An evaluation of the biological database for improving fish guidance efficiency at Bonneville Dam Second Powerhouse

Fish Ecology Division

Northwest Fisheries Science Center

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Seattle, Washington

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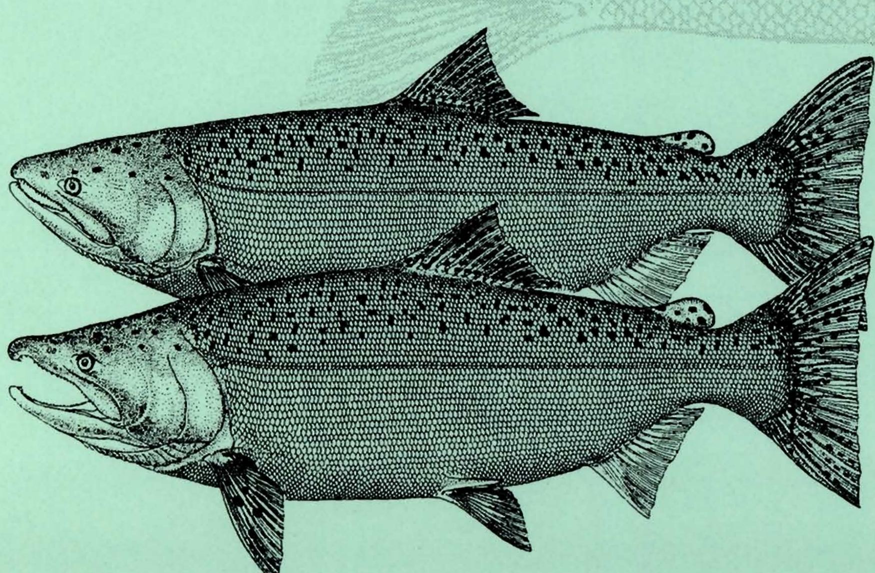

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EXECUTIVE SUMMARY

Biological and hydraulic data collected between 1983 and 1998 are reviewed and discussed. The biological data were collected using a variety of methods, including direct capture fyke netting and gatewell dipping, hydroacoustics, and radio telemetry. Hydraulic data were collected by both field measurements and model techniques. Results of the experimental period from 1983 to 1989, and the post-construction evaluation period from 1993 to 1998, are described.

During the experimental period (1983-1989) a large number of short duration tests were performed on a variety of measures designed to enhance fish guidance efficiency (FGE). Lowering the submersible traveling screen (STS) 0.8 m, streamlining the main unit trashracks to the incoming flow lines, and installing turbine intake extensions (TIEs) were the most effective measures tested. These improvements increased the effectiveness of the STSs and to a lesser degree, the vertical distribution of the targeted species, juvenile Pacific salmon (*Oncorhynchus* spp.). Together, these improvements increased FGE under experimental test conditions (partial powerhouse and partial TIEs) to approximately 70% for spring migrants. Other measures tested included a raised operating gate (ROG), blocked trashracks, and a trashrack deflector. None of these measures improved FGE. This suggested that the hydraulic environment above the screen, that is the flow field leading from the trashracks up into the gatewell slot, was limiting further FGE improvements.

Because of their apparent success, a full compliment of TIEs, streamlined trashracks, and lowered STSs were installed and tested starting in 1993. Results from the 1993-1994 FGE

evaluations produced lower FGE than expected. Spring migrant FGE was approximately 50%, compared to 70% during the 1980s testing and the regional goal of 80%.

The performance of various measures tested from 1983 to1994 was found to be highly variable. Results varied with year, season, species, intake slot, and unit operation. The number of fish entering and being guided in the non-TIE intake slots was higher under four and six than eight unit operation. This suggested that powerhouse load (number of units on) has an effect on the strength of the lateral flows directed toward each corner of the powerhouse, and that TIEs produce a varying effect on intake distribution that decreases from four to six unit operation, and disappears with eight units operating. Even with this noted variation, our review suggests the within-turbine FGE sampling conducted to date comprised an adequate series of tests and sample sizes to gain an understanding of what the dominant controlling factors are at Bonneville Dam Second Powerhouse with respect to FGE. We conclude that two hydraulic conditions must be addressed to further improve FGE: 1) the flow field above the STS and into the gatewell slot is restricted and needs to be increased, and 2) the bulk flow moving laterally across both the north and south ends of the powerhouse in the near forebay needs to be redirected into the intake.

Limited hydroacoustic evaluations in the far (50-70 m) and near (20-30 m) fields upstream from the face of the powerhouse indicate that fish vertical distributions are similar to other projects, and fish are distributed in the upper portions of the water column. We conclude that vertical fish distribution is not limiting further FGE improvements at Bonneville Dam Second Powerhouse.

We compared the physical and hydraulic aspects of Bonneville Dam Second Powerhouse to other powerhouses to identify similarities and differences that may be responsible for the low FGE observed at Bonneville Dam Second Powerhouse. The comparison focused on total discharge up the bulkhead gatewell (upstream) slot, velocity at the trashracks, general intake shape, main unit hydraulic capacity, and FGE. The most pertinent differences between the Bonneville Dam Second Powerhouse and other projects is the high trashrack velocity, low discharge up the gatewell slot, and low FGE when compared to Bonneville Dam First Powerhouse, John Day Dam, and McNary Dam.

Hydroacoustic evaluations conducted in 1998 with the southern-most TIEs removed indicated that the sluice chute located in the corner south of Unit 11 is a highly effective route of fish passage. Combined fish passage efficiency (FPE) for the chute and Units 11-13 was 90% for both the spring and summer. In contrast, when the chute was closed , FGE of the STSs in Units 11-13 averaged 55 and 30% during the spring and summer, respectively.

We conclude by speculating that FGE is limited by a constrained hydraulic environment above the STSs. In addition, the near forebay hydraulic environment greatly complicates the sensory cues presented to the fish. We suggest that fish vertical distributions are appropriate to achieve high FGE levels as close as 20-30 m upstream from the dam face. Therefore, we believe that subsequent hydraulic model investigations should closely examine the complex interactions between bulk forebay flow and the flat face and intake structures for clues on how to improve FGE. We suggest four approaches for further study to increase FGE and FPE at Bonneville Dam Second Powerhouse. These range from solving the intake gatewell flow and hydraulic restriction only, to a combination of intake and surface bypass corner collector modifications.

INTRODUCTION

This report is a synthesis of the biological data sets pertinent to the goal of improving the number of juvenile Pacific salmon (*Oncorhynchus* spp.) guided into the Bonneville Dam Second Powerhouse juvenile fish bypass system. These data sets were developed from evaluations conducted between 1983 and 1998, using a variety of direct capture, hydroacoustic, and radio telemetry methods. Limited hydraulic model data collected at the U.S. Army Corps of Engineers (COE) Waterways Experiment Station (WES) in Vicksburg, MS and field velocity measurements are also reviewed.

The COE, Portland District, has been directed by the Regional Forum to evaluate new measures that could increase the number of fish diverted from the Second Powerhouse turbine intakes and into the newly modified juvenile bypass system. The newly modified juvenile bypass system at the Second Powerhouse will be operational in spring 1999. Through the Regional Forum, the System Configuration Team (SCT) approved the use of FY99 Columbia River Fish Mitigation Program funds to investigate alternatives to enhance the number of juveniles guided away from turbines and into the new bypass system.

The COE, Portland District, developed a study plan and implementation schedule in early FY99 for the Bonneville Dam Second Powerhouse Fish Guidance Efficiency (FGE) Improvement Project. The National Marine Fisheries Service (NMFS) has been contracted by the COE to provide a synthesis of the available biological information. This synthesis will suggest a number of potential fish guidance efficiency design alternatives. If warranted, new alternatives will be hydraulically modeled at WES, the merits of each analyzed and judged, and the selected alternative(s) will then be designed, constructed, and prototype tested. Through this synthesis, the biological data are reviewed and presented in a single report. Based on the NMFS Northwest Fisheries Science Center's critical review of the data sets, hypotheses are presented to explain the potential causes of low FGE at the Second Powerhouse.

RELEVANCE

The NMFS Biological Opinion on the Operation of the Federal Columbia River Power System and Juvenile Transportation Program in 1995 and Future Years (NMFS 1995) stated under Section VIII, Reasonable and Prudent Alternative 14, that the "interim performance objective for these bypass improvements is an 80% fish passage efficiency and 95% passage survival at each dam." To meet these performance objectives, the Bonneville Dam Second Powerhouse FGE Improvement Program was developed with the following goals in mind:

1). Improve the survival of listed and non-listed smolts that enter the Bonneville Dam Second Powerhouse forebay and pass the powerhouse structure and tailrace.

2). Improve the percentage of smolts that pass the Bonneville Dam Second Powerhouse through a non-turbine route (FPE).

3). Maximize benefits to non-salmonids, to the extent practicable.

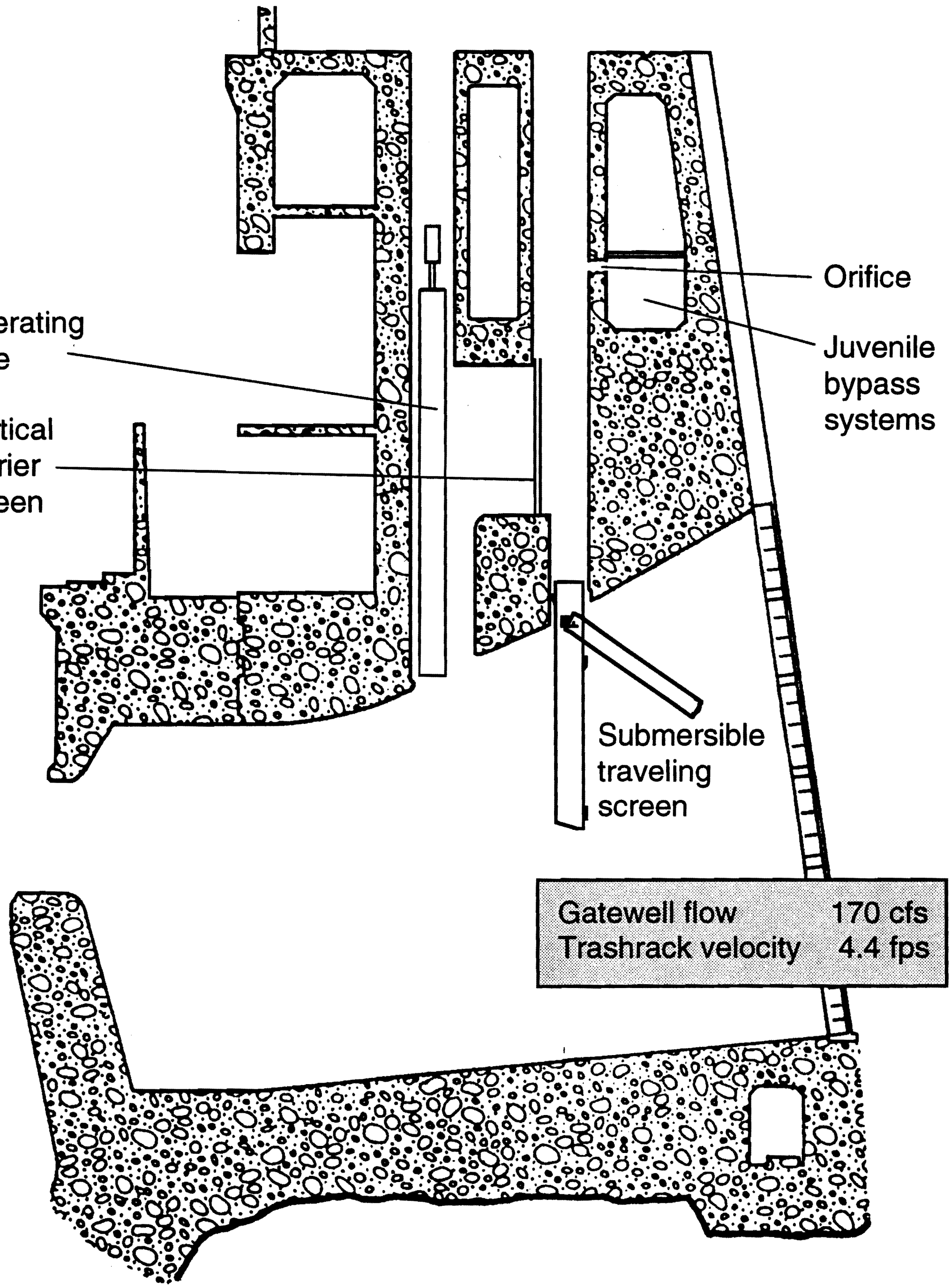
4). Maintain current project operational flexibility, to the extent practicable.

BACKGROUND

In 1970, in response to concerns over the effect additional dams may have on juvenile Pacific salmon during their seaward migration, NMFS began investigating means to decrease impacts to juvenile salmonids passing through Columbia River Kaplan turbines. NMFS focused on developing submersible traveling screens (STSs) to establish a hydraulic flow field above the STSs that diverts juvenile salmonid migrants into specially designed bypass systems. These bypass systems convey the guided fish to release points below the dam (Fig. 1). The performance of STSs was measured by Fish Guidance Efficiency (FGE) tests which measured the percentage of fish guided by the STS into the bypass system relative to the total number of fish entering the turbine intake.

Based on the successful development of the STSs, most Snake and Columbia River projects operated by the COE were retrofitted with STSs (Mighetto and Ebel 1995). As Snake and Columbia River dams were constructed starting in the 1970s, each incorporated the best juvenile bypass system design known at that time. Many of the original juvenile bypass systems were redesigned and upgraded as additional improvements were made and tested (Whitney et al. 1997). The Bonneville Dam Second Powerhouse was the last of nine powerhouses installed on the mainstem Snake and Columbia Rivers by the COE. COE designers incorporated a state-of-the-art juvenile bypass system into the Second Powerhouse. This included STSs, vertical barrier screens, and orifices (see Fig. 1). A total of 24 STSs were installed at the Second Powerhouse. Construction of the powerhouse was completed in 1982.

Bonneville Dam Second Powerhouse 1983



Yearlings		***Subyearlings***	
TFGE	50%	TFGE	42%
FGE	25%	FGE	25%
STS efficiency	50%	STS efficiency	60%

Figure 1. Cross-section of turbine intake at Bonneville Dam Second Powerhouse showing original design and resulting Fish Guiding Efficiency (FGE) and Theoretical Fish Guiding Efficiency (TFGE) results for yearling and subyearling chinook salmon.

