Fish Guiding Efficiency of Submersible Traveling Screens at Lower Monumental Dam—1986

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INTRODUCTION

Lower Monumental Dam is a hydroelectric project operated since 1969 on the Snake River by the U.S. Army Corps of Engineers (COE) at River Kilometer (RKm) 67. Raymond (1979) reported that up to 33% of the juvenile salmonids passing through turbines at dams are lost due to direct mortality from turbines and related predation by fish and birds. For the past several years, the majority of juvenile salmon, *Oncorhynchus* sp., and steelhead, *Salmo gairdneri*, have been collected from the Snake River at Little Goose Dam (RKm 113) and Lower Granite Dam (RKm 173) and transported around Lower Monumental and other dams to downstream release sites (Park et al. 1984). In recent years, however, large numbers of juvenile chinook salmon, *O. tshawytscha*, and steelhead have been released from a new hatchery complex (Lyons Ferry) located downstream (RKm 95) from the collector dams and upstream from Lower Monumental Dam. These additional fish plus requirements of the Columbia River Fish and Wildlife Program (Section 404, B8 amended) have required improved fish protection at Lower Monumental Dam.

During 1986, personnel of the National Marine Fisheries Service (NMFS), under contract to the COE, undertook the initial steps for improved fish protection at Lower Monumental Dam--to evaluate a method of screening juvenile salmonids from the power-generating turbines. The most effective method of achieving this at other dams has been to employ submersible traveling screens (STS) to guide fish out of the turbine intakes into the gateslots where they can be bypassed around the turbines (Swan et al. 1983) (Fig. 1).

Research over the years by NMFS has shown that fish guiding efficiency (FGE) of STSs can vary considerably between dams and during different periods in the smolt migration. Because of this variability, the fishery agencies and the COE have agreed that FGEs be carefully measured at each dam to assure adequacy before installation of a full complement of STSs.

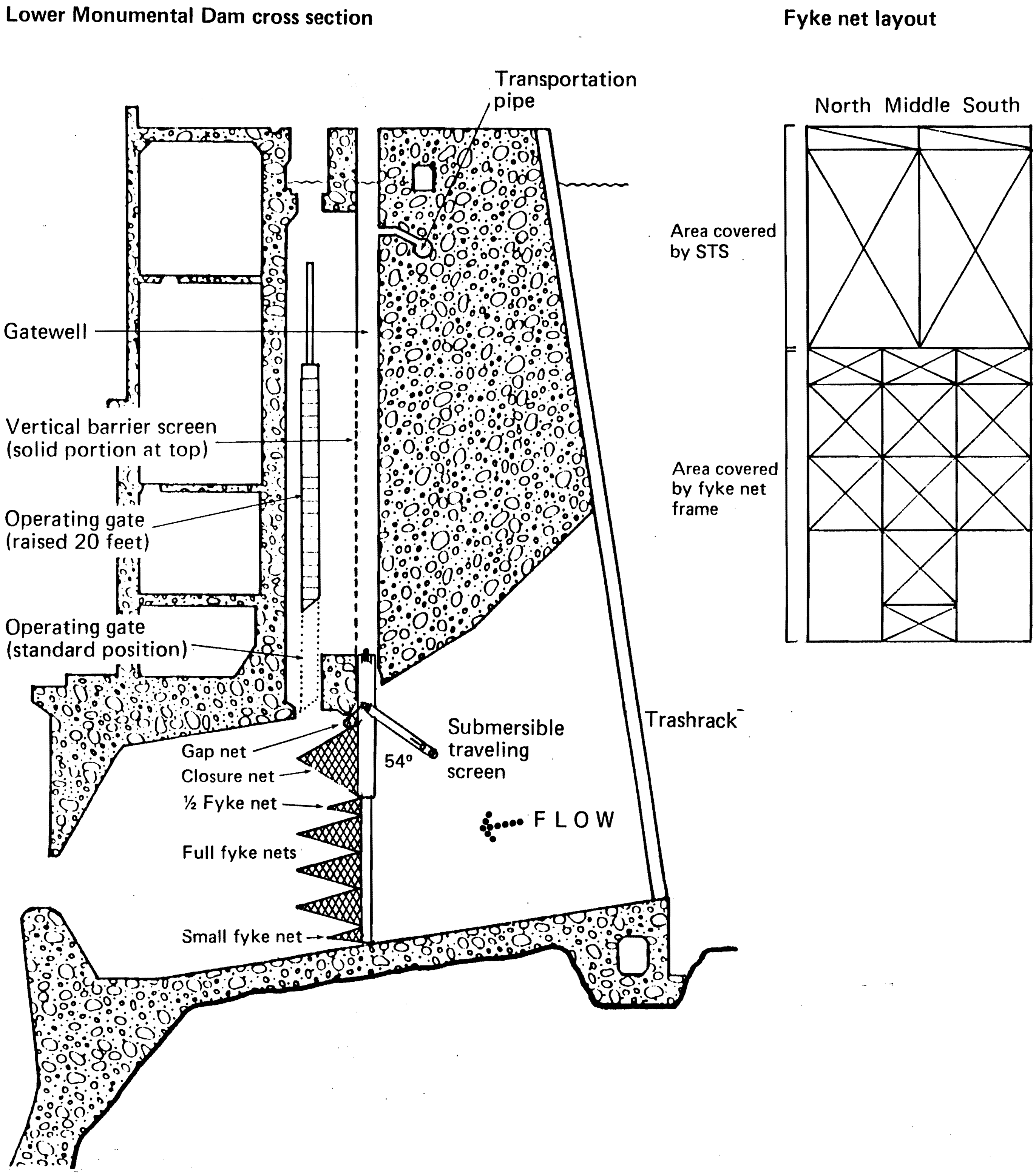

Figure 1.--Cross section of a typical turbine intake at Lower Monumental Dam showing STS in the 30-inch lowered position with varying positions of operating gate for FGE testing (A); a facing view of the net layout used during 1986 (B) is also shown.

The objectives of the studies conducted at Lower Monumental Dam during 1986 were to determine the FGE and vertical distribution (VD) of juvenile salmonids in a typical turbine intake. Juvenile chinook salmon were the target species for the tests because FGEs measured for these fish at other dams have been marginal at best and generally much lower than measured for steelhead. The testing program covered two general periods of the chinook salmon smolt migration. The first period involved primarily yearling chinook salmon that migrate during April and May, and the second period targeted subyearling chinook salmon released from Lyons Ferry Hatchery in early June.

Hydraulic model studies (WES) have shown that increased flow into the gatewells, which can increase FGE, can be obtained by partially raising the operating gate (Swan et al. 1985). Therefore, initial tests compared the benefits to FGE of a 20-foot raised operating gate versus the standard gate setting flush with the intake ceiling. Subsequent tests were conducted using the best operating gate setting determined during the earlier tests.

METHODS AND MATERIALS

The STSs and vertical barrier screens used for the study were borrowed from John Day Dam. Fyke net frames, a dipbasket (Swan et al. 1979), and other equipment were fabricated or modified from existing equipment by NMFS personnel and delivered to the dam site. Mobile crane service, provided by the COE, was used to transport and assemble equipment on the deck of the dam.

All tests were conducted in Turbine Unit 4 located centrally in the powerhouse. Generally, tests began at dusk (1800 h) and required about 5 h of turbine operation to collect sufficient numbers of fish for validation. A few tests took considerably longer than 5 h to complete (Appendix Tables A1 and A2).

Tests began on 15 April and continued periodically through 15 June (Table 1). Tests originally planned for mid to late May were canceled due to low numbers of yearling chinook salmon collected under the smolt monitoring program (R. Strain 1/).

