Continuing Studies to Measure and Improve Fish Guidance Efficiency of Submersible Traveling Screens at Bonneville Dam First Powerhouse, 1992

by
Bruce H. Monk, Julia A. Ross,
Benjamin P. Sandford, and Douglas B. Dey

July 1993

COASTAL ZONE AND ESTUARINE STUDIES

CONTINUING STUDIES TO MEASURE AND IMPROVE FISH GUIDANCE EFFICIENCY OF SUBMERSIBLE TRAVELING SCREENS AT BONNEVILLE DAM FIRST POWERHOUSE, 1992

by

Bruce H. Monk
Julia A. Ross
Benjamin P. Sandford
and
Douglas B. Dey

Report of Research

Funded by

U.S. Army Corps of Engineers
Portland District
Delivery Order E96920019

and

Coastal Zone and Estuarine Studies Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112-2097

July 1993

CONTENTS

	Page
INTRODUCTION	1
METHODS AND MATERIALS	5
Statistical Analysis	8
RESULTS AND DISCUSSION	9
Effects of a Lowered STS on Fish Guidance Efficiency	9
Effects of a Raised Operating Gate on Fish Guidance Efficiency	12
Theoretical Fish Guidance and Screen Efficiency	14
Other Salmonids	14
Fish Quality	17
CONCLUSIONS	19
RECOMMENDATIONS	21
ACKNOWLEDGMENTS	22
REFERENCES	23
APPENDIX	25

INTRODUCTION

In 1981, the National Marine Fisheries Service (NMFS) conducted prototype studies to evaluate the potential fish guidance efficiency (FGE) of standard-length submersible traveling screens (STS) at Bonneville Dam First Powerhouse. Initial estimates of FGE were greater than 70% (SE = 2.7) for all salmonid species during the principal period of testing, 30 April to 13 May. In tests conducted during the latter part of May 1981, FGE decreased, but this was attributed to large amounts of debris on the trashracks (Krcma et al. 1982). Based upon these results, a complete set of STSs was installed at the dam prior to the 1983 juvenile salmonid migration.

Construction of a new, larger navigation lock at Bonneville Dam began in the fall of 1988 and involved many changes in the forebay of the first powerhouse. To reduce approach velocities to the new navigation lock, the upstream tip of Bradford Island was removed and seven underwater rock groins were placed upstream from the navigation lock and perpendicular to the flow. These modifications also resulted in a straightening of the flow and the removal of a large eddy at the north end of the powerhouse.

In the spring and summer of 1988, prior to the navigation lock construction, additional studies were conducted at Bonneville Dam First Powerhouse to provide a more complete FGE baseline and to substantiate any changes in FGE which might be associated with changes in flow patterns or the addition of the new navigation lock guidewall (scheduled for completion in 1993). Guidance levels from 30 May to 5 June 1988 were considerably less

than in 1981; 55 (SE = 3.1) and 41% (SE = 6.2) for coho (*Oncorhynchus kisutch*) and subyearling chinook salmon (*O. tshawytscha*), respectively. From 6 to 27 July, FGE for subyearling chinook salmon averaged 11% (SE = 2.0) (Gessel et al. 1989).

Tests on the effects of flow pattern changes on FGE were continued in 1989 and further expanded to include both the spring and summer outmigrations of yearling and subyearling chinook salmon. From 9 to 14 May, FGE for yearling chinook salmon averaged 42% (SE = 2.3). From 27 to 30 May, FGE for yearling chinook and subyearling chinook salmon averaged 31 (SE = 7.6) and 37% (SE = 4.3), respectively; however, generally fewer than 100 fish were recovered per test. From 12 to 24 July, FGE for subyearling chinook salmon averaged 5% (SE = 0.9) (Gessel et al. 1990).

In 1977, NMFS conducted FGE studies at Bonneville Dam First Powerhouse to study the effects of raising the operating gate out of the gatewell while using a bar-screen deflector as the fish guiding device (Krcma et al. 1978). Fish guidance efficiency ranged from 16 to 62% with a stored operating gate (Fig. 1) and from 43 to 78% with a raised operating gate. The increased FGE occurred with increased gatewell flow from 90 to 250 cfs as a result of the raised operating gate. Subsequently, increased FGEs were attained at other dams, including McNary and Lower Granite Dams, when raised operating gates increased gatewell flows (Krcma et al. 1983; Swan et al. 1984).

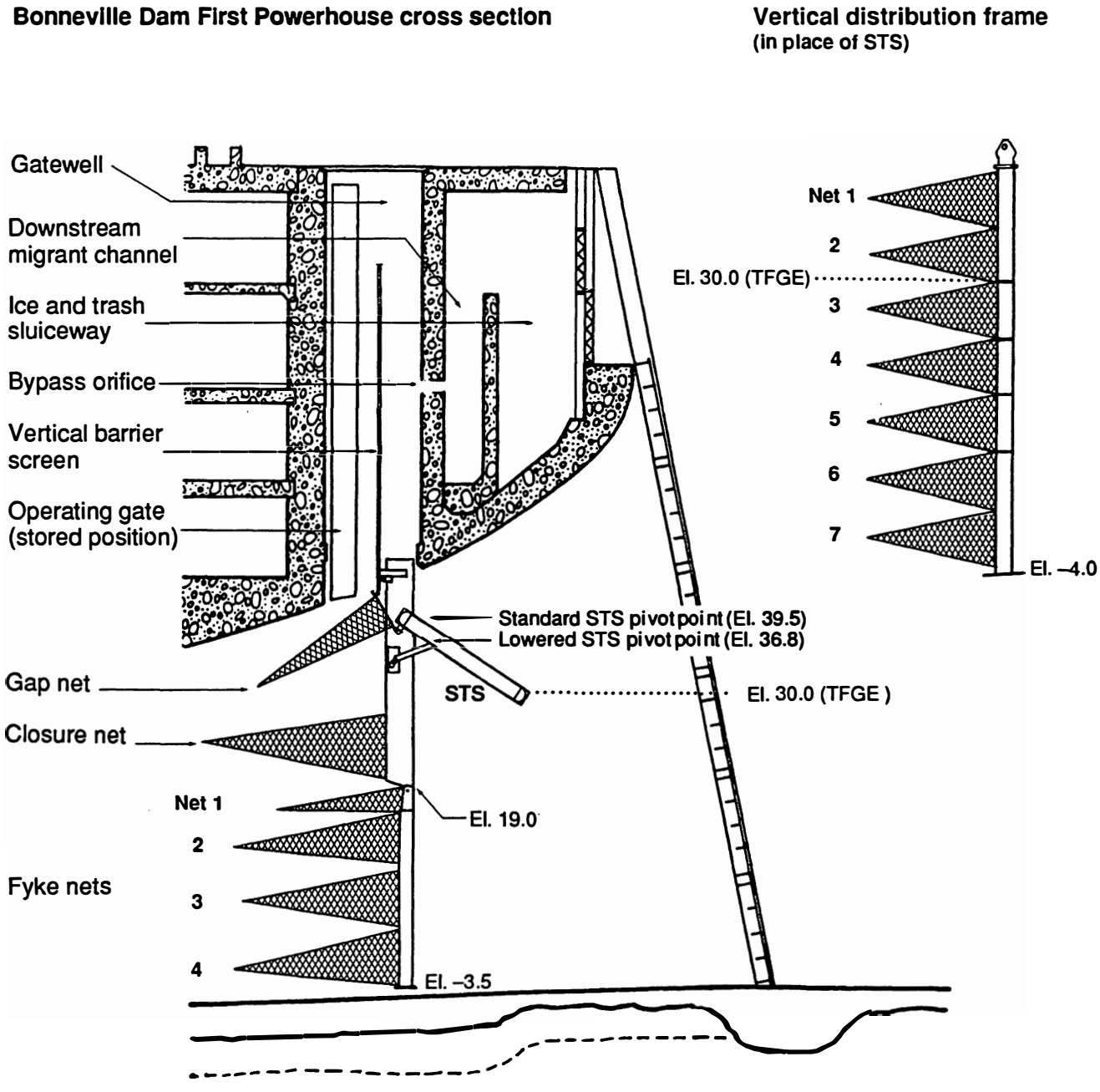


Figure 1.--Cross section of turbine unit intake at Bonneville Dam First Powerhouse, showing submersible traveling screen (STS), sampling apparatus, fish bypass system, stored operating gate, and associated structures. Also shown is the vertical distribution frame and fyke nets.