In 1983, NMFS investigated the performance of the newly completed juvenile bypass system at the Second Powerhouse and measured mean levels of FGE much lower than the original design goal of 70% for all migrating species. From 1984 to1989, a series of structural modifications were evaluated in an attempt to improve guidance into the Second Powerhouse juvenile bypass system (Gessel et al. 1991). In the early 1990s, the three most promising improvements were installed. Research in 1993 and 1994 indicated that FGE values for yearling chinook salmon were improved when compared to 1983, and ranged from 35 to 60% (Monk et al. 1994, 1995). However, FGE levels of 70% were still not approached for all species (except coho salmon) and FGE for summer migrating subyearling chinook salmon remained at 25%. Therefore, the regional goal of 70% guidance for all species was not achieved by the efforts conducted to that time.

Starting in 1995, the COE began to evaluate the potential for improving survival through the Bonneville Dam Second Powerhouse juvenile bypass system. NMFS studies documented low survival rates for subyearling fall chinook (*O. tshawytscha)* passing through the Second Powerhouse juvenile bypass system and tailrace, relative to fish released 2.5 km downstream (Ledgerwood et al. 1990). Hydraulic model studies conducted at WES, combined with information on the behavior of the primary predator in the tailrace, northern pikeminnow (*Ptychocheilus oregonensis*), led to the development of bypass outfall criteria to minimize predation in the tailraces of dams, and enhance overall smolt survival. The criteria developed by Poe (1993) were used by the COE to design a new outfall to the Second Powerhouse juvenile bypass system. The COE is currently constructing a new downstream migrant channel, dewatering structure, transportation pipe, and outfall release pipes to improve the survival of juvenile salmonids that use the bypass system. The new Second Powerhouse bypass system and outfall will be operational starting in spring 1999.

The purpose of this document is to synthesize of all the available biological information that has been developed since 1983. The information is described, reviewed, and judged as to its adequacy and completeness. The information can then be used by the COE and the regional salmon managers to formulate alternative guidance designs that provide improved, safe guidance into the new bypass system and outfall at the Second Powerhouse.

STUDY OBJECTIVES

The objectives of this report are to:

1). Review the results from biological evaluations conducted at Bonneville Second Powerhouse from 1983-1998. Present the results in such a manner that readers can understand the types of studies conducted, data generated, and the strengths and limitations of these data sets.

2). Develop testable hypotheses that may explain the lack of suitable performance from the existing STSs, bypass components, and alternative guidance configurations tested to date.

3). Develop a series of options for future direction for the COE and salmon managers to use when developing the program.

SITE DESCRIPTION

Bonneville Dam is at Columbia River Kilometer 234 (River Mile 146.1). The project was authorized by the Rivers and Harbors Act of 1935, which included authorization for the Bonneville Dam First Powerhouse, spillway, and associated fish passage facilities. The First Powerhouse and spillway were completed in 1938. The First Powerhouse has 10 axial-flow Kaplan turbine units and a total hydraulic capacity of 3,808 m^3/s (136,000 cfs). River flows in excess of 3,808 m^3/s were spilled. Prior to the addition of the Second Powerhouse, river flows typically caused involuntary spill during April-July.

Construction of the Bonneville Dam Second Powerhouse was initiated in 1974 and completed in 1982. The powerhouse is comprised of eight axial-flow Kaplan turbines; operation of these units began in 1983. Each unit has a hydraulic capacity of 329-486 m^3/s (11,733-17,344 cfs), depending on tailwater, when operated within 1% of peak efficiency per the Fish Passage Plan (U.S. Army Corps of Engineers, 1998). Total powerhouse hydraulic capacity ranges from 2,632 to 3,888 m^3/s (93,864-138,752 cfs).

In 1983, turbine intake trashracks with 15-cm (5.9 in) openings between members, STSs, vertical barrier screens (VBSs), and two 0.3-m (12 in) diameter orifices per gate slot were installed as part of the original design of the Second Powerhouse. In 1983, as part of the original powerhouse design, an ice-trash sluice chute was installed at the south end of the powerhouse to pass forebay debris to the tailrace. The sluice chute has an invert elevation of 52 and 61 ft mean sea level (msl). The reservoir elevation of the lake behind Bonneville Dam is typically maintained between 71.5 and 76.5 ft msl. The chute has a hydraulic capacity of 57-160 m^3/s (2,000-5,600 cfs), depending on forebay elevation and which invert elevation is selected by positioning the weir gate. The entrance to the chute is 4.6 m (15 ft) wide.

INITIAL FISH GUIDANCE AND VERTICAL DISTRIBUTION STUDIES AT BONNEVILLE DAM SECOND POWERHOUSE , 1983 -1989

Brief Description of Methods and Procedures

Krcma et al. (1984) and Gessel et al. (1991) describe the methods used to conduct both FGE and vertical distribution tests at most main stem dams on the Snake and Columbia Rivers. Guidance tests use a steel frame with five rows of fyke nets in three columns (15 nets) which is positioned directly below the STS (usually the middle or B gatewell slot). The orifice is closed in the gatewell slot and the test unit is then operated for 2 to 3 hours (depending on fish numbers) starting at 2000 h (when highest densities of juvenile salmon move through powerhouses at Columbia River dams). During this time, guided fish are removed from the unit with a dip-basket (Swan et al. 1979) and counted. At the end of the test, the fyke-net frame is removed from the intake and the fish removed and counted from each net. The FGE is then determined by the following formula:

$$FGE = [GW/(GW + GN + FN)] \times 100$$

Where:

GW = gatewell catch
GN = gapnet catch
FN = fyke net catch

Procedures for vertical distribution tests were similar to FGE tests except that the STS is removed and a larger fyke-net frame (with seven rows of nets) is used which encloses the entire depth of the intake. The depth distribution results from these tests are used to derive theoretical fish guiding efficiency (TFGE), which is an estimate of the percentage of fish theoretically guidable (i.e., intercepted by the STS) based upon hydraulic model studies conducted at WES. These studies indicated that TFGE includes the gatewell plus fish from the area of the intake ceiling to a depth equivalent to the center of the third net level on the vertical distribution frame. An additional comparison made during the FGE studies is the effectiveness of the various guiding devices. This is obtained by dividing FGE by the appropriate TFGE.

The Plan for Analyzing and Testing Hypotheses (PATH) Hydro Work Group (PATH 1998) analyzed estimates of FGE measured with fyke nets and compared these estimates to Passive Integrated Transponder (PIT) tag estimates of FGE at certain dams. Based on this analysis, PATH used FGE values that were adjusted downward by 20% (multiplied FGE by a factor of 0.8) for all STS FGEs in their computer models of hydro system survival. This was to account for error in the estimate associated with the fyke nets being located directly under the STS. We acknowledge these adjustments, but did not apply them to any values used in this report. This is because the hydraulic environment of the Bonneville Dam Second Powerhouse intake is fundamentally different from all other intakes, and multiplying all FGE values used by 0.8 would nor affect the outcome of our analysis.

1983 Studies

Initial guidance estimates were less than 25% for yearling and subyearling chinook and coho salmon and approximately 33% for steelhead (Table 1). Vertical distribution data indicated two problem areas. First, TFGE was only about 50%. Second, screen effectiveness was

Table 1. Modifications made to the intake structure and juvenile bypass system at Bonneville Dam Second Powerhouse and the resulting changes in fish guiding efficiency (FGE).

Year	Modifications	Yearling Chinook.	Subyearling Chinook.[a]	Coho	Steelhead.
1983	First measurements of FGE	< 25%	< 20%	< 25%	33%
1985	STS lowered 27 inches Trashracks streamlined	40%	24%	40%	44%
1986	6 TIEs in adjacent slots	60%[b] 49%[c]	21%		46%
1987	6 TIEs in alternate slots	60%	20%		53%
1989	Alternate TIEs, 33% Bar Screen	78%[d]	25%	80%	69%
	Same	60%[e]			72%
	Alternate TIEs, 25% STS	50%[e]			40%

[a] Values for summer outmigration

[b] Partial powerhouse operation

[c] Full powerhouse operation

[d] Middle May - only three replicates

[e] Late May

approximately 50%. In other words, only about half of the fish were passing through the turbine intake in an area that would be intercepted by the STS, and then only half of these fish were actually being diverted.

1984 Studies

The 1984 studies addressed the two problem areas, either intercept more fish or improve the effectiveness of the STS (Gessel et al. 1985). To intercept a larger portion of the turbine intake flow and theoretically more fish, the bottom sections of the trashrack were blocked by attaching steel panels. This was done to force more water and fish through the upper portion of the trashrack (trashrack sections were 3.05 m high and each intake had six sections). A trashrack deflector was used to simulate a lengthened STS (Fig. 2). A potential area of escapement (along each side of the STS) was blocked with side-wings or, for a few tests, small nets were attached in this area. To increase flow above the STS it was lowered 30.5 cm (12 in) and a turning vane was placed at the top of the STS to direct the gatewell flow upward. Also, during some tests the operating gate was partially raised, and the perforated plate between the two mesh panels of the STS was removed.

None of the changes showed any major improvement over the 1983 guidance. Guidance was 30 to 40% for yearling chinook, but velocity above the STS and into the gatewells was increased considerably with the blocked trashracks and deflector. This increased flow caused a dramatic increase in descaling (over 50% of the yearling chinook salmon were descaled; generally descaling is ~ 5%) and mortality was as high as 30%. Extending the length of the guiding device

Bonneville Dam Second Powerhouse

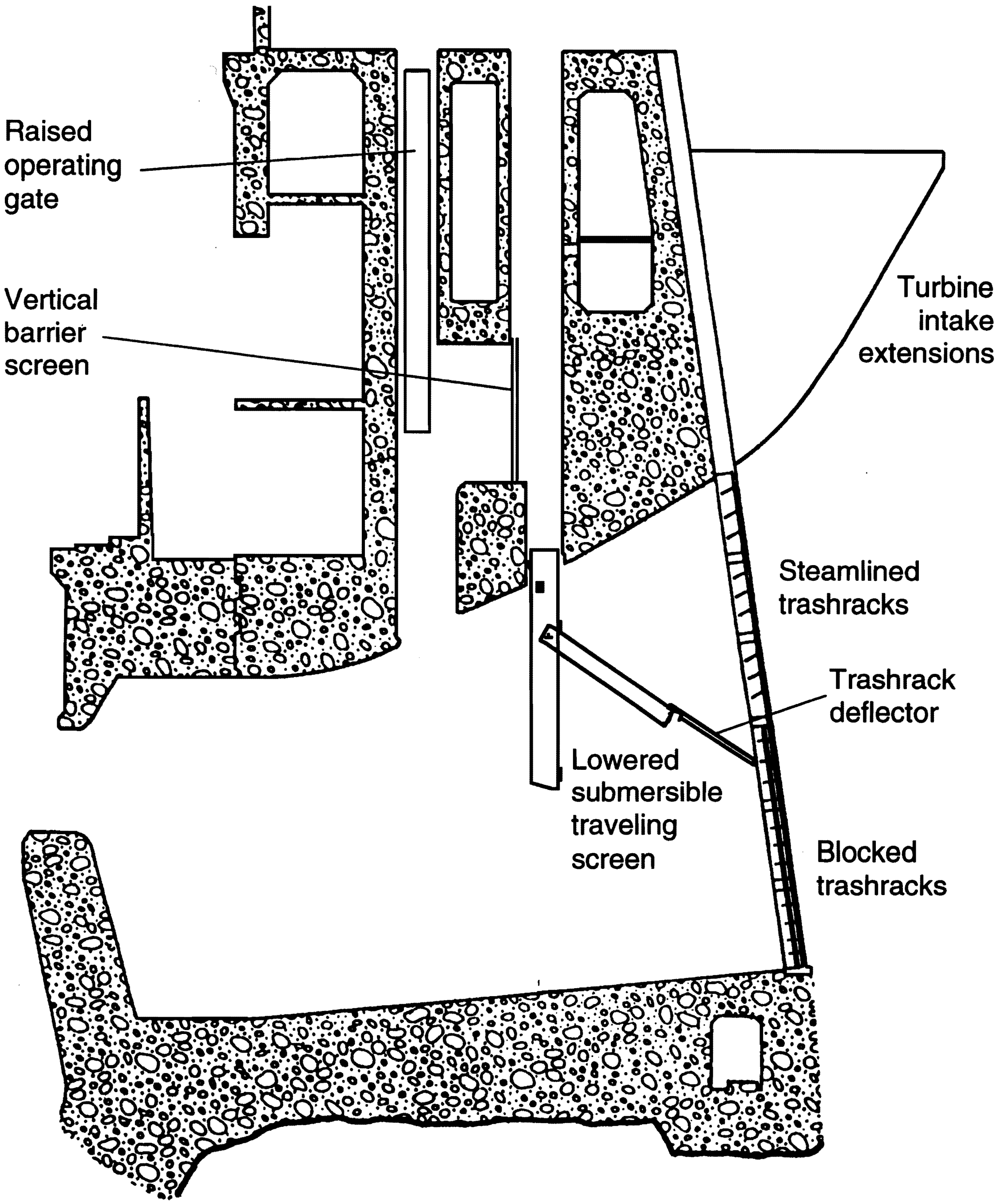


Figure 2. Cross-section of turbine intake at Bonneville Dam Second Powerhouse showing structural modifications tested from 1984 to 1989 to improve Fish Guiding Efficiency (FGE).

through the use of a trashrack deflector appeared to be counter-productive. Although it increased the intercepted area in the turbine intake by about one-third, neither fish guidance nor screen effectiveness increased. It appeared the poor guidance was at least partially caused by fish avoidance of or deflection from the STS. A reduction in this avoidance was the major goal for the next year's study.

1985 Studies

Studies in 1985 at the Second Powerhouse tested the affects of altering the flow in the area intercepted by the STS. This was accomplished by lowering the STS and by using streamlined trashracks (the top three sections of trashrack were designed so that the angle of the horizontal bars matched the theoretical flow lines). The trashrack deflector was again used to extend the length of the guiding device (see Fig. 2) (Gessel et al. 1986).

