Black Canyon Hydroelectric Project
FERC Project No. P-14110
Fish Passage Report
February 2014

Prepared for
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1 EXECUTIVE SUMMARY

Two preferred water diversion and intake alternatives have been selected. Each alternative proposes to divert water to an off channel intake system composed of fish screens and appurtenances for the intake screening system. To divert water each intake proposes to use a control sill, and engineered roughened channel downstream of the control sill. These alternatives will also provide upstream and downstream fish passage while allowing current movement of drift macroinvertebrates, large woody debris, and sediment. The primary difference between the two intake alternatives is that one uses a vertical screen configuration with a mechanical screen cleaning system, while the other uses a horizontal screen configuration with a passive, non-mechanical screen cleaning system. A final intake design will be selected from the two above identified preferred alternatives and presented by Black Canyon Hydro, LLC (BCH) in the upcoming Preliminary Licensing Proposal.

Over the course of the study, four potential design alternatives were developed and subsequently evaluated in consultation with stakeholders and the aquatic working group members. These designs were developed using regulatory requirements, engineering, and operational criteria. Staff also visited operational diversion structures, and allowed an evaluation of these projects through informal interviews with the relevant designers, builders, and operators. Consultation with stakeholders also helped guide the development of design alternatives. The alternatives were evaluated numerically on the basis of whether they would successfully meet the written criteria as well as general objectives identified by BCH staff and stakeholders. These included engineering and operational constraints, minimizing in stream maintenance and terrestrial habitat disturbance, and capital cost. The two preferred alternatives were similarly effective in meeting both the engineering design criteria and stakeholder identified general objectives.

An additional component of this report briefly summarizes natural fish passage barriers within the project reach (segment of river between the water diversion and tailrace return flow sites). Specifically, it discusses how, while there are a significant number of naturally occurring barriers to fish passage within the project reach, the application of appropriate instream flow requirements and ramping rates developed in other studies will allow for post-project fish passage that is, at a minimum, equivalent to fish passage conditions that currently exist during lower flow seasons without negative impacts.

2 INTRODUCTION

BCH ultimately plans to file an application for an original license for the Black Canyon Hydroelectric Project (Project), FERC Project Number P-14110, and associated facilities on the North Fork Snoqualmie River (North Fork), approximately 4-miles northeast of North Bend in King County, Washington. The Project has a proposed generating capacity of 25-megawatts (MW) and would be located predominantly on private lands. The combined maximum hydraulic capacity of the four project turbines would be 900 cubic feet per second (cfs). The run-of-river Project would divert water from an approximately 2.7-mile-section of the North Fork.

As required by the Integrated Licensing Process of FERC, BCH conducted several studies to evaluate a wide range of potential impacts associated with the Project. BCH will incorporate the information provided by these studies into ongoing Project design and operations planning. BCH conducted an environmental flows study within the segment of the North Fork that would be affected by the proposed Project. This portion of the river, which extends from approximately river mile (RM) 5.3 to RM 2.6, is referred to as the Project Reach. This document presents the study results as part of the overall program of studies evaluating how flow-dependent resources may be affected by the Project operations and informing how Project goals can be achieved.

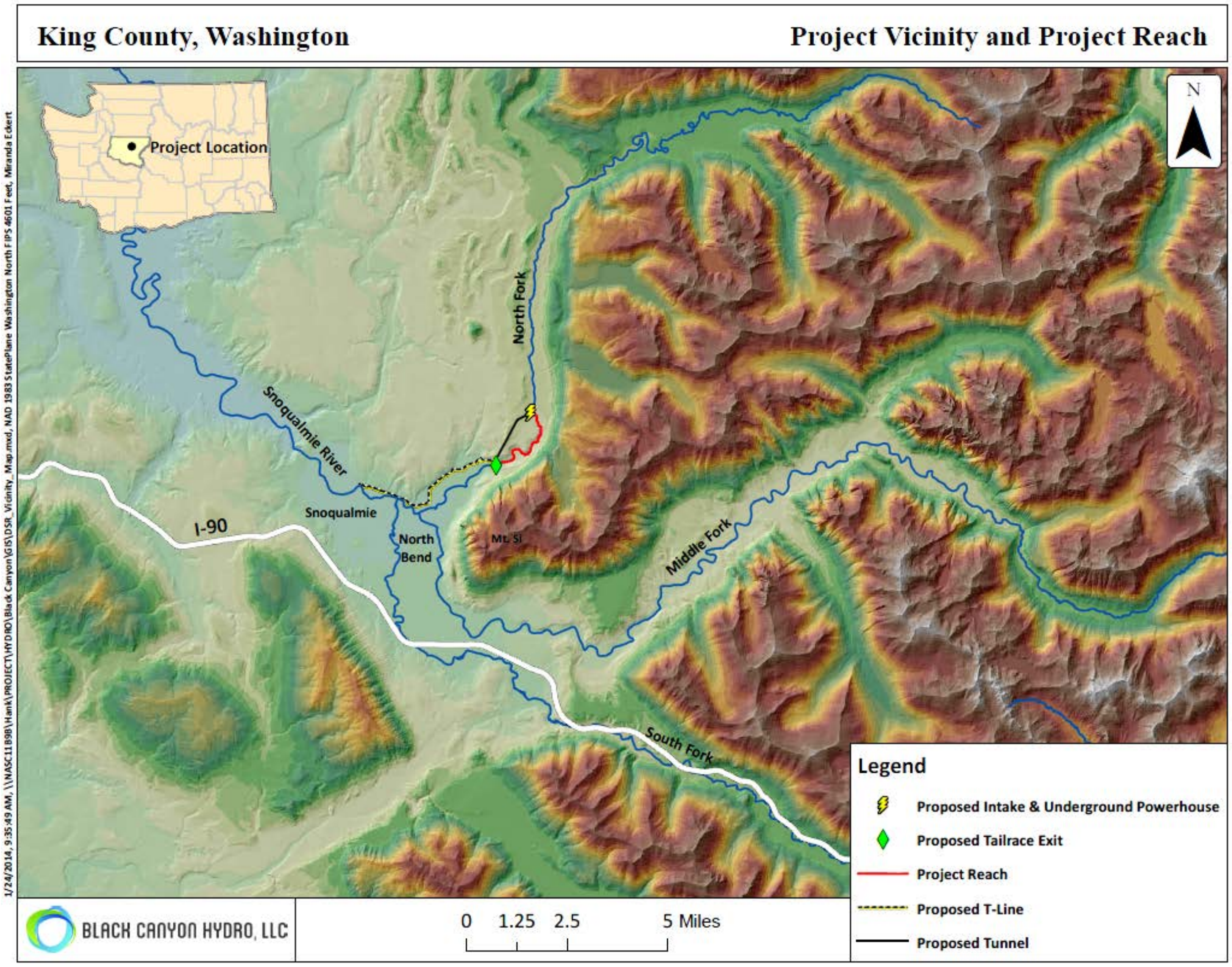


Figure 1 - Project Vicinity Map

The following is a description of Project features that have been updated since the filing of the Revised Study Plan:

PROJECT DESIGN

Intake

The following description of intake features reflects an evolution in Project design since the filing of the Pre-Application Document (PAD) through scoping, stakeholder comment, and study results. As a result of completing relevant studies, two possible design alternatives have been developed for the intake. These Alternatives are called Alternative C and D. Both alternatives involve bulk water screening located at approximately RM 5.3, on the same river bend and point-bar as Alternative A.

Alternative C uses a vertical plate screening system, and Alternative D uses a horizontal plate screening system.

Both alternatives would have a (1) control sill to control the normal water surface elevation and maintain a consistent river bed elevation for a side channel bulk-water intake. The control sill would consist of a concrete weir with boulders inset on the surface over top of a sheet pile cutoff wall to capture hyporheic flow. The sill would be at the newly established grade of the river bed and would allow uninterrupted flow through a natural looking re-profiled river as a roughened channel series of step pools, riffles, and boulder weirs. (2) An intake structure with a coarse trashrack, jib crane, and radial gate with sluiceway located on the east bank of the river. Diverted water would be conveyed through; (3) an open channel to a; (4) head gate control structure and into a; (5) fish and debris screening structure. (6) Fish and debris would be screened and bypassed back into the river. Screened water would then flow through a power conduit to the underground powerhouse. (7) Access to the intake site would use an existing logging road and approximately 400 feet of new roadway extending to the intake site.

Powerhouse

The powerhouse location would be located underground beneath the selected intake site. This would include a (1) 450-feet tall, 30-foot diameter vertical shaft to allow space for the power penstock(s), elevator, stairs, ducting, mechanical, and electrical chases. Screened water from the intake screen system would be delivered down a (2) vertical power penstock(s) to the powerhouse. The powerhouse would (3) use four Pelton Turbines each rated at 6.25-MW, as well as appurtenant facilities. The (4) powerhouse substation and (5) elevator building would be located near the intake structure.

Tailrace

The tailrace will be an approximately (1) 8,600 foot long 12 foot diameter tunnel, and is anticipated to be constructed primarily in bedrock. The tailrace water return to the North Fork would be located at approximately the same location as proposed in the PAD at approximately RM 2.6.

Transmission

Transmission would consist of a 34.5-kilovolt (kV) underground transmission line and overhead transmission that transmits project power to the regional grid. The transmission line would be sited predominantly on an existing power line corridor. The transmission line would originate at the powerhouse substation located at the intake site at RM 5.3.

Subsurface transmission would follow the vertical shaft to the underground powerhouse, and down the 1.6 mile long tunnel. After exiting the tunnel the transmission would travel underground 1.0 miles on new and existing roads then 4.2 miles as 34.5- kV overhead transmission line predominantly following an existing power line corridor to the point of interconnection. The point of interconnection is located at an existing overhead transmission line near the intersection of 396th Drive SE and SE Reinig Road approximately 0.4 miles from the City of Snoqualmie. A new switch and substation would be added at the point of interconnection to transform voltage from 34.5-kV to 115-kV.

3 STUDY DESCRIPTION AND OBJECTIVES

In accordance with 18 CFR §5.11(d)(1), this section describes the goals and objectives of the Fish Passage Study. This document describes the process that BCH implemented to identify different water diversion, intake, and discharge structures and configurations. And how each alternative was evaluated with respect to their ability to avoid injuring or killing fish, or to prevent or delay fish from swimming up- and downstream. BCH will also investigated how fish passage conditions in the Project Reach are likely to change in response to changes in streamflows, hydraulics, and habitat structure in the North Fork caused by the Project. This analysis will require input from and coordination with several other studies.

The specific study objectives:

- Define desired fish passage conditions within the Project Reach and at points where water will be diverted from and returned to the North Fork Snoqualmie under anticipated project operations.
- Identify multiple design alternatives for Project diversion, intake, and discharge structures that would potentially satisfy the goals of the project.
- In consultation with outside experts, evaluate and rank the design alternatives with respect to selected biological, technical feasibility, and cost criteria.
- For the most promising alternatives, evaluate their fish passage suitability with respect to the swimming abilities of target fish species, and the range of flows expected when the project is operational.
- In consultation with the ARWG, select and refine the preferred design alternatives.
- Evaluate the potential impacts of Project flows on fish passage within the Project Reach. Identify measures that can be taken to eliminate or improve existing fish passage barriers, and avoid creating new barriers to fish movements within the Project Reach.

4 STUDY AREA

The study reach on the North Fork covers approximately a 5 mile section of river from river mile 1.6 to river mile 6.54. The lower boundary of the study reach is about 1 mile downstream of the point where water from the tailrace is discharged back into the river, and the upper portion of the study reach is about 1.2 miles upstream of the point of diversion. See Figure 2. The section of river between the water intake and the tailrace discharge point is referred to as the Project Reach. It features steep banks and valley sidewalls, and a relatively steep gradient over its 2.7-mile length that is characterized by falls and riffles.

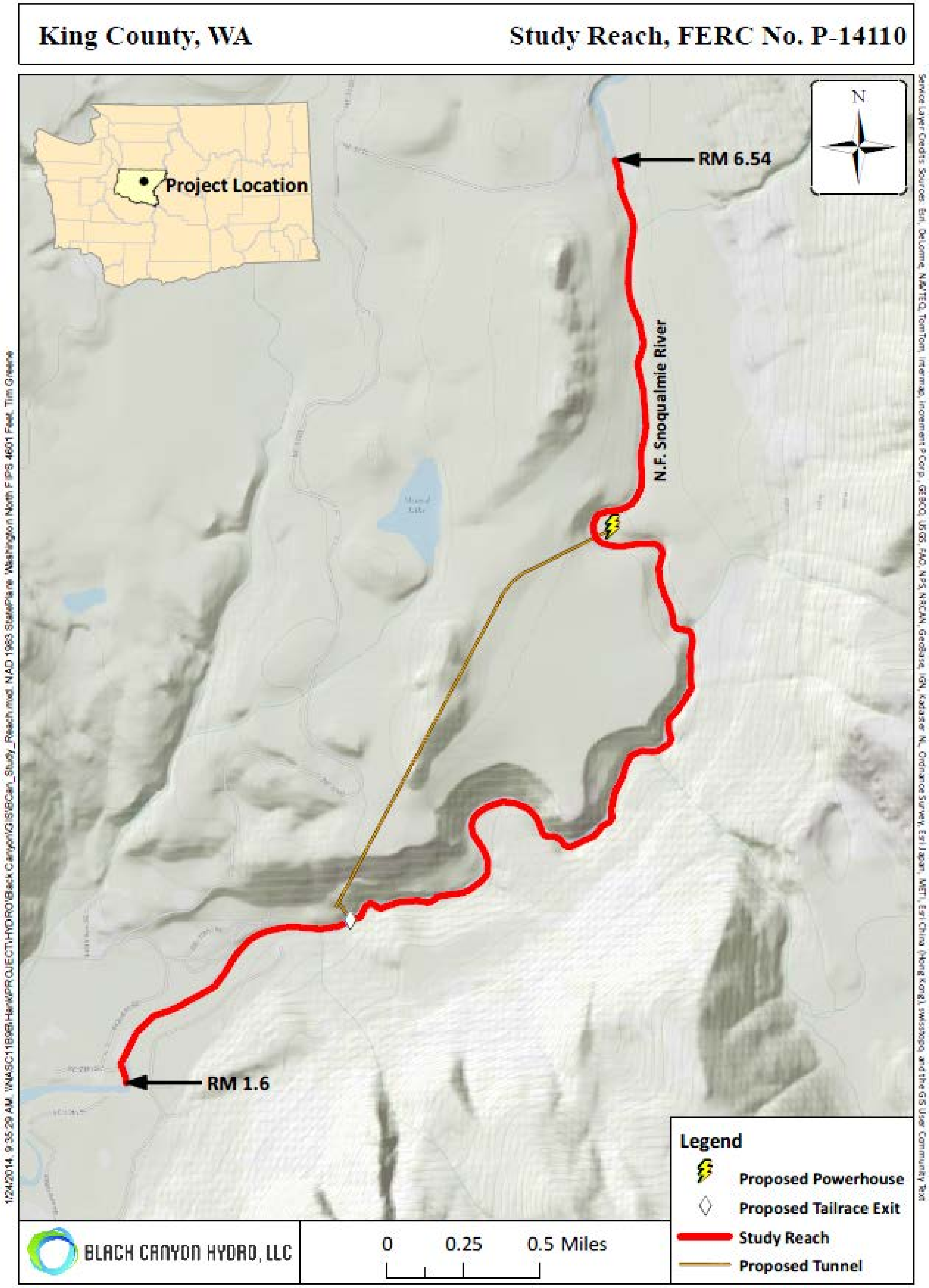


Figure 2 - Study Reach

5 EXISTING INFORMATION

In accordance with 18 CFR §5.11(d)(3), this section describes existing information on fish passage within the Project study area, and the need for additional information.

Several fisheries studies and habitat inventories conducted previously in the North Fork Snoqualmie River have identified known or putative fish barriers (Sweeney et al. 1981; R.W. Beck and Associates 1985; Thompson et al. 2011) within the Project study area. Although these studies were not intended to identify fish barriers in the Project Reach, and in fact did not include surveys of the entire reach, they all described Fantastic Falls, present at the lower end (RM 2.9) of the Project Reach as impassible to fish. Fish passage conditions within the Project study area, including the difficult-to-access Black Canyon segment, were inventoried by a crew of experienced fisheries biologists retained by BCH to conduct fish and fish habitat surveys in 2012 (Jamie Thompson, personal communication). Based on the observed distribution of rainbow trout, mountain whitefish, largescale suckers, sculpins, and dace in the lower river, these species are unable to ascend Fantastic Falls under all flow conditions. The 2012 inventory identified several other potential fish passage barriers and recommended that they be evaluated further in subsequent studies.

A wide range of design options and specifications for fish passage suitable for the development of water diversion, intake, and discharge structure design alternatives are described in the following reference documents:

- Anadromous Salmonid Passage Facility Design (NOAA Fisheries 2011),
- Draft Fishway Guidelines for Washington State (WDFW 2000), and
- Fish Passage Barrier and Surface Water Diversion Screening Assessment and Prioritization Manual (WDFW 2009).
- Fish Passage and Screening Design, Technical Supplement 14N, Part 654 National Engineering Handbook (USDA August 2007)

Fish passage performance criteria are addressed in the following reports:

- Fisheries Handbook of Engineering Requirements and Biological Criteria (Bell 1990),
- Mill Creek Fish Passage Assessment (Burns et al. 2009), and
- New Concepts in Fish Ladder Design: Analysis of Barriers to Upstream Fish Migration (Powers and Orsborn 1985).

Additional information that will be developed through other project studies, and that will be useful in the context of the proposed Fish Passage Study, includes:

- Fish presence, timing, and population characteristics (Aquatic Resources Study),
- Historical streamflows and those predicted under future project conditions (Hydrology and Hydropower Potential and Project Economics studies), and
- Hydraulic and fish habitat conditions within the Project reach under historical and future conditions (Instream Flow Study).

6 NEXUS TO PROJECT

In accordance with 18 CFR §5.11(d)(4), this section describes any nexus between Project operations and effects on fish passage.

The proposed project may affect the passage of fish and other aquatic organisms in the North Fork as a result of the proposed water diversion, intake, and discharge structures. The proposed project may include modifications to the existing channel that would, at times, alter local hydraulic and structural conditions to the detriment of fish.

7 METHODS

7.1 Identifying Preferred Intake and Fish Passage Alternative

The following process was used to develop and identify a preferred intake structure:

- Define desired fish passage conditions (objectives) associated with water diversion, intake, and discharge structures under anticipated project operations.
- For each structure, identify and conceptually design a range of fish passage alternatives that would potentially satisfy the defined objectives.
- In consultation with outside experts, evaluate the fish passage design alternatives identified relative to the defined objectives and specified biological, technical, and cost criteria.
- Refine and select a preferred alternative for each structure.

7.1.1 Define objectives and criteria for evaluating fish passage success at structures under anticipated Project conditions.

The engineering criteria for evaluating fish passage at the water diversion, intake, and discharge structures were defined by reviewing relevant literature on designing and engineering such structures. The State of Washington has published two manuals (WDFW 2000 and WDFW 2009) that provide design guidance for fish passage. This information was supplemented with relevant federal guidance in designing appropriate fish passage facilities (NOAA Fisheries 2011). Additionally, general objectives were solicited from stakeholders at the ARWG sessions in December 2012 and November 2013. Some general objectives were also submitted as formal comments to FERC staff by a variety of stakeholders and included as attributes in the alternatives analysis.

7.1.2 For each structure, identify and conceptually design a range of fish passage alternatives that would potentially satisfy the objectives defined.

Each design alternative was developed to a level detailed enough for a range of overall surface affect parameters to be calculated, and operational affects to be considered. These calculated parameters were then compared to the state and federal fish passage design criteria identified above and other general objectives the ARWG and other stakeholders proposed during an alternatives analysis.

7.1.3 In consultation with outside experts, evaluate the fish passage design alternatives identified relative to the objectives defined.

An alternatives analysis was performed to compare the pros and cons as well as the benefits and costs of each alternative. The various alternatives that were developed to a conceptual design level will be evaluated based on the following feasibility criteria:

- Site conditions (e.g., ease of construction, minimal environmental disturbance);
- Effectiveness of design in passing relevant fish species and life stage types under the expected flow regime;
- Effects on other biophysical processes and resources (e.g., minimizing disturbance of terrestrial habitat);
- Engineering and operational constraints; and
- Cost.

7.1.4 Select a Preferred Alternative

Based on the results of the consultation and evaluation of fish passage alternatives, and other study plans, BCH selected two preferred alternative fish passage designs. The selected water diversion, intake, and discharge structures include a site plan, and cross sections of each proposed facility.

7.2 Fish Passage in Project Reach

7.2.1 Characterize existing natural fish passage barriers within the study area based on the swimming abilities of the fish species present, and then assess their passability under a range of anticipated project flows.

This study component will document the physical characteristics of existing natural fish passage barriers within the study area and, based upon the swimming abilities of the fish species present, determine whether they are passable under existing and predicted post-project flows.

Available scientific literature identifies methods for evaluating the ability of specific species and age classes of fish to pass upstream at specific river bed features, such as chutes and waterfalls, or to navigate various combinations of water velocity, bed slope, and length in locally steep river reaches. We propose to initially map the river and identify the most likely locations where fish passage barriers currently exist or are likely to exist under post-project flow conditions.

The methods developed by Powers and Orsborn (1985) will then be used to determine which of the previously identified river features in the study area are natural fish passage barriers. The approach considers the swimming capabilities of resident fish species and life stages, along with observed spatial and flow-dependent variations in local water surface elevations and hydraulic characteristics. For this project, the primary fish species of interest are cutthroat and rainbow trout. Their size, abundance, and presence within the study area will be documented in the Aquatic Resources Study. Based on known swimming capabilities for these species, we will be able to determine whether, to what degree, and under what flow conditions a putative barrier blocks the upstream movement of fish. The information developed under several of the studies, including the Aquatic Resources, Instream Flow, and Hydrology will likely be considered in combination to determine how much flow should be maintained in the Project reach during different times of the year.

7.2.2 Identify measures that can be taken to eliminate or improve the passability of existing fish passage barriers, and avoid creating new barriers to fish movements within the Project Reach.

The results of the fish passage inventory of the Project Reach will inform decisions regarding minimum flows and project operations, with the goal of maintaining or improving fish passage conditions within the reach under post-project conditions.

Cascades or other fast water areas that have potential to block or delay fish under post-project flows will be identified and, if feasible, recommended for physical modification to create conditions that are more conducive for fish passage.

8 RESULTS

8.1 Fish Passage in Project Reach

8.1.1 Characterize existing natural fish passage barriers within the study area based on the swimming abilities of the fish species present, and then assess their passability under a range of anticipated project flows.

The BCH Study Area boundaries are at the transition of one habitat unit to another at approximately 1.0 mile downstream of the proposed tailrace and approximately 1.2 miles upstream of the proposed intake site. The boundaries of the Study Area are shown in Figure 2, and the GPS coordinates are listed below in Table 1.

Table 1 - GPS coordinates of downstream and upstream boundary of the study area.

Study Area Boundary	GPS Coordinates
Downstream	47.5302° N 121.7498° W
Upstream	47.5737° N 121.7164° W

The Project Reach between the proposed intake and tailrace has four distinct segments where the gradient and ratio of habitat types differ. These four segments are:

1. Lower Canyon; from proposed tailrace to top of the incised channel
2. Canyon Springs; from top of the lower canyon to upstream of the City of Snoqualmie’s Canyon Springs water source.
3. Upper Canyon; deeply incised river channel with numerous cascades and pools
4. Upper Project; from top of the upper canyon to the proposed intake site.

In total, there were six distinct river segments in the Study Area; The Ernie’s Grove and Hancock segments were similar, and the lower canyon and upper canyon segments are similar. Figure 3 illustrates the location of the Aquatic Reaches as distinct river segments.

8.1.2 Habitat Typing

The five-mile study reach has six distinct segments where the gradient, substrate and habitat composition of pools, riffles, glides and cascades are different. The Project Reach is subdivided into the lower canyon, Canyon Springs, upper canyon, and upper project segments (Figure 3). Each segment is listed below in Table 2 with length, slope, and habitat characteristics.

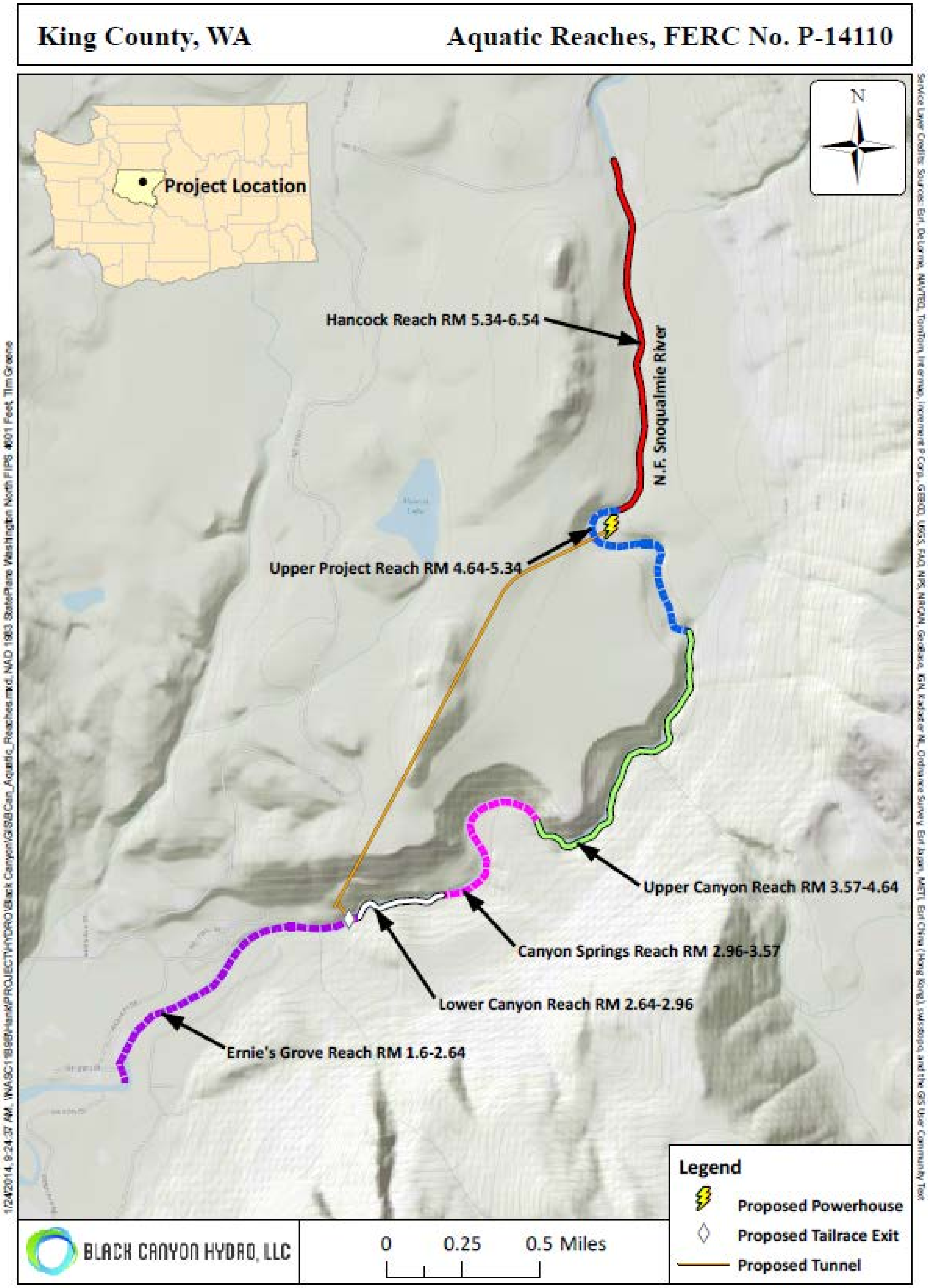


Figure 3 - Aquatic Reaches

Table 2 - Description of six distinct river segments in the BCH study area

Reach Segment	Length (miles)	Slope (%)	Number of Habitat Units	Habitat units per mile	Average Width		Depth		Average W:D (wetted)
					Wetted	Bank full	Average	Maximum	
Ernie's Grove	1.04	0.89	27	26.0	48	79	1.8	11.0	34.3
Lower Canyon	0.39	4.61	21	53.8	41	85	2.4	12.0	21.8
Canyon Springs	0.54	2.18	25	46.3	67	104	2.4	15.0	36.9
Upper Canyon	1.07	4.46	57	53.3	36	75	3.3	24.0	13.6
Upper Project	0.70	1.88	24	34.3	60	95	2.1	12.0	43.5
Hancock	1.21	0.94	47	38.8	64	102	1.9	12.0	41.7

Ernie's Grove segment has a low gradient and a moderate wetted width to average depth ratio which indicates that this river segment is moderately confined. This confinement is likely due to the placement of levees along the river bank in this reach. Both the lower canyon and upper canyon segments are confined by bedrock; the relatively narrow channel width and deep pools result with a low wetted width to average depth ratio. The Canyon Springs segment is moderately confined as are the upper project and Hancock segments. The ratio of habitat types are also different in these river segments, the figures below show a comparison of the percentage of habitat types for the study reaches identified in 2012 and 2013 and for the four study sites. Riffle and glide habitat were the dominant type where the gradient was low to moderate such as in the Ernie's Grove, upper project, and Hancock reaches. Pools and cascades were the dominant habitat in the reaches with steep gradient and more confined by bedrock channel sides. The lower and upper canyon reaches were very similar; steep gradient with cascades, pools and falls with very large boulders. These two reaches were not mapped in 2013 due to safety considerations. The Canyon Springs reach has an intermediate gradient with pools, cascades and riffles, with boulder, cobble and gravel substrate.

8.1.3 Fish and Fish Passage Barriers

The population of trout in the Project Reach may be vulnerable to extreme high flow events and may fluctuate from year to year. In addition to Fantastic Falls, a documented fish passage barrier, Thompson and Donahue (2012) mapped several potential fish-passage barriers to upstream migration in the Project Reach that would severely limit upstream migration of resident trout. The barriers shown in Figure 4 - Fish Passage Barriers Map, were identified perennial fish passage barrier using the same criteria as the

Snoqualmie River Game Fish Enhancement Plan (Thompson et al. 2011). Perennial passage barriers prevent upstream fish passage due to single falls or a series of cascades chutes and plunge pools which cause water velocity that exceeds the fish burst speed and create turbulence that entrails air into the water that decreases the swimming ability of fish. Although these barriers do not necessarily fit the WDFW criteria of a single 12-foot falls or a reach with a gradient >20% for a distance of 525 feet (WDFW 2000) that are barriers to anadromous salmon, the identified barriers in the Project Reach present a very high degree of difficulty for resident trout to migrate upstream. Trout may move a short distance upstream to find more favorable rearing habitat but, extreme high flow events likely move fish downstream. The net movement of the trout population is downstream. In addition, spawning gravel is very sparse in the Project Reach and although spawning may occur, recruitment of trout is likely from fish moving from upstream river segments and tributaries. Figure 5-Figure 8 are representative of the perennial barriers in the Project Reach; 'Crash-test dummy Falls' is located at RM 2.7, downstream of Fantastic Falls, and is a barrier to largescale sucker and mountain whitefish. Fantastic Falls is a 16-foot vertical falls and is barrier to resident trout located at RM 2.89.

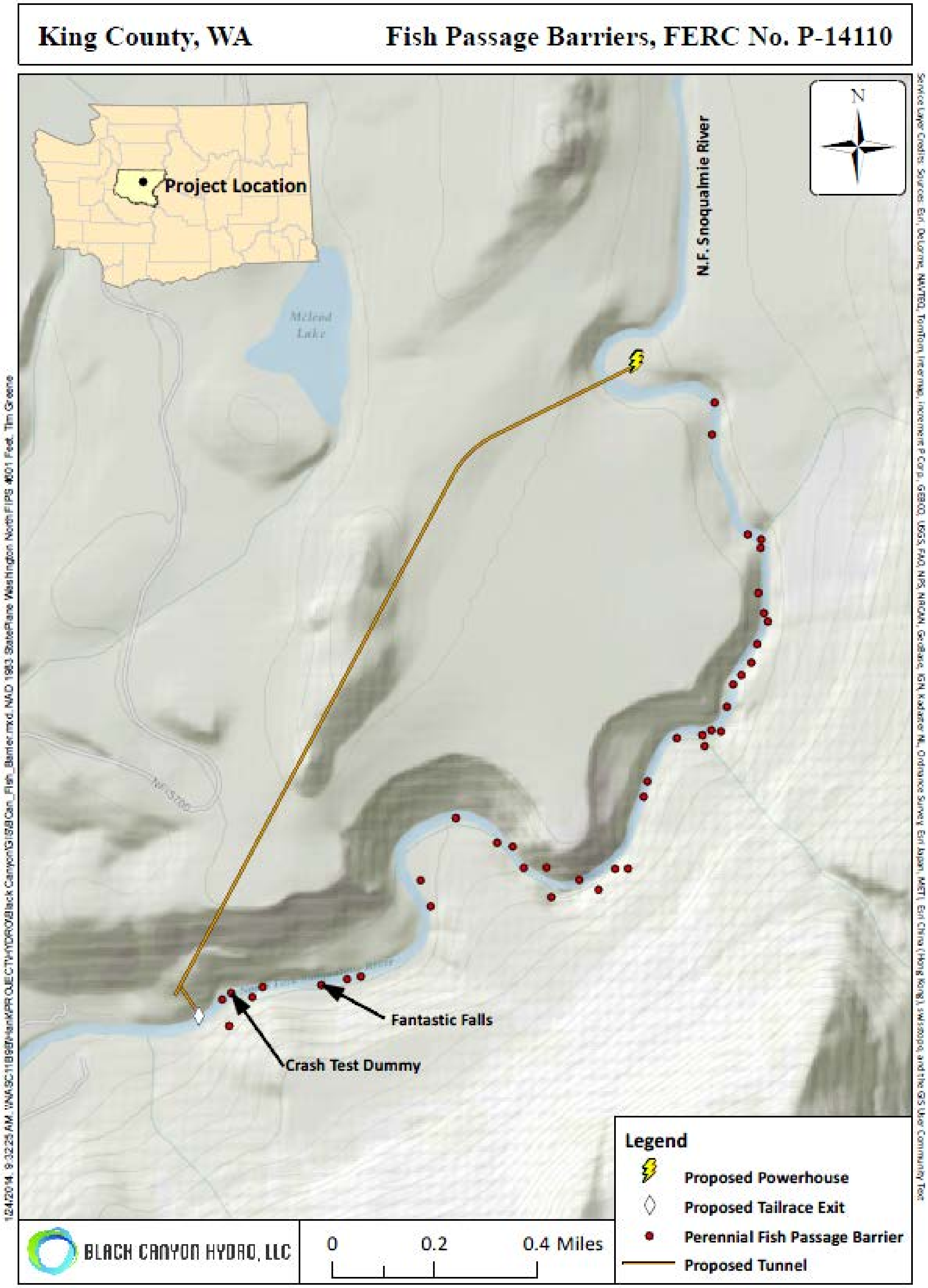


Figure 4 - Fish Passage Barriers Map

Figure 5 - Crash-test dummy Falls at RM 2.70 blocks upstream passage of largescale sucker, mountain whitefish and likely resident trout.

Figure 6 - Fantastic Falls at RM 2.89 blocks upstream passage of resident trout.

Figure 7 - Typical fish passage barrier in upper canyon. August 13, 2013, flow=70 cfs at BCH upper gage.

Figure 8 - Cascade in upper project reach identified as a perennial fish passage barrier at RM 5.0. August 14, 2013, flow=65 cfs at BCH upper gage.

8.1.4 Identify measures that can be taken to eliminate or improve the passability of existing fish passage barriers, and avoid creating new barriers to fish movements within the Project Reach.

There are no feasible measures that can be taken to improve the passability of the existing natural fish passage barriers beyond physical modification of the streambed. However, modification of the existing streambed to improve passability was not a recommendation made by stakeholders and is not being proposed as mitigation by BCH staff.

Instead, to avoid creating new barriers to fish movement, the Environmental Flows Study Report will recommend appropriate instream flow and ramping rate requirements.

8.2 Fish Passage Structures

8.2.1 Define objectives and criteria for evaluating fish passage success at structures under anticipated Project conditions.

The general objectives and criteria for evaluating fish passage at the water diversion, intake, and discharge structures have been defined by reviewing and citing relevant literature. The State of Washington has available two manuals (WDFW 2000 and WDFW 2009) that provide design guidance for fish passage. This information has been supplemented with relevant federal guidance in designing appropriate fish passage facilities (NOAA Fisheries 2011). These guidelines provide the regulatory framework under which project approvals can be expected and are based upon proven approaches to designing fish passage facilities. WDFW has also suggested the two following preliminary objectives, which will be further developed along with other objectives in the ARWG:

- Passage should be as similar to current baseline conditions as possible; and
- Minimize maintenance, specifically instream maintenance activity.

8.2.1.1 Preliminary Design Development

The preliminary design development includes the following:

- Defining basin hydrology and project diverted flows. See the Environmental Flows Study Report. The diverted flows range from 40 cfs to 900 cfs.
- Site plans showing the location and layout of the proposed fishways relative to existing project feature facilities are included for the Intake Alternatives in Drawing Numbers 100, 110, & 120.

- Topographic and bathymetric surveys. Topographic information was collected in a 2012 LiDAR survey. LiDAR information was supplemented with additional topographic and bathymetric data in certain areas that was also collected in 2012.
- Drawings showing elevations and a plan view of existing flow diversion structures, including details showing the intake configuration, location and capacity of project hydraulic features. Intake Alternative Drawings are included as Drawing Numbers 100, 110, 120, 121, 130, 131, & 209.
- Project operational information such as flow capacity, period of operation, and other powerhouse operations that could affect flows.
- Project forebay and tailwater rating curves encompassing the entire operation range. See Environmental Flows Study Report.
- River morphology trends. See Geomorphology, Large Wood, and Sediment Transport Study Report. Each intake alternative would be designed to pass sediment, and exclude large wood from the screen structure. Large wood in each alternative would be designed to pass in the main river channel.

8.2.1.2 Design Flows

- Design low flow: Mean daily average streamflow that is exceeded 95% of the time during periods when migrating fish are normally present at the site. This has been determined in the Environmental Flows Study Report
- Design high flow: Mean daily average streamflow that is exceeded 5% of the time during periods when migrating fish are normally present at the site.
- Flood Flows: The facility should have sufficient river freeboard to minimize overtopping by a 100 year flood event.

Table 3 - Flow exceedance

Flow Duration		
Time Flow is Equal or Exceeded	5%	95%
Average Flow (cfs)	1470	59
Data based on mean daily average streamflow from USGS Gage No. 12142000		

Design flows required for project operation range from 40 cfs to 900 cfs.

8.2.1.3 Upstream and downstream Adult Fish Passage Systems

Per the Aquatic Resource Study Report Chap. 5.3.1 “The primary species of fish that were observed in the Study Area are resident cutthroat trout and resident rainbow trout.

Downstream of ‘crash test dummy falls’ and Fantastic Falls, largescale sucker and mountain whitefish were also observed, and native sculpin were observed throughout the study area.”

In each Intake Alternative upstream adult fish passage would be provided following the criteria outlined in the NMFS Anadromous Salmonid Passage Facility Design, 2011, WDFW Fishway Design Guidelines (2000), WDFW Passage Barrier and Surface Water Diversion Screening Assessment and Prioritization Manual (2009), and the National Engineering Handbook Part 654 Technical Supplement 14N.

A roughened channel is proposed for upstream and downstream passage in each intake alternative for adult trout. Alternative A proposal uses an off channel roughened channel. Alternatives B, C, and D propose a roughened channel design for the main river channel. A Roughened Channel can also be referred to as stream or streambed simulation, rock channels, or nature-like fishways, or as the WDFW Fishway Design Guidelines refer to it as an Engineered Steepened Stream Channel.

Objectives for this would follow design requirements referenced providing reliable safe upstream and downstream passage for adult trout, and only downstream travel for juvenile trout identified in the Aquatic Resource Study Report. The roughened channel design would be designed to a 50 year event, pass debris, and allow adult trout passage upstream and downstream for the required range of flow conditions. All species life stages would have the ability to safely pass downstream through the roughened channel throughout the range of flow conditions.

Fish screen systems will be designed to provide safe downstream passage for all life ages of species identified in the Aquatic Resource Study Report following the referenced design requirements.

8.2.2 For each structure, identify and conceptually design a range of fish passage alternatives that would potentially satisfy the objectives defined.

ARWG and project participants requested that BCH explore design concept further along with other alternatives that would reduce potential impacts on fish migrating in up-or downstream directions. This process has generated four intake alternatives located in the Upper Project Reach that include the following:

- Intake Alternative A – River Mile 5.23. Inflatable/deflatable rubber dam sited in the main river channel, with a side channel vertical plate fish screen system, and an engineered off channel natural type fishway.
- Intake Alternative B – River Mile 5.39. Engineered roughened channel, and control sill sited in the main river channel, with a side channel vertical plate fish screen system.
- Intake Alternative C – River Mile 5.33. Engineered roughened channel, and control sill sited in the main river channel, with an off channel vertical plate fish screen system.
- Intake Alternative D – River Mile 5.33. Engineered roughened channel sited, and control sill sited in the main river channel, with an off channel horizontal fish screen system.

Drawings 100 through 131 show plan, profiles, and sections of the various alternatives. Drawing 209 is a Location Map showing the four intake alternative sites and existing conditions located approximately between river mile 5.23 and 5.39.

8.2.2.1 Intake Alternative A

Alternative A was proposed in the PAD. Alternative A would consist of the following new facilities located at approximately river mile 5.23: (1) an 8-foot-high, 162.4-foot-long inflatable rubber diversion with an associated water intake structure; (2) a side channel vertical screen fish exclusion system with a trash rack, jib crane, sluiceway for debris, and fish bypass return flow back to the river channel; (3) a constructed fish passage channel with natural streambed features; (4) a variable pooling area behind the diversion with a normal water surface elevation of approximately 971 feet above mean sea level and a maximum pooling of approximately 2.83 acres; (5) a power conduit penstock consisting of an approximately 450-foot-deep vertical shaft to an underground powerhouse; (6) with approximately 8,600-foot-long, 12-foot-diameter horizontal tunnel tailrace; (7) for intake and powerhouse access, Alternative A would utilize an existing logging road to minimize disturbance, and require approximately 770-feet of additional road. Drawing No. 100 illustrates Intake Alternative A at river mile 5.23.

Figure 9 - Photo of intake Alternative "A" site, RM 5.23

Water impoundment would be necessary to create a reliable pool elevation, and adequate elevation differential required to adequately "sluice" sediment and debris through the screen bay. An inflatable rubber dam provides both a reliable pool and required elevation differential across the structure. The inflatable rubber dam is also able to deflate under various flow conditions to allow sediment and debris to pass during high flow events. For typical rubber dam photos see Figure 10 - Photo of rubber dam in deflated position and Figure 11 - Photo of rubber dam inflated position.

Figure 10 - Photo of rubber dam in deflated position

Figure 11 - Photo of rubber dam inflated position

8.2.2.2 Intake Alternative B

The goals, objectives, methods, and expected outputs of the studies described differ in only a few respects from those presented in the Proposed Fish Passage Study. In their comments on the Proposed Fish Passage Plan, agency and stakeholder representatives encouraged BCH to consider alternatives to the inflatable dam or other structure originally proposed to divert water from the North Fork into the water intake. At the study plan review and ARWG meetings, BCH presented a conceptual design of a water diversion system now called Alternative B.

This alternative concept consists of the following new facilities: (1) a bulk-water intake structure and fish screening facility. The intake structure with trash racks, coarse screen and jib crane would be constructed on the west bank of the river. (2) The vertical screen bank located within the west bank bulk-water intake structure and fish screening facility would also require means for mechanical sediment removal. (3) A roughened channel and control sill to control a consistent river bed and normal water surface elevations. The control sill would consist of a concrete weir with boulders inset on the surface over top of a cutoff wall of sheet pile, to capture hyporheic flow. The sill would be at the newly established grade of the river bed and would allow uninterrupted water flow through a re-profiled river as a roughened channel series of step pools, riffles, and boulder weirs that would allow upstream and downstream fish passage. (4) A vertical power conduit shaft consisting of an approximately 450-foot-deep vertical tunnel into an underground powerhouse. (5) Approximately 9,175-foot-long, 12-foot-diameter horizontal tunnel; and (6) would utilize an existing logging road to minimize disturbance, and require approximately 3,075 feet of additional road. The intake site would be located at approximately river mile 5.39. Drawing No. 110 illustrates the preliminary Intake Alternative B concept at river mile 5.39. See Figure 13

Without a large impoundment structure it was determined from site topography and design considerations that the Intake Alternative B location did not have adequate river gradient needed to move debris and sediment through the screen structure using passive flow. A mechanical debris removal system would be required to move sediment and debris from the screen bays for Alternative B. The siting on the west bank is also on an inside river bend which would make maintaining an adequate pool depth difficult. Therefore it has been determined that Alternative B will no longer be considered a viable intake alternative.

Figure 12 - Photo of alternative "B" site, RM 5.39

8.2.2.3 Intake Alternative C

After researching the viability of Alternative B engineers continued analyzing available topographic information in the vicinity off the Alt B site and discovered adequate elevation differences across a natural point bar feature near river mile 5.3 downstream of the Alternative B site. This revised location using similar concepts to the Alternative B proposal is called Alternative C. The Alternative C location is near the end of an outside river bend which improves the ability to maintain adequate flow depth and flow direction at the point of diversion, see Figure 13.

Alternative C would use a roughened channel and control sill to control a consistent river bed and normal water surface elevations. Water would be diverted from the east bank of the river approximately 475 feet upstream of the proposed Alternative A intake site. This alternative would consist of the following new facilities: (1) A control sill to control the normal water surface elevation and consistent river bed elevation for a side channel bulk-water intake. The control sill would consist of a concrete weir with boulders inset on the surface over top of a cutoff wall of sheet pile driven to a depth of approximately 10-20 feet, or to refusal, to capture hyporheic flow. The sill would be at the newly established grade of the river bed and would allow uninterrupted water flow through a re-profiled river as a roughened channel series of step pools, riffles, and boulder weirs that would allow upstream and downstream fish passage. (2) An intake structure with a coarse trashrack, jib crane, sluiceway, and radial gate with sluiceway would be located on the east bank of the river, diverted water would be conveyed through; (3) an open channel to a; (4) head gate control structure and into a; (5) fish and debris screening structure. Fish screens in this structure would be mounted vertically, and would have; (6) an automated mechanical wiper system to clear the screen of debris. Screened water would then flow through a; (7) 10-foot-diameter, 450-foot tall vertical penstock; to an underground powerhouse. (8) An approximately 8,600-foot long, 12-foot-diameter tail race tunnel would convey water back to the river near RM 2.6 in the upstream section of the Ernie's Grove reach. (9) Access to the intake site via an existing logging road with an additional 400 feet of new roadway. (10) Fish and debris would be screened and bypassed back into the river using 2 screen bays each consisting of two walls of vertical fish screens in an approximately 6-foot deep pool with a V-shaped configuration (V-screen). Drawing numbers 120 and 121 illustrate Intake Alternative C at river mile 5.3.

Figure 13 – Photo of proposed alternative "C" location, view of west bank, RM 5.3

8.2.2.4 Intake Alternative D

Alternative D is a horizontal flat plate screen system sited in the same location as Alternative C. The screen system proposes to use at least four, approximately 230-foot long horizontal fish screens using the Farmer's Conservation Alliance system, http://farmerscreen.org. Screen dimensions can be reduced with the addition of more bays in numerous configurations to achieve the required maximum flow of 900 cfs.

A roughened channel and control sill would be constructed to control a consistent river bed elevation for Alternative D, in the same configuration as described above in Alternative C. The coarse trashrack, jib crane, head gates, sluiceway, radial gate, access road, and powerhouse would also be very similar to Alternative C. The landward footprint of the Alternative D intake and screen facility is larger than other alternatives. However the Farmer's screen is a passive system, utilizing gravity, and flow to transport debris away from the screen. Fish bypass flow returns to the river channel allowing fish to move downstream safely over the screen. Drawing numbers 130 and 131 illustrate Intake Alternative D at river mile 5.3.

8.2.3 In consultation with outside experts, evaluate the fish passage design alternatives identified relative to the objectives defined.

Engineering staff investigated numerous fish screen facilities in Oregon and Washington in an effort to identify other intake alternatives beyond Alternative A that could potentially be used. This process helped staff make informed decisions about developing a fish screen system for the Black Canyon project. Through the process of interviewing irrigators, operators, and designers BCH has taken knowledge of the visited intakes sites and incorporated those into the preliminary plans for the various intake alternatives. Staff consulted with Irrigation Districts, hydroelectric operators, WDFW Staff, and Farmers Conservation Alliance in this effort. The following is a list of selected projects that BCH staff visited:

Table 4 - Existing selected fish screens visited by staff

Project	Capacity (cfs)	Screen Type	Watershed	Location
Deadpoint Creek	15	Horizontal	Hood River	Oregon
Scotts Ditch	26	Horizontal	Naches River	Washington
Coe Creek	36	Horizontal	Hood River	Oregon
Elliot Creek	30	Horizontal	Hood River	Oregon
Davenport	80	Horizontal	Hood River	Oregon
Whychus Creek	160	Horizontal	Deschutes River	Oregon
Wapatox	450	Vertical	Naches River	Washington
Pilot Butte	500	Vertical	Deschutes River	Oregon
Twin Falls	710	Horizontal	S.F Snoqualmie River	Washington
Weeks Falls	780	Vertical	S.F Snoqualmie River	Washington

All visited sites except Twin Falls and Weeks Falls are on Andaromous water ways. Project sites were visited April through September of 2013.

The Farmers Conservation Alliance Horizontal Screen system was reviewed as a viable Alternative for fish screening. Engineering staff met with Farmers Conservation Alliance (FCA) staff on numerous occasions and also toured the FCA screen sites called Deadpoint Creek, Scotts Ditch, Coe Creek, Elliot Creek, Davenport, and Whychus Creek. All but the Elliot Creek screen were in operation at the time of the site visits. More information can be found on the FCA screens at http://farmerscreen.org/. A Brief History of the Farmers Screen is provided in Appendix B.

The FCA screens are able to operate over a large range of flows. The screen system has been functioning for a large range of screen capacities ranging from 0.5 cfs to 80 cfs. It is calculated that the FCA screen could be scaled up to accommodate the required range of flows needed for the project. It is possible to use the FCA screen bays in parallel or series with other FCA screen bays to meet the project maximum capacity of 900 cfs. Functioning FCA screens have been scaled up by a factor of 160 from 0.5 cfs to 80 cfs. Multiple operational FCA projects have used screens in parallel. The largest operating FCA project uses two 80 cfs screens in parallel for a total combined flow of 160 cfs.

All of the operating FCA screens clearly demonstrated the ability to pass debris and sediment in various conditions. Some of the operating FCA screens are sited on waterways that are glacially feed from Mt. Hood. These waterways are flashy, and have extreme amounts of sediment movement. To date the installed screens have all been successful passing sediment in the challenging environmental conditions.

No fish were observed at the time of the site visits. However biological testing and reports are provided in the appendices documenting the FCA screen is safe for fish passage.

The FCA screen system is a NMFS approved screen that has been documented and tested by various governmental agencies, universities and engineers. National Marine Fisheries Service provided a letter to Farmers Conservation Alliance dated January 27, 2006 in regards to the Overshot Horizontal Flat Plate Fish Screen. In the letter NOAA acknowledges the success of the FCA screen and its suitability for the protection of juvenile salmon and steelhead. The letter also acknowledges the positive relationship between FCA, NOAA, USFWS, ODFW and the Confederated Tribes of the Warm Springs Indian Reservation of Oregon. The letter summarizes the extensive monitoring, studies, and physical models that were used in the successful development of the Davenport screen, and subsequent FCA screen designs. See Appendix A for a copy of the January 27, 2006 NOAA letter.

The Farmers Screen reports for the following studies are attached in Appendix D through L.

- Mefford & Frizell, 2005, Hydraulic Performance of a Horizontal Flat-Plate Screen: U.S Bureau of Reclamation
- Beyers, D.W. and Bestgen, K.R, 2002, Bull Trout Performance in a Horizontal Flat Plate Screen: U.S Bureau of Reclamation
- Craven, 2003, Draft Evaluation of Overshot Horizontal Flat Plate Fish, Farmers Irrigation District
- Mesa, M.G., Rose, B.P., and Copeland, E.S., 2010, Biological Evaluations of an Off-Stream Channel, Horizontal Flat-Plate Fish Screen – The Farmers Screen: U.S. Geological Survey Open-File Report 2010-1042
- Craven, 2001, Horizontal Flat Plate Fish Screen Project - Biological Assessment for Species under National Marine Fisheries Service Jurisdiction
- National Marine Fisheries Service, 2001, Endangered Species Act – Section 7 Consultation Biological Opinion & Magnuson-Stevens Act Essential Fish Habit Consultation – Replacement of an Existing Fish Screen, Construction of a New

Bypass Flow Return System, and Modifications of the Diversion Intake in the Farmers Irrigation District Canal Hood River Watershed

- Craven, 2003, Monitoring Plan for Farmers Canal Overshot Horizontal Flat Plate Fish Screen Hood River, Oregon
- Mesa, M., Rose, B., Zydlewski, G., 2005, Evaluation and Development of hydraulic and biological criteria for two unique horizontal flat plate fish screens Final Report 2005: U.S. Geological Survey, and University of Maine
- Mesa, M.G., Rose, B.P., and Copeland, E.S., 2012, North American Journal of Fisheries Management, Field-Based Evaluations of Horizontal Flat-Plate Fish Screens, II: Testing of a Unique Off-Stream Channel Device-the Farmers Screen: U.S. Geological Survey

Figure 14 – Photo of sampling water velocity on the Deadpoint Creek screen, OR

One of the larger FCA operating screens called the Davenport Screen located on a canal diversion on Hood River, installed in 2002. The capacity of this screen is 80 cfs, see Figure 15. Hood River also has Anadromous/ESA species present. Diverted water is used for irrigation and hydroelectricity. Project partners included Confederated Tribes of the Warm Springs, BPA, ODFW, USFW, NOAA Fisheries, Hood River Watershed Group, and Anderson Perry & Associates.

The screen was designed to be adjustable for experimentation and was designed to be retro-fit with an air burst cleaning system if deemed necessary. Once the screen was operational, it was proven that the air burst cleaning system was not necessary. A monitoring plan for the newly constructed Davenport Screen was created by Farmers Irrigation District in February of 2003. Biological testing was performed by Richard Craven of Craven Consulting Group in the spring of 2003. Craven's report was completed in July of 2003, showing a very high level of protection for species of concern. Biological test and monitoring reports for the Davenport screen are provided in the appendices.

Figure 15 – Photo of Davenport screen, Hood River OR

To date the largest FCA Screen installed is the Wychus Creek screen located in Sisters Oregon. The screen became fully operational in 2011. Project partners included USFS, NOAA/NMFS, Oregon Dept. of Fish & Wildlife (ODFW), DEQ, USFWS, Three Sisters Irrigation District, Upper Deschutes Watershed Council, River Design Group, and Anderson Perry & Associates. Whychus Creek has Anadromous/ESA species. Diverted water is used for irrigation and is planned to also be used for hydroelectricity.

