BIOLOGICAL PERFORMANCE TESTS

of

EAST FORK IRRIGATION DISTRICT'S

SAND TRAP AND FISH SCREEN FACILITY

PHASE I – 1999

conducted for

EAST FORK IRRIGATION DISTRICT

J. W. Buell, Ph.D.

BUELL & ASSOCIATES, Inc.

2708 S.W. Bucharest Ct.
Portland OR 97225
(503) 203-1248
buell@interserv.com

January 2000

ABSTRACT

East Fork Irrigation District (EFID) operates an irrigation diversion on the East Fork Hood River, withdrawing up to 127 cfs, near Parkdale, OR. Very high glacial sand/silt content of the diverted water necessitates separation of sand at a facility near the point of diversion. A fish screen incorporated into the sand separation facility uses a "prototype" technology with a horizontal profile-bar "Coanda" screen fitted into the downstream face of an overflow ogee-shaped weir. This design results in calculated approach velocities significantly exceeding generally accepted fish protection criteria, although sweeping velocities are very high and exposure times for fish passing over the weir/screen are less than one second. Biological performance tests were conducted in the spring of 1999 to determine if passage over the weir/screen components of the sand separation and fish screen facility would result in fish injury or latent mortality. Newly buttoned-up chinook salmon and steelhead fry (30-50 mm FL) and steelhead smolts (130-260 mm FL) were used for the tests. Results indicate that no injuries, behavioral anomalies or latent mortalities resulted from passage over the weir/screen for any of the three species / life stages of fish tested. Results are compared to other biological performance studies of fish screens throughout the region. It is concluded that the static, horizontal profile bar overflow weir "Coanda" type fish screens incorporated into EFID's sand trap and fish screen facility perform at least as well as any of the other screening systems reported and better than most. It is also concluded that incorporation of this technology into the EFID facility does not pose an injury or latent mortality threat to juvenile salmonid fishes in the system.

ACKNOWLEDGMENTS

Mike Lambert and Mick Jennings of the Confederated Tribes of the Warm Springs (CTWS) and Jim Newton of Oregon Department of Fish and Wildlife (ODFW) made very significant contributions of time, effort and expertise to the execution of these tests. All three of these individuals and some of their staff were present and participated in the actual testing and evaluation, and their efforts are gratefully acknowledged. Mark Wharry of SJO Consulting Engineers and John Buckley of East Fork Irrigation District and some of his staff were also present and participated in the execution of these tests, and their efforts are also gratefully acknowledged. Both ODFW and CTWS contributed test fish, without which these tests would have been impossible.

BIOLOGICAL PERFORMANCE TESTS OF EAST FORK IRRIGATION DISTRICT'S SAND TRAP AND FISH SCREEN FACILITY

PHASE I – 1999

J.W. Buell, Ph.D.

BACKGROUND

East Fork Irrigation District operates an irrigation diversion on the East Fork Hood River near Parkdale OR. This diversion is operated pursuant to a Water Right issued by Oregon Water Resources Department, which permits withdrawal of up to 127 cfs. Since the East Fork Hood River is primarily of glacial origin and carries a prodigious sand load, a sand trap has been operated approximately 1/2 mi from the diversion point, with sand sluiced back to the main river. In recent years it had become apparent that the aging sand trap structure was in need of replacement. SJO Consulting Engineers Inc. (SJO) was retained by the District to design a replacement sand trap facility and to investigate passive fish screening facility options in order to comply with Oregon Department of Fish and Wildlife (ODFW) requirements for a suitable protective screen on this sediment-laden diversion. Final design and construction of the sand trap and screening facility was fast-tracked as a result of complete destruction of the old sand trap by the 1996 flood.

Diversion of water from the East Fork Hood River presents some relatively unusual and difficult problems. The glacial origin of this stream results in an unusual hydrology, with relatively high discharge occurring during the warmer summer months, especially during sunny periods, and with large daily fluctuations due to higher altitude temperature cycles. In addition, a large proportion of the sand load is delivered during the irrigation season, when water is being diverted. One design specification which affects selection of a screening approach is the need to separate, retain and eventually dispose of at least 1,000 yards of sand within an 8-hour period. This need and the direct experience of the District with excessive wear caused by suspended fine sand particles on moving parts associated with conventional fish screen designs, along with certain site limitations, led the District and SJO to explore "unconventional" designs for fish screens. After review of several alternative passive approaches, SJO recommended a system incorporating a horizontal profile bar screen surface fitted into the face of an overflow weir, sometimes called a "Coanda" type screening system. This static, overflow weir, horizontal profile bar screen was conceptually developed and presented to ODFW and the Confederated Tribes of the Warm Springs Reservation of Oregon (CTWS) as the preferred solution to fish screening requirements. This design was then incorporated into a "sectionalized" sand trap facility which could be constructed near the head of the EFID East Fork Hood River irrigation ditch and which would be capable of continuously separating sand from diverted water during periods of high suspended load concentration and sluicing it back to the river.

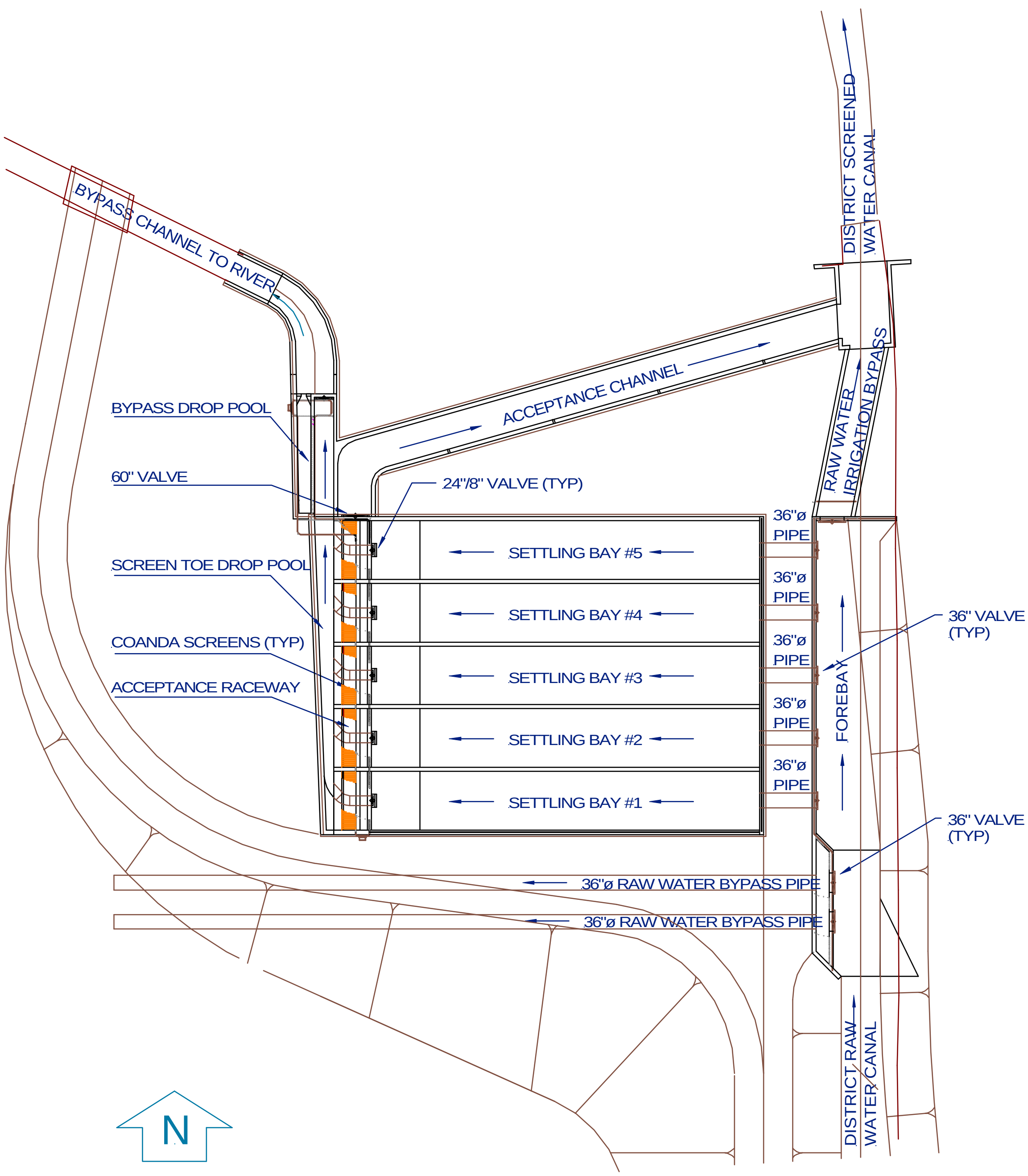
Although several systems of this type had been installed in the West, notably in Montana and California and usually across entire natural stream channels, biological performance tests to ascertain the safety of these facilities for fish passing over them had not been conducted. In addition, calculated and measured approach velocities for screens of this type are significantly in excess of those generally applied to fish screens to prevent impingement or injury (Wahl, 1995; NMFS, 1995), although sweeping velocities are very high and exposure times for fish passing over the screen is extremely short compared to most other screen designs (less that one second). Regulatory agencies and other interested parties, such as CTWS, were therefore reluctant to endorse application of the overflow weir face screen concept, especially for systems supporting anadromous fish.

Due to the lack of biological performance data for Coanda-type screening facilities, it was agreed among the District, ODFW and CTWS that biological performance tests would be conducted on a small prototype version of a full-height section of the proposed screening system. The purpose of these tests was to address the lack of knowledge regarding the biological performance of overflow weir profile bar ("Coanda") screens. Biological performance tests were conducted by Buell and Associates, Inc. with the participation of Mick Jennings and Mike Lambert, CTWS, and Jim Newton, ODFW. Tests were conducted in late June and early July, 1996 at the powerhouse of the Middle Fork Irrigation District's hydroelectric project on the Middle Fork Hood River. Results of these tests are included in a report "Biological Performance Evaluation of an Overflow Weir Profile Bar Fish Screen for East Fork Irrigation District" (Buell & Associates, Inc. 1996). Test results demonstrated no adverse consequences for juvenile chinook salmon and steelhead passing over the screen section, and it was concluded that there was no reason based on the potential for fish injury due to passage over the overflow screen to delay installation of this type of screen in the new sand trap facility. It was agreed among the parties, however, that a similar test of the fully constructed and operational facility would be appropriate, in order to confirm the results of prototype tests.

