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COASTAL ZONE AND ESTUARINE STUDIES

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INTRODUCTION

Lower Granite Navigation Lock and Dam, built and operated by the U.S. Army Corps of Engineers (COE), is the first dam encountered by most juvenile salmon and steelhead (Oncorhynchus spp.) migrating downstream in the Snake River Basin (Fig. 1). It contains submersible traveling screens (STS) (Farr 1974) that guide juvenile salmonids from the turbine intakes into gatewells to decrease the direct and indirect mortalities measured as high as 33% at other dams for juvenile salmonids passing through turbines (Raymond 1979) (Fig. 2). The guided fish pass from the gatewells to collection facilities, where the majority are subsequently loaded into barges or trucks for transport to a release site in the Columbia River downstream from Bonneville Dam (Park et al. 1984).

The turbine intakes at Lower Granite Dam are unique. They have special fish screen slots (FSS) located upstream from the bulkhead slots (Fig. 2). Submersible traveling screens were initially operated in the FSS, but research by the National Marine Fisheries Service (NMFS) found that STSs operated in the FSS had low fish guidance efficiency (FGE) and created unacceptable descaling rates for fish. Therefore, the STSs were moved to the bulkhead slot (Park et al. 1978).

In 1983, FGE research indicated that an STS in the bulkhead slot in conjunction with a raised operating gate (a condition which increases water flow into the gatewell) successfully guided over 70% of the juvenile salmonids (Swan et al. 1984). Subsequent replication of the 1983 FGE test conditions during the early part of the 1984 and 1985 yearling chinook salmon migrations resulted in guidance levels consistently <40%. However, guidance levels increased as the migration progressed (Swan et al. 1985, 1986). This suggested that a biological rather than a mechanical factor might be affecting FGE of yearling chinook salmon.

In an effort to improve guidance levels above those attainable with a standard STS, research efforts were begun in 1987 to test the concept of an extended STS. This

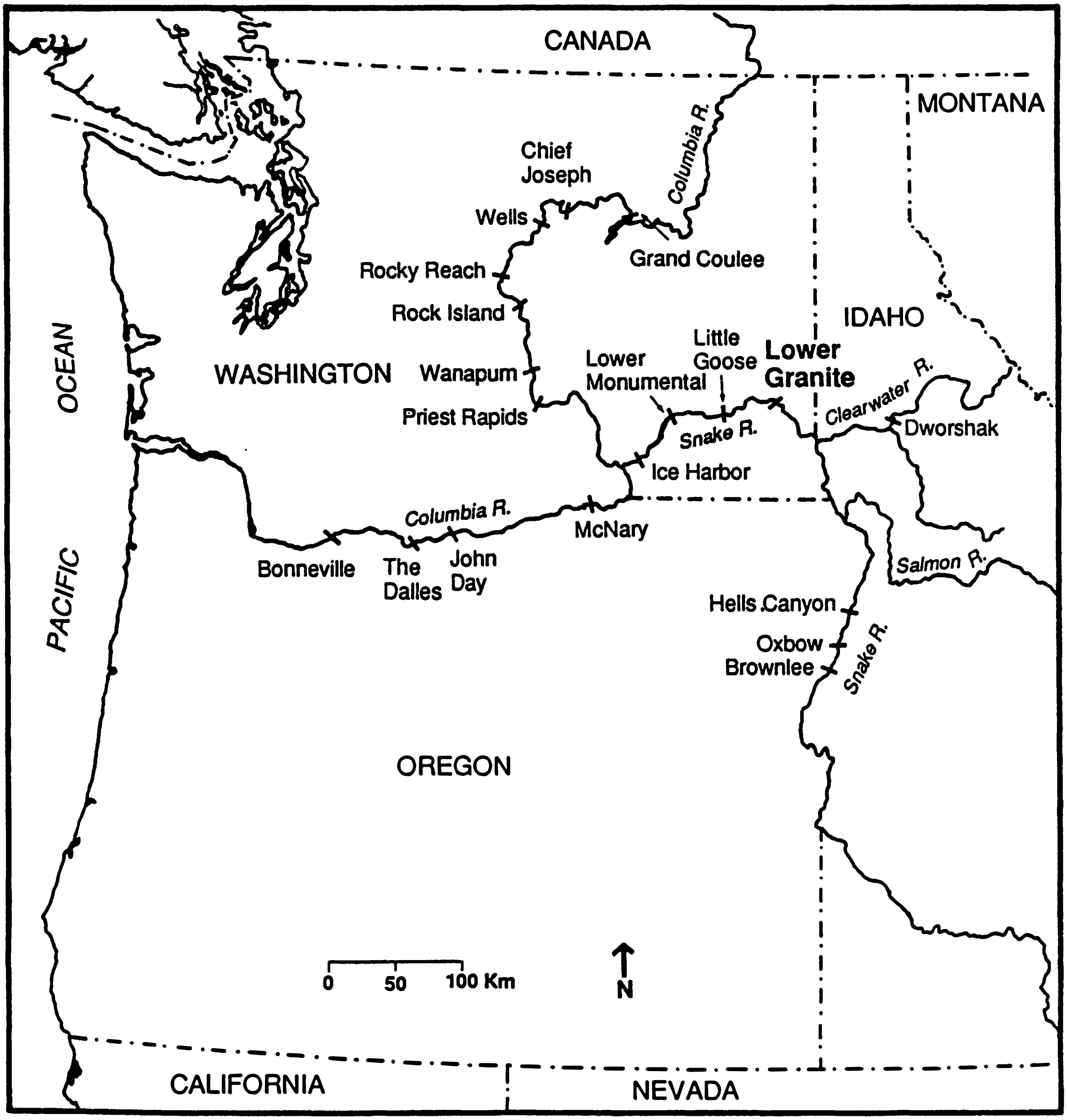

Figure 1.--Location of Lower Granite Dam relative to other hydroelectric projects of the Snake and Columbia Rivers.

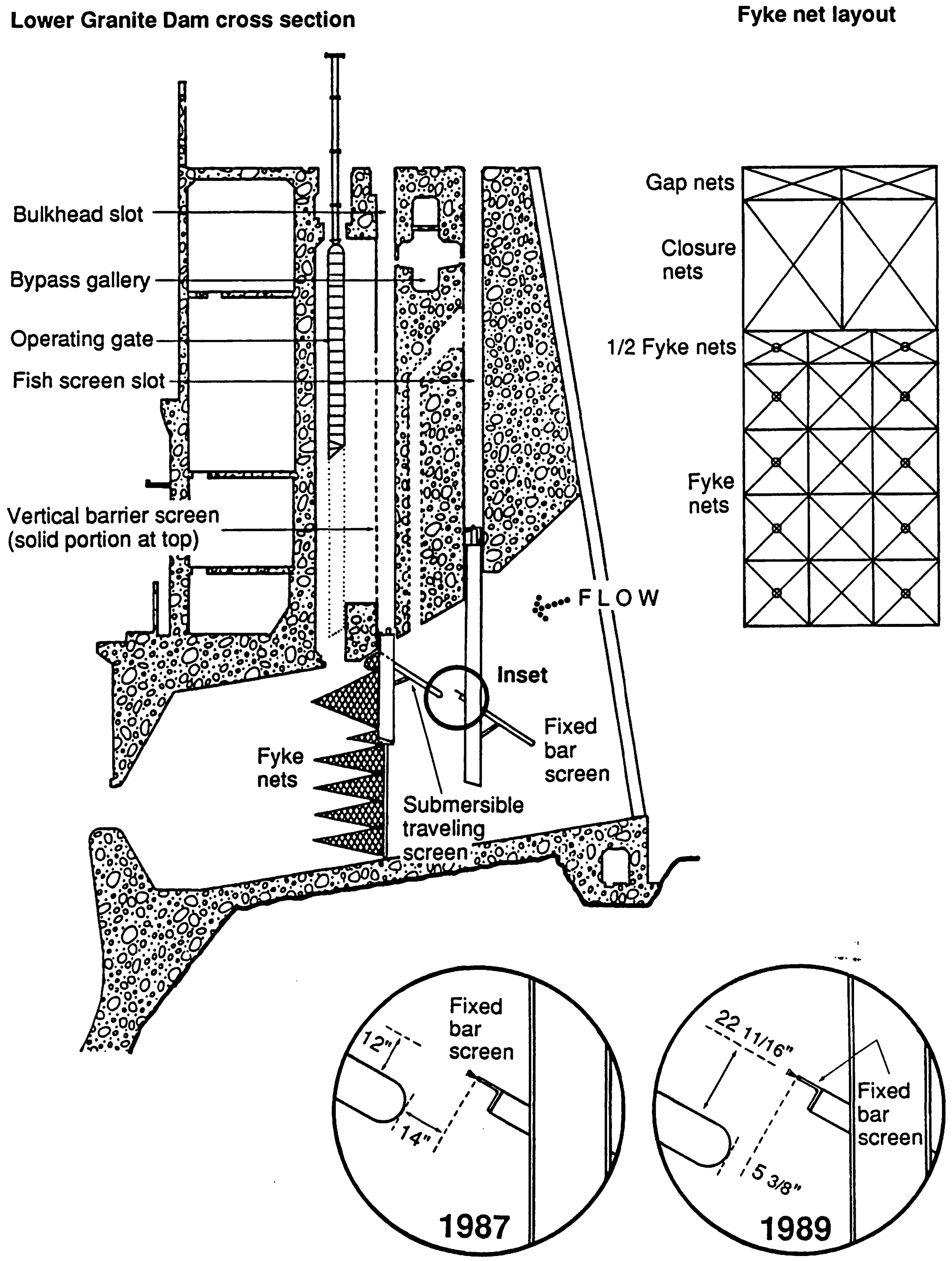

Figure 2.--Cross-section of a turbine intake at Lower Granite Dam showing a submersible traveling screen in the bulkhead slot with experimental fyke nets attached, the experimental fixed bar screen in the fish screen slot, and the alignment of both during fish guidance tests in 1987 and 1989. (Nets with the image O indicate nets fished without cod end bags.)

was done by placing a non-traveling fixed bar screen (FBS) (formerly referred to as a bar screen deflector or BSD) in the FSS. The FBS provided an additional guidance surface, which in conjunction with the STS in the bulkhead slot, was designed to simulate a one piece extended guidance device (Fig. 2). The STS/FBS combination when tested with a 62-foot raised gate increased FGEs approximately 15% compared to the condition without the FBS; however, significantly fewer fish entered the gateslot on nights when the FBS was tested (Ledgerwood et al. 1988). This raised concern that fish rejecting the turbine intake slot with the FBS affected the observed differences between treatments and controls (if the displaced fish were located higher in the water column, FGE for the FBS slot would have dropped while FGE in neighboring slots may have increased).

In 1989, NMFS in conjunction with the COE conducted further research at Lower Granite Dam with the primary objective to determine if a full complement of FBSs in one turbine unit would cause lateral diversion of fish to adjacent units. Secondary objectives were to verify improved FGE for yearling chinook salmon with an STS and a FBS simulating an extended STS, measure FGE and fish condition for yearling chinook salmon throughout their migration period, and periodically measure the vertical distribution of yearling chinook salmon during their migration.

We also provided samples of guided and non-guided yearling chinook salmon to other researchers for disease and smoltification studies and monitored PIT-tagged fish entering the test units. Hydroacoustic monitoring of fish movement into the turbine units was conducted simultaneously by a separate contractor. Results from these studies will be reported elsewhere.

METHODS AND MATERIALS

The FGE tests were scheduled to start as near the beginning of the yearling chinook salmon outmigration as possible to complete the testing prior to the influx of juvenile steelhead. Testing began 10 April following installation and inspection of research equipment by commercial divers (Table 1).

The FGE tests and vertical distribution measurements were conducted in Slot 4B which contained a balanced flow vertical barrier screen. Operating gates were fully raised in all test gateslots. The vertical barrier screen was previously used for orifice passage efficiency research (Swan et al. 1985) and was not considered to have an effect on the guidance tests. On treatment days, FBSs were placed in all three Unit 4 FSSs (Fig. 2). On control days, the FBSs were raised to the intake deck level and temporarily stored. Closure devices were installed in the Unit 4 FSSs in an attempt to block entry by fingerlings into the FSSs. All STSs operated in Unit 4 were identical to others at Lower Granite Dam but were equipped with attachments for mounting various net frames.[1]

Test procedures were similar to those reported by Ledgerwood et al. (1988). Tests began shortly before dusk (about 1930 h) and required about 1 to 1.5 hours of turbine operation to collect sufficient numbers of fish for a test (a total of 200 to 250 yearling chinook salmon entering the test slot and nets below the STS). Fish movement into the turbine unit, which increased rapidly just after dark, was monitored by periodically removing fish from the gatewell with a dipbasket (Swan et al. 1979). It was assumed the early turbine start would allow normal flow patterns to develop and stabilize in the forebay before large numbers of fish entered the unit. The test STS with fyke net

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[1] For future test reference, STSs operated in Unit 4 during 1989 FGE testing were No. 15 in Gateslot 4A, No. 13 in Gateslot 4B, and No. 5 in Gateslot 4C.

Table 1.--Schedule for fish guidance efficiency and vertical distribution testing at Lower Granite Dam, 1989.

Test day	Test date	Condition	Fixed bar screen condition
1	10 Apr	Vertical distribution[a]	Up
2	11 Apr	Control[b]	Up
3	12 Apr	Treatment[c]	Down
4	13 Apr	Treatment	Down
5	14 Apr	Control	Up
6	15 Apr	Vertical distribution	Up
7	16 Apr	Control	Up
8	17 Apr	Treatment	Down
9	18 Apr	Control	Up
10	19 Apr	Treatment	Down
11	20 Apr	Control	Up
12	21 Apr	Treatment	Down
13	22 Apr	Vertical distribution	Up
14	23 Apr	Control	Up
15	24 Apr	Treatment	Down
16	25 Apr	Control	Up
17	26 Apr	Treatment	Down
18	27 Apr	Control	Up
19	28 Apr	Treatment	Down
20	29 Apr	Treatment	Down
21	30 Apr	Control	Up
22	01 May	Vertical distribution	Up

[a] No submersible traveling screen (STS).
[b] STS and gate raise.
[c] STS, gate raise, and fixed bar screen.

frame and attached nets was removed after a test and stored at intake deck level in another gateslot. A spare STS was installed in Slot 4B, and Unit 4 was operated between tests to allow hydroacoustic data gathering.