The screen consists of two 80 cfs horizontal screen bays in parallel that result in a net flow of 160 cfs. See Figure 16 – Photo of Whychus Creek screen, Sisters OR. Each screen bay is approximately 10 feet wide by 160 feet in length. In comparison the dimensions for a 225 cfs screen bay would need to be approximately 15 feet wide by 230 feet in length. A screen of this size is calculated to have the required project components necessary to adhere to the NMFS design criteria.

The Whychus Creek project also has a concrete cut off wall and re-profiled roughened channel downstream of the diversion. Figure 17 and Figure 18 are photos of the diversion and roughened channel. The Whychus Creek project provides a great example of an engineered roughened channel on an Anadromous stream that is currently operating and being monitored.

Figure 16 – Photo of Whychus Creek screen, Sisters OR

Figure 17 – Photo of Whychus Creek intake, Sisters OR

Figure 18 - Photo of Whychus Creek, Sisters OR, at the existing diversion with an engineered roughened channel downstream of the diversion.

Another horizontal screen investigated (that is not a Farmers Screen) was at the Twin Falls hydroelectric project FERC No. 4885, located on the South Fork of the Snoqualmie River. The South Fork does not have Andromous species present, and is assumed to be very similar in nature to the North Fork. Engineering Staff met with the Enel Group operator at the project. The project was built in the 1980's and is a run of river 24 MW facility with a 9-foot high collapsible steel diversion weir, with two horizontal fish screen bays that each have auxiliary air burst systems for debris management. Total capacity is 710 cfs, utilizing two screen bays at a maximum capacity of 355 cfs each. See Figure 19 – Photo of Twin Falls Hydro, horizontal fish screen. The project does not provide upstream passage as the diversion is sited at the head of a steep canyon.

The auxiliary air burst system was demonstrated to engineering staff successfully showing the ability to pass debris that had been collected on the screen. The air burst system typically is operated by automation, but for the purpose of demonstration is was operated manually.

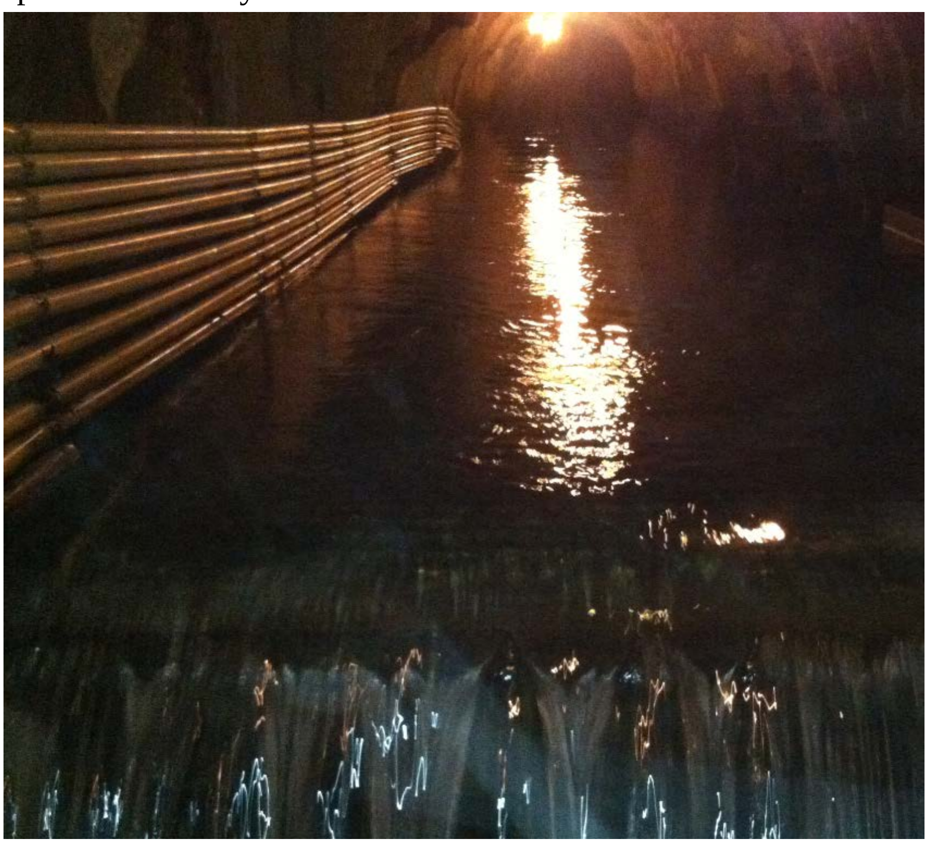


Figure 19 – Photo of Twin Falls Hydro, horizontal fish screen

Engineering staff also visited the Weeks Falls Hydroelectric site. The project is operated by the Enel Group using the same operator as the Twin Falls project.   The Weeks Falls Hydroelectric project is located downstream of Twin Falls on the South Fork of the Snoqualmie River. This project is also located upstream of Snoqualmie Falls and no Anadromous species are present. Flow and debris loading are very similar to the Twin Falls project.   Week Falls uses motorized vertical traveling screens. The cover of the screen facility precluded close observation of the screen operation, see Figure 20. The operator of both Twin Falls and Weeks Falls clearly preferred the operation of the Twin Falls horizontal screens over the Weeks Falls vertical traveling screens. The operator stated that the horizontal screens take significantly less time to maintain versus the vertical screens. The project does not provide for upstream passage as the diversion is sited at the top of Weeks Falls.

Figure 20 – Photo of Weeks Falls Hydro, vertical screens

Other vertical plate screens visited by engineering staff were the Pilot Butte Screen (500 cfs) located in Bend Oregon on the Deschutes River, and the Wapatox Screen (450 cfs) on the Naches River in Washington. Both are on Anadromous waterways and use automated traveling screen cleaners to help manage debris. Pilot Butte is managed by the Central Oregon Irrigation District and Wapatox is managed by the U.S. Bureau of Reclamation. The components used for either screen facility are similar and meet NMFS criteria for fish screening. Elements of each project could be used for the Black Canyon Hydroelectric project for the Intake Alternative C scenario.

Figure 21 – Photo of Pilot Butte screen, Deschutes River OR

Figure 22 – Photo of Wapatox screen, Naches River WA

8.2.4 Select a Preferred Alternative

Alternative selection is primarily based on the following criteria:

- Site conditions (e.g., ease of construction, minimal environmental disturbance);
- Effectiveness of final design in passing relevant fish species and life stage types under the expected flow regime;

- Surface effects on other biophysical processes and resources (e.g., minimizing disturbance of terrestrial habitat);
- Engineering and operational constraints; and
- Cost

8.2.4.1 Alternative Summary

A decision matrix is attached Appendix C which summarizes the primary criteria used to evaluate the alternatives.

Alternative A

Site conditions: Access to the Alternative A site is possible with an extension of an existing logging road on the east side of the river. A steep slope exists on the west bank of the river at the Alternative A site. This slope has the possibility of being unstable. Further analysis would need to be performed to completely understand the geology of the slope. The intake is sited on the inside of a river bend potentially creating problems with sediment build up in front of the intake structure. The intake site is predominantly sited within the flood way and would require significant grading and structural walls to ensure the maintenance platform is sited above the flood stage. During a flood the intake site could become isolated due to the location of the natural fishway bypass system.

Effectiveness of design: Alternative A is effective for upstream and downstream fish passage using an engineered off channel natural fishway. Fish entering the screen facility would pass downstream past the screen unharmed. The inflatable/deflatable rubber dam design is a technology that has been repeated on other similar projects. The rubber dam technology coupled with available screen technology meeting NMFS and WDFW criteria could be used to create a reliable effective fish passage screen facility. The rubber dam design also provides the ability to pass large volumes of bed load and debris during large events. Deflating the rubber dam allows for the ability to pass large debris and sediment past the diversion during flood events and non-flood events as needed such that obstructions at the trashrack are able to freely pass downstream.

Surface effects: Alternative A has the largest in channel temporary construction surface effect versus other alternatives. However, it has the lowest in water footprint for the final in place structure than other alternatives. The final in place shoreline impact for this option ranked higher than other alternatives.

Engineering and cost: The engineering for this alternative is feasible. It is estimated the project capital cost for this intake alternative to be around $5 million.

Alternative B

Site conditions: Access to the Alternative B site is possible with an extension of an existing logging road on the west side of the river. A steep slope exists on the east bank of the river immediately across from the Alternative B site. This slope has the possibility of being unstable. Further analysis would need to be performed to completely understand the geology of the slope. The intake is sited on the inside of a river bend potentially creating problems with sediment build up in front of the intake structure.

Effectiveness of design: Alternative B is effective for fish passage using a control sill and an engineered roughened channel. This could be designed to meet NMFS and WDFW criteria such that it would create a reliable effective fish passage screen facility. However the site does not have much river gradient. Therefor a mechanical sediment removal system would be required to remove all sediment that enters the screen facility. This process would require a large amount of power over the life of the project. It would also require more maintenance and operational costs than the other alternatives.

Surface effects: Overall surface effects are similar to Alternatives C & D, and would be slightly higher than the Alternative A scenario.

Engineering and cost: The engineering for this alternative is feasible. It is estimated the project capital cost for this intake alternative to be around $6.3 million.

Alternative C

Site conditions: Access to the Alternative C site is possible with an extension of an existing logging road similarly to Alternative A on the east side of the river. However, the distance of this road would be shorter than Alternative A. There are no known unstable slope concerns at the Alternative C location. Further analysis would need to be performed to completely understand the geology of the site. The intake location is on the tail end of an outside river bend, which is beneficial for the intake location.

Effectiveness of design: Alternative C is effective for upstream and downstream fish passage using a control sill and an engineered roughened channel on the main river channel. The diversion weir and sheet pile cutoff wall would create minimal upstream pooling as located. Fish that entered the screen facility would pass downstream over the screen unharmed, to open channel conveyance, and discharged to the river at approximately river mile 5.2. This could be designed to meet NMFS and WDFW criteria such that it would create a reliable effective fish passage screen facility. This site has the required gradient for the ability to pass sediment and debris with the assistance of gravity. Therefore a mechanical sediment removal system would not be required to remove the sediment that enters the screen facility. It would require an automated mechanical screen cleaner to keep the screens clear of debris. A radial gate and sluiceway would be required to pass sediment that would collect on the upstream side of the diversion weir and trash rack. A mechanical trash rack cleaner such as a jib crane to remove debris at the trash rack is required. Maintenance would primarily be done off channel, or on the side of the main river channel at the trash rack entrance, keeping in channel maintenance to a minimum. All of the described elements in combination make Alternative C effective.

Surface effects: Overall surface effects are similar to Alternatives A, and would be slightly higher than the Alternative A scenario.

Engineering and cost: The engineering for this alternative is feasible. It is estimated the project capital cost for this intake alternative to be around $6 million.

Alternative D

Site conditions: Access to the Alternative D site is possible with an extension of an existing logging road similarly to Alternative A on the east side of the river. However, the distance of this road would be shorter than Alternative A. There are no known unstable slope concerns at the Alternative D location. Further analysis would need to be performed to completely understand the geology of the site. The intake location is on the tail end of an outside river bend, which is beneficial for the intake location. Note: This is the same location as Alt. C.

Effectiveness of design: Alternative D is effective for upstream and downstream fish passage using a control sill and an engineered roughened channel on the main river channel. The diversion weir and sheet pile cutoff wall would create minimal upstream pooling as located. Fish that entered the screen facility would pass downstream over the screen unharmed, to open channel conveyance, and discharged to the river at approximately river mile 5.2. The design could meet the NMFS and WDFW criteria such that it would create a reliable effective fish passage screen facility. This site has the required gradient for the ability to pass sediment and debris with the assistance of gravity.

Therefore a mechanical sediment removal system would not be required to remove the sediment that enters the screen facility. A radial gate and sluiceway would be required to pass larger sediment that would build up on the upstream side of the diversion weir and trash rack. A mechanical trash rack cleaner such as a jib crane to remove debris at the trash rack is required. Maintenance would primarily be done off channel, or on the side of the main river channel at the trash rack entrance, keeping in channel maintenance to a minimum. All of the described elements in combination make Alternative D effective.

Surface effects: Excavation above the ordinary high water mark is highest with this scenario as the footprint for the facility would be larger than other alternatives.

Engineering and cost: The engineering for this alternative is feasible. It is estimated the project capital cost for this intake alternative to be around $6.4 million.

8.2.4.2 Alternative Selection

Alternative A
This alternative is no longer being considered as a viable option, primarily because it uses a rubber inflatable/deflatable dam with an off channel fish way. WDFW has requested BCH look into other alternatives other than this scenario. Investigating other alternatives has shown that there are other possible alternatives that have less impact and are more effective at fish passage that resemble natural conditions.

Alternative B
This alternative is no longer being considered as a viable option, primarily because it does not have the necessary river gradient available to function without extensive mechanical equipment needed to remove sediment from the screen bays. It is also located near a potential unstable slope. It is sited on the inside corner of a river bend which makes sediment management difficult.

Preferred Alternative C
This alternative ranks the second highest on the decision matrix, see Appendix C. The screen configuration is widely understood and adopted by regulatory agencies for bulk water fish screen facilities throughout the northwest for the capacity required for the Black Canyon Hydroelectric Project. The screen facility is able to effectively manage downstream fish passage and debris while meeting agency criteria.

Overall surface effects are similar to other options. The roughened channel design concept has been implemented in other locations and has the functions necessary to pass adult trout upstream and downstream at the proposed diversion location. The final shoreline visibility is lower than Alternatives A, & B. And has approximately the same visual impact viewed from the river as Alternative D. It is sited on the tail end of an outside river bend, resulting in the river thalwag being close to the proposed intake which assists in movement of sediment at the trashrack, and minimizes changes to the existing thalwag location.

Preferred Alternative D

The FCA screen system is also a viable intake alternative, and score ranks the highest on the Appendix C Decision Matrix.   Biological testing, monitoring, successful implementations, acceptance by NOAA and other agencies have shown that this technology is proven and should continue to be considered as a viable screen option. The FCA screen has demonstrated the ability to safely pass anadromous and ESA species of all life stages downstream over the screen. The screen also manages debris and sediment very well as demonstrated on glacial fed streams with extreme bed load movement.

The screen has been scaled up in size from 0.5 cfs to 80 cfs, and calculation show that it can be scaled to higher capacities with additional engineering. However it would be prudent to perform additional hydraulic modeling with a computational fluid dynamic (CFD) model for larger flows up to 225 cfs. This would ensure the hydraulic properties required for the screen are achievable at the higher capacities. The BCH project would require a minimum of 4 bays at 225cfs resulting in a total flow of 900 cfs.

Potentially a higher number of screen bays at lower capacities per bay could be used to reach the project capacity of 900 cfs. Site conditions are almost the same as Alternative C, both of which are preferred over the Alt A and B site conditions. The roughened channel design has been implemented in other locations and has the functions necessary to pass adult trout upstream and downstream. Alternative D should continue to be investigated as a viable project alternative.

9 DISCUSSION

This report summarizes a collaborative process among stakeholders to identify two preferred intake alternative concepts. Based on preliminary design and analysis, both alternatives would be able to successfully divert water from the North Fork, while also minimizing impacts on environmental and recreational resources in the study area.

The primary environmental concerns considered prior to design related to the possibility that a diversion structure might cause fish mortality during screening or interfere with the natural movement of fish, drift macroinvertebrates, or large woody debris (LWD) and sediment in the North Fork. A secondary set of environmental concerns were the size of the terrestrial footprint of the intake facility and the creation of new access roads. The preferred intake design alternatives addressed concerns of fish mortality by meeting the relevant agency screening criteria. The current movement of fish, drift macroinvertebrates, LWD, sediment, and other debris through the project reach has been maintained by incorporating a control sill, a roughened channel design and re-profiling of a segment of the North Fork downstream of the control sill. The terrestrial impact of the facility's footprint and addition of new roads on wildlife has been minimized through careful site selection. As shown in Drawing Number 209, extensive clear cut logging in the vicinity of the Project and the presence of nearby roads will also reduce additional, new impacts to the area. Less than two acres of land will be required for the permanent facility footprint and only 400-feet of additional road to the intake will be needed.

Recreation occurring in the North Fork created another set of concerns. Recreational users are present near the intake location and instream users all pass through the project reach. Again a thorough analysis of possible siting locations led to designs that minimized the amount of land needed for the facility; limiting the possible displacement of users. The use of a control sill and roughened channel will also ensure that instream users such as anglers and kayakers will not be significantly impeded when moving past the intake location. Since the preferred intake designs locate most of the screening facility off channel, the amount of shoreline disturbed and the amount of the facility visible from the North Fork has been minimized.

A final intake design will be selected from the two above identified preferred alternatives and presented by BCH staff in the upcoming Preliminary Licensing Proposal.

10 REFERENCES

BCH (Black Canyon Hydro, LLC). 2012. Pre-application document for Black Canyon Hydroelectric Project FERC Project No. 14110. March 27.

Burns, B, Powers, P.D., Bates, K.K., and Kidder, J. 2009. Mill Creek Fish Passage Assessment. Prepared for Tri State Steelheaders. October.

Fu, X.C., T. Tang, W.X. Jiang, F.Q. Li, N.C. Wu, S.H. Zhou, and Q.H. Cai. 2008. Impacts of small hydropower plants on macroinvertebrate communities. Acta Ecological Sinica 28(1): 45-52.

Mann, J. 2009. Mirabel Fish Screen Reconfiguration Feasibility and Alternatives Study. Sonoma County Water Agency, Santa Rosa, California. December.

NOAA Fisheries (National Marine Fisheries Service). 2011. Anadromous Salmonid Passage Facility Design. NOAA Fisheries Northwest Region, Portland, Oregon. July.

Powers, P.D., and J.F. Orsborn. 1985. New Concepts in Fish Ladder Design: Analysis of Barriers to Upstream Fish Migration, Volume IV of IV: Investigation of the Physical and Biological Conditions Affecting Fish Passage Success at Culverts and Waterfalls. 1982-1984 Final Report, Project No. 198201400. BPA Report DOE/BP-36523-1. Bonneville Power Administration. 134 pp. August.

R.W. Beck and Associates. 1985. Black Canyon North Fork Snoqualmie Instream Flow Study. Report prepared for Weyerhaeuser Corporation. 42 pp + appendices.

Sweeney, S.J., K.W. Kurko, and T.C. Juelson. 1981. North Fork Snoqualmie River Basin Wildlife Study. Final report of the Washington Department of Game to the U.S. Army Corps of Engineer. Contract DACW67-79-C-0050. 239 pp. + Appendices.

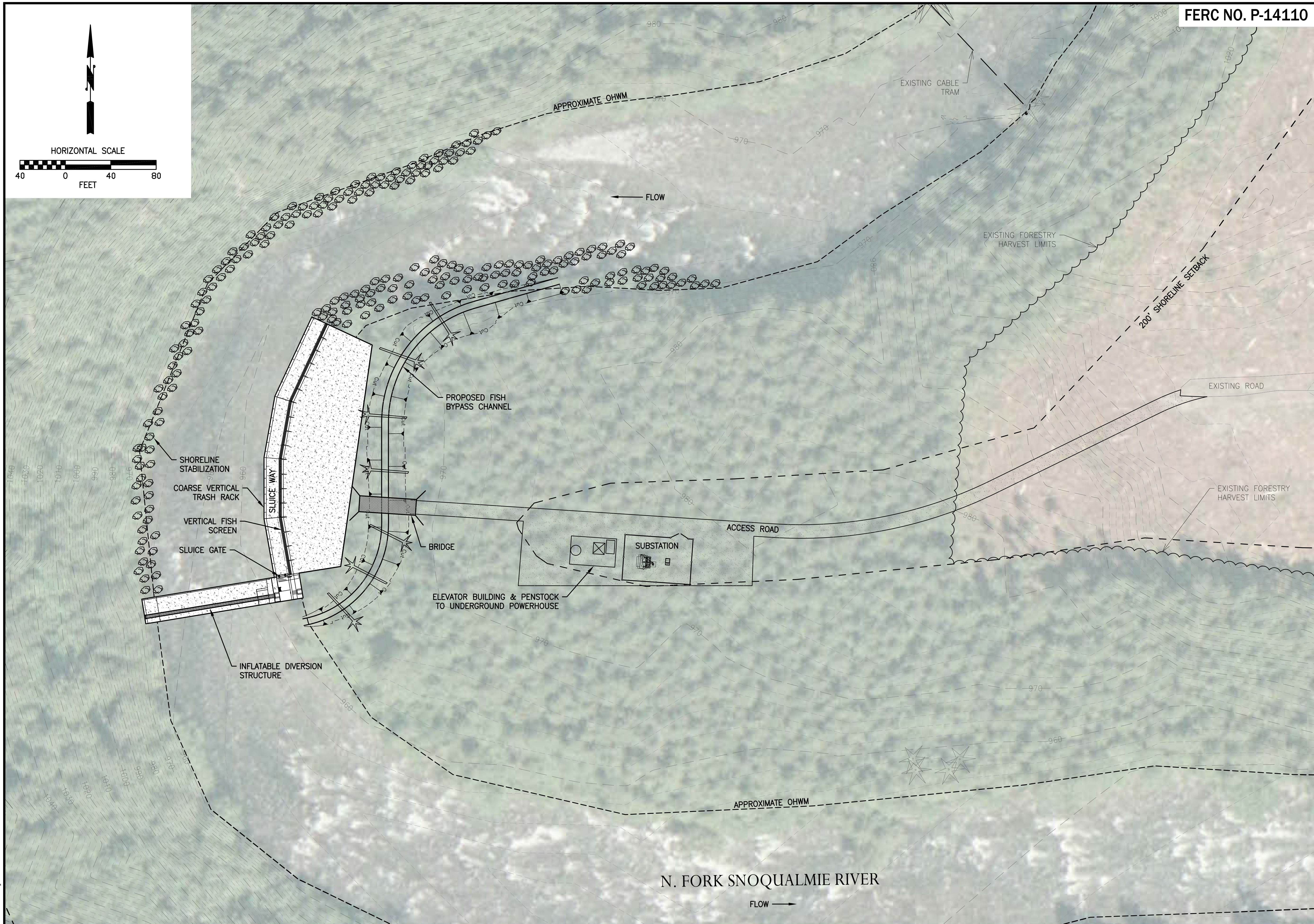
Thompson, J.N., J.L. Whitney, and R.E. Lamb. 2011. Snoqualmie River Game Fish Enhancement Plan – final report of research. Washington Department of Fish and Wildlife. Submitted to Puget Sound Energy in partial fulfillment of the Snoqualmie Falls Hydroelectric Project FERC No. 2493.

Wahl, T.L. 1995. Hydraulic Testing of Static Self-Cleaning Inclined Screens. Prepared for The First International Conference on Water Resources Engineering. American Society of Civil Engineers. August.

WDFW (Washington State Department of Fish and Wildlife). 2000. Draft Fishway Guidelines for Washington State. Available at http://wdfw.wa.gov/publications/00048/. April.

———. 2009. Fish Passage Barrier and Surface Water Diversion Screening Assessment and Prioritization Manual, Washington Department of Fish and Wildlife. Olympia Washington. Available at http://wdfw.wa.gov/publications/00061/.

DRAWINGS



NO.	DATE	REVISION	BY	CK

PRELIMINARY NOT FOR CONSTRUCTION

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PH: 360-738-9999 FAX: 360-733-3056

BLACK CANYON HYDROELECTRIC

INTAKE ALTERNATIVE A INFLATABLE DIVERSION & INTAKE PLAN

KING COUNTY WASHINGTON

SCALE: AS SHOWN

DESIGN: B. HAUSMANN
DRAWN: T. GREENE
CHECKED:
DATE: 12/5/2013
JOB#: 11030000

SHEET 1 of 1

DRAWING 100

DATE AND TIME PLOTTED
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CADD SYSTEM
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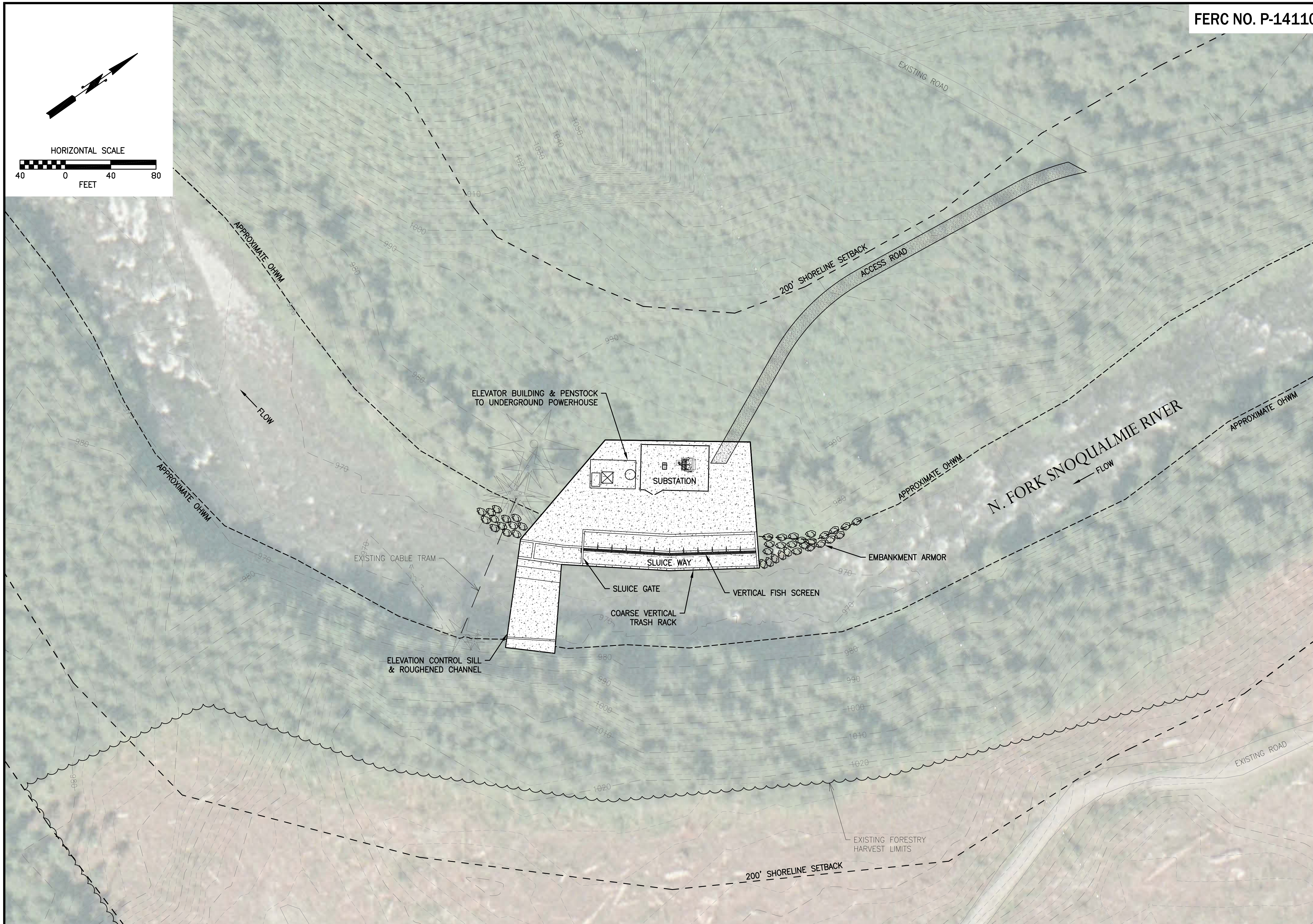

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PRELIMINARY NOT FOR CONSTRUCTION

WHITEWATER engineering corporation
3633 ALDERWOOD AVENUE
BELLINGHAM, WASHINGTON 98225
PH: 360-738-9999 FAX: 360-733-3056

BLACK CANYON HYDROELECTRIC

INTAKE ALTERNATIVE B
EXHIBIT-1 PLAN

KING COUNTY WASHINGTON

SCALE	AS SHOWN
DESIGN:	B. HAUSMANN
DRAWN:	T. GREENE
CHECKED:	
DATE:	12/05/2013
JOB#:	11030000
SHEET	1 of 1
DRAWING	110

DATE AND TIME PLOTTED
December 6, 2013 03:26
PLOTTED BY
BRANDON

CADD SYSTEM
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CADD FILENAME
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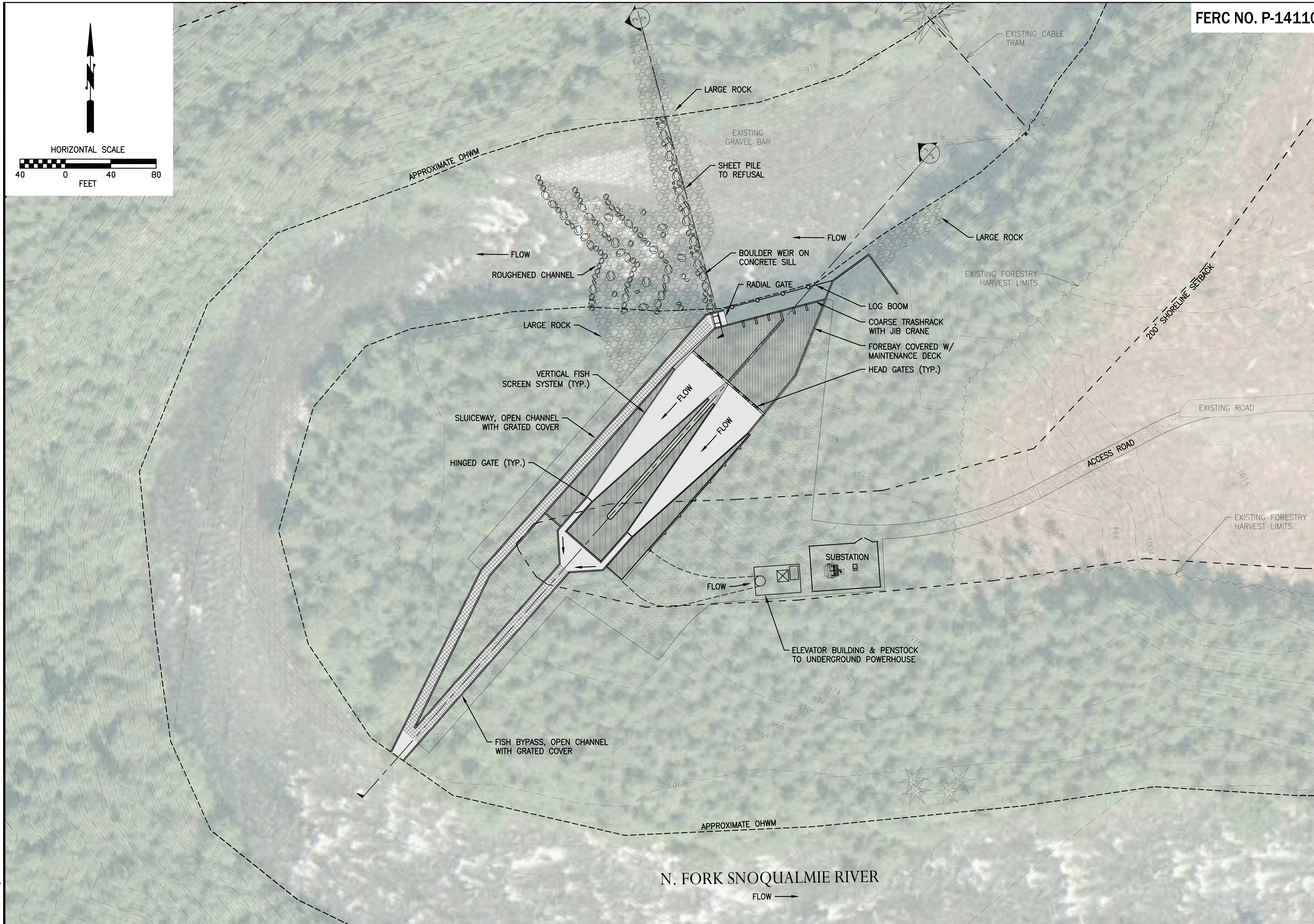
FERC NO. P-14110



NO.	DATE	REVISION	BY	CK

PRELIMINARY NOT FOR CONSTRUCTION

WHITEWATER engineering corporation
3633 ALDERWOOD AVENUE
BELLINGHAM, WASHINGTON 98225
PH: 360-738-9999 FAX: 360-733-5056

BLACK CANYON HYDROELECTRIC

INTAKE ALTERNATIVE C VERTICAL SCREEN PLAN

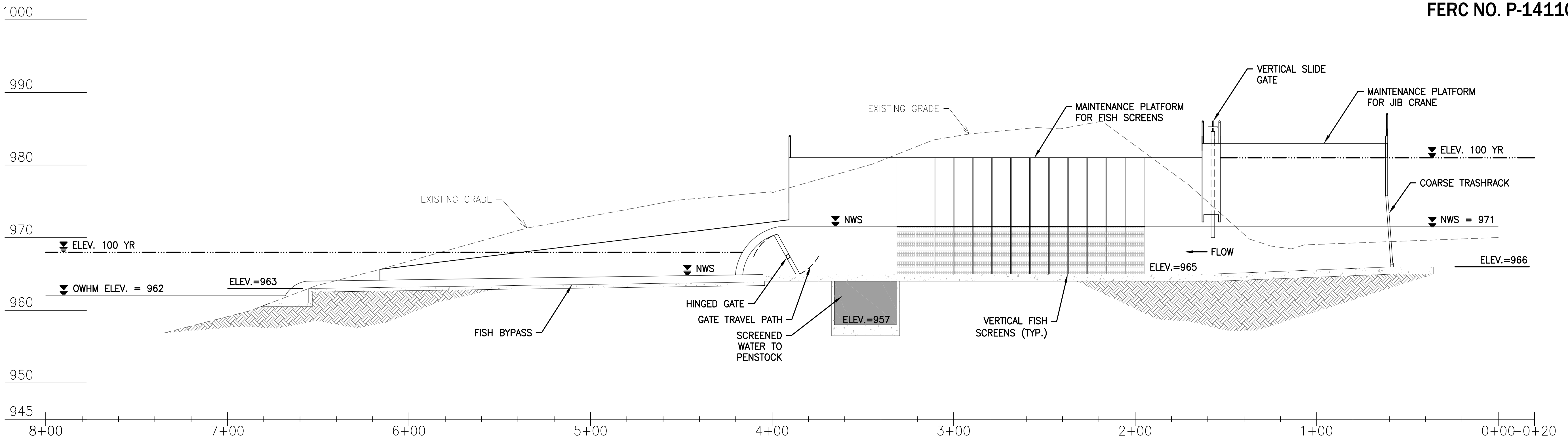
KING COUNTY WASHINGTON

SCALE	AS SHOWN
DESIGN:	B. HAUSMANN
DRAWN:	B. HAUSMANN
CHECKED:	
DATE:	11/22/2013
JOB#:	11030000
SHEET	1 of 2
DRAWING	120

DATE AND TIME PLOTTED
December 6, 2013 03:53
PLOTTED BY
BRANDON

CADD SYSTEM
AutoCAD Rel. 18.2s (LMS Tech)
CADD FILENAME
INTAKE-ALT C.dwg

FERC NO. P-14110



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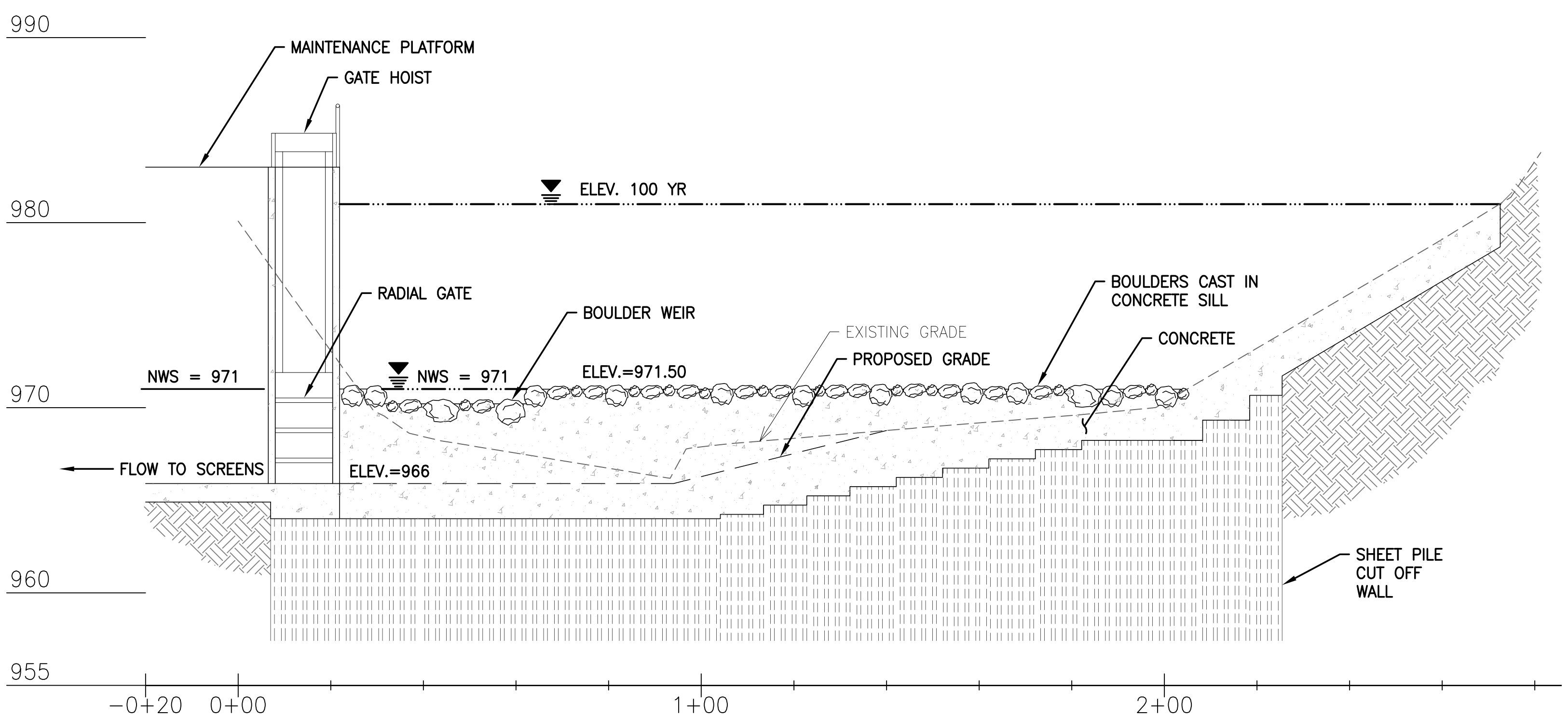

2/1 PROPOSED RIVER CROSS SECTION

NO.	DATE	REVISION	BY	CK

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WHITEWATER engineering corporation
3633 ALDERWOOD AVENUE
BELLINGHAM, WASHINGTON 98225
PH: 360-738-9999 FAX: 360-733-3056

BLACK CANYON HYDROELECTRIC

INTAKE ALTERNATIVE C
VERTICAL SCREEN SECTIONS

KING COUNTY WASHINGTON

SCALE: AS SHOWN
DESIGN: B. HAUSMANN
DRAWN: B. HAUSMANN
CHECKED:
DATE: 11/22/2013
JOB#: 11030000

SHEET 2 of 2

DRAWING 121

DATE AND TIME PLOTTED
December 6, 2013 01:49
PLOTTED BY
BRANDON

CADD SYSTEM
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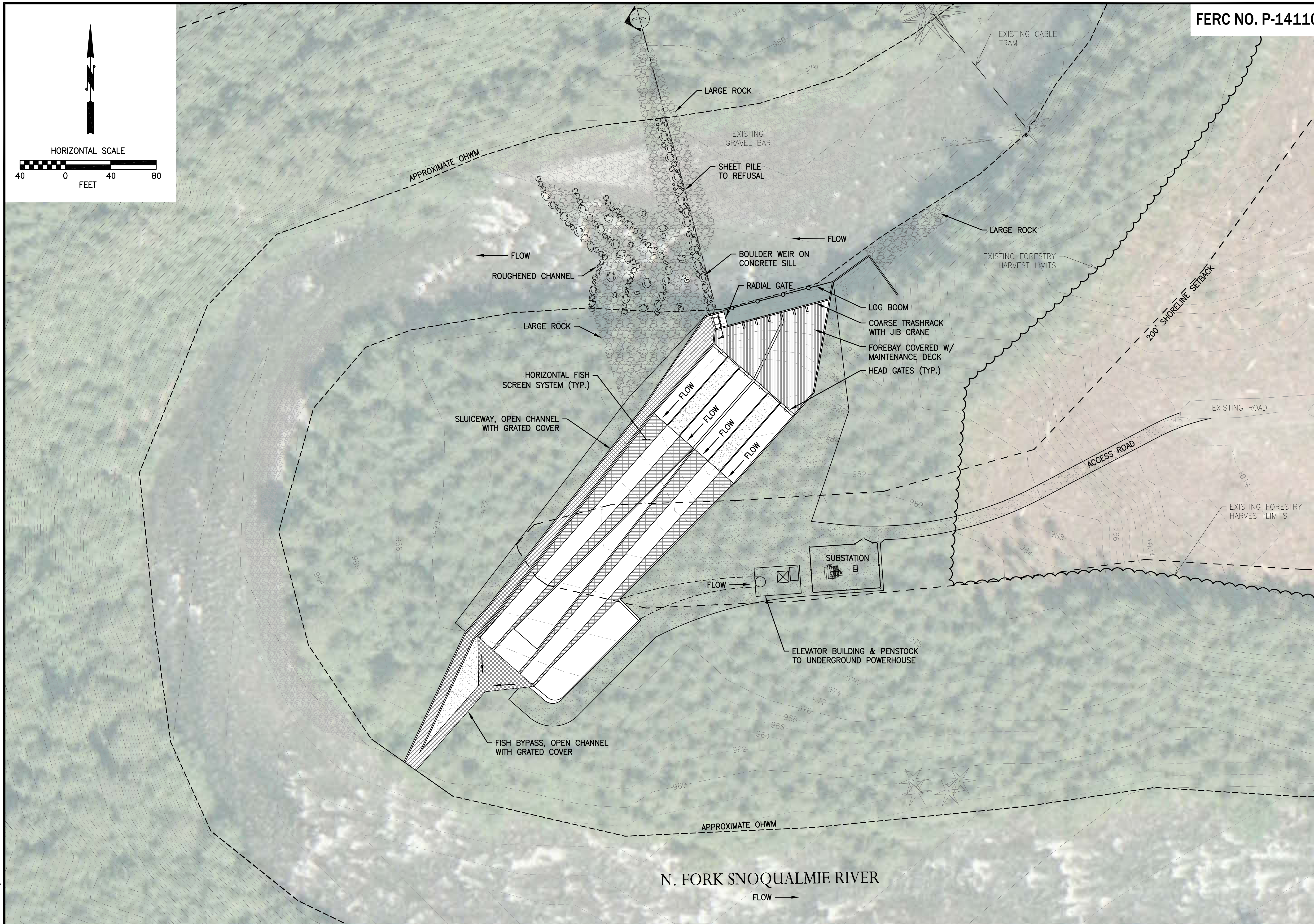
FERC NO. P-14110



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PLOTTED BY BRANDON

CADD SYSTEM AutoCAD Rel. 18.2s (LMS Tech)
CADD FILENAME INTAKE-ALT D.dwg

NO.	DATE	REVISION	BY	CK

PRELIMINARY NOT FOR CONSTRUCTION

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3633 ALDERWOOD AVENUE
BELLINGHAM, WASHINGTON 98225
PH: 360-738-9999 FAX: 360-733-3056

BLACK CANYON HYDROELECTRIC

INTAKE ALTERNATIVE D HORIZONTAL SCREEN PLAN

KING COUNTY WASHINGTON

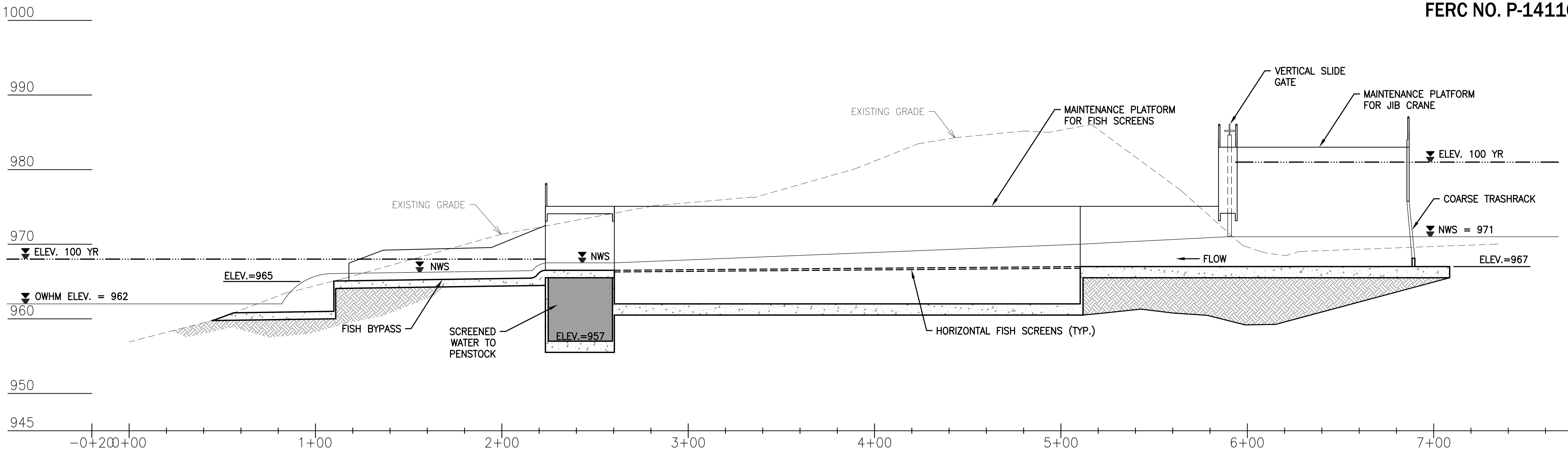
SCALE AS SHOWN

DESIGN:	B. HAUSMANN
DRAWN:	T. GREENE
CHECKED:	
DATE:	11/5/2013
JOB#:	11030000

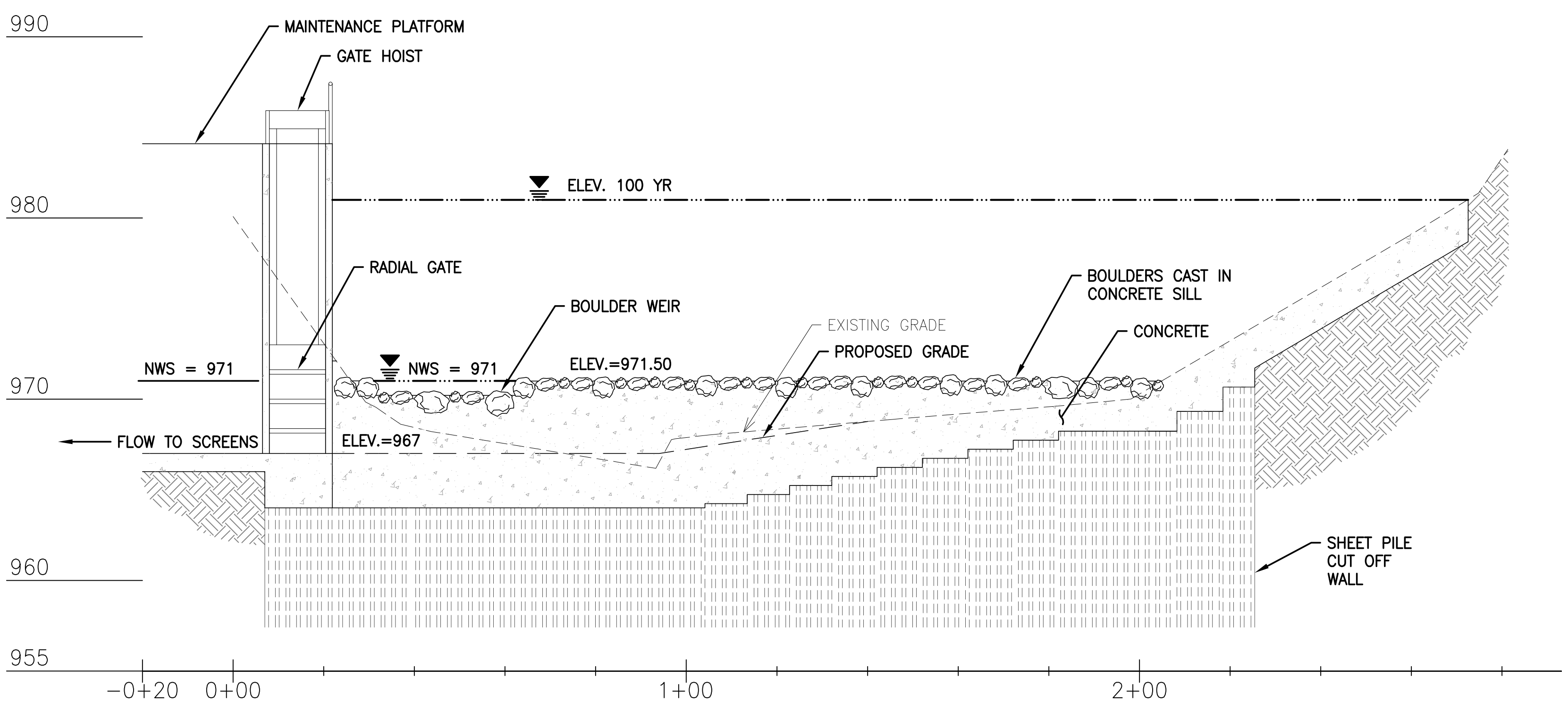
SHEET 1 of 2

DRAWING 130

FERC NO. P-14110



TYPICAL INTAKE SECTION VIEW



2/1 BOULDER WEIR CROSS SECTION

NO.	DATE	REVISION	BY	CK

PRELIMINARY NOT FOR CONSTRUCTION

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3633 ALDERWOOD AVENUE
BELLINGHAM, WASHINGTON 98225
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BLACK CANYON HYDROELECTRIC
INTAKE ALTERNATIVE D
HORIZONTAL SCREEN SECTIONS
KING COUNTY WASHINGTON

SCALE AS SHOWN

DESIGN: B. HAUSMANN
DRAWN: T. GREENE
CHECKED:
DATE: 11/19/2013
JOB#: 11030000

SHEET 2 of 2

DRAWING 131

DATE AND TIME PLOTTED December 6, 2013 01:55
PLOTTED BY BRANDON

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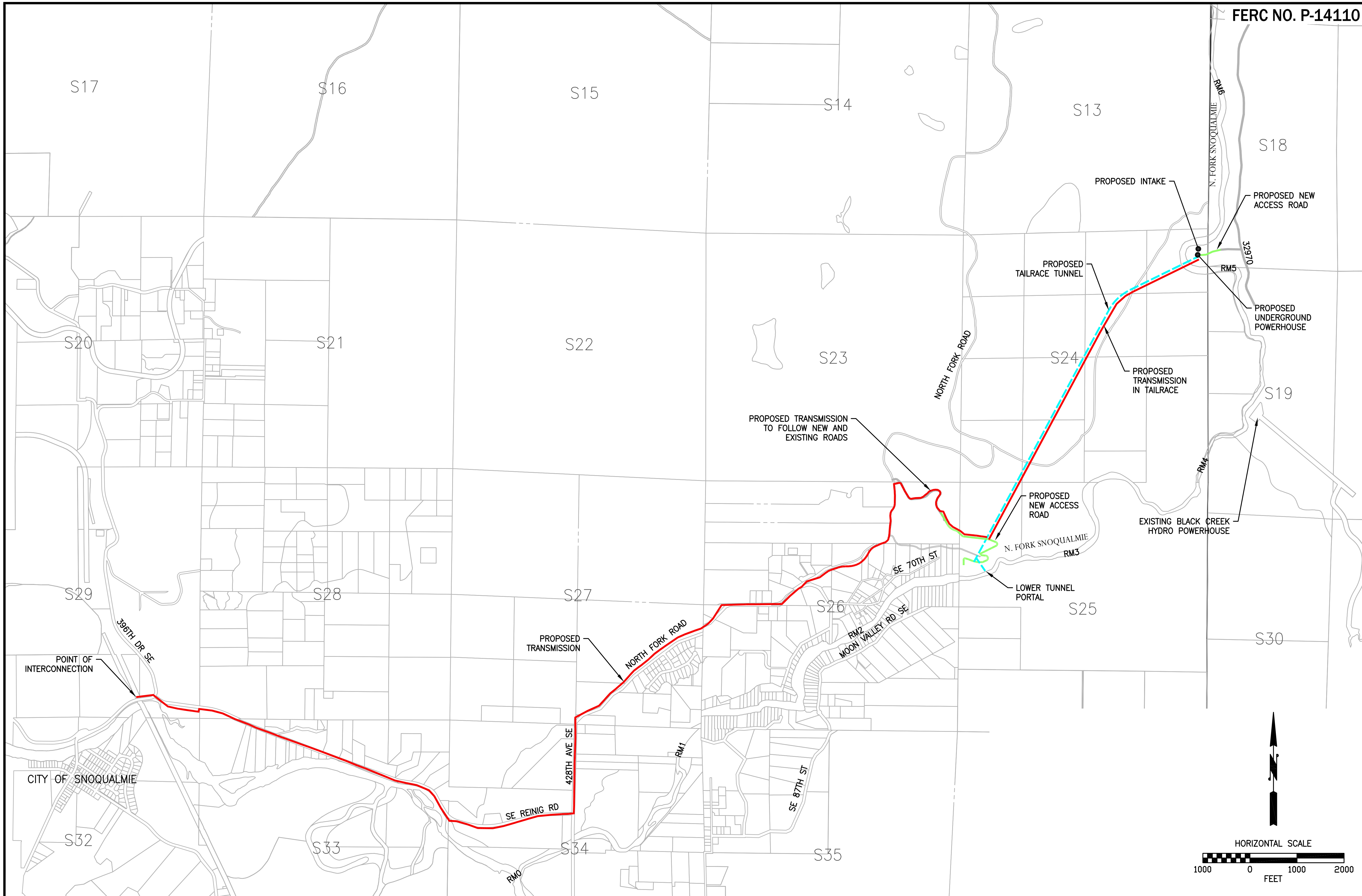

NOTE:

THIS IS NOT A SURVEY. MAP FEATURES SHOWN ARE APPROXIMATE. THE PARCEL DATA SHOWN WAS DOWNLOADED FROM THE KING COUNTY GIS WEBSITE AT HTTP://WWW5.KINGCOUNTY.GOV/GISDATAPORTAL/DEFAULT.ASPX

NO.	DATE	REVISION	BY	CK

PRELIMINARY NOT FOR CONSTRUCTION

WHITEWATER engineering corporation
3633 ALDERWOOD AVENUE
BELLINGHAM, WASHINGTON 98225
PH: 360-738-9999 FAX: 360-733-3056

BLACK CANYON HYDROELECTRIC

LOCATION MAP

KING COUNTY WASHINGTON

SCALE	AS SHOWN
DESIGN:	B. HAUSMANN
DRAWN:	T. GREENE
CHECKED:	B. HAUSMANN
DATE:	12/12/2013
JOB#:	11030000
SHEET	1 of 1
DRAWING	200

DATE AND TIME PLOTTED February 3, 2014 04:43 PLOTTED BY BRANDON

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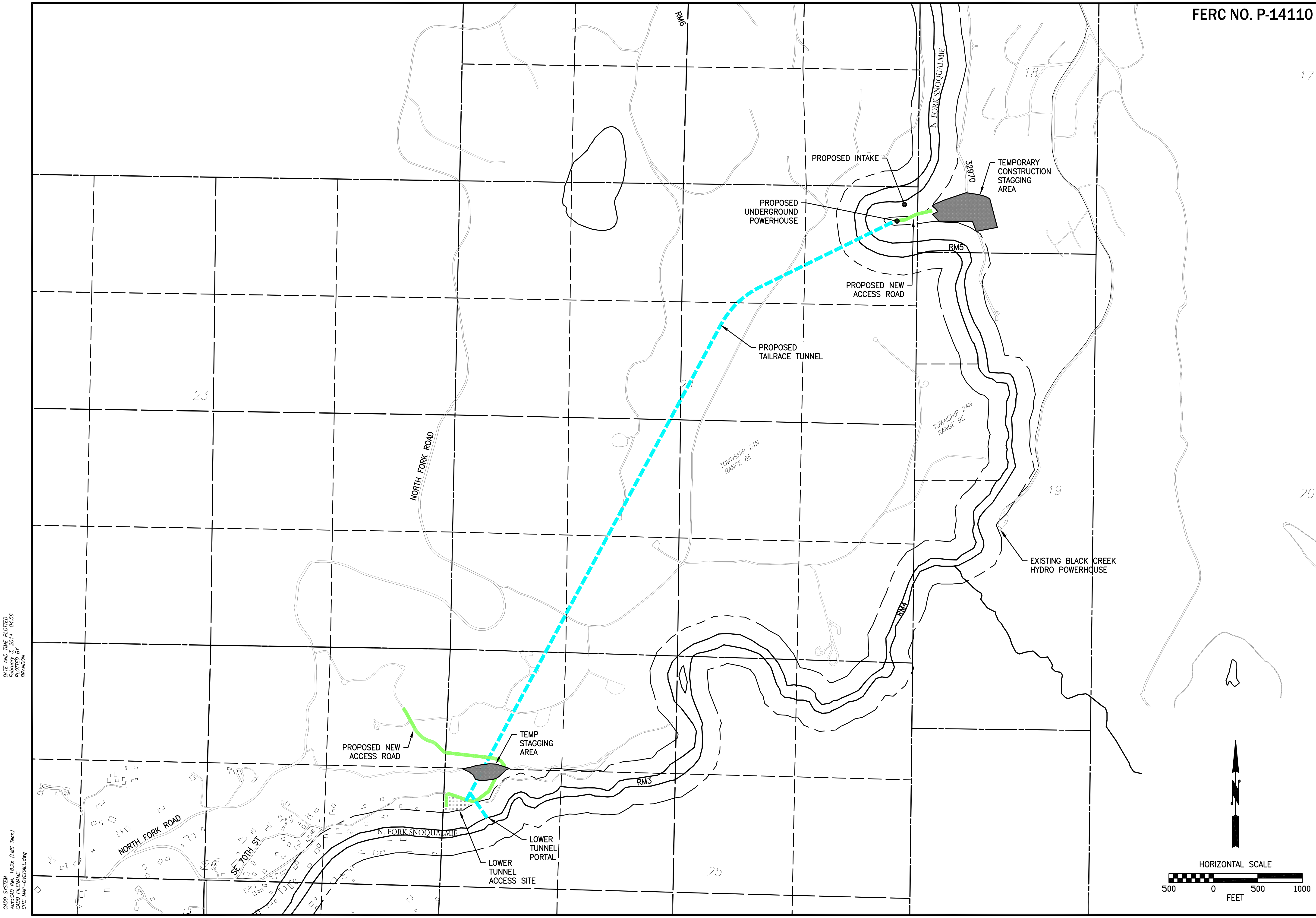


NO.	DATE	REVISION	BY	CK

PRELIMINARY NOT FOR CONSTRUCTION

WHITEWATER engineering corporation
3633 ALDERWOOD AVENUE
BELLINGHAM, WASHINGTON 98225
PH: 360-738-9999 FAX: 360-733-3056

BLACK CANYON HYDROELECTRIC

PROJECT SITE MAP

KING COUNTY WASHINGTON

SCALE: AS SHOWN

DESIGN: B. HAUSMANN
DRAWN: T. GREENE
CHECKED: B. HAUSMANN
DATE: 12/12/2013
JOB#: 11030000

SHEET 1 of 1

DRAWING 201

FERC NO. P-14110

NO.	DATE	REVISION	BY	CK

PRELIMINARY NOT FOR CONSTRUCTION

WHITEWATER engineering corporation
3633 ALDERWOOD AVENUE
BELLINGHAM, WASHINGTON 98225
PH: 360-738-9999 FAX: 360-733-3056

BLACK CANYON HYDROELECTRIC

INTAKE ALTERNATIVE LOCATION MAP & EXISTING CONDITIONS

KING COUNTY WASHINGTON

SCALE AS SHOWN

DESIGN: B. HAUSMANN
DRAWN: T. GREENE
CHECKED:
DATE: 12/5/2013
JOB#: 11030000

SHEET 1 of 1

DRAWING 209

DATE AND TIME PLOTTED December 23, 2013 09:47
PLOTTED BY BRANDON

CADD SYSTEM AutoCAD Rel. 18.2s (LMS Tech)
CADD FILENAME INTAKE-ALT LOCATION MAP.dwg

Appendix A - January 27, 2006 NOAA Letter to Farmers Conservation Alliance

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
PORTLAND OFFICE
1201 NE Lloyd Boulevard, Suite 1100
PORTLAND, OREGON 97232-1274

F/NWR5

January 27, 2006

Julie O'Shea
Farmers Conservation Alliance
PO Box 1621
Hood River, OR 97031

Les Perkins
Farmers Conservation Alliance
PO Box 1621
Hood River, OR 97031

RE: Overshot Horizontal Flat Plate Fish Screen

Dear Ms. O'Shea and Mr. Perkins:

The National Marine Fisheries Service (NMFS) appreciates Farmers Conservation Alliance's (FCA) efforts in developing the Overshot Horizontal Flat Plate Fish Screen (horizontal screen) and proposing thoughtful additional installation of this technology. As we noted in our January 16, 2004, letter to the Farmers Irrigation District (FID), the horizontal screen technology is promising and is a suitable technology for protection of juvenile salmon and steelhead. This letter details NMFS' anticipation of proposals by the FCA for installation of horizontal screens and our intent to work closely with the FCA on the development of the new installations.