Following approval by ODFW and concurrence on the part of CTWS, SJO commenced with fast-track final design for the new facility. Construction commenced in the Spring of 1996 and the new facility was operational by the start of the irrigation season of 1997. Modifications to correct certain hydraulic problems were implemented after the first season, and the modified, fully operational facility was completed by the spring of 1998. A plan view of the completed facility is shown in Figure 1. Screens incorporated into this facility consist of dual 6-ft wide panels in each 12-ft wide bay. The arc of the slightly concave screen surface is 4 ft in length. Clear spaces between the horizontal profile bars are 1 mm. The profile bars themselves are slightly "canted" at an angle of about 5° to the screen surface to enhance the "Coanda effect" (the tendency of a fluid to "follow" the surface over which it is flowing) and improve the efficiency of water flow through the screen.

National Marine Fisheries (NMFS) was re-engaged in discussions surrounding the East Fork Irrigation District sand trap and screen facility in the spring of 1998. Draft study plans for the biological performance evaluation of the completed facility were submitted to ODFW, CTWS and NMFS for review and comment at that time. Following incorporation of changes suggested by review by these parties, the first phase of testing, focusing on the overflow screens themselves, was scheduled for the spring of 1999.

Figure 1



FACILITY DIAGRAM
EAST FORK IRRIGATION SAND TRAP / HEAD GATE

METHODS

During the week of 17 May 1999, biological evaluation tests were conducted at the new fish screens at the EFID Sand Trap adjacent to the East Fork Hood River. Cooperating in these tests were the Confederated Tribes of the Warm Springs (CTWS) and the Oregon Department of Fish and Wildlife (ODFW). Several groups each of newly emergent fry and smolt life stages of winter steelhead and the newly emergent fry life stage of spring chinook were subjected to passage over the fish screens in order to determine if any injury or other adverse effects would result. Appropriate control groups were subjected to handling and inspection procedures, but were not passed over the screens. Water levels in the sand trap and fish screen facility were adjusted to reflect normal operating conditions, with the lower portion of the fish screen submerged and the upper portion continuously wetted (see Figure 2).

Prior to introduction into the system, all experimental and control fish were anaesthetized (MS-222) and individually inspected for prior injuries, including any scale loss, and data were recorded for comparison to comparable data taken after testing. For fry, only fish in “perfect” condition (no injuries or anomalies of any kind observed) were used. For steelhead smolts, all fish exhibited some scattered scale loss; the percent scattered scale loss on each side of the fish was recorded prior to use.

Following recovery from the anaesthetic, experimental fish were introduced to the system at the crest of the overflow weir in Bay No. 2. Figure 2 shows the arrangement of elements for settling bays and associated screens. Care was taken to assure that experimental fish were immersed fully into the water column prior to passage over the screen below. After passage over the weir and screen face, fish were retained in a specially constructed “catch net” deployed in the bypass channel below the screen (Figure 3; Appendix A). Normal operation of the facility calls for submersion of the lower one-third of the screen surface; this condition was maintained throughout testing. After all fish in each group had passed down the screen face into the catch net, the net was hoisted and fish were concentrated in a 5-gal bucket fastened to the bottom of the net. The bucket and its contents were then removed, the fish re-anaesthetized and inspected for injuries, and data were recorded. Control fish were handled identically to experimental fish, except these groups were introduced directly into the catch net without passing over the screen face.

Injuries for which fish were inspected include:

- “Excessive” descaling (sometimes considered a “presumed mortality”);
- Scattered or general scale loss
- Patterns of scale loss (scrapes, patches indicating abrasive direct contact);
- Split or frayed fins;
- Bruises, cuts or skin abrasions;
- Eye injuries including corneal abrasions, internal hemorrhages and ruptured lenses.

Specific criteria for “excessive descaling” have evolved for more than a decade. Criteria for this evaluation are the same as those given in several recent evaluation reports for large diversion facilities in Oregon and Washington (*e.g.* Neitzel *et al.* 1985; Congleton *et al.* 1988; Neitzel *et al.*

Figure 2

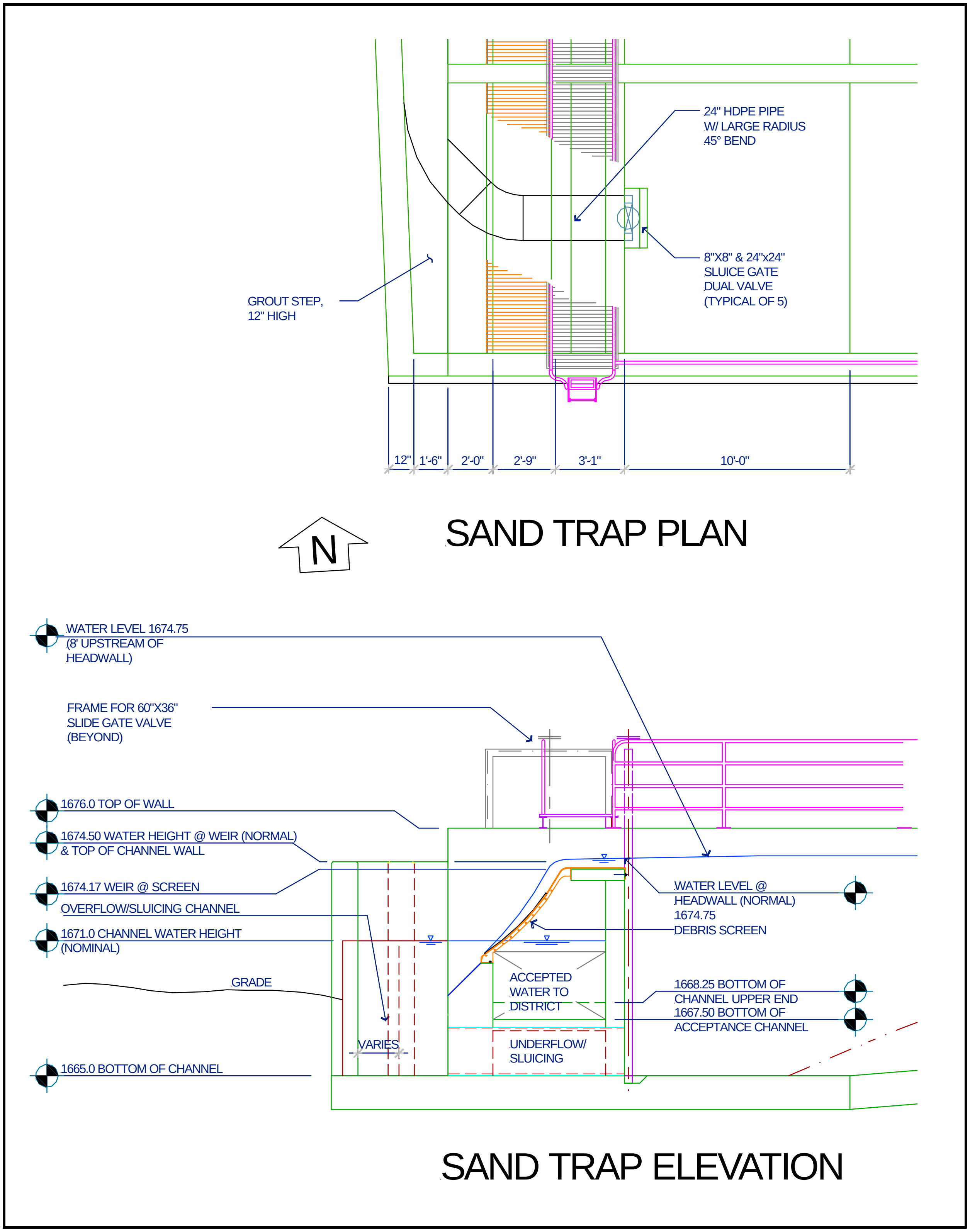
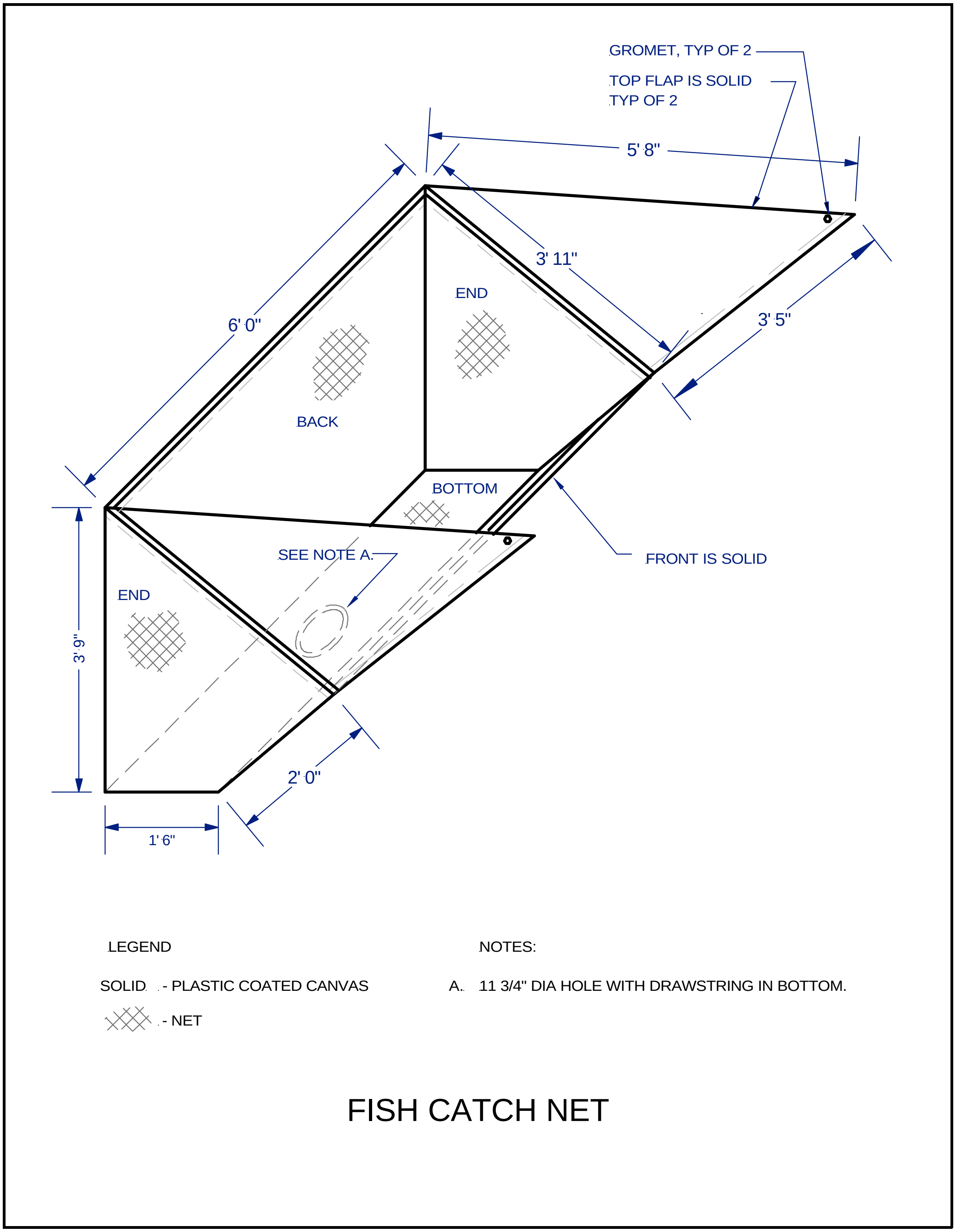