Fork length frequencies were determined from the sample of fish taken for smoltification studies. The effects of the STS and FBS on the condition of fish recovered from the gatewells were evaluated, as in previous years, by use of the standard descaling index used on the Columbia and Snake Rivers (Koski et al. 1989).

Lateral Diversion of Fish by the FBS

Initially, Slots 4A and 4C were dipped to monitor numbers of fish entering during the FGE test period. After three replicates, all gatewell dipping was discontinued in Slots 4A and 4C and instead Slot 3C was dipped for comparison of fish numbers to Slot 4B to determine if fish had diverted laterally from the test unit to an adjacent unit.

Fish Guidance Efficiency Tests

The methods for determining FGE were similar to those used in previous years (Swan et al. 1983, 1984, 1985; Ledgerwood et al. 1988). To minimize mortality of fish in fyke nets, cod-end bags were attached only to the center column of fyke nets. The FGE calculations used estimates of non-guided fish derived from a one-third sample of fish caught in a single vertical column (the center column) of fyke nets below the STS (Fig. 2).

The FGE was calculated as the number of guided fish divided by the total number of fish estimated to have passed through the intake slot during the test period:

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

where: adjusted total net catch = actual net catch adjusted for non-collecting side nets (net catch in center column X 3).

Fixed Bar Screen

Prior to the start of testing on 10 April, the new FBSs and control STSs were lowered to fishing positions and commercial divers determined the angle of alignment and the spacing between them. The new FBSs were placed in Slots 4A and 4B and the FBS from 1987 in Slot 4C (Appendix B provides design details). The inspection confirmed that all three FBSs were aligned as designed by the COE. There was a 5 and 3/8-in gap (as opposed to a 14-in gap in 1987) between the FBS and the STS (Fig. 2). When fully extended, the downstream end of each FBS was about 22 and 11/16 in higher in elevation than the upstream end of the STS. In 1987, the latter dimension was 12 in. Due to space allotted for mounting a cleaning device, about 2 ft of the downstream end of the bar screen surface of the newer FBSs lacked perforated plate, whereas the original FBS was covered with perforated plate behind the entire bar screen.

All manipulations and cleaning of the FBSs were accomplished during daylight hours by a private contractor to the COE. The top margin of the FBS frames were equipped with stationary brushes designed to prevent fish from entering the FSS (Swan et al. 1986; Ledgerwood et al. 1988). A closure device designed for the same purpose was placed by the contractor in the FSS during control tests. The brushes and the closure device were not expected to be totally effective; therefore, when the FBSs and closure devices were raised to the intake deck, counts were made of live and impinged fish. These fish were not used in FGE calculations because it was unknown when they entered the turbine intake.

Vertical Distribution Measurements

Vertical distribution measurements were made about every six test days (Table 1). To avoid influencing flows and related fish movement, all STSs in turbine Unit 4 were removed and a vertical distribution net frame was placed into Slot 4B (Fig. 3). The distribution of recovered fish was used to determine theoretical FGE (TFGE), the proportion of fish that potentially could be guided into the gatewell by an STS. Most nets were 2.0 m high and 2.1 m wide, except at Level 3. The third fyke net was divided into upper and lower halves (3U and 3L). To minimize mortality of fish in nets, only a center vertical row of nets was used. Each net was designed to sample 1/3 of the intake flow at a given depth between the ceiling and floor of the intake. The numbers of fish collected in the center nets at each level were multiplied by three to estimate the total fish passing at various depths in the intake. The cumulative percentage of fish captured from the gatewell plus the estimated percentage down through Level 2 provided the estimate of TFGE. We originally designed the net layout to use fish down through Level 3U at approximately elevation 624, which was just below the bottom elevation of the STS (elevation 624.4). Subsequent hydraulic modeling indicated that the correct flow intercept at the net was elevation 627 which was between Nets 2 and 3U. Although a half-net was placed at the bottom of the fyke net frame, no fish were caught in it.

Vertical distribution measurements and FGE treatment and control tests were conducted in the same gateslot on different nights. Termination of tests was determined from numbers of fish dipnetted from Slot 4B.

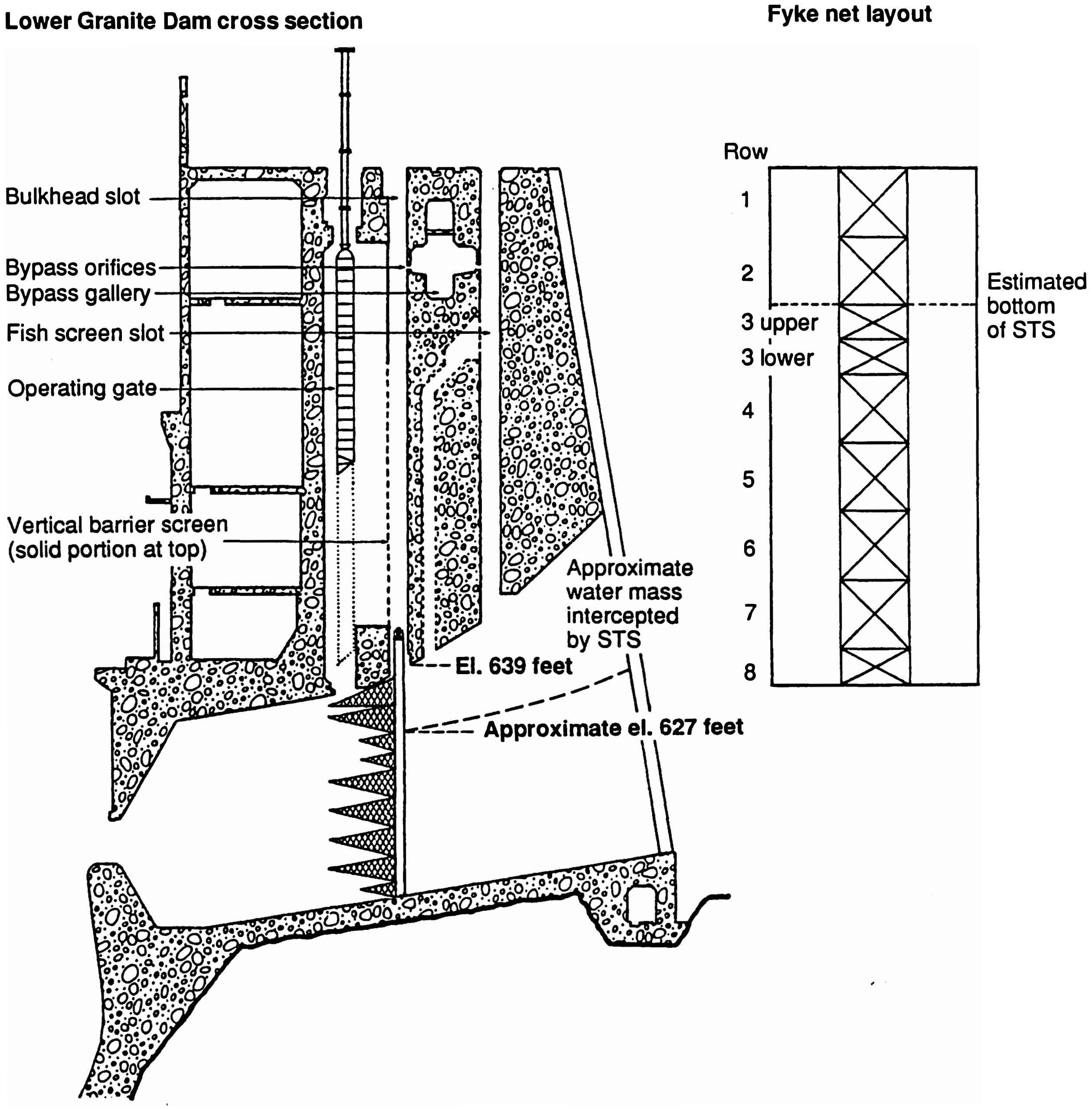

Figure 3.--Cross-section of a turbine unit with a vertical distribution net frame attached at Lower Granite Dam, 1989.

Data Analyses

To compare FGEs of the control condition (STS with gate raise) to FGEs of the treatment condition (STS with gate raise plus FBS), the FBS was alternated between successive days over a 22-day period, with four vertical distribution tests interspersed throughout the testing schedule (Table 1). Each set of two adjacent days compared a control and treatment condition. The significance of the differences between treatments and controls were analyzed by paired t-tests (Sokal and Rohlf 1981). Paired t-tests were also used to evaluate the possibility of horizontal deflection of fish away from the FBS.

Sample Size Requirements

For vertical distribution tests using a single vertical row of nets and assuming 10% volitional guidance (no STS) into the gatewell, the desired sample size was 200 actual net-caught fish. If volitional guidance was higher, slightly fewer net-caught fish were needed. For FGE tests with side nets mounted, but cod ends removed, and FGE >60%, the desired total sample size was 200 fish, including gatewell fish; if FGE was <60%, the desired sample size for validation increased to 250 fish.[2] In cases where the sample size was less than 200 fish, the adjacent replicates were combined.

RESULTS AND DISCUSSION

Tests at Lower Granite Dam were conducted from 10 April to 1 May (Table 1 and Appendix A). Yearling chinook salmon were the primary species present during most of the testing. Juvenile steelhead were present in sufficient numbers for test purposes

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[2] The sample size requirements for vertical distribution and FGE tests were established at a meeting between COE and NMFS biologists and statisticians on 11 April 1986.

beginning 20 April and were the predominant species from 26 April to the end of testing.

Lateral Diversion of Fish by the FBS

Contrary to 1987 observations of lateral movement between gateslots when a single FBS was used, lateral diversion of fish to adjacent turbine units when the test turbine unit had a full complement of FBSs did not occur based upon comparisons of fish recovered from Gateslots 3C and 4B (Table 2). Comparing tests of the treatment vs control conditions, the ratio of percentages of fish in Slot 4B compared to Slot 3C was higher under treatment conditions. With no lateral diversion, these are the expected results because the FBS should guide more fish. Additionally, no significant difference was found between numbers of yearling chinook salmon and steelhead collected in Gateslot 4B and Gateslot 3C in the comparison of treatment vs control conditions (Tables 3 and 4).

Vertical Distribution Measurements

Vertical distribution measurements indicated that between 60 and 87% of yearling chinook salmon and between 85 and 93% of juvenile steelhead were located in the water mass that could be intercepted by a standard STS (Table 5).

Fish Guidance Efficiency Tests

The temporal pattern of increasing fish guidance over time appeared to follow the general trend toward a seasonal increase noted in past years (Fig. 4). Also, the inverse relationship of lower FGEs when larger numbers of fish were collected was again noted (Appendix A). An unexplained, slight decline in FGE levels occurred briefly for both species after mid-season. Fish guidance efficiency for yearling chinook salmon during tests with the standard STS, 62-ft raised operating gate, and no FBS ranged from 43.4

Table 2.--Numbers of yearling chinook salmon and steelhead collected by dipnets from gatewells during tests to compare effects of the combined submersible traveling screen and fixed bar screen (FBS) on lateral diversion of smolts at Lower Granite Dam, 1989.

	Yearling chinook salmon		Steelhead	
	4B	3C	4B	3C
Control	4,146	2,123	3,206	2,534
(No FBSs in Unit 4)	(66.1%)	(33.9%)	(56.0%)	(44.0%)
Ratio	1.95:1		1.27:1	
Treatment	2,858	1,346	2,970	1,534
(FBSs in Unit 4)	(68.0%)	(32.0%)	(65.9%)	(34.1%)
Ratio	2.13:1		1.93:1	

Table 3.--Yearling chinook salmon smolts removed from Gateslot 4B compared to the total number of yearling chinook salmon removed from Gateslots 3C and 4B during fish guidance efficiency testing at Lower Granite Dam, 1989.

Date	Test condition	Gateslot 4B	Gateslot 3C	4B ÷ (3C + 4B)	Comparison of T-C
16 Apr	Control (C)	371	211	0.637	0.029
17 Apr	Treatment (T)	458	230	0.666	
18 Apr	Control	603	222	0.731	-0.052
19 Apr	Treatment	91	43	0.679	
20 Apr	Control	662	272	0.709	-0.082
21 Apr	Treatment	726	431	0.627	
23 Apr	Control	198	98	0.669	0.074
24 Apr	Treatment	979	338	0.743	
25 Apr	Control	479	244	0.663	-0.006
26 Apr	Treatment	216	113	0.657	
27 Apr	Control	947	455	0.675	0.060
28 Apr	Treatment	203	73	0.735	
30 Apr	Control	495	434	0.533	0.078
29 Apr	Treatment	185	118	0.611	
Mean T-C difference					0.014[a]

[a] SE of mean = 0.024
t = 0.608 N.S.

Table 4.--Juvenile steelhead removed from Gateslot 4B compared to the total number of steelhead removed from Gateslots 3C and 4B during fish guidance efficiency testing at Lower Granite Dam, 1989.