Because of the relatively low FGE measured in 1988 and 1989, NMFS conducted additional FGE tests at Bonneville Dam First Powerhouse in 1991 to 1) determine differences in FGE between turbine units (most of the research in 1981 was conducted in Unit 4, while 1988 and 1989 work was done in Unit 3), and 2) determine the change in FGE caused by raising the operating gate (Monk et al. 1992). FGE tests comparing Units 3 and 8 and Units 5 and 8 showed a significant difference between Units 5 and 8. As in 1988 and 1989, average FGE did not approach the level measured in 1981 (46.2, 29.1, and 38.3% for yearling chinook salmon in Units 3, 5, and 8, respectively, for all 1991 tests combined).

In subsequent tests in 1991, FGE for yearling chinook salmon was increased from 29.5% to 49.5% by raising the operating gate in Unit 8, indicating that optimal flows into the gatewell did not exist with the operating gate stored in the lowered position. Additionally, the mean theoretical fish guidance efficiency (TFGE) from vertical distribution measurements indicated that 71 to 78% of yearling chinook salmon were in the zone intercepted by the STS in all three turbine units. This suggested that, with the operating gate in a stored position, low FGE was due to inadequate flows up into the gatewell and deflection of fish under the STS.

In previous studies at Bonneville Dam Second Powerhouse (Gessel et al. 1986) and at The Dalles Dam (Monk et al. 1987), FGE was significantly increased by lowering the STS into the turbine intake an additional 68 cm (27 in) at Bonneville Dam and

75 cm (30 in) at The Dalles Dam. Based upon those studies and the 1991 results, NMFS conducted additional studies at Bonneville Dam First Powerhouse in 1992 to compare FGE under the following conditions: a standard elevation STS with a stored operating gate; a standard elevation STS with a raised operating gate; and a lowered STS with a raised operating gate.

The results of STS research done at other powerhouses on the Snake and Columbia Rivers suggested that lowering the STS more than 90 cm (36 in) caused a large number of the fish to go over the top of the STS and through the gap between the STS and vertical barrier screen rather than up into the gatewell. Therefore, one objective of the 1992 studies was to determine the STS elevation which maximized FGE by increasing the flows up into the gatewell and minimized the gap-net catch. Although the 1991 tests at Bonneville Dam First Powerhouse showed that a raised operating gate could significantly increase FGE compared to a stored operating gate, this was based on only 10 measurements (5 of each condition). Therefore, a second objective of the 1992 studies was to evaluate the benefits of a raised operating gate throughout the entire spring migration of yearling chinook salmon.

METHODS AND MATERIALS

To lower the STS, an adjustable fyke-net frame was constructed that held the weight of the STS. By adjusting the legs on this frame, the STS could be lowered from the standard elevation [13.3 m (44 ft) mean sea level (MSL)] in the gatewell

in 15-cm (6-in) increments, to a maximum lowered position of 1.1 m (42 in) (Fig. 1).

Procedures and methods for these FGE studies were similar to those used at Bonneville Dam in 1988, 1989, and 1991 (Gessel et al. 1989, 1990; Monk et al. 1992). Gatewell dip-net catches provided the number of guided fish; gap and fyke nets attached to the STS provided the number of unguided fish. FGE for each species was calculated as gatewell catch divided by the total number of fish of that species passing through the intake during the test period.

$$FGE = \frac{GW}{GW + GN + 3(FN)} \times 100\%$$

GW = gatewell catch
GN = gap-net catch
FN = fyke-net catch (1/3 sample)

Vertical distribution measurements were conducted in the same turbine unit and gatewell slot used for FGE tests (but on separate days). For these tests, the STS was removed and replaced with a vertical distribution frame that measured the depth distribution of fish in the turbine intake with the operating gate in the stored position. This provided an estimate of theoretical fish guidance efficiency (TFGE), i.e., the percentage of fish entering the turbine intake within the interception area of the STS (Fig. 1). The ratio of FGE to TFGE was then used to calculate the screen efficiency, which is the percentage of fish within the interception area that were actually guided into the gatewell. Vertical distribution tests were conducted with five of the eight blocks of FGE tests.

Fish guidance efficiency tests and vertical distribution measurements conducted during the spring outmigration targeted yearling chinook salmon. Data for other salmonid species [subyearling chinook, coho, and sockeye salmon (O. nerka) and steelhead (O. mykiss)] were also collected. Individual tests lasted a minimum of 1 h, typically beginning at 2000 h and ending between 2100 and 2300 h (determined by the number of guided fish). During the tests, we attempted to maintain a turbine unit discharge of 12,000 cfs. The unit operating load varied as forebay level and power demand dictated, and the actual discharge for individual tests ranged from 11,700 to 12,300 cfs.

Analysis of data from previous FGE tests showed that at a given fyke-net level the middle net collected one-third of the fish (Gessel et al. 1986). Therefore, to minimize the number of fish captured in the fyke nets during the vertical distribution measurements, only the middle column of nets was used. The number of fish captured at each net level was expanded by a factor of three to estimate the total numbers of fish passing through the fyke-netted area.

To evaluate the effects of guidance conditions on fish collected during the tests, all guided salmonids were examined for descaling and injuries using guidelines established by the Fish Transportation Oversight Team (Ceballos et al. 1991). Descaling was measured by examining five equal parts per side on each fish; if any two areas on the same side were estimated to be 40% or more descaled, the fish was classified as descaled.

Statistical Analysis

To avoid a turbine unit effect on FGE, all tests were conducted in Unit 3. The daily tests were grouped into blocks of four days; each block included three days of testing different guidance conditions (one guidance condition per day) and one day during which a vertical distribution measurement was conducted. The three guidance conditions were:

A) STS (standard elevation) with stored (standard position) operating gate

B) STS (standard elevation) with raised operating gate

C) Lowered STS with raised operating gate

For yearling chinook salmon, the tests were grouped and randomized to permit analysis by randomized block ANOVA. The Fisher's Protected Least Significant Difference (FPLSD) method was used to compare treatments from ANOVAs with significant F-tests (Petersen 1985). Significance was established for $\alpha = 0.05$.

Conditions A and B were tested in all eight blocks while Condition C was tested only in the first five blocks. Therefore, two sets of ANOVA tests were done. The first analysis included all three conditions and used only the first five blocks (a 3x5 design) and the second analysis included Conditions A and B and used all eight blocks (a 2x8 design).

Standard errors (SE) for treatment means were calculated using the expression:

$$SE = \sqrt{\frac{MSE}{b}}$$

and the FPLSD was calculated using the expression:

$$FPLSD = t_{0.025,n-1}\sqrt{\frac{2\,MSE}{b}}$$

where,

$t_{0.025,n-1}$ = the t value corresponding to $\alpha/2 = 0.025$ and degrees of freedom = n-1

MSE = the mean square for error from the ANOVA

b = the number of blocks.