24" HDPE PIPE
W/ LARGE RADIUS
45° BEND
8"X8" & 24"x24"
SLUICE GATE
DUAL VALVE
(TYPICAL OF 5)
GROUT STEP,
12" HIGH
12"
1'-6"
2'-0"
2'-9"
3'-1"
10'-0"
N
SAND TRAP PLAN
WATER LEVEL 1674.75
(8' UPSTREAM OF
HEADWALL)
FRAME FOR 60"X36"
SLIDE GATE VALVE
(BEYOND)
1676.0 TOP OF WALL
1674.50 WATER HEIGHT @ WEIR (NORMAL)
& TOP OF CHANNEL WALL
1674.17 WEIR @ SCREEN
OVERFLOW/SLUICING CHANNEL
1671.0 CHANNEL WATER HEIGHT
(NOMINAL)
GRADE
VARIES
1665.0 BOTTOM OF CHANNEL
WATER LEVEL @
HEADWALL (NORMAL)
1674.75
DEBRIS SCREEN
ACCEPTED
WATER TO
DISTRICT
1668.25 BOTTOM OF
CHANNEL UPPER END
1667.50 BOTTOM OF
ACCEPTANCE CHANNEL
UNDERFLOW/
SLUICING
SAND TRAP ELEVATION

Figure 3


GROMET, TYP OF 2
TOP FLAP IS SOLID
TYP OF 2
5' 8"
3' 11"
END
6' 0"
3' 5"
BACK
BOTTOM
FRONT IS SOLID
SEE NOTE A.
END
3' 9"
2' 0"
1' 6"
LEGEND
SOLID - PLASTIC COATED CANVAS
- NET
NOTES:
A. 11 3/4" DIA HOLE WITH DRAWSTRING IN BOTTOM.
FISH CATCH NET

1990a,1990b; Hosey & Associates 1990), which are those developed by Basham *et al.* (1982), as modified by Neitzel *et al.* (1985). In essence, using these criteria, a fish is considered "descaled" and an "assumed mortality" if visual observation indicates that >40% of scales within any two of five zones on each side of the fish, or if the summation of scale loss is ≥40% of the area of two or more zones on one side of the fish (Neitzel *et al.* 1985). The rate of occurrence of "descaled" fish (according to the criteria given above) is added to the direct mortality rate to arrive at an assumed mortality for the test. In the evaluations cited above, other injuries were noted, but were apparently not taken into account in calculating a mortality rate in the performance evaluation. More recently, the use of zones on the sides of fish is not often used; NMFS has indicated that researchers instead tend to report the percent scale loss on each side of the body. A criterion for "descaling" presently being used is ≥20% per side of the body (total possible maximum of ≥40%). This criterion was chosen for these tests since it is more simple and straightforward.

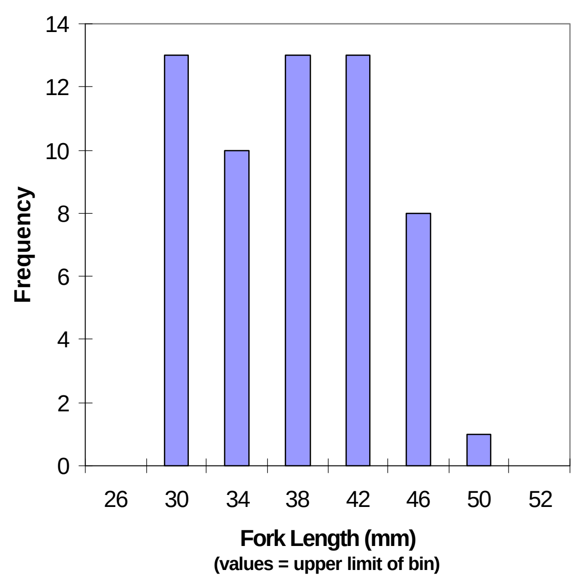
All experimental and control fish were held in net pens in Settling Bay No. 1 for 96 hours after testing to see if latent mortality would occur and could be attributable to exposure to the screen. These fish were checked daily for latent mortalities and anomalous behavior.

STEELHEAD FRY TESTS

Winter steelhead fry were obtained from ODFW's Oak Springs Hatchery. These fish averaged 36.4 mm in fork length (FL) (n=58; S.D.=5.80). A length-frequency histogram for a sub-sample of these fish (n=58) is given in Figure 4. Test fish were held in 64 ft^3 net pens in the sand trap section of the facility until use, and thereafter for a 96-hr latent mortality observation.

Figure 4

Steelhead Fry
Length-Frequency Histogram



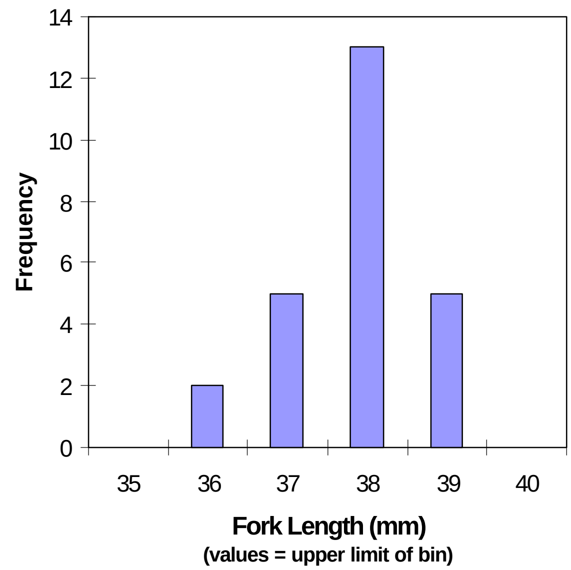
Five experimental groups of approximately 50 winter steelhead fry were carefully inspected for physical condition (Appendix A) and released at the crest of the screen weir and allowed to pass naturally over the screen to the bypass pool below. Following recovery, fish were again carefully inspected for physical condition and behavior, and any change in condition was noted. Five control groups of approximately 50 fish each were inspected, released directly into the net at the toe of the screen and subjected to the same recovery and inspection procedures as experimental fish. Since it was impossible to render the recovery net completely "fish-tight", especially for fry, fewer fish were sometimes recovered than were released. This does not invalidate the tests, however, since sufficient fish were recaptured to evaluate the groups for injury or other effects of passage and handling. All fish were held for a 96-hr latent mortality test.

SPRING CHINOOK FRY TESTS

Newly emergent spring chinook fry were obtained from CTWS' Parkdale facility for use in these tests. These fish averaged 36.8 mm FL (n=25; S.D.=0.85). A length-frequency histogram of a sub-sample of these fish (n=25) is given in Figure 5. Five experimental groups and three control groups of approximately 50 spring chinook fry each were carefully inspected for physical condition and released at the crest of the screen weir and allowed to pass naturally over the screen to the bypass pool below. In some cases, chinook fry were not completely "buttoned up" (the ventral slit through which the yolk sac had protruded during embryonic and "sac fry" development, was not yet closed); these fish, although otherwise in good condition, were rejected for use in these tests. Fish were recaptured and inspected using the same procedures as for steelhead fry. As with steelhead fry, the recapture net proved not to be completely "fish-tight", and not all released fish were recaptured; as with winter steelhead fry, this does not invalidate these tests since sufficient fish were recaptured to evaluate the groups for injury and other effects of passage and handling. All fish were held for a 96-hr latent mortality test.