The following sequence of events was typical for conducting a test:

1) Unit 4 was shut down, and the orifices opening into the fish bypass pipe were closed.
2) The gatewells were dipnetted to remove all fish (Swan et al. 1979).
3) Fyke net frames and STSs, as required, were lowered by gantry crane into the intake and the screen extended to a 54° angle.
4) Unit 4 was started, and the start time was recorded when the turbine reached full load (135 MW).
5) The STS motors were started to rotate the traveling screen (Farr 1974).
6) Numbers of fish entering the unit were monitored by periodic dipnetting of the gatewells.
7) The test was terminated (unit shut down) when adequate numbers of fish for statistical needs were estimated to have entered the unit (see Sample Size Requirements Section). When VD and FGE tests were conducted simultaneously, the termination number was determined from dipnetting the gatewell containing the STS.

1/ R. Strain, Washington Department of Game, Smolt Monitoring Program, Rt, Box 686, Warrenton, Oregon 97146 pers. commun. 1986.

Table 1.--Vertical distribution (VD) and fish guiding efficiency (FGE) test schedule conducted at Lower Monumental Dam, 1986.

Dates	Gatewell slot Unit 4 A	B	C
15-17 April	-[a/]	VD	-
21-26 April	STS[b/]	FGE[c/]	FGE[c/]
6-8 May	STS	STS	FGE
9 May	VD	-	FGE
10-15 June	VD	-	FGE

a/ - = Slot open, no fyke net frames or STS installed.
b/ STS = Submersible traveling screen only, no fyke net frames attached.
c/ Operation gate raised 20 feet from standard position on alternating days.

8) All remaining fish were dipped from the gatewells, and the STS was retracted from the extended position.

9) The net frames were lifted back to deck level, and net-caught fish were removed for identification and enumeration.

Fork length frequencies ($\pm$2.5 mm) were determined from a sample of captured fish. Generally a sample of both gatewell and netted fish were measured. In general, yearling chinook salmon pass the project during the spring (April-May) whereas subyearling chinook salmon (mostly from Lyons Ferry Hatchery) migrate in June (R. Strain [1/]). Chinook salmon were separated into yearling and subyearling categories on the basis of fork length (Dawley et al. 1985). During April and May, chinook salmon exceeding 57 mm in length were defined as yearlings, and during June, 112 mm was used as the separation point. The separation point during June was determined in part by length/frequency measurements of subyearling chinook salmon measured at Lyons Ferry Hatchery on the day the fish were released (D. Brown [2/]).

The effects of the STS on fish quality were determined using a descaling index for fish recovered from the gatewells. Descaling was determined by visually dividing each side of the fish into five equal areas; if any two areas on a side were 50% or more descaled, the fish was classified as descaled.[3/]

2/ D. Brown, Washington Department of Fisheries, Lyons Ferry Hatchery, P. O. Box 278, Starbuck, Washington 99359 pers. commun. 1986.

3/ The standard fish descaling index originated at an inter agency workshop conducted by Steve Pettit, Idaho Department of Fish and Game, at McNary Dam on 29 March 1983.

VD Tests

Vertical distribution tests were conducted to verify the depth that fish enter the turbine unit and to determine the proportion of fish that potentially could be guided into the gatewell by an STS--termed theoretical FGE (TFGE). At Lower Monumental Dam, this included all fish located in approximately the upper 16 feet of the intake--down to the depth of the third fyke net (Fig. 2).

All VD tests were conducted using only a center vertical column of nine fyke nets.[4/] The nets were designed to sample 1/3 of the flow through the intake at a given depth. The nets were attached to a fyke net frame extending from the ceiling to the floor of the intake. Side nets and net frames were removed to minimize mortality of fish in the fyke nets. Most nets were 6.5 feet high by 7.0 feet wide. Nets at Level 3, though, were divided into upper and lower halves (3U and 3L) so that we could measure TFGE. The numbers of fish collected in the center nets at each level were multiplied by 3 to estimate the total fish passing at the various depths in the intake. The cumulative percentage of fish captured from the gatewell plus the estimated number down to Net Level 3U provided the measure of TFGE.

4/ The assumption that the middle nets catch 1/3 of the total fish passing through the intake was statistically evaluated using data from past years collected at various dams where a full complement of nets were fished (n=227 samples) (F. Ossiander, statistician, NMFS Seattle, WA, pers. comm. to T. Barila, COE, Walla Walla, WA, 10 March 1986). No evidence was found to reject the 1/3 assumption; consequently, only middle nets were used during VD tests at Lower Monumental Dam.

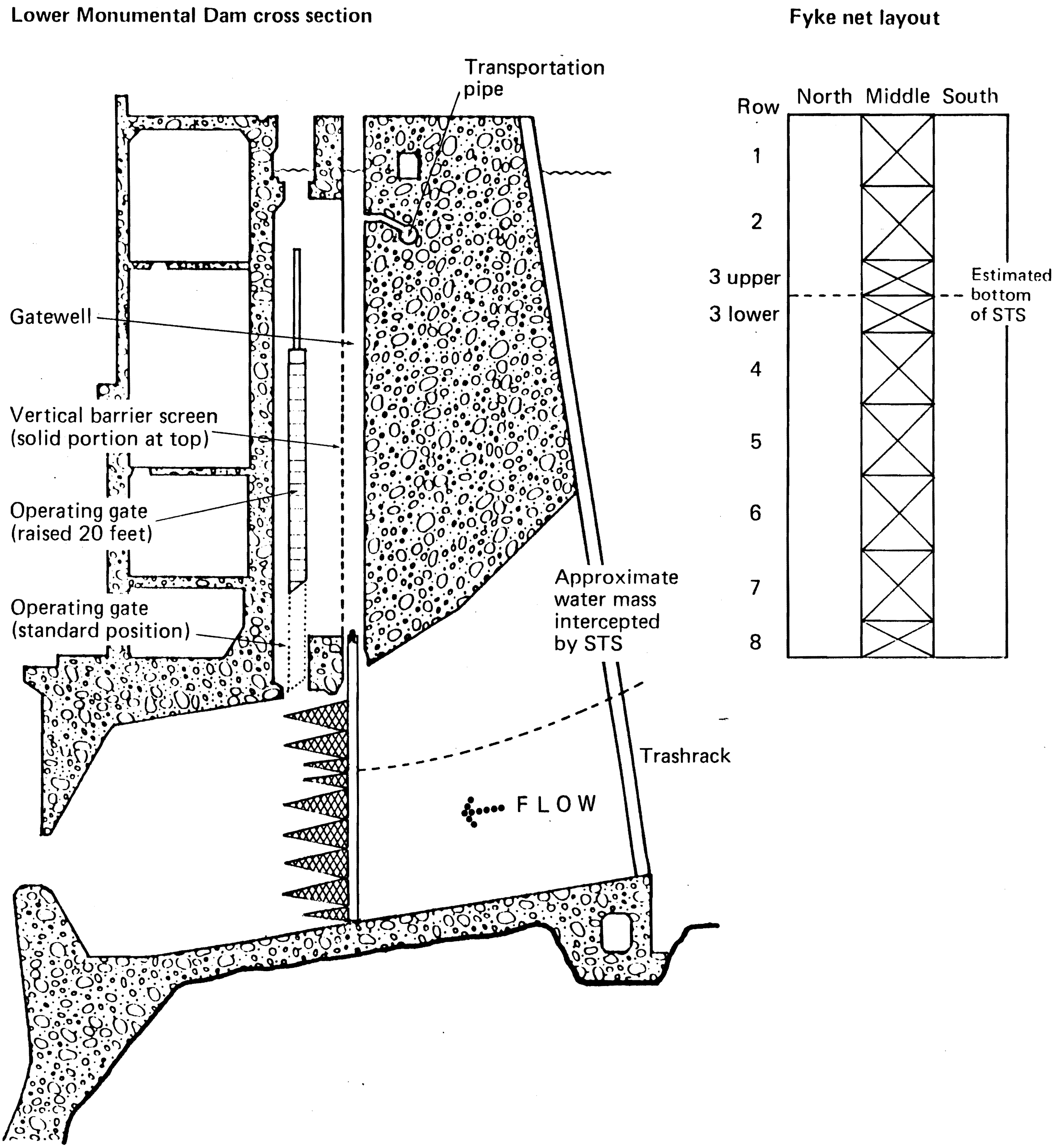

Figure 2.--Cross section of a typical turbine intake at Lower Monumental Dam showing vertical distribution net frame in place and a front view showing layout of fyke nets, 1986.