The streamlined trashracks improved FGE for yearling chinook salmon to about 33% with the STS in the standard position. Lowering the STS 0.7 m in conjunction with streamlined trashracks increased FGE to about 40% (gapnet catch remained at less than 1%), but lowering the STS 1.2 m decreased FGE to 29% and increased the gapnet catch to 12%. The trashrack deflector with the traveling screen lowered either 0.7 or 1.2 m did not improve FGE beyond the 40% level, although the 1.2 m lowered STS and deflector appeared to increase total fish intercepted slightly (gatewell plus gap catch was 44%). Also, screen effectiveness was never greater than 55%. These results directed the next series of tests toward the use of TIEs (see Fig. 2) to dampen the effect on juvenile guidance of the large eddies and lateral flows in the forebay.

1986 Studies

The initial tests in 1986 compared 0.7m lowered STSs with the standard or streamlined trashrack (Gessel et al. 1987). In these tests, mean FGE for yearling chinook and coho salmon with the streamlined trashracks was significantly higher (44%) than the standard design (34%).

These tests were repeated using a restricted powerhouse operation (four units, 11-13 and 18; 510 m^3/sec (18,000 cfs) each and with the TIEs positioned in front of six adjacent gatewells (11C, 12A, 12B, 12C, 13A, and 13B). Guidance was 60% with a mean screen effectiveness of 81% during these tests. However, when tests were conducted with full powerhouse operation FGE dropped to below 50%, leading to the conclusion that powerhouse operation could effect fish guidance. It also reinforced the idea that comparative testing of full powerhouse operation would require a full complement of modifications across the entire powerhouse. A comparison of TFGE during the period 19-30 May also indicated that changing powerhouse operation could have an effect on FGE (Table 2). Little replication occurred for some of these tests, but the general trend of TFGE varying with powerhouse operation was evident.

The tests with the TIEs were also conducted during the summer outmigration, but with no obvious improvement of FGE for subyearling chinook salmon.

1987 Studies

In 1987, the TIEs were tested in the adjacent position used in 1986 (in front of gatewells 11C, 12A, 12B, 12C, 13A, and 13B) and using an alternating configuration (in front of gatewells 11A, 11C, 12B, 13A, 13C, and 14B). Each of these configurations was tested under two powerhouse loads four unit (11-13 and 18; 510 m^3/sec each) and seven unit (11-14, 16-18; 510

Table 2. Theoretical fish guiding efficiency (TFGE) for four, seven, and eight unit operation at various discharges at Bonneville Second Powerhouse, 1986.

		Discharge/unit		
Number of Units	Units	cfs	m^3/s	TFGE
4 units	11,12,13,18	15,000	425	54%
4 units	11,12,13,18	18,000	510	79%
7 units	11-14	17,000	481	
	16-18	14,500	411	89%
8 units	11-18	18,000	510	76%

m^3/sec each). These tests were conducted to confirm the 1986 results, and because model studies had indicated the TIEs in an alternating sequence appeared to reduce the lateral flows (Gessel et al. 1988).

The results from these tests indicated that the alternate TIE configuration with seven units operating gave the highest FGE (72 and 60%) and STS effectiveness (86 and 72%) for the STSs in 12A and 12B, respectively. The four unit operation with alternate TIEs produced FGEs of 52 and 42% and STS effectiveness of 78 and 63% (12A and 12B, respectively). Also, the number of fish collected in turbine intake 12A (non-TIE) was almost 1.7 times higher than the number in 12B. Guidance with the extensions in the adjacent position ranged from 32-50% in gatewells 12A and 12B. The ratio for fish numbers in the two slots with the TIEs adjacent was nearly equal (ratio A/B = 0.96:1).

The alternate TIE configuration appeared to reduce the lateral flows across the powerhouse and created vortices between the extensions. These vortices may have helped concentrate fish near the turbine intake ceiling where they were more readily guided. The higher guidance and screen effectiveness with the seven unit operation appeared to indicate that the alternating TIE configuration was the major change required to achieve acceptable FGE for yearling chinook salmon.

These same tests did not improve FGE during the summer migration for subyearling chinook salmon. Mercury vapor lights were also tested in turbine intake 12B. The lights seemed to attract fish because during some tests using the alternate turbine extension configuration more fish were recovered in the gatewell with the TIE (12B) than without the TIE (12A).

1988 Studies

In 1988, vertical distribution of the smolts was measured in turbine intakes with and without TIEs and TFGE between the two conditions was compared (Gessel et al. 1989). Increased porosity of the guiding device was tested by comparing the 23% porosity standard STS to a 45% porosity bar screen. A trashrack deflector of the same high porosity was used for some tests with the bar screen. Identical light configurations were tested in turbine intakes 12A, 12B, and 12C with 12B used as the fish collection unit. The tests with the trashrack deflector and the lights were conducted as possible methods of improving FGE for subyearling chinook salmon. Early in the outmigration NMFS compared FGE between unit 12B (with a TIE) and 17B (without a TIE); both units used a lowered STS and streamlined trashracks. All testing in 1988 occurred with the TIEs in the alternate configuration, on the south end of the powerhouse, and under a four- unit operation (11-13 and 17 or 18). Unit load was 481 m^3/s (17,000 cfs) during the spring and 411 m^3/s (14,500 cfs) during the summer tests.

The results from these tests indicated: 1) TFGE was higher in the gatewell without the turbine intake extension (85 vs. 66%); 2) the mean number of fish recovered was also higher (1544 vs. 546); 3) a direct comparison of the bar screen and STS showed a higher mean screen effectiveness with the bar screen (81 vs. 51%), but the bar screen also increased descaling 2.5- to 3-fold; 4) FGE and screen effectiveness were approximately 55 and 80%, respectively (comparable to the four unit operation during the 1987 tests); 5) neither the mercury vapor lights nor the trashrack deflector improved guidance during the spring or summer migration periods; and 6) guidance was higher in 12B than in 17B (31.2 and 15.6%, respectively).

The increase in descaling with the bar screen was probably due to the increase in porosity. Once again, the trashrack deflector did not increase FGE, even though it was constructed from the high porosity bar screen material and substantially increased the screened area of the turbine intake.

1989 Studies

Turbine operating conditions in 1989 were similar to those in 1988 and 1987 (Gessel et al. 1990). The four units operated for all tests were 11-13 and 18; unit discharge was 481 m^3/s (17,000 cfs) in the spring and 411 m^3/s (14,500 cfs) in the summer. A raised operating gate was tested with the 45% bar screen. Raising the operating gate did not improve the effectiveness of the bar screen and it did not reduce levels of descaling. The porosity of the bar screen was also reduced to 33% in 1989, which reduced descaling and produced FGE levels of over 70%. These tests were repeated later in the outmigration and FGE dropped to 60%.

The mean FGE for subyearling chinook salmon (25%) during the summer migration period remained unchanged from previous years.

Discussion

There appeared to be two major hydraulic conditions that affect FGE at the Bonneville Dam Second Powerhouse. First was the restriction or blockage of flow in the area intercepted by the guiding device. Second was the bulk flow that moves laterally (both north and south) across the face of the powerhouse. We theorize that the modifications or additions that showed the most improvement in FGE (lowered STS, streamlined trashracks, and TIEs) specifically addressed these two conditions. Lowering the STS allowed more flow through the area intercepted by the STS. It should be noted that this improvement was limited to about a 10% increase in FGE, and other changes (e.g. the raised operating gate) that should work in tandem with the lowered STS did not increase FGE. The TIEs reduced the effect of the lateral flows by streamlining the upper forebay flow into the turbine intake and possibly through the creation of the vortices in the gaps between the TIEs. The streamlined trashrack possibly addressed both hydraulic conditions by reducing turbulence on the downstream side of the trashracks. The only other behavioral issue that was addressed (besides flow) was attraction to lights. Results were mixed. Attempts to light the forebay surface (Gessel et al. 1985) appeared to have no effect. Mercury vapor lights within the intake altered the ratio of fish collected in a TIE vs. a non-TIE slot. An incandescent light on the vertical distribution frame appeared to alter the distribution of fish captured within the intake.

The results from the first seven years of fish guidance efficiency studies at Bonneville Dam Second Powerhouse portray a complex interaction between fish guidance and flow that is not evident at any of the other COE projects on the Snake or Columbia Rivers. Generally, when smolts are predominately distributed in the upper areas of the forebay, fairly high FGE (~70%) has been the norm. Prior to the study at the Bonneville Dam Second Powerhouse, FGE studies had generally involved a few weeks of testing during the spring and/or summer outmigrations. It was thought that these data could then be condensed to provide an average FGE for the different species. The Second Powerhouse results indicated that it is necessary to sample all portions of each outmigration. Early-, mid-, and late-season information is necessary to estimate FGE for a given species. This becomes especially critical when comparing data for different types of guiding devices or specific changes to one particular guiding device at the different projects.

The uniqueness of the Bonneville Dam Second Powerhouse is underscored by the ineffectiveness of the raised operating gate and the trashrack deflector. These two modifications are important because each attempts to increase FGE in different ways. Although each modification increased FGE at other projects (at times substantially), neither had much affect on FGE at the Second Powerhouse. The raised operating gate addresses a perceived flow restriction/blockage in the area intercepted by the guiding device. The trashrack deflector basically extends the length of the guiding device. The fact that neither appeared to have much of a positive effect on guidance indicates the severity of the problem.

The fact that none of the changes made at the Second Powerhouse appeared to affect FGE for subyearling chinook salmon indicated that these fish may migrate at too great a depth, other unidentified hydraulic conditions are present, or there may be unknown behavioral/migrational responses dictating their movements. Low FGE for these fish occurs during the later stages of each year's outmigration at all COE projects that have juvenile bypass systems.

By the end of the 1989 field season, three modifications/additions appeared to be the most beneficial: lowering the guiding device (0.8 m), streamlining the upper three trashrack sections, and installing TIEs in an alternate gate slot configuration. Although there was a large amount of variation in FGE on a yearly basis, the best guidance with acceptable fish condition occurred during the seven- or eight- unit (full powerhouse) operation. The next reasonable step was to retro-fit the entire powerhouse with these changes and conduct the necessary verification study.

POST-CONSTRUCTION EVALUATION OF FGE AT BONNEVILLE DAM SECOND POWERHOUSE, 1993 -1994

In 1993, studies were conducted during the spring and summer juvenile salmon outmigration to evaluate FGE after the full installation of TIEs (in alternate slots), lowered STSs, and streamlined trashracks at the Second Powerhouse (Monk et al. 1994). To fully evaluate the effects of these modifications, tests were conducted in north, middle, and south turbine units (Units 17, 15, and 12, respectively) under full (eight unit) and partial (four and six unit) operation. During the spring outmigration, all three units were tested under full powerhouse operation, but only the high priority units (12 and 17) were tested under partial powerhouse operation. During the summer outmigration, the same units were tested at four or six unit operation only.

During spring 1993, with four turbines in operation, 75% more fish of all species (except steelhead) entered the non-TIE slot (Fig. 3). With six units in operation, 25% more yearling chinook salmon entered the non-TIE slot. With all eight units in operation, equal numbers of fish of all species entered the TIE and non-TIE slot. With four or six units in operation, FGE for yearling and subyearling chinook salmon was significantly higher in the non-TIE slot (for the other species, FGE was also higher but not significantly so)(Fig. 4). With eight units in operation, FGE for all species was not significantly different between the TIE and non-TIE slots.

By weighting FGE in the two adjacent slots by the ratio of the number of fish in the non-TIE slot to the number in the TIE slot, a average FGE for all three gatewells was derived. With four or six units in operation, the average FGE for yearling chinook salmon in Units 12 and 17 combined was 44%. With eight units in operation, mean FGE for yearling chinook salmon in Units 12, 15, and 17 combined increased to 50%.

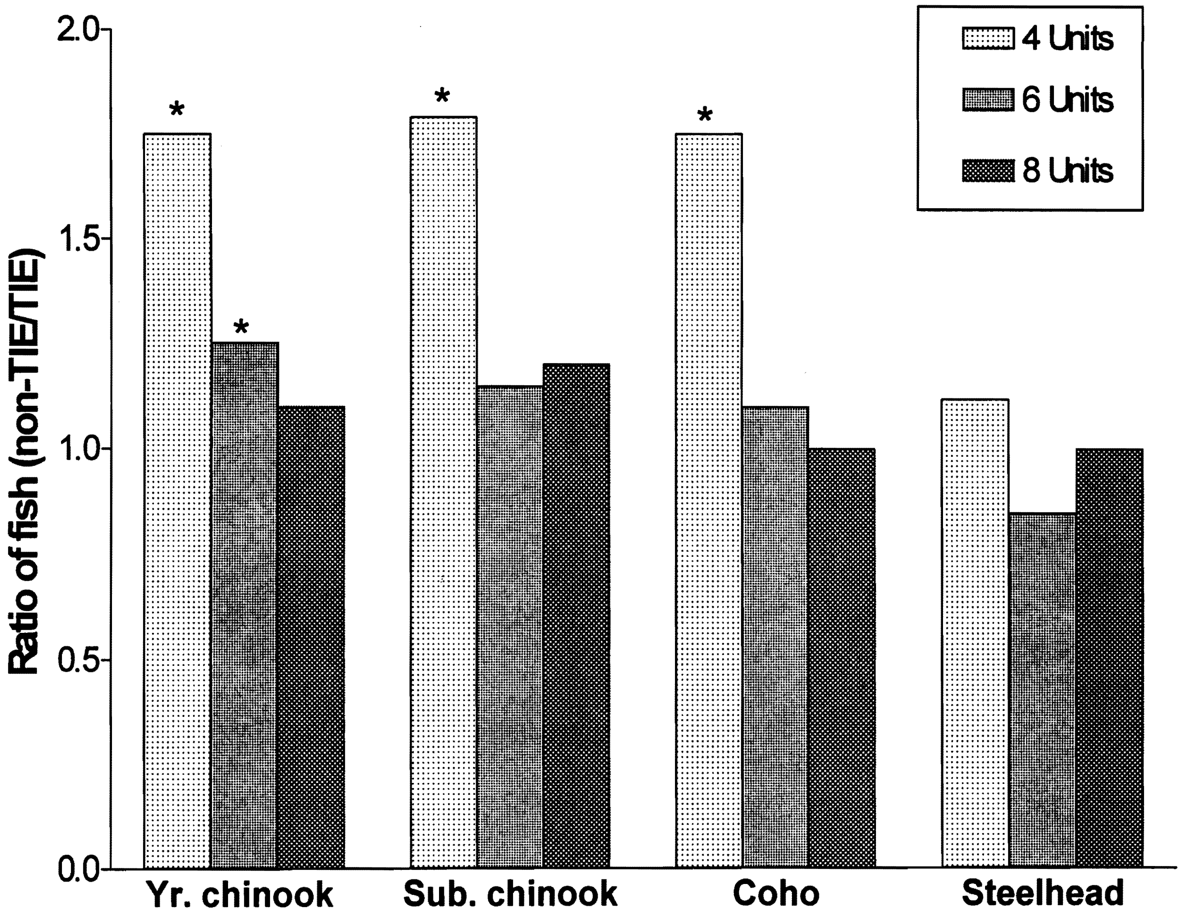


Figure 3. Ratio of number of fish in slot without a turbine intake extension (TIE) to the number of fish in gatewell with a TIE, in Turbine Units 12,15, and 17 combined, with 4, 6, or 8 units in operation, 1993 spring migration at Bonneville Dam Second Powerhouse (* denotes significant difference from 1, $\alpha = 0.05$).