Date	Test condition	Gateslot 4B	Gateslot 3C	4B ÷ (3C + 4B)	Comparison of T-C
16 Apr	Control (C)	53	42	0.558	-0.009
17 Apr	Treatment (T)	67	55	0.549	
18 Apr	Control	77	48	0.616	-0.025
19 Apr	Treatment	117	81	0.591	
20 Apr	Control	359	123	0.745	-0.190
21 Apr	Treatment	482	386	0.555	
23 Apr	Control	224	424	0.346	0.376
24 Apr	Treatment	495	191	0.722	
25 Apr	Control	482	295	0.620	0.228
26 Apr	Treatment	630	113	0.848	
27 Apr	Control	1,198	661	0.644	0.125
28 Apr	Treatment	639	192	0.769	
30 Apr	Control	758	903	0.456	0.055
29 Apr	Treatment	540	516	0.511	
Mean T-C difference					0.080[a]

[a] SE of mean = 0.070
t = 1.149 N.S.

Table 5.--Vertical distribution catch data and descaling rates for yearling chinook salmon and juvenile steelhead at Lower Granite Dam, 1989.

Date	Species	Actual catch Gatewell	Actual catch Nets	Adjusted total catch[c]	Descaled[a] (%)	TFGE[b] (%)
10 Apr	Chinook salmon	306	505	1,821	0	60
15 Apr	Chinook salmon	156	168	660	3	79
22 Apr	Chinook salmon	149	131	542	0	82
01 May	Chinook salmon	253	233	952	3	87
10 Apr	Steelhead	30	12	66	0	86
15 Apr	Steelhead	35	9	62	0	85
22 Apr	Steelhead	222	63	411	0	93
01 May	Steelhead	790	173	1,309	0	92

[a] Gatewell catch only.

[b] TFGE = Theoretical fish guidance efficiency (Gatewell catch + adjusted net catch through Row 3L ÷ Total adjusted catch) x 100.

[c] Gatewell catch + adjusted net catch (= 3 x actual net catch).

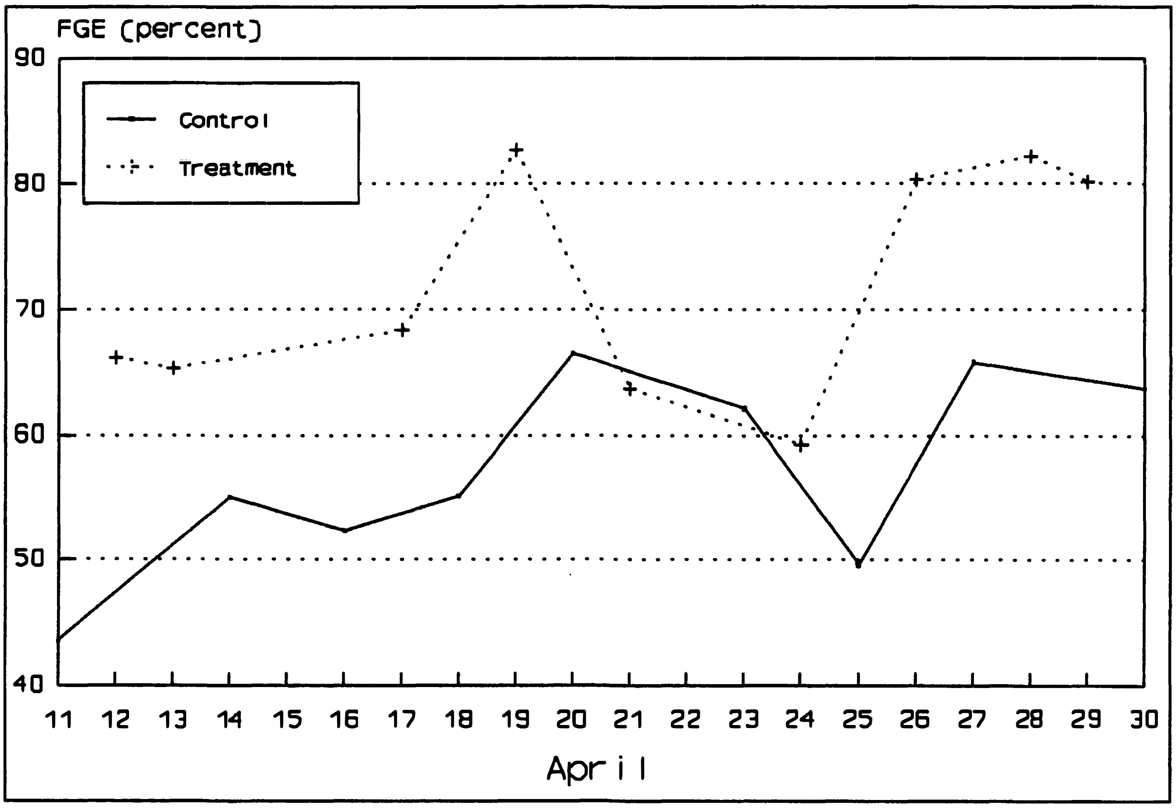

Figure 4.--Temporal patterns of fish guidance efficiency of yearling chinook salmon with a standard submersible traveling screen (STS) (control) and STS with fixed bar screen (treatment) at Lower Granite Dam, 1989.

to 66.5% with a weighted average of 57.3%. The FGE for steelhead ranged from 67.6 to 86.7% with a weighted average of 77.3%. However, the mean differences between paired control and treatment tests was 14.6% for yearling chinook salmon and 7.3% for steelhead (Table 6).

The combination of the STS and FBS, simulating an extended STS, with 62-ft raised operating gate, provided significant increases in FGE for both yearling chinook salmon and steelhead (P = 0.0027 and P = 0.0012, respectively, with a paired t-test method) (Table 6). However, the weighted FGE for yearling chinook salmon during the treatment condition was 66.0% compared to the simple FGE average of 72%. The lowest FGE values under the treatment condition occurred when large numbers of fish were caught, whereas the highest values occurred when fewer numbers of fish were caught. Possibly, when large numbers of fish pass into the turbine intake, they are spread deeper into the water column and fish at lower depths are not as guidable as ones closer to the surface.

The FSS closure devices and brushes mounted on the top margin of the FBS were not totally effective; therefore, some live yearling chinook salmon and juvenile steelhead were recovered from the top of the FBS and on the closure devices when raised. A total of 733 yearling chinook salmon were found impinged on the bars of the FBS; however, with the exception of one test day, steelhead were not impinged (Table 7). During some of the period after the actual FGE testing, the turbines were operated at loads (22,500 cfs) higher than recommended for maximum turbine survival for fish (Appendix B). This may have caused some of the impingement problems not seen in 1987. Secondly, over twice as many fish were impinged on the FBSs in Gateslots 4A and 4B as in 4C. There was no perforated plate behind the upper 1.5-2 ft of the fixed bar screen area of the newer FBSs in Gateslots 4A and 4B, which may have caused a

Table 6.--Fish guidance efficiencies (FGEs) with a fully raised operating gate comparing a standard submersible traveling screen (STS) (control) to a standard STS aligned with an fixed bar screen (FBS) (treatment) at Lower Granite Dam, 1989.

	Yearling chinook salmon			Steelhead		
Date	ST (%)	STS with FBS (%)	Mean difference (%)	STS (%)	STS with FBS (%)	Mean difference (%)
11 Apr	43.4			67.6	-	
12 Apr	-	66.2	22.8	-	75.0	7.4
13 Apr	-	65.3	7.3	-	83.1	13.5
14 Apr	55.0	-		69.6	-	
16 Apr	52.3	-		71.6	-	
17 Apr	-	68.3	15.9	-	82.7	11.1
18 Apr	55.1	-		80.2	-	
19 Apr	-	82.7	27.6	-	86.7	6.5
20 Apr	66.5	-		85.5	-	
21 Apr	-	63.7	-2.8	-	85.6	0.1
23 Apr	62.1	-		68.5	-	
24 Apr	-	59.2	-2.9	-	80.6	12.1
25 Apr	49.6	-		81.0	-	
26 Apr	-	80.3	30.7	-	85.6	4.6
27 Apr	65.8	-		77.9	-	
28 Apr	-	82.2	16.4	-	77.8	-0.1
29 Apr	-	80.1	16.4	-	85.2	10.5
30 Apr	63.7		74.7			
Average[a]	57.1	72.0		75.2	82.4	
Weighted FGE[b]	57.3	66.0		77.3	82.7	
Mean difference (Control vs Treatment)			14.6 (P < 0.01)			7.3 (P < 0.01)

[a] Average of the nightly values.

[b] FGE value when total fish captured for all tests are combined.

Table 7.--Fish impinged on the fixed bar screen during treatment tests at Lower Granite Dam, 1989.

	Gateslot 4A	Gateslot 4B	Gateslot 4C
Date	Yearling chinook salmon	Yearling chinook salmon	Yearling chinook salmon
13 Apr	30	25	12
17 Apr	31	29	17
19 Apr	55	47	10[a]
21 Apr	124	143	51
24 Apr	11	17	19
26 Apr	20	17	19
28 Apr[b]	0	0	0
29 Apr[c]	4	4	2
Totals	275	328	130
4 May[d]	30 (18,800 cfs)		
5 May[d]	0 (11,300 cfs)		
6 May[d]	5 (15,500 cfs)		
7 May[e]	8 (18,800 cfs)		

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[a] P C Power Contractors estimated that 40-50 impinged (decomposed) fish fell off when raised.

[b] Number of fish counted when the fixed bar screen was raised after operating the turbine with 11,300 cfs between tests.

[c] Number of fish counted when the fixed bar screen was raised after operating the turbine with 15,500 cfs between tests.

[d] Total fish counted from all three gateslots in Unit 4 during load testing following completion of test season.

[e] Fish counted from Gateslot 4B only, to simulate 1987 test conditions.

portion of the increased impingement. The lack of perforated plate caused a sharp increase in flows through the upper part of the screen (see Appendix B). This may have caused a behavioral barrier for some fish and in an attempt to avoid the area, they subsequently became impinged. As indicated in the hydraulic modeling, the flows most perpendicular to the FBSs were at the lower portion of the screen, but the impinged fish were on the upper 1/2 -2/3 of the screen. Finally, due to the hydraulics of the turbines, more flow with higher velocities passes through Gateslots A and B than C. This may have also attributed to increased impingement in the former two slots compared with the latter.

Following completion of the FGE test season, a series of four additional tests were conducted to measure impingement of fish on the FBSs at various turbine loads (Table 7). The first three tests included counts of impinged fish for all of Unit 4. The final test was conducted in Gateslot 4B only, under conditions simulating those tested in 1987. Results of those tests indicated that impingement of juvenile fish on the FBSs with decreased turbine loading was not a major problem. We had no means to determine the possible interaction between the STS and FBS in the alignment tested and whether it led to impingement problems, although we speculated above on possible effects on fish behavior. However, we found in work at McNary Dam that continuous operation of traveling screens would remove debris and impinged fish from the guidance device without increasing mortalities or descaling, but when the screens were cycled, mortalities occurred (McCabe and Krcma 1983). We also feel that limiting screen velocities or changing the angle of the screen may substantially decrease guidance and the benefits derivable from an extended guidance device.

The Walla Walla District COE provided their own analysis of the additional testing conducted to evaluate the impingement problem (Appendix B). The NMFS does not concur with all of the COE's interpretations of the results.

Fish Condition

Descaling rates of volitionally guided fish (no STS) recovered from gatewells at Lower Granite Dam during vertical distribution tests were 3% or less for chinook salmon and steelhead (Table 5). Descaling rates of guided yearling chinook salmon during FGE tests were 4.7 and 2.5% for control and treatment conditions, respectively, and 0% during both conditions for steelhead.

CONCLUSIONS

1) Installation of extended guidance devices will not cause lateral diversion of yearling chinook salmon and juvenile steelhead away from turbine units.
2) The installation of extended guidance devices in combination with 62-ft raised operating gates will significantly increase FGEs for yearling chinook salmon and steelhead compared to present bypass conditions.
3) Installation of bar screens in the configuration tested in 1989, while providing increased guidance, may , however, cause impingement problems with some juvenile salmonids.

RECOMMENDATION

Based on test results in 1987 and in 1989, it appears that an extended guidance device with the porosities tested will significantly increase guidance of yearling chinook salmon at Lower Granite Dam, without diversion of fish below or horizontally away from the STS. Therefore, without any further testing, we recommend installation of extended STSs at the angle and porosity tested in 1989 instead of bar screens in the fish screen slots in combination with the present STSs. Traveling mesh should alleviate problems of impingement because fish will only remain on the screen for a short period of time.

ACKNOWLEDGMENTS

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LITERATURE CITED

Farr, W. E.
1974. Traveling screens for turbine intakes of hydroelectric dams. In L. D. Jensen (ed.). Proceedings of the Second Workshop on Entrainment and Intake Screening. Pp. 199-203. The Johns Hopkins University Cooling Water Research Project, Report 15.

Koski, C. H., S. W. Pettit, J. L. McKern.
1989. Fish transportation oversight team annual report -FY88 transport operations on the Snake and Columbia rivers. NOAA (National Oceanic and Atmospheric Administration) Technical Memorandum NMFS F/NWR - 25, Washington, D.C.

Ledgerwood, R. D., W. T. Norman, G. A. Swan, and J. G. Williams.
1988. Fish guiding efficiency of submersible traveling screens at Lower Granite and Little Goose Dams--1987. Report to U.S. Army Corps of Engineers, Contract DACW68-84-H-0034, 41 p. Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.

McCabe, G. T., Jr., and R. F. Krcma.
1983. Effects of the intermittent operation of submersible traveling screens on juvenile salmonids, 1982. Report to U.S. Army Corps of Engineers, Contract DACW68-78-C-0051, 17 p. Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. e., Seattle, WA 98112-2097.

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. Report to U.S. Army Corps of Engineers, Contract DACW68-78-C-0054, 58 p. Available from Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 98112-2097.

Park, D. L., J. R. Smith, E. Slatick, G. M. Matthews, L. R. Basham, and G. A. Swan.
1978. Evaluation of fish protective facilities at Little Goose and Lower Granite Dams and review of mass transportation activities 1977. Report to U.S. Army Corps of Engineers, Contract DACW68-77-C-0043, 60 p. Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.

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.