We appreciate FID's collaborative work with NMFS, U.S. Fish and Wildlife Service (USFWS), Oregon Department of Fish and Wildlife (ODFW), and the Confederated Tribes of the Warm Springs Indian Reservation of Oregon (CTWSR) personnel. In June 2001, NMFS confirmed (in a June 26, 2001, letter to Bonneville Power Administration [BPA] dated June 26, 2001) that the horizontal screen was worthy of further development, as biological testing appeared promising and protective hydraulic conditions at the screen appeared attainable through careful design. In that letter, NMFS also stated that, "to achieve our acceptance of the facility for long-term use, the screen effectiveness must be gauged through post-construction evaluation of: 1) hydraulic conditions at the screen; and 2) biological evaluation of fish passing through the entire facility." As requested by NMFS, the FID has conducted these evaluations by following the protocol as described in the *Experimental Fish Guidance Devices Position Statement of National Marine Fisheries Service, Northwest Region*, November 1994.

The FID extensively monitored and studied the horizontal screen. The horizontal screen, as designed by criteria developed by the FID, has repeatedly performed well in biological testing. In 2000 and 2001, the U.S. Bureau of Reclamation (USBR) provided laboratory facilities, staff, and the physical model to further technical development of the horizontal screen. A multi-agency group

(NMFS, USFWS, ODFW, CTWSR, USBR, and FID) worked together on the physical model to gain an understanding of the following parameters on screen performance:

- approach and sweep velocities (and how the two work together)
- depth over the screen
- bypass flow control
- flow conditions on the screen
- diversion to bypass flow ranges
- aproach channel conditions

Concurrently, biological testing was conducted at a prototype installation in 2000 and 2001. This prototype (was built several years prior to the USBR physical model) and is located within the FID canal, in a location receiving screened flow; therefore, no listed fish were occupying this area. This prototype, even though there were some obvious design defects, tested quite well biologically, indicating low levels of injury and mortality of juvenile and smolt fish incurred due to passage over the screen.

On June 27, 2001, NMFS received a letter and biological assessment from BPA. In this letter, BPA requested formal consultation on a proposed fish screen replacement, bypass flow return system construction, and water intake modification project on the FID Canal in the Hood River watershed. The horizontal screen was proposed to replace an existing drum screen. The old drum screen did not meet the NMFS Juvenile Fish Screen Criteria and posed a danger to all fish that passed through the facility. On August 17, 2001, NMFS completed a biological opinion on this proposed project. NMFS concluded that the proposed action was not likely to jeopardize the continued existence of Endangered Species Act Lower Columbia River steelhead and Lower Columbia River Chinook salmon. The fish screen and associated facilities, later named the Davenport screen, were subsequently constructed and are now in operation.

The installation of the FID Davenport horizontal screen is a product of the lessons learned both from the prototype and the physical model. Hydraulic and biological testings of the FID canal screen were conducted in 2003. Hydraulic information developed included the assurance of:

- a uniform water surface elevation across the entire screen
- sub-critical flow at steady-state (except the "throat")
- no vortical flow
- velocity through the screen based on gross screen area = 0.083 fps
- average sweeping velocity = 3.6 fps
- total system inflow = 83.07 cfs
- diverted flow = 64.41 cfs
- bypassed flow = 18.65 cfs

Biological information gathered in 2003 included:

- fry were observed passing across the screen with no impingement
- injuries to Chinook salmon and steelhead fry and steelhead smolt were either non-existent or very minimal (the control loss (1.52%) was higher than the test loss (0.01%) and latent mortality of steelhead smolts was greater for the control fish

(1.8%) than for the test fish (0.6%))

- scale loss for smolts was not increased (over that seen in the control group) as a result of passage over the screen
- no latent mortality occurred with steelhead and Chinook salmon fry (for steelhead smolts, latent mortality was minimal and equivalent to that of the control fish)

The Davenport fish screen appears to handle debris load well and is somewhat self-cleaning; however, NMFS and FCA must proceed cautiously into development of additional sites, especially on this particular issue. NMFS anticipates that the future monitoring and reporting of debris characteristics by the FID of the Davenport screen will validate the self-cleaning nature of the screen. NMFS at this time remains concerned about this issue, but is confident that the designs of the new installations can be completed carefully to minimize occlusion of the screen by debris. Further, as we stated to the FID in 2004, on a site-by-site basis we intend to ensure that the project sites are appropriately suited for this technology. It is important that these screens are monitored, and we look forward to working with you to develop a NMFS-approved monitoring program.

NMFS is pleased that the FCA is proposing to use the design criteria (Enclosure 1) developed by the FID and to carefully implement additional projects using the horizontal screen design, as used in the Davenport installation. The future installations should be developed to work as well as, and use the same design concepts as, the Davenport screen. NMFS is prepared to actively participate in design development to ensure compliance with appropriate design criteria. Further, we are interested in continuing involvement with the screen through construction and post construction to ensure that the protectiveness seen in the Davenport installation is repeated in future installations.

Based on site-specific conditions (such as bypass flow availability), and assurance that the hydraulic conditions on the Davenport screens can be reasonably simulated (thus the positive effect is repeatable), NMFS is ready to assist the FCA in the continuing development of the horizontal screen. NMFS staff has enjoyed the collaborative design effort that the FCA has provided. We encourage the FCA to provide this same productive forum throughout the development of additional horizontal screen projects. If you have any questions, please contact Melissa Jundt of my staff at 503-231-2187 or email melissa.jundt@noaa.gov.

Sincerely,

Keith Kirkendall

Keith Kirkendall, Chief
FERC & Water Diversions Branch
Hydropower Division

Enclosure

cc: Jerry Bryan, FID; Mike Lambert, ODFW; Ray Hartlerode, ODFW; Timmie Mandish, USFWS; Ron Rhew, USFWS

Enclosure 1 - Operation, Siting, and Design Criteria[1]

Operation

The intended operation of the overshot horizontal fish screen (the Farmer's Screen) is to safely pass fish and effectively manage debris and sediment. Fish and debris are passed over the screen and off the end to the bypass channel. Diverted water passes through the screen and then flows from a sub-screen chamber over a uniform control weir to the attenuation chamber and then to the inlet of a water conveyance facility.

Water is introduced to the screen through an inlet transition section. Water flowing through the screen develops the following three velocity components:

- Sweeping velocity (V_S) is the average velocity of water moving directly across (parallel to) the screen from input to bypass output.
- Boundary layer velocity (V_B) is the velocity of water in the non-diverted (bypass) flow at or very near the screen (as opposed to V_S which is the velocity of water **above** water layer traveling at V_B).
- Normal velocity (V_N) is the velocity of water passing through the screen approximately perpendicular to the plane of the screen material.

When constant inflow is available to submerge the control weir and screen, an elevated grade line is achieved, and steady-state operation begins. Water entering the screen either sweeps above the screen at V_S (substantially unaffected by the hydraulic condition at the screen) or becomes part of the near-screen hydraulic condition. Water in the near-screen hydraulic condition is diverted between a slower moving boundary layer component, V_B, and a component that passes through the screen at V_N. The V_N flow is the diverted water flow. Water traveling at V_S preferably achieves a relatively uniform fluid flow over water closer to the screen. To the extent that propagating waveforms appear at the water surface elevation over the screen, the V_N oscillates along the vertical axis. This phenomenon enhances screen self-cleaning.

The velocity of the water passing down through the screen (V_N) is relatively uniform across the entire plane of the screen due to the uniform control weir. This uniform velocity ensures that the screen operates without "hot spots," which are non-uniform areas of velocities greater then the acceptable V_N. The uniform control weir also ensures the screen is sufficiently submerged so that fish and debris pass over the screen with adequate water depth. The screen is typically designed with a taper wall to ensure that V_S remains sufficiently high throughout the length of the screen. Correct V_S also reduces the likelihood of trapping debris or delaying fish along the screen. The V_S is typically at least fifteen times greater than V_N. Site-specific adjustments in design and operation are required to optimize system performance over a range of flow levels and site conditions.

---

[1]This enclosure is adapted from criteria developed by the Farmer's Irrigation District listed at http://www.farmerscreen.org/tech-info.htm.

Siting

The Farmer's Screen requires proper site conditions in order to function correctly and efficiently. The following information provides the minimum conditions required in order to reliably install the Farmer's Screen at a given site.

These criteria must be met in order for the Farmer's Screen to perform reliably:

- **Bypass water:** Generally, for screens 100 cfs and smaller, a minimum of 15% of the total diverted flow must be maintained for transporting fish and debris across the plane of the screen. For screens 100 to 500 cfs, a minimum of 10% of the total diverted flow must be available for proper operation.

- **Sediment type and load:** Site sediment - suspended and bed load - must be characterized. If sediment is present, then sediment management facilities must be included as an integral component of the screen project.

- **Backwater profile:** The influence of backwater from the water conveyance system must be taken into account when designing the screen system.

- **Debris type and load:** Generally, the Farmer's Screen manages even large volumes of debris in a highly effective manner. In instances where aquatic plants are present, lower V_N values, covers to block UV light, and upstream, fish-safe antifouling treatment might be required.

- **Footprint area:** Adequate area must be available to accommodate the screen structure.

Design

The Farmer's Screen requires proper flow parameters in order to function correctly and efficiently. The following information provides the minimum conditions required in order to realize optimum cleaning dynamics and fish protection from the Farmer's Screen.

The following criteria must be met in order for the Farmer's Screen to perform reliably:

- **Normal velocity (V_N):** The velocity of flow throughout the entire plane of the screen (generally perpendicular to the plane of the screen), at any given point, should not exceed 0.25 ft/s after correcting for net open area (V_N in this case is the velocity through the open parts of the screen, or through-slot-velocity is V_N).

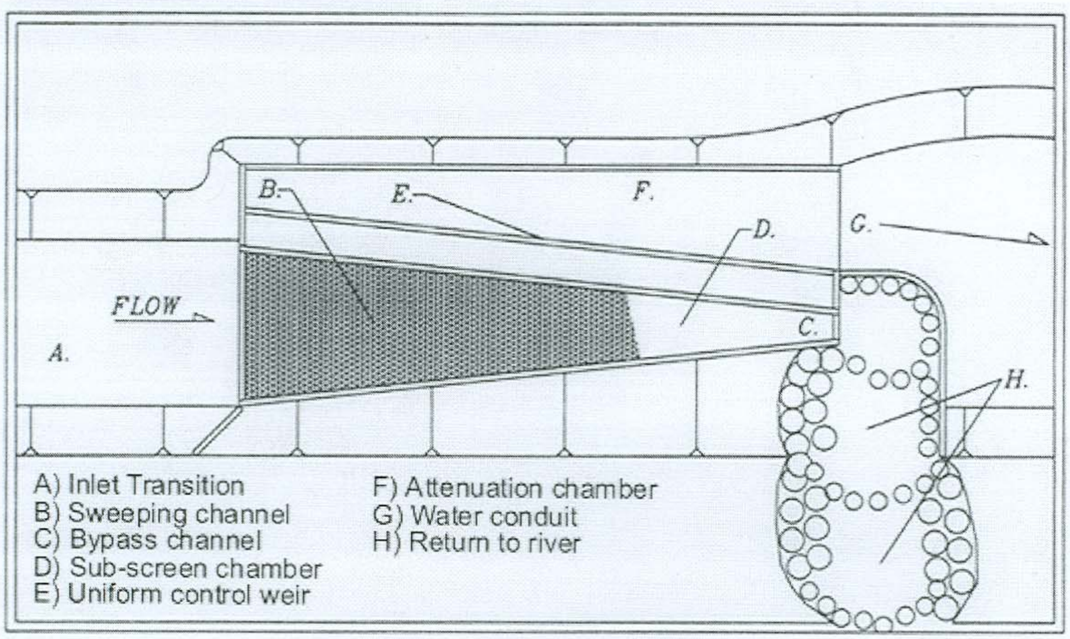
- **Sweeping velocity (V_S):** The water traveling parallel to the plane of the screen should have a sustained velocity throughout the entire length of the screen, averaging about 4 to 8 ft/sec in order to achieve the maximum cleaning dynamics and fish protection. A taper wall is usually required to maintain correct velocity parameters.

- **Depth of water over screen:** The depth of water over the entire screen area should be maintained at a uniform level between one and two feet. The actual depth will vary as a function of screen size and overall hydraulic conditions. A taper wall is usually required to maintain a uniform water surface elevation over the plane of the screen.

- **Screen area:** The total screen area must be large enough to achieve the correct V_N after correcting for net free area (calculated using through-slot-velocity).

- **Screen hole size:** Screen hole size, material, and open area should be in compliance with NMFS standards and allow for an appropriate footprint size and approach velocity.

- **Length to width ratio:** The length to width ratio must be correctly determined to avoid disruptive hydraulic conditions across the entire plane of the screen.



Features

A. Inlet transition (from canal to screen)
B. Sweeping channel
C. Bypass (output) channel
D. Sub-screen chamber
E. Uniform control weir
F. Attenuation chamber
G. Water conduit
H. Return to river

Appendix B - A Brief History of the Farmers Screen

The Farmers Screen:

A Brief History:

The Farmers Irrigation District (FID) in Hood River, OR diverts water from several sources including the main stem of the Hood River for both irrigation and to generate electricity at two hydroelectric facilities. FID has historically faced many challenges in both diverting and conveying water. Many of the points of diversion are remote and located many miles from FID's shop and are accessible only by snow cat in the winter months. The water sources also carry heavy seasonal loads of organic debris and glacial sediment. Both the remote nature of the diversions and the sediment and debris management caused FID personnel to devote an inordinate amount of man hours cleaning vertically oriented screens to maintain flow to their system.

In 1996, devastating debris flows and floods destroyed most of FID's infrastructure. The vertical fish screens in their system (primarily rotary drum screens) were ripped away or destroyed by floods. FID staff and patrons were resistant to installing more vertically oriented screens and set about coming up with a new style of fish screen that worked for their flashy, high gradient, high sediment and debris type of river system. Through several years of trial and error (as well as countless hours of both physical and mathematic analysis and modeling), FID created a horizontal fish screen that they felt had serious potential.

Based on success in the field with early horizontal screen designs, FID built a large prototype screen at the fore bay for one of their power plants (several miles down canal from their main diversion on the Hood River). In early 2000, Jim Buell and Associates performed a series of biological tests on the prototype screen. While the screen design was still somewhat crude in relation to later designs, the biological tests showed great promise both in terms of fish protection and debris management.

FID approached the regulatory agencies in 2000 to see if it would be possible to design and install a full scale screen at their largest diversion on the main stem of the Hood River (known as the Davenport Screen) to replace their out of compliance rotary drum screens. Richard Craven of Craven Consulting Group wrote a Biological Assessment for the proposed horizontal flat plate screen in June of 2001. In August of 2001, National Marine Fisheries Service (NMFS) published a Biological Opinion (OSB2001-0022-FEC) regarding the proposed horizontal fish screen.

In early 2001, FID Manager Jerry Bryan filed a patent on the fish screen design which was ultimately awarded (#6,524,028) on February 25, 2003. A second patent was filed in 2003 which was also ultimately awarded (#6,964,541) on November 15, 2005.

In late 2001 and early 2002, at the request of Brian Hamilton (BOR Engineer), The US Bureau of Reclamation performed hydraulic testing on a physical model of a horizontal fish screen that was similar to early designs of the Farmers Screen. Colorado State University's Larval Fish Laboratory performed biological testing on Bull Trout on this same model. Both reports showed a design with great promise for both handling debris and protecting fish.

The first full scale version of the current iteration of the Farmers Screen was constructed in the fall of 2002. What became known as the Davenport Screen was constructed at FID's largest point of diversion (85 CFS) located on the main stem of the Hood River. The screen was designed to be adjustable for experimentation and was designed to be retro-fit with a cleaning system if deemed necessary. Once the screen was operational, it became clear very quickly that a cleaning system would not be necessary.

A monitoring plan for the newly constructed Davenport Screen was created by Farmers Irrigation District in February of 2003. Biological testing was performed by Richard Craven of Craven Consulting Group in the spring of 2003. Craven's report was completed in July of 2003, showing a very high level of protection for species of concern.

In early 2006, FID licensed the patent for the fish screen to the non-profit corporation Farmers Conservation Alliance (FCA). In January of 2006, Keith Kirkendall (NMFS Chief of FERC Water Diversions Branch, Hydropower Division) sent a letter to FCA stating their willingness to work with FCA to install more Farmers Screens where appropriate.

From 2006 to 2011, FCA worked to get horizontal screens included in the NMFS design guide or criteria. In the process and at NMFS request, FCA hired USGS to perform additional biological testing. In 2009 and 2010, Matt Mesa and Brien Rose with USGS performed a series of tests on both an operational Farmers Screen and a test screen set up to operate with very specific entrance conditions requested by NMFS staff. The final report from this testing was published in 2010 (USGS Open File Report 2010-1042) and again showed excellent protection for fish at various life stages and under various conditions. Horizontal screens were included in the July 2011 revised NMFS criteria.

From 2006 to 2013, FCA installed 27 more Farmers Screens in 5 states ranging in capacity from 0.5 CFS to 160 CFS.

Project Experience:

FCA has spent the past 8 years installing fish screens, evaluating the performance of installed screens, and improving the technology with each new installation. Through subtle changes in design and a very deliberate and careful site analysis process, FCA has gained a high level of confidence in the ability to bring projects to a successful conclusion. FCA has also remained committed to the success of installed projects long after the construction is completed by performing annual surveys of screen performance on all installed screens and addressing any performance issues identified.

The following is a list of some of FCA's project experience:

- 28 installed Farmers Screens total
- Projects installed in Oregon, Washington, Idaho, Montana, and Wyoming
- Smallest project: 0.5 CFS
- Largest project: 160 CFS
- Developed an effective sediment management system (installed on 8 screens, including the largest)

- 9 screens installed that serve hydropower production
- Screens installed on diversions that serve: Irrigation, Fire suppression, Hydropower, Hatchery, and Municipal Water
- Multiple hydraulic and biological tests performed with results exceeding NMFS protection and hydraulic performance standards

Highlighted Projects:

- Davenport Screen: 80 CFS maximum flow single screen providing seasonal water for irrigation and year round water for hydropower production. Located on the main stem of the Hood River in Oregon. The Hood River carries a very high seasonal glacial sediment load, a high organic debris load, and is home to multiple ESA species. This screen was the first full scale version of the Farmers Screen and has been operational since 2002.
- Crabtree Creek: 65 CFS maximum flow single screen providing seasonal water for irrigation and year round water for hydropower production. Located on Crabtree Creek in Linn County, OR. Crabtree Creek carries a high sediment load, is flashy in nature, and is home to multiple ESA species. The diversion has a large range in flows, varying from a low of 15 CFS up to a high of almost 80 CFS during the spring high flow period. Became operational in 2007
- Coe Creek: 36 CFS maximum flow dual screen providing seasonal water for irrigation and year round water for hydropower production. Located on Coe Creek in the Mt. Hood National Forest, immediately below Coe Glacier on Mt. Hood, this stream carries an extremely high season glacial sediment load and is home to one of the most fragile populations of Bull Trout in the Hood River Basin. The diversion has a large range if flows, varying from a low of 5 CFS to a high of 36 CFS. This screen was one of the first to utilize the sediment control system that is now standard for screens in high sediment systems. Became operational in 2009.
- Whychus Creek: 160 CFS maximum flow dual screen providing seasonal water for irrigation and year round water for hydropower production. Located on Whychus Creek on National Forest land near Sisters, OR. Whychus Creek is a glacially fed river that carries very high levels of glacial sediment as well as organic debris from recent wildfires up river. Whychus Creek is home to a recently re-introduced run of steelhead as well as multiple trout species. The diversion has a wide range of flows with a low of 30 CFS and a high of 160 CFS (the screen successfully handled 200 CFS when the entire stream was routed through the structure during some in-stream repair work). Became operational in 2010.
- Badger Creek: 30 CFS maximum flow dual modular screen providing year round water for irrigation and storage. Located on Badger Creek and within the Badger Creek Wilderness Area, this screen represented a logistical challenge during construction due to the very remote nature of the diversion and no access to the site other than a three mile trip up the canal, making the use of concrete impractical. This diversion has a wide range in diverted flows with a low of 5 CFS and a high of 30 CFS. The remote nature of the site made the low operation and maintenance requirement of the Farmers Screen and essential component to project success. Became operational in 2012.

Testing and Assessments:

Below is a complete list of testing, assessments, and publications regarding the Farmers Screen:

Author	Participants	Title	Report Date	Study Timeline	Type	Location
J.W. Buell	CTWS ODFW FID	Fish Screen Performance	May 2000	April 2000	Biological	Farmers Prototype Hood River, Oregon
R. Craven	CTWS ODFW FID	Re-Evaluation of Farmers Irrigation District Prototype Flat Plate Fish Screen	May 2001	April 2001	Biological	Farmers Prototype Hood River, Oregon
R. Craven	CTWS ODFW FID	Biological Assessment for Species under NMFS Jurisdiction	June 2001	Spring 2001	Biological	Farmers Prototype Hood River, Oregon
National Marine Fisheries Service	BPA NMFS	Endangered Species Act – Section 7 Consultation Biological Opinion OSB 2001-0022-FEC	Aug 2001	N/A	Biological Opinion	NMFS NW Region
D.W. Beyers and K.R. Bestgen	Bureau of Reclamation and Colorado State University	Bull Trout Performance during Passage over a Horizontal Flat Plate Screen	July 2002	June 2000 to July 2001	Biological	Bureau Reclamation Horizontal Flat-Plate Screen model Denver, Colorado
Farmers Irrigation District	FID NMFS CTWS ODFW	Monitoring Plan for Farmers Canal Overshot Horizontal Flat Plate Fish Screen	Feb 2003	Feb 2003 to Uncertain Future Date	Monitoring Plan	Davenport Screen Farmers Irrigation District Hood River, OR

R. Craven	CTWS BPA ODFW FID	Evaluation of Overshot Horizontal Flat Plate Screen	July 2003	Spring 2003	Biological with brief hydraulic characterization	Davenport Screen Farmers Irrigation District Hood River, Oregon
K.H. Frizell and B.W. Mefford	Bureau of Reclamation Water Resources Research Lab including NMFS, USFWS, ODFW, CTWSR, and FID	Hydraulic Performance of a Horizontal Flat-Plate Screen	Feb 2005	June 2000 to July 2001	Hydraulic	Bureau Reclamation Horizontal Flat-Plate Screen model Denver, Colorado
B. Rose and M. Mesa	USGS Western Fisheries Research Center and Columbia River Research Lab for USFWS	Evaluation and Development of Hydraulic and Biological Criteria for Two Unique Horizontal Flat Plate Fish Screens	2005	Spring and Summer 2004 and 2005	Biological and Hydraulic	Smith and Rye Grass Inverted Weir Flat-Plate screens, Mckay and Ochoco Creeks near Prineville, Oregon and Malheur Screen on Donner and Blitzen River, Oregon
Keith Kirkendall	National Marine Fisheries Service	Overshot Horizontal Flat Plate Fish Screen	2006	2006	Opinion	NMFS NW Office
M. Mesa and B. Rose	USGS FCA NMFS ODFW	Biological Evaluations of an Off-Stream Channel, Horizontal Flat-Plate Fish Screen – The Farmers Screen Open File Report 2010-1042	2010	2009 to 2010	Biological and Hydraulic	Herman Creek Horizontal Flat Plate ODFW Fish Hatchery Screen Cascade Locks, Oregon
M. Mesa and B. Rose	USGS NAJFM	Field Based Evaluations of Horizontal Fish Screens, II: Testing of a Unique Off- Stream Channel Device –	June 2012	2009 to 2012	Journal Article	Herman Creek Horizontal Flat Plate ODFW Fish Hatchery Screen

		The Farmers Screen				Cascade Locks, Oregon

Appendix C - Decision Matrix

Alternative	Description	screen meets NMFS criteria yes/no	Existing Steep Slope concerns yes/no	New access Road Lf	Estimated Off Channel Excavation cubic yards	Operational cost low or high	Intake location type	Pass sediment using gravity yes/no	Mechanical req'd for sediment removal yes/no	Mechanical screen cleaning yes/no	Mechanical trash rack cleaning yes/no	Power Consumption	Upstream & Downstream Fish Passage, adult trout yes/no	Construction In-channel disturbance below OHWM acres	Final In-channel foot print below OHWM acres	Landward Footprint above OHWM acres	Final footprint in 100yr floodway acres	Final shoreline impact viewed from river feet	Approximate Total Intake Capital Cost	Score
Alternative A	Inflatable/deflatable rubber dam with side channel vertical plate screen	yes	yes	770	5,000	low	inside bend	yes	no	yes	yes	medium	yes	2.4	0.46	0.7	0.7	1126	$5 million	0
Alternative B	Side channel vertical plate screen with roughened channel	yes	yes	3075	5,000	high	inside bend	no	yes	yes	yes	high	yes	1.3	0.89	1.8	0.5	608	$6.3 million	-6
Alternative C	Off channel vertical plate screen with roughened channel	yes	no	400	23,000	high	outside bend	yes	no	yes	yes	medium	yes	1.64	0.89	1.8	0.6	400	$6 million	2
Alternative D	Off channel horizontal (FCA) screen with roughened channel	yes	no	400	30,000	low	outside bend	yes	no	no	yes	low	yes	1.64	0.89	1.9	0.6	400	$6.4 million	6

Color Scoring
Green = 1
Yellow = 0
Red = -1

Note: Costs, dimensions, earthwork volumes, and surface area effects are approximate only and are based off of preliminary feasibility plans. These values could change as a result of future design requirements. The intent of this matrix is to create a reasonable comparasion between the available alternatives.

Appendix D - Mefford & Frizell, 2005, Hydraulic Performance of a Horizontal Flat-Plate Screen: U.S Bureau of Reclamation

RECLAMATION

Managing Water in the West

Hydraulic Laboratory Report HL-2004-05

Hydraulic Performance of a Horizontal Flat-Plate Screen

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Water Resources Research Laboratory
Denver, Colorado

February 2005

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

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Prepared in cooperation with Colorado State University. The biological documentation is reported in "Bull Trout Performance During Passage Over A Horizontal Flat-plate Screen" by Beyers and Bestgen.

14. ABSTRACT
The Bureau of Reclamation with the assistance of the Colorado State University Larval Fish Laboratory has conducted hydraulic and biological tests of a horizontal flat-plate fish screen in the Water Resources Research Laboratory. Investigating the hydraulic characteristics of the screen will provide valuable information on how the screen operates and provide limitations on the zones of operation to ensure meeting biological needs. A laboratory-based biological assessment of the screening concept using bull trout will provide a pilot study that evaluates fish behavior and potential damage when exposed to the screen.

15. SUBJECT TERMS
horizontal flat-plate fish screen, hydraulic evaluation, sweeping velocity, approach velocity, diversion structure, bull trout fish passage, debris testing

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Hydraulic Laboratory Report HL-2004-05

Hydraulic Performance of a Horizontal Flat-Plate Screen

Kathleen H. Frizell
Brent W. Mefford

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Water Resources Research Laboratory
Denver, Colorado

February 2005

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Acknowledgments

Mr. Brian Hamilton of Reclamation's Pacific Northwest Region requested this work. Reclamation's Pacific Northwest Region and the Science and Technology Research Program supplied funding. The team formed by members of the National Marine Fisheries Service, Fish and Wildlife Service, and the Oregon Department of Fish and Wildlife provided invaluable guidance to the study.

Dr. Kevin Bestgen and Dr. Daniel Beyers from the Colorado State University Larval Fish Laboratory cultured the bull trout from eggs to the appropriate life stage. Their expertise in handling and performing the biological studies in the Water Resources Research Laboratory (WRRL) provided validity to the biological testing.

Thanks to WRRL technicians Jerry Fitzwater and Billy Baca for data collection assistance. The WRRL shop personnel expertly constructed the model and made changes to the model quickly, often with short notice.

Peer review was provided by Leslie Hanna, Hydraulic Engineer, in the Water Resources Research Laboratory.

Hydraulic Laboratory Reports

The Hydraulic Laboratory Report series is produced by the Bureau of Reclamation's Water Resources Research Laboratory (Mail Code D-8560), PO Box 25007, Denver, Colorado 80225-0007. At the time of publication, this report was also made available online at **http://www.usbr.gov/pmts/hydraulics_lab/pubs/HL/HL-2004-05.pdf**

Disclaimer

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INTRODUCTION

Reclamation's Pacific Northwest Region has a site where they have proposed using a horizontal flat-plate screen to divert water for irrigation. The site, located on the Powder River near Baker, Oregon, is in a potential bull trout habitat area. The proposed screen is considered experimental under current regulatory agency criteria for fish screen design because no method to automatically clean the screen is provided. In addition, there have been no statistically based biological studies performed on this type of screen. Initial field tests of several small screens have shown that horizontal flat-plate screens exhibit low fouling rates when operated at sweeping-to-approach-flow velocity ratios of greater than about 10:1. The low fouling attribute of the screening concept could reduce screen construction, operation and maintenance costs. Therefore, if the level of fish protection is comparable with accepted fish screening technology, the horizontal fish screen could potentially be used extensively.

The Bureau of Reclamation with the assistance of the Colorado State University Larval Fish Laboratory has conducted hydraulic and biological tests of a horizontal flat-plate fish screen in the Water Resources Research Laboratory. Investigating the hydraulic characteristics of the screen will provide valuable information on how the screen operates and provide limitations on the zones of operation to ensure meeting biological needs. A laboratory-based biological assessment of the screening concept using bull trout will provide a pilot study that evaluates fish behavior and potential damage when exposed to the screen.

This report presents the hydraulic assessment of the performance of the horizontal screen. The report of the biological assessment, "Bull Trout Performance in a Horizontal Flat-Plate Screen", prepared by Drs. Dan Beyers and Kevin Bestgen from the Colorado State University Larval Fish Laboratory, is available separately [1].

OBJECTIVE

The objective is to conduct laboratory hydraulic and biological testing of an experimental horizontal flat-plate fish screen. The screen will be evaluated to determine the effect of the following hydraulic parameters on screen performance:

- Approach and sweeping velocities,
- Depth over screen,
- Bypass flow control issues,
- Flow conditions including eddy zones,
- Diversion to bypass flow ranges,
- Approach channel conditions and,
- Debris.

The hydraulic aspects of the screen performance are discussed in this report. The biological aspects of bull trout passage over the screen are reported separately in a July 2002 report [1]. The draft hydraulic report was completed in June 2001. This final report is being published under this new report series for better distribution of the material and is dated accordingly.

CONCLUSIONS

The hydraulic modeling effort has resulted in a better understanding of how a horizontal flat-plate screen operates. The initial screen design had several very positive aspects that were discovered and other aspects that have been dealt with now that the screen operation is understood. A brief discussion of the final results of the screen testing is presented. The conclusions are general in nature and are given as guidance for future horizontal flat-plate screen designs.

- Uniform approach channel geometry of at least five depths in length upstream from the screen is recommended. A longer screen approach channel produces better flow conditions over the screen. A flat non-porous section upstream from the screen is ideal, as this will prevent a change in flow direction at the upstream edge of the screen.
- Depth is maintained over the screen by the use of a weir that must extend the entire length of the screen in the diversion channel. The diversion weir provides two important features. First, the weir wall ensures the screen will not dewater and maintains a minimum bypass flow. Second, the weir forces a nearly constant flow depth over the entire screen and therefore, a fairly uniform approach velocity field to the screen. Screen baffling is not required to maintain uniform approach velocity across the width and along the length of the screen.
- A flat non-perforated section with a length of at least two flow depths is recommended downstream from the screen section to alleviate possible non-uniformity in the approach flow near the end of the screen.
- Sweeping velocity will gradually decrease downstream along the length of the screen for all flows except those near the design flow.
- Depth will be constant over the screen when operating under the design condition, with the exception of surface waves across the width and length of the screen.
- Any approach velocity may be designed for and will be reasonably well maintained across and down the length of the screen with appropriate approach and bypass channel geometry.
- Head loss through the screen is minimal as expected with small screen approach velocities.

- Sweeping and approach velocities are generally consistent across the width of the screen section whether rectangular or with a converging side wall.
- As the depth increases over the screen the sweeping velocity decreases.
- Recirculation, ponded water, or the presence of a hydraulic jump over the screen increases the screen approach velocity and should be avoided during operation.
- Rectangular screen geometry is only appropriate for smaller diversion to channel flow ratios of about 25 percent or less.
- Debris handling issues were only briefly investigated with the following observations:
    - Higher sweeping velocities produce better debris handling performance.
    - Debris or gravel the size of the screen perforations is likely to become lodged in the screen.
    - Gravel smaller than the screen perforations will pass through the screen or remain suspended in the bypass flow and travel downstream. Gravel larger than the screen perforations will travel over the screen and out through the bypass.
    - Vegetation and algae were not fully tested in the laboratory, but initial tests revealed a tendency for waterlogged vegetation to stick to the screen and other types to pass downstream.
    - A sediment trap located upstream from the screen would be a wise design feature.
    - Dislodging gravel wedged in the screen perforations will be difficult.
    - Cleaning the area beneath the screen will be a difficult maintenance issue.
- Better overall screen performance exists with operation in the supercritical flow range.
- A change in flow condition over the screen, i.e. from supercritical to subcritical flow, is unacceptable.
- Downstream control of the bypass flow is not recommended, as it will likely produce an undesirable flow condition on the downstream end of the screen.
- A drop below the elevation of the screen structure is recommended, if possible, at a field installation. A solid or non-perforated section should be placed at the downstream end of the

screen before entering the drop to prevent excessive approach velocities or reverse flow at the bypass opening when operating with a drop at the end of the screen. The screen bypass discharge and bypass width will control the critical flow depth and control the sweeping velocity at the end of the screen. A drop below the elevation of the screen will generally produce increasing sweeping velocity into the bypass.

- NMFS screen exposure time criteria of 60 seconds would allow a very long screen with a reasonable sweeping velocity of 1 to 3 ft/s. Screen exposure time may be less critical depending upon the findings of the bull trout testing.
- For a given channel discharge and bypass flow, sweeping velocity and depth may be attained several ways. If larger flow depths are desired then a narrower channel is needed. However, larger flow depths decrease sweeping velocities and increase approach velocities. The best compromise that will attain both the highest sweeping velocity and most depth would be to optimize the screen geometry to produce a high length to width ratio.

A simple spreadsheet was developed in Microsoft Excel to help narrow down the range of operation in the model. This spreadsheet will allow a designer to hone in on a screen geometry option prior to making the final design computations using a backwater computation or software program.

These observations of the hydraulic performance of the screen should be interpreted with the results of the bull trout testing program. Studying both aspects of the screen performance will, hopefully, determine if a horizontal flat-plate screen is a viable alternative for water diversions where ESA listed species are located.

SIMILITUDE

The model testing was performed using Froude similitude where the geometric and kinematic parameters for a 1:3 scale are as follows:

$L_r = L_p/L_m = 3$
$A_r = (L_r)^2 = 9$
$V_r = (L_r)^{1/2} = 1.732$
$Q_r = (L_r)^{5/2} = 15.59$

Where:
L_p = prototype characteristic length
L_m = model characteristic length
L_r = length ratio
A_r = area ratio
V_r = velocity ratio
Q_r = discharge ratio

The screen hole-size in the model is the same as the screen hole-size in the prototype with 3/32 in diameter holes and a 37 percent open area on the perforated plate. The Reynolds number was high enough in the model to eliminate scale effects; therefore, the model and prototype screen openings can be the same [2].

Various Froude model scales were used for the hydraulic testing. By using different model scales a larger range of flow conditions could be tested. Model results may be scaled to the prototype by using the above ratios or other ratios as needed to produce the desired prototype range of flows, velocities, or depths.

The biological investigations were performed as if the model were full field scale. The model was assumed to be of an actual prototype or field size for the biological testing. As a result, no scaling of discharge, velocities or depths is needed to interpret the biological results.

PHYSICAL MODELS OF THE SCREEN GEOMETRIES TESTED

A model of a water diversion containing a horizontal flat-plate screen was constructed in the Water Resources Research Laboratory (WRRL) in Denver, Colorado, figure 1. The model has a 6 ft wide rectangular channel approximately 40 ft long. A 10:1 (H:V) ramp slopes up to a 4-ft-long non-porous flat section, then to the screen about midway down the channel. The 6-ft-wide by 12-ft-long screen is supported 1 ft above the channel floor. The screen is composed of nine, 2-ft-wide by 4-ft-long punch plate screen panels supported on a metal frame. The screen has 3/32 in diameter holes on 3/16 in stagger. Flow passes from beneath the screen through a 12 ft long by 1 ft high rectangular opening in one side wall to the diversion channel. A 1-ft-high weir was placed across the diversion channel to ensure the screen cannot totally dewater channel flow. Slats were used in the downstream diversion channel to control diversion flow and depth over the weir. The downstream bypass channel consisted of a 2-ft-flat section immediately downstream of the screen leading to a 10:1 ramp down to the floor of the box. A flap gate was located downstream in the bypass channel to provide backwater or a control point, as needed.

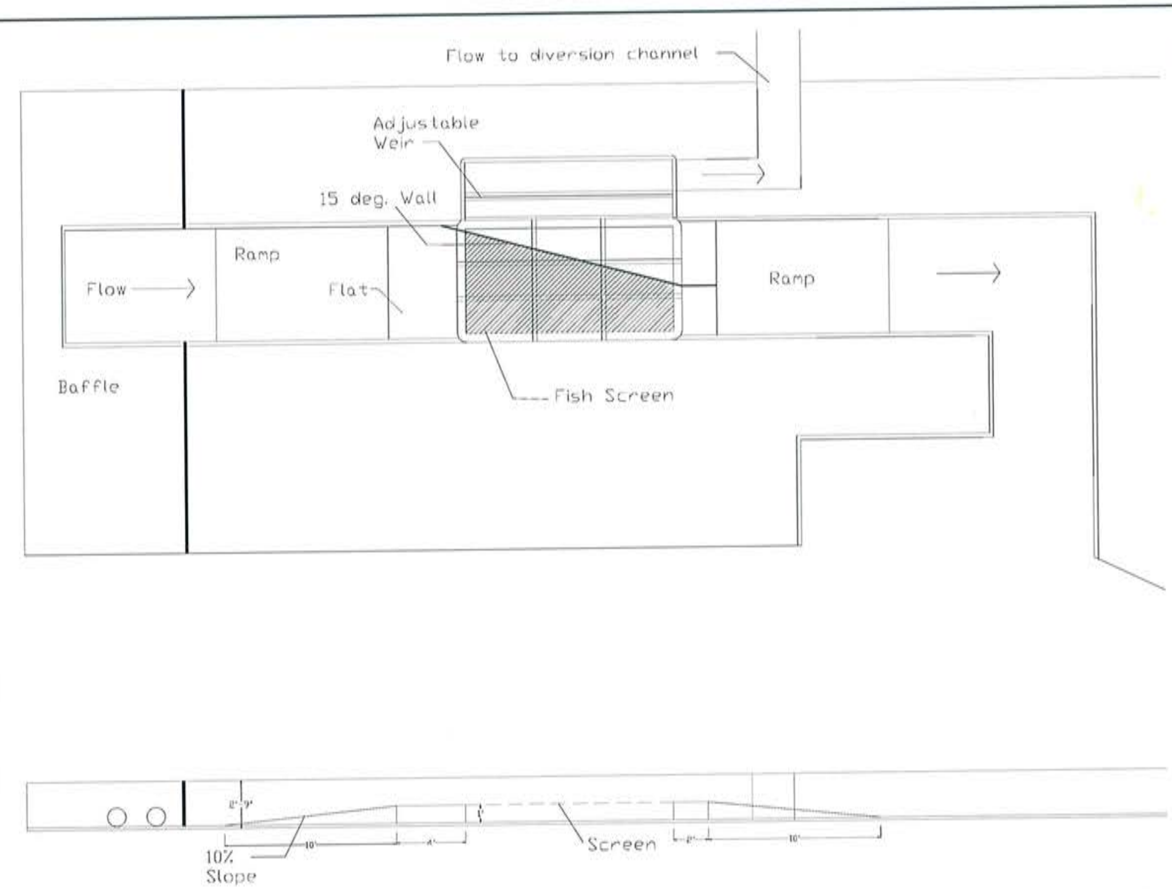


Figure 1.—Schematic of the physical fish screen model with the original design and the basic layout of the 15-degree wall convergence.

Flow was supplied to the model either using the permanent laboratory Venturi measurement system or a portable pump with an acoustic strap-on pipe flow meter for measurement. The bypass flow was measured using a contracted rectangular sharp-crested weir mounted in a box at the end of the bypass channel. The head on the weir was measured using a pressure cell in a stilling well and converted to flow using a continuous flow meter that updated and constantly displayed the flow rate. This allowed accurate setting of the flow volumes between the diversion and bypass flows.

A large compressor and heat exchanger was installed in the WRRL water storage channel to cool the water temperature to an acceptable range for the bull trout testing.

Initial model testing was conducted with a rectangular screen. The next tests were conducted with a converging wall on the left side. A portion of the screen was omitted and covered with a 15-degree sloping wall that began about 1 ft upstream from the screen, converged through the screen area, and continued straight through the flat section downstream from the screen producing a 2.54-ft-wide bypass opening. After completing testing on this geometry, the flat section in the bypass channel was extended an additional 2 ft to make the bypass section 4 ft long before entering the downstream ramp.

Final testing was conducted with the model modified to produce a 1 ft wide bypass with a 15-degree wall producing a 4.22-ft-wide upstream channel width. The upstream channel width of 4.22 ft extended upstream to the beginning of the ramp to provide good approach conditions. The downstream flat section was removed to produce a drop at the downstream end of the screen. The gate in the downstream bypass channel was still available to provide control as necessary.

HYDRAULIC INVESTIGATIONS

Hydraulic investigations of the flow field near the screen were conducted for three screen and channel geometries. First, a rectangular screen with a constant width channel and a full width downstream bypass channel was tested. Second, a triangular screen with a converging wall from the same upstream width leading to a narrowed downstream bypass channel was tested. The third configuration consisted of a converging side wall from a narrower upstream channel leading to a 1 ft wide bypass channel. This configuration was tested using a Froude scale of 2:1 to provide a comparison to existing vertical screen and bypass technology. The model was operated over a range of diversion flow to channel flow ratios and flow depths. Tests were also conducted with and without downstream control in the bypass channel. For each flow tested three-dimensional point velocity measurements were measured three inches above the screen. These data were used to evaluate flow field uniformity, screen approach velocity, and screen sweeping velocity. Debris testing was also conducted to determine the self-cleaning characteristics of the screen. Testing covered sweeping to approach flow velocity ratios from 5:1 to about 30:1. The flow range tested included sweeping velocities in both the subcritical and supercritical range.

Operations

The channel discharge, Qc, approaches the screen with a 10:1 ramp and a 4-ft-long flat section leading up to the screen. The screen is mounted on a rack 1 ft off the floor of the model with the downstream end underneath closed off and the left side of the underneath area open for the diversion flow, Q_d. The bypass flow, Q_b, continues on over the screen and out to a laboratory return channel. These flow areas are shown on figure 2. Control of the diversion and bypass flows, for a given incoming channel flow, determines the flow ratios. A weir is set in the diversion channel along the entire length of the screen preventing the screen from dewatering either during operation or during shutdown of diversion operations.

There are innumerable ways to operate the screen based upon the importance of various parameters to the operator, owner, or agency. However, the range of acceptable operation of the screen is quite limited for a given diversion flow. The weir wall on the diversion must be set to keep the desired minimum water surface over the screen for the design diversion flow. The velocity of approach and the area of the screen exposed determine the diversion flow amount. As the depth over the screen increases the sweeping velocity decreases. Depth and velocity are nearly uniform across the width of the screen.

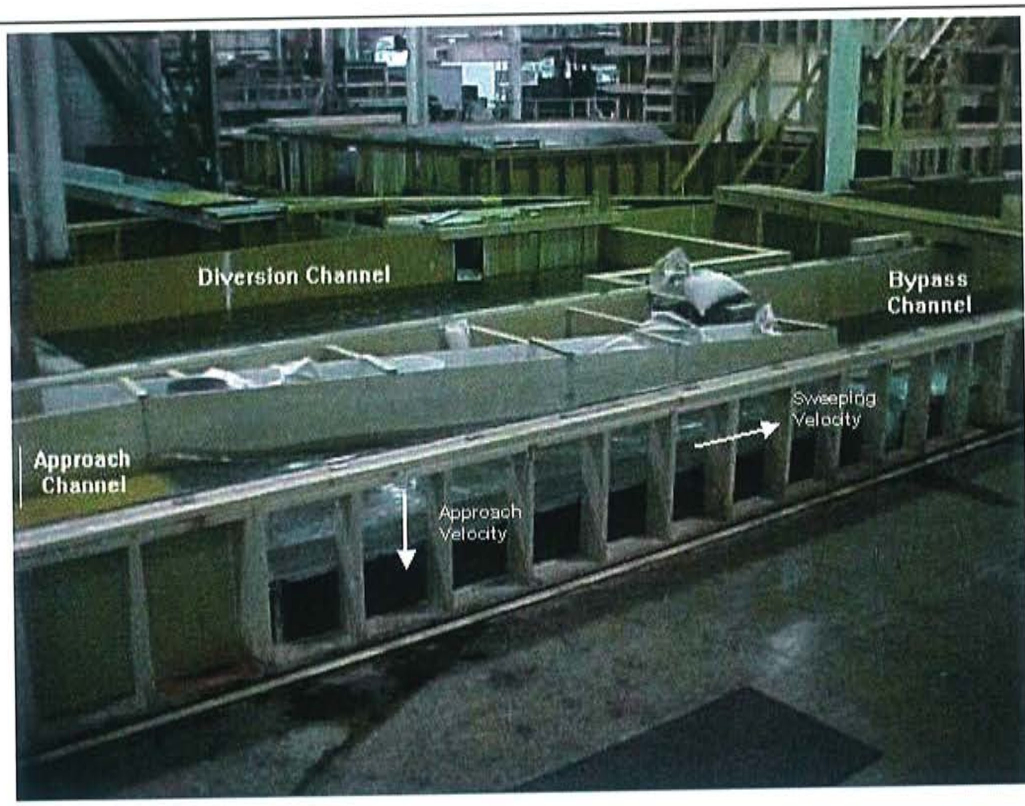


Figure 2.—Overall view of the horizontal screen model showing the flow channel designations and velocity orientations.

Screen Sweeping Velocity Prediction Spreadsheet

A spreadsheet was developed to help define parameters for design and testing of the horizontal screen. The spreadsheet computes discharge ratios and predicts sweeping velocity based upon variable screen dimensions and depths. The spreadsheet model assumes uniform approach velocity to the screen and a constant flow depth over the screen. It is also a one-dimensional simulation that assumes uniform flow across the width of the screen regardless of wall convergence. The program also does not discern where the control is for the depth over the screen. Control of the flow downstream of the bypass that causes backwater onto the screen is not characterized in the program. Also, a drop at the downstream end of the bypass producing critical depth and flow control is not modeled. With critical depth at the bypass entrance, the physical model shows that the bypass discharge is controlled by the depth at the end of the screen and not by just the channel discharge, the approach velocity, and the area of the screen, as computed by the program.

Originally, the program was developed for subcritical flow conditions. As testing continued, it became apparent that higher sweeping velocities were desirable. Therefore, the supercritical flow range was included in the acceptable range of flow.

Several conditions were determined to limit the range of operation for the screen. A minimum sweeping velocity, and a maximum change in sweeping velocity per ft of screen may be entered. A change in flow regime, i.e. from supercritical to subcritical, and violation of parameters entered is checked by the spreadsheet. When any of these conditions are violated, the screen would be operating in an unacceptable range.

The U.S. Geological Service Conte Anadromous Fish Laboratory has performed tests with accelerating flow over weirs that states that a velocity change of 1 ft/s per ft of distance will cause avoidance [3]. Agencies have expressed an interest in keeping the sweeping velocity as high as possible from a debris and fish passage point of view. The minimum acceptable sweeping velocity and percent acceleration or deceleration per foot of screen may be changed as necessary.

Irrigators will know the channel discharge or river discharge and how much water they would like diverted. Therefore, the spreadsheet evolved into entering the channel and diversion discharges, the flow depth and screen geometry and letting the spreadsheet compute the sweeping velocity, velocity of approach, and acceptable range of operation. The pivot table in the spreadsheet shows the acceptable ranges of operation for the geometry and hydraulic parameters entered. The desired design flow ratio or velocities may not be obtainable with the specified geometry. The geometry should then be modified until acceptable flow conditions occur. The desired and generally fairly small range of diversion to channel flow ratio is shaded for a range of approach velocities.