FGE Tests

Fish guiding efficiency tests were conducted to determine what proportion of the fish entering the intake were being guided into the gatewell slot by the STS and to determine the increase in FGE obtained by raising the operating gate 20 feet. All STSs were modified to extend about 30 inches lower in the intake than standard (Swan et al. 1983) and were extended into the flow at a 54° operating angle (Fig. 1).

A composite of nets was attached to the STS to recover unguided fish that would normally pass through the turbine (Fig. 1). Guided fish were recovered from the gatewell above the STS. The following net configuration was used for most tests: gap nets (two) attached near the top of the STS to capture fish which pass through the space between the top of the STS and the ceiling of the intake, closure nets (two) attached to the back of the STS for capturing unguided fish escaping below the STS above the attached fyke net frame, and fyke nets (five rows) suspended below the STS on the attached net frame. The top three rows of fyke nets contained three nets and each net row extended completely across the intake; the bottom two rows contained only the center net.5/ The fyke nets at Row 1 were about one-half the size of the other fyke nets (2.3 by 7.0 feet vs 6.5 by 7.0 feet) except for the Level 5 net which was 3.2 by 7.0 feet.

For the evaluation of the raised operating gate test condition, Gatewell Slots 4B and 4C each contained an STS with fyke net frame; Slot 4A contained only an STS (Table 1).6/ On alternate days, the operating gate was raised 20

5/ During FGE tests on 10, 11, and 12 June, only middle nets were fished at Levels 1-5.

6/ Gatewell slots, three per turbine unit, are designated A, B, and C in a north to south direction (right to left facing downstream) across the dam--this is opposite from slot designations used at most other dams.

feet above the ceiling of the intake in either Slot 4B or 4C--the other slots had a standard operating gate. This cross-over method (Cochran and Cox 1957) was followed for six consecutive days, providing a balanced design containing three trials in each gatewell slot for each test condition.

FGE was calculated as the number of guided fish divided by the total number of fish passing through the intake during the test period (Swan et al. 1983):

$$\text{FGE (\%)} = \frac{\text{gatewell catch}}{(\text{gatewell catch} + \text{adjusted total net catch})} \times 100$$

where:

adjusted total net catch = total catch by net row adjusted for any missing nets.

Data Analyses

Sample Size Requirements

On 11 April 1986, a meeting was held between NMFS and COE biologists and statisticians to provide guidelines for the numbers of fish required for statistical validation of VD and FGE tests given various net configurations and guidance values. For VD tests using a single vertical row of nets and assuming 10% volitional guidance into the gatewell, the desired sample was 200 actual net-caught fish. If volitional guidance was higher, slightly fewer net-caught fish were needed. For FGE tests with full net coverage down to Level 3 and only center nets at Levels 4 and 5, the desired sample was 200 fish, including gatewell fish. This number assumes FGE>60%; if FGE<60%, side nets could be removed and the desired sample for validation increased to 250 fish.

Number of Required Replicates

For comparing differences between treatment conditions, a minimum of three but preferably five replicates were recommended. A total of six tests were conducted in adjacent gatewells to compare the raised to the standard operating gate condition--three tests for each condition, on alternate days.

Statistical Comparisons

Cross-over analysis of variance using the Latin square method (Cochran and Cox 1957) was used to determine if the raised operating gate significantly increased FGE over the standard gate setting ($P \geq 0.05$, 1-tailed test) (Appendix B). The analysis was a balanced design (equal number of trials for each test condition) evaluating a single test extending over 6 days.

RESULTS

There were no apparent seasonal differences for VD or FGE for yearling or subyearling chinook salmon (Fig. 3) so the data were pooled to discuss depth distributions and seasonal averages.

VD Tests

Vertical distribution tests showed that about 91, 87, and 61% of yearling chinook salmon, steelhead, and subyearling chinook salmon, respectively, were located in the water mass that could potentially be intercepted and diverted into the gatewell by the STS (Appendix A, Table A3). Lowering the minimum accepted sample from 200 to 60 net-caught fish allowed retention of data for steelhead and yearling chinook salmon from the single May test (67 and 60 fish, respectively) and for subyearling chinook salmon on 13 June (104 fish) with little effect on the average TFGE (Table 2). Volitional guidance (no STS) was higher than the expected 10% during April and May (average 18%) and lower during June (5%). Descaling rates of gatewell caught fish were less than 10% for all species (Table 2).