Figure 5

Spring Chinook Fry
Length-Frequency Histogram

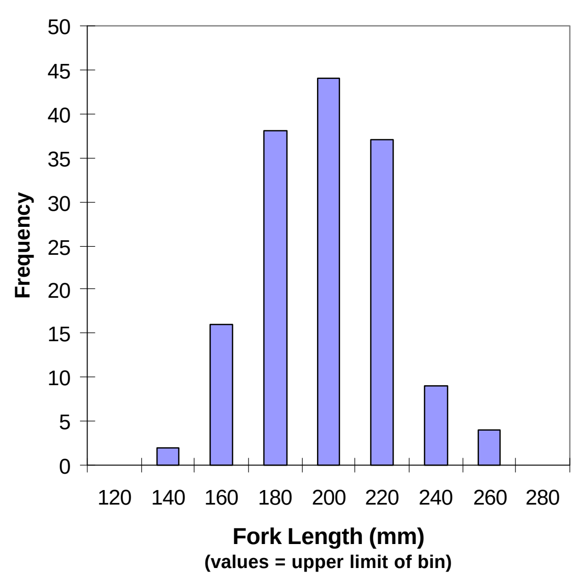


STEELHEAD SMOLT TESTS

Steelhead smolts for these tests were originally derived from ODFW's Oak Springs Hatchery and had been held for about two weeks as part of CTWS's steelhead enhancement program in one of the EFID sand trap bays for acclimation and imprinting to the East Fork Hood River water prior to release. Individuals used in these tests had not yet migrated volitionally from the facility and were therefore readily available as test subjects. These fish averaged 189 mm FL (n=150; S.D.=23.7) and 725 gm in weight (n=150; S.D.=296). A length-frequency histogram of these fish is given in Figure 6; the length-weight relationship is depicted in Figure 7. Twelve experimental groups and eleven control groups of

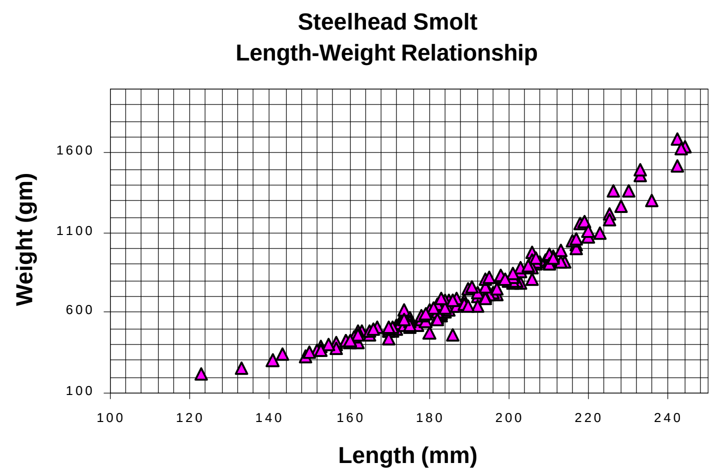
Figure 6

Steelhead Smolt
Length-Frequency Histogram



approximately 20 winter steelhead smolts were carefully inspected for physical condition and released into a specially constructed holding net immediately upstream of the crest of the screen weir (Appendix A). This net was then slowly tipped toward the weir crest to "encourage" the fish to pass over the weir, down the screen face and into the bypass pool below. At the request of NMFS, some of these fish were placed in this net enclosure, which was open to the crest of the weir, to observe how long it would take before these fish would voluntarily move over the weir crest, and whether there would be behavioral or injury rate differences between "volunteers" and fish "encouraged" to pass. As in the fry tests, recaptured fish were carefully inspected for physical condition and data were recorded. All fish were held for a 96-hr latent mortality test.

Figure 7



Particular attention was given to the degree of scale loss for steelhead smolts, since these fish have "deciduous" scales which are easily shed, and since the degree of scale loss for this life stage has been traditionally used in fish screen biological performance tests as a measure of fish injury or stress. It was noted that virtually all fish in the lot from which both experimental and control fish were drawn showed some scattered scale loss (Appendix A). This was attributed to collection from the sand trap bay in which the fish had been held for acclimation. Since it is virtually impossible to estimate the percent of missing scales with this loss pattern with great precision, estimates were made to the nearest 5%. Scale loss data for the left and right sides of each fish were recorded separately to increase statistical power and to determine if any discernable scale loss patterns (*e.g.* one side only) would be produced by passage over the fish screens. Only fish with scattered scale loss of less than 10% on any one side were selected for use either as experimental or control fish. No fish was encountered with less than 5% scattered scale loss on any one side. As with the fry tests, the recapture net proved not to be completely "fish-tight", and not all released fish were recaptured. In addition, steelhead smolts are powerful enough swimmers that a few individuals left the release net and were able to swim against the rather strong current at the weir crest and escape into the sand trap bay, accounting for most of the incomplete recapture. These differences did not invalidate the statistical tests, however.

RESULTS

STEELHEAD FRY TESTS

Of the 260 experimental fish released in five groups, 202 were recaptured and inspected for any injuries or other anomalies. No injuries or behavioral or other anomalies of any kind were observed. Of the 260 control fish released, 250 were recovered and inspected. No injuries or behavioral or other anomalies of any kind were observed. Data are summarized in Table 1.

Both experimental and control fish were held for 96 hours in net pens to determine if any latent mortalities attributable to passage over the fish screens would result. No mortalities or behavioral anomalies were observed for any fish in either group during this period.

SPRING CHINOOK FRY TESTS

Of the 260 experimental fish released in five groups, 244 were recovered and inspected. No injuries or behavioral or other anomalies of any kind were observed. Of the 156 control fish released in three groups, 134 were recovered and inspected. No injuries or behavioral or other anomalies of any kind were observed. Data are summarized in Table 1. The reason that only three control groups were used is because it was apparent from observations of experimental fish that neither passage over the screen nor handling/inspection was causing any injuries or behavioral anomalies, and there would be little or no utility in proceeding with all five control groups.

Both experimental and control fish were held for at least 96 hours in net pens to determine if any latent mortalities attributable to passage over the fish screens would result. No mortalities or behavioral or other anomalies were observed for any fish in either group during this period.

STEELHEAD SMOLT TESTS

Of the 240 experimental fish released (in 12 groups), 232 were recovered and inspected. A slight increase in the amount of scattered scale loss was generally detected (Table 2). Scattered scale loss for experimental fish increased from about 7.5% to about 8.1 % of the body surface, an increase of 0.5 - 0.6%. Beyond this slight but rather consistent increase in scattered scale loss, no injuries or behavioral anomalies of any kind were observed. No pattern of scale loss (*e.g.* one side only; "scrapes" or "patches") was detected.

Of the 224 control fish released (in 11 groups), 219 were recovered and inspected. As with the experimental fish, a slight increase in the amount of scale loss was generally detected (Table 2). Scattered scale loss for experimental fish increased from about 6.7% to about 7.2 - 7.3% of the body surface, an increase of 0.5 - 0.6%. Beyond this slight but rather consistent increase in scattered scale loss, no injuries or behavioral anomalies of any kind were observed. No pattern of scale loss was detected. The slight increase in scattered scale loss for control fish is almost exactly the same as that for experimental fish.

TABLE 1

EAST FORK IRRIGATION DISTRICT
FISH SCREEN BIOLOGICAL PERFORMANCE TESTS – 1999

DATA SUMMARY

STEELHEAD FRY TESTS

	Trial	# released	# recovered (n)	Observations
Test fish:	1	52	45	
	2	52	54	
	3	52	42	
	4	52	29	
	5	52	32	
		260	202	No injuries of any kind
Control fish:	1	52	52	
	2	52	52	
	3	52	51	
	4	52	44	
	5	52	51	
		260	250	No injuries of any kind

SPRING CHINOOK FRY TESTS

	Trial	# released	# recovered (n)	
Test fish:	1	52	50	
	2	52	49	
	3	52	48	
	4	52	51	
	5	52	46	
		260	244	No injuries of any kind
Control fish:	1	52	49	
	2	52	35	
	3	52	50	
		156	134	No injuries of any kind

TABLE 2

EAST FORK IRRIGATION DISTRICT
FISH SCREEN BIOLOGICAL PERFORMANCE TESTS – 1999

DATA SUMMARY – STEELHEAD SMOLT TESTS

	Trial	# released	# recovered (n)	Observations	
Test fish:					
	1	20	20	Average scattered scale loss	
	2	20	16	*before* release/recovery:	
	3	20	20		
	4	20	20	Left side:	7.58 %
	5	20	21 *	Right side:	7.50 %
	6	20	19		
	7	20	19	Average scattered scale loss	
	8	20	20	*after* release/recovery:	
	9	20	19		
	10	20	18	Left side:	8.18 %
	11	20	20	Right side:	8.03 %
	12	20	20		
		240	232	Difference:	
				Left side:	+ 0.60 %
				Right side:	+ 0.53 %
Control fish:					
	1	20	20	Average scattered scale loss	
	2	20	20	*before* release/recovery:	
	3	20	20		
	4	20	20	Left side:	6.70 %
	5	20	20	Right side:	6.73 %
	6	20	20		
	7	20	20	Average scattered scale loss	
	8	20	20	*after* release/recovery:	
	9	20	20		
	10	20	20	Left side:	7.20 %
	11	24	19	Right side:	7.35 %
		224	219	Difference:	
				Left side:	+ 0.50 %
				Right side:	+ 0.62 %

Statistical tests (Mann-Whitney Rank Sum Test; data were non-normal) were performed to determine if any of the differences between pre-treatment and post-treatment scattered scale loss within experimental groups and control groups were significant. Each side of the fish was treated as an individual observation to increase the power of the statistical tests (*e.g.* 40 observations per 20 fish). For control fish, only two of the 11 groups exhibited significant differences in scattered scale loss before and after handling ($P<0.05$). For experimental fish, only one of the 12 groups exhibited significant differences in scattered scale loss before and after exposure to the screen. When all data were pooled, however, pre-treatment and post-treatment differences were found to be significant for both experimental and control groups ($P<0.004$ and $P<0.001$ respectively).

Although slight increases in scattered scale loss before and after treatments were observed for both experimental and control fish, this is not in itself a measure of any effect of exposure to the fish screen. Such a measure is the difference between experimental and control results, and answers the question: "Is the increase in scattered scale loss for experimental fish greater than the increase in scattered scale loss for control fish?" Since the average scattered scale loss for experimental fish prior to release was noted to be greater than that for control fish, a Mann-Whitney Rank Sum Test (data distribution was non-normal) was performed to determine the significance of the difference in starting fish condition. This test showed that the starting condition of experimental fish was significantly different from that of control fish ($P<0.001$).

The significant difference in starting condition of the fish, with experimental fish exhibiting greater starting scattered scale loss than control fish, means that the ending condition of experimental and control fish cannot be directly compared. For this reason, experimental and control *groups* were treated as observations, and mean differences in scattered scale loss before and after treatments were compared for each group. The average scattered scale loss for each experimental and control group, and differences before and after treatment, are given in Table 3 and presented graphically in Figure 8. The differences were subjected to a Mann-Whitney Rank Sum Difference Test (data distribution is non-normal) to determine if pre-treatment / post-treatment differences for experimental fish were significantly different from those for control fish. The results of that test are also given in Table 3. These results show that scattered scale loss following exposure to the fish screen is not significantly different from control fish handling ($P>0.90$). This is a very powerful result, given the P-value which was produced by the test.