In addition to using the spreadsheet, with caution, to narrow down the acceptable screen geometry, a backwater computation must be performed using a program such as HEC-RAS. This will ensure that the downstream influence is appropriately accounted for in the design.

The spreadsheet is given in Appendix A with the equations shown in the cells should a designer wish to replicate the computations.

Instrumentation

A SonTek 19 MHz Micro Acoustic Doppler Velocimeter (ADV) was used to gather three-dimensional velocity data over the horizontal screen. The probe has 3 "arms" that receive the signal from the control volume located about 5 cm from the transmitter. The control volume is only 0.09 cm. The ADV measures all three velocity components simultaneously, providing a complete description of the flow field. Figure 3 shows the ADV mounted on a carriage with a motorized screw mechanism allowing travel up and down. The mount could also be moved along the carriage to traverse both the length and width of the approach channel and the entire screen area.

Data were gathered at a rate of 10 Hz with 600 samples gathered at each data location and stored onto a PC. The data were input into the WinAdv software program that allowed filtering and reduction of the data and exporting into a format acceptable for spreadsheet use.

Initially, seeding was necessary to overcome the acoustic reflection off the screen surface. Eventually, the screen surface was sprayed with a very thin rubbery substance (Sure Grip) that minimized the reflection from the screen and increased the data quality without seeding.

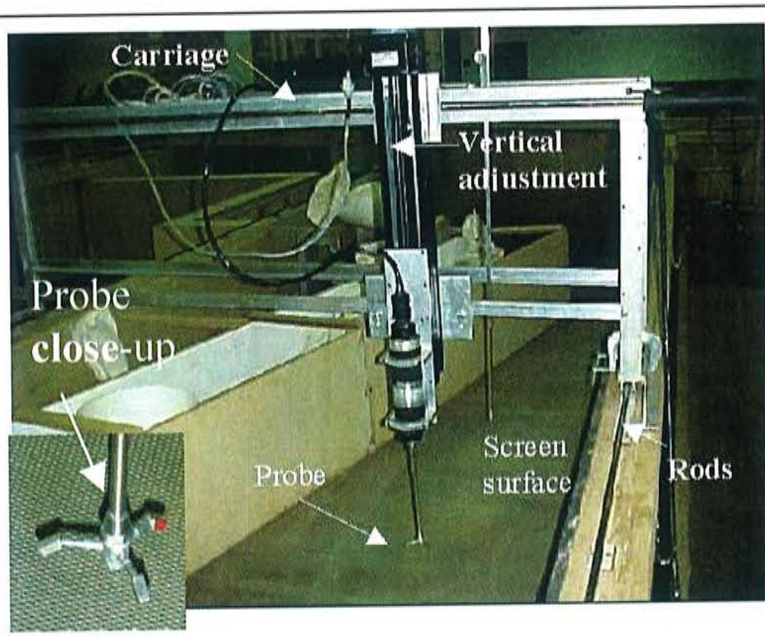


Figure 3.—ADV probe close-up and instrument setup over screen.

Data were collected 3 inches above the screen to correspond to the standard measurement distance in the prototype. Velocity measurements were obtained at grid points that were established for the screen geometry tested.

Flow depths were also gathered from a point gage mounted on the traversing system.

Sweeping Velocity

Investigation of the sweeping velocity provided very interesting results. Once the screen operation was determined, it was realized that sweeping velocity would typically decrease as a function of screen length. This occurs because with a constant inflow and depth, the volume of flow, thus velocity, passing over the screen decreases as the diversion flow leaves through the screen. The sweeping velocity can be maintained by constructing a converging side wall, but for fairly limited operating range. Because setting the hydraulic model was quite tedious, the previously mentioned spreadsheet program that defines sweeping velocity conditions for any geometry was utilized and aided in defining the model test range.

Continuity of flow dictates that the sweeping velocity will decrease if the flow decreases and the depth remain constant for a given area [4]. This is seen by the equation: Q=VA where the area, A, is the width times the depth. Therefore, a converging wall will help to maintain sweeping velocity by decreasing the area at a rate that will offset the flow loss. Balancing the area with the flow withdrawn is the key to maintaining sweeping velocity.

It seems reasonable to define the bypass channel as the channel at the downstream end of the screen where the flow passing over the screen exits back to the river. Using this definition, unless there is a recirculation zone or eddy over the downstream end of the screen, it would usually be possible to maintain or have velocities increase into the bypass channel at the end of the screen to provide attraction flow for downstream migrants.

Diversion Weir Wall

Operation of the screen model soon showed the importance of the diversion weir wall. The diversion weir wall was set at the elevation of the screen with capability to adjust the level. Baffles were initially included in the model, but the effectiveness of the weir wall in controlling the depth and providing uniform approach velocities soon made it clear that the baffles were not needed. The elevation of the diversion wall will set the minimum depth on the screen for any given diversion flow. A downstream diversion gate may then be used to further increase depth over the diversion weir wall and the screen, if deemed necessary. The flow depth affects the sweeping velocity and higher flow depths for the same diversion rate produce lower sweeping velocities. The elevation of the diversion wall will prevent the screen from dewatering until the channel flow is stopped.

Depths were measured over the screen and in the basin formed by the weir wall leading to the diversion channel. There is very little head loss through the screen and through the opening to the weir wall. The head loss is a function of the approach velocity and since this is very small there is only a very slight difference in depth between that over the weir wall and over the screen.

The diversion weir wall is a valuable asset to the horizontal screen design, providing uniform depth and approach velocities over the screen and aiding in the prevention of surface irregularities. This may be seen in the screen approach velocity data shown later for each screen geometry tested.

Converging Wall Angle

The side wall angle improves the design of the horizontal screen by reducing the screen area as the channel flow is diverted, thus maintaining the sweeping velocity. The angle of the side wall; however, can produce some undesirable effects to water surface over the screen. Any angle will produce some buildup of flow depth along the wall that could lead to increased approach velocities. Given a severe enough angle this could be a problem. Also, cross-waves will form caused by the contraction. The height of the waves and the pattern is dependant upon the wall angle, Froude number, and depth [4]. The contraction or side wall angle may be designed to minimize flow disturbances. With this in mind, the maximum convergence angle should probably be 15 degrees. With high sweeping velocities, this angle should probably be minimized. The possible perturbations from the converging side wall will be minimized with a longer screen and smaller convergence angle.

Debris Testing

Debris is a big concern with the horizontal screen because in this experimental stage there is no plan to use a mechanical cleaning device. Eliminating the cleaning device makes the screen economical and more likely to be used, but riskier from a biological standpoint. Published vertical screen criteria require a minimum sweeping velocity of two times the approach velocity. Higher sweeping velocities are expected to produce optimal cleaning characteristics. Debris can be leaves, sand, fine sediment, evergreen needles, gravel, algae or trash.

Rigorous debris testing was not performed in this study. Various types of plants, and sand or gravel, were introduced upstream from both the rectangular and converging screen geometries and observed while traveling over the screen. Amounts passing through or bypassing the screen were not measured, but these tests did provide general information about the self-cleaning capability of the screen. Good self-cleaning characteristics were observed for various flow rates when the sand or gravel size exceeded or was smaller than the screen opening size. Particles larger than the screen hole-size would continue over the screen and into the bypass. Particles smaller than the screen hole-size would pass through the holes or remain suspended and be carried downstream. If smaller particles pass through the screen, a maintenance issue could develop if large amounts accumulate under the screen.

To investigate a predicted worse case, a test was performed with the majority of the test material graded to be about the size of the 3/32 or 0.0.0938 in screen openings. The material used was graded between a #8 and #4 sieve, or larger than very fine gravel (0.0925 in) and smaller than fine gravel (0.1811 in). The material was trickled into the channel on the flat section upstream from the screen geometry with a 15 degree wall convergence and a channel flow rate of 9.0 ft^3/s, $Q_d/Q_c = 0.82$ and subcritical flow conditions over the screen. A sweeping velocity, $V_s = 2.7$ ft/s, at the upstream end and about 1 ft/s at the downstream end of the screen produced ratios of sweeping to approach velocity ratios of 18:1 and 6:1 at the upstream and downstream portions of the screen, respectively. The approach velocity averaged about 0.15 ft/s over the screen with a depth of 7 in. In addition, the bypass flow was being controlled by the weir gate downstream from the screen that caused a recirculation back up onto the end of the screen and a potentially poor flow condition for self-cleaning, figure 23. The fine gravel material wedged in the openings of the screen at the upstream end of the screen area and at the downstream end due to the backwater present on the screen. Particles lodged into the screen openings were difficult to remove. Sand and debris will clearly be less of an issue with the highest possible sweeping velocities over the screen.

Rectangular Horizontal Flat-plate Screen Performance

The initial hydraulic investigations were conducted with the full 6- by 12-ft rectangular screen. Data were gathered at the centerline of each of the three 2-ft by 4-ft screen sections throughout the length of the 12-ft-long screen section, figure 4. In the final tests, data were also gathered near the walls and further upstream and downstream from the screen to investigate flow conditions approaching and leaving the screen. Depth data were also gathered with a point gage along the length of the screen. Depth measurements were taken in the basin created by the weir wall to look at head loss through the screen to the diversion channel. The flow rates and diversion to channel flow ratios tested over the rectangular screen are shown in table 1.

Table 1.—Flow rates tested with the rectangular screen geometry

Test	Channel Discharge, Q_c (ft^3/s)	Diversion Discharge, Q_d (ft^3/s)	Bypass Discharge, Q_b (ft^3/s)	Q_d/Q_c (percent)	Theoretical Approach Velocity (ft/s)	Depth (ft)
1	10.04	8.30	1.74	83	0.115	0.5
2	11.76	8.25	3.51	70	0.115	0.5
3	15.25	8.35	6.90	55	0.116	0.5
4	10.01	5.78	4.23	58	0.115	0.67
5	10.00	3.92	6.08	40	0.054	0.5
6	10.01	2.08	7.93	21	0.03	0.583
7	17.36	14.29	3.07	82	0.2	0.5
8	20.4	14.35	6.05	70	0.2	0.67

Data are plotted on contour maps with the sweeping velocity forming the contours. The edges of the contours are the most outside locations where data were taken. The labels at the nodes show the approach velocity at that point, with negative values indicating flow into the screen. The accompanying tables show the actual distance along the screen that measurements were taken. At each section, the sweeping velocities in the tables are averaged across the width and a Froude number computed to show the flow conditions that the screen is experiencing. Raw velocity data are shown in the appendix for test series 1-8.

Traditional screen flow conditions were initially investigated by operating the screen under specific sweeping to approach velocity ratios of 5, 10 and 20:1. The sweeping velocity ratios were computed at the downstream end of the screen using the bypass discharge, the screen width of 6 ft, and the depth over the screen. These flow conditions were tests 1, 2 and 3 with channel flows of 10, 11.76, and 15.25 ft^3/s with Q_d/Q_c=0.83, 0.70, and 0.55, respectively. The diversion flow, approach velocity, and depth were kept the same at 8.25 ft^3/s and 0.115 ft/s, and 0.5 ft, respectively. In all three cases, backwater was present on the downstream end of the screen under these flow divisions, figures 5, 6, and 7.

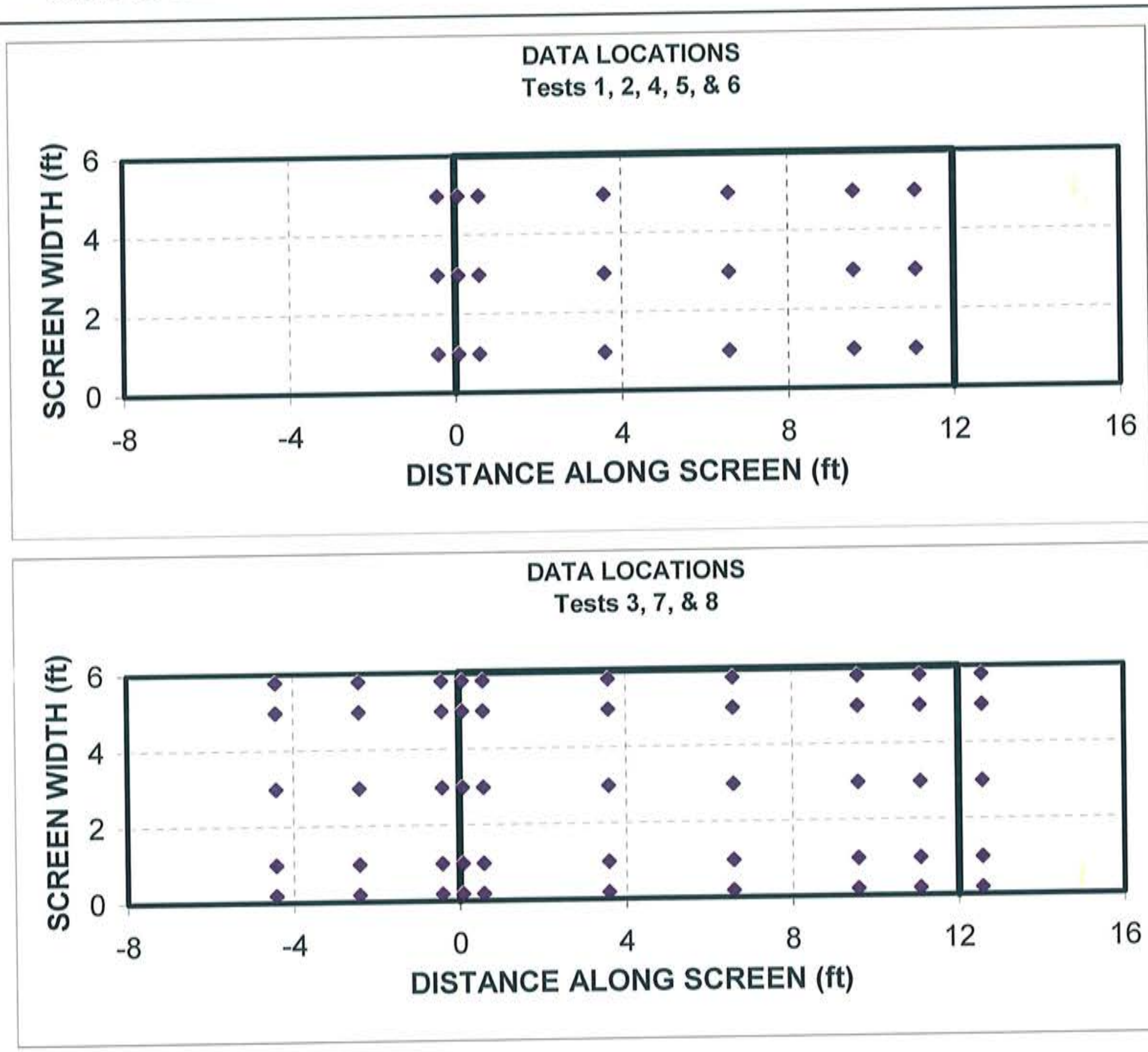


Figure 4.—Locations where velocity data were gathered for the rectangular horizontal fish screen. The 6 by 12 ft screen area is highlighted with the screen beginning at 0 ft. Data were gathered primarily along screen panel centerlines. For tests 3, 7, and 8, data were also gathered upstream from the screen and along the walls.

The first series shows a plan and side view of Test 1 with $Q_d/Q_c = 0.83$ and downstream control of the bypass flow, figure 5. Under this operating condition, recirculating eddies form over the downstream end of the screen caused pooled flow and an increase in the approach velocity above 0.2 ft/s. Figure 8 gives the velocity and Froude number data for this flow condition. The flow is subcritical throughout but would not be an acceptable operating condition with the eddy over the downstream end of the screen. Tests 2 and 3 are similar with the flow condition changing from subcritical to supercritical in test 3.

These tests showed higher sweeping velocities for increasing channel discharge and decreasing diversion ratios for the same diversion discharge and depth, figures 8, 9, and 10. The screen area is too large for high diversion ratios, and the sweeping velocities decreased down the length of the screen.

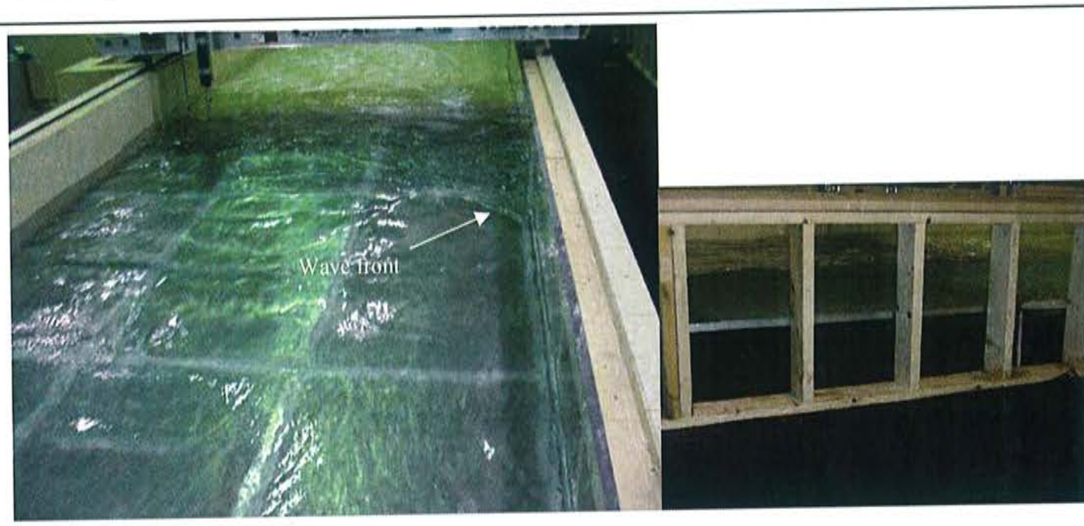


Figure 5.—Test 1 with the rectangular screen geometry, $Q_c = 10$ ft^3/s, and $Q_d/Q_c = 0.83$ and downstream control of the bypass. The flow over the screen is subcritical and downstream control is causing a recirculation pattern over the downstream portion of the screen. The wavy, higher water surface indicates the location of the recirculation. The velocity of approach increases above 0.2 ft/s in this area because of the ponded flow. This would be an unacceptable flow condition.

Figure 6.—Test 2 looking down onto the downstream end of the rectangular screen. Subcritical flow over the screen with Q_d/Q_c=0.70 and V_a= 0.115 ft/s. The upstream V_s/V_a = 34:1, and the downstream V_s/V_a =10:1 with the channel discharge, depth, and screen width used to compute the sweeping velocity. Compare to test 1 and test 3 with same approach velocity, depth and V_s/V_a=5 and 20 to 1.

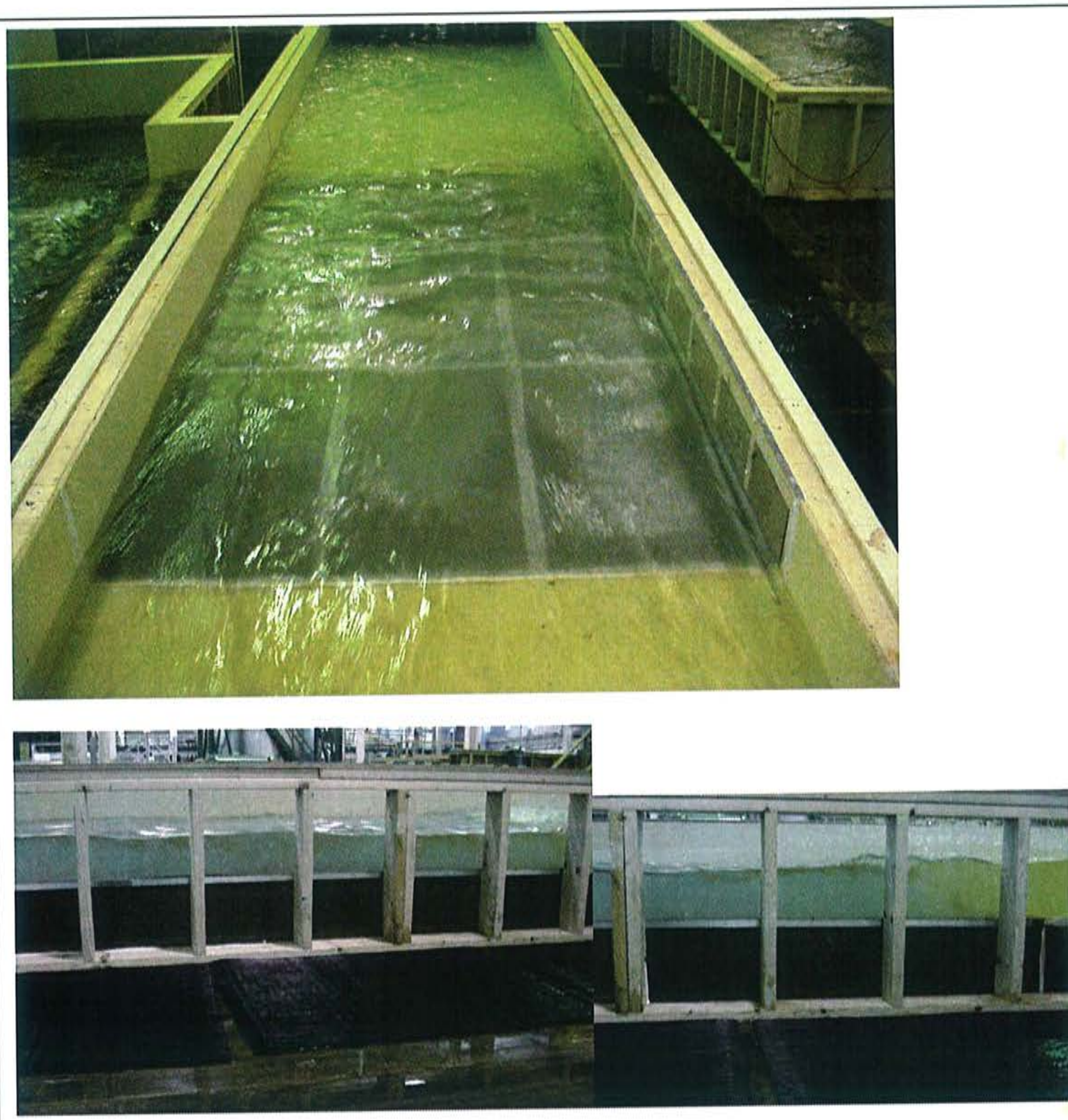
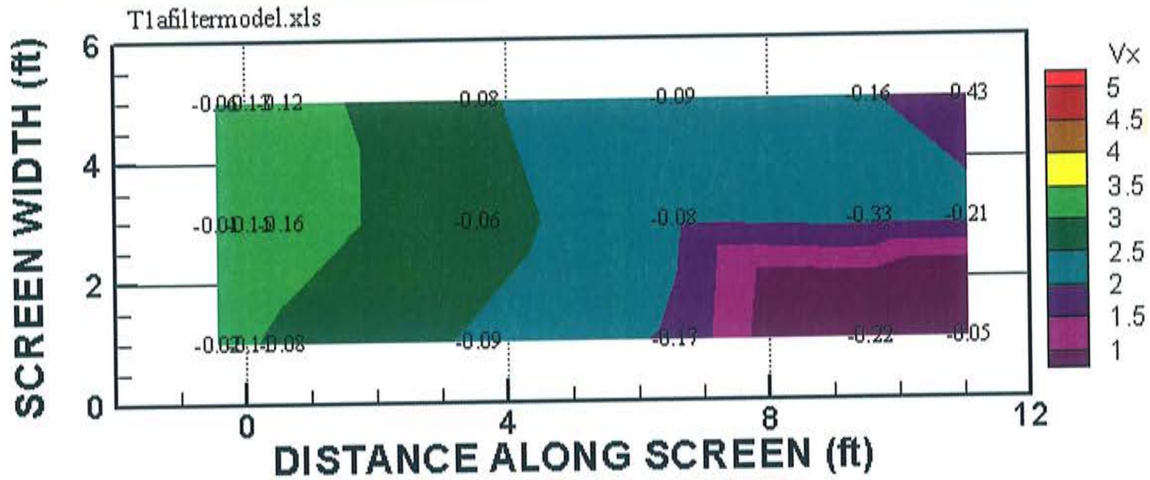
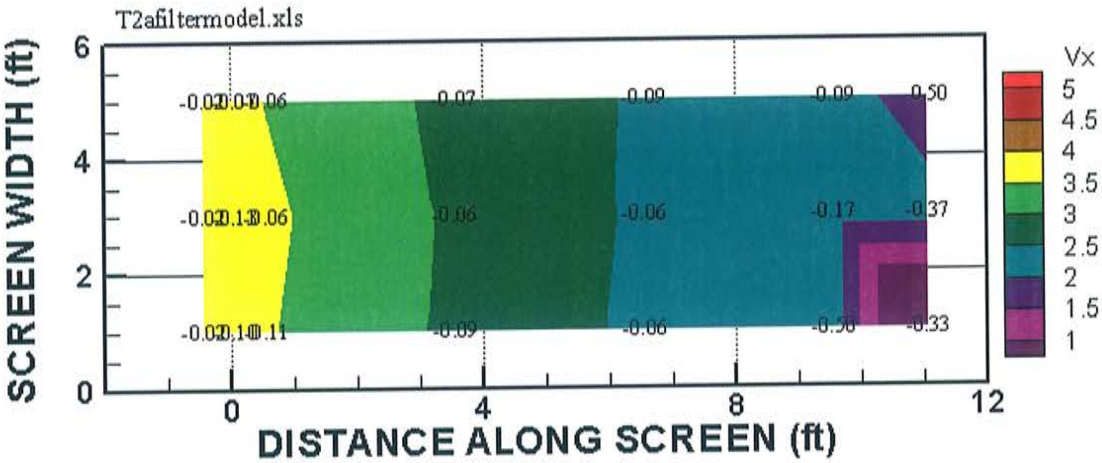


Figure 7.—Top and side views of test 3 with supercritical flow at the upstream end of the screen transitioning to subcritical with a jump over the downstream end of the screen. Q_d/Q_c=0.55 and V_a= 0.115 ft/s. The upstream V_s/V_a = 44:1, and the downstream V_s/V_a =20:1, with the channel discharge, depth, and screen width used to compute the sweeping velocity. Compare to test 1 and test 2 with same approach velocity, depth, and V_s/V_a=5 and 10 to 1.



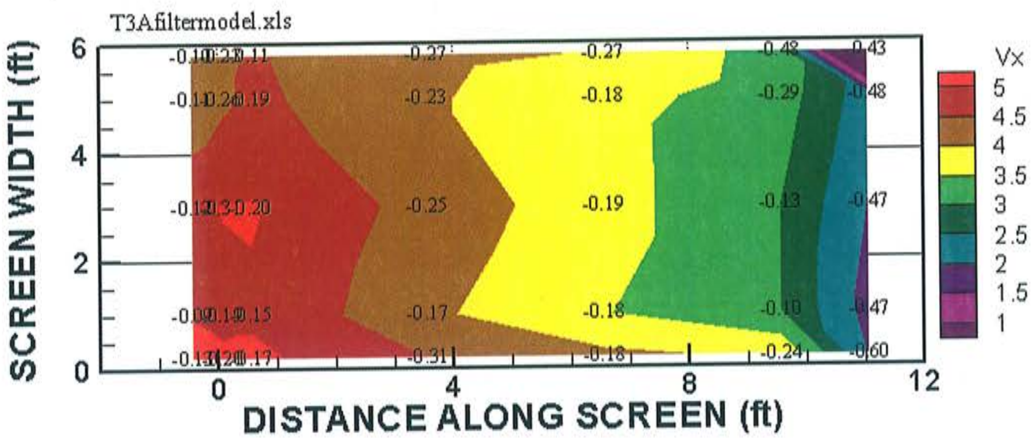
Qc=10.04 ft^3/s, Qb=1.74 ft^3/s, Qd=8.30 ft^3/s		
Depth = 0.5' or 6"		
Screen Distance (ft)	Average Sweeping Velocity Vs (ft/s)	Average Froude No. based on Vs
-0.4271	3.30	0.830
0.0729	3.113	0.776
0.5729	3.102	0.773
3.5729	2.569	0.640
6.5729	2.001	0.499
9.5729	1.241	0.393
11.0729	0.846	0.428

Figure 8.—Test 1. Rectangular 6-by-12 ft screen. Channel discharge, Q_c=10.04 ft^3/s, diversion discharge, Q_d=8.30 ft^3/s, bypass discharge, Q_b=1.74 ft^3/s. Diversion ratio, Q_d/Q_c = 0.83. Depth over screen=0.5 ft. Contours represent the sweeping velocity and indicate a wave front with some recirculating flow over the downstream right corner of the screen. Labels are the screen approach velocity values which increase under the influence of the pooled water over the screen. The theoretical average approach velocity of 0.115 ft/s produces 27:1 and 7:1 for sweeping to approach velocity ratios for the upstream and downstream portions of the screen, respectively. This screen flow condition is operating under the subcritical flow regime.



Qc=11.76 ft^3/s, Qb=3.51 ft^3/s, Qd=8.25 ft^3/s		
Depth = 0.5' or 6"		
Screen Distance (ft)	Average Sweeping Velocity Vs (ft/s)	Average Froude No. based on Vs
-0.4271	3.774	0.940
0.0729	3.629	0.904
0.5729	3.536	0.881
3.5729	2.895	0.721
6.5729	2.421	0.603
9.5729	2.272	0.566
11.0729	1.149	0.357

Figure 9.—Test 2. Rectangular 6-by-12 ft screen. Channel discharge, Q_c=11.76 ft^3/s, diversion discharge, Q_d=8.25 ft^3/s, bypass discharge, Q_b=3.51 ft^3/s. Diversion ratio, Q_d/Q_c = 0.7. Depth over screen=0.5 ft. Contours represent the sweeping velocity and indicate a wave front with some re-circulating flow over the downstream right corner of the screen. The screen approach velocity values increase under the influence of the pooled water over the screen. The theoretical average approach velocity of 0.115 ft/s produces 33:1 and 10:1 for sweeping to approach velocity ratios for the upstream and downstream portions of the screen, respectively. This screen flow condition is operating under the subcritical flow regime.

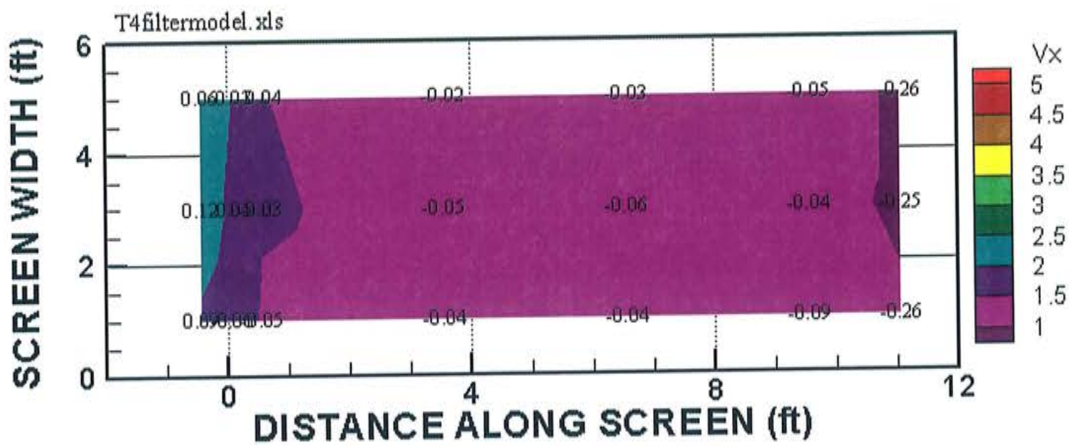


Qc=15.25 ft³/s, Qb=6.90 ft³/s, Qd=8.35 ft³/s		
Depth = 0.5' or 6"		
Screen Distance (ft)	Average Sweeping Velocity Vs (ft/s)	Average Froude No. based on Vs
-0.4271	4.667	1.163
0.0729	4.767	1.188
0.5729	4.847	1.208
3.5729	4.211	1.050
6.5729	3.795	0.946
9.5729	3.293	0.821
11.0729	1.283	0.473

Figure 10.—Test 3. Rectangular 6-by-12 ft screen. Channel discharge, Q_c=15.25 ft³/s, diversion discharge, Q_d=8.35 ft³/s, bypass discharge, Q_b=6.90 ft³/s. Diversion ratio, Q_d/Q_c = 0.55. Depth over screen=0.5 ft. Contours represent the sweeping velocity and indicate a hydraulic jump over the downstream end of the screen. The screen approach velocity values increase under the influence of the higher water surface and slower velocities associated with the jump. The theoretical average approach velocity of 0.116 ft/s produces 40:1 and 11:1 for sweeping to approach velocity ratios for the upstream and downstream portions of the screen, respectively. The flow was supercritical on the upstream portion of the screen and subcritical downstream of the jump.

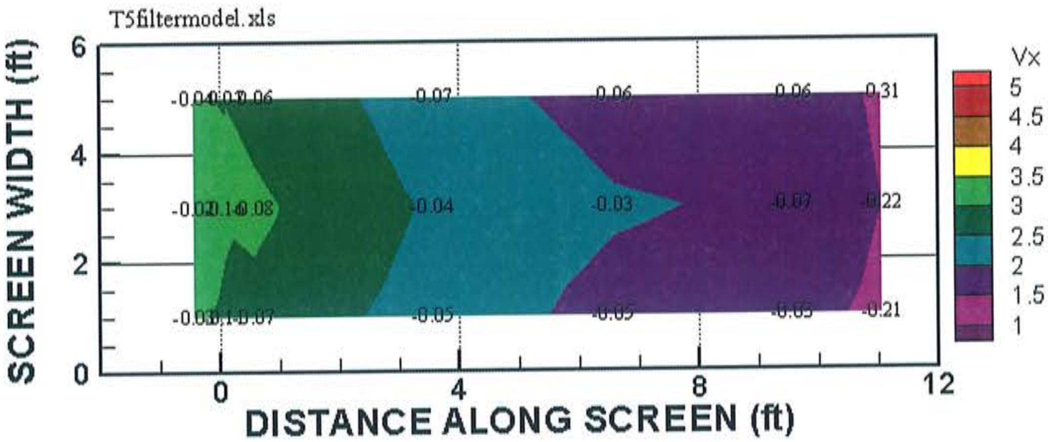
The next series tested the same channel discharge with varying diversion flows, thus attempting to define the practical range of flow conditions possible with rectangular screen geometry while keeping one variable constant.

The next tests, 4, 5, and 6, were conducted with Q_d/Q_c =0.58 and 0.4 and 0.21, respectively, with the channel discharge constant and the diversion flow decreasing. The sweeping velocity contours are shown on figures 11, 12, and 13. Figure 14 shows a plan and side view of the rectangular screen for test 6 operating under Q_d/Q_c = 0.21. The diversion flow is only a small portion of the channel flow. The flow is subcritical across the screen and a jump occurs downstream from the screen. The diversion flow is returning back up through the downstream portion of the screen as shown on figure 13 with a positive approach flow at the downstream end of the screen. Flow comes back up through the screen to provide a mass balance of the flow. This flow condition may not necessarily be a poor flow condition as there is no recirculation on the screen. This test series indicated that smaller diversion ratios are better suited for rectangular screens.



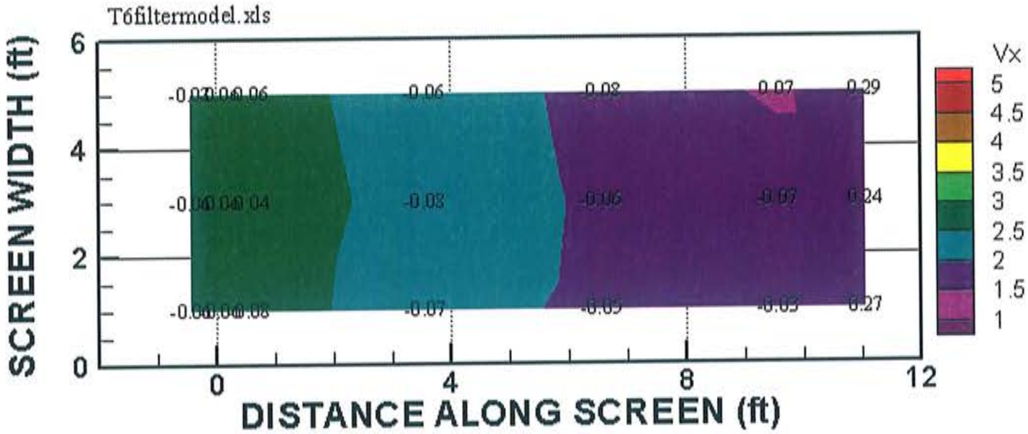
Qc=10.01 ft³/s, Qb=4.23 ft³/s, Qd=5.78 ft³/s		
Depth = 0.667' or 8"		
Screen Distance (ft)	Average Sweeping Velocity Vs (ft/s)	Average Froude No. based on Vs
-0.4271	2.092	0.451
0.0729	1.914	0.413
0.5729	1.497	0.323
3.5729	1.308	0.282
6.5729	1.265	0.273
9.5729	1.185	0.256
11.0729	0.977	0.211

Figure 11.—Test 4. Rectangular 6-by-12 ft screen. Channel discharge, Q_c=10.01 ft^3/s, diversion discharge, Q_d=5.78 ft^3/s, bypass discharge, Q_b=4.23 ft^3/s. Diversion ratio, Q_d/Q_c = 0.58. Depth over screen=0.67 ft. Contours represent the sweeping velocity and indicate a wave front with some recirculating flow over the downstream right corner of the screen. The screen approach velocity values increase under the influence of the pooled water over the screen. The theoretical average approach velocity of 0.115 ft/s produces 33:1 and 10:1 for sweeping to approach velocity ratios for the upstream and downstream portions of the screen, respectively. This screen flow condition is operating under the subcritical flow regime.



Qc=10.0 ft³/s, Qb=6.08 ft³/s, Qd=3.92 ft³/s		
Depth = 0.5' or 6"		
Screen Distance (ft)	Average Sweeping Velocity Vs (ft/s)	Average Froude No. based on Vs
-0.4271	3.094	0.771
0.0729	2.995	0.746
0.5729	2.940	0.733
3.5729	2.318	0.578
6.5729	1.895	0.472
9.5729	1.830	0.456
11.0729	1.422	0.354

Figure 12.—Test 5. Rectangular 6-by-12 ft screen. Channel discharge, Q_c=10.0 ft^3/s, diversion discharge, Q_d=3.92 ft^3/s, bypass discharge, Q_b=6.08 ft^3/s. Diversion ratio, Q_d/Q_c = 0.4. Depth over screen=0.5 ft. Contours represent the sweeping velocity and indicate a weak wave front over the downstream end of the screen. The theoretical average approach velocity of 0.054 ft/s produces 57:1 and 26:1 for sweeping to approach velocity ratios for the upstream and downstream portions of the screen, respectively. This flow condition operated entirely under the subcritical flow regime.



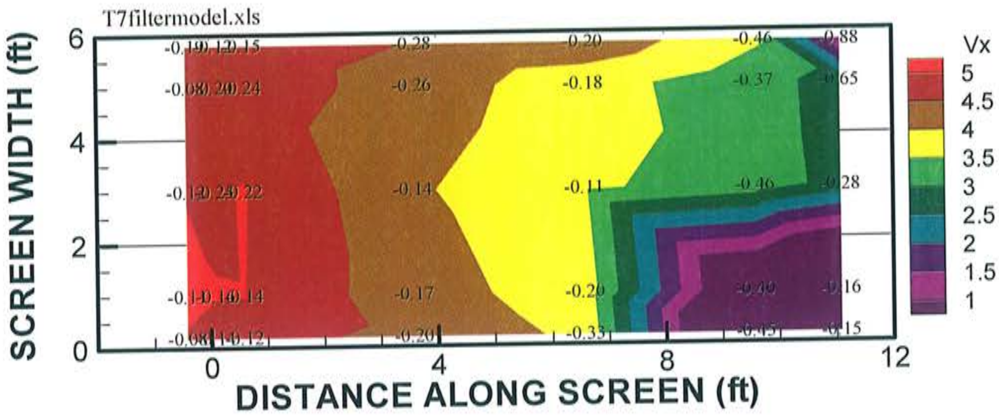
Qc=10.01 ft³/s, Qb=7.93 ft³/s, Qd=2.08 ft³/s		
Depth = 0.583' or 7"		
Screen Distance (ft)	Average Sweeping Velocity Vs (ft/s)	Average Froude No. based on Vs
-0.4271	2.882	0.665
0.0729	2.822	0.651
0.5729	2.760	0.637
3.5729	2.240	0.517
6.5729	1.904	0.439
9.5729	1.616	0.373
11.0729	1.824	0.421

Figure 13.—Test 6. Rectangular 6-by-12 ft screen. Channel discharge, Q_c=10.01 ft^3/s, diversion discharge, Q_d=2.08 ft^3/s, bypass discharge, Q_b=7.93 ft^3/s. Diversion ratio, Q_d/Q_c = 0.21. Depth over screen=0.583 ft. Contours represent the sweeping velocity and indicate no downstream interference over the screen. The approach velocity still increases right at the end of the screen. The theoretical average approach velocity of 0.03 ft/s produces 96:1 and 60:1 for sweeping to approach velocity ratios for the upstream and downstream portions of the screen, respectively. This flow condition operated under the subcritical flow regime.

Figure 14.—Test 6. Subcritical flow occurs across the rectangular screen with a jump downstream of the screen forced by tailwater control. Q_c = 10 ft^3/s, and Q_d/Q_c = 0.21. The bypass flow is much greater than the diversion flow and flow is coming back up through the screen at the downstream end as indicated by positive V_a values and producing unacceptable flow conditions.

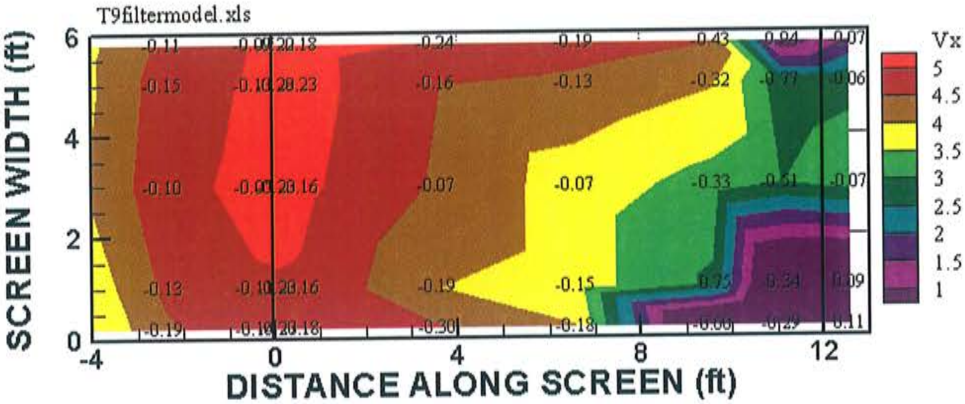
Additional data were recorded as tests 7 and 8 and are shown on figures 15 and 16. Both of these tests had high Q_d/Q_c ratios with the flow unacceptably transitioning from supercritical to subcritical over the screen.

Sweeping velocity is difficult to maintain on a rectangular screen because the continual loss of diversion flow over a constant area reduces the flow, thus velocity as the flow travels over the length of the screen. The depth is essentially constant over the screen except near the end depending upon whether there is control downstream or a transition on the screen or critical flow at the end of the screen. This arrangement might be used when the diversion flow rate is small compared to the channel flow rate.



Qc=17.36 ft³/s, Qb=3.07 ft³/s, Qd=14.29 ft³/s		
Depth = 0.5' or 6"		
Screen Distance (ft)	Average Sweeping Velocity Vs (ft/s)	Average Froude No. based on Vs
-0.4271	4.843	1.207
0.0729	4.841	1.207
0.5729	4.864	1.212
3.5729	4.264	1.063
6.5729	3.861	0.962
9.5729	1.684	0.585
11.0729	0.578	0.514

Figure 15.—Test 7. Rectangular 6-by-12 ft screen. Channel discharge, Q_c=17.36 ft^3/s, diversion discharge, Q_d=14.29 ft^3/s, bypass discharge, Q_b=3.07 ft^3/s. Diversion ratio, Q_d/Q_c = 0.82. Depth over screen=0.5 ft. Contours represent the sweeping velocity and indicate a wave front with re-circulating flow over the downstream right corner of the screen. The screen approach velocity values increase under the influence of the pooled water over the screen. The theoretical average approach velocity of 0.2 ft/s produces 24:1 and 3:1 for sweeping to approach velocity ratios for the upstream and downstream portions of the screen, respectively. The flow is supercritical over the upstream portion of the screen and transitions to subcritical about halfway down the screen.



Qc=20.4 ft³/s, Qb=6.05 ft³/s, Qd=14.35 ft³/s		
Depth = 0.667' or 8"		
Screen Distance (ft)	Average Sweeping Velocity Vs (ft/s)	Average Froude No. based on Vs
-4.4271	3.602	0.777
-2.4271	4.650	1.003
-0.4271	5.007	1.080
0.0729	5.069	1.094
0.5729	5.087	1.098
3.5729	4.488	0.968
6.5729	4.135	0.892
9.5729	2.818	0.668
11.0729	0.832	0.369
12.5729	1.030	0.444

Figure 16.—Test 8. Rectangular 6-by-12 ft screen. Channel discharge, Q_c=20.4 ft^3/s, diversion discharge, Q_d=14.35 ft^3/s, bypass discharge, Q_b=6.05 ft^3/s. Diversion ratio, Q_d/Q_c = 0.7. Depth over screen=0.67 ft. Contours represent the sweeping velocity and indicate a wave front with recirculating flow over the downstream corners of the screen. Recirculation is strong over the downstream right corner of the screen. The screen approach velocities increase under the influence of the pooled water over the screen. The theoretical average approach velocity of 0.2 ft/s produces 25:1 and 5:1 for sweeping to approach velocity ratios for the upstream and downstream portions of the screen, respectively. The flow is supercritical over the upstream portion of the screen and transitions to subcritical about halfway down the screen.

Screen Performance with a Converging Side wall

The concept of the converging side wall over a flat-plate screen is to decrease the exposed flow area to match the rate at which the channel flow is being diverted. This geometry will diminish or prevent a decrease in sweeping velocity along the screen.

Two wall convergences were tested in the model with the first discussed in this section. This geometry had the original 6 ft upstream width with the convergence beginning 1 ft upstream from the screen and ending at a bypass width of 2.54 ft. In addition, a non-perforated floor at the same elevation as the screen extended 2 to 4 ft downstream into the bypass. Table 2 shows the discharge conditions for the first series of converging side wall tests. The biological testing was also performed using this screen geometry.

Table 2.—Tests conducted with the 15-degree converging side wall to 2.54-ft-wide bypass with a flat, non-perforated bypass extension.

Test	Channel Discharge, Q_c (ft^3/s)	Diversion Discharge, Q_d (ft^3/s)	Bypass Discharge, Q_b (ft^3/s)	Q_d/Q_c (percent)	Theoretical Approach Velocity (ft/s)	Depth (ft)
9	7.38	5.70	1.68	77	0.115	0.42
10	6.92	4.00	2.92	58	0.10	0.42
11	7.00	4.95	2.05	71	0.10	0.42
12	9.08	7.45	1.63	82	0.15	0.58
13	15.00	9.89	5.11	66	0.2	0.58
14	12.00	9.89	2.11	82	0.2	0.58
15	11.5	7.42	4.08	64	0.15	0.42

Figures 17 and 18 show the flow conditions representing the opposite ends of the operating range with the converging side wall at 15-degrees, the 2.54-ft wide bypass, and a supported jet with downstream control. Figure 17, test 10, shows subcritical flow over the entire screen area. Figure 18, test 13, shows supercritical flow transitioning to subcritical flow over the screen. At the beginning of the study it was probably felt that the screen should operate in the subcritical range, however, observations of the flow conditions revealed that supercritical flow over the entire screen would be acceptable, if not preferable. The flow regime transition in figure 18 is, however, not acceptable as the wave front over the screen would cause fish to hold on the screen and a change in velocities over the screen.

Figure 17.—Test 10. Converging side wall test with $Q_c = 6.92\ ft^3/s$, $Q_d/Q_c = 0.58$ and no influence on the screen from downstream control. Flow is subcritical throughout and sweeping velocities are constant from upstream to downstream. This screen geometry and flow condition was used for the bull trout testing under a sweeping velocity of 2 ft/s.

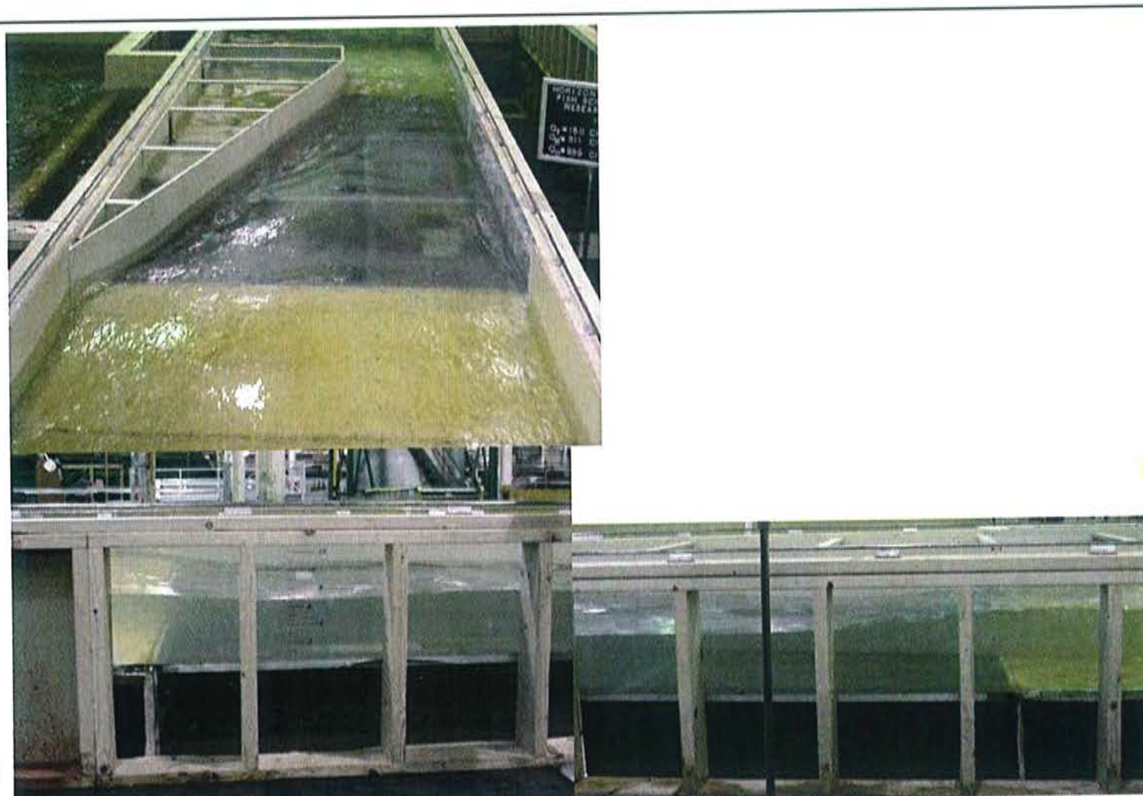


Figure 18.—Test 13. Test of converging side wall with Q_c=15 ft^3/s, Q_d/Q_c=66 percent. Supercritical flow at the upstream end of the screen transitioning to subcritical about 7 ft onto the screen.

Velocity data were recorded in the positions shown on figure 19 for tests 9-15 with the 15 degree converging side wall geometry. The sweeping velocity contour plots and longitudinal velocity and Froude number profiles are shown on figures 20-26. Velocity profiles were created by extracting data longitudinally along the screen from the data tables in the appendix at the centerline of the right screen 1 ft from the right wall, looking downstream. These data show the overall trends of the sweeping and approach velocities. The contour plots show that the sweeping velocities are very consistent across the width of the screen as with the rectangular screen. The approach velocities are slightly higher along the converging wall with the slight wave formed along the wall producing a slightly greater depth. The converging wall helps to keep the sweeping velocity deceleration rate less than with the rectangular screen. As the flow enters the bypass, the velocity does increase if there is no backwater present on the screen. Overall, the 15-degree converging side wall provided improved flow conditions and larger diversion to channel ratios than with the rectangular screen geometry.

In addition, the Froude number was plotted along the second y-axis to show sub or super-critical flow conditions. In test 13, shown on figure 18, the flow transitioned over the screen from supercritical to subcritical flow and would not be an acceptable condition for operation.