RESULTS AND DISCUSSION

Effects of a Lowered STS on Fish Guidance Efficiency

On 22, 23, and 24 April, preliminary FGE tests were completed with the STS lowered 80 cm (32 in) (two tests) and 95 cm (38 in)(one test) below the standard elevation. For the two tests with the STS lowered 80 cm, FGE for yearling chinook salmon averaged 48% with an average gap-net loss of 5%. Since this gap-net loss was low compared to the 10% loss with the 95-cm lowered STS (FGE = 58%), the 80-cm lowered STS was chosen for continued testing. This moved the pivot point of the STS from 12.0 m (39.5 ft) above MSL (standard elevation) to 11.2 m (36.8 ft) above MSL (Fig. 1).

From 25 April to 20 May, five blocks of FGE tests with yearling chinook salmon as the target species were completed comparing guidance Conditions A, B, and C (Table 1 and Fig. 2,

Table 1.--Fish guidance efficiency (FGE) and gap-net catch for yearling chinook salmon for all tests conducted at Bonneville Dam First Powerhouse, 1992. Condition A = standard elevation submersible traveling screen (STS) with stored operating gate, B = standard elevation STS with raised operating gate, and C = lowered STS (80 cm, except as otherwise noted) with raised operating gate.

Block no.	Date	Condition A FGE (%)	Condition A Gap (%)	Condition B FGE (%)	Condition B Gap (%)	Condition C FGE (%)	Condition C Gap (%)
1	25-27 Apr	60	3	63	0	55	9
2	29 Apr-1 May	47	1	54	0	45[a]	11[a]
3	3-5 May	34	3	55	0	34	15
4	11-14 May	35	5	50	0	24	15
						31[b]	0[b]
5	17-20 May	52	3	35	0	20	10
						34[b]	2[b]
6	26-27 May	27	4	33	5		
7	28-29 May	27	2	29	0		
8	31 May-1 June	24	1	29	1	—	—
Means (Blocks 1-5)		46	3	51	0	36[c]	12[c]
Means (Blocks 1-8)		38	3	43	1		

[a] STS lowered 65 cm.
[b] STS lowered 35 cm.
[c] Mean does not include values for 35-cm lowered STS tests because of insignificant gap-net catch.

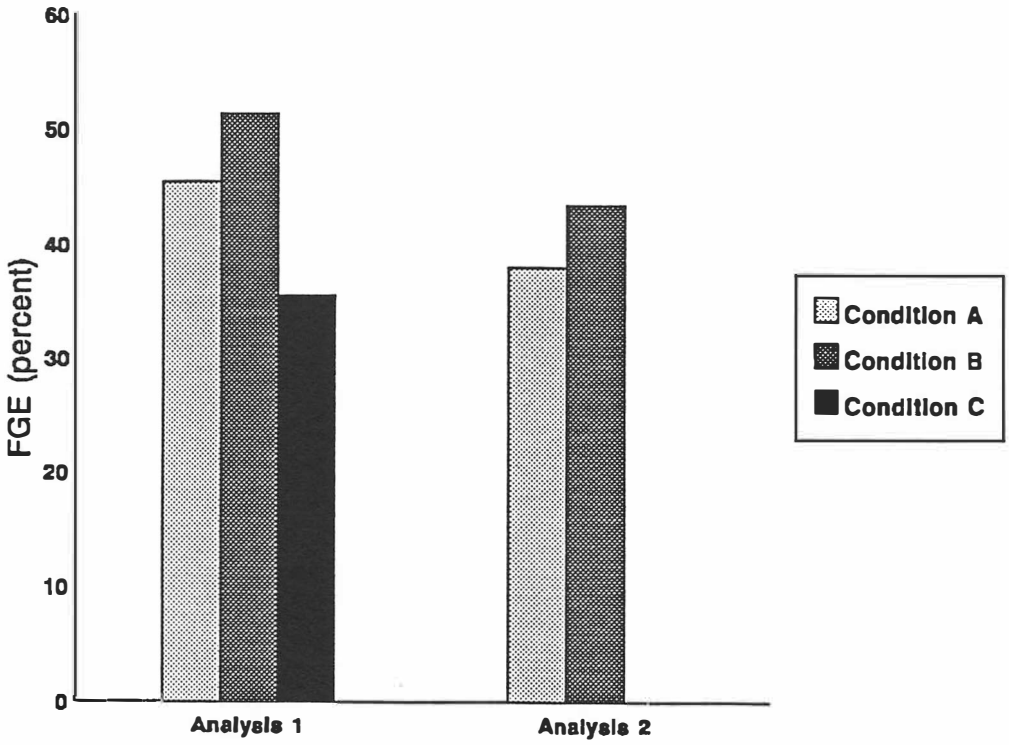


Figure 2.--Mean fish guidance efficiency (FGE) for yearling chinook salmon at Bonneville Dam First Powerhouse, 1992. Analysis 1 included first five test blocks and Analysis 2 included all eight test blocks. Condition A = standard elevation submersible traveling screen (STS) with stored operating gate, B = standard elevation STS with raised operating gate, and C = lowered STS with raised operating gate.

Analysis 1). The mean FGE for the lowered STS (Condition C) was 36% [included four tests with the screen lowered 80 cm and one test with the screen lowered 65 cm (26 in)]. Mean FGE for Condition B was 51%, which was significantly higher than for Condition C (36%) and a marginal improvement over FGE for Condition A (46%).

Condition C had a lower FGE because a large percentage of the fish moved over the top of the STS into the gap net instead of up into the gatewell. The mean gap-net catch with the 80-cm lowered STS was 12.0%, which was much higher than the 4.8% measured in preliminary tests. However, even if these fish had been guided into the gatewell, the average FGE for Condition C would still have been lower than for Condition B.

To determine if FGE could be improved by changing the elevation of the lowered STS from 80 cm to reduce the gap-net catch, FGE tests were also conducted with a 65-cm (1 test) and 35-cm (14-in) (2 tests) lowered STS (Table 1). In the one 65-cm lowered test, the gap-net catch was higher and FGE was lower than in Condition B. In both tests with the 35-cm lowered STS, the mean gap-net catch decreased to nearly 0%; however, FGE was still not improved compared to Condition B with the STS at standard elevation.

Effects of a Raised Operating Gate on Fish Guidance Efficiency

The effects of a raised operating gate on FGE for yearling chinook salmon were tested in two different analyses. Analysis 1 compared all three conditions (A, B, and C) and only considered

the first five blocks of tests. Analysis 2 compared Conditions A and B only and considered all eight blocks of tests.

In the first five blocks of tests, mean FGE with the raised operating gate (Condition B) was 51% compared to 46% with the stored operating gate (Condition A) (Fig. 2 and Appendix Table 1, Analysis 1). This difference was not statistically significant. During the latter part of the migration, when three more blocks of tests were completed (Blocks 6-8), FGE for Conditions A and B decreased to 26 and 30%, respectively, and any benefit derived from raising the operating gate was less apparent than in the earlier tests. The mean FGE for all eight blocks of tests in 1992 was 43% with the raised operating gate (Condition B) and 38% with the stored operating gate (Condition A) (Fig. 2 and Appendix Table 1, Analysis 2). This, again, was not a statistically significant difference and was in contrast to the significant increase realized with a raised operating gate in 1991 when the mean FGE for yearling chinook salmon was 50% with a raised operating gate and 29% with a stored operating gate.