VOLUNTARY PASSAGE TEST (Steelhead smolts)

The first experimental group of 20 steelhead smolts was placed in a special holding net immediately upstream of the crest of the screen weir and allowed to pass voluntarily over the screen. These fish were observed for over an hour and data were recorded on elapsed time before passage and behavior, including orientation of the fish as they passed down the screen face. These data are summarized in Table 4. The first few fish moved out of the holding net soon after having been placed there, and had exhibited "nervous" or "agitated" behavior prior to passing over the weir. Once the remaining fish had settled down, movement was much less frequent. Although difficult to test, crowding probably played a role in stimulating movement of individual fish over the weir. As the group thinned out, the urge to move appeared to decrease. The voluntary behavior test was terminated after a little more than an hour, since to prolong it would have been impractical.

TABLE 3

EAST FORK IRRIGATION DISTRICT
FISH SCREEN BIOLOGICAL PERFORMANCE TESTS – 1999

STEELHEAD SMOLT SCATTERED MEAN PERCENT SCALE LOSS AND DIFFERENCES BEFORE AND AFTER TREATMENT

CONTROL GROUPS				EXPERIMENTAL GROUPS			
Group	**Pre**	**Post**	**Difference**	**Group**	**Pre**	**Post**	**Difference**
1	6.875	6.375	-0.500	1	7.000	7.375	0.375
2	6.500	6.875	0.375	2	6.375	6.719	0.344
3	5.875	8.125	2.250	3	6.750	8.500	1.750
4	6.250	6.250	0.000	4	7.625	7.750	0.125
5	6.125	6.667	0.542	5	7.125	7.738	0.613
6	7.750	7.750	0.000	6	7.525	8.421	0.896
7	6.750	7.875	1.125	7	8.375	8.553	0.178
8	7.625	8.125	0.500	8	8.250	8.625	0.375
9	6.375	7.375	1.000	9	8.375	8.947	0.572
10	7.250	7.375	0.125	10	8.000	8.472	0.472
11	6.458	8.026	1.568	11	7.750	8.000	0.250
				12	7.375	8.000	0.625
Means	6.712	7.348	**0.635**		7.541	8.092	**0.548**

MANN-WHITNEY RANK SUM DIFFERENCE TEST RESULTS

Group	**Median**	**25%**	**75%**
Control	0.4520	0.03125	1.094
Experimental	0.4235	0.2970	0.6190

T = 129.500 P = 0.902

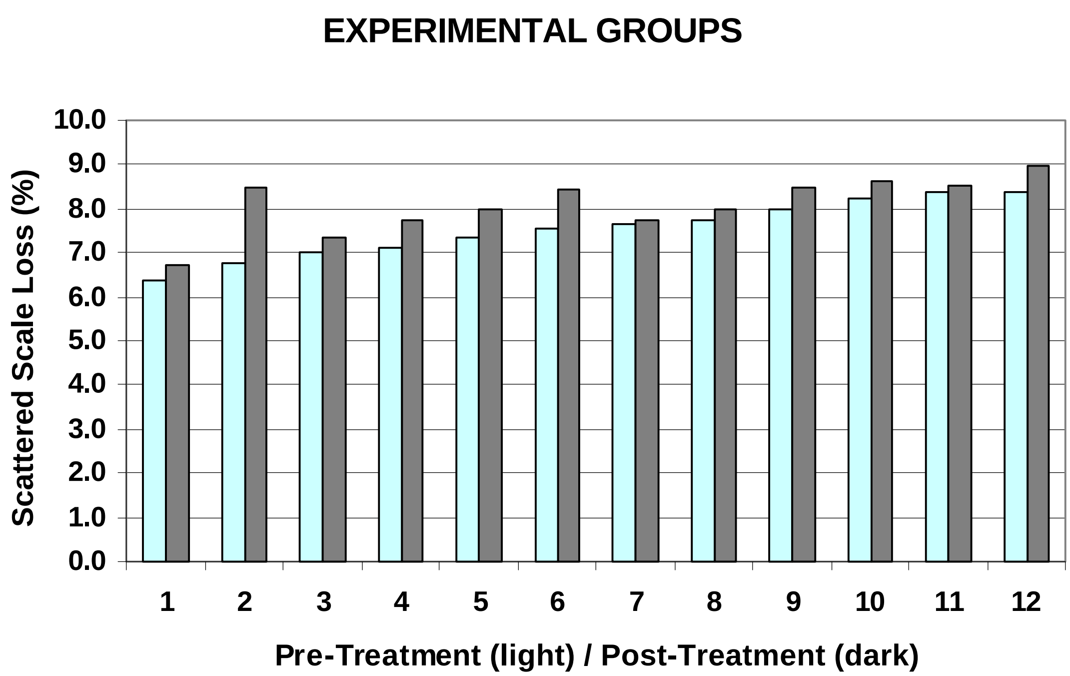
Conclusion: There is no statistical difference between differences in group means (P=0.902)

When fish moved voluntarily, they nearly always moved up into the faster current immediately upstream of the weir, held there for a moment, and then let the current move them backward over the crest. Occasionally, fish would move into the current and then out again, appearing uncertain of what they would do. Once “captured” by the current, the general response was to begin to turn and

Figure 8

EAST FORK IRRIGATION DISTRICT SCREEN TESTS – 1999

Steelhead Smolt Scattered Scale Loss Data



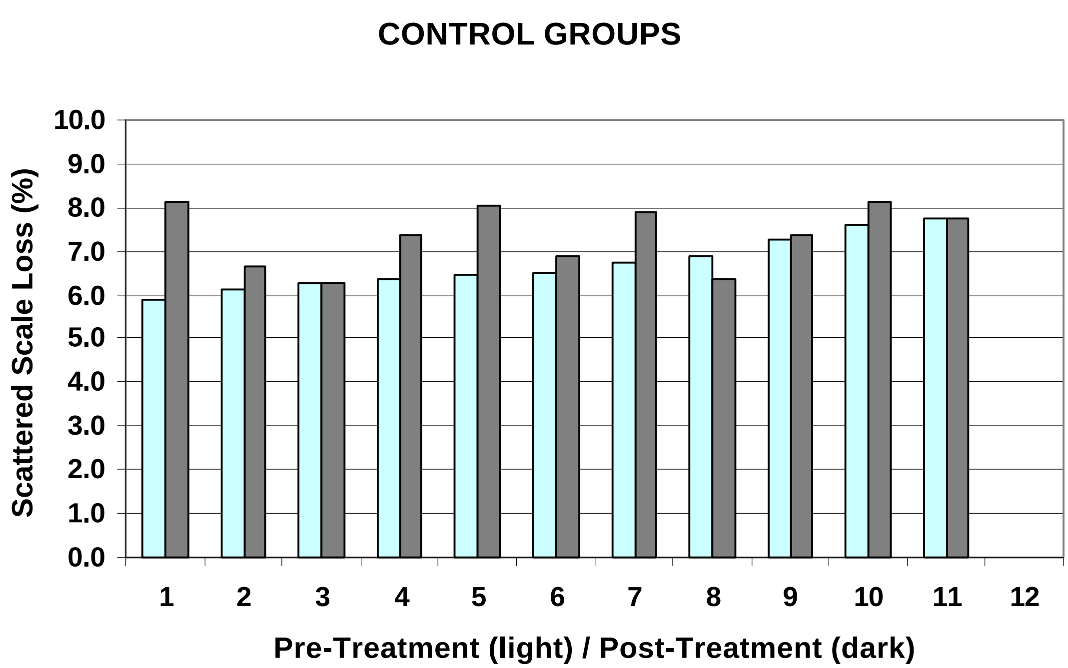


TABLE 4

EAST FORK IRRIGATION DISTRICT
FISH SCREEN BIOLOGICAL PERFORMANCE TESTS – 1999

STEELHEAD SMOLT VOLUNTARY PASSAGE TEST

Fish	Elapsed Time (min.)	Orientation	Notes
1	1	Tail first	Did not fight the current; no rotation
2	2	No obs.	
3	3	No obs.	
4	7	Rotated	Started tail first; rotated to head first half way down
5	13	Rotated	Started tail first, then rotated to head first
6	13	Rotated	Started tail first, then rotated to head first
7	55	Sideways	Rotated to sideways at weir crest, continued
8	60	Tail first	Started to rotate to head first near screen toe
End test	65		

Some human movement occurred from time to time near the release net. At these times, fish generally responded by moving deeper in the net and schooling more "tightly".

continue head first. However, the passage down the screen face is so fast, most fish did not have an opportunity to complete the rotation into a downstream-facing attitude. These results indicate that "voluntary" movement by steelhead smolts is strongly affected by the recent "history" of the fish, and that once individuals become accustomed to their environment, movement will be in "due time", which can be a long time. When fish were "encouraged" over the face of the weir, movement was often resisted and fish orientation was generally random. Occasionally, vigorous swimming occurred as fish tried to "fight" the current. Behavior was obviously different from voluntary passage, with some fish thrashing wildly as they passed down the screen face into the catch net.

Data on scattered scale loss for "volunteers" and "encouraged" fish were recorded separately so that they could be analyzed to see if the more "active" behavior associated with being "encouraged" over the weir crest would result in more scale loss. A Mann-Whitney Rank Sum Test (data distribution was non-normal) was applied to the data, and the results indicate that there was no significant difference in scattered scale loss between fish which engaged in "volunteer" passage and those which were "encouraged" over the weir ($P=0.750$).

LATENT MORTALITY TESTS

Steelhead Fry

Both experimental and control fish were held for at least 96 hours in net pens to determine if any latent mortalities attributable to passage over the fish screens would result. No mortalities or behavioral anomalies were observed for any fish in either group during this period.

Spring Chinook Fry

Both experimental and control fish were held for at least 96 hours in net pens to determine if any latent mortalities attributable to passage over the fish screens would result. No mortalities or behavioral anomalies were observed for any fish in either group during this period.