Sokal, R. R., and J. F. Rohlf.
1981. Biometry. The principles and practice of statistics in biological research. 2nd edition. Freeman and Company: San Francisco, California. 779 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. Report to U.S. Army Corps of Engineers, Contract DACW68-78-C-0051, 20 p. + Appendixes. Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.

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

Swan, G. A., R. F. Krcma, and F. Ossiander.
1985. Development of an improved fingerling protection system for Lower Granite Dam--1984. Report to U.S. Army Corps of Engineers, Contract DACW68-84-C-0034, 32 p. Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.

Swan, G. A., R. F. Krcma, and F. Ossiander.
1986. Continuing studies to improve and evaluate juvenile salmonid collection at Lower Granite Dam--1985. Report to U.S. Army Corps of Engineers, Contract DACW68-84-C-0034, 37 p. Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.

APPENDIX A
Data Tables

Appendix Table A1.--Numbers of fish collected in the individual replicates of fish guidance efficiency tests at Lower Granite Dam, 1989.

	Date, condition and (Test Number)[a]					
	11 April, Control (2)		12 April, Treatment (3)		13 April, Treatment (4)	
Location	YC[b]	ST[b]	YC	ST	YC	ST
Gatewell	402	25	905	54	697	59
Gap Net	7	-	23	3	23	2
Closure	83	-	76	-	63	4
First	33	3	27	9	48	-
Second	213	9	168	3	108	6
Third	126	-	99	3	90	-
Fourth	48	-	69	-	33	-
Fifth	15	-	-	-	6	-
Totals	927	37	1,367	72	1,068	71
	14 April, Control (5)		16 April, Control (7)		17 April, Treatment (8)	
Gatewell	391	55	371	53	458	67
Gap Net	3	-	7	-	7	3
Closure	68	6	64	9	35	2
First	39	-	48	-	21	-
Second	144	9	117	6	69	3
Third	51	6	69	6	57	-
Fourth	15	3	30	-	24	6
Fifth	-	-	3	-	-	-
Totals	711	79	709	74	671	81

Appendix Table A1.--Continued.

	Date, condition and (Test Number)[a]					
	18 April, Control (9)		19 April, Treatment (10)		20 April, Control (11)	
Location	YC	ST	YC	ST	YC	ST
Gatewell	603	77	91	117	662	355
Gap Net	3	-	-	-	3	3
Closure	89	7	6	3	49	12
First	48	3	6	-	75	18
Second	219	0	3	9	132	21
Third	99	9	3	6	54	6
Fourth	33	-	1	-	18	-
Fifth	-	-	-	-	3	-
Totals	1,094	96	110	135	996	415
	21 April, Treatment (12)		23 April, Control (14)		24 April, Treatment (15)	
Gatewell	726	482	198	224	979	495
Gap Net	18	6	1	-	28	1
Closure	63	9	18	19	75	13
First	18	3	18	9	39	6
Second	144	30	48	33	261	63
Third	120	24	27	39	180	21
Fourth	42	9	6	3	93	15
Fifth	9	-	3	-	-	-
Totals	1,140	563	319	327	1,655	614

Appendix Table A1.--Continued.

	Date, condition and (Test Number)[a]					
	25 April, Control (16)		26 April, Treatment (17)		27 April, Control (18)	
Location	YC	ST	YC	ST	YC	ST
Gatewell	479	482	216	630	947	1,198
Gap Net	4	5	2	4	12	13
Closure	63	9	12	6	138	63
First	93	27	15	6	84	42
Second	213	45	21	33	147	156
Third	99	21	3	27	84	45
Fourth	15	3	-	24	21	21
Fifth	-	3	-	6	6	-
Totals	966	595	269	736	1,439	1,538
	28 April, Treatment (19)		29 April, Treatment (20)		30 April, Control (21)	
Gatewell	203	639	185	540	495	758
Gap Net	1	11	2	7	5	9
Closure	10	15	2	9	55	50
First	-	9	-	3	51	45
Second	18	69	27	36	123	105
Third	12	51	6	21	39	36
Fourth	3	27	6	12	9	12
Fifth	-	-	3	6	-	-
Totals	247	821	231	634	777	1,015

[a] Test numbers correspond to those in Table 1, this report.

[b] YC = Yearling chinook salmon
ST = Steelhead

Appendix Table A2.--Vertical distribution data for yearling chinook salmon and steelhead collected at Lower Granite Dam, 1989.

Test Date	10 April	15 April	22 April	1 May
Test No.	1	6	13	22
		Yearling Chinook Salmon		
Gatewell	306	156	149	253
First Net	399	204	189	351
Second Net	405	159	108	222
Third Net	300	57	48	87
Fourth Net	216	39	30	24
Fifth Net	105	21	12	12
Sixth Net	66	21	6	3
Seventh Net	24	3	-	-
Totals	1,821	660	542	952
		Juvenile Steelhead		
Gatewell	30	35	222	790
First Net	21	12	132	288
Second Net	6	6	30	132
Third Net	6	6	12	42
Fourth Net	3	-	9	33
Fifth Net	-	3	6	18
Sixth Net	-	-	-	6
Seventh Net	-	-	-	-
Totals	66	62	411	1,309

APPENDIX B

Hydraulic Evaluation

This section was prepared by the Walla Walla District Corps of Engineers. The results and analysis do not necessarily reflect the views or opinions of the National Marine Fisheries Service.

APPENDIX B - HYDRAULIC EVALUATION

1. Scope

This document identifies the specifics of the equipment tested and the flow situations which occurred at Lower Granite Dam during the 1989 fish guidance efficiency (FGE) testing season. The impingement problem observed during the FGE testing is evaluated and suspected reasons for the occuring impingement are identified. A solution to the problem is suggested.

2. Description of Equipment.

a. General

The system of equipment tested simulated an extended screening device 40 feet in length actuated at a 55 degree angle from the vertical (see Exhibit 1).

b. Submerged Traveling Screens.

A 20′ standard submerged traveling screen (STS) was installed in each bay of unit 4. The standard STS is composed of a steel frame with a rotating mesh belt and a 46% perforated plate mounted within the steel framework. The STS was installed with a pivot point elevation of 635.4 feet and extended to a 55 degree angle from the vertical.

c. Fixed Bar Screens.

A 20′ fixed bar screen (FBS) was installed in the fish screen slots of each bay of turbine unit 4. The FBS is composed of a steel framework with wedge wire bar screen mounted on top of the framework and a perforated plate installed between the framework members approximately 8 inches behind the bar screen. The bar screen is Hendricks screen with 40% open area and 1/16 inch spacing between bars. The bar screen was oriented parallel to the outer frame side beams. The perforated plate has a porosity of 46% similar to that of a standard STS. The computed overall porosity of the FBS was comparable to that of a standard STS (26%). A cleaning device was not installed on the fixed bar screens. The FBS's were actuated to a 55 degree angle from the vertical with a pivot point elevation of 623.9 feet.

d. Operating Gates.

Operating gates in each bay of unit 4 were raised to avoid restricting flow down the operating gate slot.

3. Fish Impingement.

a. General.

In 1987, a single bay of unit number 4 at Lower Granite dam was screened with a standard length STS installed in the bulkhead slot and a FBS installed in the fish screen slot. With both devices in place, the system represented a double length screen (40 feet) installed at a 55 degree angle from the vertical. Prototype tests indicated improved FGE with low descaling and no incidence of impingement detected (Ledgerwood et. al. 1988).

In 1989, an additional prototype field test was conducted with all three bays of unit 4 screened with STS's and fixed bar screens. The biological data showed improved FGE but some level of fish impingement. During the FGE testing, the unit 4 turbine was run at 135 megawatts output. This loading corresponds to a discharge of 18,800 cfs. Following the 1-1/2 hour FGE test, screens were left in place (up to 12 hours) and the turbine loading was allowed to vary to meet demands. The turbine was operated at times up to 155 megawatt output which corresponds to a discharge of approximately 22,500 cfs. Refer to Exhibits 9 and 10 for the Unit 4 operating record for 1989. In 1987, the single FBS was in place during the 1-1/2 hour FGE test and raised and dogged off at deck level until the next FGE test was conducted.

The differences observed between 1987 and 1989 testing (with regard to impingement) could be explained by the facts that only one bay was screened in 1987, the length of time that screens were in place (1-1/2 hour in 1987 vs. 12 hours in 1989) and the equipment tested between years was slightly different in component makeup. The bar screen type utilized in 1987 was provided by the Wedge Wire Corporation and consisted of Lo Pro 304 S.S. wire with a .05 clear spacing between profile wires (35% open area) and a S.S. support rod, 1/2 inch in diameter on 2-1/2 inch centers. In 1989, a Hendricks profile wire (profile no. B-6) with 0.062 inch clear spacing (40.2% open area). The support bars on the Hendricks screen are U-clips on 2-3/4 inch centers. The perforated plate backing up the profile wire for both 1987 and 1989 test years was 46% open area, 1/2 inch diameter holes on 11/16 inch staggered centers. With a single bay screened, head loss was increased in that particular bay causing water to be diverted to the other two bays. In 1989, all three bays were identically screened which balanced the head loss in each bay and exaggerated velocities through the screens.

b. Summary of Additional Prototype Tests.

Several additional tests were run near the end of the FGE testing in 1989 to attempt to evaluate the impingement of spring chinook. The significant tests are summarized below.

(1) April 29. Turbine output set at 80 megawatts for 12 hours. This corresponds to a turbine flow of approximately 11,300 cfs. At conclusion of the tests, no fish were impinged on the FBS's.

(2) April 30. Turbine output set at 110 megawatts for 12 hours. This corresponds to a turbine flow of approximately 15,500 cfs. A total of five spring chinook were impinged on the

FBS's.

(3) May 3. STS lowered by 2 feet in an attempt to assess impact of separation distance between STS and FBS. Turbine output set at 135 megawatts from 1300 hours to 1000 hours on 4 May. A total of 30 fish were found impinged on FBS.

(4) May 4. Turbine output adjusted to 80 megawatts from 1300 to 1000 hours on 5 May. No fish were found impinged.

(5) May 5. Turbine output adjusted to 110 megawatts from 1300 to 1000 hours on 6 May. Five fish were found impinged.

(6) May 6. FBS installed in 4B only to simulate 1987 test conditions. Turbine output at 135 megawatts until 0900 on 7 May. Eight fish were found impinged.

c. Model Examination of Impingement Problem.

A model study is currently being conducted at the Waterways Experiment Station (WES) in Vicksburg, Ms. utilizing a 3-bay sectional model of McNary dam. Models of the Lower Granite FBS's were constructed and installed in the 3-bay model of McNary dam. The differences between intake shape between McNary and Lower Granite are significant but the McNary model was the only tool available for use. It was felt that an examination of conditions would at least indicate trends. Lower Granite discharges were utilized in the model for evaluation of conditions.

The prototype flow conditions representing 155 megawatt (22,500 cfs) and 110 megawatt (16,000 cfs) turbine loadings were replicated in the model. The results are illustrated in attached Exhibits 2 and 3. Exhibits 2a and 3a show resultant velocity magnitude, angle and velocity components perpendicular and parallel to the screen surface for both STS and FBS. Comparison of prototype results from the additional tests (described in paragraph 3b) to the model results appear to indicate that velocities normal to the screen in excess of about 3.8 - 4.0 feet per second will cause fish to be impinged. Telephone conversations with Mr. Dana Jeske (mechanical engineer with the Public Utility District of Grant County, Priest Rapids and Wanapum Hydroelectric Dams) concerning their field experiences at the Priest Rapids project and Dr. Jacob Odgaard (Assoc. Prof., Civil and Environmental Engrg., and Research Engr. Iowa Inst. of Hydraulic Research, The Univ. of Iowa) confirmed that impingement could be expected with velocities normal to the screen surface of 4 feet per second or greater. Dr. Odgaard investigated alternative fish screening devices utilizing a hydraulic model of the Priest Rapids project. Impingement was not observed at Priest Rapids when modifications to their prototype test screens limited normal velocities to less than 4 feet per second.

It is evident (from prototype testing at Lower Granite) that the correct porosity and/or angle is not known since fish were impinged on the FBS's, i.e. the velocities were too high hence discharge through the screens was too high. Corrections to porosity, screen angle or both may be required to alleviate this problem.

Utilizing this information, additional tests were conducted in the hydraulic model at WES to determine adjustments to the screening system which would limit velocites normal to the screen surface to an upper limit of 3.8 to 4.0 feet per second at a turbine discharge of 22,500 cfs (155 mw). The perforated plate behind the bar screen on the FBS's was changed from a 46 % open area to a 30% open area. This change effected velocities along the FBS but also exaggerated velocities through the standard STS to unacceptable conditions. In order to relieve this situation, the FBS was raised so that less flow would be intercepted thus lowering velocities through the screen. This however, increased the flow between the STS and FBS since the gap was opened up. This also was felt to be an unacceptable condition. To achieve both limiting velocities and decrease the gap opening, the STS was rotated to a 65 degree position and the FBS was raised just high enough to clear the bottom of the STS (4.75 feet). The final required screen configuration is illustrated in Exhibit 4. Model determined normal velocities for this arrangement were less than 4 fps except near the end of the FBS (see Exhibit 5 and 6).

The final FBS/STS modifications required to limit normal velocities to 3.8 - 4.0 feet per second and limit gap losses are listed below.

(1) Standard STS in the Bulkhead slot extended to 65 degrees from vertical.

(2) FBS in Fish Screen Slot.
    (a) Extended to 55 Degrees from vertical
    (b) Pivot point elevation 628.65 (4.75 feet higher than 1989).
    (c) Perforated plate changed from 46% to 30%
    (d) Perforated plate added to upper 2 feet of bar screen.

This arrangement imitates a 38 foot screening device installed at approximately a 65 degree angle from the vertical. The percent of flow intercepted is estimated to be 41 percent to the tip of the FBS and 37% to the zero parallel velocity point (effective intercept) on the FBS (see Exhibit 7 and 8).