The ANOVAs and FPLSDs used to compare Conditions A, B, and C (Analysis 1) for yearling chinook salmon and Conditions A and B (Analysis 2) for all salmonids (except sockeye salmon) are given in Appendix Table 1. A summary of the FGE results for non-target species is given in Appendix Table 2. The numbers of fish (by species) collected for each FGE and vertical distribution measurement are in Appendix Tables 3 and 4, respectively.

Theoretical Fish Guidance and Screen Efficiency

Vertical distribution measurements were also conducted in Unit 3 with yearling chinook salmon as the target species (Table 2). Because of time constraints, only five vertical distribution measurements were conducted (in Blocks 1-4 and 7; vertical distribution results from measurements conducted on 16 and 30 May were used to calculate TFGEs for Blocks 5, 6, and 8). Although the TFGEs in Blocks 1 and 2 were similar to results obtained in previous years at Bonneville Dam First Powerhouse (Gessel et al. 1990; Monk et al. 1992), there was a steady decline in TFGE from 78 to 38% as the season progressed (Fig. 3). This seemed to parallel the FGE results for all test conditions.

In all blocks except one (Block 5) the screen efficiency for the standard elevation STS was increased by raising the operating gate (Fig. 3). The mean screen efficiency for Condition A (standard elevation STS, stored operating gate) was 66% (SE = 3.5) and for Condition B (standard elevation STS, raised operating gate), 76% (SE = 3.8).

Other Salmonids

Additional FGE data were also collected for subyearling chinook and coho salmon, and steelhead. To compare Conditions A and B for these species, only those tests which included a catch of at least 50 fish were included in the FGE analysis. Using this criterion, the last four blocks of tests were used for FGE analyses of subyearling chinook salmon, and the last seven blocks of tests for FGE analyses of coho salmon and steelhead. The raised operating gate (Condition B) significantly increased FGE

Table 2.--Cumulative percentages of yearling chinook salmon caught in the gatewell and at each fyke-net level, from top to bottom, during vertical distribution measurements in Slot 3B at Bonneville Dam First Powerhouse, 1992. Cumulative percent at fyke-net level 2 represents theoretical fish guidance efficiency.

	28 Apr	2 May	6 May	16 May	30 May
Gatewell	11.5	10.5	8.1	10.9	3.6
Fyke-net level					
1	48.7	34.0	32.3	54.3	30.3
2	77.6	73.1	65.2	67.4	37.5
3	88.5	85.7	80.7	86.9	57.1
4	96.8	93.7	93.2	95.6	73.1
5	99.3	95.2	97.5	97.8	83.9
6	100.0	97.6	99.4	100.0	92.8
7	100.0	100.0	100.0	100.0	100.0

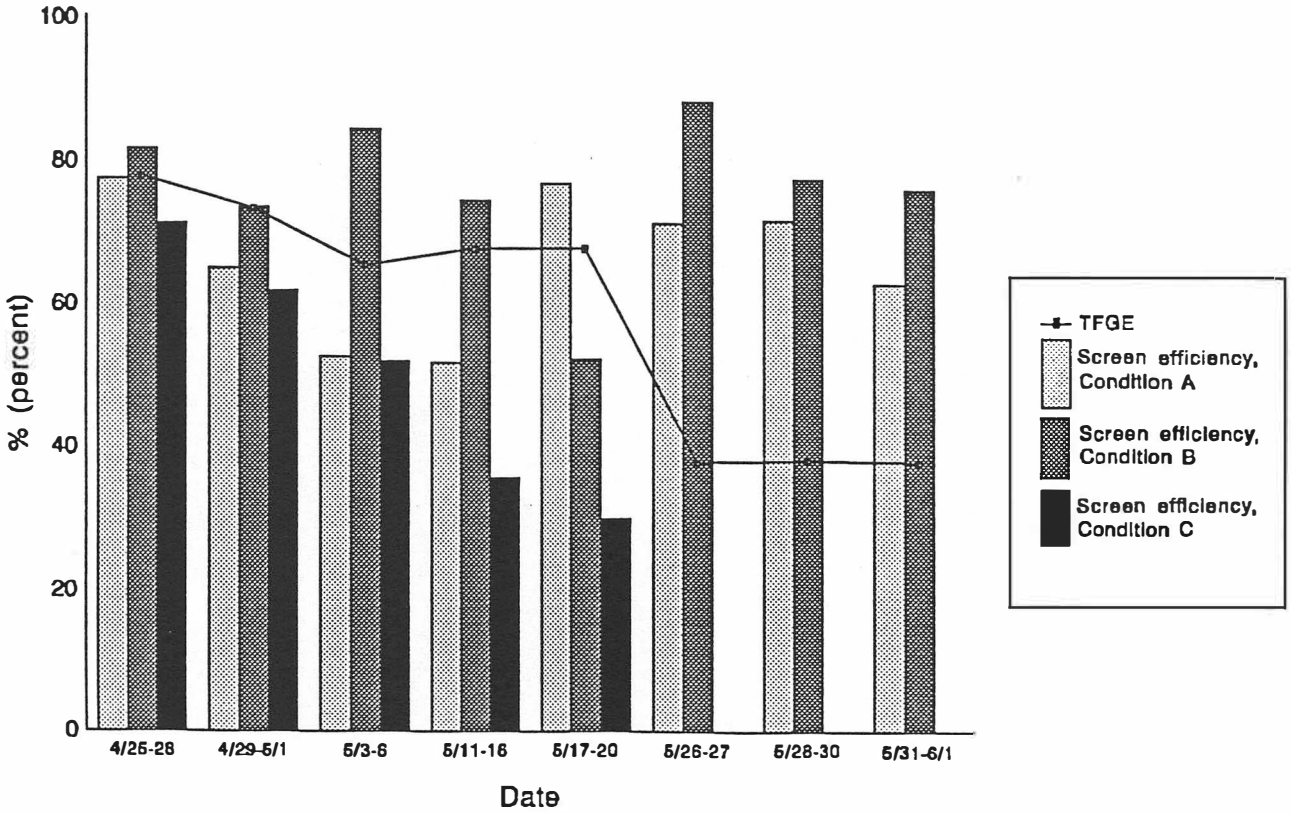


Figure 3.--Theoretical fish guidance efficiency (TFGE) and screen efficiency of submersible traveling screens (STS) for yearling chinook salmon at Bonneville Dam First Powerhouse, 1992. Condition A = standard elevation submersible traveling screen (STS) with stored operating gate, B = standard elevation STS with raised operating gate, and C = lowered STS with raised operating gate.