Steelhead Smolts

Both experimental and control fish were held for at least 96 hours in net pens to determine if any latent mortalities attributable to passage over the fish screens would result. In addition, the lot of fish from which both experimental and control fish were taken was held for the same 96-hour period. Of the 232 experimental fish, two died within the first 24 hours, and three died thereafter for a total of five fish or 2.16%. The first two mortalities were attributed by Mike Lambert (CTWS biologist performing the pre-test and post-test inspections) as "possibly" due to a "dry skin" condition (lack of the normal mucous coat) noted *prior* to release of these fish over the screens; fish with such condition were rejected for use in subsequent experimental and control groups. If these fish are considered "outliers", the percent latent mortality for the experimental fish would be 1.29%. Of the 219 control fish, two died during the 96-hr holding period yielding a 0.91% mortality rate. Several hundred fish remained in the lot from which both experimental and control fish were taken. Of these, a little over 6% died during the 96-hour post-test holding period, a considerably higher mortality than that for either the experimental or control groups. This higher rate might be attributable to a more crowded holding pen or the presence of some fish in "inferior" condition (rejected for use in tests), or both. In any case, this higher mortality suggests presence of factors other than the tests or control handling which caused mortality in these fish.

A statistical test was performed to determine if the mortality rate observed for experimental fish was higher than that observed for control fish, including the two fish in the experimental group which may have died due to a "dry skin" condition noted prior to release (one-tailed "Z" test):

Experimental mortality rate = 0.0216 (n=232);
Control mortality rate = 0.0091 (n=219).

$Z = 1.174$ ($Z < 1.645$; n.s., $\alpha = 0.05$)

The mortality rate for the experimental group is not statistically greater than that for the control group at the α=0.05 level of significance.

INTERPRETATION

GENERAL

Overall performance of the combination of elements of the East Fork Irrigation District sand trap and fish screen facility which were the subject of these tests was excellent. Hydraulic control was precise and easy to maintain. Flows over the weir and screen were nearly laminar (the desired condition). Turbulence at the point of entry of "excess" (bypass) flow over the screen into the bypass pool at the toe of the screen was very minor. Hydraulic conditions in the bypass pool were placid. There were no problems associated with debris accumulation.

The biological performance tests proceeded with no significant difficulties. Results of biological tests in general showed no adverse consequences of passage over the weir and fish screen. For the winter steelhead and spring chinook newly emergent fry tests, no effect of any kind of exposure to the screen was detected. All fish were found to be in the same condition after exposure to the screen and handling/inspection procedures as prior to exposure, and no mortalities or behavioral anomalies were detected either in association with the tests or with the 96-hr post-test holding period.

For the winter steelhead smolt tests, a slight increase in scattered scale loss was observed for both experimental and control fish, with the increase being almost identical in the two groups. None of this scale loss approached that which is generally considered debilitating for these fish. No scale loss patterns (*e.g.* scrapes or patches) suggestive of injury-inducing contact with the screen or recovery net were observed. These results very strongly suggest no adverse consequences for steelhead smolt passage over these fish screens. The P-value obtained from the Mann-Whitney Rank Sum test of the differences between experimental and control group means ($P>0.90$) is very high for tests of this kind and indicates that the probability that there is an effect on steelhead smolts due to passage over the weir crest and screen face at the EFID facility is extremely low. This is a considerably more positive result than is normally required when scientifically rejecting the idea of an effect ($P \geq 0.05$).

Observations of fish behavior during voluntary passage tests indicate a relatively consistent pattern of starting over the weir crest tail-first followed by a rotation toward a head-first orientation. Very little "fighting" of the current at the crest of the weir or "agitated" behavior was noted for voluntary passage. This was in stark contrast to behavior patterns observed when fish were "encouraged" over the weir crest. In these cases, most fish resisted passage, often swimming vigorously against the current and sometimes thrashing as they passed down the screen face. It was felt by the observers that the potential for detectable scattered scale loss or other injury or stress would be much greater for "encouraged" fish than for "volunteers". In this sense, encouraging fish over the weir crest constitutes a "worst case" test more likely to result in an observable effect of passage over the EFID fish screen than would be expected during normal facility operation. This adds strength to the conclusion of "no effect" which can be drawn from the scattered scale loss data.

A few mortalities were observed for both experimental and control groups of steelhead smolts during the 96-hr post-test holding period. Mortality rates for both groups are quite low, even though that for the experimental group was about twice that for the control group. Nevertheless, it was determined that the mortality rate for the experimental group was not significantly greater than that for the control group, even when two of the five experimental mortalities included in the analysis could be attributed to their poor condition prior to the test. Finally, it was noted by CTWS biologists (Jennings and Lambert) that the steelhead smolts used for these tests had been held without food for several weeks for acclimation to East Fork Hood River water, netted and sorted prior to the initiation of fish screen tests, and subjected to netting and sorting to select individual fish for use in the tests. Taken in the context of the relatively much higher mortality rate of over 6% for the lot of fish from which both experimental and control fish were taken, differences in holding density notwithstanding, it is not likely that any of the mortalities observed in the experimental or control groups were due to either exposure to the fish screen or to handling/inspection procedures conducted as part of these tests.

COMPARISON WITH OTHER STUDIES

Studies of biological performance of fish screens have traditionally taken two forms. One kind of study tests swimming performance in front of fish screens or in "fish treadmills", generally to ascertain the speed and direction (vector) of flow which will result in fish exhaustion and impingement onto the screen surface. Fish injury and latent mortality observations may or may not be incorporated into these studies. Another kind of study focuses on evidence of direct mortality or injury caused by exposure to fish screens. Latent mortality observations may or may not be incorporated into these studies. This study falls primarily into the second category, because exposure time to the screen surface (a small fraction of a second) is so short that swimming performance and fatigue are irrelevant.

Swimming performance studies, including "fish treadmill" studies, often assume that any contact with a screen, however brief and for whatever reason, presents "a good possibility that the fish will be injured or killed" (Smith and Carpenter 1987). In order to be conservative, regulatory agencies may adopt a set of criteria which "relies on the principle that fish should avoid contact with the screen face..." (Tuttle 1993). This assumption and the associated principle may not be well-founded in all cases, however, especially as they apply to juvenile salmonids. Fisher (1981) found that juvenile chinook salmon could "rest" on vertical plate screens for short periods and then swim off again with no apparent adverse consequences. Kano (1982) made similar observations in "fish treadmill" experiments incorporating a vertical plate screen. When a submerged, inclined plate screen (*not* an overflow type) was used, however, the incidence and duration of "resting" behavior increased, and some latent mortality was observed. Coots (1956) also noted a higher incidence of juvenile salmonid mortality associated with relatively high approach velocities and a submerged, inclined punched plate screen.

Fish treadmill studies using an advanced “endless screen” design are presently being conducted at the University of California at Davis (UCD) Hydraulics Laboratory by Drs. Joseph Cech, Tina Swanson and their colleagues (*pers. comm.*). These studies utilize juvenile chinook salmon as well as certain sensitive native California species, and are investigating various physiological parameters in addition to simple injury rates. Preliminary results for juvenile chinook indicate frequent “temporary” contacts, but very rare “impingement” (defined as sustained contact for >5 min); the vast majority of contacts are “fleeting” and are described as a “tail-touch”. Mortalities associated with these tests are very low and not significantly correlated with screen contact. Researchers have documented more frequent screen contact associated with lower approach velocities and lower sweeping velocities;

these findings are contrary to protective criteria generated by state and federal agencies. Physiological “stress” parameters monitored include blood cortisol, lactate, glucose and hematocrit. Researchers found no differences associated with approach or sweeping velocities and no differences associated with their “injury index” (composed of a variety of observable physical injuries, mostly due to handling, and the rate of occurrence of these injuries). No correlations were found between swimming speeds required to endure the treadmill tests and the physiological “stress” parameters.

In this series of tests, fish were swept rapidly across the surface of the overflow screen in a layer of water with diminishing thickness. Although the high transit speed made careful observations difficult, it is likely that the non-fluid fish body retains a thin boundary layer of water and/or slime which serves to protect from chaffing or abrasion and results in the absence of any scale loss or other injury. Certainly, impingement as it is generally conceived (a small fish flattened on a screen by approaching hydraulic forces) does not occur as fish pass down the overflow screen. Juvenile fish (fry and smolts) were observed to slip very rapidly down the nearly-vertical screen face, propelled by momentum and the continuing influence of gravity. It is apparent from the results of these tests that any short-term contact which may occur does not result in any detectable injury, anomalous behavior or other adverse consequences.

Direct mortality and injury studies often focus on "descaling" (discussed above) as a surrogate for mortality in cases where test fish are not overtly killed by screening systems. A "perfect score" using generally accepted criteria for "descaling" is unusual, but such evaluation results have occasionally been reported; most studies in the region have reported average descaling rates of fractions of a percent to, more commonly, a few percent. Neitzel *et al.* (1985) reported descaling rates for juvenile fall chinook salmon ranging from 0 to 3.1% for individual trials (averaging 0.9 to 1.5%) at the Sunnyside Canal Screening Facility in the Yakima River Basin (Washington). Although low, this is a higher rate than was observed in the present study (0% descaling). Juvenile steelhead escaped descaling at the Sunnyside facility, according to Neitzel *et al.*

Although criteria were applied differently during data analysis, preventing strictly accurate comparison, Congleton *et al.* (1988) reported very low incidence of scale loss associated with spring chinook salmon and steelhead smolts passing down flumes of various types at Lower Granite Dam (Columbia River, Washington). Given the configuration of the test apparatus used by these investigators, conditions in the Congleton *et al.* flume study most closely approximated those experienced in these tests; results are also comparable. The authors concluded that there was "no significant increase in descaling after flume passage and no significant effect of flume design. Therefore, descaling was not a problem with any of the flume designs tested."

Hosey & Associates (1990) found descaling rates for spring chinook, fall chinook and steelhead smolts ranging from 0 to 6.2% and averaging between 1 and 4% for rotary drum screen tests conducted at the Chandler, Columbia, Roza and Easton screening facilities in the Yakima River Basin. "Partial descaling" (>3% scale loss) was very high (23 - 50%) in two of three tests using spring chinook smolts at the Chandler facility, but was otherwise comparable to results obtained in the present study.