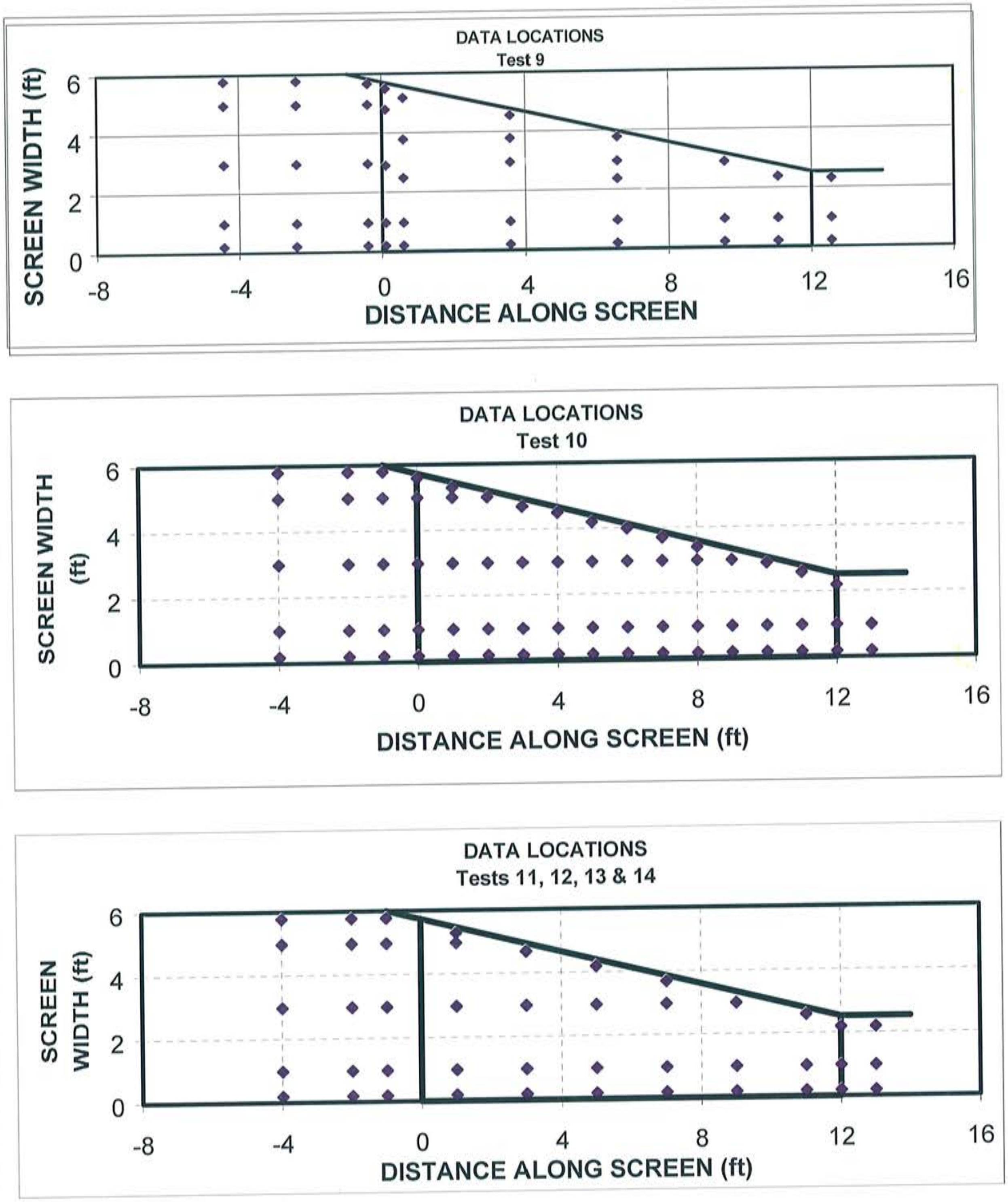
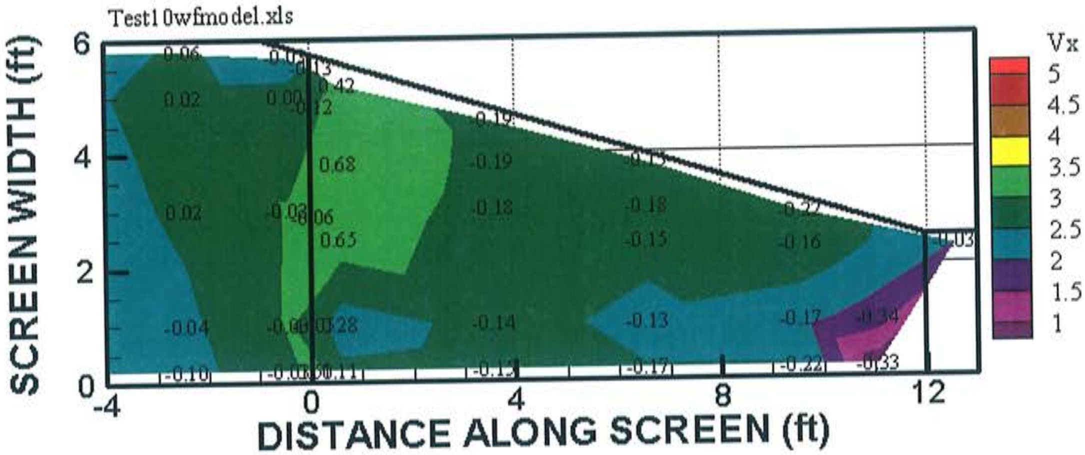
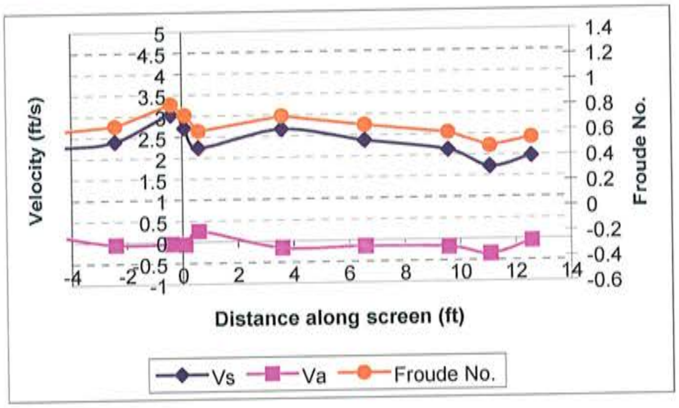


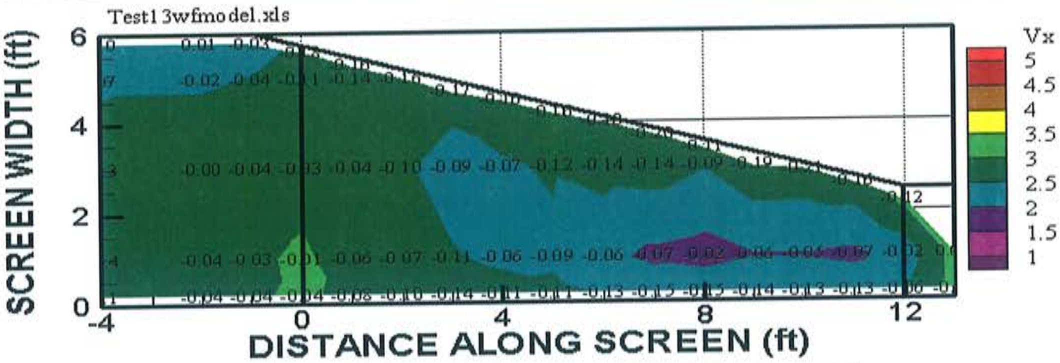
Figure 19.—Locations where velocity data were gathered for the 15° converging wall on the full-width horizontal fish screen. The exposed screen area is highlighted with the screen beginning at 0 ft. Data were gathered at various distances down the screen length primarily along screen panel centerlines and along the walls, including upstream and downstream from the screen. Test 15 data were only gathered along the screen length 1 ft from the right wall, looking downstream.

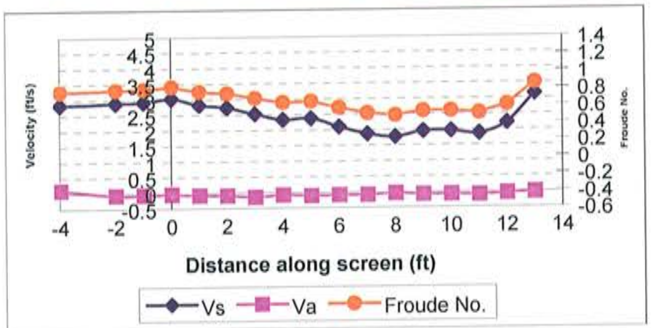




Qc=7.38 ft³/s, Qb=1.68 ft³/s, Qd=5.70 ft³/s		
Depth = 0.42' or 5"		
Screen Distance (ft)	Average Sweeping Velocity Vs (ft/s)	Average Froude No. based on Vs
-4.4271	2.299	0.627
-2.4271	2.527	0.690
-0.4271	2.758	0.753
0.0729	2.908	0.794
0.5729	2.928	0.799
3.5729	2.791	0.762
6.5729	2.666	0.728
9.5729	2.629	0.718
11.0729	1.208	0.330
12.5729	1.981	0.541

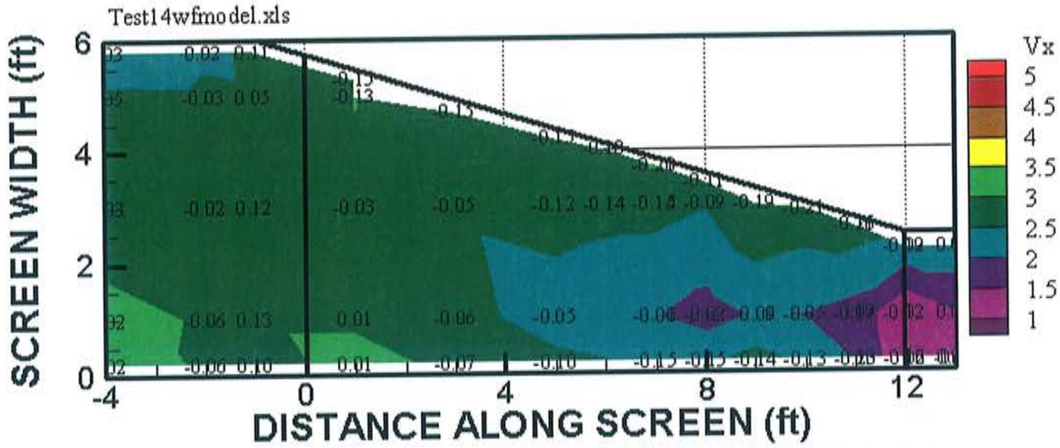
Figure 20.—Test 9. Converging wall with 15° angle. Channel discharge, Q_c=7.38 ft³/s, diversion discharge, Q_d=5.70 ft³/s, bypass discharge, Q_b=1.68 ft³/s. Diversion ratio, Q_d/Q_c = 0.77. Depth over screen=0.42 ft. Contours represent the sweeping velocity and indicate backwater from downstream control over the downstream corners of the screen. The screen approach velocities increase under the influence of the pooled water over the screen. The theoretical average approach velocity of 0.115 ft/s produces 25:1 and 16:1 for sweeping to approach velocity ratios for the upstream and downstream portions of the screen, respectively. The flow is subcritical across the screen.

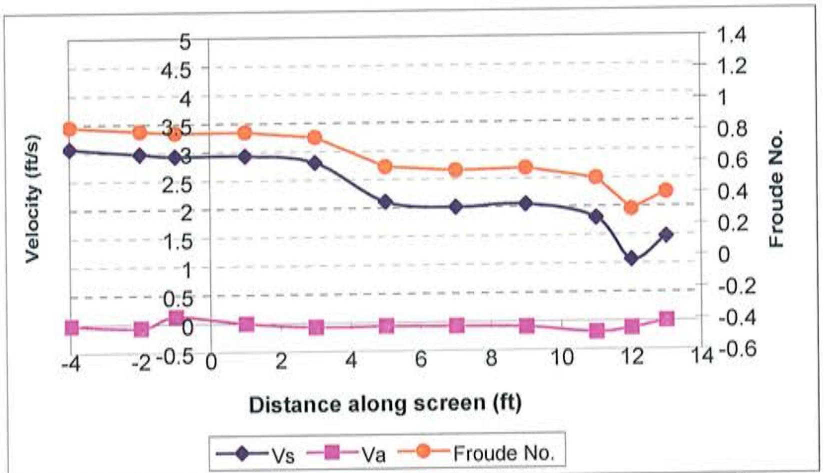




Qt=6.92 ft³/s, Qb=2.92 ft³/s, Qd=4.00 ft³/s		
Depth = 0.42' or 5"		
Screen Distance (ft)	Average Sweeping Velocity Vs (ft/s)	Average Froude No. based on Vs
-4	2.6503	0.7207
-2	2.6744	0.7272
-1	2.6691	0.7258
0	2.8318	0.7700
1	2.8487	0.7746
2	2.7738	0.7543
3	2.5915	0.7047
4	2.5868	0.7034
5	2.6021	0.7076
6	2.4936	0.6781
7	2.4330	0.6616
8	2.3269	0.6327
9	2.4654	0.6704
10	2.3951	0.6513
11	2.3249	0.6322
12	2.6083	0.7093
13	3.1960	0.8691

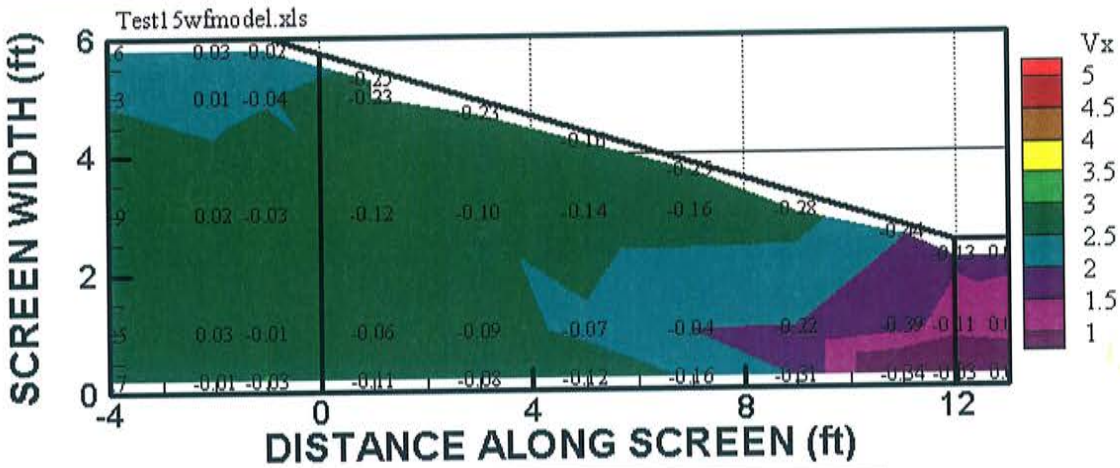
Figure 21.—TEST 10. Converging channel with 15° angle. Channel discharge, Q_c=6.92 ft³/s, diversion discharge, Q_d= 4.00 ft³/s, bypass discharge, Q_b=2.92 ft³/s. Diversion ratio, Q_d/Q_c = 0.58. Depth over screen=0.42 ft. Contours represent the sweeping velocity and indicate no influence from downstream control on the screen. The theoretical average approach velocity of 0.1 ft/s produces 28:1 and 26:1 for sweeping to approach velocity ratios for the upstream and downstream portions of the screen, respectively. The flow is subcritical across the entire screen with no decrease in sweeping velocity and a jump downstream from the screen. Bull trout tests were conducted with this screen geometry, flow rate, and sweeping velocity of about 2 ft/s.

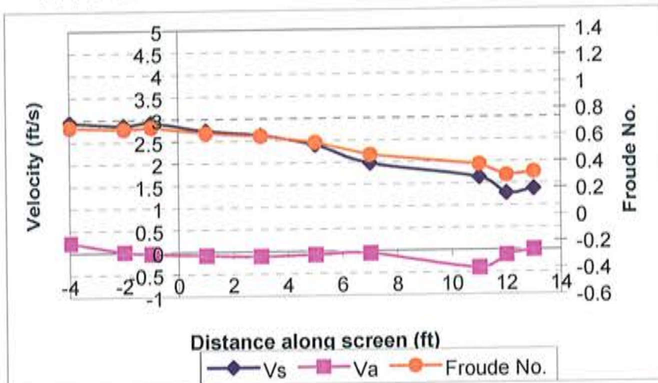




Qt=7.00 ft³/s, Qb=2.05 ft³/s, Qd=4.95 ft³/s		
Depth = 0.42' or 5"		
Screen Distance (ft)	Average Sweeping Velocity Vs (ft/s)	Average Froude No. based on Vs
-4	2.774	0.754
-2	2.753	0.748
-1	2.705	0.736
1	2.990	0.813
3	2.805	0.763
5	2.591	0.704
7	2.527	0.687
9	2.582	0.702
11	2.181	0.593
12	1.496	0.407
13	1.748	0.475

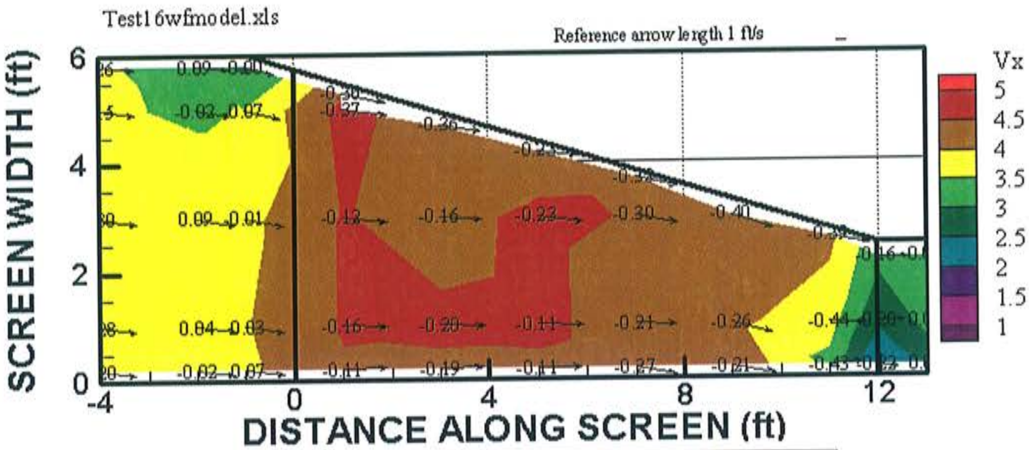
Figure 22.—Test 11. Converging walls with 15° angle. Channel discharge, Q_c=7.00 ft³/s, diversion discharge, Q_d=4.95 ft³/s, bypass discharge, Q_b=2.05 ft³/s. Diversion ratio, Q_d/Q_c = 0.71. Depth over screen=0.42 ft. Contours represent the sweeping velocity and indicate a weak wave from downstream backwater on the very end of the screen. The theoretical average approach velocity of 0.1 ft/s produces 30:1 and 15:1 for sweeping to approach velocity ratios for the upstream and downstream portions of the screen, respectively. The flow is subcritical across the screen.

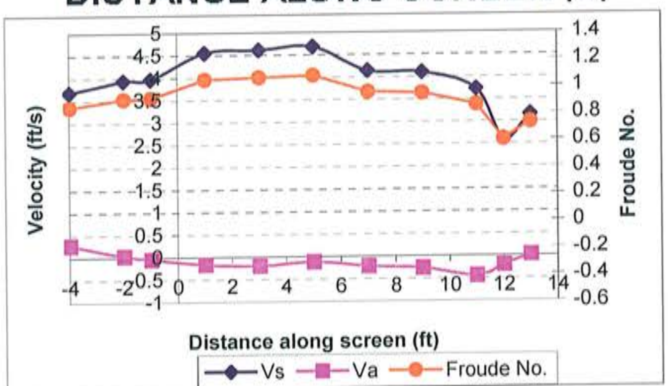




Qt=9.08 ft³/s , Qb=1.63 ft³/s , Qd=7.45 ft³/s		
Depth = 0.58' or 7"		
Screen Distance (ft)	Average Sweeping Velocity Vs (ft/s)	Average Froude No. based on Vs
-4	2.707	0.625
-2	2.646	0.611
-1	2.654	0.613
1	2.698	0.623
3	2.587	0.597
5	2.631	0.607
7	2.465	0.569
9	2.216	0.511
11	1.296	0.299
12	0.882	0.203
13	1.018	0.235

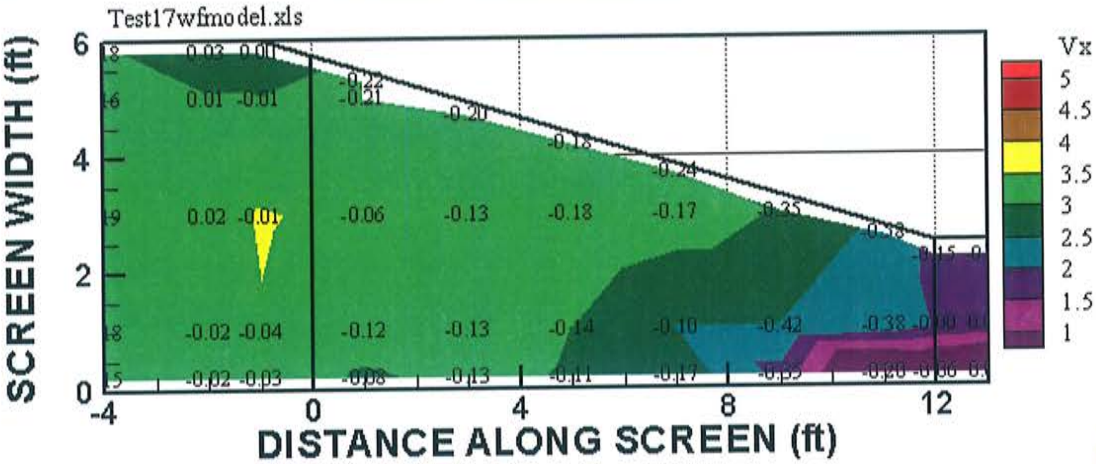
Figure 23.—TEST 12. Converging wall with 15° angle. Channel discharge, Q_c=9.08 ft^3/s, diversion discharge, Q_d=7.45 ft^3/s, bypass discharge, Q_b=1.63 ft^3/s. Diversion ratio, Q_d/Q_c = 0.82. Depth over screen=0.58 ft. Contours represent the sweeping velocity and indicate backwater over the end of the screen from downstream control. The screen approach velocities increase under the influence of the pooled water over the screen. The theoretical average approach velocity of 0.15 ft/s produces 18:1 and 6:1 for sweeping to approach velocity ratios for the upstream and downstream portions of the screen, respectively. The flow is subcritical over the entire screen. Debris testing was performed with this screen geometry and flow condition.

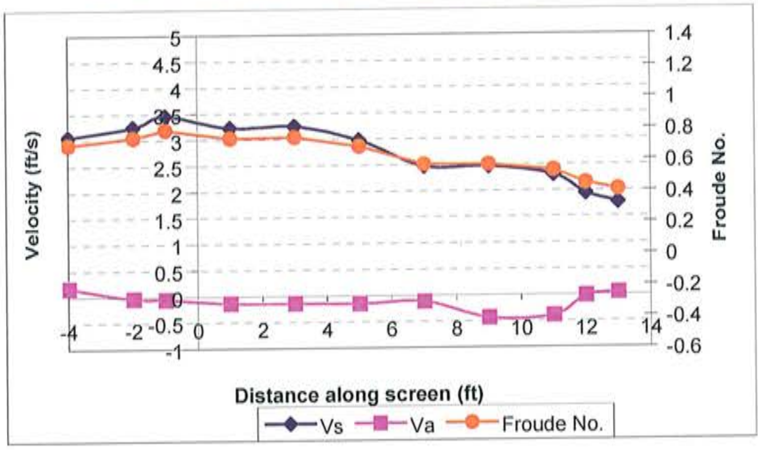




Qt=15.00 ft³/s, Qb=5.11 ft³/s , Qd=9.89 ft³/s		
Depth = 0.58' or 7"		
Screen Distance (ft)	Average Sweeping Velocity Vs (ft/s)	Average Froude No. based on Vs
-4	3.646	0.841
-2	3.674	0.848
-1	3.634	0.839
1	4.519	1.043
3	4.378	1.011
5	4.447	1.026
7	4.277	0.987
9	4.250	0.981
11	3.733	0.862
12	2.587	0.597
13	3.054	0.705

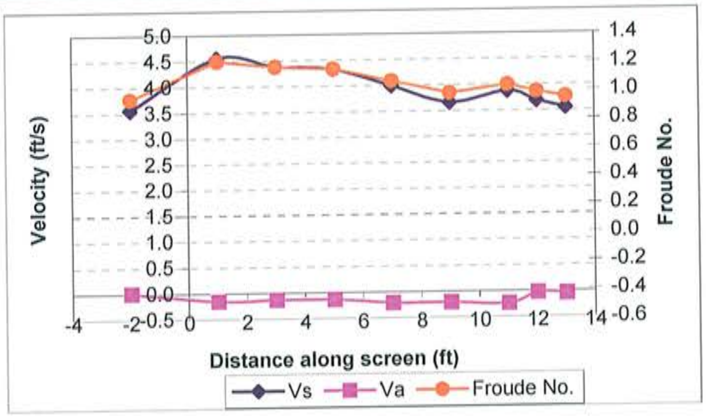
Figure 24.—TEST 13. Converging wall with 15° angle. Channel discharge, Q_c=15.00 ft^3/s, diversion discharge, Q_d=9.89 ft^3/s, bypass discharge, Q_b=5.11 ft^3/s. Diversion ratio, Q_d/Q_c = 0.66. Depth over screen=0.58 ft. Contours represent the sweeping velocity and indicate backwater over the end of the screen from downstream control. The screen approach velocities increase under the influence of the pooled water over the screen. The theoretical average approach velocity of 0.2 ft/s produces 23:1 and 13:1 for sweeping to approach velocity ratios for the upstream and downstream portions of the screen, respectively. The flow is near critical over most of the screen and transitions to subcritical as the flow is backwatered onto the screen.





Qt=12.00 ft³/s, Qb=2.11 ft³/s, Qd=9.89 ft³/s		
Depth = 0.58' or 7"		
Screen Distance (ft)	Average Sweeping Velocity Vs (ft/s)	Average Froude No. based on Vs
-4	3.128	0.722
-2	3.124	0.721
-1	3.182	0.734
1	3.274	0.756
3	3.175	0.733
5	3.180	0.734
7	2.909	0.671
9	2.426	0.560
11	1.440	0.332
12	1.262	0.291
13	1.161	0.268

Figure 25.—TEST 14. Converging wall with 15° angle. Channel discharge, Q_c=12.00 ft³/s, diversion discharge, Q_d=9.89 ft³/s, bypass discharge, Q_b=2.11 ft³/s. Diversion ratio, Q_d/Q_c = 0.82. Depth over screen=0.58 ft. Contours represent the sweeping velocity and indicate a wave front with minor re-circulating flow over the downstream right corner of the screen. The screen approach velocities increase under the influence of the pooled water over the screen. The theoretical average approach velocity of 0.2 ft/s produces 16:1 and 6:1 for sweeping to approach velocity ratios for the upstream and downstream portions of the screen, respectively. The flow is subcritical across the entire screen.



Screen Distance (ft)	Vs (ft/s)	Froude No.
-2.000	3.560	0.954
1.000	4.561	1.221
3.000	4.396	1.177
5.000	4.335	1.161
7.000	4.001	1.071
9.000	3.671	0.983
11.000	3.884	1.040
12.000	3.692	0.989
13.000	3.558	0.953

Figure 26. - Test 15. Converging wall with 15-degree angle and 2.54-ft-wide bypass opening. Channel discharge, Q_c=11.5 ft^3/s, diversion discharge, Q_d=7.42 ft^3/s, bypass discharge, Q_b=4.08 ft^3/s. Diversion ratio Q_d/Q_c=0.64. Depth over screen=0.42 ft. The profiles represent the sweeping and approach velocities measured over the screen 1 ft from the straight wall. Data were not gathered across the width; therefore, there is no contour plot. The flow is supercritical throughout the screen. Bull trout tests were conducted with this screen geometry, flow rate, and sweeping velocity of about 4 ft/s.

Screen Performance with a Converging Side Wall and a Drop at the Downstream End of the Screen

The second series of tests with a converging side wall were conducted with the model modified to form a 1-ft-wide bypass and a drop at the downstream end of the screen into the bypass. Constructing a 1-ft-bypass, while keeping the wall convergence at 15 degrees, meant reducing the upstream channel to a width of 4.22 ft. The Froude model scale that was used for these tests was 2:1. This allowed for deeper flow depths and investigation of a typical 2 ft bypass width normally used in vertical screen installations. In addition, adding a drop at the end of the screen into the bypass allowed investigation of the effects of flow depth control at the downstream end of the screen.

Critical depth occurred at the end of the screen and controlled the depth over the screen in addition to that provided by the diversion weir wall and control gate. With critical depth at the end of the screen (Froude number =1), the bypass flow is controlled for any given depth over the screen [4]. The flow conditions tested over the screen with the 15 degree wall convergence leading to the 1-ft-wide bypass with a drop at the downstream end are shown in table 3. After a few initial tests the channel flow was kept constant and the depth over the screen increased for comparison of flow conditions.

Table 3.—Flow rates tested over the screen with a 1-ft-wide bypass and a drop at the downstream end

Test	Channel Discharge, Q_c (ft^3/s)	Diversion Discharge, Q_d (ft^3/s)	Bypass Discharge, Q_b (ft^3/s)	Q_d/Q_c (percent)	Theoretical Approach Velocity (ft/s)	Depth (ft)
16	8	6.20	1.80	77	0.198	0.5
17	7	5.11	1.89	73	0.163	0.5
18	9	6.69	2.31	74	0.213	0.5
19	9	6.15	2.85	68	0.196	0.67
20	4.07	2.64	1.36	67	0.086	0.5
21	4.07	1.85	2.25	45	0.062	0.67

The flow characteristics at the end of the screen entering the bypass are complex. Two different flow conditions, represented by tests 20 and 18, are shown on figures 27 and 28. Test 20, shown on figure 27, has a fairly small channel flow and as a result the screen area is too large and flow returns back up through the screen at the downstream end. A necessary balance of flow causes flow to come up out of the screen for the given approach velocity, screen area, and depth. Test 18, shown on figure 28, has a large channel flow and cross-waves form due to the relatively short approach area causing build up of the flow at the downstream end of the screen and an increase in approach velocity at the downstream end of the screen.

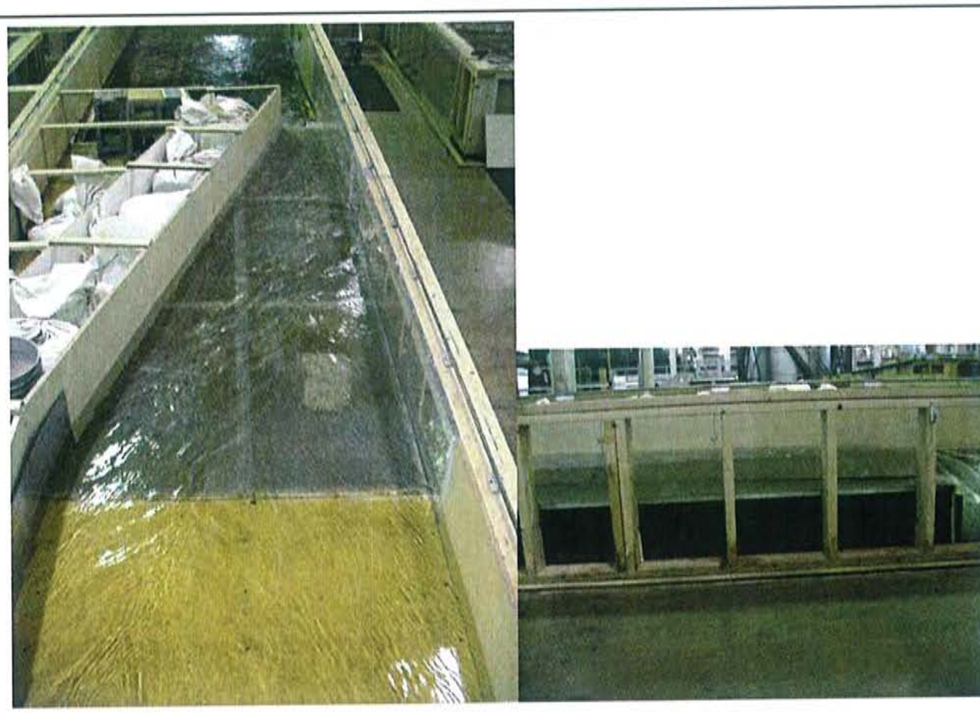


Figure 27.—Test 20. Critical flow at the downstream end of the screen with Q_c= 4.07 ft^3/s and Q_d/Q_c= 67 percent. Flow depth of 0.5 ft. The sweeping velocity is increasing across the screen and particularly as the flow enters the bypass opening. The approach velocity in the last foot of the screen is positive indicating that flow is coming up through the screen.

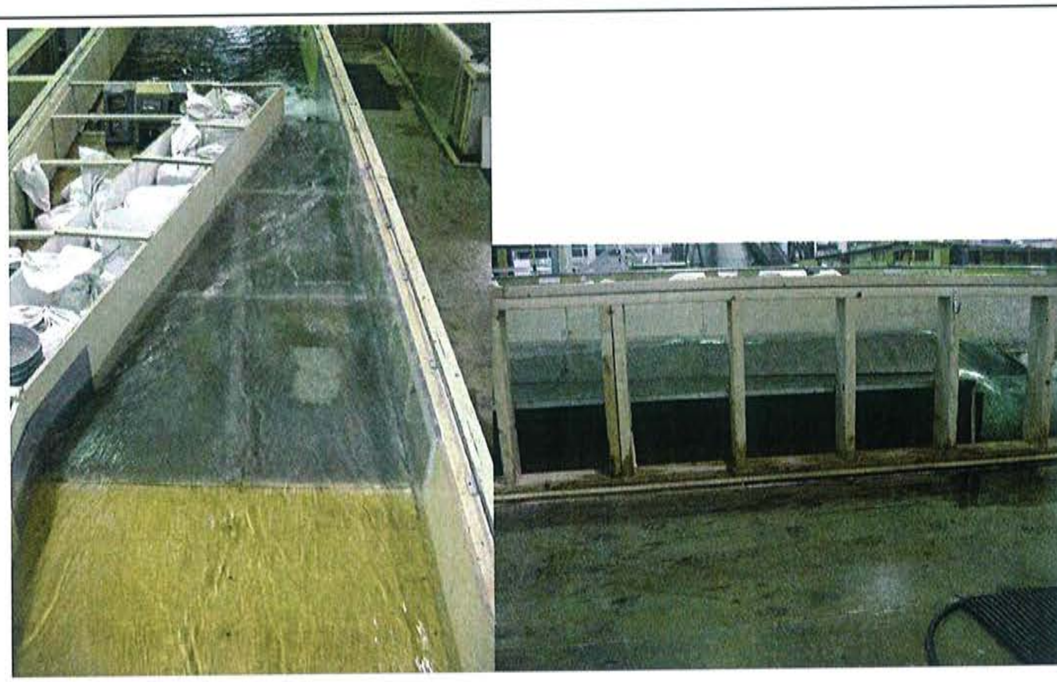


Figure 28.—Test 18. Critical flow at the downstream end of the screen with Q_c= 9 ft^3/s and Q_d/Q_c= 74 percent. Flow depth of 0.5 ft. The sweeping velocity is maintained across the screen and as the flow enters the bypass opening. The approach velocity over the last 2 feet of the screen exceeds the target of 0.2 ft/s indicating that the flow is deeper upstream from critical depth at the end of the screen. Notice the cross-waves extending the full width of the channel.

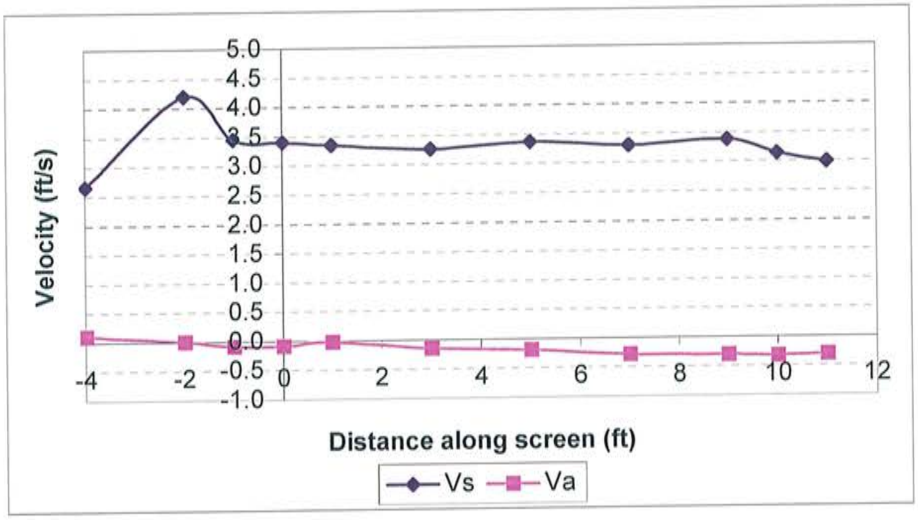
Velocity data were gathered along a profile located 0.5 ft from the straight right wall. Profiles of the depth at the end of the screen were measured to determine if the depth at the end of the screen was at, or above critical. In all cases depth measurements were equal to or greater than the computed critical depth for the bypass flow indicating subcritical flow conditions over the screen.

For all channel flow rates and Q_d/Q_c ratios tested the sweeping velocity increased or remained steady as the flow entered the bypass opening at the downstream end of the screen, figures 29-34. This is an improvement in sweeping velocity that should encourage fish passage and would be similar to bypass velocities with vertical screens.

The surface turbulence caused by the cross-waves from the wall convergence and the curvilinear flow at the drop produced some approach channel velocity anomalies at the end of the screen. In addition, the relatively short approach section to the screen section can also cause non-uniformity of the approach velocity. Approach conditions into the screen with higher sweeping velocities produced somewhat non-uniform approach velocities for every condition tested with small approach velocities at the upstream end of the screen that increased towards the downstream end of the screen.

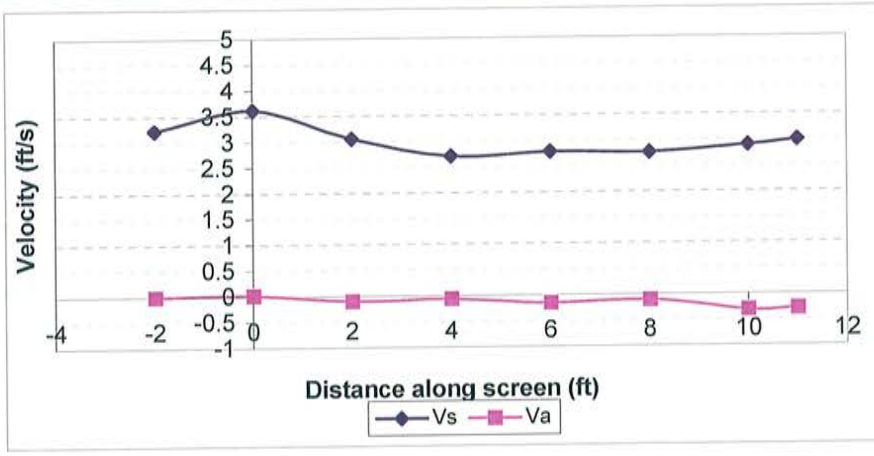
For test 18, figure 31, and test 19, figure 32, with the same channel flow rate of 9 ft^3/s, the flow condition for test 18 produced increasing downward approach velocities along the screen, with the larger depth in test 19 following the same trend, but produced upwelling at the end of the screen. Figure 33, test 20, and figure 34, test 21, show the sweeping velocity increasing into the bypass and flow coming up out of the screen with positive approach velocities for Q_c=4.07 ft^3/s with Q_d/Q_c=0.67, D=0.5 ft and Q_d/Q_c=0.45, D=0.67 ft, respectively. The larger flow depth over the screen in test 21, compared to test 20, produced quite a large upwelling of velocity from the screen. This condition is not necessarily a problem hydraulically, but could cause fish avoidance at the bypass.

A solid or non-perforated section should perhaps be placed at the end of the screen to prevent excessive approach velocities or reverse flow at the bypass opening when operating with a drop at the end of the screen. In addition, a longer screen will reduce cross-waves by decreasing the side wall convergence for a given diversion design flow.



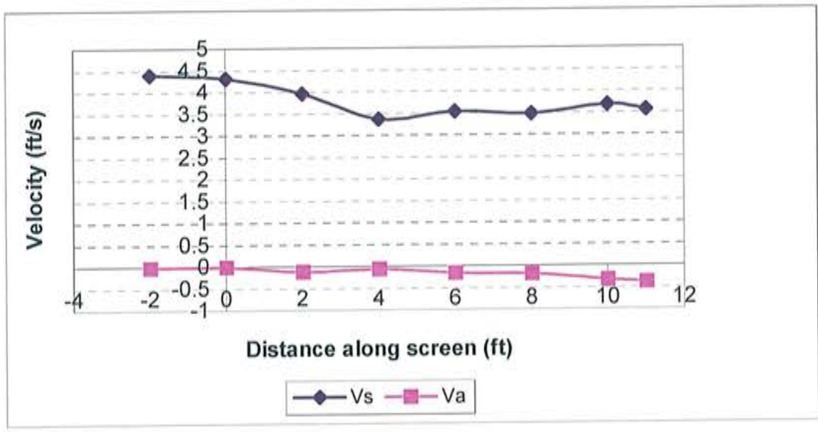
X	Vs (ft/s)	Vy (ft/s)	Va (ft/s)
-4	2.655	-0.024	0.113
-2	4.201	-0.082	0.012
-1	3.454	-0.065	-0.078
0	3.398	-0.022	-0.073
1	3.352	0.096	-0.010
3	3.269	-0.086	-0.135
5	3.374	0.040	-0.184
7	3.295	-0.504	-0.271
9	3.382	-0.342	-0.296
10	3.136	-0.523	-0.314
11	2.998	-0.504	-0.294

Figure 29.—Test 16 with 15-degree converging side wall to 1 ft wide bypass channel. Q_c=8 ft^3/s, Q_d=6.20 ft^3/s, and Q_d/Q_c=77.5 percent with a 0.5 ft depth. Approach velocities increase down the screen and sweeping velocities remain relatively constant, perhaps slightly decreasing.



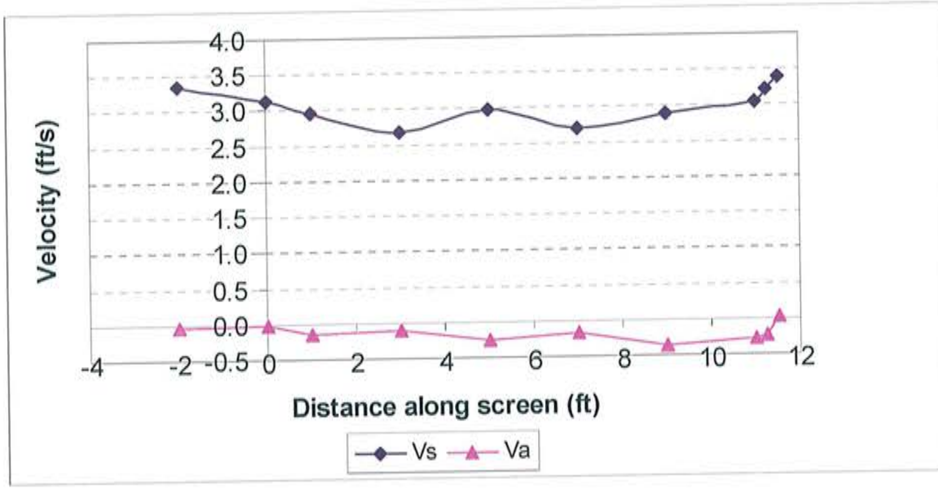
X distance (ft)	Vs (ft/s)	Vy (ft/s)	Va (ft/s)
-2	3.2365	-0.0231	0.0103
0	3.6254	-0.0447	0.0335
2	3.0673	-0.0458	-0.0847
4	2.7194	-0.1154	-0.0465
6	2.7903	-0.1694	-0.1365
8	2.7733	-0.2012	-0.0978
10	2.901	-0.3217	-0.2906
11	2.9947	-0.4747	-0.2701

Figure 30.—Test 17 with 15-degree converging side wall to 1-ft-wide bypass. Q_c=7 ft^3/s, Q_d=5.11 ft^3/s, and Q_d/Q_c=73 percent with a 0.5 ft depth. Approach velocities increase down the screen and sweeping velocities remain relatively constant once over the screen.



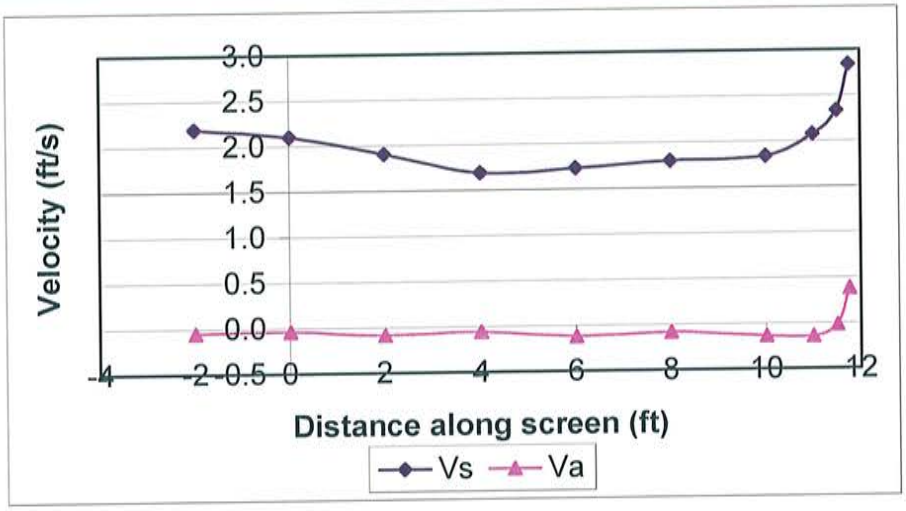
X Distance (ft)	Vs (ft/s)	Vy (ft/s)	Va (ft/s)
-2	4.4118	-0.0619	-0.0165
0	4.3276	-0.0555	-0.0006
2	3.9688	-0.0022	-0.1117
4	3.3786	-0.0721	-0.0633
6	3.5456	-0.1454	-0.1506
8	3.4904	-0.2494	-0.1771
10	3.6902	-0.2639	-0.3269
11	3.5782	-0.3731	-0.3825

Figure 31.—Test 18 with 15-degree converging side wall to 1-ft-wide bypass. Q_c=9 ft^3/s, Q_d=6.69 ft^3/s, and Q_d/Q_c=74 percent with a 0.5 ft depth. Approach velocities increase down the screen and sweeping velocities remain relatively constant once at a location 4 ft onto the screen.



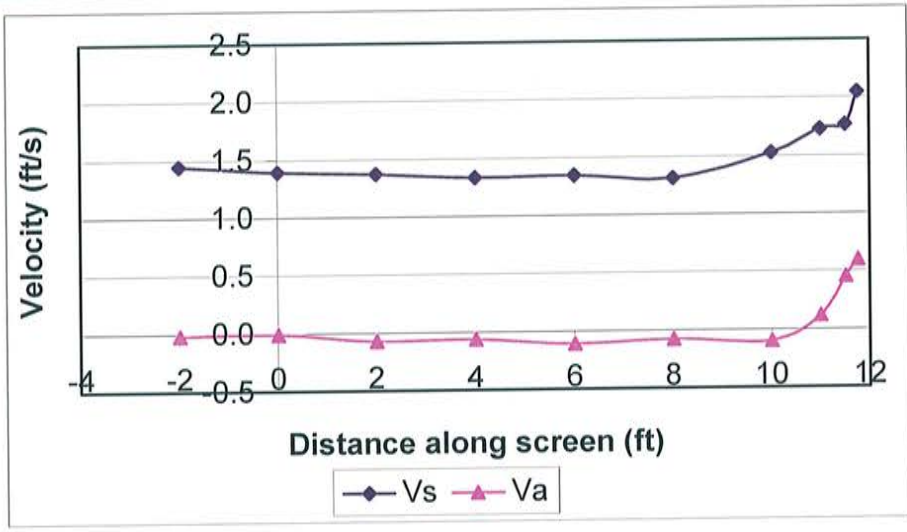
X	Vs (ft/s)	Vy (ft/s)	Va (ft/s)
-2	3.354	-0.129	-0.020
0	3.144	-0.167	0.000
1	2.976	-0.196	-0.138
3	2.687	-0.166	-0.098
5	2.994	-0.216	-0.247
7	2.718	-0.221	-0.147
9	2.912	-0.244	-0.353
11	3.056	-0.347	-0.256
11.25	3.223	-0.389	-0.212
11.5	3.404	-0.394	0.041

Figure 32.—Test 19 with 15-degree side wall to 1-ft-wide bypass. Q_c=9 ft^3/s, Q_d=6.15 ft^3/s, and Q_d/Q_c=68 percent with a 0.67 ft depth. Approach velocities increase down the screen and sweeping velocities increasing into the bypass.



X	Vs (ft/s)	Vy (ft/s)	Va (ft/s)
-2	2.193	-0.046	-0.044
0	2.110	-0.109	-0.031
2	1.914	-0.002	-0.079
4	1.699	-0.021	-0.056
6	1.737	-0.093	-0.112
8	1.807	-0.083	-0.080
10	1.841	-0.131	-0.136
11	2.078	-0.269	-0.142
11.5	2.340	-0.306	-0.012
11.75	2.845	-0.379	0.383

Figure 33.—Test 20 with 15-degree converging side wall to 1-ft-wide bypass. Q_c=4.07 ft^3/s, Q_d=2.64 ft^3/s, and Q_d/Q_c=67 percent with a 0.67 ft depth. This flow condition indicates approach velocities coming up out of the screen and sweeping velocities increasing into the bypass.



X	Vs (ft/s)	Vy (ft/s)	Va (ft/s)
-2	1.3995	-0.0291	-0.0145
0	1.3977	-0.0431	-0.0127
1	1.3796	-0.0439	-0.0618
3	1.3984	-0.073	-0.0341
5	1.3839	-0.1152	-0.1061
7	1.3715	-0.1353	-0.0468
9	1.5095	-0.175	-0.0941
11	1.5832	-0.2265	0.1052
11.5	1.9876	-0.2937	0.3614
11.75	1.8415	-0.5295	0.5617

Figure 34. - Test 21 with 15-degree side wall with 1-ft-wide bypass. Q_c=4.07 ft^3/s, Q_d=1.85 ft^3/s, and Q_d/Q_c=45 percent with 0.67 ft depth. This flow condition indicates approach velocities coming up out of the screen and sweeping velocities increasing into the bypass.

BIOLOGICAL TESTING – FLOW DESCRIPTION

The results of the biological testing of bull trout are attached under a separate report entitled "Bull Trout Performance in a Horizontal Flat-plate Screen" by Beyers and Bestgen [1]. The following is the Executive Summary from that comprehensive report.

"This investigation was conducted to the describe effects of passage of bull trout *Salvelinus confluentus* over a horizontal flat-plate screen. Experimental releases were conducted with three sizes of bull trout that averaged 28, 37, and 58 mm total length (TL). Fish were released individually and in batches to: (1) describe general behavior near and on the screen; (2) estimate physical condition and survival of fish after passage; and (3) estimate entrainment and impingement rates.

Consistent negative effects from passage of bull trout over a horizontal flat-plate screen were not observed. Potential entrainment was $\leq 3.5\%$ for 28 mm fish, and was never observed for larger fish. Impingement never occurred. Passage times increased with fish size and ranged from 4 sec to more than 10 min. Physical damage to eyes, fins, and integument was either rare (eyes) or less frequent in fish that passed over the screen than in control fish. Fish that passed over the screen did contact the bottom more frequently than control fish, but no immediate mortality occurred from screen passage. Survival at 24 h was $\leq 1.5\%$ lower for fish that passed over the screen compared to controls. At 96 h after passage, survival was reduced, but was not consistently lower for fish that passed over the screen compared to controls. Thus, physical effects of screen passage were at, or near the level of background effects induced by fish culture, handling, transport, and testing.

Water depth and orientation of bull trout changed with fish size and age despite the use of a standardized release methodology. Larger fish were more frequently observed near the bottom and more frequently oriented upstream than smaller fish. The tendency to occupy deeper water increased the likelihood that fish contacted the horizontal flat-plate screen. It also increased the likelihood that fish discovered attractive hydraulic properties of the screen. We observed several 58 mm fish that appeared to be maintaining position by using downward pressure generated by water approaching the screen. This behavior was the main factor responsible for increased passage time for larger fish. Thus, we did observe that certain hydraulic conditions of the horizontal flat-plate screen used in this investigation attracted fish and delayed their movement over the screen."

This section describes the flow conditions under which the biological testing was conducted. The testing was conducted with a 15-degree converging wall from the 6 ft wide channel to a 2.54 ft wide bypass. The wall convergence began 1 ft upstream from the 12 ft long screen section. The side wall in the downstream bypass area was extended to allow an acceptable area to net the fish below the screen.

Two sweeping velocities were selected for testing that represented large sweeping to approach velocity ratios and different flow conditions over the screen. Test 10 with subcritcal flow over the screen, $V_s = 2$ ft/s and $Q_d/Q_c = 0.58$, figures 17 and 21, were replicated for the bull trout tests. Supercritical flow, test 15, was used with $V_s = 4$ ft/s and $Q_s/Q_c = 0.62$, figure 26. Flow depths for both tests were about 0.42 feet over the length of the screen. The sweeping velocities were essentially constant over the screen and increased at the entrance to the bypass. Both control and screen exposure tests were performed. For the control tests, the screen was covered with a thin sheet of plastic and the wall geometry modified to produce the same sweeping velocity without diversion flow. The hydraulic information for the biological tests is given in table 4.

Figures 35- 37 show the geometry and flow conditions under which the bull trout testing was performed.

Table 4.—Hydraulic parameters used for the biological testing

	Q_c (ft^3/s)	Q_d (ft^3/s)	Q_b (ft^3/s)	Q_d/Q_c	V_s (ft/s)	V_a (ft/s)	V_s/V_a	Depth (ft)
Test 11	6.92	4.00	2.92	0.58	2	0.15	13:1	0.42
Control	2.05	0	2.05	0	2	N/A	N/A	0.42
Test 15	11.5	7.12	4.38	0.62	4	0.15	27:1	0.42
Control	4.08	0	4.08	0	4	N/A	N/A	0.42

Figure 35.—Bull trout testing with the 15-degree converging wall over the screen.

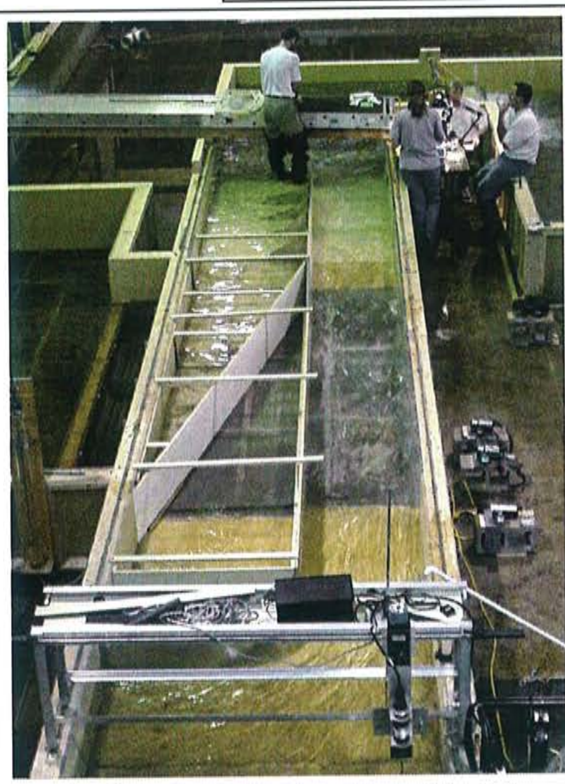


Figure 36.—Control test setup for bull trout testing with clear plastic over the screen and 2 ft/s sweeping velocity.

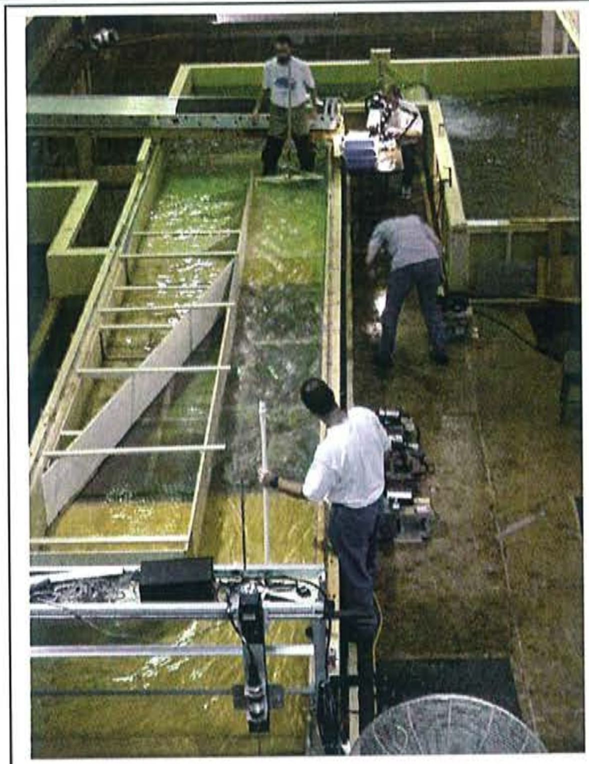


Figure 37.—Control test setup for bull trout testing with clear plastic over the screen and 4 ft/s sweeping velocity.

