-tagged fish to measure direct and indirect turbine survival at Snake River dams were above 92%. The mechanisms of turbine induced mortality are poorly understood. The COE Turbine Survival Program is designed to better understand these mechanisms. The Minimum Gap Runner design shows promise but has not been biologically evaluated.

9) Although the database developed since the 1940s on juvenile passage through the FCRPS is large, a number of critical uncertainties remain. Foremost among these are the potential effects of juvenile fish passing through multiple bypass systems, and how these passage histories or experiences affect subsequent survival outside of the mainstem hydrosystem. While estimates of direct survival through the hydropower system in recent years are similar to survival estimates made during the 1960s and 1970s when the FCRPS was only partially developed, data exist that suggest SARs may be reduced by multiple passages through existing bypass systems.

10) The conclusions discussed above can be used to identify areas where further research is needed. Estimates of reach survival have increased from less than 5% in some cases in the 1970s to approximately 50% in recent years. This suggests the changes made to improve passage through the hydrosystem have worked, but also that further improvements are possible. Continued incremental gains in the way mechanical screen bypass systems handle fish, gas abatement, increased spill, turbine operation, separator efficiency, and surface bypass systems are needed to further improve survival through the FCRPS. At the same time, research to address the uncertainty over passing through multiple bypass systems, and the through hydropower system in general, should be given a high priority. While gains can still be made within the FCRPS passage corridor, it is important to also investigate any potential effects of dam passage that may be manifested outside the hydrosystem.

Adult Passage

1) Limited data on the survival of spring/summer chinook salmon from Ice Harbor Dam to spawning grounds or hatcheries indicate that survival in the 1990s has ranged from 54 to 77%, compared to estimates made for the 1960s to 1980s of 46 to 55%. This suggests there may be little difference in survival between the two periods, before and after dams were in place. Survival of radio-tagged spring/summer chinook salmon from Ice Harbor Dam to Lower Granite Dam in the 1990s ranged from 86 to 93%, for fish tagged in the lower Columbia River.

2) Steelhead migration rates vary with season and temperature. Spring/summer chinook and sockeye salmon migration rates were 18 to 24 km/day in the Snake River prior to impoundment, and spring/summer chinook salmon migration rates were 14 to 20 km/day for the reach from Ice Harbor to Lower Granite Dams from 1996 to 1998, based on radiotelemetry. In 1998, the median migration rates for PIT-tagged fish of known Snake River origin from Bonneville Dam to Lower Granite Dam were 38, 27, and 14 km/day for fall chinook salmon, spring/summer chinook salmon, and steelhead, respectively. This suggests that rate of migration is similar between the two periods, before and after dams were in place.

3) Adult fallback rates as high as 15% have been documented recently, especially at the Bonneville Dam Bradford Island ladder exit. Establishing whether the cause of the fallback is related to fish behavior or dam operations is difficult, since many of the fish may have over-shot lower-river tributaries or hatcheries. Limited information exists on fallback mortality. For sockeye salmon that are destined to sites well above the FCRPS, the observed fallback mortality at Bonneville Dam is 8%. Estimates of fall chinook salmon mortality in the Snake River were 14 and 26% in 1994 and 1993, respectively. Therefore, fallback occurrence and mortality are serious issus that should be addressed through ongoing research.

4) Uncertainty exists regarding why spring/summer chinook salmon survival from Ice Harbor Dam to the spawning grounds or hatcheries was only 54 and 77% in 1991 and 1993, respectively. Further studies will have to be completed to determine how representative these observations are, and if these levels compare to survival in river systems that have not been impounded.

5) Another adult passage uncertainty is whether migrating through a series of reservoirs and dams affects reproductive success. This includes proper reproductive behavior such as nest building and spawning, gamete quality and quantity, proper embryonic development, and survival of offspring during the downstream migration.