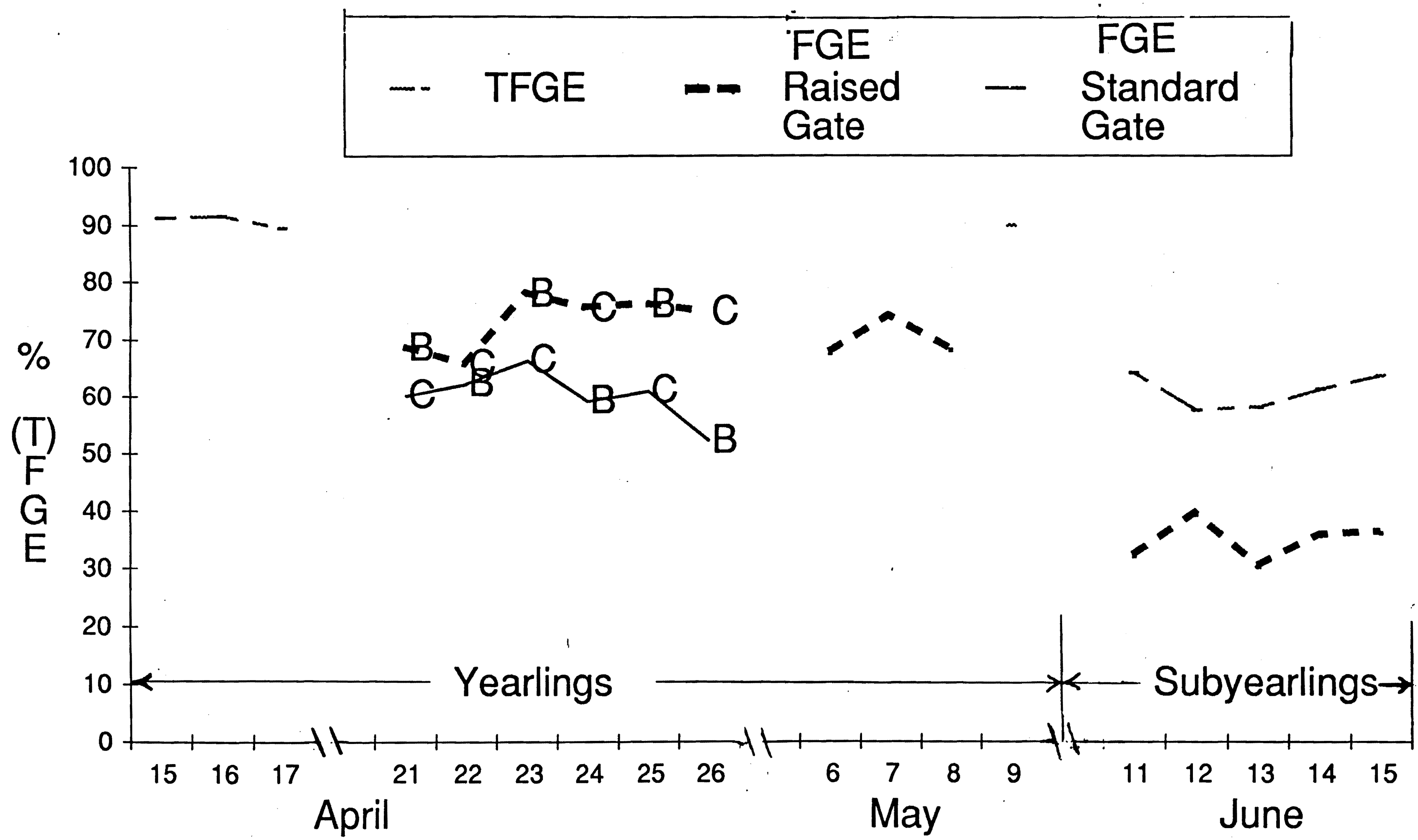

Figure 3.--Theoretical fish guiding efficiency (TFGE) and fish guiding efficiency (FGE) over time for yearling and subyearling chinook salmon at Lower Monumental Dam, 1986. Letters B and C designate the gateslot of Unit 4 where tests were conducted to compare the effects on FGE resulting from raising the operating gate 20 feet above the standard position.

Table 2.--Vertical distribution catch data[a] and descaling rate for juvenile salmonids, Lower Monumental Dam, 1986.

Date	Species	Actual catch		Adjusted total catch	Descaled[b] (%)	TFGE[c] (%)
		Gatewell	Nets			
15 April	Yr. chinook sal.	113	157	584	6.2	91.3
16 April	"	177	291	1050	2.8	91.7
17 April	"	100	150	550	7.0	89.6
9 May	"	33	60	213	9.1	90.1
9 May	Steelhead	50	67	249	4.0	89.6
11 June	Subyr. chinook sal.	54	298	948	0.0	64.2
12 June	"	30	351	1083	0.0	57.6
13 June	"	11	104	323	0.0	58.2
14 June	"	37	166	535	2.7	61.3
15 June	"	70	354	1132	1.4	63.7

a/ Data for species having at least 60 net caught fish.
b/ Gatewell catch only.
c/ TFGE = (Gatewell catch + adjusted net catch through Row 3U/Total adjusted catch) x 100.

FGE Tests

Raising the operating gate significantly ($P \leq 0.05$) increased the FGE for yearling chinook salmon (73.1 versus 60.2%) (Table 3). Numbers of steelhead collected in most tests were insufficient for a comparable analysis. Based on data from three tests where sufficient numbers of steelhead were collected, there appeared to be little benefit from the raised gate (Appendix Table A4).

Except for a single test for steelhead (6 May, 47%), there were no apparent differences in FGE between April and May test periods (raised gate only) so the data were pooled for each species (Appendix Table A5). During April and May, the mean FGEs for yearling chinook salmon and steelhead were a comparable 73.0 and 74.2%, respectively. In contrast, during June, the mean FGE for subyearling chinook salmon was only 35.2%. Descaling rates of guided fish were low: 5.0, 2.1, and 0.3% for yearling chinook salmon, steelhead, and subyearling chinook salmon, respectively, which were not significantly different ($P > 0.05$) than descaling rates of volitionally guided fish examined during VD tests when no STS was used.

There were no apparent differences in length distributions between gatewell and net-caught chinook salmon (mean lengths are presented in Appendix Table A6).

DISCUSSION

Fish guiding efficiencies of the STSs were improved to the interim acceptable level (>70%) (Swan et al. 1986) for yearling chinook salmon by lifting the operating gate 20 feet above the standard position whereas FGEs for steelhead were >70% regardless of gate position. FGE for subyearling chinook was much less than desired, even with the gate raised. The 54°

Table 3.--Effects of operating gate position on fish guiding efficiency (FGE) of yearling chinook salmon at Lower Monumental Dam, 21-26 April 1986.

Test day	FGE (%) Raised 20 ft. (test)	Standard position (control)	Difference (%)
1	68.6	60.2	8.4
2	65.6	62.3	3.3
3	78.0	66.4	11.6
4	75.5	59.2	16.3
5	76.1	61.0	15.1
6	74.8	52.2	22.6
Average	73.1	60.2	12.9[a]

a/ Significant ($P \leq 0.05$) benefit from the raised operating gate, Latin square crossover analysis of variance (Appendix B).

operating angle of the STS did not cause excessive descaling of fish. Should all turbine units at Lower Monumental Dam be fitted with STSs, permanent modification of the operating gates to sit higher in the intake would provide increased protection for chinook salmon.

The cross-over statistical design was used to isolate date and slot effects on FGE from the treatment effect (gate position) and the appropriate error term for yearling chinook salmon. From the relatively small values for square, column, and row mean squares compared to the treatment term (Appendix B, Section I, ANOVA table), it would appear that these factors played a minor role in the overall variation in FGE. The nearly 15% increase in FGE obtained by raising the operating gate was barely significant using a 1-tailed test. The difficulty in demonstrating a significant treatment effect was due to the loss of degrees of freedom (df) inherent with Latin square cross-over designs, i.e., 6 days of testing provided only 2 df for the sample error term. If an error term with greater df could be used, the cross-over design would eliminate variation due to location (slot) and time (day) and still have sufficient df to give high power. Such an error term can be obtained by pooling error terms from similar tests conducted previously at other dams. This assumes that experimental error is the same across the various studies, a seemingly realistic assumption.

Error terms obtained from cross-over studies comparing the effects of operating gate manipulations conducted at Lower Granite, Little Goose, and Lower Monumental Dams were pooled to give an error mean square=23.22 with df=11 (Appendix B, Section III). When the pooled error was used to evaluate the treatment effect at Lower Monumental Dam, the observed difference in FGE was highly significant, even using a 2-tailed test ($F=21.44$, 1 and 11 df) ($P<0.001$).

Depending on species/race, FGEs (with raised operating gate) were 13 to 26% lower than TFGEs (with standard operating gate). Theoretical guidances are generally higher than actual guidances because VD tests are performed with no STS in the gatewell. The STS serves to restrict the flow into the screened portion of the intake which evidently tends to divert some water (and fish) deeper into the intake below the screen thus lowering the numbers of fish reaching the gatewell (Krcma et al. 1986; Swan et al. 1983). The difference between theoretical and actual guidance was smaller for yearling fish than for subyearling fish which suggests that yearling fish were more concentrated in the upper portion of the water column entering the intake and were less affected by the downward diversion of water than the smaller more uniformly distributed subyearling fish.

ACKNOWLEDGMENTS

We extend a special thanks to the COE personnel at Lower Monumental Dam for their assistance and cooperation in conducting these studies. A special thanks to Mr. Jim Hay (COE, Maintenance Supervisor) and the rest of the maintenance crew for the diligent efforts to keep the gantry crane in service. Special thanks also to Mr. Ron Strain and the entire gatewell monitoring crew of the Washington Department of Game for the assistance and cooperation provided while estimating fish movement into the powerhouse during FGE and VD tests. This helped minimize the numbers of fish sacrificed during the study.

LITERATURE CITED

Cochran, W. G., and G. M. Cox.
1957. Experimental designs. John Wiley and Sons, Inc. New York. 611 p.

Dawley, E. M., R. D. Ledgerwood, and A. L. Jensen.
1985. Beach and purse seine sampling of juvenile salmonids in the Columbia River estuary and ocean plume, 1977-1983; Volume I: Procedures, Sampling Effort and Catch Data. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, F/NWC-74:260 p.

Farr, W. E.
1974. Traveling screens for turbine intakes of hydroelectric dams. In L. D. Jensen (ed.). Proc. of the second workshop on entrainment and intake screening. Pp. 199-203. The Johns Hopkins University cooling water research project, Report No. 15.