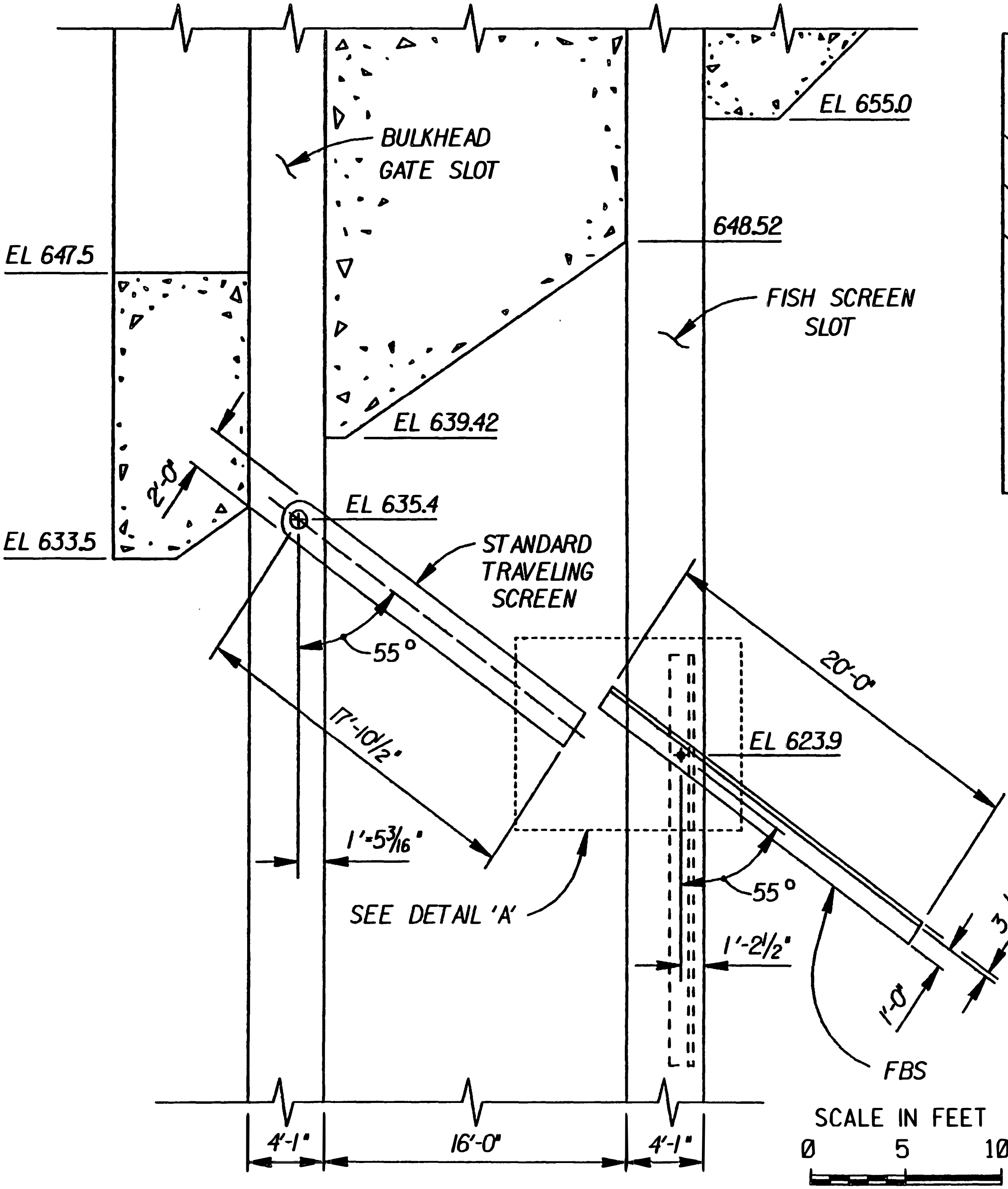
4. Conclusion

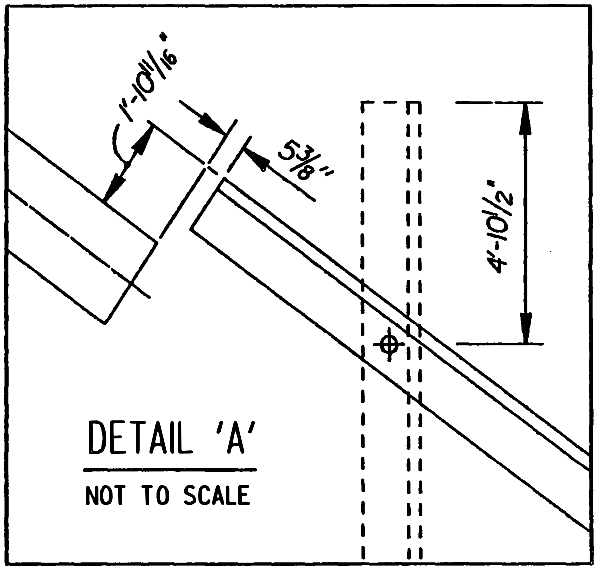
An important criterion to screen design has been identified, based on prototype experiences and model investigations. Field verification for specific species is needed. Careful documentation of fish condition will give insight to maximum normal velocities (upper limit criteria) for screen development at other hydroelectric projects.

Two devices as tested at Lower Granite in 1987 and 1989 are not recommended as a final solution. A single longer (continuous) device will provide more acceptable conditions and could probably be fished deeper in the intake (ie. more flow intercept) than the final acceptable arrangement required for the two devices. However, adjustments to a longer device will require evaluation by a hydraulic model study to determine the correct porosity and angle from the vertical for limiting velocities to the 3.8 to 4.0 feet per second range at high turbine loadings.

It should be noted that the FBS tested in 1989 a comparable overall porosity as the standard STS. Had that FBS been composed of mesh and perforated plate (similar to STS) instead of bar screen, impingement would still have been expected since velocities would have exceeded the 3.8-4.0 feet per second threshold. Any type of longer screening device, whether STS or FBS will require adjustments in porosity and/or angle (from what is now known as a standard STS) to limit velocities and prevent fish impingement and descaling.

EXHIBIT I POSITION TESTED 1989





DETAIL 'A'

NOT TO SCALE

NOTES:

1. FOR 1989 TESTING, FBS WERE INSTALLED IN UNIT 4, BAYS A, B, AND C.
2. FBS SHOWN ON THIS DWG. WERE INSTALLED IN BAYS A AND B.

LOWER GRANITE FGE

STS & FBS ALIGNMENT

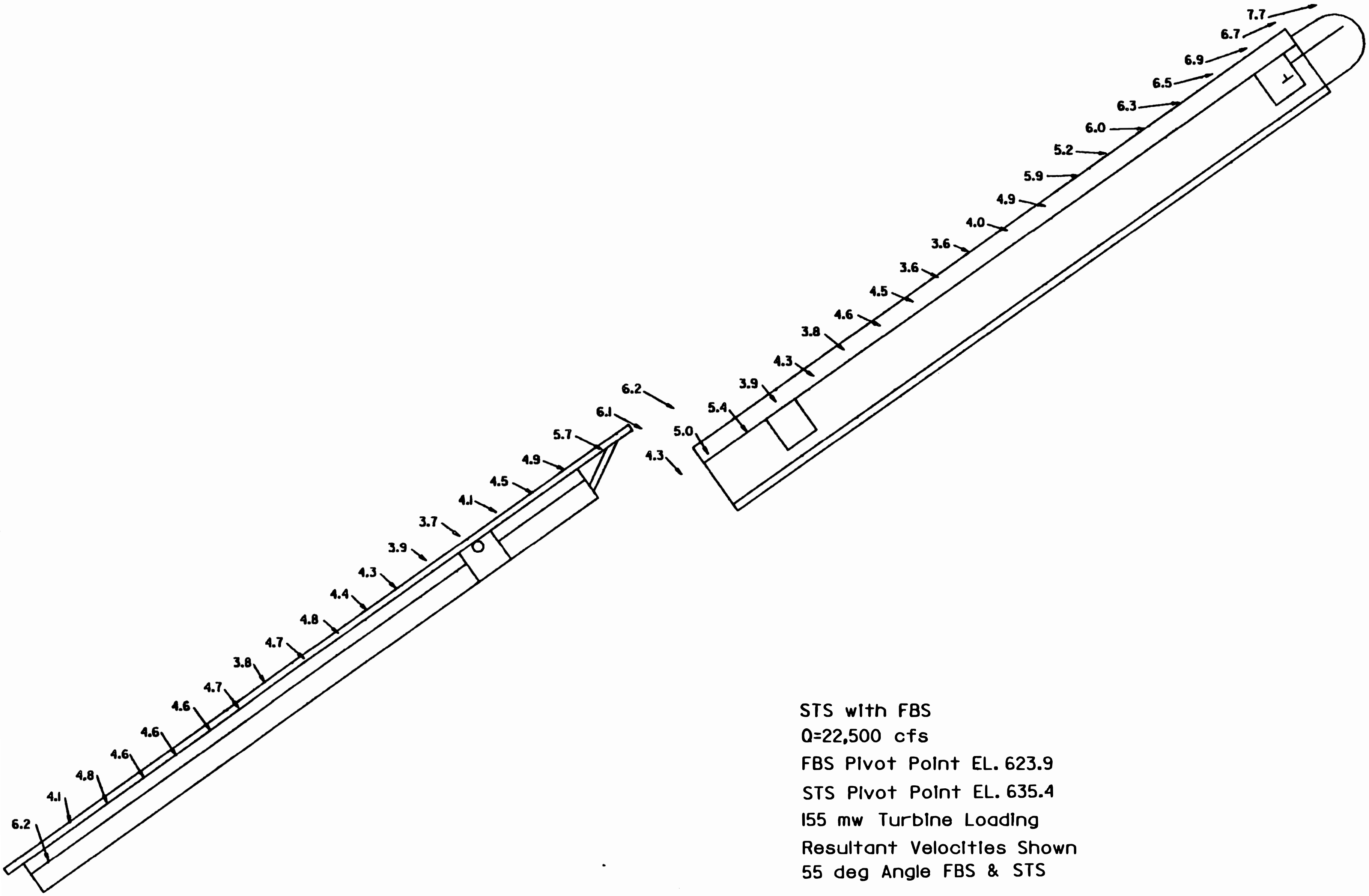
1989 TESTING

U. S. Army Engineer District
Walla Walla Hydraulic Design

Emmert/Schuster Aug 1989

DEFL89

EXHIBIT 2 - 1989 PROTOTYPE TEST CONDITIONS



STS with FBS
Q=22,500 cfs
FBS Pivot Point EL. 623.9
STS Pivot Point EL. 635.4
155 mw Turbine Loading
Resultant Velocities Shown
55 deg Angle FBS & STS

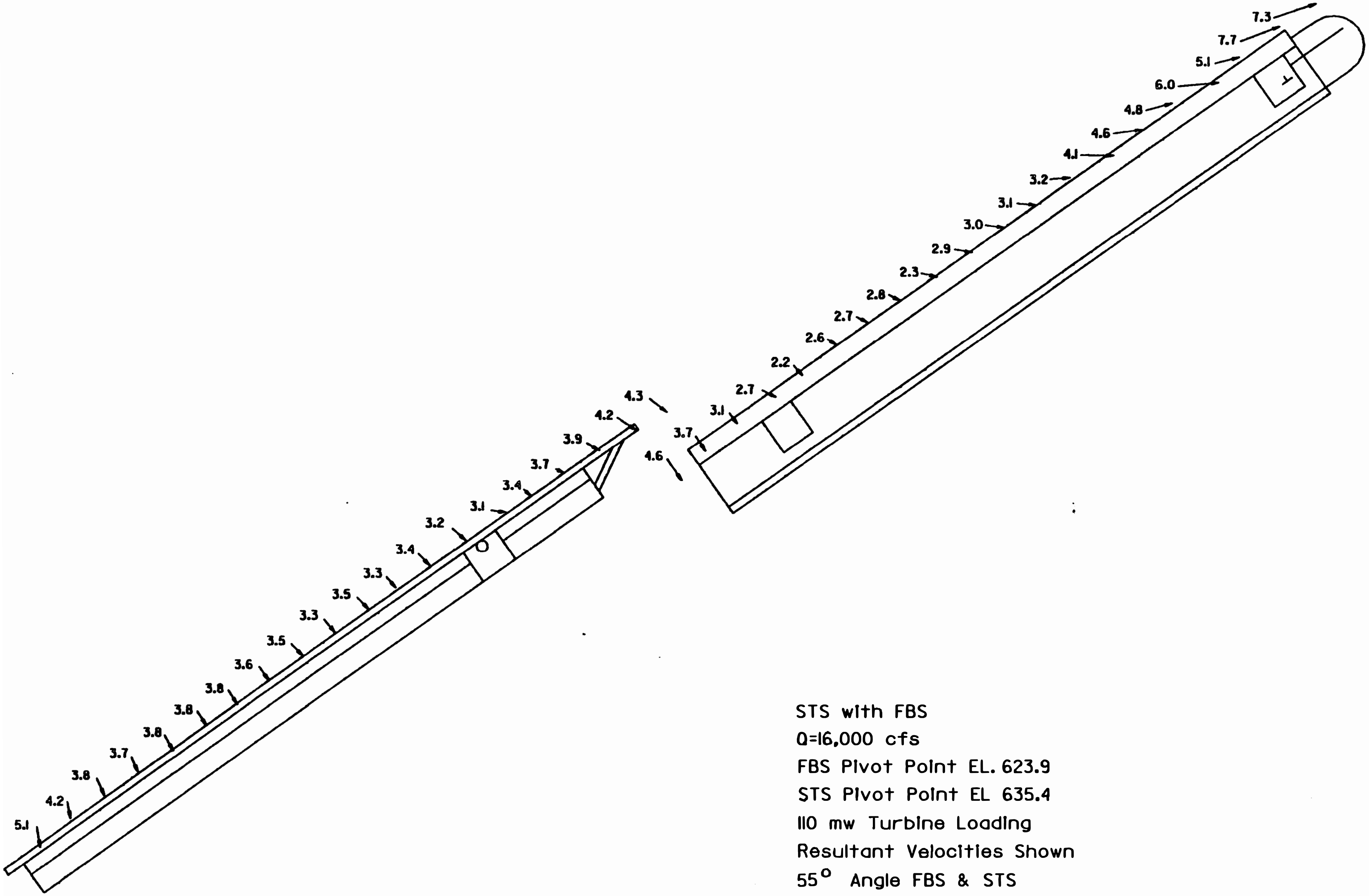
CAI:[240,8]TESTNG.DGN;1
7-DEC-1989 12:42