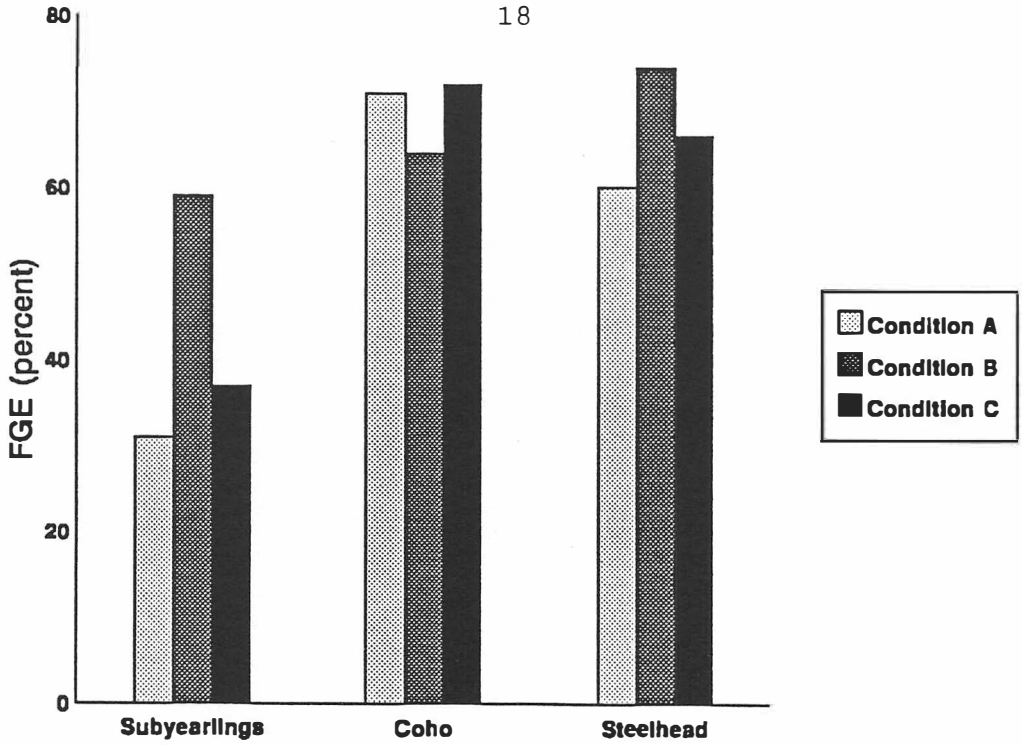
for subyearling chinook salmon, coho salmon, and steelhead (Fig. 4, bottom).

Since many of the tests had less than 50 fish of the non-target species, no statistical analyses were completed comparing Condition C to A or B. However, for all the non-target species, FGE was slightly higher for Condition C than for Condition A (Fig. 4, top); this was not the case for yearling chinook salmon. With the 80-cm lowered STS, the gap-net catch ranged from 5.7% for coho salmon to 9.2% for subyearling chinook salmon (Appendix Table 2). By changing to a 35-cm lowered STS, the gap-net catch was reduced to 0% for all the non-target species except coho salmon (0.7%) and the FGE still remained higher for Condition C than for Condition A.

Because of the consistently low numbers of sockeye salmon collected, the weighted (by total number of fish in all replicates) mean FGE was calculated to show trends in FGE but no statistical analysis was attempted. The weighted mean FGE for sockeye salmon was 18 and 30% for Conditions A and B, respectively (Fig. 4, bottom). Because of the low numbers of fish collected (<50 per test), these values should be interpreted with caution. However, the difference in FGE between the two conditions seemed to follow the same trend apparent with the other species and the FGE values were consistent with past results for sockeye salmon.

Fish Quality

Percent descaling for all salmonids taken from the gatewell (guided fish) during all FGE tests and vertical distribution



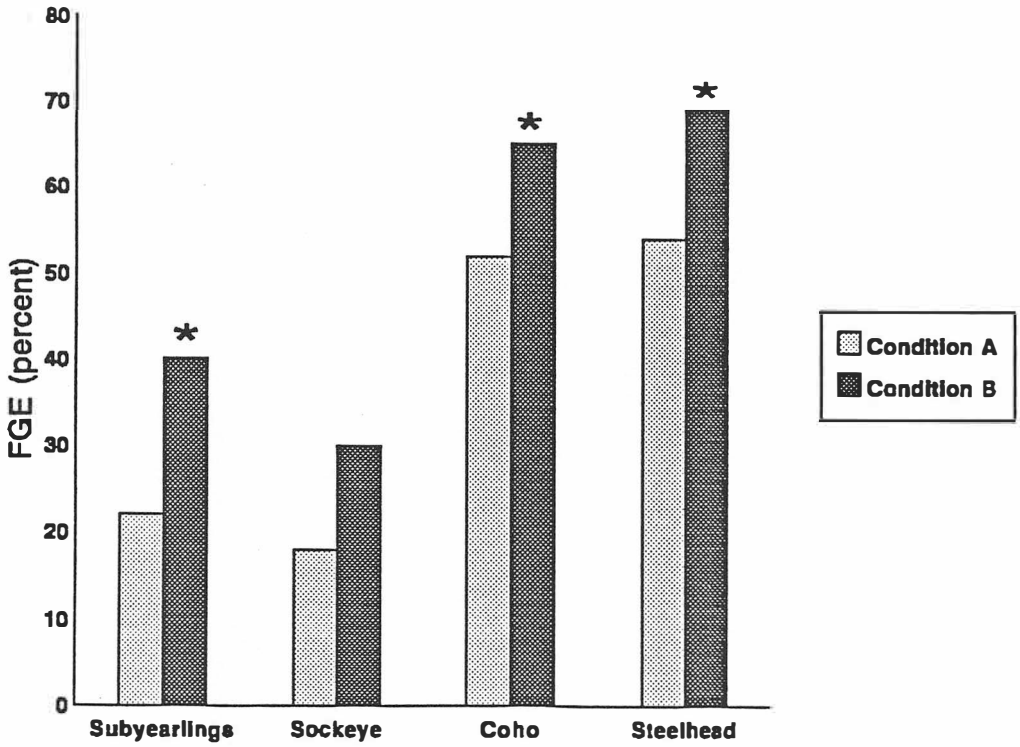


Figure 4.--Mean fish guidance efficiency (FGE) for non-target species (when n ≥ 50, except for sockeye salmon) for first five treatment blocks (top) and all eight treatment blocks (bottom) at Bonneville Dam First Powerhouse, 1992. Condition A = standard elevation submersible traveling screen (STS) with stored operating gate, B = standard elevation STS with raised operating gate, and C = lowered STS with raised operating gate. (* Denotes significant difference between A and B, α = 0.05.)

measurements was similar in range to past results at Bonneville Dam First Powerhouse (Table 3). For all species except sockeye salmon (excluded because of small sample sizes and a large variance), mean percent descaling for different FGE test conditions ranged from 0 to 5.3%, with an overall mean of 3.1%. Mean percent descaling for sockeye salmon ranged from 2.7 to 22.4% for different FGE test conditions, with an overall mean of 15.8%.

For all species except steelhead, the highest percent descaling was measured with a lowered STS and a raised operating gate (Condition C). For all species combined (except sockeye salmon), the weighted mean percent descaling for Condition C was significantly higher than for either Condition A or B, or for the vertical distribution tests. The higher descaling recorded for Condition C may have been due to increased flow up into the gatewell as a result of more water being intercepted by the lowered STS and the hydraulic effects of raising the operating gate.

CONCLUSIONS

1) Lowering the STS 80 cm below the standard elevation in the gatewell slot did not improve FGE for yearling chinook salmon at Bonneville Dam First Powerhouse. Although a 35-cm lowered STS reduced the gap-net catch for yearling chinook salmon, FGE was not improved (still <35%).
2) Contrary to results obtained in 1991 at Bonneville Dam First Powerhouse, a raised operating gate did not significantly

Table 3.--Weighted mean percent descaling for live fish taken from Slot 3B during FGE tests and vertical distribution measurements at Bonneville Dam First Powerhouse, 1992. Condition A = standard elevation submersible traveling screen (STS) with stored operating gate, B = standard elevation STS with raised operating gate, C = lowered STS with raised operating gate, and VD = vertical distribution test.