FUTURE INVESTIGATIONS

The hydraulic and biological investigations presented in this work will lead to discussions with Federal and State resource agencies regarding the feasibility of this technology. These agencies have been taking an active role in the investigations in order to resolve issues relating to requests from various irrigation districts to allow the use of the horizontal screen technology for flow diversion where ESA listed species are located.

Implementation of an experimental horizontal screen at a field site is, hopefully, the next step in these investigations. This site would require meeting the standards determined by the resource agencies and also require monitoring of hydraulic and possibly biological performance.

A few additional laboratory studies could be performed, should further research funding be available. These would include:

- Testing a wedge wire-type screen
- Testing various screen porosities
- More thorough debris tests
- Effectiveness of cleaning devices, if needed
- Further investigation of bypass exit conditions

IMPLEMENTATION PLAN FOR HORIZONTAL FISH SCREEN TECHNOLOGY

A meeting attended by Reclamation, the resource agencies, and members of the Baker Valley Irrigation District in July 2001 in Boise, ID to discuss what would be needed to utilize the horizontal flat-plate screen technology at a field site. The following items were determined to be necessary prior to use of the screen technology:

1. Obtain necessary permits and perform necessary biological assessments.
    a. Determine migration pattern for listed species during irrigation season.
2. Obtain the area hydrology.
    a. Hydrographs for all years.
    b. Q_{Design} and Q_{Ratio}.

3. Site parameters.

    a. Headwater control.

    b. Tailwater control or information.

    c. Modify site to meet optimal parameters.

    d. Downstream drop off screen if possible.

    e. Assess sediment issue with gradation information.

4. Evaluate debris type, i.e. leaves, needles, sand, etc. and quantity and design sediment traps, as needed.

5. Stay within recommended screen "criteria" (guidelines) for approach velocity and flow depth over 90 percent of the operational season.

    a. Use spreadsheet to develop initial design.

    b. Use a backwater program, such as HEC-RAS, for final design.

6. The diversion wall MUST be fixed.

7. Off-channel construction in diversion channels recommended.

8. Approach to design when outside of design with low flow.

    a. Construct 2 channels side-by-side and shut off 1 side.

    b. Use bypass control for low flows.

9. Evaluate hydraulic and biological performance throughout irrigation season.

REFERENCES

[1] Beyers, Daniel W., Bestgen, Kevin R., "Bull Trout Performance During Passage Over A Horizontal Flat-plate Screen", Contribution 128, Larval Fish Laboratory, Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins, CO 80523, July 2001.

[2] Mefford, B., Kubitschek, J., "Physical Model Studies of the GCID Pumping Plant Fish Screen Structure Alternatives, Progress Report No. 1, 1:30 Scale Model Investigations, Alternative D", R-97-02, U.S. Bureau of Reclamation, Technical Services Center, March 1997.

[3] Odeh, Mufeed, "Advances in Fish Passage Technology: Engineering Design and Biological Evaluation", American Fisheries Society, Bethesda, Maryland, 2000.

[4] Chow, Ven Te, "Open-Channel Hydraulics", McGraw-Hill Book Company, 1959.

APPENDIX A

Flat-plate screen sweeping velocity prediction model. The computations are shown with the developed pivot table using cell K26.

Flat plate screen sweeping velocity prediction model

filename: flat plate screen worksheet sample.xls
Model assumes uniform approach velocity to the screen and a constant flow depth over the screen
Input parameters are shown in yellow
Spreadsheet computes discharges based upon variable screen dimensions and depths

Table shows where velocity is outside specified limits or shows "Trans" where flow changes from subcritical to supercritical
And includes supercritical flow range as acceptable
Shaded areas in the table are for acceptable flow ratios given the specified input and approach velocity range

Row	A	B
14	**Specific Case**	
15	Qus =	10
16	Va =	0.2
17	Qdiv =	=+$G$26
18	Qby=	=+$B$15-$B$17
29	Screen length (L)	12
30	channel width (Cw)	5
31	Wall angle (A)	15
32	Bypass width (Bw) =	=+B30-(B29*TAN(B31*PI()/180))
33	Depth (D) =	1
34	%Act/Dcl per ft	1
35	Vs (min), ft/s	2
47	**Diversion ratio, Vr***	
48	Vr>0.6	
49	0.3<Vr<0.6	
50	Vr<0.3	
51	*Vr = Ratio of Diversion Flow to Channel Flow	

Row	Screen length (C)	Channel width (D)	Area lost (E)	Screen area (F)	Qdiv (G)	Qb (H)	Flow area (I)	Vs (J)	Vs acc test (K)	Critical depth (L)	Critical vel (M)	Froude # (N)
13	1 ft increments	Total u/s width-convergence angle*screen increment	Tan(A)*screen length*screen length/2	Width*length-area lost	Incremental Q thru screen	Total Q-Qdiv	Depth*channel width	Qb/flow area				
14	0	=($B$30)-(TAN(RADIANS($B$31))*C14)	0	0	0	=+$B$15-G14	=D14*$B$33	=H14/I14		=+((H14/D14)^2/32.2)^0.333	=+(32.2*L14)^0.5	=+(J14)^2/(32.2*$B$33)
15	=+B29/12	=($B$30)-(TAN(RADIANS($B$31))*C15)	=TAN(RADIANS($B$31))*C15*C15/2	=$B$30*C15-E15	=+$B$16*F15	=+$B$15-G15	=D15*$B$33	=H15/I15	=IF((M15>J15),IF((ABS(J14-J15)>$B$34),IF((J15>$B$35),1,100),-100),-1)	=+((H15/D15)^2/32.2)^0.333	=+(32.2*L15)^0.5	=+(J15)^2/(32.2*$B$33)
16	=+$C$15*2	=($B$30)-(TAN(RADIANS($B$31))*C16)	=TAN(RADIANS($B$31))*C16*C16/2	=$B$30*C16-E16	=+$B$16*F16	=+$B$15-G16	=D16*$B$33	=H16/I16	=IF((M16>J16),IF((ABS(J15-J16)>$B$34),IF((J16>$B$35),1,100),-100),-1)	=+((H16/D16)^2/32.2)^0.333	=+(32.2*L16)^0.5	=+(J16)^2/(32.2*$B$33)
17	=+$C$15*3	=($B$30)-(TAN(RADIANS($B$31))*C17)	=TAN(RADIANS($B$31))*C17*C17/2	=$B$30*C17-E17	=+$B$16*F17	=+$B$15-G17	=D17*$B$33	=H17/I17	=IF((M17>J17),IF((ABS(J16-J17)>$B$34),IF((J17>$B$35),1,100),-100),-1)	=+((H17/D17)^2/32.2)^0.333	=+(32.2*L17)^0.5	=+(J17)^2/(32.2*$B$33)
18	=+$C$15*4	=($B$30)-(TAN(RADIANS($B$31))*C18)	=TAN(RADIANS($B$31))*C18*C18/2	=$B$30*C18-E18	=+$B$16*F18	=+$B$15-G18	=D18*$B$33	=H18/I18	=IF((M18>J18),IF((ABS(J17-J18)>$B$34),IF((J18>$B$35),1,100),-100),-1)	=+((H18/D18)^2/32.2)^0.333	=+(32.2*L18)^0.5	=+(J18)^2/(32.2*$B$33)
19	=+$C$15*5	=($B$30)-(TAN(RADIANS($B$31))*C19)	=TAN(RADIANS($B$31))*C19*C19/2	=$B$30*C19-E19	=+$B$16*F19	=+$B$15-G19	=D19*$B$33	=H19/I19	=IF((M19>J19),IF((ABS(J18-J19)>$B$34),IF((J19>$B$35),1,100),-100),-1)	=+((H19/D19)^2/32.2)^0.333	=+(32.2*L19)^0.5	=+(J19)^2/(32.2*$B$33)
20	=+$C$15*6	=($B$30)-(TAN(RADIANS($B$31))*C20)	=TAN(RADIANS($B$31))*C20*C20/2	=$B$30*C20-E20	=+$B$16*F20	=+$B$15-G20	=D20*$B$33	=H20/I20	=IF((M20>J20),IF((ABS(J19-J20)>$B$34),IF((J20>$B$35),1,100),-100),-1)	=+((H20/D20)^2/32.2)^0.333	=+(32.2*L20)^0.5	=+(J20)^2/(32.2*$B$33)
21	=+$C$15*7	=($B$30)-(TAN(RADIANS($B$31))*C21)	=TAN(RADIANS($B$31))*C21*C21/2	=$B$30*C21-E21	=+$B$16*F21	=+$B$15-G21	=D21*$B$33	=H21/I21	=IF((M21>J21),IF((ABS(J20-J21)>$B$34),IF((J21>$B$35),1,100),-100),-1)	=+((H21/D21)^2/32.2)^0.333	=+(32.2*L21)^0.5	=+(J21)^2/(32.2*$B$33)
22	=+$C$15*8	=($B$30)-(TAN(RADIANS($B$31))*C22)	=TAN(RADIANS($B$31))*C22*C22/2	=$B$30*C22-E22	=+$B$16*F22	=+$B$15-G22	=D22*$B$33	=H22/I22	=IF((M22>J22),IF((ABS(J21-J22)>$B$34),IF((J22>$B$35),1,100),-100),-1)	=+((H22/D22)^2/32.2)^0.333	=+(32.2*L22)^0.5	=+(J22)^2/(32.2*$B$33)
23	=+$C$15*9	=($B$30)-(TAN(RADIANS($B$31))*C23)	=TAN(RADIANS($B$31))*C23*C23/2	=$B$30*C23-E23	=+$B$16*F23	=+$B$15-G23	=D23*$B$33	=H23/I23	=IF((M23>J23),IF((ABS(J22-J23)>$B$34),IF((J23>$B$35),1,100),-100),-1)	=+((H23/D23)^2/32.2)^0.333	=+(32.2*L23)^0.5	=+(J23)^2/(32.2*$B$33)
24	=+$C$15*10	=($B$30)-(TAN(RADIANS($B$31))*C24)	=TAN(RADIANS($B$31))*C24*C24/2	=$B$30*C24-E24	=+$B$16*F24	=+$B$15-G24	=D24*$B$33	=H24/I24	=IF((M24>J24),IF((ABS(J23-J24)>$B$34),IF((J24>$B$35),1,100),-100),-1)	=+((H24/D24)^2/32.2)^0.333	=+(32.2*L24)^0.5	=+(J24)^2/(32.2*$B$33)
25	=+$C$15*11	=($B$30)-(TAN(RADIANS($B$31))*C25)	=TAN(RADIANS($B$31))*C25*C25/2	=$B$30*C25-E25	=+$B$16*F25	=+$B$15-G25	=D25*$B$33	=H25/I25	=IF((M25>J25),IF((ABS(J24-J25)>$B$34),IF((J25>$B$35),1,100),-100),-1)	=+((H25/D25)^2/32.2)^0.333	=+(32.2*L25)^0.5	=+(J25)^2/(32.2*$B$33)
26	=+$C$15*12	=($B$30)-(TAN(RADIANS($B$31))*C26)	=TAN(RADIANS($B$31))*C26*C26/2	=$B$30*C26-E26	=+$B$16*F26	=+$B$15-G26	=D26*$B$33	=H26/I26	=IF((M26>J26),IF((ABS(J25-J26)>$B$34),IF((J26>$B$35),1,100),-100),-1)	=+((H26/D26)^2/32.2)^0.333	=+(32.2*L26)^0.5	=+(J26)^2/(32.2*$B$33)
									=IF(AVERAGE(K15:K26)=1,G26/$B$15,IF(MAX(K15:K26)=100,"Vs<Vmin",IF(MIN(K15:K26)=-100,">deltaVs",IF(AVERAGE(K15:K26)=-1,"Vs>Vc","TRANS"))))			

Screen Approach Velocity, ft/s

Channel Flow, cfs	0.15	=D31+0.025	=E31+0.025	=F31+0.025	=G31+0.025	=H31+0.025	=I31+0.025
12	Vs<Vmin	Vs<Vmin	Vs<Vmin	Vs<Vmin	>deltaVs	>deltaVs	>deltaVs
13	Vs<Vmin	Vs<Vmin	Vs<Vmin	Vs<Vmin	>deltaVs	>deltaVs	>deltaVs
14	Vs<Vmin	Vs<Vmin	Vs<Vmin	Vs<Vmin	>deltaVs	>deltaVs	>deltaVs
15	Vs<Vmin	Vs<Vmin	Vs<Vmin	Vs<Vmin	Vs<Vmin	>deltaVs	>deltaVs
16	0.494676581449592	Vs<Vmin	Vs<Vmin	Vs<Vmin	Vs<Vmin	>deltaVs	>deltaVs
17	0.412230494541326	0.61834572681199	Vs<Vmin	Vs<Vmin	Vs<Vmin	>deltaVs	>deltaVs
18	>deltaVs	0.530010622881706	0.70668083064227	Vs<Vmin	Vs<Vmin	>deltaVs	>deltaVs
19	>deltaVs	0.463759295108992	0.61834572681199	0.772932158514	Vs<Vmin	>deltaVs	>deltaVs
20	>deltaVs	>deltaVs	0.54964064605510	0.687050807566	0.824460969	>deltaVs	>deltaVs
21	>deltaVs	>deltaVs	0.49467658144959	0.61834572681	0.742014872	Vs<Vmin	>deltaVs
22	>deltaVs	>deltaVs	>deltaVs	0.56213247891	0.67455897470	0.786985470	>deltaVs
23	TRANS	TRANS	>deltaVs	0.51528810567	0.61834572681	0.72140334794	0.824460969
24	TRANS	TRANS	TRANS	TRANS	0.57078067090	0.66591078272	0.76104089453
25	TRANS	TRANS	TRANS	TRANS	0.53001062298	0.61834572681	0.70668083064
26	Vs>Vc	Vs>Vc	Vs>Vc	TRANS	TRANS	0.57712267835	0.65956877526
27	Vs>Vc	Vs>Vc	Vs>Vc	Vs>Vc	Vs>Vc	TRANS	TRANS
28	Vs>Vc	Vs>Vc	Vs>Vc	Vs>Vc	Vs>Vc	Vs>Vc	Vs>Vc
29	Vs>Vc	Vs>Vc	Vs>Vc	Vs>Vc	Vs>Vc	Vs>Vc	Vs>Vc
30	Vs>Vc	Vs>Vc	Vs>Vc	Vs>Vc	Vs>Vc	Vs>Vc	Vs>Vc

APPENDIX B

This appendix provides the actual three-dimensional velocity data as recorded by the SonTek ADV and analyzed with WinAdv. The "X" parameter is the distance down the screen in feet with 0 ft the beginning and 12 ft the end of the screen. The "Y" parameter is the distance across the screen in feet. Data were recorded for tests 16-21 only at one point 6 inches from the right or straight wall for each "X" distance when the "Y" distance is not shown.

Rectangular Screen Data

Test 1

X	Y	Vs	Vy	Va
-0.4271	1	3.196	-0.175	-0.017
-0.4271	3	3.498	-0.211	-0.014
-0.4271	5	3.295	-0.015	-0.057
0.0729	1	3.020	-0.196	-0.109
0.0729	3	3.169	-0.140	-0.152
0.0729	5	3.150	-0.010	-0.127
0.5729	1	2.903	-0.146	-0.082
0.5729	3	3.200	-0.064	-0.157
0.5729	5	3.204	0.018	-0.124
3.5729	1	2.435	-0.096	-0.091
3.5729	3	2.700	0.075	-0.059
3.5729	5	2.571	0.006	-0.085
6.5729	1	1.928	0.085	-0.170
6.5729	3	2.060	0.032	-0.084
6.5729	5	2.014	-0.075	-0.086
9.5729	1	-0.507	0.048	-0.224
9.5729	3	2.197	0.597	-0.327
9.5729	5	2.032	0.000	-0.159
11.0729	1	-1.309	-0.155	-0.055
11.0729	3	2.205	0.574	-0.214
11.0729	5	1.640	0.282	-0.428

Test 2

X	Y	Vs	Vy	Va
-0.4271	1	3.785	-0.392	-0.024
-0.4271	3	3.818	-0.568	-0.019
-0.4271	5	3.719	-0.331	-0.023
0.0729	1	3.555	-0.264	-0.101
0.0729	3	3.737	-0.369	-0.126
0.0729	5	3.595	-0.144	-0.070
0.5729	1	3.536	-0.259	-0.110
0.5729	3	3.588	-0.227	-0.061

X	Y	Vs	Vy	Va
0.5729	5	3.485	-0.157	-0.056
3.5729	1	2.896	-0.217	-0.092
3.5729	3	2.925	-0.226	-0.056
3.5729	5	2.863	-0.255	-0.069
6.5729	1	2.394	-0.223	-0.061
6.5729	3	2.427	-0.145	-0.060
6.5729	5	2.441	-0.203	-0.093
9.5729	1	2.206	0.647	-0.498
9.5729	3	2.245	-0.033	-0.168
9.5729	5	2.365	-0.147	-0.091
11.0729	1	-0.425	-0.148	-0.329
11.0729	3	2.278	0.560	-0.370
11.0729	5	1.594	0.033	-0.497

Test 3

X	Y	Vs	Vy	Va
-0.4271	0.2	5.157	0.085	-0.131
-0.4271	1	4.985	-0.074	-0.091
-0.4271	3	4.891	0.074	-0.124
-0.4271	5	4.134	0.007	-0.111
-0.4271	5.8	4.169	-0.050	-0.098
0.0729	0.2	5.078	0.236	-0.204
0.0729	1	4.907	-0.186	-0.187
0.0729	3	5.016	0.078	-0.312
0.0729	5	4.415	0.241	-0.260
0.0729	5.8	4.420	-0.021	-0.227
0.5729	0.2	5.110	0.122	-0.173
0.5729	1	4.920	-0.079	-0.152
0.5729	3	5.046	0.103	-0.203
0.5729	5	4.607	0.010	-0.189
0.5729	5.8	4.553	-0.004	-0.112
3.5729	0.2	4.504	0.135	-0.312
3.5729	1	4.092	0.081	-0.175
3.5729	3	4.295	0.256	-0.245
3.5729	5	4.052	0.117	-0.229
3.5729	5.8	4.116	-0.028	-0.274
6.5729	0.2	4.111	0.076	-0.181
6.5729	1	3.523	0.110	-0.176
6.5729	3	3.698	0.233	-0.193
6.5729	5	3.680	0.286	-0.184
6.5729	5.8	3.964	0.149	-0.274
9.5729	0.2	3.908	0.102	-0.239
9.5729	1	2.999	0.071	-0.099
9.5729	3	3.007	0.345	-0.131
9.5729	5	3.256	0.053	-0.290
9.5729	5.8	3.298	-0.267	-0.481
11.0729	0.2	1.950	0.430	-0.603

X	Y	Vs	Vy	Va
11.0729	1	1.789	0.340	-0.468
11.0729	3	1.978	0.045	-0.466
11.0729	5	2.238	-0.288	-0.477
11.0729	5.8	-1.541	-0.104	-0.425

Test 4

X	Y	Vs	Vy	Va
-0.4271	1	1.948	-0.082	0.091
-0.4271	3	2.173	-0.054	0.120
-0.4271	5	2.156	0.048	0.063
0.0729	1	1.802	-0.262	-0.058
0.0729	3	1.944	-0.302	-0.046
0.0729	5	1.995	-0.348	-0.033
0.5729	1	1.440	-0.186	-0.046
0.5729	3	1.543	-0.147	-0.027
0.5729	5	1.508	0.024	-0.035
3.5729	1	1.310	-0.036	-0.039
3.5729	3	1.352	0.061	-0.045
3.5729	5	1.262	0.017	-0.021
6.5729	1	1.238	-0.067	-0.041
6.5729	3	1.317	-0.020	-0.058
6.5729	5	1.239	-0.004	-0.031
9.5729	1	1.208	-0.008	-0.088
9.5729	3	1.146	0.023	-0.041
9.5729	5	1.201	0.051	-0.047
11.0729	1	1.055	0.010	-0.256
11.0729	3	0.933	0.032	-0.254
11.0729	5	0.945	-0.024	-0.264

Test 5

X	Y	Vs	Vy	Va
-0.4271	1	3.059	-0.241	-0.030
-0.4271	3	3.212	-0.278	-0.015
-0.4271	5	3.013	-0.208	-0.036
0.0729	1	2.944	-0.251	-0.113
0.0729	3	3.048	-0.232	-0.158
0.0729	5	2.992	-0.142	-0.069
0.5729	1	2.874	-0.173	-0.068
0.5729	3	3.095	-0.200	-0.076
0.5729	5	2.852	-0.112	-0.062
3.5729	1	2.265	-0.098	-0.048
3.5729	3	2.430	-0.140	-0.039
3.5729	5	2.259	-0.090	-0.068
6.5729	1	1.849	-0.094	-0.050
6.5729	3	2.055	-0.020	-0.033
6.5729	5	1.780	-0.086	-0.058

X	Y	Vs	Vy	Va
9.5729	1	1.719	-0.119	-0.031
9.5729	3	1.913	-0.028	-0.071
9.5729	5	1.858	-0.021	-0.060
11.0729	1	1.364	0.012	-0.210
11.0729	3	1.494	-0.022	-0.221
11.0729	5	1.408	-0.015	-0.308

Test 6

X	Y	Vs	Vy	Va
-0.4271	1	2.898	-0.180	-0.062
-0.4271	3	2.928	-0.199	-0.057
-0.4271	5	2.820	-0.227	-0.035
0.0729	1	2.816	-0.174	-0.060
0.0729	3	2.918	-0.213	-0.059
0.0729	5	2.733	-0.089	-0.057
0.5729	1	2.758	-0.125	-0.079
0.5729	3	2.798	-0.169	-0.040
0.5729	5	2.725	-0.064	-0.060
3.5729	1	2.193	-0.137	-0.070
3.5729	3	2.291	-0.185	-0.077
3.5729	5	2.235	-0.061	-0.057
6.5729	1	1.901	-0.071	-0.054
6.5729	3	1.925	-0.175	-0.064
6.5729	5	1.887	-0.057	-0.080
9.5729	1	1.643	-0.141	-0.032
9.5729	3	1.788	-0.155	-0.066
9.5729	5	1.417	-0.140	0.067
11.0729	1	1.805	-0.132	0.268
11.0729	3	1.793	-0.109	0.242
11.0729	5	1.874	-0.224	0.290

Test 7

X	Y	Vs	Vy	Va
-0.4271	0.2	5.157	0.085	-0.131
-0.4271	1	4.985	-0.074	-0.091
-0.4271	3	4.891	0.074	-0.124
-0.4271	5	4.134	0.007	-0.111
-0.4271	5.8	4.169	-0.050	-0.098
0.0729	0.2	5.078	0.236	-0.204
0.0729	1	4.907	-0.186	-0.187
0.0729	3	5.016	0.078	-0.312
0.0729	5	4.415	0.241	-0.260
0.0729	5.8	4.420	-0.021	-0.227
0.5729	0.2	5.110	0.122	-0.173
0.5729	1	4.920	-0.079	-0.152
0.5729	3	5.046	0.103	-0.203

X	Y	Vs	Vy	Va
0.5729	5	4.607	0.010	-0.189
0.5729	5.8	4.553	-0.004	-0.112
3.5729	0.2	4.504	0.135	-0.312
3.5729	1	4.092	0.081	-0.175
3.5729	3	4.295	0.256	-0.245
3.5729	5	4.052	0.117	-0.229
3.5729	5.8	4.116	-0.028	-0.274
6.5729	0.2	4.111	0.076	-0.181
6.5729	1	3.523	0.110	-0.176
6.5729	3	3.698	0.233	-0.193
6.5729	5	3.680	0.286	-0.184
6.5729	5.8	3.964	0.149	-0.274
9.5729	0.2	3.908	0.102	-0.239
9.5729	1	2.999	0.071	-0.099
9.5729	3	3.007	0.345	-0.131
9.5729	5	3.256	0.053	-0.290
9.5729	5.8	3.298	-0.267	-0.481
11.0729	0.2	1.950	0.430	-0.603
11.0729	1	1.789	0.340	-0.468
11.0729	3	1.978	0.045	-0.466
11.0729	5	2.238	-0.288	-0.477
11.0729	5.8	-1.541	-0.104	-0.425

Test 8

X	Y	Vs	Vy	Va
-4.4271	0.2	3.265	0.198	0.131
-4.4271	1.0	3.453	0.091	0.204
-4.4271	3.0	3.860	0.099	0.243
-4.4271	5.0	3.720	0.329	0.199
-4.4271	5.8	3.712	0.136	0.211
-2.4271	0.2	4.422	0.239	-0.186
-2.4271	1.0	4.591	0.126	-0.126
-2.4271	3.0	4.849	0.148	-0.100
-2.4271	5.0	4.759	0.264	-0.146
-2.4271	5.8	4.628	0.169	-0.113
-0.4271	0.2	4.871	0.176	-0.142
-0.4271	1.0	4.946	0.163	-0.110
-0.4271	3.0	5.126	0.031	-0.048
-0.4271	5.0	5.064	0.260	-0.132
-0.4271	5.8	5.029	-0.051	-0.092
0.0729	0.2	4.908	0.245	-0.271
0.0729	1.0	4.960	0.169	-0.234
0.0729	3.0	5.162	0.130	-0.226
0.0729	5.0	5.211	0.321	-0.280
0.0729	5.8	5.102	0.071	-0.224
0.5729	0.2	4.986	0.185	-0.183
0.5729	1.0	4.936	0.122	-0.156

X	Y	Vs	Vy	Va
0.5729	3.0	5.117	0.129	-0.163
0.5729	5.0	5.208	0.284	-0.226
0.5729	5.8	5.188	0.018	-0.182
3.5729	0.2	4.539	0.132	-0.302
3.5729	1.0	4.006	0.180	-0.185
3.5729	3.0	4.439	0.134	-0.074
3.5729	5.0	4.512	0.312	-0.156
3.5729	5.8	4.944	0.145	-0.240
6.5729	0.2	4.016	0.243	-0.181
6.5729	1.0	3.753	0.174	-0.151
6.5729	3.0	3.754	0.183	-0.072
6.5729	5.0	4.365	0.152	-0.129
6.5729	5.8	4.785	0.213	-0.187
9.5729	0.2	-0.696	0.136	-0.596
9.5729	1.0	2.907	0.973	-0.746
9.5729	3.0	3.325	0.605	-0.329
9.5729	5.0	4.044	0.215	-0.317
9.5729	5.8	4.510	0.068	-0.435
11.0729	0.2	-1.618	-0.119	-0.292
11.0729	1.0	-0.573	-0.368	-0.344
11.0729	3.0	2.989	1.170	-0.507
11.0729	5.0	2.748	0.328	-0.771
11.0729	5.8	0.614	-0.067	-0.936
12.5729	0.2	-1.902	-0.244	0.112
12.5729	1.0	-0.665	-0.586	0.087
12.5729	3.0	3.273	0.790	-0.071
12.5729	5.0	2.886	0.447	-0.062
12.5729	5.8	1.560	0.340	-0.070

Converging Side wall with 2.54-ft-wide Bypass Opening

Test 9

X	Y	Vs	Vy	Va
-4.427	0.2	2.272	-0.054	0.147
-4.427	1	2.276	-0.230	0.165
-4.427	3	2.275	-0.147	0.241
-4.427	5	2.409	-0.026	0.190
-4.427	5.8	2.264	-0.003	0.156
-2.427	0.2	2.308	-0.086	-0.098
-2.427	1	2.408	0.020	-0.040
-2.427	3	2.595	-0.211	0.020
-2.427	5	2.733	-0.062	0.016
-2.427	5.8	2.592	-0.093	0.061
-0.427	0.2	2.913	-0.050	-0.028
-0.427	1	3.037	-0.231	-0.027

X	Y	Vs	Vy	Va
-0.427	3	3.026	-0.324	-0.023
-0.427	5	2.747	-0.537	0.004
-0.427	5.7	2.065	-0.568	-0.029
0.073	0.2	3.120	-0.068	0.506
0.073	1	2.722	-0.148	-0.050
0.073	2.9	3.121	-0.335	-0.056
0.073	4.8	2.922	-0.373	-0.125
0.073	5.5	2.655	-0.704	-0.132
0.573	0.2	2.600	0.144	0.107
0.573	1	2.253	-0.068	0.275
0.573	2.5	3.234	-0.277	0.652
0.573	3.8	3.364	-0.354	0.683
0.573	5.2	3.192	-0.647	0.421
3.573	0.2	2.725	0.000	-0.149
3.573	1	2.670	-0.192	-0.142
3.573	3	2.819	-0.279	-0.180
3.573	3.8	2.865	-0.428	-0.195
3.573	4.55	2.878	-0.677	-0.188
6.573	0.2	2.509	-0.005	-0.170
6.573	1	2.381	-0.126	-0.131
6.573	2.4	2.623	-0.304	-0.152
6.573	3	2.981	-0.530	-0.176
6.573	3.8	2.838	-0.761	-0.149
9.573	0.2	2.509	0.022	-0.224
9.573	1	2.137	-0.110	-0.166
9.573	2.3	2.896	-0.486	-0.165
9.573	2.9	2.975	-0.664	-0.221
11.073	0.2	0.681	-0.031	-0.330
11.073	1	1.735	0.022	-0.340
12.573	2.3	1.981	-0.175	-0.033

Test 10

X	Y	Vs	Vy	Va
-4	0.2	2.847	0.013	0.107
-4	1	2.856	0.116	0.136
-4	3	2.626	0.009	0.129
-4	5	2.462	-0.034	0.066
-4	5.8	2.460	0.048	0.100
-2	0.2	2.920	0.029	-0.042
-2	1	2.923	0.031	-0.040
-2	3	2.718	-0.131	-0.001
-2	5	2.458	-0.062	-0.016
-2	5.8	2.352	0.029	0.012
-1	0.2	2.974	0.037	-0.038
-1	1	2.944	0.034	-0.031
-1	3	2.781	-0.174	-0.037
-1	5	2.512	-0.277	-0.041

X	Y	Vs	Vy	Va
-1	5.8	2.134	-0.256	-0.029
0	0.2	3.038	0.021	-0.037
0	1	3.056	0.027	-0.011
0	3	2.876	-0.257	-0.025
0	5	2.493	-0.431	-0.105
0	5.6	2.696	-0.539	-0.182
1	0.2	2.942	0.015	-0.079
1	1	2.845	0.045	-0.058
1	3	2.816	-0.235	-0.041
1	5	2.837	-0.482	-0.143
1	5.3	2.802	-0.556	-0.161
2	0.2	2.963	0.032	-0.103
2	1	2.759	0.012	-0.069
2	3	2.597	-0.229	-0.096
2	5	2.777	-0.569	-0.159
3	0.2	2.832	0.006	-0.139
3	1	2.552	-0.006	-0.110
3	3	2.237	-0.196	-0.089
3	4.7	2.745	-0.566	-0.167
4	0.2	2.744	0.030	-0.111
4	1	2.364	0.021	-0.057
4	3	2.435	-0.227	-0.067
4	4.5	2.804	-0.606	-0.099
5	0.2	2.611	0.035	-0.107
5	1	2.406	-0.005	-0.089
5	3	2.548	-0.274	-0.121
5	4.2	2.844	-0.594	-0.157
6	0.2	2.462	-0.043	-0.130
6	1	2.125	-0.002	-0.064
6	3	2.689	-0.415	-0.137
6	4	2.698	-0.540	-0.100
7	0.2	2.306	0.074	-0.148
7	1	1.894	0.022	-0.066
7	3	2.745	-0.471	-0.136
7	3.7	2.787	-0.593	-0.200
8	0.2	2.398	-0.040	-0.152
8	1	1.801	-0.024	-0.018
8	3	2.537	-0.507	-0.090
8	3.4	2.572	-0.553	-0.110
9	0.2	2.541	-0.003	-0.144
9	1	1.981	-0.059	-0.055
9	3	2.875	-0.639	-0.186
10	0.2	2.386	0.080	-0.127
10	1	1.983	-0.137	-0.053
10	2.9	2.816	-0.644	-0.212
11	0.2	2.295	0.042	-0.134
11	1	1.894	-0.206	-0.069
11	2.6	2.785	-0.554	-0.161

X	Y	Vs	Vy	Va
12	0.2	2.460	-0.040	-0.062
12	1	2.239	-0.198	-0.020
12	2.2	3.126	-0.601	-0.118
13	0.2	3.223	-0.001	-0.057
13	1	3.169	-0.057	0.003

Test 11

X	Y	Vs	Vy	Va
-4.00	0.2	3.133	0.048	-0.018
-4.00	1	3.076	0.021	-0.015
-4.00	3	2.864	-0.228	-0.031
-4.00	5	2.608	-0.250	-0.048
-4.00	5.8	2.188	-0.305	-0.030
-2.00	0.2	2.969	0.043	-0.057
-2.00	1	2.978	0.048	-0.059
-2.00	3	2.808	-0.117	-0.022
-2.00	5	2.565	-0.126	-0.026
-2.00	5.8	2.443	0.037	0.024
-1.00	0.2	2.856	0.015	0.095
-1.00	1	2.935	0.135	0.134
-1.00	3	2.664	0.009	0.123
-1.00	5	2.533	-0.008	0.052
-1.00	5.8	2.540	0.090	0.114
1.00	0.2	3.136	0.042	0.015
1.00	1	2.936	0.055	0.007
1.00	3	2.938	-0.244	-0.034
1.00	5	3.010	-0.505	-0.128
1.00	5.3	2.929	-0.578	-0.154
3.00	0.2	2.908	-0.037	-0.072
3.00	1	2.809	0.023	-0.064
3.00	3	2.631	-0.208	-0.048
3.00	4.7	2.872	-0.408	-0.151
5.00	0.2	2.685	0.175	-0.102
5.00	1	2.115	0.015	-0.051
5.00	3	2.830	-0.324	-0.123
5.00	4.2	2.733	-0.758	-0.150
7.00	0.2	2.386	0.194	-0.150
7.00	1	2.014	0.007	-0.063
7.00	3	2.672	-0.288	-0.148
7.00	3.7	3.035	-0.597	-0.209
9.00	0.2	2.676	0.146	-0.138
9.00	1	2.055	-0.003	-0.087
9.00	3	3.016	-0.617	-0.189
11.00	0.2	1.963	0.413	-0.202
11.00	1	1.809	-0.077	-0.186
11.00	2.6	2.771	-0.603	-0.210
12.00	0.2	1.086	-0.064	-0.120

X	Y	Vs	Vy	Va
12.00	1	1.078	-0.046	-0.117
12.00	2.2	2.325	-0.267	-0.087
13.00	0.2	1.406	-0.132	0.041
13.00	1	1.473	-0.051	0.006
13.00	2.2	2.365	-0.046	0.003
6.00	3	2.689	-0.415	-0.137
6.00	4	2.698	-0.540	-0.100
7.00	0.2	2.306	0.074	-0.148
7.00	1	1.894	0.022	-0.066
7.00	3	2.745	-0.471	-0.136
7.00	3.7	2.787	-0.593	-0.200
8.00	0.2	2.398	-0.040	-0.152
8.00	1	1.801	-0.024	-0.018
8.00	3	2.537	-0.507	-0.090
8.00	3.4	2.572	-0.553	-0.110
9.00	0.2	2.541	-0.003	-0.144
9.00	1	1.981	-0.059	-0.055
9.00	3	2.875	-0.639	-0.186
10.00	0.2	2.386	0.080	-0.127
10.00	1	1.983	-0.137	-0.053
10.00	2.9	2.816	-0.644	-0.212
11.00	0.2	2.295	0.042	-0.134
11.00	1	1.894	-0.206	-0.069
11.00	2.6	2.785	-0.554	-0.161
12.00	0.2	2.460	-0.040	-0.062
12.00	1	2.239	-0.198	-0.020
12.00	2.2	3.126	-0.601	-0.118
13.00	0.2	3.223	-0.001	-0.057
13.00	1	3.169	-0.057	0.003

Test 12

X	Y	Vs	Vy	Va
-4.0	0.2	2.957	-0.332	0.174
-4.0	1.0	2.958	-0.224	0.246
-4.0	3.0	2.637	-0.444	0.192
-4.0	5.0	2.487	-0.377	0.127
-4.0	5.8	2.495	-0.240	0.157
-2.0	0.2	2.949	-0.339	-0.014
-2.0	1.0	2.885	-0.292	0.030
-2.0	3.0	2.636	-0.512	0.019
-2.0	5.0	2.425	-0.418	0.010
-2.0	5.8	2.336	-0.314	0.031
-1.0	0.2	3.011	-0.380	-0.034
-1.0	1.0	2.947	-0.147	-0.011
-1.0	3.0	2.737	-0.437	-0.033
-1.0	5.0	2.479	-0.444	-0.043
-1.0	5.8	2.097	-0.422	-0.021

X	Y	Vs	Vy	Va
1.0	0.2	2.736	-0.135	-0.111
1.0	1.0	2.748	-0.107	-0.064
1.0	3.0	2.547	-0.372	-0.117
1.0	5.0	2.759	-0.585	-0.226
1.0	5.3	2.699	-0.694	-0.253
3.0	0.2	2.530	0.064	-0.079
3.0	1.0	2.640	0.014	-0.090
3.0	3.0	2.547	-0.323	-0.097
3.0	4.7	2.630	-0.519	-0.234
5.0	0.2	2.764	-0.001	-0.117
5.0	1.0	2.420	-0.048	-0.066
5.0	3.0	2.739	-0.432	-0.145
5.0	4.2	2.600	-0.424	-0.158
7.0	0.2	2.463	0.073	-0.157
7.0	1.0	1.994	-0.039	-0.044
7.0	3.0	2.728	-0.347	-0.155
7.0	3.7	2.676	-0.530	-0.254
9.0	0.2	1.972	0.253	-0.306
9.0	1.0	1.979	0.009	-0.220
9.0	3.0	2.696	-0.536	-0.280
11.0	0.2	0.216	0.139	-0.345
11.0	1.0	1.654	0.088	-0.392
11.0	2.6	2.017	-0.183	-0.435
12.0	0.2	-0.215	-0.337	-0.034
12.0	1.0	1.290	-0.076	-0.106
12.0	2.2	1.569	-0.136	-0.128
13.0	0.2	0.115	-0.104	0.020
13.0	1.0	1.391	-0.310	0.016
13.0	2.2	1.548	-0.063	0.007

Test 13

X	Y	Vs	Vy	Va
-4.00	0.2	3.598	-0.366	0.198
-4.00	1	3.683	-0.406	0.280
-4.00	3	3.798	-0.456	0.297
-4.00	5	3.588	-0.364	0.151
-4.00	5.8	3.562	-0.243	0.259
-2.00	0.2	3.825	-0.361	-0.021
-2.00	1	3.938	-0.393	0.039
-2.00	3	3.898	-0.630	0.091
-2.00	5	3.413	-0.545	-0.020
-2.00	5.8	3.298	-0.299	0.088
-1.00	0.2	3.912	-0.434	-0.069
-1.00	1	3.973	-0.498	-0.032
-1.00	3	3.869	-0.778	-0.006
-1.00	5	3.533	-0.782	-0.071
-1.00	5.8	2.884	-0.709	0.000

X	Y	Vs	Vy	Va
1.00	0.2	4.427	0.133	-0.113
1.00	1	4.558	-0.104	-0.157
1.00	3	4.541	-0.438	-0.120
1.00	5	4.661	-0.580	-0.369
1.00	5.3	4.410	-0.879	-0.363
3.00	0.2	4.398	0.173	-0.187
3.00	1	4.618	-0.069	-0.195
3.00	3	4.275	-0.334	-0.156
3.00	4.7	4.224	-0.592	-0.365
5.00	0.2	4.360	0.025	-0.113
5.00	1	4.685	-0.022	-0.113
5.00	3	4.659	-0.624	-0.226
5.00	4.2	4.083	-0.438	-0.227
7.00	0.2	4.138	-0.747	-0.268
7.00	1	4.144	-0.065	-0.212
7.00	3	4.451	-0.719	-0.297
7.00	3.7	4.375	-0.808	-0.384
9.00	0.2	4.399	-0.700	-0.212
9.00	1	4.101	-0.903	-0.262
9.00	3	4.249	-1.349	-0.396
11.00	0.2	3.347	0.340	-0.428
11.00	1	3.724	-0.159	-0.435
11.00	2.6	4.129	-0.721	-0.391
12.00	0.2	2.028	-0.188	-0.220
12.00	1	2.607	0.114	-0.198
12.00	2.2	3.127	-0.108	-0.165
13.00	0.2	2.640	-0.122	0.051
13.00	1	3.154	-0.036	0.030
13.00	2.2	3.367	0.001	0.022

Test 14

X	Y	Vs	Vy	Va
-4.00	0.2	3.104	-0.010	0.154
-4.00	1	3.070	-0.025	0.177
-4.00	3	3.246	-0.031	0.187
-4.00	5	3.174	0.126	0.159
-4.00	5.8	3.046	0.096	0.178
-2.00	0.2	3.196	-0.001	-0.020
-2.00	1	3.262	-0.006	-0.020
-2.00	3	3.301	-0.152	0.023
-2.00	5	3.027	0.008	0.011
-2.00	5.8	2.835	0.038	0.030
-1.00	0.2	3.397	0.032	-0.033
-1.00	1	3.472	0.007	-0.036
-1.00	3	3.537	-0.244	-0.007
-1.00	5	3.042	-0.187	-0.013
-1.00	5.8	2.462	-0.281	0.003

X	Y	Vs	Vy	Va
1.00	0.2	2.909	0.181	-0.084
1.00	1	3.240	0.033	-0.122
1.00	3	3.366	-0.167	-0.056
1.00	5	3.485	-0.576	-0.205
1.00	5.3	3.368	-0.563	-0.221
3.00	0.2	3.155	0.067	-0.129
3.00	1	3.267	-0.002	-0.127
3.00	3	3.276	-0.318	-0.130
3.00	4.7	3.001	-0.470	-0.196
5.00	0.2	2.946	0.035	-0.113
5.00	1	2.996	-0.026	-0.139
5.00	3	3.467	-0.518	-0.179
5.00	4.2	3.310	-0.566	-0.176
7.00	0.2	2.828	-0.056	-0.173
7.00	1	2.488	-0.151	-0.103
7.00	3	3.253	-0.367	-0.172
7.00	3.7	3.067	-0.408	-0.243
9.00	0.2	1.832	0.254	-0.345
9.00	1	2.478	0.211	-0.421
9.00	3	2.967	-0.424	-0.348
11.00	0.2	-0.355	0.053	-0.197
11.00	1	2.317	0.175	-0.378
11.00	2.6	2.356	-0.365	-0.577
12.00	0.2	-0.018	-0.549	-0.057
12.00	1	1.957	-0.363	-0.005
12.00	2.2	1.846	-0.157	-0.148
13.00	0.2	-0.223	-0.042	0.074
13.00	1	1.782	-0.589	0.057
13.00	2.2	1.925	-0.152	0.000

Test 15

X	Y	Vs	Vy	Va
-2	1	3.560	-0.025	0.026
1	1	4.561	-0.003	-0.137
3	1	4.396	0.072	-0.123
5	1	4.335	-0.057	-0.121
7	1	4.001	-0.098	-0.196
9	1	3.671	-0.282	-0.196
11	1	3.884	-0.344	-0.226
12	1	3.692	-0.336	-0.020
13	1	3.558	-0.061	-0.036

Converging Wall with 1-ft-wide Bypass Entrance

Test 16

X	Vs	Vy	Va
-4	2.655	-0.024	0.113
-2	4.201	-0.082	0.012
-1	3.454	-0.065	-0.078
0	3.398	-0.022	-0.073
1	3.352	0.096	-0.010
3	3.269	-0.086	-0.135
5	3.374	0.040	-0.184
7	3.295	-0.504	-0.271
9	3.382	-0.342	-0.296
10	3.136	-0.523	-0.314
11	2.998	-0.504	-0.294

Test 17

X distance (ft)	Vs	Vy	Va
-2	3.2365	-0.0231	0.0103
0	3.6254	-0.0447	0.0335
2	3.0673	-0.0458	-0.0847
4	2.7194	-0.1154	-0.0465
6	2.7903	-0.1694	-0.1365
8	2.7733	-0.2012	-0.0978
10	2.901	-0.3217	-0.2906
11	2.9947	-0.4747	-0.2701

Test 18

X Distance (ft)	Vs	Vy	Va
-2	4.4118	-0.0619	-0.0165
0	4.3276	-0.0555	-0.0006
2	3.9688	-0.0022	-0.1117
4	3.3786	-0.0721	-0.0633
6	3.5456	-0.1454	-0.1506
8	3.4904	-0.2494	-0.1771
10	3.6902	-0.2639	-0.3269
11	3.5782	-0.3731	-0.3825

Test 19

X	Vs	Vy	Va
-2	3.354	-0.1286	-0.0204
0	3.144	-0.167	0.0001
1	2.9758	-0.1962	-0.1375
3	2.6868	-0.1663	-0.0984
5	2.9937	-0.2155	-0.2466
7	2.7179	-0.2205	-0.1472

X	Vs	Vy	Va
9	2.9123	-0.2442	-0.3532
11	3.0562	-0.3474	-0.2561
11.25	3.2229	-0.3886	-0.2118
11.5	3.4039	-0.3942	0.041

Test 20

X	Vs	Vy	Va
-2	2.193	-0.046	-0.044
0	2.110	-0.109	-0.031
2	1.914	-0.002	-0.079
4	1.699	-0.021	-0.056
6	1.737	-0.093	-0.112
8	1.807	-0.083	-0.080
10	1.841	-0.131	-0.136
11	2.078	-0.269	-0.142
11.5	2.340	-0.306	-0.012
11.75	2.845	-0.379	0.383

Test 21

X	Vs	Vy	Va
-2	1.453	0.009	-0.014
0	1.400	-0.074	-0.003
2	1.378	-0.058	-0.064
4	1.337	-0.082	-0.056
6	1.351	-0.044	-0.103
8	1.318	-0.155	-0.071
10	1.530	-0.150	-0.090
11	1.731	-0.209	0.125
11.5	1.769	-0.458	0.457
11.75	2.048	-0.475	0.601

Appendix E - Beyers, D.W. and Bestgen, K.R, 2002, Bull Trout Performance in a Horizontal Flat Plate Screen: U.S Bureau of Reclamation

Bull Trout Performance During Passage Over a Horizontal Flat Plate Screen

Final Report

20 July 2002

Larval Fish Laboratory Contribution Number 128

Bull Trout Performance in a Horizontal Flat Plate Screen

Final Report to:

Brent Mefford and Kathy Frizell

U. S. Bureau of Reclamation
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20 July 2002

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Executive Summary

This investigation was conducted to the describe effects of passage of bull trout Salvelinus confluentus over a horizontal flat plate screen. Experimental releases were conducted with three sizes of bull trout that averaged 28, 37, and 58 mm total length (TL). Fish were released individually and in batches to: (1) describe general behavior near and on the screen; (2) estimate physical condition and survival of fish after passage; and (3) estimate entrainment and impingement rates.

Consistent negative effects from passage of bull trout over a horizontal flat plate screen were not observed. Potential entrainment was ≤ 3.5% for 28-mm fish, and was never observed for larger fish. Impingement never occurred. Passage times increased with fish size and ranged from 4 sec to more than 10 min. Physical damage to eyes, fins, and integument was either rare (eyes) or less frequent in fish that passed over the screen than in control fish. Fish that passed over the screen did contact the bottom more frequently than control fish, but no immediate mortality occurred from screen passage. Survival at 24 h was ≤ 1.5% lower for fish that passed over the screen compared to controls. At 96 h after passage, survival was reduced, but was not consistently lower for fish that passed over the screen compared to controls. Thus, physical effects of screen passage were at, or near the level of background effects induced by fish culture, handling, transport, and testing.

Water depth and orientation of bull trout changed with fish size and age despite the use of a standardized release methodology. Larger fish were more frequently observed near the bottom and more frequently oriented upstream than smaller fish. The tendency to occupy deeper water

increased the likelihood that fish contacted the horizontal flat plate screen. It also increased the likelihood that fish discovered attractive hydraulic properties of the screen. We observed several 58-mm fish that appeared to be maintaining position by using downward pressure generated by water approaching the screen. This behavior was the main factor responsible for increased passage time for larger fish. Thus, we did observe that certain hydraulic conditions of the horizontal flat plate screen used in this investigation attracted fish and delayed their movement over the screen.

Introduction

Bull trout Salvelinus confluentus is an endangered char that occurs in cool-water streams in northwestern North America (Lee et al. 1980). Presence of water diversion structures for irrigation in that area have the potential to influence movement and survival of bull trout. Horizontal flat plate screens are potentially useful to reduce negative effects of diversion structures on bull trout because rate of horizontal movement of water across the screen (sweeping velocity) is higher than the rate of movement of water through the screen (approach velocity). This characteristic enhances self cleaning and reduces the likelihood of impingement and entrainment of organisms. An evaluation of hydraulic characteristics and operation of horizontal flat plate screens was conducted with a working model constructed at the U.S. Bureau of Reclamation, Water Resources Research Laboratory, Denver, Colorado (Figure 1). A detailed description of the model is available (Frizell and Mefford 2001) and it is useful for establishing design criteria for horizontal flat plate screens deployed in the field.

Another important aspect of development of design criteria for horizontal flat plate screens is an evaluation of potential effects on resident fish. During passage through screened structures, fish may become impinged on the screen or entrained into diversions. Fish may also avoid or be attracted to physical or hydraulic characteristics of screened structures which can influence natural movement and migration. To investigate the potential effects of passage on

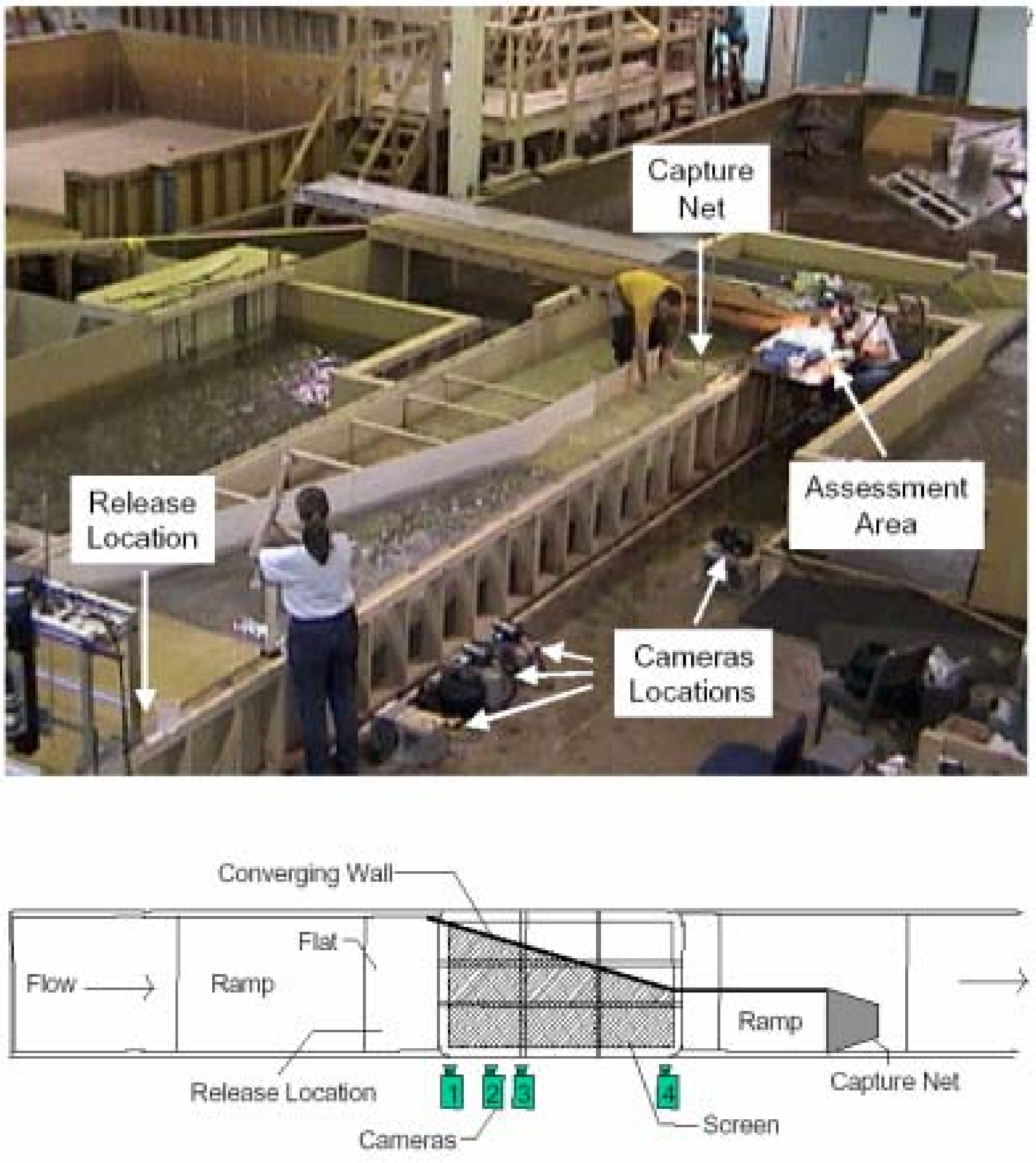

Figure 1. Picture and plan view of horizontal flat plate screen testing area.

bull trout, we conducted experimental releases with three early life stages of bull trout using the model horizontal flat plate screen at the Water Resources Research Laboratory. Fish were released individually and in batches to address three study objectives: (1) describe general behavior of fish near and on the screen; (2) estimate physical condition and survival of fish after passage over the screen; and (3) estimate entrainment and impingement rates of bull trout. Results describe bull trout behavior and effects of passage at two sweeping velocities.

Materials and Methods

Horizontal Flat Plate Screen and Testing Characteristics

The horizontal flat plate screen was 1.8×3.6-m-long with 2.4-mm (3/32 inch) perforations. The screen had a vertical 15° converging wall on one side and a vertical transparent plexiglass wall on the other side (Figure 1). The bypass entrance was 0.744-m-wide. Water for the screen was recirculated by a pump from an underground reservoir. Discharge rates were manipulated to produce the two sweeping velocities studied in this investigation: 0.6 m/s (2 ft/s) or 1.2 m/s (4 ft/s). Flow conditions over the screen were subcritical at 0.6 m/s and supercritical at 1.2 m/s. Water depth under both conditions was 13 cm. Descriptions of corresponding approach velocities and testing conditions are summarized in Table 1 and detailed elsewhere (Frizell and Mefford 2001).

Fish movements during passage over the screen were recorded using four video cameras (Figure 1). Cameras 1, 2, and 3 were positioned sequentially at the upstream end of the screen and camera 4 was positioned at the downstream end of the screen. Collectively, video cameras recorded fish passage over one-half (1.8 m) of the screen.

Fish were introduced onto the screen using release tubes constructed of 19- or 38-mm (inside diameter) PVC pipe. The 19-mm diameter release tube was used for the smallest life stage studied; the 38-mm, for the other two life stages. In preparation for a release, fish and holding water were transferred to a release tube and a rubber stopper prevented fish from escaping. The release tube was positioned on the floor of the screen structure, at the beginning of the flat, 1.2 m upstream of the screen and 0.3 m from the plexiglass wall. A release was accomplished by removing the rubber stopper and opening a valve that allowed water and fish to exit the tube. The release tube was designed so that fish emerged from the screen near the bottom of the water column, oriented in an upstream direction.