20 FT STS WITH UPSTREAM DEFLECTOR
46% PERFORATED PLATE
Q = 22,500 CFS

VEL#	θ	MAG	VEL=	VEL$_T$
1	+14.2	7.7	7.13	2.85
2	+24.0	6.7	6.56	1.40
3	+18.8	6.9	6.60	2.05
4	+16.3	6.5	6.09	2.18
5	+8.1	6.3	5.52	2.93
6	+2.7	6.0	5.03	3.31
7	-3.5	5.2	4.01	3.30
8	-1.5	5.9	4.65	3.57
9	-10.9	4.9	3.37	3.60
10	-17.8	4.0	2.36	3.22
11	-21.5	3.6	1.92	3.01
12	-26.5	3.6	1.67	3.21
13	-24.3	4.5	2.24	3.93
14	-26.8	4.6	2.10	4.09
15	-36.4	3.8	1.16	3.66
16	-35.7	4.3	1.36	4.13
17	-46.2	3.9	.53	3.85
18	-49.7	5.4	.40	5.34
19	-58.6	5.0	-.40	4.96
20	-47.4	4.3	.50	4.31
21	-30.6	6.2	2.45	5.66
22	-26.7	6.1	2.81	5.46
23	-23.8	5.7	2.89	4.97
24	-26.7	4.9	2.47	4.20
25	-27.1	4.5	2.06	4.00
26	-36.8	4.1	1.86	3.68
27	-33.5	3.7	1.09	3.51
28	-38.7	3.9	1.37	3.67
29	-40.8	4.3	1.14	4.15
30	-39.7	4.4	1.01	4.28
31	-42.7	4.8	1.19	4.66
32	-55.3	4.7	.93	4.64
33	-49.5	3.9	-.08	3.84
34	-50.5	4.7	.37	4.65
35	-55.2	4.6	.28	4.62
36	-57.8	4.6	-.10	4.63
37	-67.5	4.6	-.31	4.61
38	-69.4	4.6	-1.08	4.47
39	-73.5	4.1	-1.38	3.90
40	-70.0	6.2	-1.71	5.96

EXHIBIT 2a-1989 PROTOTYPE TEST CONDITIONS (CONT'D)

EXHIBIT 3 - 1989 PROTOTYPE TEST CONDITIONS



STS with FBS
Q=16,000 cfs
FBS Pivot Point EL. 623.9
STS Pivot Point EL 635.4
110 mw Turbine Loading
Resultant Velocities Shown
55° Angle FBS & STS

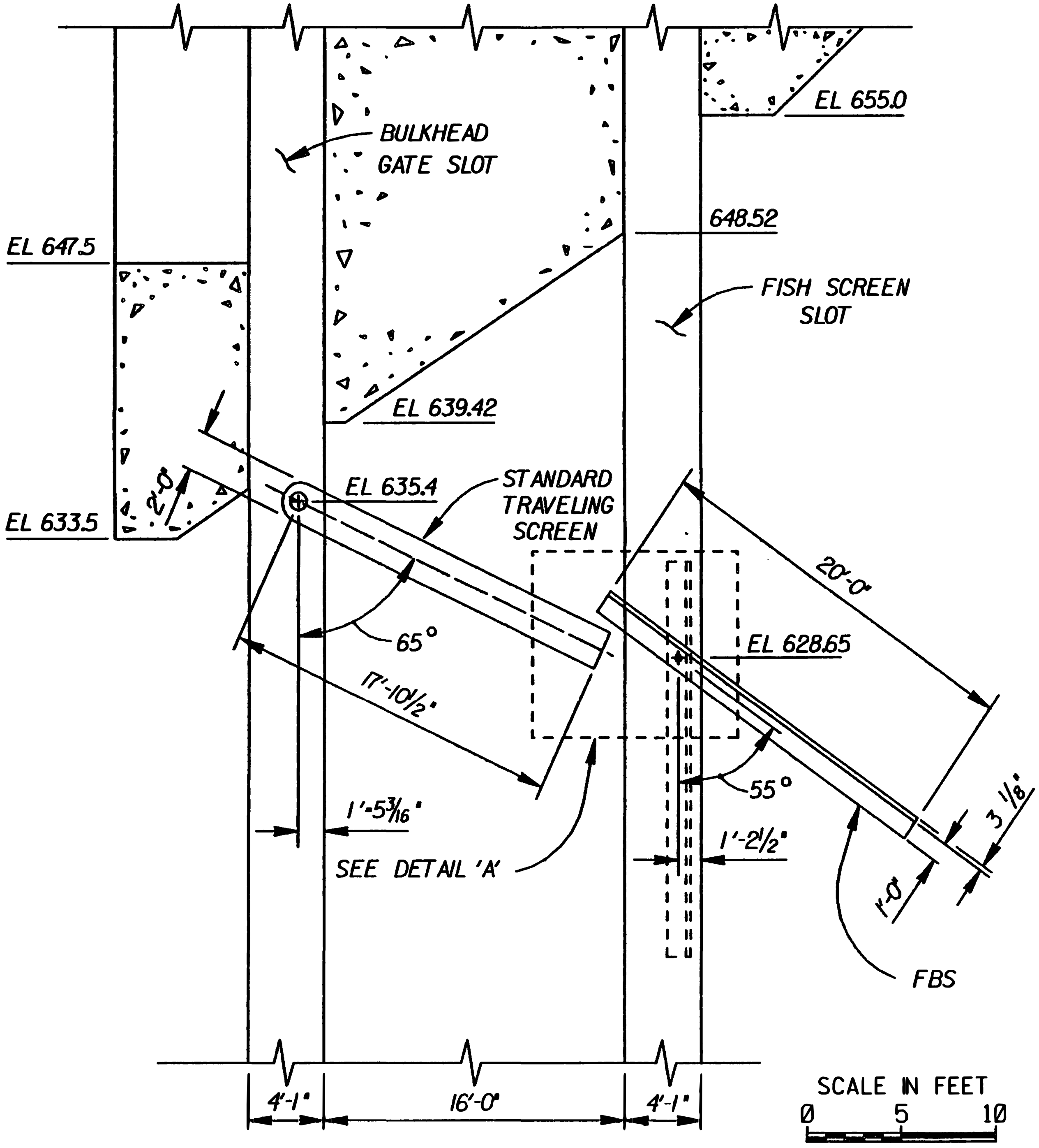
CA1:[240.83]TESTNG.DGN;1
7-DEC-1989 12:42

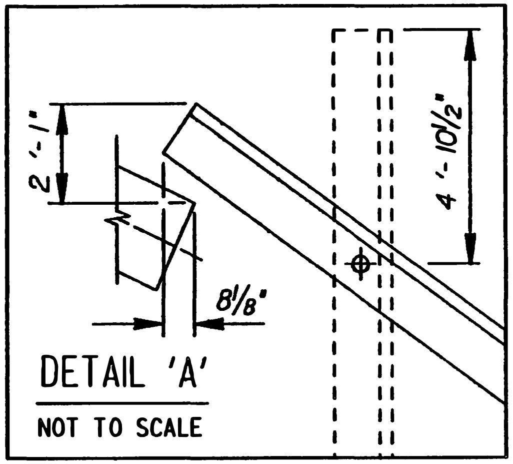
20' STS WITH UPSTREAM DEFLECTOR
46% PERFORATED PLATE
Q=16,000 CFS

VEL#	θ	MAG	VEL=	VEL$_T$
1	+17.1	7.3	6.95	2.24
2	+14.0	7.7	7.19	2.76
3	+12.7	5.1	4.72	1.94
4	+8.1	6.0	5.35	2.71
5	+12.0	4.8	4.42	1.89
6	+9.1	4.6	4.14	2.01
7	+1.0	4.1	3.40	2.29
8	+2.9	3.2	2.71	1.70
9	+0.4	3.1	2.55	1.77
10	-7.0	3.0	2.23	2.01
11	-11.0	2.8	1.95	2.01
12	-13.0	2.3	1.54	1.71
13	-27.8	2.8	1.28	2.49
14	-32.2	2.7	1.05	2.49
15	-35.3	2.6	0.88	2.45
16	-46.3	2.2	0.33	2.17
17	-31.7	2.7	1.07	2.48
18	-51.6	3.1	0.18	3.09
19	-55.9	3.7	-0.02	3.70
20	-55.9	4.6	0.08	4.60
21	-41.5	4.3	1.00	4.18
22	-35.8	4.2	1.38	3.97
23	-33.5	3.9	1.43	3.63
24	-33.2	3.7	1.37	3.44
25	-41.6	3.4	0.79	3.31
26	-24.4	3.1	1.59	2.66
27	-43.1	3.2	0.66	3.13
28	-45.4	3.4	0.57	3.35
29	-46.3	3.3	0.50	3.26
30	-46.8	3.5	0.50	3.46
31	-48.7	3.3	0.36	3.28
32	-48.7	3.5	0.38	3.48
33	-52.4	3.6	0.16	3.60
34	-54.0	3.8	0.07	3.80
35	-54.5	3.8	0.03	3.80
36	-58.2	3.9	-0.22	3.89
37	-61.2	3.7	-0.40	3.68
38	-67.5	3.8	-0.82	3.71
39	-71.1	4.2	-1.16	4.04
40	-73.3	5.1	-1.60	4.84

EXHIBIT 3a-1989 PROTOTYPE TEST CONDITIONS (CONT'D)

EXHIBIT 4 PROPOSED 1990 TESTING





DETAIL 'A'

NOT TO SCALE

NOTE:

30% PERFORATED PLATE ON FBS.