Knapp and Ward (1990) reported average descaling rates of 7.7% for hatchery steelhead smolts, 5.9% for juvenile coho salmon, 3.8% for juvenile spring chinook, 3.8% for juvenile native summer steelhead, and 1.2% for subyearling fall chinook in studies conducted at the juvenile fish bypass facilities at Three Mile Dam on the Umatilla River (Oregon). It is not clear what proportion of these injuries can be attributed to the fish bypass system, since pre-condition observations were apparently not made. Descaling rates of 11% and 5.5% were observed for experimentally released juvenile coho and chinook salmon, respectively, but these observations were based on extremely small sample sizes (18 and 9 fish), and are probably not representative of actual expected injury rates.

Neitzel *et al.* (1990) observed descaling rates of 1.0 - 2.5% (average, 1.8%) for steelhead smolts and 0 - 0.5% (average 0.3%) for spring chinook smolts at the screens associated with the Westside Ditch screening facility in the Yakima River Basin. This same study reported descaling rates of 0 - 7.5% (average 2.4%) for spring chinook smolts and 0 - 2.2% (average 1.4%) for steelhead smolts at screens at the Wapato Canal facility. A relatively high percentage of salmonid smolts (chinook, coho and steelhead) captured at these and other central Washington screening facilities were "descaled" (*e.g.* 5 - 18% at Richland Canal; 15 - 36% at Toppenish/Satus Canal), presumably from other causes associated with their seaward migrations. Other sources of fish loss at these screening facilities (a very small percentage of the total number of fish exposed) included being severely cut or crushed by the rotating drums, and fish "leaking" through gaps in the screen support structures and mechanical systems.

Hayes *et al.* (1992) reported net descaling rates of 0.1% and 0.7% for two trials using spring chinook smolts and no descaling for two trials using fall chinook and summer steelhead conducted in 1991 at the WEID Canal screens at Three Mile Falls Dam (Umatilla River). There was no significant difference between experimental groups and controls, however. Injuries, including descaling, attributable to the outfall, as opposed to the screen, were slightly higher, ranging from no injury to nearly 13%. These investigators also noted significant impingement of test fry on traveling screens at this facility. Unfavorable turbulence conditions were also noted at this facility attributable to design and operation of the screen and bypass system.

Cameron and Knapp (1993) continued investigations of fish passage and injury rates at the WEID Canal screening facility at Three Mile Dam. These investigators found that injury rates for control groups of fish exceeded injury rates for experimental groups about half the time. These investigators attribute this aspect of their findings to their experimental procedures which were dictated by the site and the facility, not the study itself. These authors cite similar problems encountered by other investigators working in the Yakima River Basin. In spite of these difficulties, differences in injury rates between experimental and control fish were found to be low, generally a few percent. Some significant latent mortality was reported by these authors, but this was attributed to warm holding water temperatures.

Mueller *et al.* (1995) reported average percent descaling rates of 0.1% for spring chinook smolts and 1.2% for sockeye smolts captured at the Dryden fish screening facility on the Wenatchee River (Washington). These investigators were unable to ascertain the pre-condition status of test fish, but the low descaling rates are interpreted by the authors as suggesting no significant descaling at this facility.

Abernethy *et al.* (1996) investigated passage of chinook salmon fry, subyearlings and smolts through orifices of different sizes and over overflow weirs. An increase in injury rate of about 15% is reported by these authors for fish passing through a 2 in dia. submerged orifice at high velocity; about 50% of the fish through the orifice were observed by underwater video to have made "significant contact" with its circumference. This result means that not all contact, even at high velocity, results in discernable injury. Injury rates for a 6 in dia. orifice were not different from control groups. No increase in descaling or other injury rate was noted for fish passing over the weir.

SUMMARY

Physical and hydraulic conditions at the wide variety of fish protection facilities throughout the Pacific Northwest and California are quite variable, in spite of efforts to keep these conditions under control and in conformance with more or less standard screening criteria. The most common problems are associated with "hot spots" or localized high approach velocity conditions and turbulence near screen surfaces. Other problems are associated with other parts of bypass facilities. The design and operation of overflow horizontal profile bar (Coanda type) screening facilities tends to significantly reduce the opportunities for "hot spot" formation and turbulence on the screen face; flow is typically very even. When comparing these results to those of other investigators, it is also important to consider the variability inherent in results from studies of this kind. The potential sources of variability are many and differ from site to site. With these caveats in mind, it is still apparent that the static, overflow weir, horizontal profile bar “Coanda type” fish screen incorporated into the East Fork Irrigation District’s sand trap and fish screen facility on the East Fork Hood River, which was the subject of these biological performance tests, performed at least as well as any of the other systems reported, and better than most. These tests support a conclusion that the incorporation of this screening technology into the facility does not pose an injury threat to juvenile salmonid fishes in the system.

REFERENCES

Abernethy, C.S., D.A. Neitzel and W.V. Mavros. 1996. Movement and injury rates for three life stages of spring chinook salmon *Oncorhynchus tshawytscha*: A comparison of submerged orifices and an overflow weir for fish bypass in a modular rotory drum fish screen. Ann. Rep. 1995 to Bonneville Power Admin. Div. of Fish and Wildlife. Portland.

Basham, L.R., M.R. Delarm, J.B. Athern, S.W. Pettit. 1982. Transport Operations on the Snake and Columbia Rivers. Fish Transportation Oversight Team Annual Report, FY 1981. NOAA Tech. Memo. NMFS F/NWR-2. Portland.

Buell, J.W. 1996. Biological performance and evaluation of an overflow weir profile bar fish screen for East Side Irrigation District. Buell & Assoc., Inc. Portland.

Cameron, W.A. and S.M. Knapp. 1993. Report "A" *in:* Evaluation of juvenile fish bypass and adult fish passage facilities at water diversions in the Umatilla River. S.M Knapp, *ed.* Ann. Rep. 1992 to Bonneville Power Admin. Div. of Fish and Wildlife. Portland.

Congleton, J.L., E.J. Wagner, R.R. Ringe. 1988. Evaluation of fishway designs for downstream passage of spring chinook salmon and steelhead trout smolts, 1987. Final Report to Bonneville Power Admin., Div. of Fish and Wildlife. Portland.

Coots, M. 1956. Some notes on biological investigations of the perforated plate fish screen. Calif. Dep. of Fish and Game, Inland Fish. Admin. Rep. 56-8.

Fisher, F.W. 1981. Long-term swimming performance of juvenila American shad, *Alosa sapidissima*, and chinook salmon, *Oncorhynchus tshawytscha*. Cal. Dept. of Fish and Game, Anad. Fish. Br. Admin. Rep. 76-9.

Hayes, M.C., S.M. Knapp, A.A. Nigro. 1992. Report "B" *in*: Evaluation of juvenile fish bypass and adult fish passage facilities at water diversions in the Umatilla River. Ann. and Interim Prog. Reps. Oct. 1990 - Sep. 1991 to Bonneville Power Admin. Div. of Fish and Wildlife. Portland.

Hosey & Associates, Inc. 1990. Evaluation of the Chandler, Columbia, Roza and Easton screening facilities. Completion Rep. to US Bureau of Reclamation. Contract No. 7-CS-10-07720.

Kano, R.M. 1982. Responses of juvenile chinook salmon, *Oncorhynchus tshawytscha*, and American shad, *Alosa sapidissima*, to long term exposure to two-vector flows. Int. Ecol. Study Prog., Calif. Dept. Wat. Res., Calif. Dep. Fish and Game, USBR, USFWS. Sacramento.

Knapp, S.M. and D.L. Ward. 1990. Operation and evaluation of the juvenile bypass system in the West Extension Irrigation District canal at Three Mile Falls Dam. Report "A" *in*: Evaluation of juvenile fish bypass and adult fish passage facilities at Three Mile Falls Dam, Umatilla River. T. Nigro, *ed.* Ann. Prog. Rep. 1989 to Bonneville Power Admin., Div. of Fish and Wildlife. Portland.

Mueller, R.P., C.S. Abernethy and D.A. Neitzel. 1995. A fisheries evaluation of the Dryden Fish Screening Facility. Ann. Rep. to Bonneville Power Admin., Div. of Fish and Wildlife. Portland.

Neitzel, D.A., C.S. Abernethy, E.W. Lusty. 1990a. A fisheries evaluation of the Wapato, Sunnyside and Toppenish Creek Canal fish screening facilities, Spring 1988. Ann. Rep. to Bonneville Power Admin., Div. of Fish and Wildlife. Portland.

Neitzel, D.A., C.S. Abernethy, E.W. Lusty. 1990b. A fisheries evaluation of the Westside Ditch and Wapato Canal fish screening facilities, Spring 1989. Ann. Rep. to Bonneville Power Admin., Div. of Fish and Wildlife. Portland.

Neitzel, D.A., C.S. Abernethy, E.W. Lusty, L.A. Prohammer. 1985. A fisheries evaluation of the Sunnyside Canal fish screening facility, Spring 1995. Annual Report to Bonneville Power Admin., Div. of Fish and Wildlife. Portland.

NMFS. 1995. Juvenile fish screen criteria. Nat. Marine Fish. Serv. (NOAA), Environ. and Tech. Serv. Div. Portland.

Oregon Dept. of Fish and Wildlife. 1995a 08 May letter from Dave Nichols, Fish Screening Prog. Mgr. to Clarence Nevelle, Manager, East Fork Irrigation District, Odell OR.

Oregon Dept. of Fish and Wildlife. 1995b. 09 June letter from Dave Nichols, Fish Screening Prog. Mgr. to Clarence Nevelle, Manager, East Fork Irrigation District, Odell OR.

Smith, L.S. and L.T. Carpenter. 1987. Salmonid fry swimming stamina data for diversion screen criteria. Final Rep. to Wash. Dept. of Fisheries and Wash. Dept. of Wildlife. Fish. Res. Inst., U. of Wash., Seattle.

Wahl, T.L. 1997. Hydraulic testing of static self-cleaning inclined screens. USBR Water Resources Research Laboratory, Denver.