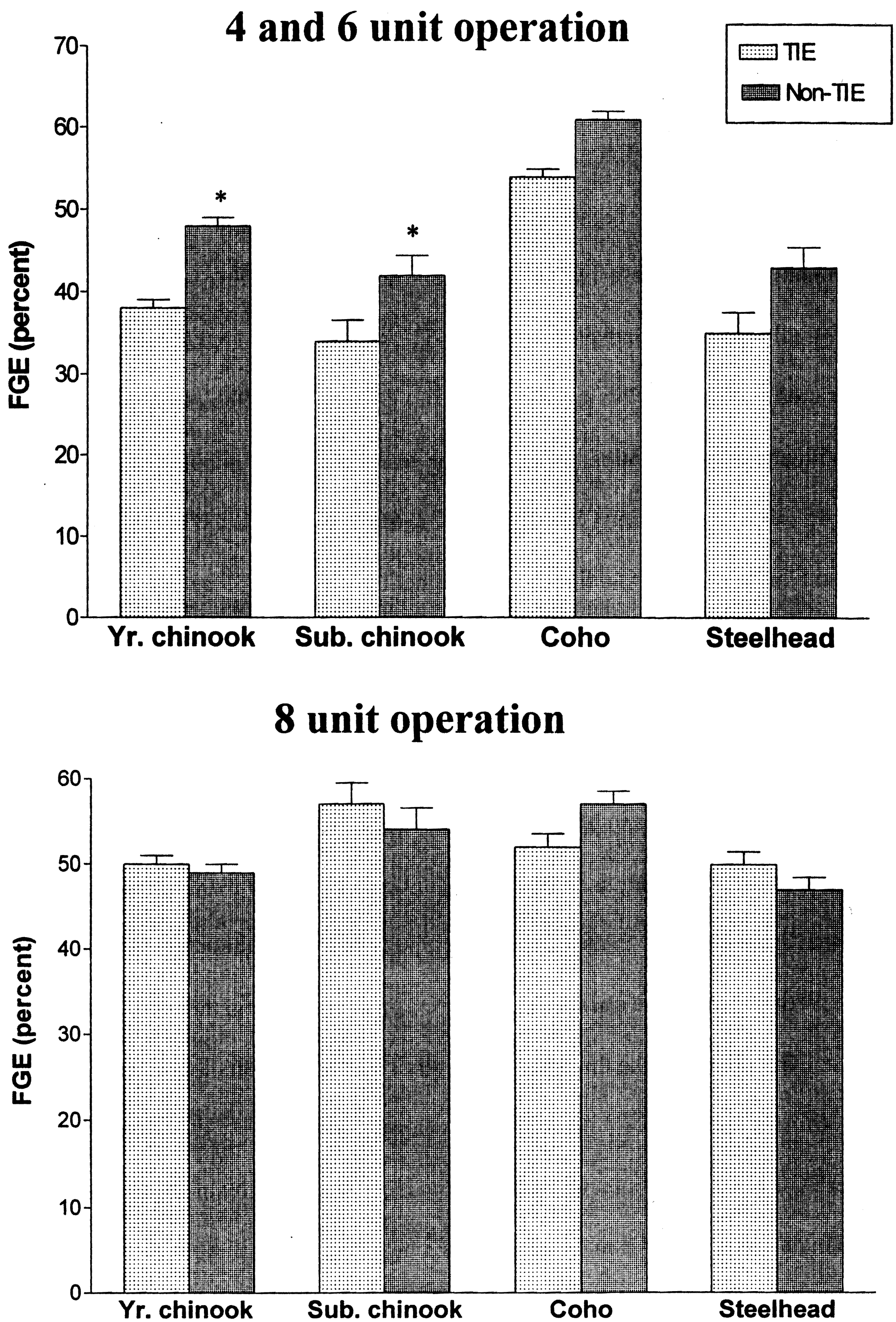


Figure 4. Mean Fish Guidance Efficiency (FGE) and standard errors in gatewells with and without turbine intake extensions (TIES) for four and six unit operation combined and eight unit operation at Bonneville Dam Second Powerhouse in spring 1993 (* denotes significant difference between TIE and non-TIE, $\alpha = 0.05$)..

During summer 1993, FGE was measured only in Units 12 and 17 with four- and six- unit operation (normal summer operation of the Second Powerhouse). Mean FGE for subyearling chinook salmon was significantly higher with six units in operation than with four. Mean FGE for subyearling chinook salmon in Unit 17 (34%) was significantly higher than in Unit 12 (25%).

In 1994, all tests were conducted in the non-TIE slots of Units 12, 15, and 17 with six- and eight-unit operation only to establish any difference in FGE across the Second Powerhouse (Monk et al.1995). With eight-unit operation, mean FGE for yearling chinook salmon was significantly higher in Unit 15 (57%) than in Units 12 (44%) or 17 (36%). With both six- and eight-unit operation, mean FGE in Unit 12 was significantly higher than Unit 17 (53 and 44% compared to 32 and 36%, respectively). In 1994, summer FGE tests with subyearling chinook were not conducted.

In 1993 and 1994, for all species tested, the highest FGE values were obtained in Unit 15, and for the most part, FGE values in Unit 12 were higher than Unit 17 (Fig. 5). A six-unit operation created the largest variation between years in Units 12 and 17 for yearling chinook salmon. This may have been due to the large daily variance in FGE in these outside units, which increased with partial powerhouse operation. However, by averaging together six- and eight unit operation, mean FGE values for the three units were similar between years for all species tested (Table 3) (Fig. 6).

Higher FGE in Unit 15 probably resulted from more laminar flow in the middle of the powerhouse than on either side. Even though the TIEs help straighten the flow across the entire width of the powerhouse, large eddies and turbulence form on both sides of the powerhouse adjacent to Units 12 and 17 when only four or six units are operating. Although these eddies tend

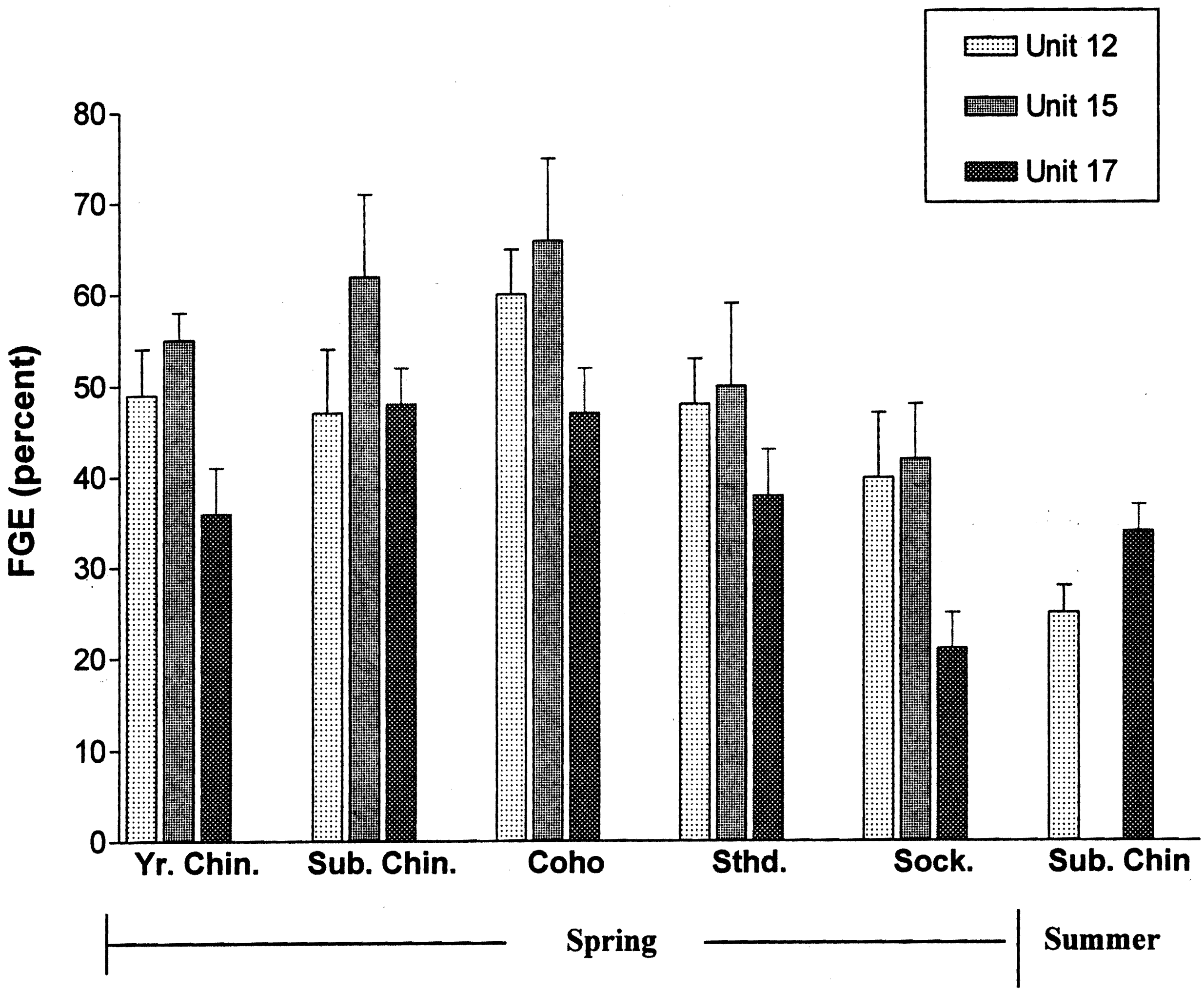


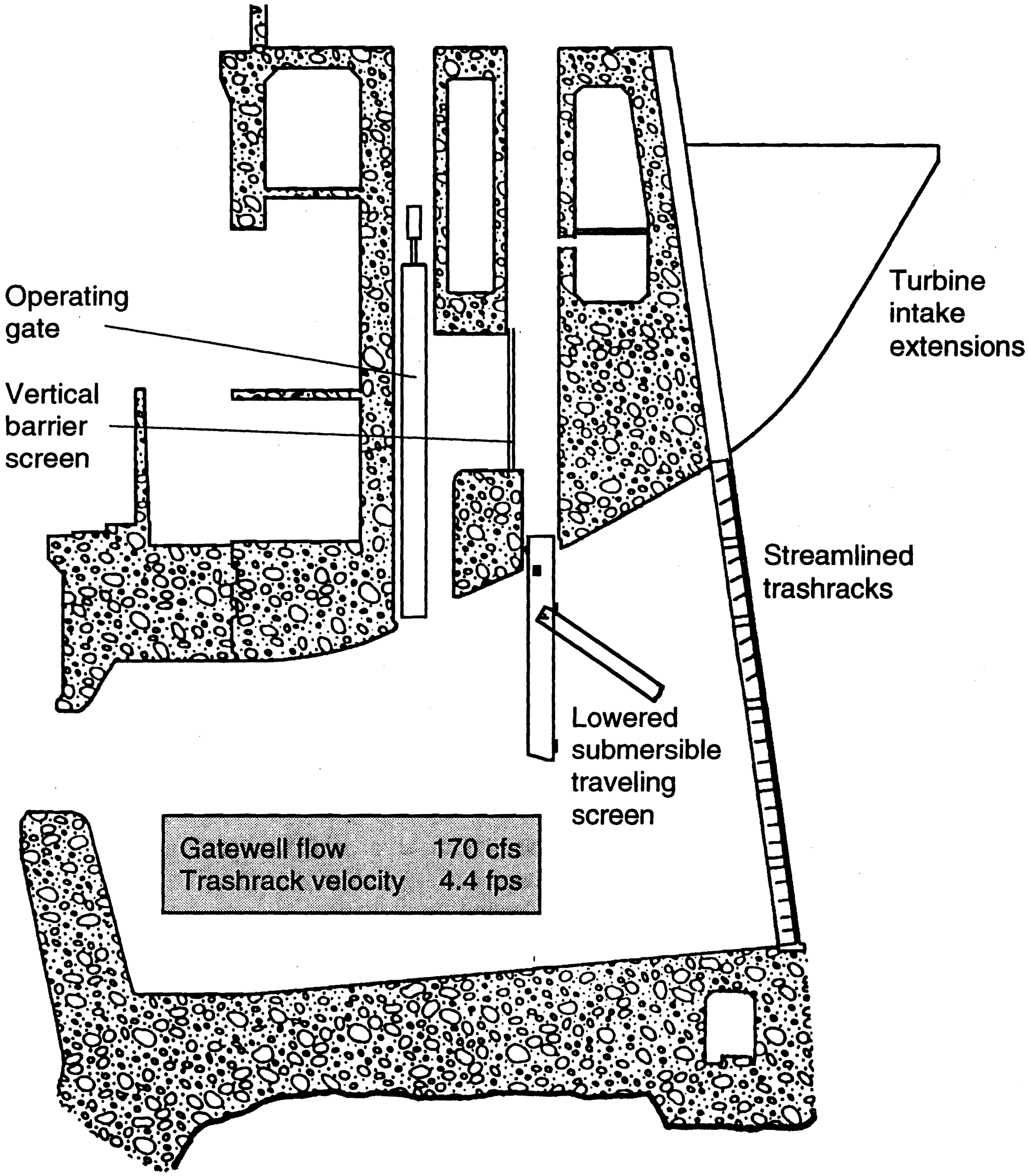
Figure 5. Fish guidance efficiency (FGE) for 1993 and 1994 combined for all species through Turbine Units 12, 15, and 17 with six and eight unit operation combined at Bonneville Dam Second Powerhouse (summer results are for 1993 only).