	FGE test condition						
	A	B	C	Mean[a]	SE	VD	SE
Yearling chinook	2.5	2.5	4.8	3.2	0.6	1.9	0.5
Subyearling chinook	0.0	0.5	4.3	0.8	1.1	0.0	-
Sockeye	2.7	16.0	22.4	15.8	3.9	-	-
Coho	2.5	3.0	3.4	2.8	0.4	0.7	0.6
Steelhead	2.0	5.3	2.6	2.5	0.6	3.2	1.2
Weighted mean[b]	2.1	3.2	3.8	3.1		1.9	
SE	0.4	0.4	0.3	0.4		0.5	

[a] Weighted mean descaling for three FGE conditions.
[b] Because of the small numbers of fish per condition and the large variance, sockeye salmon results were not used to compute this mean or to compare conditions.

improve FGE for yearling chinook salmon. However, FGE was significantly increased for subyearling chinook salmon, coho salmon, and steelhead.

3) There was a steady decline in both FGE and TFGE for yearling chinook salmon as the spring migration progressed.

RECOMMENDATIONS

1) Based upon results with yearling chinook salmon at Bonneville Dam First Powerhouse in 1991 (Monk et al. 1992), subyearling chinook salmon, coho salmon, and steelhead at Bonneville Dam First Powerhouse in 1992, and results from studies at other Snake and Columbia River dams, we recommend raising (or removing) operating gates at Bonneville Dam First Powerhouse during the juvenile salmonid outmigration. Further evaluation is needed to determine the feasibility and the most efficient method of storing operating gates out of the gatewell slot.

ACKNOWLEDGMENTS

We express our appreciation to the Project Engineer at Bonneville Lock and Dam, Virgil Goodpastor; the Chief of Maintenance, Thomas Thorsen; and the Structures and Utility Foreman, Edward Willits, for their cooperation and suggestions. We also thank their respective staffs whose help made the research possible.

We also thank Portland District Corps of Engineers personnel and the Chief of Operations, Darrell Hunt, and his staff for the extensive effort in coordinating turbine unit startups and shutdowns for the respective tests.

REFERENCES

Ceballos, J. R., S. W. Pettit, and J. L. McKern. 1991. Fish Transportation Oversight Team Annual Report - FY 1990. Transport Operations on the Snake and Columbia Rivers. NOAA Technical Memorandum NMFS F/NWR-29. 75 p. plus Appendix. (Available from Environmental and Technical Services Division, 911 N.E. 11th Avenue, Suite 620, Portland, OR 97232.)

Gessel, M. H., D. A. Brege, B. H. Monk, and J. G. Williams. 1990. Continued studies to evaluate the juvenile bypass systems at Bonneville Dam - 1989. Report to U.S. Army Corps of Engineers, Contract DACW68-84-H-0034, 19 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Gessel, M. H., B. H. Monk, D. A. Brege, and J. G. Williams. 1989. Fish guidance efficiency studies at Bonneville Dam First and Second Powerhouses - 1988. Report to U.S. Army Corps of Engineers, Contract DACW57-87-F-0322, 22 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Gessel, M. H., L. G. Gilbreath, W. D. Muir, and R. F. Krcma. 1986. Evaluation of the juvenile collection and bypass systems at Bonneville Dam - 1985. Report to U.S. Army Corps of Engineers, Contract DACW57-85-H-0001, 63 p. plus Appendices. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Krcma, R. F., D. A. DeHart, M. H. Gessel, C. W. Long, and C. W. Sims. 1982. Evaluation of submersible traveling screens, passage of juvenile salmonids through the ice and trash sluiceway, and cycling of gatewell orifice operation at the Bonneville First Powerhouse, 1981. Report to U.S. Army Corps of Engineers, Contract DACW57-81-F-0342, 36 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Krcma, R. F., M. H. Gessel, and F. J. Ossiander. 1983. Research at McNary Dam to develop and implement a fingerling protection system for John Day Dam. Report to U.S. Army Corps of Engineers, Contract DACW57-82-F-0373, 24 p. plus Appendices. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Krcma, R. F., C. W. Long, and C. S. Thompson. 1978. Research on the development of a fingerling protection system for low-head dams - 1977. Report to U.S. Army Corps of Engineers, Contract DACW-57-77-F-0307, 32 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2907.)

Monk, B. H., W. D. Muir, and M. H. Gessel. 1987. Studies to evaluate alternative methods of bypassing juvenile fish at The Dalles Dam - 1986. Report to U.S. Army Corps of Engineers, Contract DACW57-85-F-0295, 12 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Monk, B. H., G. E. Varney, and S. J. Grabowski. 1992. Continuing studies to evaluate and improve submersible traveling screens for fish guidance at Bonneville Dam First Powerhouse, 1991. Report to U.S. Army Corps of Engineers, Contract DACW57-85-H-0001, 20 p. plus Appendix. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Petersen, R. G. 1985. Design and analysis of experiments. Marcel Dekker, New York. 429 p.

Swan, G. A., R. F. Krcma, and F. J. Ossiander. 1984. Research to develop an improved fingerling protection system for Lower Granite Dam. Report to U.S. Army Corps of Engineers, Contract DACW68-78-C-0051, 20 p. plus Appendices. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Appendix Table 1.--Means of fish guidance efficiency (FGE), standard errors, ANOVAs, and Fisher's Protected Least Significant Difference (FPLSD) for yearling chinook, subyearling chinook, and coho salmon, and steelhead at Bonneville Dam First Powerhouse, 1992. Condition A = standard elevation submersible traveling screen (STS) with stored operating gate, B = standard elevation STS with raised operating gate, and C = lowered STS with raised operating gate.

Analysis 1--A vs B vs C (Blocks 1-5)

Analysis of Variance for Yearling Chinook Salmon

Source	df	Sum of squares	Mean square	F	P
Block	4	1199.26	299.82		
Treatment	2	627.43	313.71	4.41	0.0513
Error	8	569.75	71.22		
Total	14	2396.43			

Standard Error = 4% ; FPLSD = 12%

Treatment:	A	B	C
Mean FGE (%)[a]:	46	51	36

Analysis 2--A vs B (Blocks 1-8)

Analysis of Variance for Yearling Chinook Salmon

Source	df	Sum of squares	Mean square	F	P
Block	7	2107.20	301.03		
Treatment	1	114.65	114.65	1.93	0.2076
Error	7	416.35	59.48		
Total	15	2638.20			

Standard Error = 3% ; FPLSD = 9%

Treatment:	A	B
Mean FGE (%)[a]:	38	43

[a] Means connected by a line are not significantly different.

Appendix Table 1.--Continued.

Analysis of Variance for Subyearling Chinook[b] Salmon

Source	df	Sum of squares	Mean square	F	P
Block	3	391.50	130.50		
Treatment	1	658.85	658.85	12.00	0.0405
Error	3	164.70	54.90		
Total	7	1215.04			

Standard Error = 4% ; FPLSD = 17%

Treatment:	A	B
Mean FGE (%)[a]:	22	40

Analysis of Variance for Coho[b] Salmon

Source	df	Sum of squares	Mean square	F	P
Block	6	3889.16	648.19		
Treatment	1	628.06	628.06	18.04	0.0054
Error	6	208.91	34.82		
Total	13	4726.13			

Standard Error = 2% ; FPLSD = 8%

Treatment:	A	B
Mean FGE (%)[a]:	52	65

Analysis of Variance for Steelhead[b]

Source	df	Sum of squares	Mean square	F	P
Block	6	2112.66	352.11		
Treatment	1	823.60	823.60	11.92	0.0136
Error	6	414.69	69.12		
Total	13	3350.96			

Standard Error = 3% ; FPLSD = 11%

Treatment:	A	B
Mean FGE (%)[a]:	54	69

[a] Means connected by a line are not significantly different.
[b] Only the last seven blocks had n > 50.

Appendix Table 2.--Weighted mean fish guidance efficiency (FGE) and gap-net catch results for Bonneville Dam First Powerhouse, 1992. N = number of replicates, n = total number of fish in all replicates, Gap = Gap-net catch. Condition A = standard elevation submersible traveling screen (STS) with stored operating gate, B = standard elevation STS with raised operating gate, and C = lowered STS with raised operating gate.