APPENDIX A

PHOTOGRAPHS

Photo 1 Bypass pool and screen bays at the EFID sand separation and fish screen facility. The "catch net" used to retrieve test fish is shown ready to be positioned in Bay 2.

Photo 2 "Catch net" shown in the raised position. The bucket into which fish are concentrated as the net is raised is visible attached to the bottom of the net.

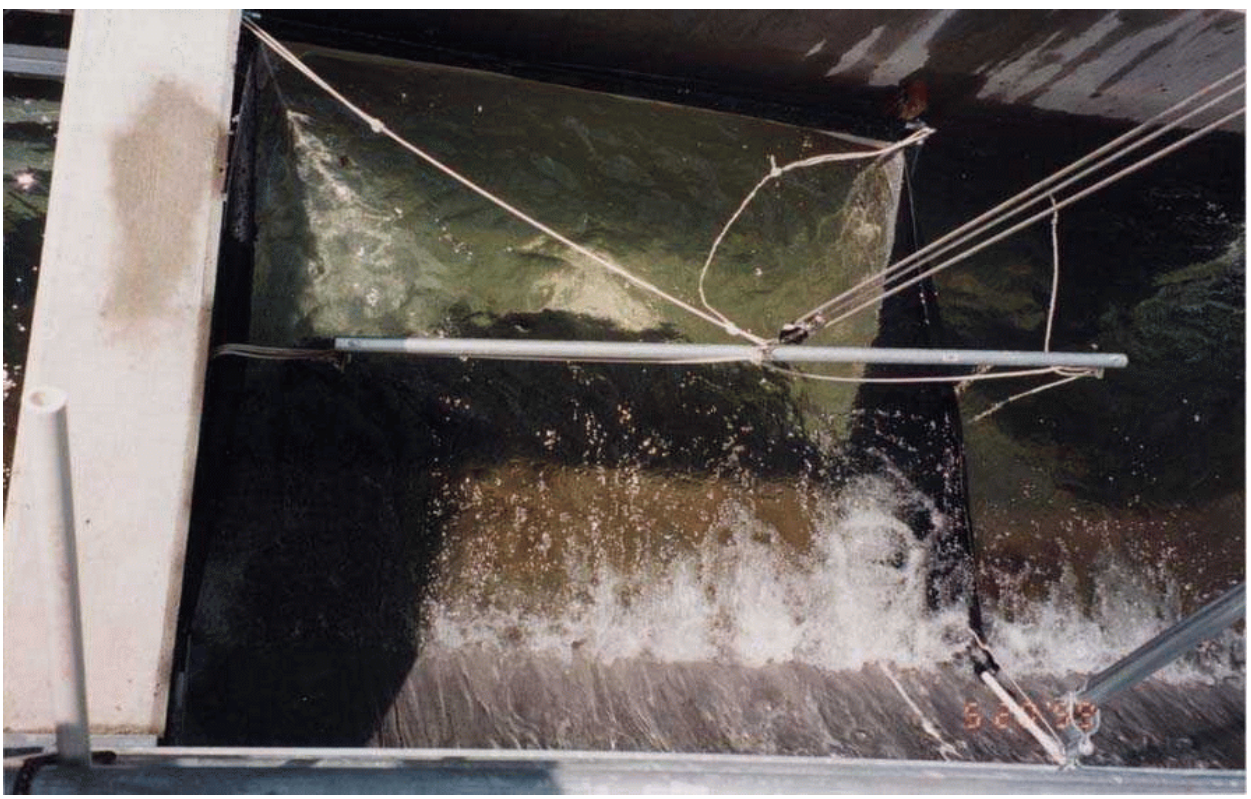


Photo 3 "Catch net" shown in its deployed position as seen from above. The screen with bypass water flowing over it and resulting minor turbulence is visible in the lower portion of the photograph.

Photo 4 “Catch net” shown in its deployed position but with the bypass pool drawn down (*not* a normal operating condition). The water level is normally near the top of the net.

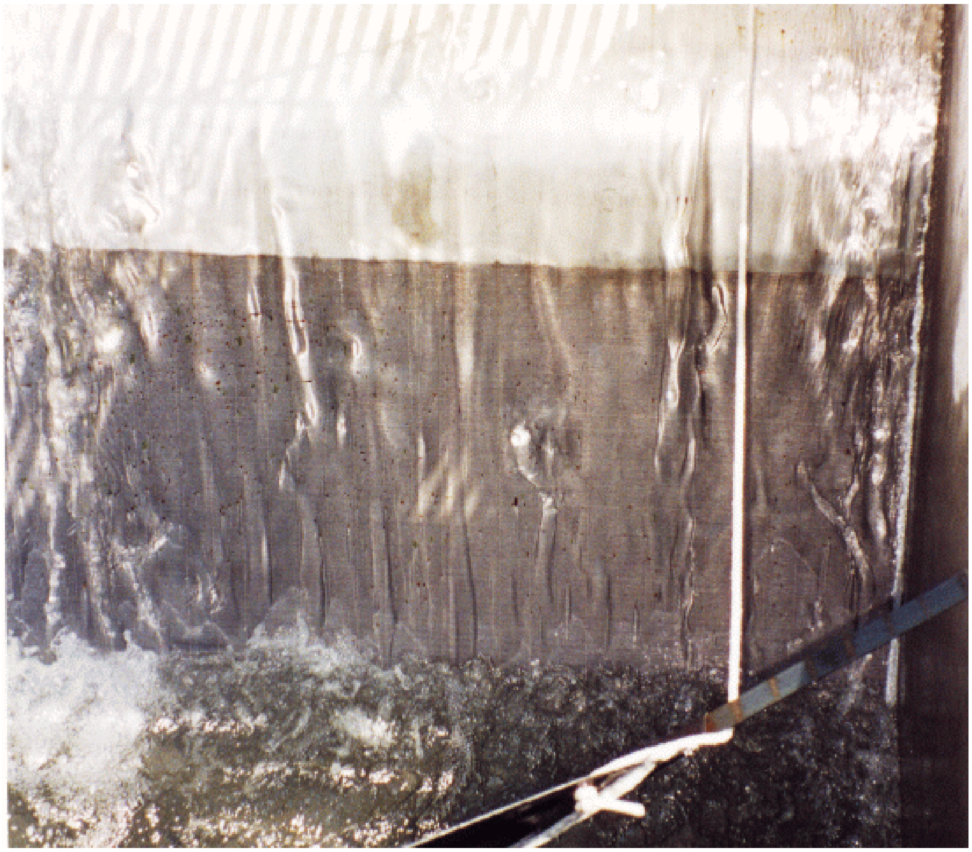


Photo 5 Water flowing over the Coanda screen surface under normal operating conditions. Note the smooth flow pattern and relatively minor turbulence at the bypass pool surface.

Photo 6 Steelhead fry being measured and inspected prior to exposure to the EFID fish screen.

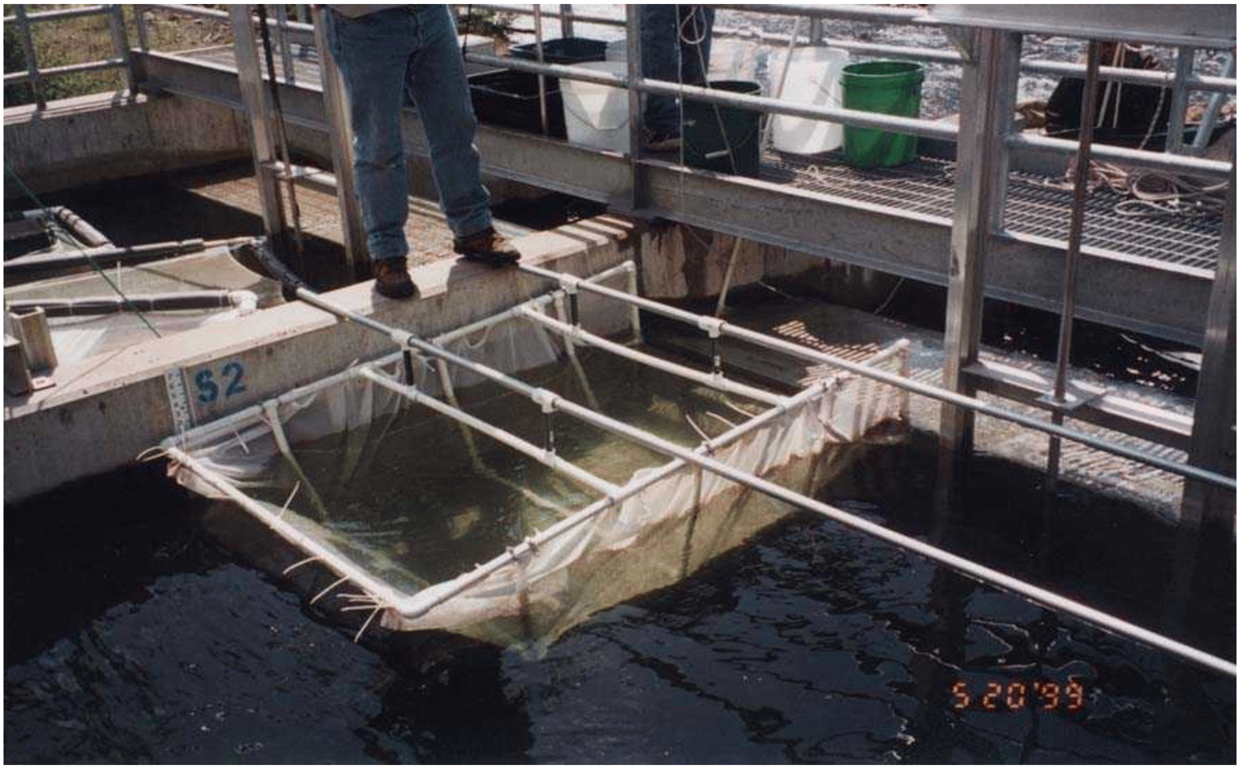


Photo 7 Release net for steelhead smolts deployed immediately upstream of the weir crest. The net is rotated up and forward to "encourage" smolts to pass over the weir crest and screen below.

Photo 8 Steelhead smolt showing the typical pattern of scattered scale loss prior to screen tests. Post-test pattern for both experimental and control fish is very similar, with only slight increases.