6) The conclusions discussed above can be used to identify areas where further research is needed. Estimates of reach survival after impoundment appear to be equal to or higher than prior to impoundment, but the data are limited. In any case, hydrosystem survival estimates of 54 and 77% indicate that further improvements may be possible. Continued incremental gains in the way adult passage systems handle fish, and attention to adult passage considerations associated with gas abatement, spill, mechanical bypass systems, and turbine operations are needed to further improve survival through the FCRPS. At the same time, research to address uncertainties regarding adult passage through the FCRPS should be given a high priority. While gains may still be made within the FCRPS passage corridor, it is important to also investigate any potential effects of passage that may be manifested outside the hydrosystem, such as survival to the spawning grounds and reproductive success.

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APPENDIX A:
NMFS Supplemental FCRPS Biological Opinion Spill Program

The Action Agencies had proposed in their Biological Assessment to modify spill levels from those specified in the 1995 BIOP RPA Measure 2 (NMFS 1995a). The NMFS undertook a comprehensive review of the new information regarding the effects of spill including revised project-specific estimates of:

- Estimates of fish guidance efficiency (the proportion of juveniles approaching turbine intakes which are guided into bypasses);
- Total dissolved gas levels associated with spill levels at each project; and
- New spill efficiency estimates for some projects (i.e., the proportion of fish approaching a project that pass via the spillway, divided by the proportion of total flow that is spilled).

The 1995 BIOP (NMFS 1995a) defined an 80% fish passage efficiency goal for spill but recognized that some projects would achieve a lower fish passage efficiency due to dissolved gas limits. The NMFS review for the 1998 Supplemental BIOP (NMFS 1998b) indicated that some projects were meeting the 80% fish passage efficiency (FPE) goal (i.e., proportion of fish passing by non-turbine routes) and others were not. Although the levels of spill provided during 1995 through 1997 were consistent with the spill recommended in the 1995 BIOP, for the 1998 Supplemental BIOP, NMFS supported additional spill on a system-wide basis to provide further benefits to steelhead while also increasing the survival of Snake River spring/summer and fall chinook and sockeye salmon. To the extent that FPE at some projects will exceed 80%, this additional spill supplements the 1995 BIOP (RPA Measure 2) for the interim period pending decisions on long-term actions.

The Action Agencies proposed that the actual dates of spill and flow augmentation be determined annually by the Technical Management Team based on inseason monitoring information. However, the planning dates are 3 April (modified from the 10 April planning date specified in the 1995 BIOP (NMFS 1995) to 20 June, and 21 June to 31 August for spring and summer, respectively, in the Snake River; 10 April to 30 June in the mid-Columbia River; and 20 April* to 30 June and 1 July to 31 August for spring and summer, respectively, in the lower Columbia River. Initial estimates of spill levels, and the basis for each estimate, are shown below (Table A-1).

The specific spill volumes listed in Table A-1 are approximate because the total dissolved gas levels measured at the monitoring site below each project vary with forebay dissolved gas level, spill patterns, and water temperature for any given level of spill. Also, there are project-specific limitations on spill levels for reasons other than dissolved gas, including adult passage, navigation, and fish passage research activities. These limitations are typically of short duration but they do reduce spill for fish passage to a limited degree. Dissolved gas and biological monitoring information and the results of research on spill effectiveness and survival should be reviewed annually so that specific spill levels can be adjusted for each project.

Table A-1. Estimated spill caps for the operations specified in this Supplemental FCRPS Biological Opinion.

Project	Estimated spill level [a]	Hours	Limiting factor
Lower Granite	45 kcfs	6 pm to 6 am	gas cap
Little Goose	60 kcfs	6 pm to 6 am	gas cap
Lower Monumental	40 kcfs	6 pm to 6 am	gas cap
Ice Harbor	75 kcfs (night) 45 kcfs (day)	24 hours	nighttime - gas cap daytime - adult passage
McNary	150 kcfs	6 pm to 6 am	gas cap
John Day	180 kcfs/60%[b]	1 hour before sunset to 1 hour after sunrise	gas cap/percentage
The Dalles	64%	24 hours	tailrace flow pattern and survival concerns
Bonneville	120 kcfs (night) 75 kcfs (day)	24 hours	nighttime - gas cap daytime - adult fallback

[a] The estimates of fish passage efficiency (FPE) used to derive these spill levels are conservative and based on fish guidance efficiencies (FGE) of hatchery spring/summer chinook salmon, rather than wild or hatchery steelhead, to protect the weakest listed stock present during the steelhead outmigration period.