Krcma R. F., D. A. Brege, and R. D. Ledgerwood
1986. Evaluation of the rehabilitated juvenile salmonid collection and passage system at John Day Dam--1985. Annual Report to U.S. Army Corps of Engineers by National Marine Fisheries Service, 2725 Montlake Boulevard East, Seattle, WA 98112. Contract DACW57-85-H-0001. 30 p.

Raymond, H. L.
1979. Effects of dams and impoundments on migrations of juvenile chinook salmon and steelhead from the Snake River, 1966 to 1975. Trans. Am. Fish. Soc., 108:505-569.

Park, D. L., G. M. Matthews, J. R. Smith, T. E. Ruehle, J. R. Harmon, and S. Achord.
1984. Evaluation of transportation of juvenile salmon and related research on the Columbia and Snake Rivers, 1983. Annual Report to U.S. Army Corps of Engineers by National Marine Fisheries Service, 2725 Montlake Boulevard East, Seattle, WA 98112. Contract DACW68-78-C-0054). 58 p.

Swan, G. A., R. F. Krcma, and W. E. Farr.
1979. Dipbasket for collecting juvenile salmon and trout in gatewells at hydroelectric dams. Prog. Fish Cult. 41(1):48-49.

Swan, G. A., R. F. Krcma, and F. Ossiander.
1983. Studies to improve fish guiding efficiency of traveling screens at Lower Granite Dam. Final Report to U.S. Army Corps of Engineers by National Marine Fisheries Service, 2725 Montlake Boulevard East, Seattle, WA 98112. Contract DACW68-78-C-0051. 20 p. plus Appendixes.

Swan, G. A., R. F. Krcma, and F. Ossiander.
1985. Development of an improved fingerling protection system for Lower Granite Dam--1984. Final Report to U.S. Army Corps of Engineers by National Marine Fisheries Service, 2725 Montlake Boulevard East, Seattle, WA 98112. Contract DACW68-84-H-0034. 33 p.

Swan, G. A., R. F. Krcma, and F. Ossiander.
1986. Continuing studies to improve and evaluate juvenile salmonid collection at Lower Granite Dam--1985. Annual Report to U.S. Army Corps of Engineers by National Marine Fisheries Service, 2725 Montlake Boulevard East, Seattle, WA 98112. Contract DACW68-84-H-0034. 37 p.

APPENDIX A

Catch and catch distribution data and mean fork lengths of juvenile salmonids.

Appendix Table A1.--Catch, descaling, and fish guiding efficiency (FGE) from submersible traveling screen evaluation studies conducted at Lower Monumental Dam, 1986.

Date a/	Time Start	Time End	Slot	Test b/ Condition	Sps. c/	Net catches d/ LG	RG	LC	RC	L1	M1	R1	L2	M2	R2	L3	M3	R3	M4	M5	Adjusted e/ total	Gatewell Catch	Gatewell Descale (%)	FGE f/ (%)
4/21	2028	2243	4B	Raised +	5	0	0	20	14	3	2	5	12	7	10	1	1	5	2	1	89	194	3.1	68.6
4/21	2028	2243	4B	Raised	6	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	3	1	0.0	25.0
4/21	2028	2243	4C	Standard+	5	nlg/	nl	16	20	1	1	3	5	4	11	7	5	6	1	0	82	124	4.0	60.2
4/21	2028	2243	4C	Standard	6	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	3	10	0.0	76.9
4/22	2000	2143	4B	Standard+	5	4	4	21	26	4	13	10	22	10	11	5	3	4	4	0	149	246	4.5	62.3
4/22	2000	2143	4B	Standard	6	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	6	0.0	85.7
4/22	2000	2143	4C	Raised +	5	1	6	13	7	2	3	3	14	13	20	nl	7	7	0	nl	103	196	2.0	65.6
4/22	2000	2143	4C	Raised	6	0	0	0	0	0	0	0	1	1	1	nl	0	1	0	nl	4	6	0.0	60.0
4/23	1828	2110	4B	Raised +	5	6	1	19	15	0	5	6	13	8	10	0	3	0	0	0	86	305	4.3	78.0
4/23	1828	2110	4B	Raised +	6	0	0	5	6	2	5	2	6	3	5	0	0	1	0	0	35	171	7.6	83.0
4/23	1828	2110	4C	Standard+	5	2	0	14	14	4	6	5	11	7	18	1	3	9	1	0	97	192	5.2	66.4
4/23	1828	2110	4C	Standard+	6	0	0	5	7	5	1	3	5	6	12	2	4	4	0	0	54	189	0.0	77.8
4/24	1820	2035	4B	Standard+	5	23	13	66	67	18	30	24	32	40	26	8	5	6	1	0	361	523	10.6	59.2
4/24	1820	2035	4B	Standard+	6	4	0	4	8	2	1	3	3	4	4	3	2	3	0	0	41	165	2.8	80.1
4/24	1820	2035	4C	Raised +	5	0	3	15	20	4	12	9	11	15	30	5	5	nl	0	0	134	412	1.3	75.5
4/24	1820	2035	4C	Raised	6	0	0	1	4	1	0	2	4	5	3	1	3	nl	1	0	29	76	0.0	72.4
4/25	1830	2043	4B	Raised +	5	5	4	15	9	9	2	3	2	10	10	0	2	1	0	0	72	229	5.7	76.1
4/25	1830	2043	4B	Raised	6	0	0	1	3	4	0	0	0	1	0	0	0	0	0	0	9	43	0.0	82.7
4/25	1830	2043	4C	Standard+	5	4	8	12	12	6	1	8	8	7	12	4	0	4	1	0	89	139	8.6	61.0
4/25	1830	2043	4C	Standard	6	0	1	4	1	1	1	1	2	1	4	0	1	0	0	0	17	43	0.0	71.7
4/26	1825	2214	4B	Standard+	5	15	14	50	28	13	13	1	15	24	22	21	18	10	5	0	259	283	3.5	52.2
4/26	1825	2214	4B	Standard	6	0	0	0	2	3	1	0	6	2	1	1	1	0	0	0	17	84	0.0	83.2
4/26	1825	2214	4C	Raised +	5	1	9	19	5	9	5	4	15	13	14	5	5	5	0	0	109	323	8.3	74.8
4/26	1825	2214	4C	Raised	6	0	0	0	2	2	1	1	3	1	5	2	0	1	0	0	18	56	7.1	75.7
5/06	1905	2315	4C	Raised +	5	4	3	12	4	2	1	3	4	2	10	0	0	5	0	1	53	111	4.5	67.7
5/06	1905	2315	4C	Raised +	6	3	4	6	5	2	4	4	3	12	19	4	5	10	0	0	81	72	1.4	47.1
5/07	1956	0010	4C	Raised +	5	14	15	17	16	4	7	8	5	11	11	3	3	3	2	0	123	352	4.5	74.1
5/07	1956	0010	4C	Raised +	6	1	1	8	9	0	6	4	7	4	8	2	0	4	1	0	57	188	1.1	76.7
5/08	1841	2342	4C	Raised +	5	8	3	8	14	6	7	4	9	8	10	0	0	3	0	0	80	172	4.7	68.3
5/08	1841	2342	4C	Raised +	6	3	4	5	8	0	6	3	6	1	8	1	1	1	1	0	50	203	1.5	80.2
5/09	2025	0020	4C	Raised	5	1	0	1	0	0	0	0	0	0	3	1	1	0	0	0	7	28	3.6	80.0
5/09	2025	0020	4C	Raised +	6	0	0	2	4	0	2	1	1	9	5	0	2	4	3	0	39	121	0.0	75.6
6/10	1958	0032	4C	Raised	9	0	0	1	0	-h/	0	-	-	0	-	-	0	-	0	0	1	0	0.0	0.0
6/10	1958	0032	4C	Raised	5	0	1	2	0	-	0	-	-	1	-	-	0	-	nl	nl	6	25	8.0	80.6
6/10	1958	0032	4C	Raised	6	0	0	0	0	-	0	-	-	0	-	-	0	-	nl	nl	0	24	0.0	100.0
6/11	2000	2248	4C	Raised +	9	17	11	28	18	-	18	-	-	61	-	-	46	-	3	0	458	218	0.0	32.2
6/11	2000	2248	4C	Raised	5	0	0	0	2	-	0	-	-	0	-	-	0	-	0	0	2	1	0.0	33.3
6/11	2000	2248	4C	Raised	6	0	0	0	1	-	0	-	-	0	-	-	2	-	0	0	7	26	0.0	78.8
6/12	2000	0021	4C	Raised +	9	6	12	26	17	-	7	-	-	51	-	-	19	-	10	0	322	210	0.0	39.5
6/12	2000	0021	4C	Raised	5	0	0	1	0	-	0	-	-	1	-	-	0	-	0	0	4	1	0.0	20.0
6/12	2000	0021	4C	Raised	6	0	0	0	1	-	2	-	-	0	-	-	0	-	0	0	7	18	0.0	72.0
6/13	2000	0016	4C	Raised +	9	4	3	18	7	3	6	3	19	20	9	5	16	7	5	1	138	60	0.0	30.3
6/13	2000	0016	4C	Raised	5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0.0	0.0
6/13	2000	0016	4C	Raised	6	0	0	0	1	0	0	1	0	0	0	0	0	2	0	0	4	4	0.0	50.0
6/14	2011	0405	4C	Raised +	9	4	5	21	14	9	6	4	38	26	27	nl	14	nl	0	0	196	109	0.9	35.7
6/14	2011	0405	4C	Raised	5	0	0	2	0	0	0	0	0	0	0	nl	0	nl	0	0	2	1	0.0	33.3
6/14	2011	0405	4C	Raised	6	0	0	0	0	0	1	1	0	0	2	nl	1	nl	0	0	5	17	0.0	77.3
6/15	2003	0209	4C	Raised +	9	6	5	45	28	11	7	9	51	49	57	27	29	28	7	0	373	212	0.5	36.2
6/15	2003	0209	4C	Raised	5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	1	0.0	33.3
6/15	2003	0209	4C	Raised	6	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	4	16	0.0	80.0