After a release, fish were recaptured using a drift net mounted 2.4 m downstream of the screen. Dimensions of the 363-μm mesh net were 40 × 80 × 86-cm long. The net sampled the entire bypass discharge from the screen. Following capture, the cod end of the net was opened and fish were rinsed into a pan for assessment.

Fish Culture, Acclimation, and Handling

Bull trout embryos were obtained from Creston National Fish Hatchery (Kalispell, Montana) and cultured at the Aquatic Research Laboratory, Colorado State University. Embryos were maintained at 4 to 6°C in a Heath incubator until hatching was complete. After hatching, larvae were transferred to fiberglass culture troughs for rearing at a water temperature of 10°C. Fish were fed a commercially prepared diet (BioDiet, Bio-Oregon, Inc., Warrenton, OR).

Table 1. Summary of discharge (m3/sec) and velocity (m/sec) conditions over a horizontal flat plate screen at two sweeping velocities.

Condition	Q_c	Q_d	Q_b	V_s	V_a	Depth (m)
0.6 m/sec treatment	0.19	0.11	0.08	0.6	0.15	0.13
0.6 m/sec control	0.06	0	0.06	0.6	NA	0.13
1.2 m/sec treatment	0.32	0.2	0.12	1.2	0.15	0.13
1.2 m/sec control	0.12	0	0.12	1.2	NA	0.13

NA = not applicable.
Q_c; channel discharge; Q_d; diversion discharge; Q_b; bypass discharge; V_s; sweeping velocity; V_a; approach velocity.

In preparation for testing at the Water Resources Research Laboratory, culture water temperature was increased to 14°C 10 days before the first fish release trials were conducted so that fish were acclimated to testing conditions. Throughout the investigation, water temperature at the Water Resources Research Laboratory ranged from 13.5 to 16.5°C and culture temperatures were manipulated to match test temperatures within ± 1°C.

During thermal acclimation, fish were also exposed to a constant water current by directing the flow of water into the culture trough. This provided a range of velocities within the culture trough and allowed fish to select preferred conditions. By positioning the automatic feeder near the water inlet, fish were forced to encounter relatively high velocities.

On the day of testing, 10 to 25 fish were placed in 4-L resealable bags containing about 1.5 L of water and oxygen-filled head space. Bags were transported to the Water Resources Research Laboratory and held in insulated coolers until selected for a test. Dissolved oxygen concentrations in bags were checked occasionally and were always > 6.0 mg/L.

Three bull trout life stages were investigated including: (1) swim-up larvae approximately the same age and size of young bull trout at the time they emerge from spawning redds in a stream, (2) a later larval stage, and (3) juveniles. Bull trout in each group were 67, 108, and 145 day old (after hatching) and had average total lengths of 28, 37, and 58 mm, respectively (Table 2).

Table 2. Summary of bull trout total lengths (mm) for three life stages studied.

Life Stage	Mean	Standard Error	Minimum	Maximum	*n*
First	27.8	0.204	23.9	32.2	98
Second	36.9	0.351	28.1	46.5	100
Third	58.0	0.409	49.8	69.1	100

Individual Releases

Releases of individual fish were used to estimate the effects of passage on physical condition, passage times, and impingement and entrainment. Twenty-five fish of each life stage were released at both sweeping velocities. Each fish was independently released and captured. Passage times were measured starting with release and ending when fish crossed the downstream edge of the screen. A maximum of 120 s was allowed for fish to exit the screen voluntarily. Fish that remained on the screen for longer than 120 sec were swept into the current and into the capture net by observers. Following capture, each fish was rinsed into a pan, anesthetized (200 mg/L tricaine methanesulfonate), and physical condition was assessed using a binocular microscope at 10X magnification. An *a priori* set of criteria were used to consistently evaluate evidence of physical damage to fish from passage. Measurements collected, and criteria used for each individual were: (1) elapsed time to pass over the screen; (2) survival: yes, no; (3) total length; (4) eyes: normal, abraded, exophthalmic, hemorrhagic, missing; (5) caudal, dorsal, right and left pectoral fins: normal, frayed, trace fin split (≤10%), fin split (.10%), broken fin rays, (one or more rays disrupted into fragments attached by intervening fin tissue), missing; (6) integument: normal, abraded, bruised, cut; and (7) scales: normal, scattered descaling (<20% per side of fish), severe descaling. After assessment, each fish was preserved in 10% formalin.

Because physical damage may arise from handling, transport, release, and capture, a control group of fish was similarly assessed. Control conditions were created by installing a transparent plexiglass sheet over the screen and releasing fish at both sweeping velocities using identical methodology. The plexiglass did not change the appearance of the screen which may be important for fish orientation but did remove turbulence and approach velocity effects due to the operation of the screen. Control batches allowed the effect of screen passage on survival to be separated from effects caused by other sources.

Batch Releases

Batch releases of fish were used to estimate immediate, 24-, and 96-h survival rates after passage, batch passage times, and potential for impingement and entrainment. Twenty batch releases of 10 fish from each life stage were studied at both sweeping velocities. Batches were released and captured using the same methods described for individuals. Following capture fish were rinsed into a pan where the number of survivors was counted. The live fish were placed into 4-L resealable bags containing about 1.5 L of water and oxygen-filled head space, and transported in insulated coolers to the Aquatic Research Laboratory at Colorado State University. Bags containing fish were transferred to a water bath for 1 hour to allow acclimation to culture conditions (14°C). Batches of fish were then released into separate flow-through aquaria and survival was monitored daily for 96 h. Aquaria were 20 × 40 × 25 cm high, and water depth was about 15 cm. Water temperature was 14°C. Fish were fed once daily during the monitoring period. Cool-white fluorescent lamps were the only source of illumination (530 lx), and a 12:12-h light:dark photoperiod was maintained.

Control batches of fish were also used to assess effects of handling, transport, release, and capture on survival. Control batches were treated similarly to fish released over the screen, except they were released at the downstream end of the screen about 2.4 m from the capture net.

Control fish were not removed from the net until an amount of time equal to the average time required for fish in treatment batches to traverse the screen had elapsed. Control batches allowed the effect of screen passage on survival to be separated from effects caused by other sources.

Video Interpretation

Video recordings of movement of individually release fish were interpreted to quantify several responses including: number of times a fish contacted the screen over the 1.8-m camera observation area; orientation (upstream or downstream) at cameras 1 and 4; and depth in the water column (bottom third, middle third, or top third) at cameras 1 and 4. Fish that were on the surface were difficult to detect during video interpretation, but because fish in the middle and bottom third were easily detected, a depth classification of “top third” was given when a fish was not observed.

Descriptive and Statistical Analysis

In general, descriptive statistics were calculated for the endpoints investigated and summary tables were constructed to facilitate inspection of the data. Because of the number of fins and categories involved in fin assessment, the data were re-classified as normal or non-normal, then the frequency of occurrence of fish with four, three, two, one or no normal fins was calculated.

Survival data were analyzed using the Genmod procedure (options link = logit, dist = binomial, and dscale; SAS Institute 1993). The procedure estimatee mean survival and associated 95% confidence intervals. In several cases, confidence intervals could not be estimated because no mortality was observed in most or all of the replicates. Lack of variation in treatments precluded useful statistical comparisons. Consequently, data were analyzed by inspection. It should be noted that the responses of the same batches of fish were used to estimate survival at 24 and 96 h. Because the same batches were used, there is a lack of independence between 24- and 96-h estimates (e.g., a replicate with 80% survival at 24 h can only have ≤ 80% survival at 96 h). We advocate that because little is known about effects of horizontal flat plate screens on bull trout, this violation of statistical assumptions is relatively unimportant and that the analysis provides valuable insight about the pattern of mortality that may occur after passage.

Results

Entrainment

No incidences of entrainment of fish through the screen were observed for 37- or 58-mm fish. Reliable estimates of entrainment for 28-mm fish were not obtained because unrecovered fish may have been lost via entrainment, through seams in the screen structure, or escaped the capture net. Data suggested that if entrainment occurred, the rate was low because 99.5% of control fish and 96.0% of treatment fish were recovered at the 1.2 m/s sweeping velocity, and 99.0% of control fish and 98% of treatment fish were recovered at the 0.6 m/s sweeping velocity. Thus, potential entrainment was not greater than 3.5% (maximum difference between recovery rates of control and treatment fish) for any of the conditions studied.

Impingement

No incidences of impingement of fish on the screen were observed for fish in the 28- or 37-mm size groups. Some fish in the 58-mm size group were observed on the screen, but observations suggested that the fish were maintaining desired positions by using downward pressure generated by water approaching the screen (Figure 2). Behaviors that suggested fish were attracted to these areas and were not involuntarily impinged included: (1) demonstration of volitional movement (upstream and downstream) at these locations; (2) demonstration of ability to control body position on the screen; and (3) returning to the locations after being disturbed by an observer. Preliminary observations showed that some fish continued this behavior for at least 10 min.

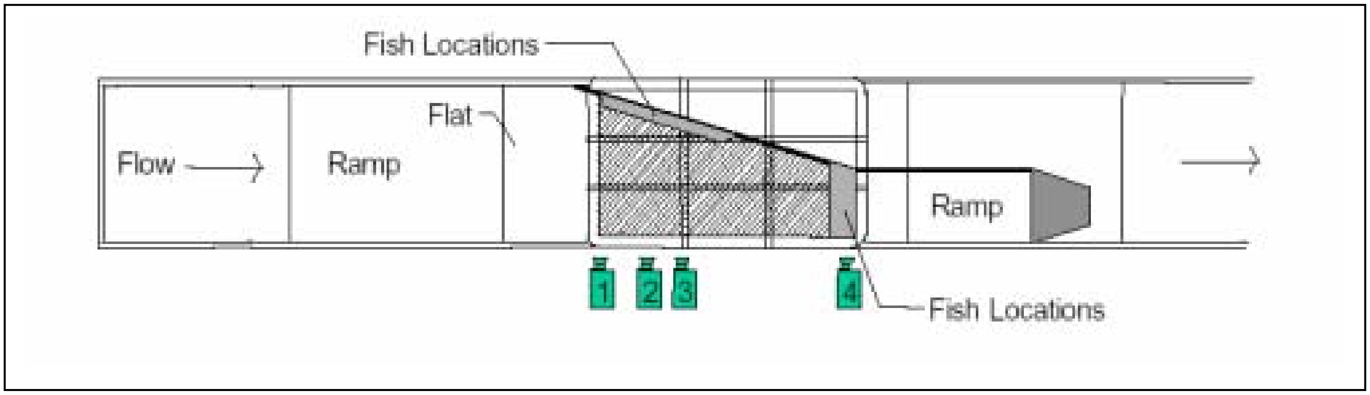

Figure 2. General areas (shaded) on a horizontal flat plate screen occupied by 58-mm bull trout for long periods of time. Downward pressure generated by the approach velocity of water passing through the screen in these areas allowed fish to hold position with relatively little swimming activity.

Passage Times

Average passage times for individual fish ranged from 4 to 17 sec at 1.2 m/sec sweeping velocity and 10 to 61 sec at 0.6 m/sec sweeping velocity (Table 3). Passage times increased with fish size at both sweeping velocities and were generally longer for control fish than for treatment fish.

Average batch passage times ranged from 7 to 45 sec at 1.2 m/sec sweeping velocity and 23 to 120 sec at 0.6 m/sec sweeping velocity (Table 4). Passage times generally increased with fish size at both sweeping velocities. At least one fish in every batch released for the 58-mm, 0.6 m/sec treatment remained over the screen for the maximum time allowed of 120 sec.

Physical Condition After Passage

In general, physical condition of bull trout did not appear to be affected by passage over the screen (Tables 5-10). The effect of passage on condition and coverage of scales was not assessed because the first two life stages did not have scales and very small scales were patchily distributed over the surface of fish in the 58-mm group. Other characteristics were measured as proposed.

Eyes - Only one occurrence of a non-normal (abraded) eye was observed out of 600 fish examined. The single occurrence was for a 58-mm fish (Table 9). Because eye damage was rare, and it was not observed in smaller fish, it is unlikely that the abrasion was caused by screen passage.

Table 3. Summary of elapsed times (sec) for passage of individual bull trout over a horizontal flat plate screen at two sweeping velocities.

Sweeping Velocity = 1.2 m/sec

Treatment	Mean	Standard Error	Minimum	Maximum	*n*
		Life Stage (28 mm)			
Control	10	1.1	5	29	22
Treatment	4	0.2	3	5	22
		Life Stage (37 mm)			
Control	10	0.8	29	46	25
Treatment	5	0.2	4	7.2	20
		Life Stage (58 mm)			
Control	17	2.3	5	54	25
Treatment	10	0.7	5	22	25

Sweeping Velocity = 0.6 m/sec

Treatment	Mean	Standard Error	Minimum	Maximum[a]	*n*
		Life Stage (28 mm)			
Control	13	1.1	5	27	25
Treatment	10	1.0	5	28	23
		Life Stage (37 mm)			
Control	20	1.8	11	54	25
Treatment	12	0.8	7	23	25
		Life Stage (58 mm)			
Control	61	10	9	120	25
Treatment	50	8.0	14	120	25

[a]120 sec was the maximum time allowed.

Table 4. Summary of elapsed times (sec) for passage of batches of 10 bull trout over a horizontal flat plate screen at two sweeping velocities.

Sweeping Velocity = 1.2 m/sec

Life Stage (mm)	Mean	Standard Error	Minimum	Maximum[a]	n[b]
28	7	0.2	6	9	20
37	7	0.4	4	12	20
58	45	6.2	20	120	20

Sweeping Velocity = 0.6 m/sec

Life Stage (mm)	Mean	Standard Error	Minimum	Maximum[a]	n[b]
28	26	1.4	18	47	20
37	23	2.0	17	56	20
58	120	0	120	120	20

[a]120 sec was the maximum time allowed.
[b]n = 20 is equivalent to 20 batches of 10 fish.

Table 5. Summary of condition of 25 28-mm individual bull trout assessed after handling (C) or after passage over a horizontal flat plate screen (T) at a sweeping velocity of 1.2 m/sec.

		Frequency		Percent		Cumulative Percent	
Characteristic	Condition	C	T	C	T	C	T
Eyes	Normal	25	25	100	100	100	100
Fins[a]	4 of 4 normal	2	6	8	24	8	24
	3 of 4 normal	9	5	36	20	44	44
	2 of 4 normal	8	8	32	32	76	76
	1 of 4 normal	4	6	16	24	92	100
	0 of 4 normal	2		8		100	
Integument	Normal	24	25	96	100	96	100
	Abrasion	1		4		100	
	Bruise						
	Cut						
Total contacts[b]	0	91	92	91	92	91	92
	1	8	8	8	8	99	100
	2	1		1		100	
	3						
	4						
	5						
Depth, camera 1	Bottom third	14	12	56	48	56	48
	Middle third	0	5	0	20	56	68
	Top third	11	8	44	32	100	100
Depth, camera 4	Bottom third	8	9	32	36	32	36
	Middle third	0	2	0	8	32	44
	Top third	17	14	68	56	100	100
Orientation, camera 1	Upstream	6	8	43	42	43	42
	Downstream	8	11	57	58	100	100
Orientation, camera 4	Upstream	11	7	79	54	79	54
	Downstream	3	6	21	46	100	100

[a]Number of fins assessed as normal; fins were caudal, dorsal, and right and left pectoral.
[b]A total of 100 observations were possible because four cameras were used for all 25 fish released. Collectively, video cameras recorded potential contacts over 1.8 m of the horizontal flat plate screen.

Table 6. Summary of condition of 25 28-mm individual bull trout assessed after handling C) or after passage over a horizontal flat plate screen (T) at a sweeping velocity of 0.6 m/sec.

Characteristic	Condition	Frequency C	Frequency T	Percent C	Percent T	Cumulative Percent C	Cumulative Percent T
Eyes	Normal	25	25	100	100	100	100
Fins[a]	4 of 4 normal	3	5	12	20	12	20
	3 of 4 normal	6	8	24	32	36	52
	2 of 4 normal	10	8	40	32	76	84
	1 of 4 normal	5	3	20	12	96	96
	0 of 4 normal	1	1	4	4	100	100
Integument	Normal	25	24	100	96	100	96
	Abrasion		1		4	100	100
	Bruise						
	Cut						
Total contacts[b]	0	81	82	81	82	81	82
	1	11	10	11	10	92	92
	2	8	6	8	6	100	98
	3		2		2		100
	4						
	5						
Depth, camera 1	Bottom third	6	13	24	52	24	52
	Middle third	1	2	4	8	28	60
	Top third	18	10	72	40	100	100
Depth, camera 4	Bottom third	12	14	48	56	48	56
	Middle third	1	1	4	4	52	60
	Top third	12	10	48	40	100	100
Orientation, camera 1	Upstream	7	10	78	59	78	59
	Downstream	2	7	22	41	100	100
Orientation, camera 4	Upstream	11	7	44	47	44	47
	Downstream	14	8	56	53	100	100

[a]Number of fins assessed as normal; fins were caudal, dorsal, and right and left pectoral. [b]A total of 100 observations were possible because four cameras were used for all 25 fish released. Collectively, video cameras recorded potential contacts over 1.8 m of the horizontal flat plate screen.

Table 7. Summary of condition of 25 37-mm individual bull trout assessed after handling (C) or after passage over a horizontal flat plate screen (T) at a sweeping velocity of 1.2 m/sec.

		Frequency		Percent		Cumulative Percent	
Characteristic	Condition	C	T	C	T	C	T
Eyes	Normal	25	25	100	100	100	100
Fins[a]	4 of 4 normal	1	0	4	0	4	0
	3 of 4 normal	2	1	8	4	12	4
	2 of 4 normal	7	2	28	8	40	12
	1 of 4 normal	9	8	36	32	76	44
	0 of 4 normal	6	14	24	56	100	100
Integument	Normal	23	24	92	96	92	96
	Abrasion	2	0	8	0	100	96
	Bruise		1		4		100
	Cut						
Total contacts[b]	0	98	94	98	94	98	94
	1	2	6	2	6	100	100
	2						
	3						
	4						
	5						
Depth, camera 1	Bottom third	13	3	52	3	52	3
	Middle third	0	0	0	0	52	3
	Top third	12	22	48	88	100	100
Depth, camera 4	Bottom third	13	13	52	52	52	52
	Middle third	0	0	0	0	52	52
	Top third	12	12	48	48	100	100
Orientation, camera 1	Upstream	12	3	92	100	92	100
	Downstream	1		8		100	
Orientation, camera 4	Upstream	14	10	67	71	67	71
	Downstream	7	4	33	29	100	100

[a]Number of fins assessed as normal; fins were caudal, dorsal, and right and left pectoral.
[b]A total of 100 observations were possible because four cameras were used for all 25 fish released. Collectively, video cameras recorded potential contacts over 1.8 m of the horizontal flat plate screen.

Table 8. Summary of condition of 25 37-mm individual bull trout assessed after handling (C) or after passage over a horizontal flat plate screen (T) at a sweeping velocity of 0.6 m/sec.

Characteristic	Condition	Frequency C	Frequency T	Percent C	Percent T	Cumulative Percent C	Cumulative Percent T
Eyes	Normal	25	25	100	100	100	100
Fins[a]	4 of 4 normal	0	1	0	4	0	4
	3 of 4 normal	1	2	4	8	4	12
	2 of 4 normal	4	6	16	24	20	36
	1 of 4 normal	8	12	32	48	52	84
	0 of 4 normal	12	4	48	16	100	100
Integument	Normal	25	24	100	96	100	96
	Abrasion		1		4	100	100
	Bruise						
	Cut						
Total contacts[b]	0	94	90	94	90	94	90
	1	5	7	5	7	99	97
	2	1	3	1	3	100	100
	3						
	4						
	5						
Depth, camera 1	Bottom third	15	13	60	52	60	52
	Middle third	1	0	4	0	64	52
	Top third	9	12	36	48	100	100
Depth, camera 4	Bottom third	20	21	80	84	80	84
	Middle third	0	0	0	0	80	84
	Top third	5	4	20	16	100	100
Orientation, camera 1	Upstream	15	13	94	100	94	100
	Downstream	1		6		100	
Orientation, camera 4	Upstream	19	22	83	100	83	100
	Downstream	4		17		100	

[a]Number of fins assessed as normal; fins were caudal, dorsal, and right and left pectoral.
[b]A total of 100 observations were possible because four cameras were used for all 25 fish released. Collectively, video cameras recorded potential contacts over 1.8 m of the horizontal flat plate screen.

Table 9. Summary of condition of 25 58-mm individual bull trout assessed after handling (C) or after passage over a horizontal flat plate screen (T) at a sweeping velocity of 1.2 m/sec.

Characteristic	Condition	Frequency C	Frequency T	Percent C	Percent T	Cumulative Percent C	Cumulative Percent T
Eyes	Normal	25	24	100	96	100	96
	Abrasion		1		4		100
Fins[a]	4 of 4 normal	0	0	0	0	0	0
	3 of 4 normal	0	2	0	8	0	8
	2 of 4 normal	2	5	8	20	8	28
	1 of 4 normal	8	8	32	32	40	60
	0 of 4 normal	15	10	60	40	100	100
Integument	Normal	24	24	96	96	96	96
	Abrasion	0	0	0	0	96	96
	Bruise	1	0	4	0	100	96
	Cut		1		4		100
Total contacts[b]	0	82	78	82	78	82	78
	1	17	21	17	21	99	99
	2	0	1	0	1	99	100
	3	0		0		99	
	4	0		0		99	
	5	1		1		100	
Depth, camera 1	Bottom third	22	24	88	96	88	96
	Middle third	0	1	0	4	88	100
	Top third	3		12		100	
Depth, camera 4	Bottom third	25	24	100	96	100	96
	Middle third		0	0	0	80	96
	Top third		1	20	4	100	100
Orientation, camera 1	Upstream	20	23	91	92	91	92
	Downstream	2	2	9	8	100	100
Orientation, camera 4	Upstream	25	24	100	100	100	100
	Downstream						

[a]Number of fins assessed as normal; fins were caudal, dorsal, and right and left pectoral.
[b]A total of 100 observations were possible because four cameras were used for all 25 fish released. Collectively, video cameras recorded potential contacts over 1.8 m of the horizontal flat plate screen.

Table 10. Summary of condition of 25 58-mm individual bull trout assessed after handling (C) or after passage over a horizontal flat plate screen (T) at a sweeping velocity of 0.6 m/sec.

Characteristic	Condition	Frequency C	Frequency T	Percent C	Percent T	Cumulative Percent C	Cumulative Percent T
Eyes	Normal	25	25	100	100	100	100
	Abrasion						
Fins[a]	4 of 4 normal	0	0	0	0	0	0
	3 of 4 normal	0	2	0	8	0	8
	2 of 4 normal	4	7	16	28	16	36
	1 of 4 normal	5	10	20	40	36	76
	0 of 4 normal	16	6	64	24	100	100
Integument	Normal	20	24	80	96	80	96
	Abrasion	3	1	12	4	92	100
	Bruise	2		8		100	
	Cut						
Total contacts[b]	0	95	82	95	82	95	82
	1	3	11	3	11	98	93
	2	2	6	2	6	100	99
	3		1		1		100
	4						
	5						
Depth, camera 1	Bottom third	25	25	100	100	100	100
	Middle third						
	Top third						
Depth, camera 4	Bottom third	19	21	76	84	76	84
	Middle third	0	2	0	8	76	92
	Top third	6	2	24	8	100	100
Orientation, camera 1	Upstream	24	25	96	100	96	100
	Downstream	1		4		100	
Orientation, camera 4	Upstream	19	21	100	91	100	91
	Downstream		2		9		100

aNumber of fins assessed as normal; fins were caudal, dorsal, and right and left pectoral.
[b]A total of 100 observations were possible because four cameras were used for all 25 fish released. Collectively, video cameras recorded potential contacts over 1.8 m of the horizontal flat plate screen.

Fins - The frequency of fish in control and treatment groups with undamaged fins declined with fish size. The occurrence of fish with damage on all four fins ranged from 0 to 8% for 28-mm fish to 24 to 64% for 58-mm fish. In four cases, occurrence of fish with damage on all four fins was higher for controls than for treatments (Tables 5, 8, 9, 10), in one case the occurrence was equal (Table 6), and in the last case, the occurrence of damage on all fins was higher in treatment fish (Table 7). The types of fin damage most frequently observed were frayed, trace split, and split. Broken fins were observed only on one control and one treatment fish. Both fish had broken pectoral fins and were from the 28-mm size group.

Integument - A total of 9 abrasions were observed: six were on control fish and three were on treatment fish (Tables 5, 6, 7, 8, 10). Also, a total of 4 bruises were observed; three on control fish; one on a treatment fish (Tables 7, 9, 10). Only one occurrence of cut integument was detected (Table 9).

Screen Contacts

Video interpretation showed most fish never contacted the screen. Treatment fish contacted the screen more frequently than control fish. The percentage of one or more contacts was higher for treatment fish in four of the six size-velocity conditions studied (Tables 7, 8, 9, 10). The greatest number of screen contacts observed for a single fish was five. Fish that contacted the screen more than once tended to tumble and swim erratically after the first contact.

Depth in Water Column

Larger fish, especially the 58-mm size group, more frequently inhabited the bottom third of the water column. The percentages for 28-mm fish in the bottom third of the water column ranged from 24 to 56, whereas the percentages for 58-mm fish ranged from 76 to 100. The percentages of fish in the bottom, middle and top thirds for both cameras and treatments combined were: 44, 6, and 50% for 28-mm fish; 56, 0, and 44% for 37-mm fish; and 92, 2, and 6% for 58-mm fish.

Orientation

The percentage of fish oriented upstream increased with fish size. Forty-two to 79% of 28-mm fish were oriented upstream, compared to 91 to 100% for 58-mm fish. The frequencies of fish oriented upstream for both cameras and treatments combined were 53% for 28-mm fish; 86% for 37-mm fish; and 96% for 58-mm fish.

Survival

An initial assessment of survival was conducted at the time fish were removed from the capture net. The assessments showed that all fish were alive immediately after passage.

The 24-h survival estimates showed that effects of screen passage were small with survival rates ranging from 98.5 to 100% (Table 11). Survival rates were consistently lower for fish that passed over the screen compared to controls, but with a maximum difference of only 1.5%. Lack of variability in the data prevented calculation of 95% confidence intervals in every case. At least one fish died in every 28-mm control or screen treatment (Table 11). Survival was higher for other size classes with no mortalities in five treatments. Very low rates of mortality in some other treatments resulted in estimated 100% (with rounding error) survival rates (denoted by footnote "a"; Table 11). Consequently, values of "100%" in Table 11 should be interpreted with caution because mortality occurred in some treatments.

In general survival rates were lower at 96 h (Table 12) than at 24 h. At 96 h, only two treatments had 100% survival. Survival was lowest for 58 mm fish in the 0.6 m/sec sweeping velocity treatment. Most mortality for fish in this treatment occurred at 72 and 96 h, and was probably caused by a pathogen. The source of the pathogen was unknown, but water temperatures at the Water Resources Research Laboratory were higher for 58-mm fish (16 to 16.5°C) than for other trials (13.5 to 14°C) because the water cooling system failed. Evidence that some other factor may have influenced survival rates of 58-mm fish, suggested observed 96-h survival rates should be interpreted with caution, or even excluded from analyses intended to infer effects of screen passage. Alternatively, the observed survival rates can be used as worse-case estimates of effects if it is acknowledged that some other factor may have increased mortality. If the 58-mm size is excluded, survival rates were higher for controls in three of four passage conditions; if 58-mm fish are included, survival rates were higher for controls in four of six passage conditions. Lack of variability in the data prevented calculation of 95% confidence intervals in four cases.

Table 11. Summary of 24-h survival for batches of 10 bull trout after passage over a horizontal flat plate screen at two sweeping velocities.

1.2 m/sec Sweeping Velocity

Treatment	Mean % Survival	Lower 95% CI	Upper 95% CI	*n*
		Life Stage (28 mm)		
Control	100[a]	NE	NE	20
Treatment	98.9	NE	NE	20
		Life Stage (37 mm)		
Control	100	NE	NE	20
Treatment	100	NE	NE	19
		Life Stage (58 mm)		
Control	100	NE	NE	20
Treatment	100	NE	NE	19

0.6 m/sec Sweeping Velocity

Treatment	Mean % Survival	Lower 95% CI	Upper 95% CI	*n*
		Life Stage (28 mm)		
Control	100[a]	NE	NE	20
Treatment	98.5	NE	NE	20
		Life Stage (37 mm)		
Control	100[a]	NE	NE	20
Treatment	99.5	NE	NE	20
		Life Stage (58 mm)		
Control	100	NE	NE	20
Treatment	100[a]	NE	NE	20

NE = no estimate.

[a]Some mortality occurred in this treatment group, but estimated survival rates were 100% with rounding error.

Table 12. Summary of 96-h survival for batches of 10 bull trout after passage over a horizontal flat plate screen at two sweeping velocities.

1.2 m/sec Sweeping Velocity

Treatment	Mean % Survival	Lower 95% CI	Upper 95% CI	*n*
		Life Stage (28 mm)		
Control	98.0	95.8	99.2	20
Treatment	94.7	91.5	97.0	20
		Life Stage (37 mm)		
Control	100	NE	NE	20
Treatment	95.3	NE	NE	19[a]
		Life Stage (58 mm)		
Control	98.5	NE	NE	20
Treatment	100	NE	NE	19[a]

0.6 m/sec Sweeping Velocity

Treatment	Mean % Survival	Lower 95% CI	Upper 95% CI	*n*
		Life Stage (28 mm)		
Control	96.4	93.4	98.3	20
Treatment	97.9	95.4	99.3	20
		Life Stage (37 mm)		
Control	98.5	96.7	99.5	20
Treatment	98.0	96.0	99.2	20
		Life Stage (58 mm)		
Control	91.0	84.9	95.3	20
Treatment	81.8	74.1	88.1	20

NE = no estimate.
[a]One replicate lost.

Discussion

Consistent negative effects from passage of bull trout over a horizontal flat plate screen were not observed. Potential entrainment was ≤ 3.5% for 28-mm fish, and was never observed for larger fish. Impingement never occurred. Physical damage to eyes, fins, and integument was either rare (eyes) or less frequent in fish that passed over the screen than in control fish. Fish that passed over the screen did contact the bottom more frequently than control fish, but no immediate mortality occurred from screen passage. Survival at 24 h was consistently lower for fish that passed over the screen compared to controls, but the difference was small (≤ 1.5%). At 96 h after passage, overall survival was reduced, but was not consistently lower for fish that passed over the screen. Thus, the effects of screen passage were at, or near the level of background effects induced by fish culture, handling, transport, and testing.

Water depth and orientation of bull trout changed with fish size and age despite the use of a standardized release methodology. Larger fish were observed near the bottom and oriented upstream more frequently than smaller fish. This tendency to occupy deeper water increased the likelihood that fish contacted the horizontal flat plate screen. It also increased the likelihood that fish discovered attractive hydraulic properties of the screen. We observed several 58-mm fish that appeared to be maintaining position by using the downward pressure generated by the approach velocity of water passing through the screen. This behavior was the main factor responsible for increased passage time for larger fish. Thus, we did observe that certain hydraulic conditions of the horizontal flat plate screen used in this investigation attracted fish and delayed their movement.

Bottom-oriented behavior may have also contributed to the number of times that fish contacted the screen. Fish that contacted the screen more than once tended to tumble and swim erratically after the first contact. Loss of orientation combined with burst swimming to regain orientation resulted in fish colliding with the screen. Under normal conditions, this behavior would allow a fish to discover microhabitats on the bottom of a stream that offer refuge from water velocity. However, within the confines of a horizontal flat plate screen, the behavior results in multiple screen contacts.

The source of the pathogen presumed to have killed several 58-mm fish in the 0.6 m/sec sweeping velocity treatment was unknown. There was strong evidence that the mortality was caused by a pathogen because fish appeared healthy at 0, 24, and 48 h after passage, but then mortality began to occur at 72 and 96 h. Other evidence of a pathogen was that mortality was clustered within tanks suggesting that infected individuals transferred the disease within an aquarium. Two characteristics were different during 58-mm trials compared to previous trials: (1) the water temperature was 2 to 2.5°C warmer; and (2) passage times were longer which would have increased exposure to resident pathogens. Regardless of the cause(s), the presence of additional sources of mortality should be acknowledged when interpreting results for 58-mm fish.

References

Frizell, K., and B. Mefford. 2001. Hydraulic Performance of a Horizontal Flat Plate Screen. Final report. U.S. Bureau of Reclamation, Water Resources Research Laboratory, Denver, Colorado.

Lee, D.S, C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. 1980. Atlas of North American freshwater fishes. North Carolina State Museum, Raleigh, North Carolina.

SAS Institute. 1993. SAS Technical Report P-243, SAS/STAT Software: GENMOD procedure, release 6.09. Cary, North Carolina.

Appendix F - Craven, 2003, Draft Evaluation of Overshot Horizontal Flat Plate Fish, Farmers Irrigation District

DRAFT

Data Report

Evaluation of Overshot Horizontal Flat Plate Fish Screen,

Farmers Canal, Hood River, Oregon

Prepared by:

Farmers Irrigation District
1985 Country Club Road
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July 28, 2003

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1.0 INTRODUCTION

Hydraulic and fish tests (injury and mortality) on the prototype horizontal flat plate fish screen were conducted and results presented in 2000 and 2001. Based on the tests, Farmers Irrigation District (FID) was allowed by the Oregon Department of Fish and Wildlife (ODFW), U.S. Fish and Wildlife Service (USFWS), and NOAA Fisheries to install a full-sized screen in the Farmers Canal and to conduct various hydraulic analyses and biological tests to determine injury and mortality to juvenile fish. Tests were conducted during spring 2003.

2.0 OBJECTIVES

The preliminary results for the tests of the Overshot Horizontal Flat Plate Fish Screen installed in the Farmers Canal are presented in this report. The report is intended to be a description of the screen, a summary of the test conditions, preliminary test results, and the raw data. The objective of presenting preliminary results is to allow the reviewers to quickly review and provide preliminary comments on the test conditions and results to date.

3.0 DESCRIPTION OF OVERSHOT HORIZONTAL FLAT PLATE FISH SCREEN

Plan and section views and photographs of the fish screen are shown in Appendix A. Screen parameters and hydraulics characteristics during tests are provided in Table 1. The screen is 160 feet long and tapers from 9 feet wide at the upstream end to 2 feet wide at the downstream end where bypass flows exit the screen to a receiving pool for water and bypassed fish.

The overshot horizontal flat plate fish screen is a perforated plate stainless steel screen with 3/32-inch openings. The water depth over the screen is controlled by an adjustable stop log weir and adjustable taper wall to regulate width in the lower 20 feet of the canal. The theoretical velocity through the screen openings (Va) is 0.083 feet per second (ft/s) based on gross screen area. The theoretical value of Va based on net free area (33%) of the screen is 0.251. This value is similar to 0.3 ft/s measured with an Acoustic Doppler flow meter by ODFW during biological testing.

Total flow in the canal during the tests was approximately 83 cubic feet per second (cfs). The system can be operated up to approximately 95 cfs. Of the 83 cfs, approximately 65 cfs was delivered to the irrigation system while 18 cfs was bypassed to the receiving pool and Hood River via Joe's Creek. Depth of water over the screen was 2.1 feet for 150 feet of screen length. For the remaining 10 feet in the bypass throat, the depth was 1.25 feet. Velocities were in the range of 3.91 to 4.40 ft/s, except in the bypass throat where velocity increased to 7.46 ft/s to provide a capture velocity.

Table 1. Screen Hydraulics for the Horizontal Overshot Flat Plate Fish Screen Tests in Spring 2003.

Parameter	Value	Parameter	Value
Q total, cfs	83.07	Mannings, n	0.014
Q diverted, cfs	64.41	Bed Slope, s	0.0001
Q bypassed, cfs	18.65	Va, ft/s based on Net Free Area	0.251
Bypass width, ft	2.00	Va, ft/s, based on Gross Screen Area	0.083
Channel width, ft	9	Net Free Area, %	33
Screen length, ft	160	Screen Area (ft^2)	775
Wall angle, deg	3	Net Screen Area	255.75

Length (feet)	Depth (feet)	Velocity (ft/s)	Froude #
0.00	2.10	4.40	0.53
10.00	2.10	4.30	0.52
20.00	2.10	4.28	0.52
30.00	2.10	4.22	0.51
40.00	2.10	4.29	0.52
50.00	2.10	4.25	0.52
60.00	2.10	4.30	0.52
70.00	2.10	4.32	0.53
80.00	2.10	4.30	0.52
90.00	2.10	4.22	0.51
100.00	2.10	4.14	0.50
110.00	2.10	4.14	0.50
120.00	2.10	4.15	0.50
130.00	2.10	4.27	0.52
140.00	2.10	3.91	0.48
150.00	2.10	4.10	0.50
160.00	1.25	7.46	1.18
Average	2.05	4.41	0.55
Minimum	1.25	3.91	0.48
Maximum	2.10	7.46	1.18

The plan and section views show a vertical screen in the lower 10 feet of the bypass and a screened horizontal ramp that extends to the receiving pool. Preliminary tests conducted without the vertical screen and ramp resulted in significant injuries to fish in the retrieval net due to excessive turbulence. The vertical screen and ramp were installed to allow dissipation of flows into the receiving pool and away from the fish collection net to prevent injury and mortality to fish collected in the net. The use of the vertical screen and ramp reduced the bypass flows into the net from an unacceptable nearly 19 cfs to approximately 1 cfs. The bypass of 19 cfs into the net resulted in excessive churning and turbulence that resulted in injury and mortality to fish. Previous memos have described the necessity for the vertical screen and ramp for the fish tests. Under normal operation the vertical screen and ramp are not necessary.

4.0 TEST FISH

Table 2 summarizes details of fish source and other experimental conditions.

Table 2. Test Fish Sources and General Experimental Design.

Test Fish	Fish Source	Acclimation Period	Test Fish	Control Fish	Latent Mortality Period
Winter steelhead smolts (Hood River stock)	Oak Springs Fish Hatchery	120-144 hours	750 (30 groups of 25)	250 (10 groups of 25)	96 hours
Summer steelhead fry (Skamania stock)	Oak Springs Fish Hatchery	96 hours	750 (15 groups of 50)	250 (5 groups of 50)	96 hours
Spring Chinook fry (Deschutes stock)	Round Butte Fish Hatchery	96 hours	300 (6 groups of 50)	150 (3 groups of 50)	96 hours

4.1 Fish Source, Species, and Test Dates

Fish sources were Oak Springs Fish Hatchery and Round Butte Fish Hatchery. Summer steelhead fry, winter steelhead smolts, ands spring Chinook fry were the experimental and control fish. Steelhead smolt tests occurred on May 27 and 28, 2003. Steelhead and Chinook fry tests occurred on June 2 and 3, 2003. Sizes of fish used in the tests were as follows:

	Chinook Fry	Steelhead Fry	Steelhead Smolts
Average (millimeters)	70	63	207
Range (millimeters)	51-84	48-75	148-264

4.2 Delivery, Holding Facilities, and Acclimation

All fish were delivered to the site several days prior to actual tests. Fish were acclimated and unfed for at least 96 hours in net pens in the canal water prior to tests. Net pens were sited within the canal system so that clean, cool flows were passed through the net pens. Mortality in the net pens during acclimation was limited to less than 10 fish for all net pens combined.

4.3 Latent Mortality

Latent mortality was evaluated. After each test was conducted, fish recovered were evaluated and placed in a net pen. All fish of the same species tested on a given day were placed in the same net pen or net pens, depending on density of fish in the pen. Daily evaluation was made of latent mortality in the net pens by observing the number of dead fish in the net pens each morning for four days.

5.0 TEST PROCEDURE

The test procedure will be discussed as it was sequentially implemented in the field. Test evaluations were conducted by subjecting the fish to passage over the screen and collection in the retrieval net in the receiving pool. Control tests also were conducted by releasing fish directly into the distal end of the bypass throat so that the fish were not subjected to passage over the screen to attempt to account for any injuries or mortalities that might be attributable to the retrieval net.

5.1 Smolt Pre-Test Evaluation

- Smolts were taken from the net pens in the canal to the processing station adjacent to the canal. At the processing station, the fish were anesthetized with MS222.
- After anesthetization, each smolt was evaluated for scale loss and other injuries and results were recorded before they were included in the experiment. The characteristics evaluated were:

    - <u>Scale Loss</u> - One observer was used for the entire study to ensure consistency in the estimation of scale loss. Prior to the experiment, the observer evaluated approximately 300 fish to obtain a "standardized eye" with regards to scale loss and other injuries. U.S. Army Corps of Engineers, NOAA technical memorandum, and National Marine Fisheries Service scale loss criteria were referenced for visual evaluation methodology. Each side of the fish, left and right, was recorded separately. The entire body of the fish except for the ventral surface from the pectoral fins to the vent was evaluated. Fish were classified as 0, 5, 10, or 15% scale loss, based upon visual inspection. The visual inspection consisted of an estimation of scales that were apparently missing from the fish body in proportion to the amount of scales that were intact. All visual estimations were performed using the naked eye. Any fish with more than 15% scale loss was not used in the experiment.
    - <u>Eye injuries</u> - Fish with eye abrasions or injuries were not included in the experiment.
    - <u>Abrasions and bruises</u> - Smolts with abrasions and/or bruises were not included in the experiment.
    - <u>Gill injuries</u> - Smolts with gill injuries were not included in the experiment.

- Deformities - Fish with deformities were not included in the experiment.
- Fungus - Smolts with fungus on any body part and/or badly eroded snouts were not included in the experiment.

- After the smolts were characterized for injuries, they were placed in clean water to revive from the effects of MS222. After revival (using 5 to 10 minutes), the fish were taken to the upstream end of the fish screen for release over the screen.
- A decision was made to release only 25 fish at one time for each test. This was based on preliminary experimentation with releasing 50 fish per test in which a significant amount of injury occurred. The injury was attributed to crowding in the capture net during net retrieval. The decrease to 25 fish per test resolved the injury problem attributed to the net.

?? I thought we didn't do 50 b/c they would not fit in one bucket

- The release of fish over the screen occurred to evaluate impingement, injury, and mortality. Fish were transported in a 5-gallon bucket to the release location and then carefully poured with the water into the flow of the canal by partially submerging the bucket in the water column. Then, fish were observed (as possible) as they moved down the screen and into the collection net in the receiving pool.
- A decision was made on how long to leave the retrieval net in the receiving pool before retrieval. The retrieval net was pulled out of the bypass flow 10 minutes after the first fish was observed entering the net after passing over the screen. To standardize the time in the retrieval net, the control fish were released at the vertical screen, in the middle of the water column, exposing the fish to the retrieval net for the corresponding length of time (10 minutes). Ten minutes was allowed because of the ability of the smolt to swim upstream or to slowly move downstream to the retrieval net. The control fish were released at the vertical screen, in the middle of the water column, and retrieved after ten minutes. — redundant
- Fish captured in the receiving net were placed in a 5-gallon bucket of water from the receiving pool and transported to the fish processing station.

5.2 Smolt Post-Test Evaluation

Fish were again anesthetized with MS222 and evaluated for number of recoveries, injuries, and mortality. The results of the tests are in Appendix B and are summarized in Tables 3, 4 and 5. After the evaluation, the fish were put into a net pen to evaluate latent mortality for 96 hours (Table 6 and Appendix F).

Table 3. Summary of Number of Tests, Number of Fish per Test, and Number Not Recovered for the evaluation of the Overshot Horizontal Flat Plate Fish Screen for Year 2003.

Parameter	Chinook Fry	Steelhead Fry	Steelhead Smolts
1. Number of Tests	9	21	40
a) No. of Tests	6	15	30
b) No. of Controls	3	6	10
2. Number of Fish per Test	50	50	25
3. Total No. of Fish	450	1,050	1,000
a) No. in Tests	300	750	750
b) No. in Controls	150	300	250
4. Fish Not Recovered	4	46	117
a) Tests	4	46	91
b) Controls	0	0	26
5. Average Size of Fish (millimeters)	70	63	207
6. Size Range (millimeters)	51 to 84	48 to 75	148 to 264

Table 4. Injury Data for Chinook and Steelhead Fry for the Overshot Horizontal Flat Plate Fish Screen Evaluation for Year 2003.

	INJURY					
	Fin		Gill/Eye		Bruise	
Species	Test	Control	Test	Control	Test	Control
Chinook Fry	0	0	0	0	0	0
Steelhead Fry	0	0	5	1	0	0

Table 5. Average Scattered Scale Loss for Steelhead Smolts for the Overshot Horizontal Flat Plate Fish Screen Evaluation for Year 2003.

Test	Average Scattered Scale Loss (%)	Delta Scattered Scale Loss (%)
Pre-Test	9.39	0.01
Post-Test	9.41	
Pre-Control	8.84	1.52
Post-Control	10.36	

Table 6. Latent Mortality Data for Steelhead and Chinook Fry, and Steelhead Smolts for Spring 2003 Tests.

Holding Time (hrs)	Chinook Fry		Steelhead Fry		Steelhead Smolts	
	Test	Control	Test	Control	Test	Control
24	0	0	0	0	0	0
48	0	0	0	0	0	1
72	0	0	0	0	0	0
96	0	0	0	0	4	3
Total Count	**0**	**0**	**0**	**0**	**4**	**4**
Fish Held	**296**	**150**	**704**	**300**	**659**	**224**
% Mortality	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.6%**	**1.8%**

Retrieval of Test and Control Fish – Retrieval of test and control fish was considered excellent given the size of the screen area (160 feet long). Only 91 steelhead smolt test fish (out of 750 fish) were not recovered. For control fish (250 fish), 26 fish were not recovered. The non-recovery of control fish reflects the ability of smolt to swim upstream in the throat of the bypass flow even when the fish are released in relatively high velocity flow (7.46 ft/s). Fish that were not recovered were not seen on the screen during numerous observations. They may have escaped via the bypass when the retrieval net was raised or they may have escaped upstream.

Injuries and Mortalities – No fin, gill/eye, or bruises were observed for steelhead smolt. Scale loss was virtually identical for pre- and post-test smolt (0.01% difference). For the control fish the difference in pre- and post-test results was 1.52%. The higher percentage in control fish is attributed to an artifact of the way the control fish were released. The way the releases were made was observed to basically crowd the fish into the bypass throat and into the net virtually at the same time. This likely resulted in loss of scales.

Latent Mortality – Latent mortality occurred equally in the test (4 fish – 0.6%) and control net pens (4 fish – 1.8%).

5.3 Steelhead and Chinook Fry Pre-Test Evaluation

The steelhead and Chinook fry were evaluated and results recorded before they were included in the experiment. Scale development on the fry was virtually non-existent, but other characteristics evaluated were:

- Eye injuries - Steelhead fry with eye injuries were not included in the experiment. Chinook with eye injuries were noted and included in the experiment due to the limited number of Chinook available for the tests.
- Gill injuries - Fish with gill injuries or deformities were not included in the experiment.
- Fin injuries - Fish with fin injuries were noted and included in the experiment.

- Abrasions/bruises - Fish with large abrasions and/or bruises were not included in the experiment.
- Deformities - Fish with deformities were not included in the experiment.

The procedure for the tests was virtually the same as for the steelhead smolts. The only exception was the number of fish released. Because of the small size of the fry (Table 3), releases were made in groups of 50 fish.

The retrieval net was pulled out of the receiving pool approximately five minutes after the first fish showed up in the net during the fry experiments. The control fish were released at the vertical screen, in the middle of the water column, exposing the fish to the retrieval net for the corresponding length of time to standardize the amount of time fish were in the net.

5.4 Fry Post-Test Evaluation

The results are in Appendix C and D and are summarized in Tables 3, 4, and 5. No injuries were observed to either Chinook or steelhead fry by passing them over the fish screen or into the retrieval net. In addition, there was no latent mortality recorded.

Recoveries – Recovery of test and control fish was considered excellent given the size of the screen length. Only 4 Chinook test fish (out of 300 fish) were not recovered. All control fish (150 fish) were recovered. For steelhead, 46 test fish (out of 750 fish) were not recovered. All control fish (300) were recovered. The recovery of all control fish reflects the limited ability of fry to swim upstream in the throat of the bypass flow.

Injuries and Mortalities – Fin and bruise injuries did not occur for either Chinook or steelhead fry. No gill and/or eye injuries were documented for Chinook fry. For steelhead fry, 5 test fish (0.67%) and 1 control fish (0.33%) had gill/eye injuries.

Does this mean the injuries occur after test but not before?

Latent Mortality – Latent mortality did not occur for either steelhead or Chinook fry.

6.0 PRELIMINARY SUMMARY

6.1 Hydraulic Tests

- uniform water surface elevation across entire screen
- sub-critical flow at steady-state (except exit throat)
- no vortical flow
- velocity through screen openings (Va) based on gross screen area - 0.083 ft/s
- velocity through screen openings (Va) based on net free area of 33% - 0.251
- average sweeping velocity - 3.6 ft/s
- total system inflow - 83.07 cfs
- diverted flow - 64.41 cfs
- bypass flow - 18.65 cfs

6.2 Biological

- Fry passed across the screen with no apparent impingement.
- Smolt desired to swim against the current or moved down the screen without difficulty.
- Injuries to Chinook and steelhead fry and steelhead smolt were either non-existent or very minimal and not attributable to the fish screen.
- Scale loss for steelhead smolt did not appear to be increased by passing fish over the screen (as compared to controls not passed over the screen). Fry did not have developed scales and there was no apparent loss.
- No latent mortality occurred with Chinook and steelhead fry. For steelhead smolts, latent mortality was minimal and equivalent in both test and control fish.

7.0 FUNDING ENTITIES

A number of agencies have contributed to the success of the project to date. Since the inception of this fish screening concept, ODFW and Confederated Tribes of the Warm Springs Reservation of Oregon (CTWSRO) representatives have worked directly with FID staff to continually refine the evaluation process. Once these local resource managers felt the concepts were sound, ODFW, CTWSRO, and FID made presentations to regional NOAA Fisheries and USFWS representatives. NOAA Fisheries and USFWS representatives encouraged FID, CTWSRO, and ODFW to complete two biological tests across the prototype screen installed at one of FID's hydropower facilities. The results from these tests were very positive.

Furthermore, the United States Bureau of Reclamation (USBR) has historically shown a strong interest in FID screen concepts and conducted additional hydraulic and biological testing in its Denver, Colorado hydraulics laboratory with the support of Colorado State University. Very favorable results also were obtained in these tests and, consequently, approval to proceed with construction of a full-scale version of the screen was received from NOAA Fisheries, USFWS, ODFW, and CTWSRO. FID began design and construction of a screen for FID's Farmers Canal diversion from the Hood River in fall 2001.

With the strong support of the Hood River Watershed Group, CTWSRO, USFWS, and NOAA Fisheries, FID has received grant funding from Bonneville Power Administration (BPA), CTWSRO, Oregon Watershed Enhancement Board (OWEB), National Fish and Wildlife Foundation (NFWF), United States Department of Agriculture (USDA), and Pacific Coastal Salmon Recovery Fund (through Columbia River Intertribal Fish Commission). Without the support and thinking of all of the representatives of the aforementioned agencies, this project would never have moved ahead. The dedicated consultants and agency personnel associated with this project have helped to develop what appears to be a very promising alternative technology to address fish screen and passage issues.

APPENDIX B

Steelhead Smolt Test Data for Year 2003

OREGON DEPARTMENT of FISH and WILDLIFE

FISH SCREENING PROGRAM

SMALL PUMP SCREEN SELF CERTIFICATION

The Oregon Water Resources Department in coordination and cooperation with the Oregon Department of Fish and Wildlife includes screen requirements on pumps to protect fish as a condition of many surface water and/or reservoir water right permits. This is done in accordance with ORS 537.153.

The Oregon Department of Fish and Wildlife does not usually inspect small pump screens at **pumped diversions less than 225 gpm** (gallons per minute), but furnishes the following general fish screening criteria information to the water right permit holder:

- **Screen material open area** must be at least 27% of the total wetted screen area.
- **Perforated plate:** Circular screen face openings must not exceed 3/32 or 0.0938 inch (2.38 mm) in diameter.
- **Mesh/Woven wire screen:** Square screen face openings must not exceed 3/32 or 0.0938 inch (2.38 mm) on a diagonal.
- **Profile bar screen/Wedge wire:** Slotted screen face openings must not exceed 0.0689 inch (1.75 mm) in the narrow direction.
- **Screen area** must be large enough not to cause fish impact. The wetted screen area required depends on the water approach velocity.
- **Approach velocity** is the water velocity perpendicular to and upstream of the vertical projection of the screen face.
- **An Active pump screen** is a self-cleaning screen that has a proven automatic cleaning system. The **screen approach velocity for active pump screens** must not exceed 0.4 ft/s (feet per second) or 0.12 m/s (meters per second). The minimum wetted screen area needed in square feet is calculated by dividing the maximum water flow rate in cubic feet per second (1 cfs = 449 gpm) by 0.4 ft/s.
- **A Passive pump screen** is a screen that has no automated cleaning system. **Screen approach velocity for passive pump screens** must not exceed 0.2 ft/s or 0.06 m/s. The minimum wetted screen area needed in square feet is calculated by dividing the maximum water flow rate in cubic feet per second by 0.2 ft/s.
- **Pump screen depth:** The screen must be submerged at least one screen radius below the minimum water surface with a minimum of one screen radius between the screen bottom and the water bottom or constructed surface.

For further information on fish screening please contact:

Alan Ritchey: 503-947-6229
Alan.D.Ritchey@state.or.us

OREGON DEPARTMENT of FISH and WILDLIFE

FISH SCREENING PROGRAM

SMALL PUMP SCREEN SELF CERTIFICATION

As evidence of having met fish screen installation requirements, please provide the information requested below, sign the certification, and send copies to:

Oregon Water Resources Department,
Water Rights Section,
725 Summer Street NE, Suite A,
Salem, OR 97301-1271.

and

Alan Ritchey
Oregon Dept. Fish and Wildlife
3406 Cherry Ave NE
Salem, OR 97303

Water right amount:_________

Is pump screen self-cleaning:_______

Screen Length_______________ Screen Diameter__________

If screen is not a cylinder shape, please provide a diagram and measurements.

Certification: I certify that my small pumped diversion of less than 225 gpm meets fish screening criteria, and that I will maintain it to comply with regulatory criteria. I also understand that should fish screening standards change, I may be required to modify my installation to meet applicable standards.