Subyearling chinook salmon

	N	n	FGE (%)	Gap (%)
Condition A	8	467	22	1.5
Condition B	7	484	40	0.2
Condition C (80 cm)	5	178	37	9.2
Condition C (35 cm)	2	36	64	0.0

Coho salmon

	N	n	FGE (%)	Gap (%)
Condition A	8	872	52	2.6
Condition B	8	923	65	0.4
Condition C (80 cm)	5	775	72	5.7
Condition C (35 cm)	2	237	75	0.7

Steelhead

	N	n	FGE (%)	Gap (%)
Condition A	8	795	54	0.4
Condition B	8	812	69	0.1
Condition C (80 cm)	5	715	66	6.6
Condition C (35 cm)	2	325	67	0.0

Appendix Table 3.--Numbers of fish collected in replicates of FGE tests in Slot 3B at Bonneville Dam First Powerhouse, 1992 (SC = subyearling chinook, YC = yearling chinook, ST = steelhead, CO = coho, and SO = sockeye). Test Condition A = standard elevation submersible traveling screen (STS) with stored operating gate, B = standard elevation STS with raised operating gate, and C = lowered STS (90 cm except as noted) with raised operating gate. FGE provided for n ≥ 50.

	Date - Test Condition														
	22 April - A					23 April - A					24 April - B				
Location	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO
Gatewell	20	180	8	5	0	15	197	18	37	0	8	299	18	43	0
Gap Net	3	12	1	0	0	7	47	1	1	0	3	37	0	2	0
Closure	5	37	0	0	0	6	39	0	0	0	5	49	3	2	0
First	0	9	0	0	0	0	6	3	0	0	0	6	0	3	0
Second	0	111	3	0	0	0	75	9	3	0	3	93	3	6	0
Third	12	78	3	0	0	6	24	3	3	0	0	24	3	3	0
Fourth	3	42	0	0	0	0	6	0	0	0	6	12	0	0	0
Totals	**43**	**469**	**15**	**5**	**0**	**34**	**394**	**34**	**44**	**0**	**25**	**520**	**27**	**59**	**0**
FGE (%)		**38**					**50**					**58**		**73**	

	25 April - C					26 April - A					27 April - B				
Location	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO
Gatewell	12	227	50	37	0	5	121	66	33	0	7	142	6	6	0
Gap Net	3	35	0	0	0	0	6	0	0	0	0	0	0	0	0
Closure	0	27	3	0	0	1	18	1	1	0	0	14	6	0	0
First	0	15	0	9	0	0	21	0	0	0	0	24	0	3	0
Second	9	90	3	0	0	6	18	12	0	0	3	42	0	3	0
Third	3	9	3	0	0	0	12	0	0	0	0	3	0	0	0
Fourth	3	9	0	0	0	0	6	0	3	0	0	0	0	0	0
Totals	**30**	**412**	**59**	**46**	**0**	**12**	**202**	**79**	**37**	**0**	**10**	**225**	**12**	**12**	**0**
FGE (%)		**55**	**85**				**60**	**84**				**63**			

	29 April - A					30 April - B					1 May - C (65 cm)				
Location	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO
Gatewell	3	138	25	41	0	0	186	65	82	0	6	190	88	120	0
Gap Net	0	3	0	1	0	0	0	0	0	0	1	48	8	5	0
Closure	2	13	3	0	0	0	26	1	0	0	1	33	4	4	0
First	3	24	0	0	0	0	30	0	0	0	0	12	0	0	0
Second	0	87	9	6	0	0	72	9	6	0	3	93	12	12	0
Third	0	24	0	0	0	0	24	0	0	0	0	33	12	3	0
Fourth	0	3	9	0	0	0	9	0	0	0	0	12	6	3	0
Totals	**8**	**292**	**46**	**48**	**0**	**0**	**347**	**75**	**88**	**0**	**11**	**421**	**130**	**147**	**0**
FGE (%)		**47**					**54**	**87**	**93**			**45**	**68**	**82**	

Appendix Table 3.--Continued.

Date - Test Condition

	3 May - B					4 May - A					5 May - C				
Location	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO
Gatewell	10	135	75	63	0	7	95	97	105	0	9	82	95	83	1
Gap Net	0	0	0	0	0	0	7	2	3	0	3	35	17	8	0
Closure	1	15	0	2	0	2	18	4	5	0	3	20	10	2	0
First	0	24	3	9	0	0	39	9	18	0	0	9	3	3	0
Second	6	54	6	6	0	3	84	21	21	0	9	63	15	3	3
Third	3	12	3	3	0	0	30	3	0	0	0	30	12	9	0
Fourth	0	6	6	0	0	3	6	0	0	0	0	3	3	0	0
Totals	**20**	**246**	**93**	**83**	**0**	**15**	**279**	**136**	**152**	**0**	**24**	**242**	**155**	**108**	**4**
FGE (%)		**55**	**81**	**76**			**34**	**71**	**69**			**34**	**61**	**77**	

	11 May - A					12 May - B					14 May - C				
Location	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO
Gatewell	3	95	118	73	27	15	64	134	84	22	12	35	97	81	21
Gap Net	1	13	0	4	1	0	0	0	0	0	4	22	11	15	7
Closure	5	10	22	6	4	2	10	10	1	3	4	11	9	6	1
First	3	18	33	18	24	0	15	12	0	9	0	3	6	3	0
Second	12	105	60	3	18	0	30	57	39	12	15	36	18	24	12
Third	12	30	18	15	12	6	6	0	0	6	9	27	9	3	9
Fourth	0	3	3	6	6	3	3	0	0	6	0	12	0	0	9
Totals	**36**	**274**	**254**	**125**	**92**	**26**	**128**	**213**	**124**	**58**	**44**	**146**	**150**	**132**	**59**
FGE (%)		**35**	**46**	**58**	**29**		**50**	**63**	**68**	**38**		**24**	**65**	**61**	**36**

	15 May - C (35 cm)					17 May - C (35 cm)					18 May - C				
Location	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO
Gatewell	9	28	143	103	20	14	44	78	73	11	8	33	111	55	14
Gap Net	0	0	0	0	0	0	3	0	1	0	2	16	11	16	2
Closure	2	12	9	1	2	2	6	8	5	3	8	19	6	4	2
First	0	0	6	6	0	0	6	3	3	3	0	6	6	6	9
Second	3	33	21	36	15	6	42	21	0	3	6	63	54	6	15
Third	0	18	18	0	3	0	12	3	3	3	6	21	30	6	0
Fourth	0	0	6	6	0	0	15	9	3	3	3	6	3	9	0
Totals	**14**	**91**	**203**	**152**	**40**	**22**	**128**	**122**	**88**	**26**	**33**	**164**	**221**	**102**	**42**
FGE (%)		**31**	**70**	**68**			**34**	**64**	**83**			**20**	**50**	**54**	

Appendix Table 3.--Continued.