a/ Month/day.
b/ Raised=Operation gate up 20 feet; Standard= operation gate in normal position; + = 150 or more actual fish in the test.
c/ Species codes; 5= yearling chinook salmon, 6= steelhead, 9= subyearling chinook salmon.
d/ Net codes: 1st character, L=left, M=middle, R=right; 2nd character, G=gap, C=closure, 1-5 = fyke net level (Fig. 1).
e/ Actual net catch adjusted for any missing nets.
f/ FGE =Gatewell catch/(Gatewell catch + Total adjusted net catch) X 100.
g/ Net lost during test, catch estimated.

Appendix Table A2.--Catch, descaling, and theoretical fish guiding efficiency (TFGE) for vertical distribution tests conducted at Lower Monumental Dam, 1986.

Date a/	Time Start	Time End	Slot	Flag b/	Sps. c/	Net catches d/ M1	M2	M3U	M3L	M4	M5	M6	M7	M8	Adjusted total e/	Gatewell Catch	Gatewell Descale (%)	TFGE f/ (%)
4/15	2024	2248	4B	+	5	93	41	6	11	5	0	1	0	0	471	113	6.2	91.3
4/15	2024	2248	4B		6	0	1	0	0	0	0	0	0	0	3	10	0.0	100.0
4/16	1858	2158	4B	+	5	162	81	19	13	11	4	1	0	0	873	177	2.8	91.7
4/16	1858	2158	4B		6	7	2	0	0	0	0	0	0	0	27	10	0.0	100.0
4/17	1830	2250	4B	+	5	86	35	10	11	6	1	0	1	0	450	100	7.0	89.6
4/17	1830	2250	4B		6	8	1	0	0	0	0	0	0	0	27	16	6.3	100.0
5/09	2025	0020	4A	+	5	32	16	5	1	2	4	0	0	0	180	33	9.1	90.1
5/09	2025	0020	4A	+	6	45	8	3	3	6	1	0	1	0	201	50	4.0	86.9
6/10	1958	0032	4A		5	5	1	0	0	1	0	0	0	0	21	10	10.0	90.3
6/10	1958	0032	4A		6	4	5	0	0	1	0	0	0	0	30	14	7.1	93.2
6/10	1958	0032	4A		9	2	0	0	0	0	0	0	1	0	9	3	0.0	75.0
6/11	2000	2248	4A		5	0	2	0	0	0	0	0	0	0	6	0	0.0	100.0
6/11	2000	2248	4A		6	0	1	0	0	0	1	0	0	0	6	10	0.0	81.3
6/11	2000	2248	4A	+	9	94	63	28	21	48	34	9	0	1	894	54	0.0	64.2
6/12	2000	0021	4A		5	2	0	0	0	0	0	0	0	0	6	0	0.0	100.0
6/12	2000	0021	4A		6	2	2	1	0	0	0	0	0	0	15	8	0.0	100.0
6/12	2000	0021	4A	+	9	94	78	26	38	56	41	11	7	0	1053	30	0.0	57.6
6/13	2000	0016	4A		6	2	0	0	1	0	0	0	0	0	9	2	0.0	72.7
6/13	2000	0016	4A	+	9	31	20	8	9	15	17	3	0	1	312	11	0.0	58.2
6/14	2011	0405	4A		5	3	0	1	0	0	0	0	0	0	12	3	0.0	100.0
6/14	2011	0405	4A		6	4	3	0	0	0	0	0	0	0	21	12	0.0	100.0
6/14	2011	0405	4A	+	9	44	39	14	21	31	13	3	1	0	498	37	2.7	61.3
6/15	2003	0209	4A		5	1	0	0	0	0	0	0	0	0	3	1	0.0	100.0
6/15	2003	0209	4A		6	4	4	0	0	0	0	0	0	0	24	7	0.0	100.0
6/15	2003	0209	4A	+	9	114	76	27	25	64	31	17	0	0	1062	70	1.4	63.7

a/ Month/day.
b/ Records with a + indicate an actual net catch greater than 60.
c/ Species codes: 5=yearling chinook salmon, 6=steelhead, 9=subyearling chinook salmon.
d/ Only middle nets used; net codes: 1st character, M=middle; 2nd character=net level (Fig. 2); 3rd character U=upper L=lower net.
e/ Actual net catch adjusted for any missing nets.
f/ TFGE=(Adjusted net catch through level 3U + Gatewell catch)/(Total adjusted net catch + Gatewell catch) X 100

Appendix Table A3.--Vertical distribution and theoretical fish guiding efficiency (TFGE) of juvenile salmonids at Lower Monumental Dam in 1986.

	YEARLING CHINOOK SALMON a/			STEELHEAD b/			SUBYEARLING CHINOOK SALMON c/		
Vertical position	Actual catch d/	Adjusted catch e/	Accumulative percent	Actual catch	Adjusted catch	Accumulative percent	Actual catch	Adjusted catch	Accumulative percent
Gatewell	423 f/	423	17.6	50 g/	50	19.9	202 e/	202	5.0
Net row 1	373	1119	64.3	45	135	73.7	377	1131	33.2
" " 2	173	519	86.0	8	24	83.3	276	828	53.7
" " 3U	40	120	91.0=TFGE	3	9	86.9=TFGE	103	309	61.4=TFGE
" " 3L	36	108	95.5	3	9	90.4	114	342	69.9
" " 4	24	72	98.5	6	18	97.6	214	642	85.9
" " 5	9	27	99.6	1	3	98.8	136	408	96.0
" " 6	2	6	99.9	0	0	98.8	43	129	99.3
" " 7	1	3	100.0	1	3	100.0	8	24	99.9
" " 8	0	0	100.0	0	0	100.0	2	6	100.0
Totals	1081	2397		117	251		1477	4021	

a/ Accumulated catch from 15-17 April and 9 May.
b/ Catch from 9 May.
c/ Accumulated catch from 11-15 June.
d/ Middle nets only (side nets removed).
e/ Middle net catch X 3 for misssing side nets.
f/ Descaled (%) = 6.3
g/ Descaled (%) = 4.0
h/ Descaled (%) = 0.8

Appendix Table A4.--Catch distribution and fish guiding efficiency (FGE) of yearling chinook salmon and steelhead comparing[a] effects of operating gate position on FGE at Lower Monumental Dam, 1986.