[b] The total dissolved gas cap at John Day Dam is estimated at 180 kcfs and the spill cap for tailrace hydraulics is 60%. At project flows up to 300 kcfs, spill discharges will be 60% of instantaneous project flow. Above 300 kcfs project flow, spill discharges will be 180 kcfs (up to the hydraulic capacity of the powerhouse).

Comparison of these new spill objectives with those set out in the 1995 BIOP (NMFS 1995a) is difficult. Whereas the previous spill objectives were defined as a spill percentage, the proposed objectives (which, in most cases, are based on the spillway flows at which gas caps are reached) are described in terms of "kcfs over the spillway." These changes are described in detail in Appendix 1: Basis for NMFS Determinations Concerning the Use of Spill as Mitigation for Operation of the Federal Columbia River Power System, of the 1998 Supplemental BIOP (NMFS 1998b) and are briefly outlined for each project below.

Lower Granite--The 1995 BIOP (NMFS 1995a) set a spill level at Lower Granite of 80% instantaneous spill for 12 hours per day. However, under most conditions, this level of spill could not be implemented because the gas cap was reached at spillway flows of 40 kcfs. The Action Agencies now estimate that the gas cap will be reached at 45 kcfs and propose this level as the spill limit. At a river flow of 100 kcfs, the new standard will provide an instantaneous spill 45 kcfs and an estimated 85% FPE. Based on radio-tracking studies on adult chinook salmon performed at Lower Granite Dam during 1996 and 1997, a spill level of 45 kcfs should not adversely affect adult passage (T. Bjornn, fax to R. Kalamasz (COE), S. Pettit (IDFG), and J. Ceballos (NMFS), dated 4 April 1998).

It may be necessary to consider a lower spill limit to accommodate safety concerns when juveniles are being loaded directly onto barges and the barges must be docked for extended periods. Spill operations must also consider research needs critical to the proposed evaluation of the prototype surface bypass/collector (i.e., project operations are modified to spill for 24-hours per day instead of only at night, and powerhouse operations are modified to provide the required hydraulic conditions in the immediate forebay). Data from this research are critical to the long-term regional decision due by the end of 1999. BPA specified 11.5 kcfs as the minimum powerhouse flow for system reliability. However, this may not be necessary at all times, depending on the status of generation at other projects.

Little Goose--The 1995 BIOP (NMFS 1995a) described a spill level for Little Goose Dam of 80% instantaneous spill for 12 hours per day. The Action Agencies could not usually implement this level because the gas cap was reached at spillway flows of approximately 35 kcfs. The Action Agencies now estimate that the gas cap will be reached at 60 kcfs at this dam and propose this limit. At a river flow of 100 kcfs, the new standard will provide an instantaneous 60 kcfs spill, and an estimated 86% FPE. Based on 1997 radio-tracking studies with adult chinook, 60 kcfs spill should not adversely affect adult passage (C. Peery, Idaho Cooperative Fish and Wildlife Research Unit (ICFWRU) fax to J. Ceballos (NMFS), dated 9 April 1998). BPA specified 11.5 kcfs as the minimum powerhouse flow for system reliability. However, this may not be necessary at all times, depending on the status of generation at other projects.

Lower Monumental--The 1995 BIOP (NMFS 1995a) set a spill level at Lower Monumental Dam of 81% of instantaneous spill for 12 hours per day. This level of spill was not provided voluntarily because the gas cap was reached at spillway flows of approximately 40 kcfs. The Action Agencies have not changed this estimate of spill at the gas cap. Therefore, spill levels at this dam are not expected to change. Because the gas cap is presently reached at approximately 40 kcfs, no reduction in spill is necessary between 0500 to 0600 hours. Because spill is limited, the maximum achievable FPE is limited to approximately 61%. Based on radio-tracking studies with adult chinook, performed during 1997, a spill level of 40 kcfs should not adversely affect adult passage (C. Peery (ICFWRU), fax to J. Ceballos (NMFS) dated 9 April 1998). BPA specified 11.5 kcfs as the minimum powerhouse flow for system reliability. However, this may not be necessary at all times, depending on the status of generation at other projects.