Table 3. Mean fish guidance efficiency (%) and standard error for all species in Turbine Units 12, 15, and 17 (non-TIE slots) with six- and eight-unit operation combined at Bonneville Dam Second Powerhouse, spring 1993 and 1994.

	12A		15B		17B	
Species	1993	1994	1993	1994	1993	1994
Yearling chinook salmon	49 (5)	49 (5)	54 (2)	56 (3)	37 (5)	34 (3)
Subyearling chinook salmon	44 (8)	49 (5)	64 (3)	60 (9)	51 (4)	45 (4)
Coho salmon	58 (5)	62 (4)	63 (3)	69 (9)	47 (4)	47 (5)
Steelhead	52 (5)	44 (2)	50 (5)	50 (9)	36 (5)	40 (3)
Sockeye salmon	41(7)	38 (4)	35 (5)	49 (6)	*	21 (4)

* All tests excluded because of insufficient numbers of fish.

Bonneville Dam Second Powerhouse 1993



Yearlings
FGE 49%

Subyearlings
FGE 25%

Figure 6. Cross-section of turbine intake at Bonneville Dam Second Powerhouse showing permanent modifications and resulting Fish Guiding Efficiency (FGE) values (in Unit 15) for yearling chinook (in spring)and subyearling chinook salmon (in summer).

to recede at full powerhouse operation, they still exist and apparently either pull fish away from the water surface or disorient fish so that they seek greater depth.

COMPARISONS OF BONNEVILLE DAM SECOND POWERHOUSE TO OTHER LOWER COLUMBIA RIVER DAMS

Site Description of Bonneville Dam Second Powerhouse

Initial research at the Second Powerhouse from 1983 to 1988 revealed two major reasons for unsatisfactory guidance: 1) the percent of salmon entering the turbine intakes at a depth intercepted by the STS at approximately 4.6 m (14 ft) from the surface was less than expected (Fig. 7), and 2) the STSs were not effectively guiding fish that were in this zone of interception (i.e. low screen efficiency). To better understand reasons for these differences, Bonneville Dam Second Powerhouse was compared to the First Powerhouse and to McNary and John Day Dams on the Columbia River. Differences were noted in forebay hydraulics, configuration of the intake structure, and the components of the fish bypass system, all of which seem to contribute to the lower TFGE and FGE at the Bonneville Dam Second Powerhouse.

Forebay Hydraulics

Bonneville Dam Second Powerhouse forebay hydraulics are different from all other COE powerhouse forebays, because of the unique configuration of the forebay channel. The forebay is excavated instead of naturally formed. The inlet to the forebay from the main river was dredged to a depth of approximately 30 ft mean sea level (msl), which produces an approximate depth of 45 ft (14 m) when the reservoir is operated between 71 and 76 ft msl. This initial approach to the

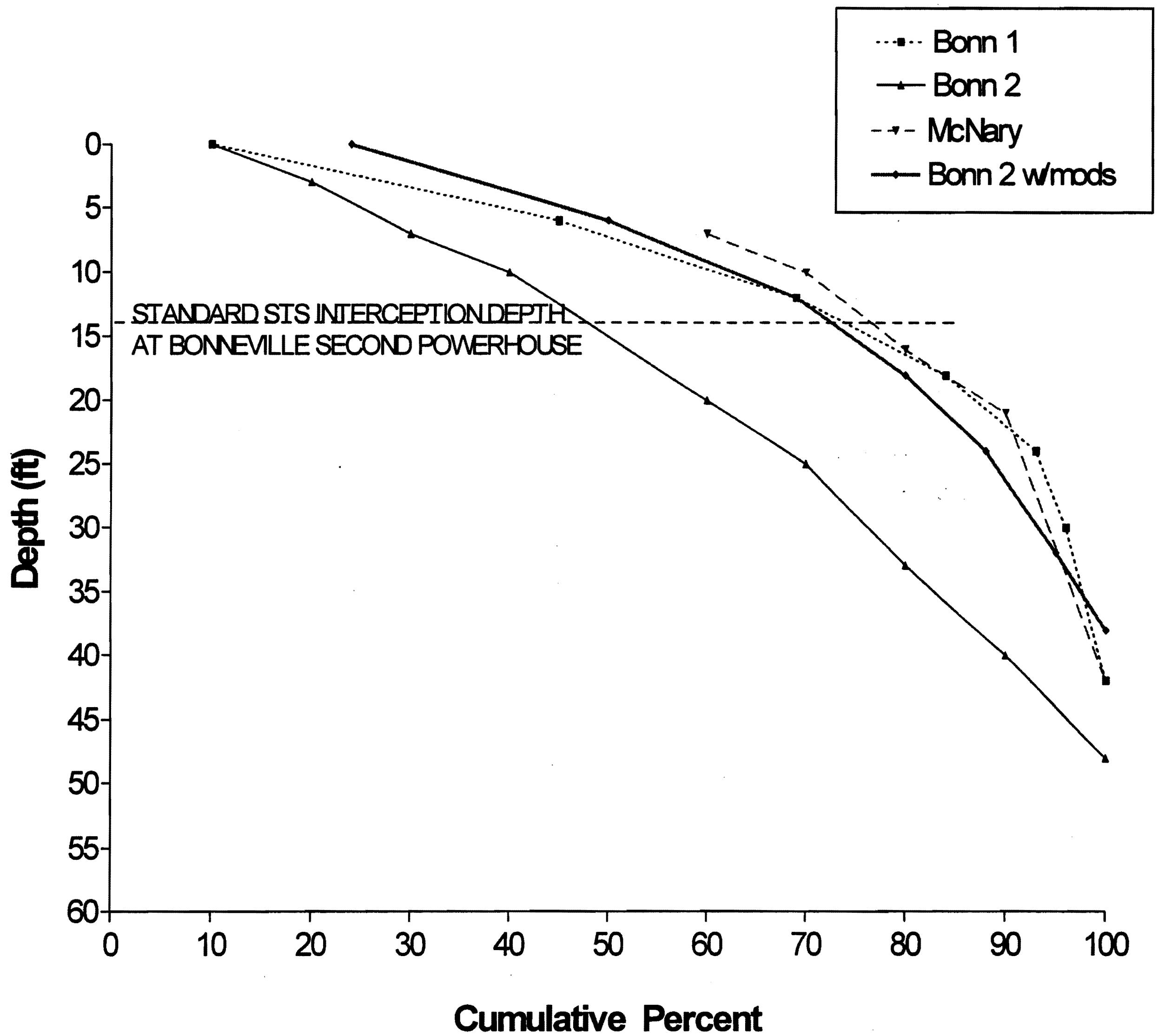


Figure 7. Vertical distribution of yearling chinook salmon (cumulative percent) in intakes at Bonneville Dam First Powerhouse, Second Powerhouse (with and without modifications), and McNary Dam.

powerhouse is shallow and roughly half the forebay depth of a typical COE mainstem Snake or Columbia River powerhouse. The forebay was excavated at an angle of approximately 30° to the alignment of the original river bank. Thus, the forebay is a shallow, man-made, "off channel" approach. Hydraulic model data from WES indicates high velocities in this shallow forebay. Velocities observed in the model range from 1.0 to1.9 m/s (3.2-6.2 fps), with the highest velocities near the surface (U.S. Army Corps of Engineers 1985). While we did not compare the Second Powerhouse approach velocities to other dams, these appear much higher than other COE projects, based on forebay hydraulic conditions in the field, observed by NMFS personnel.

Starting approximately 100 m upstream from the face of the Second Powerhouse, the forebay was excavated to form a sloped floor terminating at the unit intakes at a depth of approximately 20 ft msl. Hydraulic model data from WES indicate that water velocity decelerates as flow expands to fit the now enlarged area leading to the turbine intakes. These data also suggest that a high degree of momentum exists from the shelf to the face of the powerhouse. This momentum carries the surface-oriented flow to the face of the powerhouse in a velocity range of 0.6 to 1.4 m/s (2.1-4.5 fps) (U.S. Army Corps of Engineers 1985).

Intake Structure

Bonneville Dam Second Powerhouse has a back-sloping, flat face structure, similar to powerhouses at John Day, Lower Monumental, Little Goose and Lower Granite Dams. This design causes the high velocity forebay flow, that has momentum coming off the shallow shelf, to be deflected laterally once it reaches the flat face of the powerhouse intake. This approach momentum, combined with the flat face of the intake and the somewhat hooked upstream tip of

Cascade Island, produces strong lateral flows across the face of the powerhouse toward each corner.

Time-lapse photographs in Mih et al. (1985) showed these large eddies. Ott Water Engineers (1985) reported that hydraulic studies at WES indicated eddies at either end of the powerhouse extending deep into the forebay. It was hypothesized by Mih that FGE was lower at this powerhouse because the main flow (and fish) was diverted to a greater depth by these eddies (i.e., the eddies acted as a surface barrier causing part of the main flow to plunge). Hydraulic model testing also showed that installation of TIEs reduced the lateral flows along the headwall and reduced the eddies, leading to the design, installation, and testing of prototype TIEs in front of Units 11-13 in 1986.

In summary, the forebay at Bonneville Dam Second Powerhouse is unique. The configuration of the approach channel, the basin in front of the intake, and the flat face of the intake combine to set up decelerating flows that circulate toward each corner of the powerhouse. It is the physical configuration of the forebay that produces the complicated forebay hydraulics at the face of the powerhouse, that in turn have been such a challenge to improving FGE at the Second Powerhouse.

Fish Bypass Configuration

Inside the intake, the major differences in the fish bypass system are: 1) the distance from the trashracks to the upstream edge of the STS is approximately 2.1 m (7 ft), compared to 6.1 m (20 ft), 9.1 m (30 ft) and 12.2 m (40 ft) for the Bonneville Dam First Powerhouse and for McNary and John Day Dams, respectively; 2) the height of the vertical barrier screen support beam is much greater than at the other dams; and 3) consequently the total area of the vertical barrier screen is less than half that of the other projects.

To better understand the flow into and through the gatewell, a comparison of gatewell flow paths was developed by Ott Water Engineers (1985). This showed potential flow restrictions in the throat area and at the vertical barrier screen. In 1985, by lowering the STS 0.7 m (27 in), the throat area increased from 4.1 to 8.4 m^2 (44 to 90 ft^2) and FGE (in combination with the streamlined trashracks) increased from less than 25 to 40%. This seemed to substantiate the Ott Water Engineers premise that a significant change in the amount of flow diverted beneath the STS can occur when the gatewell flow is varied. Increasing the throat area by lowering the screen was the only modification made to the bypass system which consistently increased FGE.

Model studies by Mih et al. (1985) showed large eddies on both sides of the forebay just upstream from the powerhouse. These data were similar to mapping studies done by Jensen (1987) which compared velocity patterns at the trashracks at the Bonneville Dam Second Powerhouse to the First Powerhouse and to McNary Dam. These studies found very little transverse flow across the latter two structures compared to the Bonneville Dam Second Powerhouse, where these flows were severe with large erratic vortices.

To understand some of the possible reasons for low FGE at the Second Powerhouse, it is important to have an understanding of FGE problems and solutions which have occurred at other Columbia River projects. Lower Columbia River projects (McNary Dam, John Day Dam, and Bonneville First Powerhouse) were chosen for this comparison so the composition of migrating salmon were comparable.

Bonneville Dam First Powerhouse

In 1981, NMFS and the COE conducted prototype studies to evaluate the potential FGE of STS at Bonneville Dam First Powerhouse (Krcma et al. 1982). Initial estimates of FGE were greater than 70% for all salmonid species during the test period 30 April to 13 May. Guidance was lower during individual tests conducted later in May, but the decrease was attributed to large amounts of debris on the trashracks. Based on these results, a complete set of STSs was installed at the First Powerhouse prior to the 1983 juvenile salmonid out-migration.

With the construction of a new, larger navigation lock at Bonneville Dam, placement of rock groins in the forebay, removal of the tip of Bradford Island, and dredging modified the forebay of the First Powerhouse. In spring and summer 1988, prior to installation of a new guidewall, additional studies were conducted at the First Powerhouse so that any changes in FGE associated with changes in flow or the addition of the new guidewall could be identified in later tests. Between 30 May and 5 June 1988, FGE for subyearling chinook salmon averaged 41%, which was well below the 72% FGE measured for these fish during the same time in 1981. Between 6 and 27 July 1988, FGE for subyearling chinook salmon averaged 11% (Gessel et al. 1989).

Because of the lower than expected FGE in 1988, tests were expanded in 1989 to include both the spring and summer juvenile salmonid outmigration. Between 9 and 14 May 1989, FGE for yearling chinook salmon averaged 42%. Between 27 and 30 May 1989, FGE for yearling and subyearling chinook salmon averaged 31 and 37%, respectively. Between 12 and 24 July 1989, FGE for subyearling chinook salmon averaged 4% (Gessel et al. 1990) (Fig 8).