YEARLING CHINOOK SALMON

	20 ft. Raised Gate (test)				Standard gate (control)			
	Actual catch			Adjusted	Actual catch			Adjusted
Net	Left	Middle	Right	Catch	Left	Middle	Right	Catch
Gap	13	b/	23	36	48	b/	39	87
Closure	101	b/	70	171	179	b/	167	346
Fyke row 1	27	29	30	86	46	64	51	161
Fyke row 2	67	66	94	227	93	92	100	285
Fyke row 3	18	23	23	64	46	34	39	119
Fyke row 4	c/	2	c/	6	c/	13	c/	39
Fyke row 5	c/	1	c/	3	c/	0	c/	0

Catch Totals

Gatewell: 1659	Nets:	Gatewell: 1507	Nets:
Descaled (%): 4.1	Actual: 587	Descaled (%): 6.1	Actual: 1011
FGE (%): 73.7	Adjusted: 593	FGE (%): 59.2	Adjusted: 1037

STEELHEAD

	20 ft. Raised Gate (test)				Standard gate (control)			
	Actual catch			Adjusted	Actual catch			Adjusted
Net	Left	Middle	Right	Catch	Left	Middle	Right	Catch
Gap	0	b/	0	0	4	b/	0	4
Closure	5	b/	6	11	9	b/	15	24
Fyke row 1	2	5	2	9	7	2	6	15
Fyke row 2	6	3	5	14	8	10	16	34
Fyke row 3	0	0	1	1	5	6	7	18
Fyke row 4	c/	0	c/	0	c/	0	c/	0
Fyke row 5	c/	0	c/	0	c/	0	c/	0

Catch totals

Gatewell: 171	Nets:	Gatewell: 354	Nets:
Descaled(%): 7.6	Actual: 35	Descaled (%): 1.4	Actual: 95
FGE (%): 83.0	Adjusted: 35	FGE (%): 78.8	Adjusted: 95

a/ Only data for tests having a daily minimum of 150 fish were used.
b/ Gap and closure nets (two each) extended half way across the row.
c/ Only middle nets were used at rows 4 and 5.

Appendix Table A5.--Fish guiding efficiency (FGE) and catch distribution for juvenile salmonids with operating gate raised 20 feet, Lower Monumental Dam 1986.

Net	YEARLING CHINOOK SALMON a/				STEELHEAD b/				SUBYEARLING CHINOOK SALMON c/			
	Actual catch			Adjusted	Actual catch			Adjusted	Actual catch d/			Adjusted
	Left	Middle	Right	Catch	Left	Middle	Right	Catch	Left	Middle	Right	Catch
Gap	39	e/	44	83	7	e/	9	16	37	e/	36	73
Closure	138	e/	104	242	26	e/	32	58	138	e/	84	222
Fyke row 1	39	44	45	128	4	23	14	41	48	44	41	133
Fyke row 2	85	87	125	297	23	29	45	97	220	207	205	632
Fyke row 3	21	26	34	81	7	8	20	35	111	124	114	349
Fyke row 4	f/	4	f/	12	f/	5	f/	15	f/	25	f/	75
Fyke row 5	f/	2	f/	6	f/	0	f/	0	f/	1	f/	3

Catch totals

Yearling chinook salmon		Steelhead		Subyearling chinook salmon	
Gatewell: 2294	Nets:	Gatewell: 775	Nets:	Gatewell: 809	Nets:
Descaled (%): 5.0	Actual: 837	Descaled (%): 2.0	Actual: 252	Descaled (%): 0.3	Actual: 1435
FGE (%): 73.0	Adjusted: 849	FGE (%): 74.2	Adjusted: 262	FGE (%): 35.2	Adjusted: 1487

a/ Accumulated catch data from nine tests conducted 21 April-8 May.
b/ Accumulated catch data from five tests conducted 23 April-9 May.
c/ Accumulated catch data from five tests conducted 11-15 June.
d/ On 10,11, and 12 June only middle nets were used at row's 1-3 and the data shown for left and right actual catch has been adjusted for missing nets.
e/ Gap and Closure nets (two each) extended half way across the net row.
f/ Only middle nets were used at row's 4 and 5.

Appendix Table A6.--Mean fork lengths (mm) of chinook salmon [a/] during vertical distribution (VD) and fish guiding efficiency (FGE) tests at Lower Monumental Dam, 1986.

			Mean lengths (mm)	
Date	Test	Gatewell	Gatewell	Nets
15 April	VD	4B	147.6	149.4
16 April	VD	4B	145.5	136.8
17 April	VD	4B	141.4	136.2
21 April	FGE	4B	143.4	143.7
21 April	FGE	4C	149.1	140.3
22 April	FGE	4B	151.9	148.9
22 April	FGE	4C	-----	154.3
23 April	FGE	4B	-----	-----
23 April	FGE	4C	150.2	149.8
24 April	FGE	4B	145.1	144.4
24 April	FGE	4C	150.9	153.3
25 April	FGE	4B	138.9	137.4
25 April	FGE	4C	142.8	140.6
26 April	FGE	4B	142.9	142.4
26 April	FGE	4C	141.2	140.9
6 May	STS[b/]	4A	133.5	-----
6 May	FGE	4B	134.2	-----
6 May	FGE	4C	132.7	-----
7 May	STS	4A	135.8	-----
7 May	FGE	4B	134.5	-----
7 May	FGE	4C	133.3	131.3
8 May	STS	4A	133.8	-----
8 May	FGE	4B	135.7	-----
8 May	FGE	4C	131.5	-----
9 May	FGE	4C	131.5	-----
10 June	VD	4A	60.0	58.8
11 June	VD	4A	85.2	84.3
11 June	FGE	4C	87.7	84.5
12 June	VD	4A	84.8	----
12 June	FGE	4C	86.6	85.6
13 June	VD	4A	85.5	----
13 June	FGE	4C	87.4	84.0
14 June	VD	4A	86.2	84.0
14 June	FGE	4C	89.0	79.7
15 June	VD	4A	----	88.6
15 June	FGE	4C	89.2	86.1

a/ Yearling chinook salmon 15 April through 9 May, subyearling chinook salmon 10 through 15 June.

b/ STS=Submersible traveling screen only--no fyke net frame attached.

APPENDIX B

Analysis of variance based upon the Latin square cross-over design (Cochran and Cox 1957). An example using a pooled error term to provide a better test of the treatment effect. Fish guiding efficiency (FGE) data from the operating gate evaluation study conducted at Lower Monumental Dam from 21 to 26 April 1986 were used in the example.

I. Latin square crossover analysis of variance.

Data set-up, FGE% for yearling chinook salmon.