Ice Harbor--The 1995 BIOP (NMFS 1995a) described spill levels at Ice Harbor Dam of 27% in the spring and 70% in the summer, each for 24 hours per day. The 27% spring objective was often reached, even though the gas cap limited voluntary spill to flows of 25 kcfs. The summer target of 70% was also reached at the lower flow levels. Due to the installation of spillway flow deflectors, the Action Agencies now estimate that the gas cap will be reached at 75 kcfs. At a river flow of 100 kcfs, the new standard will provide an instantaneous spill level of 75 kcfs and an estimated spring chinook FPE of 84%. Based on research performed during the early 1980s, concerns for adult passage would limit daytime (0500 to 1800 hours) spill to 45 kcfs. However, preliminary information from 1996 radio-tracking studies suggests spill greater than 45 kcfs did not adversely impact adult passage (C. Perry (ICFWRU) fax to J. Ceballos (NMFS) dated 9 April 1998). Thus, the 45 kcfs daytime spill cap for adult passage may be reconsidered once the final analysis of adult radiotelemetry data has been completed. Short-term limits to spill may be imposed to address safety concerns when barges are exiting the lock in the downstream direction. BPA has specified 7.5 to 9.5 kcfs as minimum powerhouse flows for system reliability. However, this may not be necessary at all times, depending on the status of generation at other projects.

McNary--The 1995 BIOP (NMFS 1995a) set a spill level at McNary Dam of 50% for 12 hours per day. Due to limited powerhouse capacity and because the gas cap was reached at spillway flows of 120 kcfs, these spill levels were reached under most conditions. The Action Agencies now estimate that the gas cap will be reached at 150 kcfs and proposed this level of spill as the limit. At a river flow of 240 kcfs, the new standard will provide an instantaneous spill level of 150 kcfs and an estimated FPE of 89%. BPA has specified a minimum powerhouse flow of 50 kcfs to maintain power transmission system stability.

John Day--The 1995 BIOP (NMFS 1995a) set spill levels of 33% during spring and 86% during summer, 12 hours per day. The gas cap was reached at spillway flows of 20 to 50 kcfs (depending on the spill pattern), prohibiting voluntary spill under most river flow conditions. Because spillway flow deflectors have been installed at this project, the Action Agencies now estimate that the gas cap will be reached at spillway flows of approximately 180 kcfs. The Action Agencies therefore propose a spill limit of 180 kcfs except when river flows are less than approximately 250 to 300 kcfs. At these low flows, poor tailrace conditions at the bypass outfall will limit spill to 60% of the total river flow.

A change in hours to 1 hour before sunset to 1 hour after sunrise is also proposed to partially offset the high cost of the increased spill levels at John Day. At a river flow of 240 kcfs, the new standard will provide an instantaneous spill level of 60% and an estimated spring chinook FPE of 79%, from 1 hour before sunset to 1 hour after sunrise.

The Action Agencies began investigating 24-hour spill at John Day Dam in 1999. The cost and transmission system effects of 24-hour spill at John Day Dam are a concern. However, high spillway effectiveness and high daytime passage were noted during 24-hour spill in 1997 (COE Memorandum for the Record from Bob Dach, 3 February 1998). Spill effectiveness was highest during the summer but daytime passage was much higher than expected during both spring and summer, indicating a potential decrease in forebay residence time and exposure to predators. BPA has specified a minimum powerhouse flow of 50 kcfs to maintain power transmission system stability.

The Dalles--The 1995 BIOP (NMFS 1995a) set a spill level at The Dalles Dam of 64% for 24 hours. Because the gas cap was reached at spillway flows of 230 kcfs, the BIOP spill level was met most of the time. At a river flow of 240 kcfs, 64% spill will provide an estimated 79% FPE. However, poor tailrace conditions and recent estimates of poor survival through the spillway are a concern. Therefore, changes in spill operations may be proposed once spill survival research is completed. BPA has specified a minimum powerhouse flow of 50 kcfs to maintain power transmission system stability.