Bonneville Dam First Powerhouse 1989

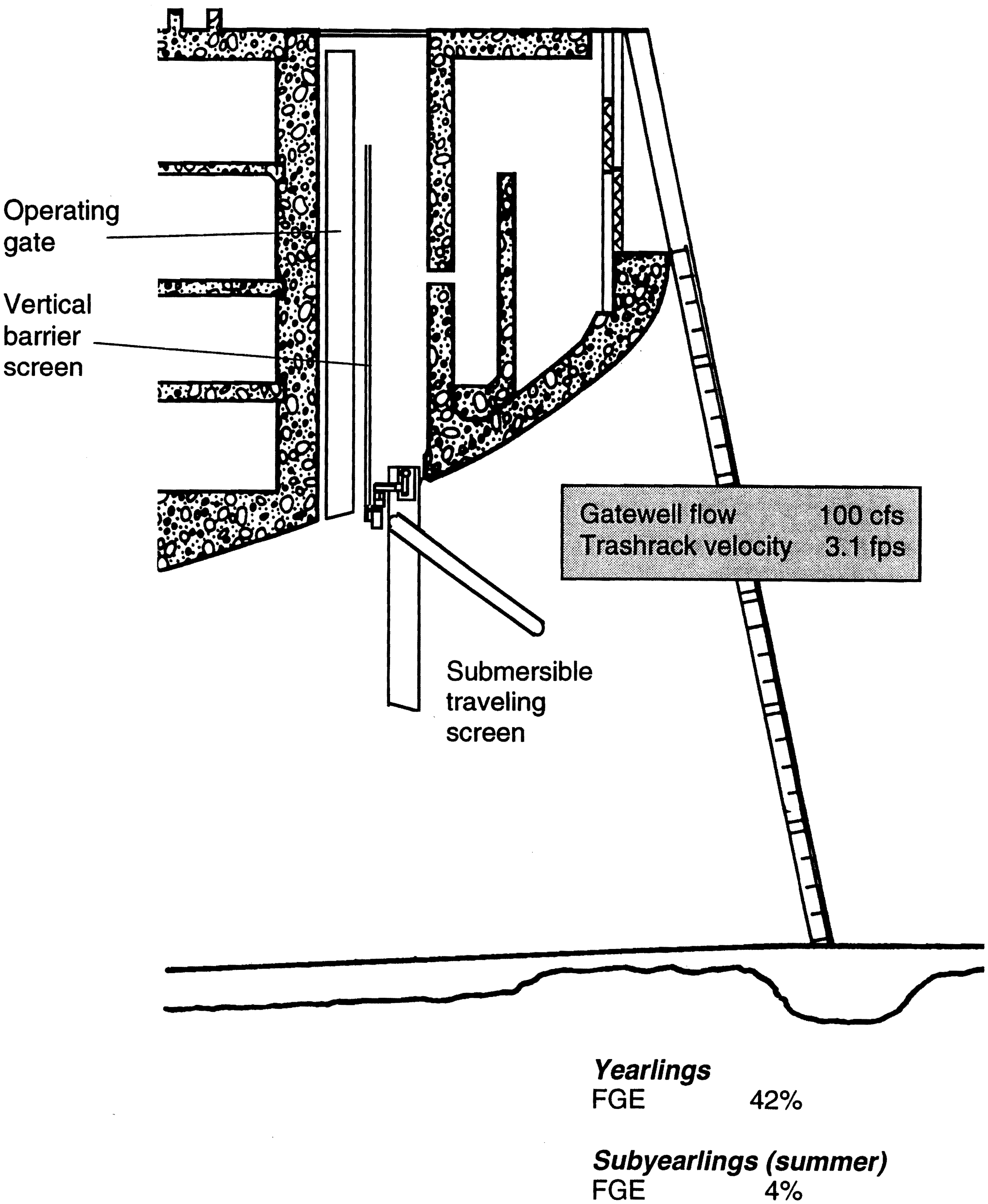


Figure 8. Cross-section of turbine intake at Bonneville Dam First Powerhouse showing fish bypass system and 1989 Fish Guiding Efficiency (FGE) results.

During the juvenile salmonid outmigration in 1991 and 1992, NMFS and the COE conducted additional FGE studies at Bonneville Dam First Powerhouse to examine other methods of improving guidance, including lowering the STS and raising the operating gate (Monk et al. 1992, 1993). In both years, raising the operating gate in Unit 8 increased FGE for yearling chinook salmon. This increase was significant in 1991, (from 29 to 50%), but not in 1992. However, raising the operating gate in 1992 significantly increased FGE for subyearling chinook salmon, coho salmon, and steelhead. In 1992, lowering the STS 0.8 m (30 in) did not improve FGE for yearling chinook salmon. However, results from vertical distribution measurements indicated that 71 to 78% of the yearling chinook salmon were in the zone intercepted by the STS, which suggested that inadequate flows into the gatewell and deflection of fish under the STS were responsible, in part, for the low FGE. This information and the results of physical model studies and research at other Snake and Columbia River dams comparing STSs and extended-length submersible bar screens (ESBSs) indicated the potential for significant increases in FGE at Bonneville Dam First Powerhouse with ESBSs.

In spring and summer 1998, FGE with an ESBS was measured for the first time at the First Powerhouse. In 22 tests, conducted from 24 April to 19 May, FGE for yearling chinook salmon averaged 72% . For subyearling chinook, steelhead, coho, and sockeye, FGE was 67, 85, 80, and 51%, respectively. The improvement in FGE with an ESBS and no operating gate compared to the standard length STS and stored operating gate (measured in 1991), ranged from 26 to 34% for each species, in some cases more than doubling FGE values (Table 4). For subyearling chinook, with an ESBS and no operating gate, FGE averaged 55% from 22 June to 27 June 1998, and then dropped to 27% from 29 June to 17 July. The later tests had two to three times higher FGE than

Table 4. Mean Fish Guidance Efficiency (FGE) and standard errors an Extended-Length Bar Screen (ESBS) in 1998 and a Submersible Traveling Screen (STS) in 1988, 1989, and 1991 at Bonneville Dam First Powerhouse .

	ESBS[a]		STS[b]	
	FGE (%)	SE	FGE (%)	SE
Spring Testing				
Subyearling chinook	67	4.7	33	4.0
Yearling Chinook	72	1.9	36	2.4
Steelhead	85	1.5	58	3.5
Coho	80	2.3	53	4.9
Sockeye	51	5	25	3.1
Summer Testing				
Subyearling chinook				
22 June - 2 July	48	2.7		
6 July - 17 July	23	1.1		
6 July - 27 July[c]			11	2.0
12 July - 24 July[d]			4	1.0

[a] All tests conducted in 1998 in Unit 8.

[b] Spring tests conducted in 1991 in Unit 8

[c] Summer tests conducted in 1988 in Unit 3

[d] Summer tests conducted in 1989 in Unit 3

tests during the same time in 1988 and 1989 with an STS and stored gate (11 and 4%, respectively)(Monk et al. in prep.)(Fig. 9).

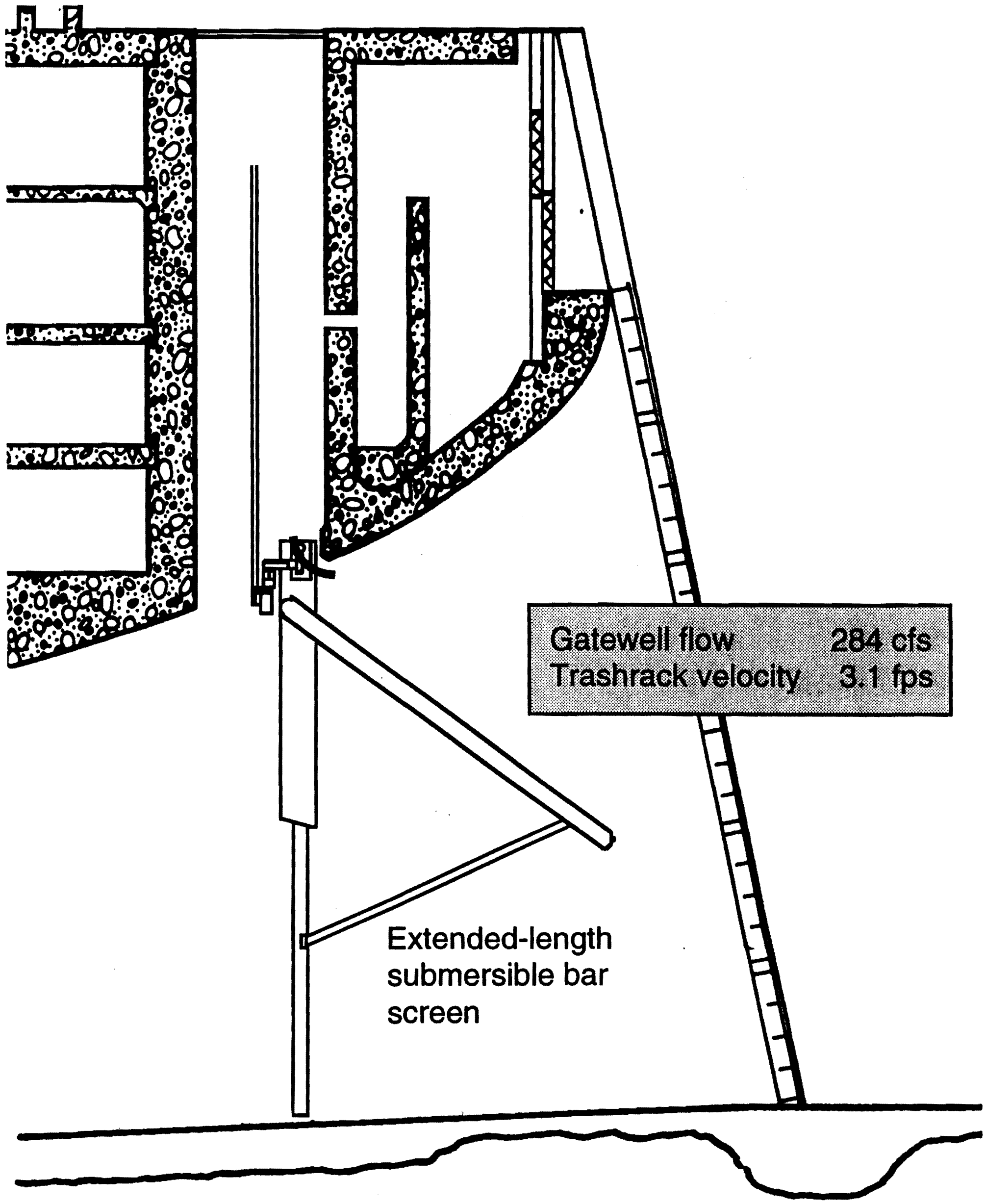
John Day Dam

John Day Dam is similar to the Bonneville Dam Second Powerhouse in that the head wall extends deep below the water surface. However, the distance from the trashrack to the tip of the STS is 12.2 m (40 ft) at John Day Dam compared to only 2.1 m (7 ft) at the Bonneville Dam Second Powerhouse and the open area of the vertical barrier screen at John Day Dam is almost three times that of the Second Powerhouse.

Initial renovation of the juvenile fish bypass system at John Day Dam began in 1984 and continued through 1986, with installation of STSs in gatewell slots of Units 1 through 16 (no turbines are installed in bays 17 to 20). In 1985, FGE was estimated to be over 70% for yearling chinook salmon in the spring but much lower (21%) for subyearling chinook during the summer migration (Krcma et al. 1986). In 1986, FGE tests were conducted with only subyearling chinook and averaged 35% (Brege et al. 1987). This was higher than in 1985, but still considerably lower than target levels of 70%.

Based on encouraging results at McNary Dam (Brege et al. 1992), ESBSs were tested at John Day Dam in 1996 in hopes of improving FGE, for yearling chinook and especially for subyearling chinook salmon. In tests with an ESBS, an inlet flow vane, a reconfigured vertical barrier screen, a beam extension, and a downstream fillet assembly, FGE for yearling and subyearling chinook salmon averaged 84 and 60%, respectively. With the same configuration,

Bonneville Dam First Powerhouse 1998



Yearlings
FGE 72%

Subyearlings
FGE 67%

Figure 9. Cross-section of turbine intake at Bonneville Dam First Powerhouse showing extended length submersible bar screen and no operating gate, tested in 1998, with resulting Fish Guiding Efficiency (FGE) results for yearling and subyearling chinook salmon.

descaling rates averaged less than 1 and less than 1.5% for yearling and subyearling chinook salmon, respectively (Fig. 10) (Brege et al. 1997).

McNary Dam

The intakes at McNary Dam are similar to those at Bonneville Dam First Powerhouse with a short headwall of 3.7 m (12 ft). However, the distance from the STS to the trashrack is relatively long and velocities through the trashrack are a low 0.8 m/s (2.6 fps) compared to 0.9 m/s (3.1 fps) and 1.3 m/s (4.4 fps) at Bonneville Dam First and Second Powerhouses, respectively.

Originally, McNary Dam had no specific provisions for juvenile fish passage. However, by the 1981 spring outmigration, STSs were installed in all 14 units, and FGE was estimated at over 70% for yearling chinook salmon, coho, and steelhead (Krcma et al. 1985, Swan and Norman 1987, Brege et al. 1988). Studies of subyearling chinook during summer 1982 and 1984 revealed FGEs of 33 to 46% (Krcma et al. 1985).

In 1986, additional research was conducted to test varying strategies to improve FGE for subyearling chinook salmon. The approach involved lowering an STS 0.83 m (33 in), raising the operating gate to increase the flow into the gatewell, and using a trashrack deflector to guide the deeper subyearling chinook salmon into the influence of the STS. With all three of these modifications, FGE for subyearling chinook (in the summer) was increased significantly from 39 (standard STS, stored gate) to 61%. These results led to the conclusion that extended-length guiding devices (either STS or bar screens) could be used to increase FGE for subyearling chinook at McNary Dam (Swan and Norman 1987).