LOWER GRANITE FGE

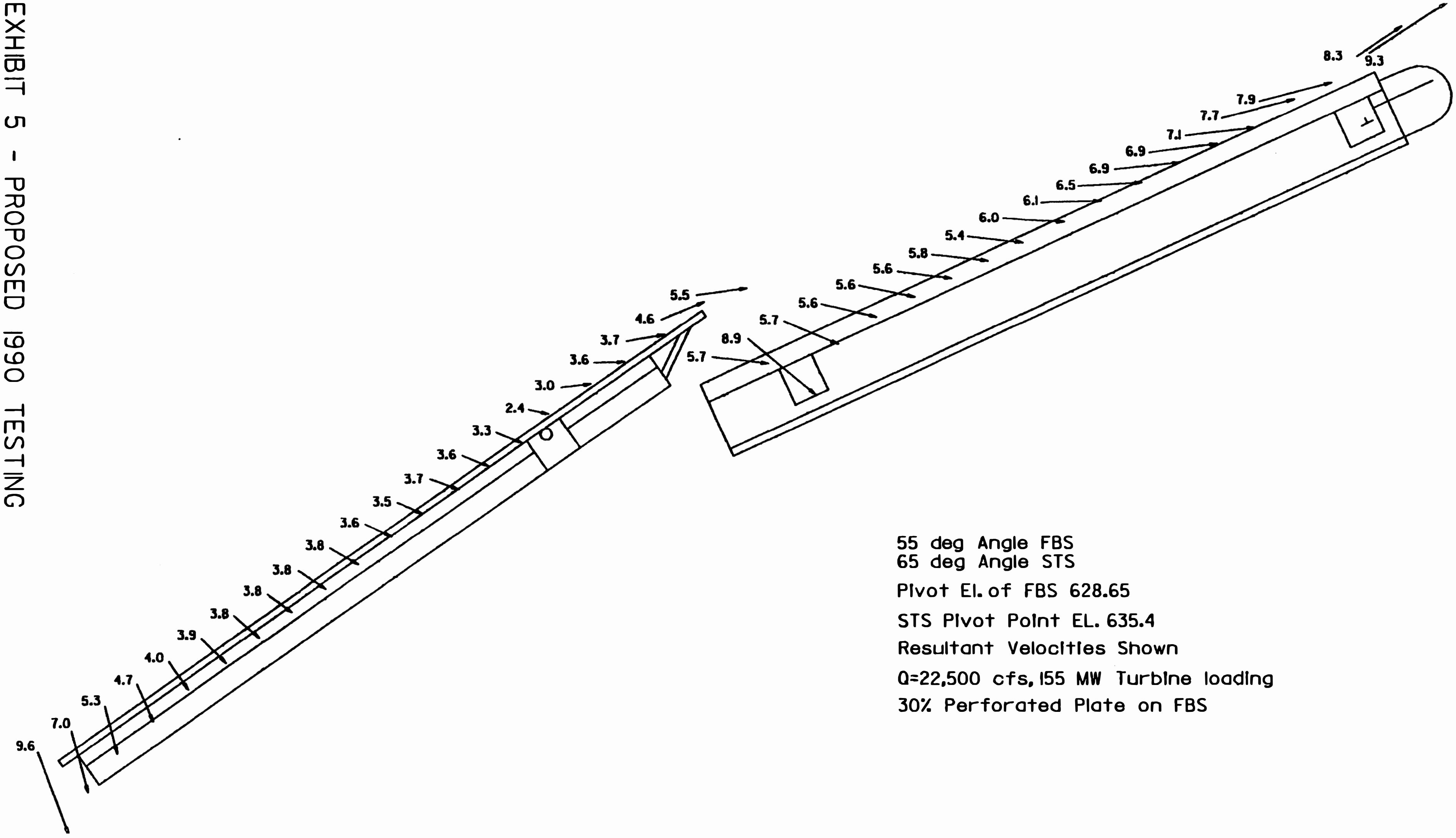
STS & DEFLECTOR ALIGNMENT

PROPOSED 1990 TESTING

U. S. Army Engineer District
Walla Walla Hydraulic Design
Emmert/Schuster Aug 1989

89ROTATE

EXHIBIT 5 - PROPOSED 1990 TESTING



55 deg Angle FBS
65 deg Angle STS

Pivot El. of FBS 628.65

STS Pivot Point EL. 635.4

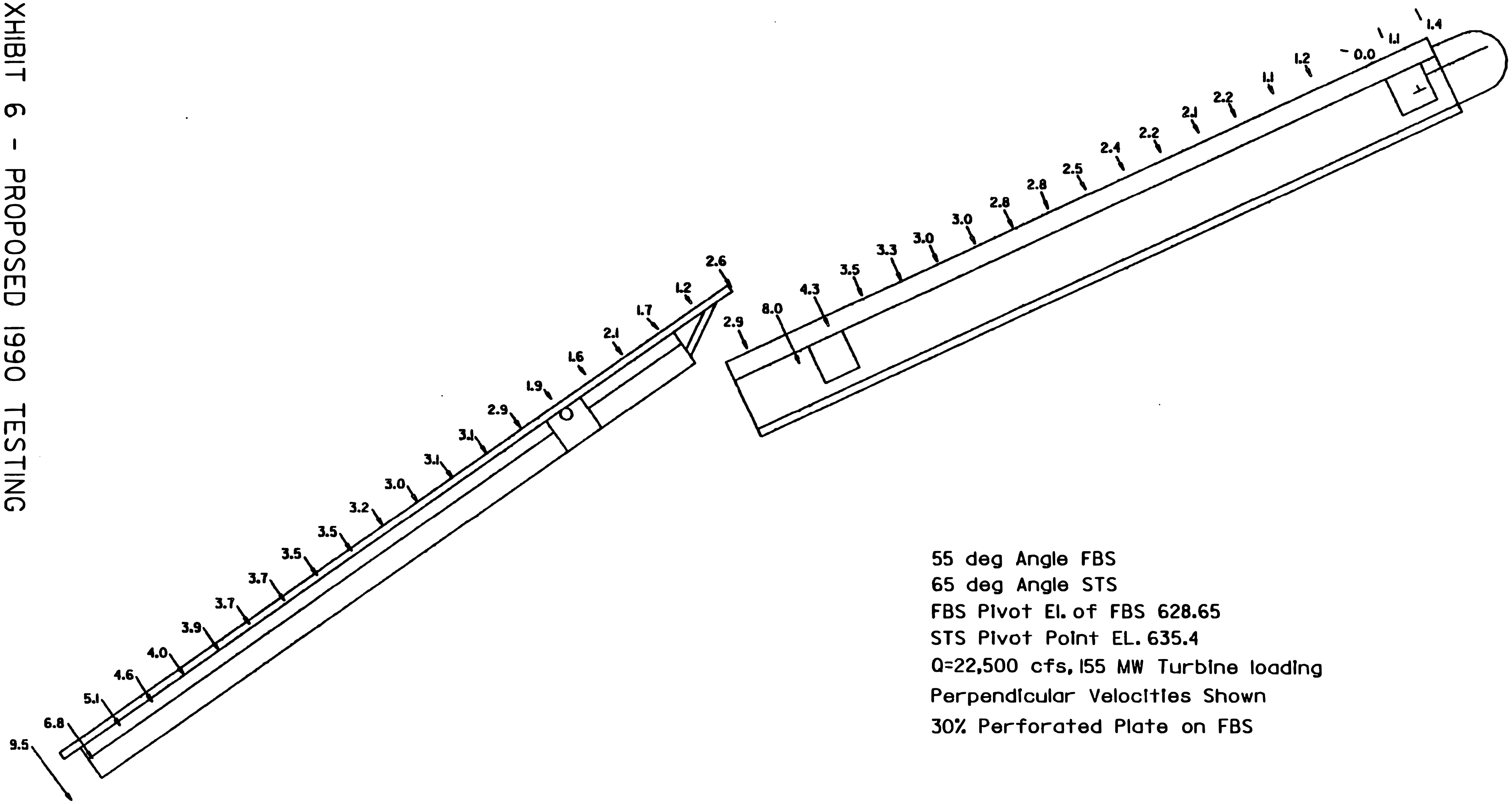
Resultant Velocities Shown

Q=22,500 cfs, 155 MW Turbine loading

30% Perforated Plate on FBS

CAI:[240.63]TESTNG.DGN;1
7-DEC-1989 12:42

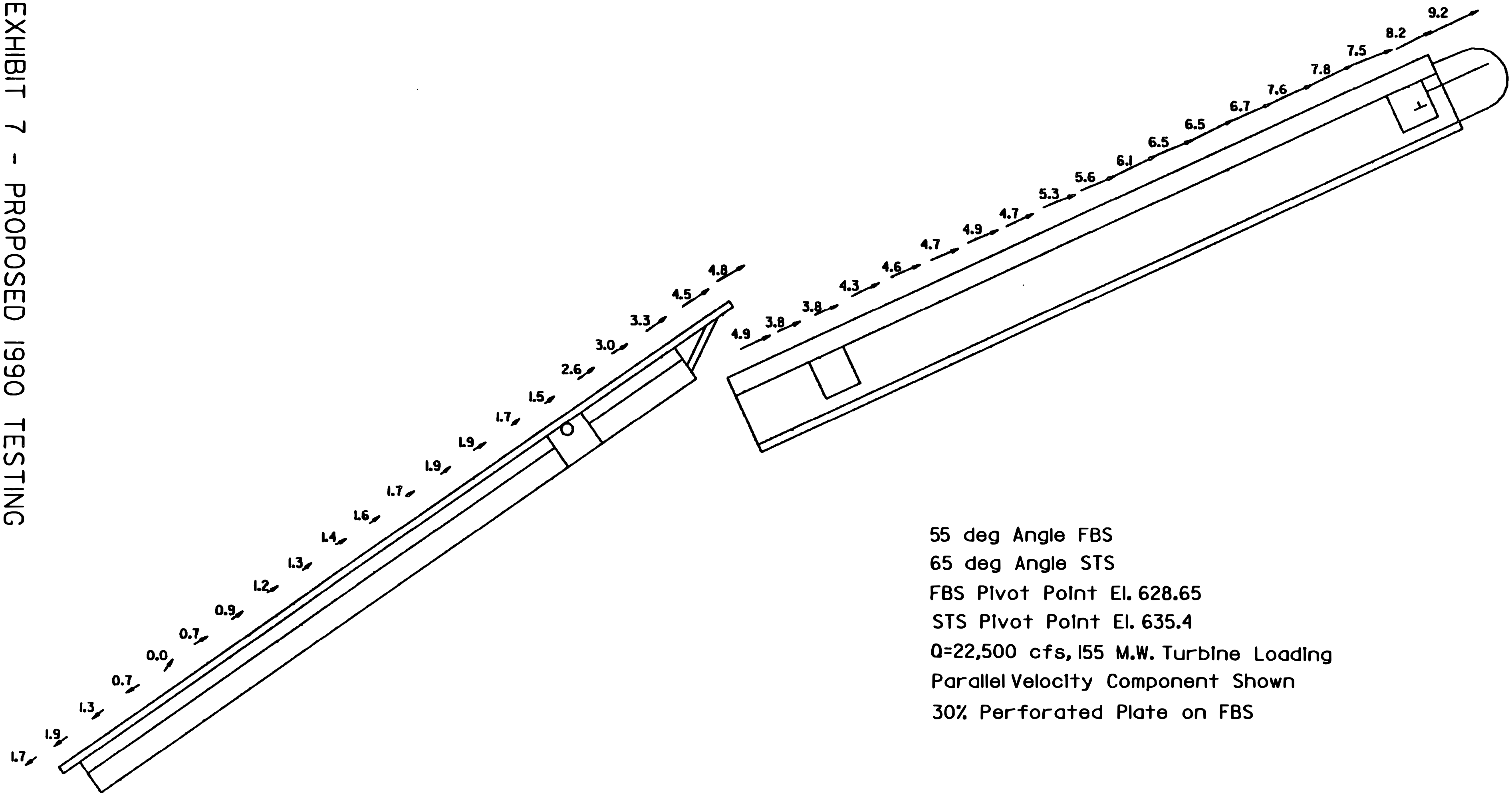
EXHIBIT 6 - PROPOSED 1990 TESTING



55 deg Angle FBS
65 deg Angle STS
FBS Pivot El. of FBS 628.65
STS Pivot Point EL. 635.4
Q=22,500 cfs, 155 MW Turbine loading
Perpendicular Velocities Shown
30% Perforated Plate on FBS

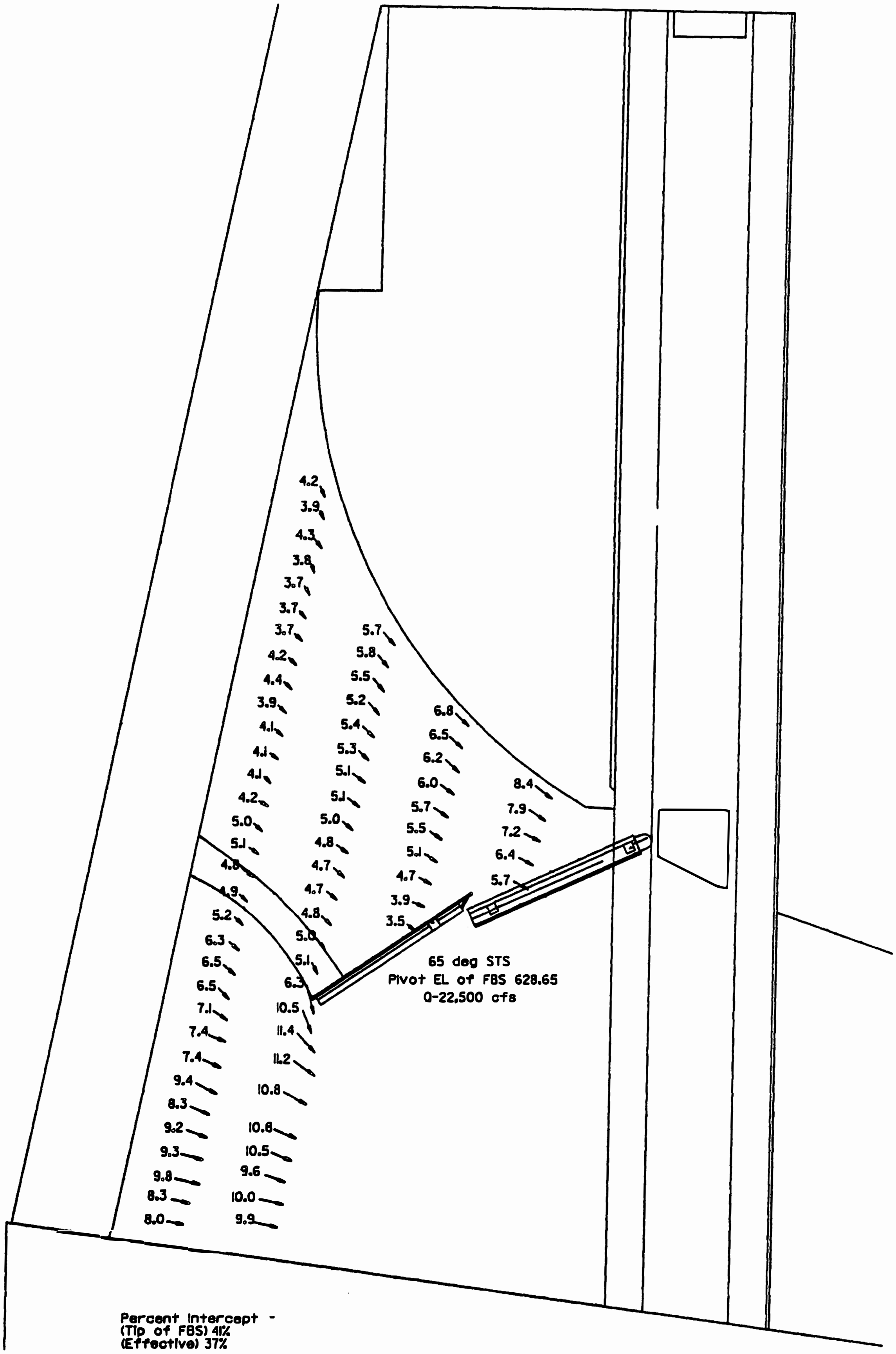
CA1:[240.6]TESTNG.DGN;1
7-DEC-1989 12:42

EXHIBIT 7 - PROPOSED 1990 TESTING



55 deg Angle FBS
65 deg Angle STS
FBS Pivot Point El. 628.65
STS Pivot Point El. 635.4
Q=22,500 cfs, 155 M.W. Turbine Loading
Parallel Velocity Component Shown
30% Perforated Plate on FBS

CAI:[240,6]TESTNG.DGN;1
7-DEC-1989 12:42



Percent Intercept -
(Tip of FBS) 41%
(Effective) 37%

EXHIBIT 8 - PROPOSED 1990 TESTING
PERCENT OF INTERCEPTED FLOW

EXHIBIT 9

UNIT #4 DATES & TIMES EXCEEDED 135 M.W. 10 APRIL - 1 MAY

LOWER GRANITE 1989

DATE	TIMES	HOURS & MINUTES	LOAD - M.W.
4-12	0805-1025	2 HRS. 20 MINUTES	140 M.W.
4-16	0215-0600	3 HRS. 45 MINUTES	140-150 M.W.
4-17	0150-155	0 HRS. 05 MINUTES	145 M.W.
4-20	0155-0525	3 HRS. 30 MINUTES	140 M.W.
4-20	0525-0600	0 HRS. 45 MINUTES	150 M.W.
4-21	0220-0655	4 HRS. 35 MINUTES	140 M.W.
4-21	1340-1510	1 HRS. 30 MINUTES	140-150 M.W.
4-22	0015-0800	0 HRS. 45 MINUTES	145-155 M.W.
4-22	1530-1610	0 HRS. 40 MINUTES	145-155 M.W.
4-23	0000-1330	13 HRS. 30 MINUTES	145-155 M.W.
4-23	2310-2400	0 HRS. 50 MINUTES	140-150 M.W.
4-24	0120-0755	8 HRS. 05 MINUTES	155 M.W.
4-25	2310-2340	0 HRS. 30 MINUTES	140-145 M.W.
4-26	0705-0720	0 HRS. 15 MINUTES	150 M.W.
4-26	0910-1000	0 HRS. 50 MINUTES	152 M.W.
4-27	0725-1030	3 HRS. 05 MINUTES	150-155 M.W.
4-27	1620-1740	1 HRS. 20 MINUTES	155 M.W.
4-27	2130-2300	1 HRS. 30 MINUTES	150-155 M.W.
4-28	1225-1510	2 HRS. 45 MINUTES	140-145 M.W.
4-29	2300-2400	1 HRS. 00 MINUTES	150-155 M.W.
4-30	0000-0100	1 HRS. 00 MINUTES	145-155 M.W.