Bonneville--The 1995 BIOP (NMFS 1995a) did not recommend specific spill percentages at Bonneville Dam because spill was limited by measures to prevent adult fallback. In addition, the gas cap was reached at 120 kcfs spillway flow. Research is being conducted to address the adult fallback issue. At a river flow of 240 kcfs, the limited spill capability will provide an estimated 59% FPE. BPA has specified a minimum powerhouse flow of 30 kcfs to maintain power transmission system stability.

APPENDIX B:
NMFS Juvenile Fish Monitoring Facility Criteria

Bypass Flume--To minimize fish impacts if a decision is made not to operate the sampling facility or if it becomes necessary to shut down the sampling facility, the bypass flume should allow flow from the transportation flume to proceed uninterrupted to the outfall location without any further dewatering, and effectively bypass any juvenile fish monitoring facility (JFMF) (COE 1999).

Switchgate--A switchgate is required to divert flow from the transportation flume into the JFMF (COE 1999). Generally, these switchgates are large swing gates that traverse the flume and divert the fish and flow either into the bypass flume or into the monitoring facility. When the JFMF is operating, the flow from the transport flume should be in a straight alignment with the JFMF primary dewatering screen to provide uniform flow conditions on the dewatering screen. When the facility is not operating, the switch gate should divert the flow into the bypass flume. The velocity through the switchgate should closely match the velocity in the transport flume to reduce holding in the switchgate area. The nose of the switchgate should be recessed into the wall of the flume in both the normal and bypass mode. A removable filler panel is required to cover this recess when it is not occupied by the gate. This prevents fish from holding in the flow separation caused by flow expanding into the area.

Primary Dewatering Structure (PDS)--When sampling flow, fish and debris enter a primary dewatering structure once past the switchgate, which reduces transport flume flow approximately 30 cfs to 1 to 2 cfs (COE 1995a). Velocity and design requirements for dewatering are similar to those used for juvenile fish screen criteria (NMFS 1995b). Screen material can be either profile bar screen or perforated plate. It is important to match the incoming velocity from the switchgate and maintain this velocity through the screening structure, accelerating or decelerating only slightly (no more than 0.1 ft/linear ft). Generally, some form of porosity control behind the screens is required to achieve uniform velocity distribution at the screen face. Velocities at the downstream end of the screen are generally about 10 fps. At a velocity of 10 fps and a flow of 1 to 2 cfs, depth at this area is about 0.25 to 0.5 in (COE 1995a, 1997a). Since this is so shallow, it may be necessary to adjust the flow through the screens to ensure that the screen area does not become totally dewatered.

Cleaners--The PDS should include an mechanical brush cleaner that is automated and stored out of the water when not in operation (COE 1997). Manual cleaning is also a possibility but may require that personnel be present continuously during operation of the system.

Adult, Juvenile, and Debris Separator/Size Separators--There are two types of separators: "wet" separators which separate juveniles by size for transportation, and "dry" separators which separate juveniles from adults and debris.

a) Criteria for “wet” separator - A wet separator consists of two pools. Water from the PDS flows into the upstream pool and then over a small bulkhead into the downstream pool. Located in the upper pool are longitudinal separator pipes/bars with a 0.625 in opening between bars. This allows smaller fish to drop or swim through the bars into the upstream pool underneath the separator. The downstream pool is similar but the submerged separator bars have 1.125 in clearances that allow larger juvenile fish to sound. Adults and debris can be trapped in either of the two pools until manually removed. Fish passing through the separator bars are transported to interrogation facilities, to raceways for delayed loading, or are directly loaded onto barges.

b) Criteria for “dry” separator - The separator consists of a series of smooth, horizontal bars (sloping downstream) which run parallel to the water flow. These bars are generally 2- to 2.5-in diameter pipe with 1.5-in clear space in between (COE 1995a, 1997a). Juvenile fish and flow coming off the PDS drop though these bars into the hopper below. Adults and debris slide along the top of the bars until they drop off the end into a return flume downstream. Add-in water is provided to the pool underneath the separator bars to provide a cushion as well as flushing fish from this area (COE 1997). The separator is generally 8 to 10 ft long. To maintain a slick surface, the separator bars need to be kept wet either from an overhead spray system or from an up-spray system integral with the separator bars (COE 1995a, 1997a). Large debris will become trapped on the separator bars and must be removed manually or by an automated cleaner.