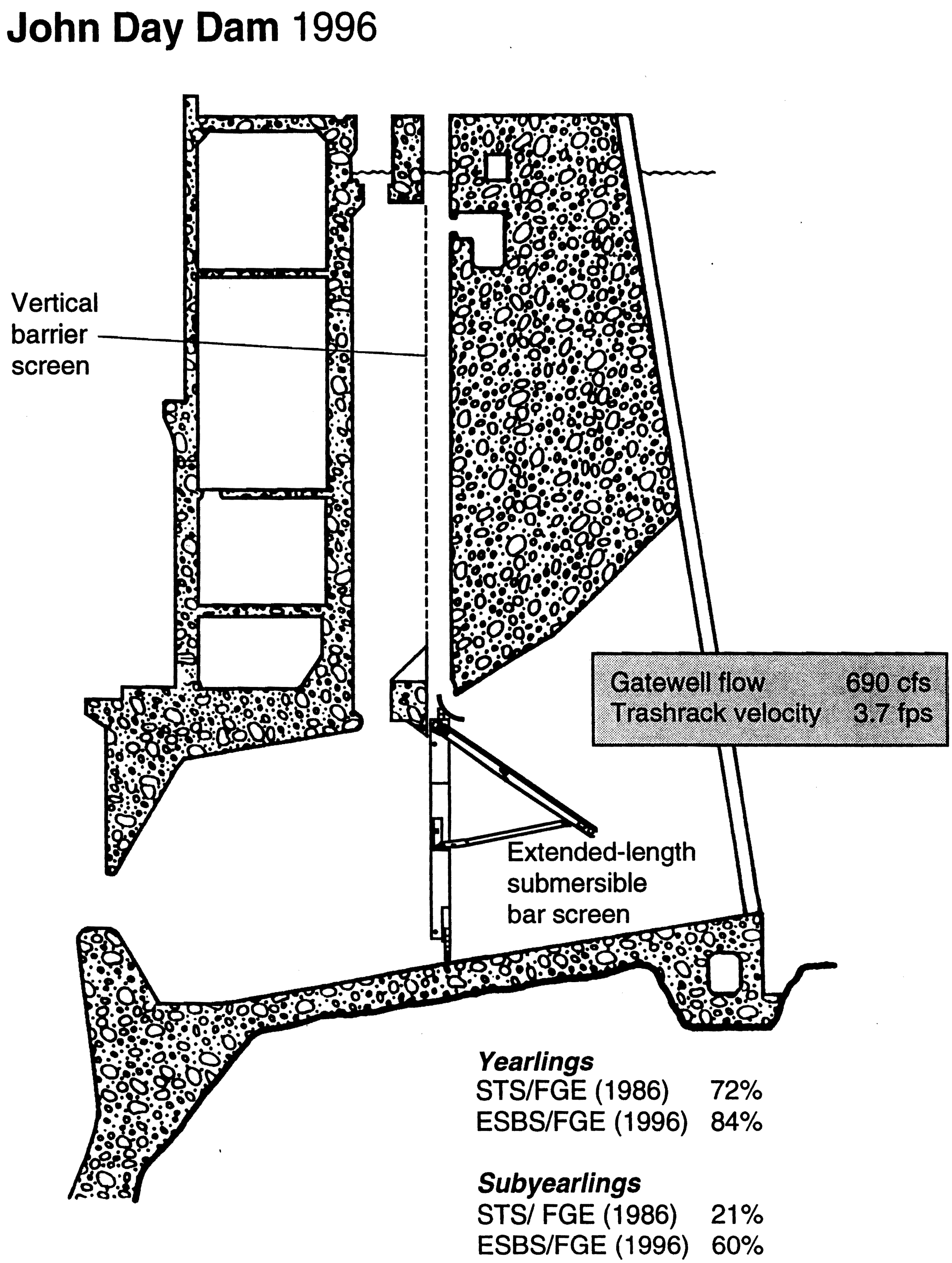


Figure 10. Cross-section of turbine intake at John Day Dam showing extended- length bar screen tested in 1996 with resulting Fish Guiding Efficiency (FGE) values for yearling and subyearling chinook salmon (including results from 1986 testing with submersible traveling screen).

From 1991 to 1993, comparisons of FGE and descaling between a ESBS and extended-length STS were conducted at McNary Dam, and both devices produced estimates of FGE over 80% for yearling chinook (81% for the ESBS and 88% for the extended-length STS). For subyearling chinook salmon, mean FGE of 67% was measured for the extended-length STS and 52% with the extended bar screen (Fig. 11). In 1993, descaling for subyearling chinook using the extended-length STS (12.2%) was significantly higher than all other operating gate/screen type combinations, including the STS (McComas et al. 1993,1994).

Because of the noted improvements in FGE (with no significant increases in descaling), installation of ESBSs was initiated in 1996 at McNary and completed in all 14 units by spring 1997. Inlet flow-control vanes and ceiling beam extensions were also found to further increase screen effectiveness and were installed across the powerhouse (McComas et al. 1994).

HYDROACOUSTIC EVALUATIONS

Starting in 1984, hydroacoustic evaluations were conducted to further understand vertical and horizontal fish distributions upstream from the Bonneville Dam Second Powerhouse. Magne (1984) found that under partial powerhouse load, horizontal fish distributions were skewed toward both the north and south corners of the immediate forebay. These two areas held 91% of the fish observed in what he described as the "basin," which is the forebay nearest the face of the powerhouse. Mobile surveys conducted under full powerhouse load detected too few fish to be meaningful. In both full and partial loadings, over 80% of the fish were in the top 10 m (32 ft) of the water column. Magne reported a somewhat lower vertical distribution under partial versus full powerhouse load. He concluded smolts generally should be intercepted by STSs.

McNary Dam

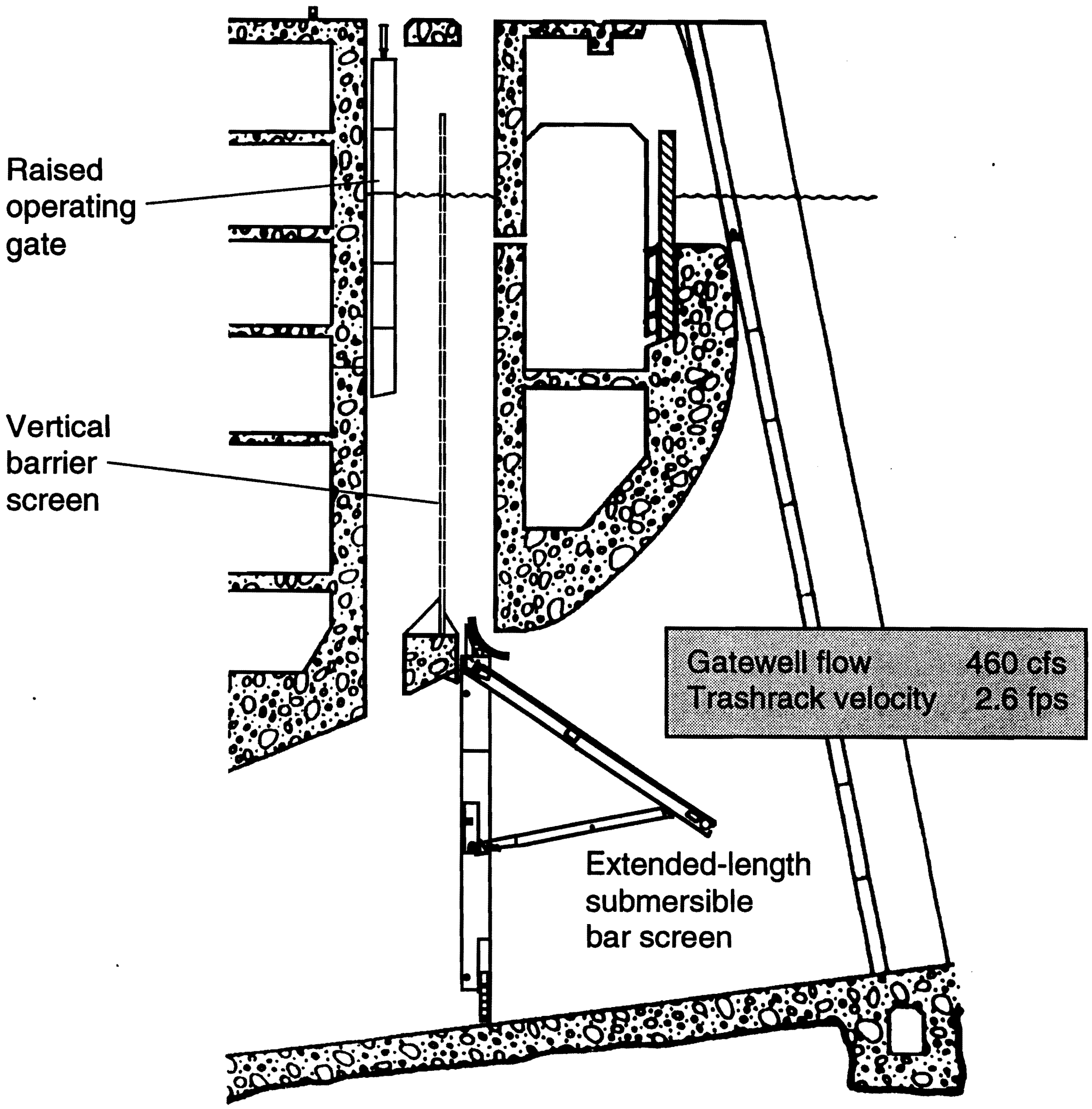


Figure 11. Cross-section of turbine intake at McNary Dam showing extended- length bar screens installed in 1996.

In 1985, hydroacoustic evaluations complemented the direct FGE measurements conducted by NMFS. Nagey and Magne (1986) observed a downward shift in vertical distribution with time at Unit 12, which corresponded with low FGEs measured with fyke nets during July. They also observed that 95% of the fish detected inside the intake in the region over the STS showed no obvious signs of rejecting guidance (movement away from the gatewell). Equipment problems prevented an adequate assessment of lateral fish movement in front of Unit 12.

In 1986, hydroacoustic sampling was again used to determine vertical and horizontal distributions (Magne et al. 1986). Differences in vertical distributions at Unit 12 were observed between 1985 and 1986. The mean and median depths of fish passing were 2.1 m (7 ft) lower in 1986, and the cumulative percent passage to the 10.7 m (35 ft) msl theoretical STS intercept was lower in 1986 by 23 and 16% for the spring and summer, respectively. Fish detected in front of Unit 11B without a TIE were slightly deeper than Unit 12B which had a TIE. Vertical distributions of fish in front of Unit 11B before and after the TIEs were installed showed fish to be slightly deeper after the roof extensions were installed. In 1986, sluice chute sampling was initiated, which indicated under four unit operation that 18% of the total fish observed were guided through the chute in 1.2% of the powerhouse discharge.

In 1988, Magne et al. (1989) concluded that hydroacoustic and NMFS fyke-net estimates of total passage, rates of passage, and FGE agreed reasonably well when averaged over many days. FGE in Unit 17 was observed to be considerably lower than Unit 13. They noted a higher mean target strength at the sluice chute relative to the turbines, and suggested that this may be due to multiple targets at the sluice chute or to a different orientation of the fish at the two locations.

In 1989, Stansell et al. (1990) concluded that single-beam transducers were detecting multiple targets at essentially the same range at the sluice chute, indicating many fish entering the chute simultaneously and passing in tight groups. Because of this pattern, comparisons to single targets passing turbines were difficult, and estimates of passage through the chute were probably underestimated. Passage through the sluice chute was primarily through the middle third of the entrance. The use of video cameras to enumerate passage through the sluice chute proved unsuccessful. Fish distribution was found to be higher for Unit 11 than Unit 18 during both spring and summer.

Ploskey et al. (1998) conducted mobile and fixed hydroacoustic surveys at Bonneville Dam in 1996. At the Second Powerhouse, they observed a downward shift in the vertical distribution of smolts at transects within 30 m, relative to 50-75 m upstream. Like Magne (1984), they observed the highest smolt densities in the north and south corners of the forebay, just upstream from the powerhouse. On days when the sluice chute was open they observed lower densities upstream from Units 11-13, when compared to days when the chute was closed. They saw no effect of chute operation on the FGE of screens in adjacent units. Sampling at the chute was problematic due to high background noise levels from entrained air and surges in turbulence coming from the TIE in Unit 11A.

BioSonics (1998) conducted mobile and fixed hydroacoustic surveys at Bonneville Dam in 1997. They concluded from their mobile surveys that fish densities at the Second Powerhouse were high in the south eddy. Most fish were distributed in the top 15 m of the water column. In contrast to 1996 (Ploskey et al. 1998), they found that fish distribution during 1997 tended to be the same or shallower within 20 m of the powerhouse, when compared to 50-75 m upstream. The effect of sluice chute operations was difficult to detect due to a small sample size and low fish numbers observed. However, when the spring and summer data were pooled, daytime densities were significantly higher when the chute was closed..

Ploskey et al. (undated) conducted fixed aspect hydroacoustic sampling at Bonneville Dam Second Powerhouse in 1998. They observed less turbulence associated with the bulk flows moving along the face of the powerhouse toward the sluice chute when the six southern-most TIEs were not installed. Removal of the TIEs produced a low noise environment that was conducive to hydroacoustic sampling. They estimated that FPE into the chute and Units 11-13 remained high (90%) throughout the spring and summer, compared to FGE of Units 11-13, which averaged 55 and 30% in the spring and summer, respectively. They also observed that of the total population that passed through the chute or into Units 11-13, 83 and 81% passed through the chute during the spring and summer, respectively. They estimate the chute effectiveness was 5.8 and 4.6 in the spring and summer, respectively. Effectiveness is defined as the proportion of fish passing the chute, relative to the proportion of water passing through the chute relative to Units 11-13. Ploskey et al. (undated) concluded that the sluice chute has "great potential" as a surface bypass corner collector.

RADIO TELEMETRY

Holmberg et al. (1998) released approximately 750 radio-tagged yearling and subyearling chinook salmon in 1996 above John Day, The Dalles, and Bonneville Dams. Although sample sizes were generally small at Bonneville Dam Second Powerhouse, some useful information was noted. Of 247 yearling chinook salmon contacted at Bonneville Dam, 47 or 19% were last contacted at the Second Powerhouse. The median forebay residence time for Bonneville Dam was 0.1 h. At the Second Powerhouse, the highest percentage of observations was recorded near Unit 18 and between Units 11-15. Daytime observations were recorded mostly at Units 11 to16 and along Cascade Island, while night observations peaked at Units 15 and 18. Powerhouse discharge ranged from 350 to 447 m^3/s (12,000-15,800 cfs). While flow was distributed evenly across turbine units, the authors noted that more fish passed toward the south end of the powerhouse, through Units 11-13. A total of 12 radio-tagged yearling chinook were contacted near the sluice chute opening, but no fish were last contacted there, suggesting passage through the chute was not common.

For radio-tagged subyearling chinook, Holmberg et al. (1998) found that 33% (43 of 128) of the total contacted were first recorded at Bonneville Dam Second Powerhouse in 1996. Median residence time for both powerhouses was 0.8 h, which was higher than the 0.1 h median residence time at the spillway. The majority of contacts were recorded at Unit 13. Passage locations were distributed toward the south end of the Second Powerhouse. Powerhouse discharge at the time was 269 to 308 m^3/s (9,500-10,900 cfs). A total of 25 radio-tagged subyearling chinook were contacted in the area of the sluice chute. Of these, none was last contacted in the area of the chute opening, suggesting that passage through the chute was uncommon.