EXHIBIT 9

CAI:[240.S3]TESTNG.DGN;1
7-DEC-1989 12:50

EXHIBIT 10-OPERATING RECORD

UNIT SERVICE RECORD

UNIT NO. 4

MONTH APRIL YEAR 1989

TOTALS	STANDBY	IN SERVICE	OUT OF SERVICE	TOTAL
TOTAL FOR MONTH				
PREV. TOTAL FOR YEAR	1185.15	739.50	234.75	2160.00
PRESENT TOTAL				

PAGE 1 OF 4

SERVICE HOURS, DECIMAL FORM					STANDBY		GENERATING		OUTAGES				
DAY	STBY	GEN	OOS	CHK TOT	TIME BEGIN	TIME END	TIME BEGIN	TIME END	TIME BEGIN	TIME END	TYPE OUT-AGE	NOTE NO.	REASON FOR OUTAGE
1	4.00	20.00		24.0	000	0400	0400	M					
2	1.50	2.50	TIME CHANGE		0330	0500	M	0330					
-	1.00	18.00		23.0	2300	M	0500	2300					
3	6.00	9.50			M	0600	0600	1530					
	8.50			24.0	1530	M							
4	11.75		4.00		M	1145			1145	1545	3A	4	INSTALL TRANSDUCER
-	8.25			24.0	1545	M							
5	7.00		17.00	24.0	M	0700			0700	M	3A	5	INSTALL TRANSDUCER
6			24.0	24.0					M	M			
7			24.0	24.0					M	M			
8			24.0	24.0					M	M			
9	0.50	7.00	16.50	24.0	1630	1700	1700	M	M	1630			
10		6.50	14.50				M	0630	0630	2100	3A	6	INSTALL TRANSDUCER
		3.00		24.0			2100	M					
11		1.00	4.25				M	0100	0100	0515	3A	7	FISH EFFICIENCY TESTING
-		10.30	7.25				0515	1545	1545	2300	3A	8	INSTALL BARRIER SCREENS AND FLAG NETS
-		1.00		24.0			2300	M					
12		1.25	3.50				M	0115	0115	0445	3A	9	TEST SCREEN REMOVAL
		5.50	9.75					1015	1015	2000	3A	10	INSTALL BAR SCREENS
-		1.25	2.75	24.0			2000	2115	2115	M	3A	11	TEST SCREEN REMOVAL
13		14.50	1.50				0130	1600	M	0130			
-		1.75	3.75				1945	2130	1600	1945	3A	12	TEST SCREEN INSERTION
-			2.50	24.0					2130	M	3A	13	TEST SCREEN REMOVAL
14		9.75	0.50				0030	1015	M	0030			
-		1.00	4.25				1430	1530	1015	1430	3A	14	INSTALL BAR SCREENS

CAI:[240,5]REC4.DGN;2

7-DEC-1989 12:47

UNIT SERVICE RECORD

UNIT NO. 4

MONTH APRIL YEAR 1989

TOTALS	STANDBY	IN SERVICE	OUT OF SERVICE	TOTAL
TOTAL FOR MONTH				
PREV. TOTAL FOR YEAR				
PRESENT TOTAL				

PAGE 2 OF 4

SERVICE HOURS, DECIMAL FORM					STANDBY		GENERATING		OUTAGES				
DAY	STBY	GEN	OOS	CHK TOT	TIME BEGIN	TIME END	TIME BEGIN	TIME END	TIME BEGIN	TIME END	TYPE OUT-AGE	NOTE NO.	REASON FOR OUTAGE
-		1.00	4.00				1930	2030	1530	1930	3A	15	FISH GUIDANCE TESTS
-			3.50	24.0					2030	2400	3A	16	FISH GUIDANCE TESTS
15		16.00	3.75				0000	1600	1600	1945	3A	17	FISH GUIDANCE TESTS
-		1.50	2.75	24.0			1945	2115	2115	M	3A	18	FISH GUIDANCE TESTS
16		15.50	.75				0045	1615	M	0045	3A		
-		1.50	3.25				1930	2100	1615	1930	3A	19	FISH GUIDANCE TESTS
-			3.00	24.0					2100	2400	3A	20	FISH GUIDANCE TESTS
17		10.00	9.50				0000	1000	1000	1930	3A	21	FISH GUIDANCE TESTS
-		1.50	3.00	24.0			1930	2100	2100	2400	3A	22	FISH GUIDANCE TESTS
18		8.00	11.50				0000	0800	0800	1930	3A	23	FISH GUIDANCE TESTS
-		1.25	2.50				1930	2045	2045	2315	3A	24	FISH GUIDANCE TESTS
-		.75		24.0			2315	M					
19		9.75	4.75				M	0945	0945	1430	3A	25	FISH GUIDANCE TESTS
-		1.75	3.25				1430	1615	1615	1930	3A	26	FISH GUIDANCE TESTS
-		1.00					1930	2030	2030	2300	3A	27	FISH GUIDANCE TESTS
-		1.00	2.50	24.0			2300	M					
20		9.25	4.75				M	0915	0915	1400	3A	28	FISH GUIDANCE TESTS
-		2.50	3.00				1400	1630	1630	1930	3A	29	FISH GUIDANCE TESTS
-		1.25	2.50				1930	2045	2045	2315	3A	30	FISH GUIDANCE TESTS
		.75		24.0			2315	M					
21		9.00	4.50				M	0900	0900	1330	3A	31	FISH GUIDANCE TESTS-INSTALL BAR SCREEN
		2.75	3.25				1330	1615	1615	1930	3A	32	FISH GUIDANCE TESTS-INSTALL BAR SCREEN
	.75	1.00	2.75	24.0	2315	2400	1930	2030	2030	2315	3A	33	FISH GUIDANCE TESTS-INSTALL BAR SCREEN
22		8.25	3.75				0000	0815	0815	1200	3A	34	FISH GUIDANCE TESTS-INSTALL BAR SCREEN
-		4.50	3.00				1200	1630	1630	1930	3A	35	FISH GUIDANCE TESTS-INSTALL BAR SCREEN

CAI:[240,5]REC2.DGN;2
7-DEC-1989 12:54

EXHIBIT 10-OPERATING RECORD (CONT'D)

EXHIBIT 10-OPERATING RECORD (CONT'D)

UNIT SERVICE RECORD

UNIT NO. 4

MONTH APRIL YEAR 1989

TOTALS	STANDBY	IN SERVICE	OUT OF SERVICE	TOTAL
TOTAL FOR MONTH				
PREV. TOTAL FOR YEAR				
PRESENT TOTAL				

PAGE 3 OF 4

SERVICE HOURS, DECIMAL FORM					STANDBY		GENERATING		OUTAGES				
DAY	STBY	GEN	OOS	CHK TOT	TIME BEGIN	TIME END	TIME BEGIN	TIME END	TIME BEGIN	TIME END	TYPE OUT-AGE	NOTE NO.	REASON FOR OUTAGE
-		1.00	3.25				1930	2030	2030	2345	3A	36	FISH GUIDANCE TESTS-INSTALL BAR SCREEN
		.25		24.0			2345	M					
23		16.25	3.25				M	1615	1615	1930	3A	37	FISH GUIDANCE TESTS
-		1.00	2.50				1930	2030	2030	2300	3A	38	FISH GUIDANCE TESTS
-		1.00		24.0			2300	M					
24		10.50	3.50				M	1030	1030	1400	3A	39	FISH GUIDANCE TESTS
-		2.25	3.25				1400	1615	1615	1930	3A	40	FISH GUIDANCE TESTS
-		1.25	2.25				1930	2045	2045	2300	3A	41	FISH GUIDANCE TESTS
-		1.00		24.0			2300	M					
25		9.75	3.75				M	0945	0945	1330	3A	42	FISH GUIDANCE TESTS
-		2.75	3.25				1330	1615	1615	1930	3A	43	FISH GUIDANCE TESTS
-		1.25	2.00				1930	2045	2045	2245	3A	44	FISH GUIDANCE TESTS
-		1.25		24.0			2245	M					
26		9.25	3.25				M	0915	0915	1230	3A	45	FISH GUIDANCE TESTS
-		3.75	3.25				1230	1615	1615	1930	3A	46	FISH GUIDANCE TESTS-SWAN
-		1.25	2.50				1930	2045	2045	2315	3A	47	FISH GUIDANCE TESTS-SWAN
-		.75		24.0			2315	M					
27		9.25	4.00				M	0915	0915	1315	3A	48	N.M.F.S. TESTS
-		3.00	3.25				1315	1615	1615	1930		49	N.M.F.S. TESTS
-		1.25	2.50				1930	2045	2045	2315		50	N.M.F.S. TESTS
-		.75		24.0			2315	M					
28		11.00	8.75				M	1100	1100	1945	3A	51	FISH GUIDANCE TESTS
		.75	3.50	24.0			1945	2030	2030	M	3A	52	
	.75	143.25	96.00	240.00									
SUB	49.25	314.25	307.50	671.00									

CAI:[240.5]REC3.DGN;2
7-DEC-1989 12:57

EXHIBIT 10-OPERATING RECORD (CONT'D)

UNIT SERVICE RECORD
UNIT NO. 4

MONTH APRIL YEAR 1989

TOTALS	STANDBY	IN SERVICE	OUT OF SERVICE	TOTAL
TOTAL FOR MONTH				
PREV. TOTAL FOR YEAR				
PRESENT TOTAL				

PAGE 4 OF 4

SERVICE HOURS, DECIMAL FORM					STANDBY		GENERATING		OUTAGES				
DAY	STBY	GEN	OOS	CHK TOT	TIME BEGIN	TIME END	TIME BEGIN	TIME END	TIME BEGIN	TIME END	TYPE OUTAGE	NOTE NO.	REASON FOR OUTAGE
29		13.00	1.00				0100	1400	M	0100	3A	52	N.M.F.S. TESTS
-		1.50	5.50				1930	2100	1400	1930	3A	53	N.M.F.S. TESTS
			3.00	24.0					2100	2400	3A	54	N.M.F.S. TESTS
30		11.00	8.50				0000	1100					
		2.00	2.50	24.0			1930	2130	1100	1930	3A	55	
									2130	M	3A	56	N.M.F.S. TESTS
		27.30	2050	48.00									
SUB	49.25	314.25	307.50	671.00									
	49.25	341.75	328.00	719.00									

CAI:[240.5]REC5.DGN;2
7-DEC-1989 12:59

EXHIBIT 10-OPERATING RECORD (CONT'D)

UNIT SERVICE RECORD

UNIT NO. 4

MONTH MAY YEAR 1989

TOTALS	STANDBY	IN SERVICE	OUT OF SERVICE	TOTAL
TOTAL FOR MONTH				
PREV. TOTAL FOR YEAR	1235.00	1081.25	562.75	2879.00
PRESENT TOTAL				

PAGE 1
OF

SERVICE HOURS, DECIMAL FORM					STANDBY		GENERATING		OUTAGES				
DAY	STBY	GEN	OOS	CHK TOT	TIME BEGIN	TIME END	TIME BEGIN	TIME END	TIME BEGIN	TIME END	TYPE OUT-AGE	NOTE NO.	REASON FOR OUTAGE
1		16.25	.25				0015	1630	M	0015	3A	56	CONTINUED
-		1.50	3.50				2000	2130	1630	2000	3A	57	N.M.F.S. FISH TESTS
-			2.50	24.0					2130	M	3A	58	N.M.F.S. FISH TESTS
2		3.75	1.00				0100	0445	M	0100			
-		16.00	3.25	24.0			0800	M	0445	0800	3A	59	N.M.F.S. FISH TESTS
3		9.00	6.75				M	0900	0900	1545	3A	60	N.M.F.S. FISH TESTS
-		8.25		24.0			1545	M					
4		10.00	2.25				M	1000	1000	1215	3A	61	N.M.F.S. FISH TESTS
-		11.75		24.0			1215	M					
5		10.00	2.00				M	1000	1000	1200	3A	62	N.M.F.S. FISH TESTS
-		12.00		24.0			1200	M					
6		9.00	2.75				M	0900	0900	1145	3A	63	N.M.F.S. FISH TESTS
-		12.25		24.0			1145	M					
7		9.25	1.00				M	0915	0915	1015	3A	64	N.M.F.S. FISH TESTS
-		13.75		24.0			1015	M					
8		7.00					M	0700	0700		3A	65	EXCHANGE STS

CA1:[240.5]REC1.DGN;2
7-DEC-1989 13:01