Separator Hopper--The separator hopper os located directly below the separator bars. This captures the fish and debris which come through the separator system. The volume of the separator should be minimized to reduce fish holding. Add-in water/flush water should be added to the upper end of the hopper (just below the end of the primary dewatering screen) and opposite the hopper exit. The water under the end of the PDS acts as a pillow to cushion the fall of the juveniles as well as to sweep the fish out of the hopper. The floor of the hopper should slope to the exit of the hopper to drain the hopper when the facility is dewatered. This add-in flow should be 1 to 2 cfs for a total flow out of the hopper of 2 to 4 cfs (COE 1997).

Adult and Debris Return Flume--The adult and debris return flume should be in line with the flow coming off the dewatering screen. The adults should come off the separator bars and drop a very short distance (less than 6 in) onto a wetted, sloped floor which transitions to the return flume. This sloped floor should be constructed of perforated plate. Add-in water (generally up to 5 cfs) should come up through this plate to provide a cushion of water for the fish to fall on before it washes them down the flume (COE 1995a). Adjusting the amount of add-in water can change the depth and velocity in the return flume.

Depth of flow in the adult return flume should be between 0.3 and 0.4 ft and velocity should be between 5 and 10 fps (COE 1995a). The flow in the flume should be shallow and relatively fast to prevent adults from being able to either hold in the flume or swim back upstream. A U-shaped flume cross-section is preferred for inspection purposes and shading should be provided. Minimum flume size for adult return line is 14 in inside diameter; 18 in diameter is preferred (COE 1995a). The adults and debris should be returned to the bypass flume as quickly as possible.

Secondary Dewatering Screens--Another set of dewatering screens is located just downstream of the separator hopper. Flow into these screens is 2 to 4 cfs. These screens dewater the flow to 1 to 2 cfs prior to entering transportation/sample flumes. Standard NMFS screening criteria apply (NMFS 1995b).

Juvenile Transportation/Sample Flumes--The transport flumes are generally U-shaped have a diameter of 10 in. Flow is 1 to 2 cfs at a velocity between 5 and 10 fps (COE 1995a). Flow into the PIT-tag detectors has special requirements depending on the size of the detector involved. In general, flow should approach the PIT-tag detector in a straight alignment with an velocity of 8 to 10 fps (COE 1995a, 1997a). The diversion gate to the sample loop should be just downstream from the detector for most diversion rates (the detectors trip the diversion gates which are timed to open when the target fish passes the gate opening).

Add-in Flow--Add-in flow is required beyond each diversion gate (including switchgates) so that during diversion gate operations fish remaining in the flumes or being diverted to new flumes are flushed downstream.

Trim Screens--Trim screens should be located as close as possible to the sample holding tanks. Their purpose is to reduce the flow in the flumes from 1 to approximately 0.25 cfs, which is just enough flow to move the fish into the sample tanks.

Holding/Sample Tanks--Holding and sample tanks should be sized according to the number of fish expected from a maximum sample rate during the outmigration peak, and conservative criteria of 15 fish /pound and a holding volume of 0.25 pounds of fish/gallon (COE 1995a). Flow through the holding tanks should provide 1 gpm of flow for every five pounds of fish (COE 1995a). Holding and sample tanks should be equipped with fish-friendly drains that return the fish to the bypass flume or directly to the river in case of emergency (COE 1997).

Crowders--Holding/sampling tanks should be equipped with manual crowders or motorized crowders with manual override. Crowders should effectively sweep the holding tank and efficiently move fish into the preanesthetic tanks, where the fish are anesthetized prior to handling and transfer to the recovery tanks.

Recovery Tanks--Recovery tanks are required to allow the fish to fully recover from the anesthetic prior to being rapidly returned to the main transportation flume leading to the outfall.