Date - Test Condition

	19 May - B					20 May - A					26 May - B				
Location	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO
Gatewell	20	71	96	100	8	13	35	28	32	1	64	62	97	89	13
Gap Net	0	0	0	1	0	2	2	0	3	0	0	10	1	1	0
Closure	4	9	7	4	1	3	4	2	4	0	13	8	1	5	1
First	6	15	12	12	3	0	12	6	0	0	3	18	9	6	3
Second	12	66	27	45	15	30	3	15	18	6	18	51	9	21	21
Third	3	33	6	30	0	6	9	12	15	0	9	36	9	15	3
Fourth	0	9	0	3	0	3	3	0	3	0	6	3	0	6	3
Totals	**45**	**203**	**148**	**195**	**27**	**57**	**68**	**63**	**75**	**7**	**113**	**188**	**126**	**143**	**44**
FGE (%)		**35**	**65**	**51**		**23**	**51**	**44**	**43**		**57**	**33**	**77**	**62**	

	27 May - A					28 May - A					29 May - B				
Location	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO
Gatewell	23	70	63	66	6	17	44	46	40	3	30	52	69	91	6
Gap Net	1	10	1	4	0	2	3	0	5	1	0	0	0	1	0
Closure	13	27	4	8	3	12	10	8	5	2	13	8	5	7	2
First	6	18	3	6	6	12	39	0	12	6	6	36	15	3	3
Second	33	75	6	36	12	30	42	15	42	6	39	51	12	33	6
Third	9	57	9	12	12	15	24	6	27	6	15	24	12	15	6
Fourth	6	6	0	3	0	6	3	0	6	3	0	9	0	3	3
Totals	**91**	**263**	**86**	**135**	**39**	**94**	**165**	**75**	**137**	**27**	**103**	**180**	**113**	**153**	**26**
FGE (%)	**25**	**27**	**73**	**49**		**18**	**27**	**61**	**29**		**29**	**29**	**61**	**59**	

	31 May - B					1 June - A				
Location	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO
Gatewell	49	45	17	58	1	32	34	15	47	0
Gap Net	1	2	0	1	0	1	1	0	3	0
Closure	12	18	0	6	0	22	14	2	5	1
First	12	18	0	3	0	9	9	0	12	0
Second	57	39	3	27	3	57	48	27	42	0
Third	24	33	12	21	0	24	21	12	45	0
Fourth	12	3	0	9	0	9	18	0	9	0
Totals	**167**	**158**	**32**	**125**	**4**	**154**	**145**	**56**	**163**	**1**
FGE (%)	**29**	**28**		**46**		**21**	**23**	**27**	**29**	

Appendix Table 4.--Numbers of fish collected in the individual replicates of vertical distribution tests at Bonneville Dam First Powerhouse, 1992. For all tests, the operating gate was in the stored position (SC = subyearling chinook, YC = yearling chinook, ST = steelhead, CO = coho, and SO = sockeye).

	Date (Test Unit and Slot)														
	28 April (3B)					2 May (3B)					6 May (3B)				
Location	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO
Gatewell	0	54	29	31	0	2	40	46	34	0	2	39	58	42	0
First	6	174	15	15	0	3	129	18	9	0	3	117	96	24	3
Second	0	135	9	9	0	0	108	27	15	0	21	159	66	18	0
Third	9	51	3	6	0	0	48	9	6	0	21	75	51	12	0
Fourth	3	39	0	6	0	0	30	3	3	0	0	60	6	3	0
Fifth	0	12	0	0	0	0	6	12	6	0	0	21	3	0	3
Sixth	3	3	0	0	0	3	9	0	0	0	0	92	3	3	0
Seventh	0	0	0	0	0	0	9	0	0	0	0	3	3	0	0
Totals	**21**	**468**	**56**	**67**	**0**	**8**	**379**	**115**	**73**	**0**	**47**	**483**	**286**	**102**	**6**

	16 May (3B)					30 May (3B)				
Location	SC	YC	ST	CO	SO	SC	YC	ST	CO	SO
Gatewell	0	15	37	23	4	25	6	18	15	0
First	9	60	33	30	21	57	45	6	33	3
Second	9	18	33	39	12	33	12	6	18	0
Third	12	27	18	0	6	42	33	3	33	12
Fourth	6	12	9	3	3	60	27	0	3	0
Fifth	0	3	3	9	0	24	18	6	0	0
Sixth	0	3	3	0	0	33	15	6	0	0
Seventh	3	0	0	0	0	0	12	3	0	0
Totals	**39**	**138**	**136**	**104**	**46**	**274**	**168**	**48**	**102**	**15**

Appendix Table 5.--Total numbers of fish in the gatewells and percent descaling for all salmonids examined during FGE and vertical distribution (VD) measurements conducted at Bonneville Dam First Powerhouse, 1992. Condition A = standard elevation submersible traveling screen (STS) with stored operating gate, B = standard elevation STS with raised operating gate, and C = lowered STS (80 cm, except as noted) with raised operating gate (ND = no data).

				Yearling Chinook		Subyear Chinook		Sockeye		Coho		Steelhead	
Unit	Date	Test	Cond.	No.	%	No.	%	No.	%	No.	%	No.	%
3B	4-25	FGE	C	227	3.4	12	0.0	0	NA	37	0.0	50	2.0
3B	4-26	FGE	A	121	0.8	5	0.0	0	NA	33	6.1	66	6.1
3B	4-27	FGE	B	142	1.4	7	0.0	0	NA	41	4.9	51	5.9
3B	4-28	VD	-	54	1.9	0	NA	0	NA	31	3.2	29	6.9
3B	4-29	FGE	A	138	2.9	3	0.0	0	NA	41	4.9	25	0.0
3B	4-30	FGE	B	186	1.6	11	0.0	0	NA	82	2.4	65	9.2
3B	5-1	FGE	C(65 cm)	190	5.3	6	33.3	0	NA	120	5.0	88	5.7
3B	5-2	VD	-	40	0.3	2	0.0	0	NA	34	0.0	46	2.2
3B	5-3	FGE	B	135	6.7	10	0.0	0	NA	63	3.2	75	8.0
3B	5-4	FGE	A	95	7.4	7	0.0	0	NA	105	2.9	97	3.1
3B	5-5	FGE	C	82	7.3	9	0.0	1	0.0	83	2.4	95	2.1
3B	5-6	VD	-	39	2.6	2	0.0	0	NA	42	0.0	58	5.2
3B	5-11	FGE	A	95	0.0	3	0.0	27	0.0	73	0.0	118	0.0
3B	5-12	FGE	B	53	3.8	15	0.0	22	9.1	84	2.4	134	5.2
3B	5-14	FGE	C	35	5.7	12	0.0	21	4.8	81	1.2	97	3.1
3B	5-15	FGE	C(35 cm)	28	7.1	9	0.0	20	50.0	103	4.9	143	2.1
3B	5-16	VD	-	15	0.0	0	NA	4	25.0	23	0.0	37	0.0
3B	5-17	FGE	C(35 cm)	44	9.1	14	0.0	11	18.2	73	4.1	44	1.3
3B	5-18	FGE	C	33	3.0	8	0.0	14	14.3	55	3.6	111	1.8
3B	5-19	FGE	B	71	0.0	20	0.0	8	37.5	100	4.0	96	1.0
3B	5-20	FGE	A	35	0.0	13	0.0	1	0.0	32	3.1	28	0.0
3B	5-26	FGE	B	62	1.6	64	0.0	13	15.4	89	3.4	97	6.2
3B	5-27	FGE	A	70	0.0	23	0.0	6	16.7	66	0.0	63	3.2
3B	5-28	FGE	A	44	6.8	17	0.0	3	0.0	40	2.5	46	0.0
3B	5-29	FGE	B	52	3.8	30	0.0	6	16.6	91	1.1	69	4.3
3B	5-30	VD	-	6	0.0	25	0.0	0	NA	15	0.0	18	0.0
3B	5-31	FGE	B	45	0.0	49	2.0	1	0.0	58	3.4	17	0.0
3B	6-1	FGE	A	34	2.9	32	0.0	0	NA	47	4.3	15	0.0