Gate slot	Test I[a] C1[b]	C2	row subto.	Test II C3	C4	row subto.	Test III C5	C6	row subto.	Row Totals
B	68.6+	62.3-	r1	78.0+	59.2-	r3	76.1+	52.2-	r5	396.4
C	60.2-	65.6+	r2	66.4-	75.5+	r4	61.0-	74.8+	r6	403.5
Test totals	256.7(T1)			279.1(T2)			264.1(T3)			799.9(GT)

Treatment totals:

Treatment 1 = raised gate FGE (+'s)

= 68.6+65.6+78.0+75.5+76.1+74.8= 438.6

Treatment 2 = standard gate FGE (-'s)

= 60.2+62.3+66.4+59.2+61.0+52.2= 361.3

[a] A test is defined as a set of paired days where both rows (slots) have a balanced set of treatment conditions.

[b] Individual columns represent different sampling dates.

ANOVA calculations

A. Sums of squares for squares (tests) (SSS) = $SST/a - GT^2/N$

where:

a = number of observations per test, i.e., 4

N = number of observations in total test series, i.e., 12

SST = sum of squares for individual square totals

$= T1^2+T2^2+T3^2 = 256.7^2+279.1^2+264.1^2$

$= 213540.5$

GT = Grand total all observations = 799.9

therefore:

$SSS = (213540.5/4) - (799.9^2)/12 = 53385.1 - 53320$

$= 65.1$

B. Column sum of squares (CSS) = $(C1^2+C2^2+C3^2+\ldots Cn^2)/b - (SST/a)$

where:

b = number of rows (slots), i.e., 2

therefore:

$CSS = [(68.6+60.2)^2+(62.3+65.6)^2+(78.0+66.4)]^2+\ldots(52.2+74.8)^2/2 - 53385.1$

$= 49.2$

C. Row sum of squares (RSS) = $(r1^2+r2^2+r3^2+\ldots r6^2)/c - (SST/a)$

where:

c = number of observations totaled per row per square, i.e., 2

therefore:

$RSS = ((68.6+62.3)^2+(60.2+65.6)^2+(78.0+59.2)^2+ -$

$\ldots(61.0+74.8)^2/2) - 53385.1$

$= 26.1$

D. Treatment sum of squares (TSS) = $(\text{sum treatment 1} - \text{sum treatment 2})^2/N$

$= (438.6-361.3)^2/12$

$= 497.9$

E. Total sum of squares (TOSS) = $((68.6)^2+(60.2)^2+(62.3)^2+\ldots(74.8)^2) - GT^2/N$

$= 54044.6 - 53320.0$

$= 724.6$

F. Error sum of squares (ESS) (by subtraction)

= TOSS - (SSS+CSS+RSS+TSS)

= 86.2

Degrees of freedom (df)

Source/symbol	Formula	df
Squares (tests), SSS	No. of tests - 1	2
Columns within squares, CSS	No. of dates - No. of tests	3
Rows within squares, RSS	No. of squares	3
Treatments, TSS	Total treatments - 1	1
Error, ESS	No. of squares - 1	2
Total, TOSS	Total samples - 1	11

ANOVA table

Source	df	Sum of squares	Mean squares	F calculated
Squares (tests), SSS	2	65.1	32.6	0.76ns[c/]
Columns within squares, CSS	3	49.2	13.41	0.38ns
Rows within squares, RSS	3	26.1	8.7	0.20ns
Treatments, TSS	1	497.9	497.9-	11.55**[d/]
Error, ESS	2	86.2	43.1	18.5 (2 tailed) 0.05
Total	11	724.6		8.53 (2 tailed) 0.10

c/ ns = non-significant (P>0.05) variance contribution.

d/ ** = significant (P≤0.05) variance contribution, 1-tailed test.

II. A shortcut method may be used to analyze cross-over studies involving two treatments (Dr. Lyle Calvin, COE consulting statistician, pers. comm.). Based on Student's t-test, this method of analysis is equivalent to the longer F-test method of treatment evaluation. The shortcut method also serves as a mathematical check for the F-test method--the t-calculated value squared equals the treatment F-calculated value.

Data set-up, FGE% for yearling chinook salmon.

	Slot 4B		Slot 4C	
Gate position	+ 20 ft.	Standard	+ 20 ft.	Standard
Symbol[e/]	Y1B	Y2B	Y1C	Y2C
21-22 April	68.6	62.3	65.6	60.2
23-24 April	78.0	59.2	75.5	66.4
25-26 April	76.1	52.2	74.8	61.0

e/ The treatment effect for each pair of days (test) can be measured by the statistic, T = 1/2(Y1B+Y1C-Y2B-Y2C).

where:

Y1B = FGE for treatment 1 in unit 4B

Y2B = FGE for treatment 2 in unit 4B

Y1C = FGE for treatment 1 in unit 4C

Y2C = FGE for treatment 2 in unit 4C

therefore:

Test 1, T = 1/2(68.6+65.6-62.3-60.2) = 5.85

Test 2, T = 1/2(78.0+75.5-59.2-66.4) = 13.95

Test 3, T = 1/2(76.1+74.8-52.2-61.0) = 18.85

The mean value of the T's, $\bar{T} = \Sigma T/n = 12.88$ is the estimated treatment effect (the mean difference between FGE for treatment 1 and treatment 2). A statistical test of the hypothesis of no treatment effect is given by the *t* test: $t = \bar{T}/\sqrt{s^2/n}$, where s^2 = variance among the the *n* T values (in the example above, $s^2 = 43.103$, n = 3 and $t = 12.88/\sqrt{43.103/3} = 3.398$). There are n-1 (2) degrees of freedom for this test. The t value squared (3.398^2)= 11.55, which agrees with the treatment effect F-calculated value above.

III Pooling error terms.

The hypothesis tested above had a 1-tailed alternative, i.e., H_a: raised operating gate significantly increases guidance. The 1-tailed alternative hypothesis is justified from hydraulic model studies and from the expected direction of the change based on previous studies of the effect of the raised gate on FGE. Obtaining only 2 df from 6 days of testing seems somewhat conservative and makes it difficult to demonstrate a significant treatment effect. By pooling error terms from several tests to obtain an estimate of the error term with more df, a better test can be made of the treatment effect.

An example of pooling using error terms from studies of the effects of operating gate position on FGE (cross-over designs) at Lower Granite[f/] (1985), Little Goose[g/] (1986) and Lower Monumental (1986) Dams is provided below:

Dam	Sample error term: df	Sample error term: Sum of squares	Sample error term: Mean squares	Treatment[h/] F-calculated: original	Treatment[h/] F-calculated: pooled	Operating gate test conditions
Granite	1	8.000	8.000	0.18ns	0.06ns	+20 ft. vs +62 ft.
Granite	1	6.613	6.613	0.10ns	0.03ns	+20 ft. vs +62 ft.
Granite	1	31.205	31.205	1.48ns	1.98ns	+62 ft. vs standard
Granite	1	6.845	6.845	29.22ns	8.64**	+62 ft. vs standard
Monumental	2	86.200	43.103	11.55ns	21.44***	+20 ft. vs standard
Goose	5	116.590	23.318	44.26***	44.55***	+20 ft. vs standard
Overall	11	255.453	23.223			

Pooled error = (total sum of squares)/df = 255.453/11 = 23.223, which has 11 df.

f/ Swan et al. 1986, Appendix Table B1.

g/ W. Norman, NMFS, Pasco, WA, pers. comm.

h/ Significance levels testing a 2-tailed hypothesis of no difference: ns = not significant ($P>0.05$), ** = $P\leq0.05$, *** = $P\leq0.001$

Pooling is generally justified if there is less than a 10 fold difference in the range of the sample error mean squares (Dr. Lyle Calvin, COE consulting statistician, pers. comm.). In the above example there was a 6.5 fold difference in the sample mean squares--within the guideline.

Consequently, if we reevaluate the Lower Monumental data using the pooled error term, i.e., treatment mean square/pooled error = 497.94/23.223 = 21.44 (column F-pooled above). When this F value is compared to the tabular value using 1 and 11 df, the observed increase in FGE obtained by raising the operating gate is highly significant, even with a 2-tailed test ($P<0.001$).