Hensleigh et al. (1998a) released approximately 983 radio-tagged yearling and subyearling chinook salmon and hatchery steelhead in 1997 above John Day, The Dalles, and Bonneville Dams. This was a high flow year and discharge at Bonneville Dam ranged from 9,100 to 16,000 m^3/s (322,000-567,000 cfs) during the spring and 6,300 to 8,900 m^3/s (222,000-314,000 cfs) during the summer. Less than 8 and 49.1% of the spring and subyearling chinook, respectively, were last contacted at the Second Powerhouse. The majority of observations were recorded along the south end of the powerhouse for all species, and a few observations were recorded at the north end of the powerhouse for yearling chinook salmon. Spring migrants were generally contacted at fewer antennas than summer migrants, and overall there appeared to be a moderate amount of lateral movement at both powerhouses. Hensleigh et al. (1998a) reported an overall Bonneville Dam forebay residence time of 0.9 h for subyearling chinook, and less than 0.1 h for other species in 1997. This compared to Holmberg et al. (1998) who reported an overall Bonneville Dam forebay residence time of 0.4 h for subyearling chinook and 0.1 h for yearling chinook in 1996. Samples of radio-tagged fish were too small to make conclusions regarding passage through the sluice chute in 1997. However, 101 radio-tagged subyearling chinook passed through the Second Powerhouse when the chute was alternately opened and closed. Hensleigh et al. (1998a) reported that when the chute was open the distribution was shifted toward the south end of the Second Powerhouse where the chute is located. They only detected two radio-tagged subyearling chinook salmon actually passing through the chute, in contrast to a hydroacoustic evaluation which indicated significant numbers of fish passing through the chute during the summer (BioSonics 1998).

Approximately 1,765 radio-tagged yearling and subyearling chinook salmon and hatchery steelhead were released in 1998 above John Day, The Dalles, and Bonneville Dams (Hansel et al. 1998, Hensleigh et al. 1998b). This was an above average flow year and discharge at Bonneville Dam ranged from 3,900 to 11,900 m^3/s (138,000 - 420,000 cfs) during the spring and 5,200 to 7,900 m^3/s (184,000-280,000 cfs) during the summer. In contrast to 1997, when fish were predominantly first contacted at the spillway, in 1998 the location of first contact for spring migrants was generally evenly distributed between the two powerhouses and the spillway. In the summer of 1998, most subyearling chinook were first contacted at the spillway (45%), followed by the Second Powerhouse (32%) and the First Powerhouse (24%). During the spring, the majority of observations were recorded along the south end of the Second Powerhouse, with the remaining observations equally divided between the north end and the eddy near Cascade Island. However, during the spring, 62% passed at the north end of the powerhouse, 31% passed at the south end, and 5-8% were last contacted at the eddy. During the summer, the majority of observations were along the north end of the powerhouse (56%), followed by the south end (33%) and the eddy (10%). However, the majority of fish (54%) passed at the south end of the powerhouse during the summer, compared to 42% passing through the north end of the powerhouse and 4% last contacted in the eddy. In 1998, the increased number of radio-tagged fish released allowed for a comparison of sluice chute passage under alternating conditions of the chute open and closed. When the sluice chute was open, 52% (42 of 81) of the steelhead and 36% (25 of 70) of the yearling chinook that contacted the Second Powerhouse were detected passing through the sluice chute. Another 21 and 14% of the steelhead and chinook salmon, respectively, were detected passing through the juvenile fish bypass system. Hensleigh et al. (1998b) estimated that when the chute was open, 73% of the steelhead and 50% of the yearling chinook that passed through the Second Powerhouse did so through a non-turbine route. When the chute was closed, 50% of the steelhead and 30% of the yearling chinook passed the Second Powerhouse through a non-turbine route. For steelhead, the 55% that passed through the chute were first contacted near Units 11-14, 19% were first contacted in the eddy off Cascade Island, and 26% were first contacted off Units 15-18. For yearling chinook salmon, the 52% that passed through the chute were first contacted near Units 11-14, 36% in the eddy off Cascade Island, and 12% were first contacted off Units 15-18. Hensleigh et al. (1998b) concluded that when the sluice chute was open, 71-76% of the spring migrants that came within less than 3 m of the chute entrance, entered and passed through the chute. When the chute was closed, the majority of the fish came within close proximity (less than 3 m) to the entrance, but could not enter. Limited data were collected for subyearling chinook salmon during the sluice chute tests. However, for two releases when the chute was open, 37% (10 of 27) of the subyearling chinook detected at the Second Powerhouse passed through the chute.

CONCLUSIONS

We reviewed biological and hydraulic data collected between 1983 and 1998 at Bonneville Second Powerhouse with respect to improving FGE. When all of the fyke net, radio telemetry, hydroacoustic, hydraulic model, and flow measurements are taken as a whole, we make the following conclusions about the information:

1) During the experimental period (1983-1989), a large number of short-duration tests were conducted, involving a wide range of structural modifications. Each test was designed to provide a response to a specific concern. During this period, researchers were looking for large improvements in hydraulic conditions in the intake or immediate forebay, or to extend the effective "guiding range" of the STSs. If a large improvement was not observed, another configuration was evaluated. Taken individually, the results from these tests can be confusing. Taken as a whole, they are sufficient to draw conclusions about trends and relationships between cause (measured or theoretical hydraulic conditions) and effect (fish response). We base many of the following conclusions on our use and interpretation of these data sets.

2) The intake flow conditions at Bonneville Dam Second Powerhouse are not conducive to high fish guidance. The area above the STSs leading to the gatewell slot is hydraulically constrained by the low upward flow up the gate slot. The 4.8 m^3/s (170 cfs) into the Bonneville Dam Second Powerhouse gate slots compares to 8.0-19.5 m^3/s (284-690 cfs) at other powerhouses evaluated in this review (Bonneville First Powerhouse, McNary, and John Day), where high guidance was achieved through the use of raised operating gates and extended-length bar screens. There is a high flow velocity at the trashrack, 1.3 m/s (4.4 fps) for the Second Powerhouse compared to 0.8-1.1 m/s (2.6-3.7 fps) for the other powerhouses evaluated. This suggests that the high velocity intake flow has nowhere to go above the STSs, so it diverts to below the STSs, causing a low FGE. The STSs at the Second Powerhouse are also much closer to the trashracks than at any other project evaluated This suggests that hydraulic flow disruptions from the standard trashracks were sensed by the smolts, perhaps causing them to follow the flow under the STSs. Partially lowering the STSs (0.7 m) addressed the flow constriction above the STSs, and improved FGE for yearling chinook by 8-9%. Streamlining the top three unit trashracks to their incoming flow lines addressed the vortices and flow disruptions from the trashracks, and increased FGE for yearling chinook by 8-9%. Installing TIEs in every other intake was evaluated to change the way flow transitions from the forebay into the turbine intake. The TIEs break up the lateral flow across the face of the powerhouse and redirect the flow into the intake. TIEs increased FGE by approximately 20% for yearling chinook.

3) Additional efforts to substantially improve FGE were unsuccessful. Blocking trashracks and forcing the fish above the screen, opening up the porosity of the STS, and adding a deflector to extend the guidance device to the trashrack provided no benefits to FGE. In some

cases these configurations greatly increased descaling and mortality. These data sets further support our conclusion that the hydraulic environment above the STSs is constrained, and indicate that increased STS porosity is not the solution to low FGE. Based on these observations we conclude that the standard STS and ESBS design criteria of approximately 0.9 m/s (3.0 fps) velocity normal to the screen should be used. Also, because of the constrained hydraulic environment above the STSs, we recommend that future hydraulic model studies pay close attention to the sweeping component of flow from the STS toward the gatewell slot at the Bonneville Dam Second Powerhouse, keeping the flow field moving along the face of the screen and into the gatewell slot. Raising the operating gate increased flow into the gatewells from 4.8 to 6.2 m^3/s (170 - 220 cfs). FGE was not improved under this condition, further supporting our conclusion that the hydraulic environment above the STSs is constrained. We recommend that flows into the gatewell be increased to at least 8.0 m^3/s (284 cfs) (similar to the Bonneville Dam First Powerhouse under raised gate and ESBS conditions), and higher if possible. Improving the amount of flow deflected into the gatewell slots will likely increase TFGE, screen effectiveness, and FGE. Due to the short distance from the guiding device to the trashrack, we speculate that improved gatewell flows may increase TFGE by extending into the intake the hydraulic flows leading into the zone above the STSs. Based on the data collected on the deflectors, unless flow above the STS is increased we do not see the need to conduct additional deflector or ESBS evaluations.

4) During the 1980s testing, FGE approaching 70% was measured with certain combinations of TIEs, streamlined trashracks, and lowered STSs. These results were typically achieved when Units 11-13 and 17 or 18 were operated, and TIEs were installed in an alternating

configuration in Units 11-14. Based on these promising results, a full and permanent complement of TIEs, streamlined trashracks, and lowered STSs were installed. These were tested in 1993 and 1994 under partial powerhouse load and full powerhouse load. Under partial powerhouse load, Units 11,12, 17 and 18, or Units 11-13 and 16-18 were operated. All tests were conducted with a full complement of TIEs installed across the entire powerhouse in the alternating configuration. During these tests, FGE for yearling chinook typically averaged 45-55%. The lower than expected FGE could have been the result of the full complement of TIEs or operation of different units during the 4-unit operation or both. In 1993 and 1994, the highest FGE was achieved in the middle of the powerhouse under full powerhouse operation, but values still did not approach 70%. It is likely that the Bonneville Dam Second Powerhouse forebay, and how water is drawn from the forebay into the intakes, is highly dynamic and dependent on powerhouse operation and configuration. It is clear that based on present information, we do not fully understand the relationship between forebay and intake flows under the variety of conditions at the Second Powerhouse because of its unique structure and hydraulics. A closer examination of these relationships is warranted, possibly through fine-scale observations of radio-tagged fish in the very near forebay, in conjunction with hydraulic model information of this area, under a variety of operations and configurations.

5) Lacking specific information on the relationships between very near-field forebay hydraulic conditions and associated fish responses, we can only speculate. We know from field observations that strong lateral flows exist at the face of the Bonneville Dam Second Powerhouse. These are no doubt established by the configuration of the forebay, in conjunction with the flat face of the powerhouse and the high ambient velocity and momentum of the incoming surface flow. It

appears that a partial powerhouse operation enhances these lateral flows, possibly because the middle units are closed and the water in front of these intakes promotes the lateral flows. This appears to draw or carry fish into the corner eddies. We theorize that flow in the corner eddies eventually circulates back upstream, re-approaches at depth, enters the lower portions of the intake, and carries fish with it. We based this in part on the hydraulic conditions, and on the observed behavior of radio-tagged fish in the forebay. While retention time in the forebay is generally very short, we see a high incidence of the estimated point of fish passage differing from the point of first contact. Fish are moving or are being drawn around the forebay before they enter a specific intake. This may explain the somewhat lower FGEs observed under partial powerhouse loads. Full powerhouse operation, again with TIEs, creates a more balanced flow across the powerhouse, leading into all units more evenly, and reduces the differential fish guidance observed between slots under partial powerhouse conditions. With the full complement of TIEs, FGE is higher under of full powerhouse operation, probably because the intake flows project into the forebay upstream or perpendicular to the intake, rather than sideways or parallel to the intake. These incoming flows are more typical of those at other powerhouses, and theoretical screen intercept or guidance in increased.

6) The observations at Bonneville Dam Second Powerhouse are highly variable. They vary with date, year, species, season, and stock (e.g.,local hatchery vs. upriver migrants). Therefore, we recommend that future test conditions be replicated over at least 2 years, under a variety of powerhouse operations.

7) At the Bonneville Dam Second Powerhouse, vertical fish distribution in the far forebay near the shelf (100 m upstream) and in the near forebay (20-70 m upstream) is typical of that at

other projects, and should produce high FGE. We conclude that fish distribution in the forebay is not the limiting factor. The vertical distributions further support our contention that it is the area of the very near forebay, perhaps as close as 10 m to the TIEs, that must be investigated with radio-tagged fish and hydraulic model studies.

8) One quantitative (with the six southern-most TIEs removed) and a number of qualitative hydroacoustic evaluations of the sluice chute suggest that this is an effective smolt collector and should be considered in future improvements of fish passage efficiency at the Bonneville Dam Second Powerhouse.

9) Improving guidance of subyearling chinook salmon at the Bonneville Dam Second Powerhouse is problematic. None of the improvements tried during the 1980s or installed during the 1990s dramatically improved FGE. We speculate that the number of spring migrant subyearling chinook guided may be increased through additional evaluations and modeling studies. However, due to their greater depth, especially as temperatures increase during the summer, we would not anticipate an improvement in guidance during the summer. Based on the 1998 results of sluice chute passage, the sluice chute or a surface bypass corner collector may have to be seriously considered as the primary route of summer passage.

10) Based on our review of the information collected between 1983 and 1998, we have developed the following four options for consideration by the COE and salmon managers regarding how to proceed toward improvements to FGE at the Bonneville Dam Second Powerhouse:

Option A. Focus on the intake only. Make significant improvements in the amount of flow guided into the gatewell slots and the lateral flow component above the STSs leading to the gatewell slots. If this can be accomplished, it may be possible to extend the influence of these improved hydraulic conditions into the forebay, increasing TFGE, screen effectiveness, and FGE. Existing TIEs would remain in place under this option. Operation of the full powerhouse to streamline incoming flows should be considered. If the gatewell environment can be addressed, perhaps additional guidance could be achieved through an extension of the guiding device through the use of a trashrack deflector or ESBS.

Option B. Focus on the intake and the near forebay. In addition to those actions discussed under Option A, where the gatewell and above-screen environments are improved, evaluate the near forebay hydraulics. This may lead to additional FGE gains through improved TIE designs. Full or partial powerhouse operation would be considered, depending on results.

Option C. Focus on the intake and near forebay, but add a corner collector. In addition to actions discussed under Option B, where the gatewell, above screen, and near forebay hydraulics are improved, install additional fish passage through the a surface bypass corner collector. The corner collector would be designed with TIEs installed. Optimum full or partial powerhouse loads would have to be modeled and field tested.

Option D. Focus on the intake and corner collector. In addition to actions discussed for the gatewell environment under Option A, the existing TIEs would be removed to enhance guidance into the lateral flow fields. In addition, a corner collector would be designed and installed. A variation of this option would remove the TIEs in Units 11-14 to enhance corner collector fish passage, and leave the TIEs installed at Units 15-18 to enhance FGE.

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