Applicant Signature:______________________________ Date: __/__/__ WRD File #: ___________

Printed Name and Address:____

Phone: (   )________________ Fax: (   )____________________

Pumpcert (5.27.2008).doc

APPENDIX A

Plan and Section Views of Fish Screen for Year 2003

Horizontal Flat Plate Fish Screen Tests, Year 2003 - Steelhead Smolts
Average Percent Scale Loss and Average Delta Percent Scale Loss Data

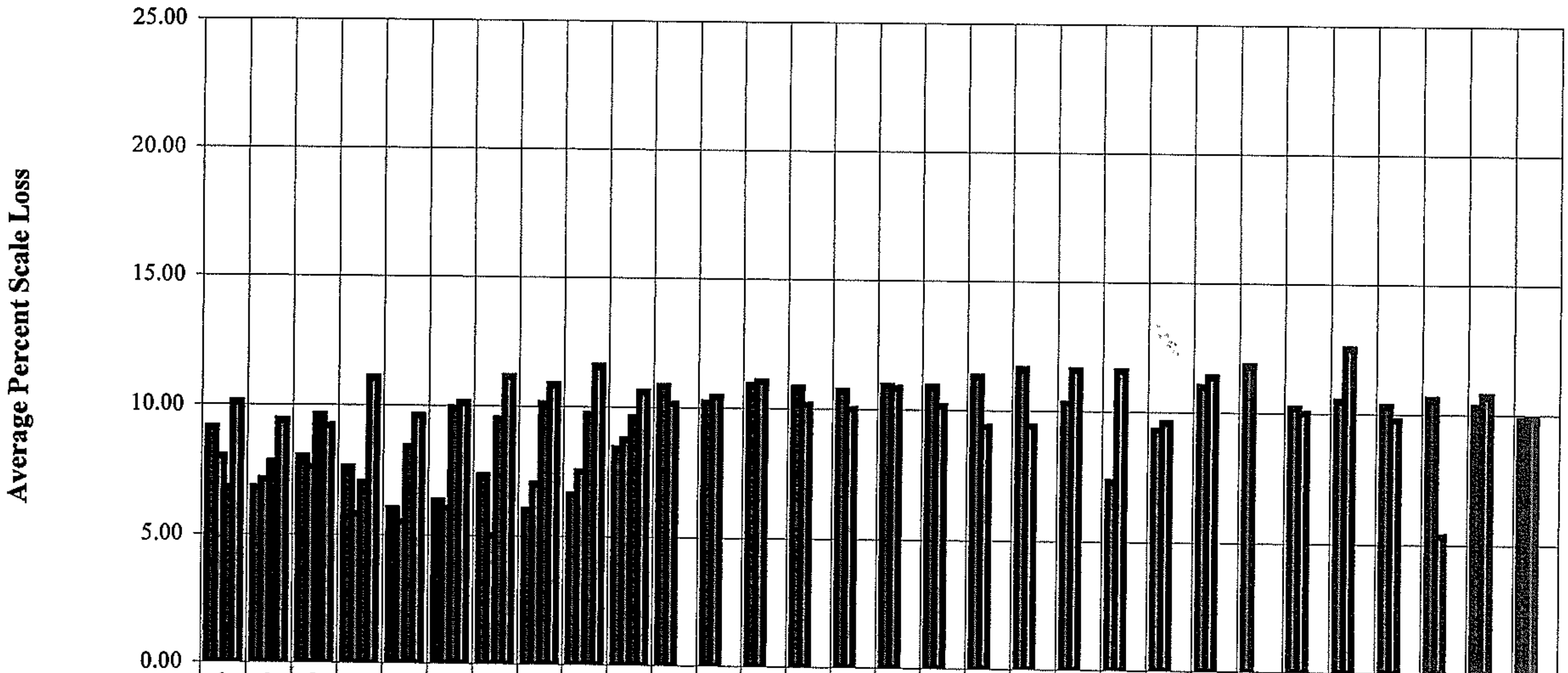
	TRIAL									
	1	2	3	4	5	6	7	8	9	10
Pre-Test	9.10	6.80	8.00	7.60	6.00	6.30	7.30	6.00	6.60	8.40
Post-Test	8.00	7.11	7.63	5.80	5.50	6.04	5.00	7.00	7.50	8.75
Pre-Control	6.80	7.80	9.60	7.02	8.40	9.90	9.50	10.10	9.70	9.60
Post-Control	10.10	9.40	9.20	11.04	9.60	10.11	11.13	10.83	11.56	10.60
Delta Test	-1.10	0.31	-0.38	-1.80	-0.50	-0.26	-2.30	1.00	0.90	0.35
Delta Control	3.30	1.60	-0.40	4.02	1.20	0.21	1.63	0.73	1.86	1.00

	TRIAL									
	11	12	13	14	15	16	17	18	19	20
Pre-Test	10.80	10.20	10.90	10.80	10.70	10.90	10.90	11.30	11.60	10.30
Post-Test	10.13	10.42	11.03	10.16	10.00	10.83	10.15	9.38	9.40	11.58
Pre-Control										
Post-Control										
Delta Test	-0.67	0.22	0.13	-0.64	-0.70	-0.07	-0.75	-1.93	-2.20	1.28
Delta Control	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	TRIAL									
	21	22	23	24	25	26	27	28	29	30
Pre-Test	7.30	9.30	11.00	11.80	10.20	10.50	10.30	10.60	10.30	9.80
Post-Test	11.56	9.58	11.36	#DIV/0!	10.00	12.50	9.76	5.30	10.71	9.87
Pre-Control										
Post-Control										
Delta Test	4.26	0.28	0.36	#DIV/0!	-0.20	2.00	-0.54	-5.30	0.41	0.07
Delta Control	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

?

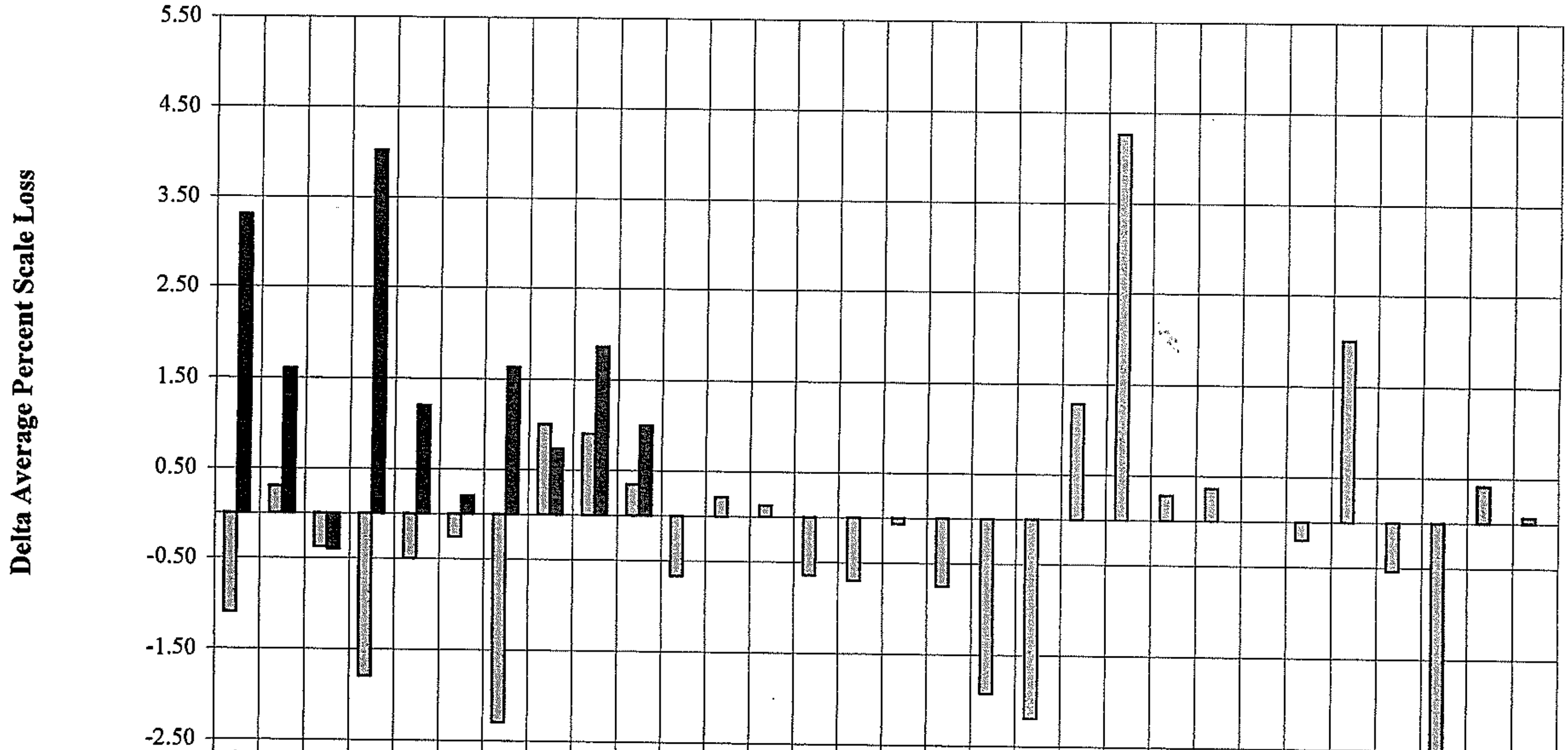
Horizontal Flat Plate Fish Screen Tests, Year 2003 - Steelhead Smolts
Average Percent Scale Loss



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Pre-Test	9.10	6.80	8.00	7.60	6.00	6.30	7.30	6.00	6.60	8.40	10.8	10.2	10.9	10.8	10.7	10.9	10.9	11.3	11.6	10.3	7.30	9.30	11.0	11.8	10.2	10.5	10.3	10.6	10.3	9.80
Post-Test	8.00	7.11	7.63	5.80	5.50	6.04	5.00	7.00	7.50	8.75	10.1	10.4	11.0	10.1	10.0	10.8	10.1	9.38	9.40	11.5	11.5	9.58	11.3	0.00	10.0	12.5	9.76	5.30	10.7	9.87
Pre-Control	6.80	7.80	9.60	7.02	8.40	9.90	9.50	10.1	9.70	9.60																				
Post-Control	10.1	9.40	9.20	11.0	9.60	10.1	11.1	10.8	11.5	10.6																				

Trials

Horizontal Flat Plate Fish Screen Tests, Year 2003 - Steelhead Smolts
Delta Average Percent Scale Loss



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Delta Test	-1.1	0.31	-0.3	-1.8	-0.5	-0.2	-2.3	1.00	0.90	0.35	-0.6	0.22	0.13	-0.6	-0.7	-0.0	-0.7	-1.9	-2.2	1.28	4.26	0.28	0.36	0.00	-0.2	2.00	-0.5	-5.3	0.41	0.07
Delta Control	3.30	1.60	-0.4	4.02	1.20	0.21	1.63	0.73	1.86	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Trials

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date: Time: Species: Test #:	May 27, 2003 8:50 AM Steelhead Smolt Trial 1		May 27, 2003 8:50 AM Steelhead Smolt Trial 1		May 27, 2003 12:55 PM Steelhead Smolt Trial 1		May 27, 2003 12:55 PM Steelhead Smolt Trial 1	
	PRE-TEST		POST-TEST		PRE-CONTROL		POST-CONTROL	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	10	15	10	10	5	5	5	5
2	10	5	5	5	10	5	10	10
3	15	10	10	10	5	5	10	10
4	10	5	5	10	0	5	5	5
5	5	5	15	15	5	5	15	10
6	10	10	10	10	10	10	5	140
7	10	10	5	5	5	5	10	10
8	15	15	5	5	5	5	5	5
9	10	5	5	5	5	5	5	10
10	5	10	10	10	5	5	15	15
11	5	5	15	5	5	10	10	10
12	5	5	10	5	5	5	10	5
13	10	15	10	5	5	5	10	10
14	5	5	5	5	10	10	5	5
15	5	5	5	10	10	15	5	5
16	10	10	*	*	10	15	5	5
17	15	5	*	*	5	5	5	5
18	15	15	*	*	10	5	5	5
19	10	10	*	*	15	10	10	5
20	10	5	*	*	10	10	5	5
21	5	10	*	*	5	5	5	5
22	15	10	*	*	10	5	5	5
23	15	10	*	*	5	5	15	5
24	10	10	*	*	5	5	5	5
25	5	5	*	*	5	5	10	10
Average	9.60	8.60	8.33	7.67	6.80	6.80	7.80	12.40
Minimum	5.00	5.00	5.00	5.00	0.00	5.00	5.00	5.00
Maximum	15.00	15.00	15.00	15.00	15.00	15.00	15.00	140.00
Combined	9.10		8.00		6.80		10.10	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date:	May 27, 2003		May 27, 2003		May 27, 2003		May 27, 2003	
Time:	9:05 AM		9:05 AM		1:00 PM		1:00 PM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 2		Trial 2		Trial 2		Trial 2	
	PRE-TEST		POST-TEST		PRE-CONTROL		POST-CONTROL	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	10	10	10	10	5	10	15	10
2	10	5	10	5	5	5	15	10
3	10	5	5	5	15	10	5	5
4	5	5	5	5	5	5	15	15
5	5	5	5	5	10	15	10	10
6	10	5	10	15	5	5	10	10
7	5	5	5	5	10	10	15	15
8	5	5	10	10	10	5	10	5
9	5	5	15	5	15	15	15	10
10	10	5	10	10	5	5	10	10
11	5	5	5	5	10	5	5	10
12	10	10	5	5	15	10	15	10
13	5	10	5	5	5	5	10	5
14	5	5	10	5	5	5	10	5
15	15	10	10	10	5	10	15	15
16	5	5	10	5	5	5	15	15
17	5	5	5	5	5	5	5	5
18	10	5	5	5	10	5	5	5
19	10	15	5	5	10	5	10	10
20	5	5	*	*	5	5	5	5
21	10	5	*	*	5	5	5	5
22	5	5	*	*	10	10	5	10
23	5	5	*	*	10	5	5	5
24	5	10	*	*	10	15	5	5
25	5	5	*	*	5	10	10	15
Average	7.20	6.40	7.63	6.58	8.00	7.60	9.80	9.00
Minimum	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Maximum	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Combined	6.80		7.11		7.80		9.40	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date:	May 27, 2003		May 27, 2003		May 27, 2003		May 27, 2003	
Time:	9:30 AM		9:30 AM		1:20 PM		1:20 PM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 3		Trial 3		Trial 3		Trial 3	
	PRE-TEST		POST-TEST		PRE-CONTROL		POST-CONTROL	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	5	5	10	10	10	10	5	5
2	5	5	10	5	10	10	5	10
3	5	5	10	10	10	15	10	15
4	10	10	10	10	15	10	15	10
5	10	10	5	5	15	10	15	15
6	10	10	5	5	10	10	10	5
7	10	5	5	5	15	10	10	10
8	15	15	5	5	10	10	15	15
9	5	5	5	5	10	5	10	10
10	10	5	5	10	10	15	5	10
11	5	5	5	5	10	5	5	5
12	5	5	10	10	5	5	10	5
13	5	5	5	5	15	10	5	5
14	5	5	10	10	10	5	10	5
15	10	5	5	5	10	10	10	15
16	15	15	10	15	10	15	5	5
17	10	10	5	5	5	5	20	10
18	10	5	5	5	5	5	10	10
19	10	10	15	15	10	10	5	5
20	10	5	10	10	10	5	5	5
21	5	10	*	*	5	5	5	5
22	5	5	*	*	5	5	5	10
23	10	15	*	*	10	15	15	15
24	5	5	*	*	10	10	15	10
25	10	15	*	*	15	15	10	10
Average	8.20	7.80	7.50	7.75	10.00	9.20	9.40	9.00
Minimum	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Maximum	15.00	15.00	15.00	15.00	15.00	15.00	20.00	15.00
Combined	8.00		7.63		9.60		9.20	

* Not captured, fish moved up stream.
** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003

WINTER STEELHEAD SMOLTS

Date:	May 27, 2003		May 27, 2003		May 27, 2003		May 27, 2003	
Time:	9:43 AM		9:43 AM		1:37 PM		1:37 PM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 4		Trial 4		Trial 4		Trial 4	
	PRE-TEST		POST-TEST		PRE-CONTROL		POST-CONTROL	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	10	10	5	5	10	10	10	5
2	15	10	10	5	10	10	10	10
3	10	5	5	10	5	10	10	15
4	10	10	5	5	5	5	15	15
5	5	5	5	5	10	10	10	5
6	15	10	5	5	10	10	10	10
7	15	5	5	5	15	1	10	10
8	10	15	5	5	5	5	15	10
9	10	5	5	5	10	5	15	10
10	5	5	5	5	5	5	10	10
11	5	10	5	5	5	5	10	15
12	10	10	5	5	5	10	15	15
13	15	10	5	5	10	5	15	15
14	5	5	5	10	10	5	15	15
15	5	10	5	5	10	5	15	10
16	5	5	5	5	5	5	10	10
17	5	5	10	10	5	5	15	5
18	5	5	5	5	5	5	10	10
19	5	5	5	5	5	5	10	10
20	5	5	5	5	10	15	10	15
21	15	5	5	5	5	5	10	5
22	5	5	5	5	5	10	10	15
23	5	5	5	10	5	5	5	10
24	5	5	5	5	5	5	10	5
25	5	5	10	10	5	10	**	**
Average	8.20	7.00	5.60	6.00	7.20	6.84	11.46	10.63
Minimum	5.00	5.00	5.00	5.00	5.00	1.00	5.00	5.00
Maximum	15.00	15.00	10.00	10.00	15.00	15.00	15.00	15.00
Combined	7.60		5.80		7.02		11.04	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date:	May 27, 2003		May 27, 2003		May 27, 2003		May 27, 2003	
Time:	9:55 AM		9:55 AM		1:50 PM		1:50 PM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 5		Trial 5		Trial 5		Trial 5	
	PRE-TEST		POST-TEST		PRE-CONTROL		POST-CONTROL	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	5	10	5	5	5	5	10	5
2	10	10	10	5	10	5	15	5
3	5	5	5	5	5	5	10	5
4	5	5	15	10	5	10	5	5
5	5	5	5	0	5	10	10	10
6	5	5	5	5	5	10	10	15
7	10	10	5	10	10	15	15	5
8	10	10	5	5	10	5	5	10
9	5	10	5	5	15	10	10	5
10	5	0	5	0	10	5	10	5
11	5	5	5	5	10	15	10	15
12	5	5	5	5	10	5	10	10
13	5	5	5	5	5	5	15	15
14	10	10	5	5	15	10	15	5
15	5	0	5	5	10	5	15	15
16	5	5	10	5	5	5	5	5
17	5	5	5	5	10	5	10	5
18	5	5	5	5	10	5	10	15
19	5	10	5	5	10	5	10	5
20	10	5	5	5	10	5	10	15
21	5	5	*	*	15	5	5	10
22	5	5	*	*	5	15	10	15
23	10	5	*	*	15	15	10	10
24	5	0	*	*	10	5	15	10
25	5	5	*	*	10	5	5	5
Average	6.20	5.80	6.00	5.00	9.20	7.60	10.20	9.00
Minimum	5.00	0.00	5.00	0.00	5.00	5.00	5.00	5.00
Maximum	10.00	10.00	15.00	10.00	15.00	15.00	15.00	15.00
Combined	6.00		5.50		8.40		9.60	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date:	May 27, 2003		May 27, 2003		May 28, 2003		May 28, 2003	
Time:	10:10 AM		10:10 AM		4:39 PM		4:39 PM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 6		Trial 6		Trial 6		Trial 6	
	PRE-TEST		POST-TEST		PRE-CONTROL		POST-CONTROL	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	10	5	5	5	10	5	10	10
2	10	5	10	5	15	10	10	10
3	5	5	5	5	5	5	15	15
4	5	5	5	5	10	5	10	10
5	5	5	5	5	10	10	10	10
6	10	10	5	5	10	5	15	15
7	5	5	5	10	15	15	10	10
8	10	10	10	10	10	15	10	5
9	5	5	5	5	10	5	10	15
10	5	5	5	5	5	5	15	10
11	5	5	5	10	15	15	15	10
12	10	5	5	5	10	10	10	10
13	10	5	*	*	15	15	10	10
14	5	10	*	*	10	10	15	15
15	10	5	*	*	10	5	10	10
16	5	5	*	*	10	10	10	10
17	5	5	*	*	15	15	10	5
18	5	5	*	*	5	10	5	10
19	5	5	*	*	10	10	5	5
20	5	5	*	*	5	5	10	10
21	10	5	*	*	5	5	10	5
22	5	5	*	*	10	5	10	10
23	5	5	*	*	10	10	5	5
24	5	5	*	*	15	15	*	*
25	10	10	*	*	15	15	*	*
Average	6.80	5.80	5.83	6.25	10.40	9.40	10.43	9.78
Minimum	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Maximum	10.00	10.00	10.00	10.00	15.00	15.00	15.00	15.00
Combined	6.30		6.04		9.90		10.11	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date:	May 27, 2003		May 27, 2003		May 28, 2003		May 28, 2003	
Time:	10:20 AM		10:20 AM		4:50 PM		4:50 PM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 7		Trial 7		Trial 7		Trial 7	
	PRE-TEST		POST-TEST		PRE-CONTROL		POST-CONTROL	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt.side (%)	Rt side (%)
1	10	5	5	5	10	10	15	10
2	5	5	5	5	10	10	10	10
3	5	5	5	5	10	10	15	10
4	5	5	5	5	10	5	10	10
5	10	10	5	5	5	5	10	10
6	10	10	5	5	10	15	10	5
7	10	15	*	*	10	10	10	10
8	10	5	*	*	10	10	5	10
9	5	10	*	*	10	5	15	15
10	5	5	*	*	10	10	10	10
11	5	5	*	*	10	10	10	5
12	10	5	*	*	15	10	10	15
13	15	5	*	*	15	15	15	15
14	5	5	*	*	10	10	15	10
15	10	10	*	*	10	10	10	10
16	15	15	*	*	10	5	10	10
17	5	5	*	*	10	10	15	15
18	5	5	*	*	5	5	15	10
19	5	5	*	*	10	10	10	10
20	10	10	*	*	10	5	15	10
21	5	5	*	*	10	10	*	*
22	5	5	*	*	15	10	*	*
23	10	5	*	*	10	5	*	*
24	5	5	*	*	10	5	*	*
25	5	10	*	*	10	10	*	*
Average	7.60	7.00	5.00	5.00	10.20	8.80	11.75	10.50
Minimum	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Maximum	15.00	15.00	5.00	5.00	15.00	15.00	15.00	15.00
Combined	7.30		5.00		9.50		11.13	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date:	May 27, 2003		May 27, 2003		May 28, 2003		May 28, 2003	
Time:	10:35 AM		10:35 AM		5:22 PM		5:22 PM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 8		Trial 8		Trial 8		Trial 8	
	PRE-TEST		POST-TEST		PRE-CONTROL		POST-CONTROL	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	10	5	5	5	10	10	15	10
2	5	5	10	5	10	10	10	15
3	5	5	10	10	15	10	15	15
4	5	5	5	5	10	10	15	10
5	5	5	5	5	10	15	10	10
6	10	5	5	5	10	15	10	10
7	5	5	5	5	10	15	10	10
8	5	5	5	5	10	10	15	10
9	5	5	5	10	10	10	5	10
10	10	5	5	10	10	10	10	5
11	10	10	10	10	5	10	10	10
12	10	10	5	10	10	15	10	15
13	5	5	15	10	10	10	10	10
14	5	5	10	5	10	10	10	10
15	5	5	5	5	10	10	10	10
16	5	5	*	*	5	10	10	10
17	5	5	*	*	10	10	10	15
18	5	5	*	*	10	5	10	10
19	10	10	*	*	10	10	*	*
20	5	5	*	*	10	10	*	*
21	10	5	*	*	10	10	*	*
22	5	5	*	*	10	10	*	*
23	5	5	*	*	15	10	*	*
24	5	5	*	*	10	5	*	*
25	5	5	*	*	10	5	*	*
Average	6.40	5.60	7.00	7.00	10.00	10.20	10.83	10.83
Minimum	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Maximum	10.00	10.00	15.00	10.00	15.00	15.00	15.00	15.00
Combined	6.00		7.00		10.10		10.83	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date:	May 27, 2003		May 27, 2003		May 27, 2003		May 27, 2003	
Time:	10:47 AM		10:47 AM		11:25 AM		11:25 AM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 9		Trial 9		Trial 9A		Trial 9A	
	PRE-TEST		POST-TEST		CLEANING		CLEANING	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	10	5	10	5	5	5	5	5
2	5	5	10	5	5	5	10	5
3	5	5	10	10	10	10	5	5
4	5	5	5	5	10	5	10	5
5	10	10	5	5	10	10	10	5
6	5	5	5	5	10	10	10	5
7	10	5	10	10	5	5	5	5
8	5	5	15	10	5	5	10	10
9	5	5	15	10	5	5	10	5
10	5	5	5	5	10	5	5	5
11	10	5	5	5	5	5	5	5
12	5	5	10	10	5	5	5	5
13	10	10	5	5	5	5		
14	5	5	5	5	10	10		
15	5	5	*	*	5	5		
16	10	10	*	*	5	5		
17	5	5	*	*	10	10		
18	5	5	*	*	5	10		
19	0	5	*	*	5	5		
20	10	10	*	*	5	5		
21	10	15	*	*	5	5		
22	10	5	*	*	10	10		
23	5	10	*	*	10	15		
24	10	5	*	*	10	10		
25	5	5	*	*	15	15		
Average	6.80	6.40	8.21	6.79	7.40	7.40	7.50	5.42
Minimum	0.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Maximum	10.00	15.00	15.00	10.00	15.00	15.00	10.00	10.00
Combined	6.60		7.50		7.40		6.46	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date:	May 28, 2003		May 28, 2003		May 28, 2003		May 28, 2003	
Time:	5:35 PM		5:35 PM		8:50 AM		8:50 AM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 9		Trial 9		Trial 10		Trial 10	
	PRE-CONTROL		POST-CONTROL		PRE-TEST		POST-TEST	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	10	10	15	10	10	5	15	15
2	10	10	15	15	5	5	5	10
3	10	15	10	5	10	15	10	15
4	10	5	15	15	5	5	5	15
5	5	10	10	5	10	10	5	5
6	15	10	15	15	10	5	10	15
7	10	15	10	10	5	5	10	5
8	10	10	10	15	10	10	15	10
9	10	10	1	15	10	10	5	5
10	10	10	15	10	10	10	5	10
11	10	10	10	15	5	5	10	10
12	10	10	15	10	15	10	5	10
13	5	10	15	15	10	10	10	10
14	10	5	15	10	5	5	10	5
15	10	10	10	10	10	5	5	5
16	10	10	15	10	10	5	10	10
17	10	10	10	10	5	10	5	5
18	10	5	5	10	10	5	5	10
19	10	5	*	*	5	5	*	*
20	10	10	*	*	5	5	*	*
21	10	15	*	*	5	5	*	*
22	10	10	*	*	5	10	*	*
23	10	10	*	*	15	15	*	*
24	10	5	*	*	15	15	*	*
25	10	10	*	*	10	15	*	*
Average	9.80	9.60	11.72	11.39	8.60	8.20	8.06	9.44
Minimum	5.00	5.00	1.00	5.00	5.00	5.00	5.00	5.00
Maximum	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Combined	9.70		11.56		8.40		8.75	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date:	May 28, 2003		May 28, 2003		May 28, 2003		May 28, 2003	
Time:	5:50 PM		5:50 PM		9:10 AM		9:10 AM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 10		Trial 10		Trial 11		Trial 11	
	PRE-CONTROL		POST-CONTROL		PRE-TEST		POST-TEST	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	10	10	10	5	10	5	10	5
2	5	5	10	10	15	10	10	5
3	15	10	10	15	10	10	15	10
4	10	10	10	10	15	10	10	10
5	15	10	15	15	10	15	10	10
6	15	5	10	10	10	10	15	15
7	10	10	5	5	10	10	5	5
8	10	10	10	10	15	10	10	10
9	10	15	10	5	15	10	10	5
10	5	5	10	10	10	10	10	5
11	10	10	10	10	10	10	15	10
12	10	5	10	10	10	10	10	5
13	10	10	10	10	15	10	15	15
14	5	5	10	15	15	10	10	10
15	10	10	10	10	10	5	15	10
16	5	10	10	10	10	5	10	10
17	10	10	10	15	10	5	10	10
18	10	10	15	10	15	15	10	10
19	10	10	10	15	10	5	15	10
20	10	15	10	15	10	10	*	*
21	10	10	15	10	15	15	*	*
22	10	10	*	*	10	10	*	*
23	10	15	*	*	10	5	*	*
24	10	10	*	*	15	10	*	*
25	10	5	*	*	15	15	*	*
Average	9.80	9.40	10.48	10.71	12.00	9.60	11.32	8.95
Minimum	5.00	5.00	5.00	5.00	10.00	5.00	5.00	5.00
Maximum	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Combined	9.60		10.60		10.80		10.13	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date:	May 28, 2003		May 28, 2003		May 28, 2003		May 28, 2003	
Time:	9:30 AM		9:30 AM		9:45 AM		9:45 AM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 12		Trial 12		Trial 13		Trial 13	
	PRE-TEST		POST-TEST		PRE-TEST		POST-TEST	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	15	15	10	10	10	10	15	15
2	10	15	15	15	15	10	10	5
3	10	10	15	10	5	10	10	10
4	15	10	15	10	10	15	15	10
5	15	15	10	10	10	10	10	15
6	15	10	10	10	10	15	10	10
7	10	10	15	10	15	10	10	10
8	15	10	10	10	15	15	15	15
9	10	10	5	5	10	10	15	15
10	10	10	5	10	10	5	10	10
11	10	15	5	5	10	10	15	10
12	10	10	15	15	10	10	10	15
13	10	5	*	*	10	15	10	10
14	10	10	*	*	15	10	10	15
15	10	5	*	*	10	5	5	5
16	15	15	*	*	10	10	10	5
17	10	5	*	*	10	10	10	10
18	5	5	*	*	10	5	*	*
19	5	5	*	*	15	10	*	*
20	5	10	*	*	10	10	*	*
21	5	10	*	*	15	15	*	*
22	10	10	*	*	5	5	*	*
23	10	15	*	*	10	15	*	*
24	10	10	*	*	15	15	*	*
25	10	5	*	*	15	10	*	*
Average	10.40	10.00	10.83	10.00	11.20	10.60	11.18	10.88
Minimum	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Maximum	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Combined	10.20		10.42		10.90		11.03	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date:	May 28, 2003		May 28, 2003		May 28, 2003		May 28, 2003	
Time:	10:08 AM		10:08 AM		10:20 AM		10:20 AM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 14		Trial 14		Trial 15		Trial 15	
	PRE-TEST		POST-TEST		PRE-TEST		POST-TEST	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	15	15	15	10	15	10	10	15
2	10	10	10	15	15	10	10	5
3	15	15	10	10	5	5	10	10
4	15	15	10	5	10	10	10	10
5	5	10	5	5	10	5	10	10
6	10	10	10	15	5	10	10	10
7	15	10	15	10	5	10	15	15
8	15	10	5	10	10	10	10	10
9	10	10	5	5	10	15	5	10
10	15	10	15	15	10	10	5	10
11	10	10	5	10	10	5	*	*
12	15	15	10	10	10	15	*	*
13	5	5	10	15	15	10	*	*
14	10	5	10	10	10	15	*	*
15	15	15	10	10	15	15	*	*
16	10	10	10	15	10	15	*	*
17	15	10	*	*	10	10	*	*
18	15	10	*	*	15	15	*	*
19	10	5	*	*	10	15	*	*
20	5	5	*	*	15	15	*	*
21	10	10	*	*	15	10	*	*
22	10	10	*	*	5	10	*	*
23	10	10	*	*	10	10	*	*
24	10	10	*	*	10	10	*	*
25	10	10	*	*	10	5	*	*
Average	11.40	10.20	9.69	10.63	10.60	10.80	9.50	10.50
Minimum	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Maximum	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Combined	10.80		10.16		10.70		10.00	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date:	April 12, 2001		April 12, 2001		May 28, 2003		May 28, 2003	
Time:	12:53 PM		12:53 PM		11:15 AM		11:15 AM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 15a		Trial 15a		Trial 16		Trial 16	
	CLEANING		CLEANING		PRE-TEST		POST-TEST	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	15	15	10	10	15	15	5	10
2	10	15	10	15	5	10	10	10
3	15	15	10	10	15	10	15	10
4	10	10	10	10	10	10	10	10
5	15	15	10	10	15	10	10	10
6	10	15	10	10	15	15	15	15
7	10	10	10	10	10	15	5	10
8	10	10	10	10	15	10	10	10
9	10	10	10	5	15	10	10	15
10	15	10	10	10	10	5	10	5
11	15	15	10	10	5	5	15	15
12	15	10	15	15	10	5	10	10
13	10	15	10	10	5	5	15	15
14	10	15	10	10	15	15	10	10
15	10	15	10	10	15	5	10	10
16	10	15	10	5	15	15	*	*
17	15	15	5	10	10	10	*	*
18	15	15	10	10	10	10	*	*
19	10	15	10	10	10	10	*	*
20	20	15	10	10	15	15	*	*
21	15	10	10	10	10	10	*	*
22	15	15	15	10	10	10	*	*
23	10	10			15	15	*	*
24	15	15			10	10	*	*
25	15	15			10	5	*	*
Average	12.80	13.40	10.23	10.00	11.60	10.20	10.67	11.00
Minimum	10.00	10.00	5.00	5.00	5.00	5.00	5.00	5.00
Maximum	20.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Combined	13.10		10.11		10.90		10.83	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date:	May 28, 2003		May 28, 2003		May 28, 2003		May 28, 2003	
Time:	11:30 AM		11:30 AM		11:45 AM		11:45 AM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 17		Trial 17		Trial 18		Trial 18	
	PRE-TEST		POST-TEST		PRE-TEST		POST-TEST	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	5	10	15	10	5	5	10	10
2	15	10	10	10	15	15	10	10
3	5	5	15	15	10	10	10	15
4	10	15	10	5	10	10	5	10
5	10	5	15	10	15	10	5	10
6	15	15	10	10	5	10	10	15
7	10	5	10	5	15	15	10	10
8	5	10	5	5	15	10	10	15
9	15	10	10	15	15	15	15	15
10	15	15	5	10	15	15	10	5
11	10	5	10	5	15	15	5	10
12	10	10	15	10	10	15	5	10
13	15	15	10	10	15	15	15	10
14	10	10	10	10	15	15	5	5
15	10	15	10	15	10	10	5	10
16	10	15	10	10	10	10	5	5
17	5	10	10	10	10	10	*	*
18	10	10	*	*	5	10	*	*
19	10	15	*	*	10	15	*	*
20	15	15	*	*	10	10	*	*
21	15	15	*	*	10	10	*	*
22	5	5	*	*	10	15	*	*
23	15	10	*	*	10	5	*	*
24	15	15	*	*	10	10	*	*
25	10	10	*	*	10	5	*	*
Average	10.80	11.00	10.59	9.71	11.20	11.40	8.44	10.31
Minimum	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Maximum	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Combined	10.90		10.15		11.30		9.38	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date:	May 28, 2003		May 28, 2003		May 28, 2003		May 28, 2003	
Time:	12:00 PM		12:00 PM		12:47 PM		12:47 PM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 19		Trial 19		Trial 20		Trial 20	
	PRE-TEST		POST-TEST		PRE-TEST		POST-TEST	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	10	10	15	15	10	10	15	15
2	10	10	15	10	10	10	10	15
3	15	15	15	10	10	10	15	10
4	10	10	10	10	10	10	15	15
5	10	10	10	10	10	10	10	15
6	10	15	10	10	15	15	10	10
7	10	10	10	10	10	15	15	15
8	15	10	5	5	5	5	10	10
9	15	15	10	15	5	10	10	10
10	10	10	15	10	10	10	15	15
11	10	10	10	10	10	15	10	10
12	15	10	10	5	5	5	5	10
13	10	5	5	5	10	10	10	10
14	10	10	5	5	15	10	10	10
15	15	10	5	10	10	10	10	10
16	15	10	10	10	10	10	15	15
17	10	10	10	5	10	15	10	10
18	15	15	10	10	5	10	10	10
19	15	15	5	5	10	10	10	10
20	10	10	10	10	10	10	*	*
21	10	15	10	10	10	5	*	*
22	10	15	*	*	10	10	*	*
23	10	10	*	*	15	15	*	*
24	10	15	*	*	15	15	*	*
25	15	10	*	*	10	10	*	*
Average	11.80	11.40	9.76	9.05	10.00	10.60	11.32	11.84
Minimum	10.00	5.00	5.00	5.00	5.00	5.00	5.00	10.00
Maximum	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Combined	11.60		9.40		10.30		11.58	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date:	May 28, 2003		May 28, 2003		May 28, 2003		May 28, 2003	
Time:	1:04 PM		1:04 PM		1:24 AM		1:24 AM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 21		Trial 21		Trial 22		Trial 22	
	PRE-TEST		POST-TEST		PRE-TEST		POST-TEST	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	10	10	10	10	10	5	10	10
2	15	10	15	10	15	10	15	10
3	10	10	10	15	15	10	10	10
4	15	10	15	5	10	5	5	10
5	10	15	15	10	10	15	10	5
6	5	5	15	10	10	10	5	10
7	15	15	15	15	10	10	5	5
8	10	10	10	5	10	5	10	10
9	10	10	*	*	5	10	10	10
10	10	10	*	*	5	5	15	10
11	10	10	*	*	5	5	5	10
12	10	10	*	*	10	10	15	15
13	5	5	*	*	10	10	*	*
14	10	15	*	*	10	10	*	*
15	10	5	*	*	15	15	*	*
16	5	10	*	*	15	10	*	*
17	5	10	*	*	15	10	*	*
18	10	10	*	*	10	10	*	*
19	10	5	*	*	15	10	*	*
20	15	15	*	*	5	5	*	*
21	10	15	*	*	10	10	*	*
22	5	5	*	*	5	5	*	*
23	10	10	*	*	5	10	*	*
24	10	5	*	*	10	10	*	*
25	5	15	*	*	5	5	*	*
Average	9.60	10.00	13.13	10.00	9.80	8.80	9.58	9.58
Minimum	5.00	5.00	10.00	5.00	5.00	5.00	5.00	5.00
Maximum	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Combined	9.80		11.56		9.30		9.58	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003

WINTER STEELHEAD SMOLTS

Date:	May 28, 2003		May 28, 2003		May 28, 2003		May 28, 2003	
Time:	1:40 PM		1:40 PM		1:57 PM		1:57 PM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 23		Trial 23		Trial 24		Trial 24	
	PRE-TEST		POST-TEST		PRE-TEST		POST-TEST*	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	10	10	15	15	5	10	*	*
2	10	10	10	15	15	10	*	*
3	15	5	10	15	15	15	*	*
4	15	15	15	10	10	10	*	*
5	15	15	15	10	10	10	*	*
6	5	5	15	5	10	10	*	*
7	10	10	10	10	10	10	*	*
8	10	10	10	10	15	10	*	*
9	5	10	10	10	10	10	*	*
10	10	10	10	10	10	10	*	*
11	10	5	10	10	15	15	*	*
12	10	10	*	*	10	15	*	*
13	15	10	*	*	5	5	*	*
14	15	5	*	*	15	10	*	*
15	15	15	*	*	15	15	*	*
16	15	10	*	*	15	15	*	*
17	10	15	*	*	15	10	*	*
18	10	10	*	*	10	10	*	*
19	15	15	*	*	10	15	*	*
20	15	10	*	*	15	15	*	*
21	10	5	*	*	15	10	*	*
22	10	5	*	*	15	15	*	*
23	15	15	*	*	15	10	*	*
24	15	10	*	*	10	5	*	*
25	10	15	*	*	15	15	*	*
Average	11.80	10.20	11.82	10.91	12.20	11.40	#DIV/0!	#DIV/0!
Minimum	5.00	5.00	10.00	5.00	5.00	5.00	0.00	0.00
Maximum	15.00	15.00	15.00	15.00	15.00	15.00	0.00	0.00
Combined	11.00		11.36		11.80		#DIV/0!	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date:	May 28, 2003		May 28, 2003		May 28, 2003		May 28, 2003	
Time:	2:07 PM		2:07 PM		2:23 PM		2:23 PM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 25		Trial 25		Trial 26		Trial 26	
	PRE-TEST		POST-TEST		PRE-TEST		POST-TEST	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	10	10	5	10	10	15	10	15
2	10	10	15	10	10	10	15	10
3	10	10	10	10	15	15	*	*
4	10	10	10	10	10	10	*	*
5	15	10	*	*	15	15	*	*
6	15	15	*	*	10	10	*	*
7	5	5	*	*	10	10	*	*
8	5	5	*	*	10	10	*	*
9	10	10	*	*	10	10	*	*
10	10	10	*	*	10	5	*	*
11	10	10	*	*	10	10	*	*
12	10	10	*	*	10	5	*	*
13	10	10	*	*	10	10	*	*
14	10	10	*	*	5	10	*	*
15	15	15	*	*	10	10	*	*
16	10	5	*	*	10	10	*	*
17	5	10	*	*	10	15	*	*
18	10	10	*	*	10	15	*	*
19	10	15	*	*	10	5	*	*
20	15	5	*	*	10	10	*	*
21	10	10	*	*	10	5	*	*
22	10	10	*	*	10	15	*	*
23	5	10	*	*	15	15	*	*
24	15	15	*	*	15	15	*	*
25	15	10	*	*	5	5	*	*
Average	10.40	10.00	10.00	10.00	10.40	10.60	12.50	12.50
Minimum	5.00	5.00	5.00	10.00	5.00	5.00	10.00	10.00
Maximum	15.00	15.00	15.00	10.00	15.00	15.00	15.00	15.00
Combined	10.20		10.00		10.50		12.50	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date:	May 28, 2003		May 28, 2003		May 28, 2003		May 28, 2003	
Time:	2:45 PM		2:45 PM		2:45 PM		2:45 PM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 26a		Trial 26a		Trial 26a		Trial 26a	
	CLEANING		CLEANING		CLEANING		CLEANING	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	10	10	15	10	15	10	5	10
2	5	5	10	5	10	15	10	10
3	15	10	10	5	10	5	10	10
4	10	15	5	5	15	10	10	10
5	15	10	10	10	5	10	15	15
6	5	5	10	10	10	10	10	10
7	15	15	10	5	10	10	10	10
8	15	20	10	10	15	15	15	10
9	10	10	10	5	15	15	15	5
10	15	15	10	5	15	10	15	15
11	10	10	10	10	15	15	15	10
12	15	10	5	5	15	10	15	10
13	5	10	10	10	10	5	10	5
14	10	5	15	10	15	15	15	10
15	10	10	10	15	10	10	5	5
16	15	10	10	15	15	10	10	10
17	10	15	10	5	10	10	10	10
18	10	10	5	5	15	10	10	10
19	5	10	10	10	10	10	10	10
20	10	10	10	10	15	10	10	15
21	10	10	10	10	10	10	10	5
22	15	15	15	15	15	10	10	5
23	15	10	10	15	10	15	5	5
24	10	10	10	15	15	15	5	5
25	10	10	10	5	5	10	15	20
Average	11.00	10.80	10.00	9.00	12.20	11.00	10.80	9.60
Minimum	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Maximum	15.00	20.00	15.00	15.00	15.00	15.00	15.00	20.00
Combined	10.90		9.50		11.60		10.20	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003

WINTER STEELHEAD SMOLTS

Date:	May 28, 2003		May 28, 2003		May 28, 2003		May 28, 2003	
Time:	2:45 PM		2:45 PM		3:40 PM		3:40 PM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 26a		Trial 26a		Trial 27		Trial 27	
	CLEANING		CLEANING		PRE-TEST		POST-TEST	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	10	10			5	10	10	15
2	10	10			5	10	15	10
3	5	10			10	10	10	15
4	5	5			10	10	5	10
5	5	5			10	10	5	10
6	5	10			10	10	10	10
7	10	5			10	10	10	10
8					10	10	10	10
9					15	15	10	10
10					15	10	10	10
11					10	5	15	10
12					15	10	10	10
13					15	15	10	15
14					10	10	10	10
15					10	10	5	10
16					10	10	10	5
17					15	10	10	10
18					15	15	5	5
19					10	15	10	5
20					5	5	10	10
21					10	10	10	10
22					10	10	*	*
23					10	5	*	*
24					10	10	*	*
25					10	5	*	*
Average	7.14	7.86	#DIV/0!	#DIV/0!	10.60	10.00	9.52	10.00
Minimum	5.00	5.00	0.00	0.00	5.00	5.00	5.00	5.00
Maximum	10.00	10.00	0.00	0.00	15.00	15.00	15.00	15.00
Combined	7.50		#DIV/0!		10.30		9.76	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date:	May 28, 2003		May 28, 2003		May 28, 2003		May 28, 2003	
Time:	3:22 PM		3:22 PM		3:37 PM		3:37 PM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 28		Trial 28		Trial 29		Trial 29	
	PRE-TEST		POST-TEST		PRE-TEST		POST-TEST	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	10	5	15	15	10	10	15	5
2	15	10	15	15	10	10	10	10
3	15	10	15	10	15	15	10	10
4	15	15	10	10	15	10	10	10
5	10	10	10	10	15	15	10	5
6	15	10	10	10	15	15	10	10
7	10	5	5	10	5	10	15	15
8	10	10	5	5	10	5	15	15
9	10	5	10	10	10	10	10	5
10	10	10	15	10	5	5	10	10
11	10	5	10	10	10	10	10	10
12	15	10	10	5	10	10	5	10
13	10	10	10	15	10	10	10	15
14	10	10	10	10	10	5	15	10
15	15	15	15	10	15	10	15	15
16	10	15	15	10	10	10	15	10
17	10	10	15	15	10	10	10	10
18	10	10	5	5	10	15	10	15
19	15	10	10	10	15	10	10	10
20	10	10	15	15	10	10	10	5
21	10	10	10	10	15	15	10	10
22	10	10	5	5	10	5	*	*
23	15	15	5	10	10	15	*	*
24	5	10	10	5	5	5	*	*
25	10	5	10	10	5	5	*	*
Average	11.40	9.80	10.60	10.00	10.60	10.00	11.19	10.24
Minimum	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Maximum	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Combined	10.60		10.30		10.30		10.71	

* Not captured, fish moved up stream.

** Fish Escaped

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
WINTER STEELHEAD SMOLTS

Date:	May 28, 2003		May 28, 2003		May 28, 2003		May 28, 2003	
Time:	3:37 PM		3:37 PM		4:15 PM		4:15 PM	
Species:	Steelhead Smolt		Steelhead Smolt		Steelhead Smolt		Steelhead Smolt	
Test #:	Trial 30		Trial 30		Trial 30a		Trial 30a	
	PRE-TEST		POST-TEST		CLEANING		CLEANING	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	15	10	15	10	10	5		
2	15	15	10	5	10	10		
3	10	15	15	10	10	5		
4	10	5	10	5	15	10		
5	10	10	10	10	15	10		
6	5	10	15	15	10	10		
7	10	15	10	10	15	15		
8	10	5	10	10	15	10		
9	10	10	10	10	10	10		
10	10	10	5	5	15	15		
11	10	10	5	10	15	10		
12	10	15	5	10	10	5		
13	10	5	10	15	10	5		
14	10	5	10	10	5	5		
15	10	10	10	10	10	10		
16	15	15	15	10	15	15		
17	15	10	10	5	10	10		
18	10	10	10	10	15	15		
19	10	5	10	10	15	10		
20	10	5	*	*				
21	10	10	*	*				
22	10	5	*	*				
23	10	10	*	*				
24	10	5	*	*				
25	5	5	*	*				
Average	10.40	9.20	10.26	9.47	12.11	9.74	#DIV/0!	#DIV/0!
Minimum	5.00	5.00	5.00	5.00	5.00	5.00	0.00	0.00
Maximum	15.00	15.00	15.00	15.00	15.00	15.00	0.00	0.00
Combined	9.80		9.87		10.92		#DIV/0!	

* Not captured, fish moved up stream.

** Fish Escaped

APPENDIX C

Chinook Fry Test Data for Year 2003

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
SPRING CHINOOK FRY

Date:	June 2, 2003		June 2, 2003		June 2, 2003		June 2, 2003	
Time:	4:19 PM		4:19 PM		3:55 PM		3:55 PM	
Species:	Chinook Fry		Chinook Fry		Chinook Fry		Chinook Fry	
Test #:	Trial 1 PRE-TEST		Trial 1 POST-TEST		Trial 1 PRE-CONTROL		Trial 1 POST-CONTROL	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

* -Not captured
0 -No Injury
1 -Eye Injury
2 -Fin Injury
3 -Gill Injury
4 -Bruise

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
SPRING CHINOOK FRY

Date:	June 2, 2003		June 2, 2003		June 2, 2003		June 2, 2003	
Time:	4:35 PM		4:35 PM		4:10 PM		4:10 PM	
Species:	Chinook Fry		Chinook Fry		Chinook Fry		Chinook Fry	
Test #:	Trial 2 PRE-TEST		Trial 2 POST-TEST		Trial 2 PRE-CONTROL		Trial 2 POST-CONTROL	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0
47	0	0	*	*	0	0	0	0
48	0	0	*	*	0	0	0	0
49	0	0	*	*	0	0	0	0
50	0	0	*	*	0	0	0	0
Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

* -Not captured
0 -No Injury
1 -Eye Injury
2 -Fin Injury
3 -Gill Injury
4 -Bruise

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003

SPRING CHINOOK FRY

Date:	June 3, 2003		June 3, 2003		June 2, 2003		June 2, 2003	
Time:	9:25 AM		9:25 AM		4:55 PM		4:55 PM	
Species:	Chinook Fry		Chinook Fry		Chinook Fry		Chinook Fry	
Test #:	Trial 3 PRE-TEST		Trial 3 POST-TEST		Trial 3 PRE-CONTROL		Trial 3 POST-CONTROL	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	1	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	1	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
Average	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00

* -Not captured
0 -No Injury
1 -Eye Injury
2 -Fin Injury
3 -Gill Injury
4 -Bruise

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003

SPRING CHINOOK FRY

Date:	June 3, 2003		June 3, 2003		June 3, 2003		June 3, 2003	
Time:	10:06 AM		10:06 AM		10:57 AM		10:57 AM	
Species:	Chinook Fry		Chinook Fry		Chinook Fry		Chinook Fry	
Test #:	Trial 4 PRE-TEST		Trial 4 POST-TEST		Trial 5 PRE-TEST		Trial 5 POST-TEST	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
38	0	0	0	1	0	0	0	0
39	0	0	0	0	0	0	0	0
40	0	1	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
Average	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00

* -Not captured
0 -No Injury
1 -Eye Injury
2 -Fin Injury
3 -Gill Injury
4 -Bruise

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
SPRING CHINOOK FRY

Date:	June 3, 2003		June 3, 2003	
Time:	11:08 AM		11:08 AM	
Species:	Chinook Fry		Chinook Fry	
Test #:	Trial 6		Trial 6	
	PRE-TEST		POST-TEST	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0
14	0	0	0	0
15	0	0	0	0
16	0	0	0	0
17	0	0	0	0
18	0	0	0	0
19	0	0	0	0
20	0	0	0	0
21	0	0	0	0
22	0	0	0	0
23	0	0	0	0
24	0	0	0	0
25	0	0	0	0
26	0	0	0	0
27	0	0	0	0
28	0	0	0	0
29	0	0	0	0
30	0	0	0	0
31	0	0	0	0
32	0	0	0	0
33	0	0	0	0
34	0	0	0	0
35	0	0	0	0
36	0	0	0	0
37	0	0	0	0
38	0	0	0	0
39	0	0	0	0
40	0	0	0	0
41	0	0	0	0
42	0	0	0	0
43	0	0	0	0
44	0	0	0	0
45	0	0	0	0
46	0	0	0	0
47	0	0	0	0
48	0	0	0	0
49	0	0	0	0
50	0	0	0	0
Average	0.00	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00

* -Not captured
0 -No Injury
1 -Eye Injury
2 -Fin Injury
3 -Gill Injury
4 -Bruise

APPENDIX D

Steelhead Fry Test Data for Year 2003

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
SUMMER STEELHEAD FRY

Date:	June 2, 2003		June 2, 2003		June 2, 2003		June 2, 2003	
Time:	8:52 AM		8:52 AM		9:48 PM		9:48 PM	
Species:	Steelhead Fry		Steelhead Fry		Steelhead Fry		Steelhead Fry	
Test #:	Trial 1		Trial 1		Trial 1		Trial 1	
	PRE-TEST		POST-TEST		PRE-CONTROL		POST-CONTROL	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	1	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	*	*	0	0	0	0
32	0	0	*	*	0	0	0	0
33	0	0	*	*	0	0	0	0
34	0	0	*	*	0	0	0	0
35	0	0	*	*	0	0	0	0
36	0	0	*	*	0	0	0	0
37	0	0	*	*	0	0	0	0
38	0	0	*	*	0	0	0	0
39	0	0	*	*	0	0	0	0
40	0	0	*	*	0	0	3	0
41	0	0	*	*	0	0	0	0
42	0	0	*	*	0	0	0	0
43	0	0	*	*	0	0	0	0
44	0	0	*	*	0	0	0	0
45	0	0	*	*	0	0	0	0
46	0	0	*	*	0	0	0	0
47	0	0	*	*	0	0	0	0
48	0	0	*	*	0	0	0	0
49	0	0	*	*	0	0	0	0
50	0	0	*	*	0	0	0	0
Average	0.00	0.00	0.00	0.03	0.00	0.00	0.06	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	1.00	0.00	0.00	3.00	0.00

* -Not captured
0 -No Injury
1 -Eye Injury
2 -Fin Injury
3 -Gill Injury
4 -Bruise

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
SUMMER STEELHEAD FRY

Date:	June 2, 2003		June 2, 2003		June 2, 2003		June 2, 2003	
Time:	9:08 AM		9:08 AM		10:03 AM		10:03 AM	
Species:	Steelhead Fry		Steelhead Fry		Steelhead Fry		Steelhead Fry	
Test #:	Trial 2		Trial 2		Trial 2		Trial 2	
	PRE-TEST		POST-TEST		PRE-CONTROL		POST-CONTROL	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	3	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0
42	0	0	*	*	0	0	0	0
43	0	0	*	*	0	0	0	0
44	0	0	*	*	0	0	0	0
45	0	0	*	*	0	0	0	0
46	0	0	*	*	0	0	0	0
47	0	0	*	*	0	0	0	0
48	0	0	*	*	0	0	0	0
49	0	0	*	*	0	0	0	0
50	0	0	*	*	0	0	0	0
Average	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	3.00	0.00

* -Not captured
0 -No Injury
1 -Eye Injury
2 -Fin Injury
3 -Gill Injury
4 -Bruise

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
SUMMER STEELHEAD FRY

Date:	June 2, 2003		June 2, 2003		June 2, 2003		June 2, 2003	
Time:	9:28 AM		9:28 AM		12:45 PM		12:45 PM	
Species:	Steelhead Fry		Steelhead Fry		Steelhead Fry		Steelhead Fry	
Test #:	Trial 3		Trial 3		Trial 3		Trial 3	
	PRE-TEST		POST-TEST		PRE-CONTROL		POST-CONTROL	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	*	*	0	0	0	0
35	0	0	*	*	0	0	0	0
36	0	0	*	*	0	0	0	0
37	0	0	*	*	0	0	0	0
38	0	0	*	*	0	0	0	0
39	0	0	*	*	0	0	0	0
40	0	0	*	*	0	0	0	0
41	0	0	*	*	0	0	0	0
42	0	0	*	*	0	0	0	0
43	0	0	*	*	0	0	0	0
44	0	0	*	*	0	0	0	0
45	0	0	*	*	0	0	0	0
46	0	0	*	*	0	0	0	0
47	0	0	*	*	0	0	0	0
48	0	0	*	*	0	0	0	0
49	0	0	*	*	0	0	0	0
50	0	0	*	*	0	0	0	0
Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

* -Not captured
0 -No Injury
1 -Eye Injury
2 -Fin Injury
3 -Gill Injury
4 -Bruise

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
SUMMER STEELHEAD FRY

Date:	June 2, 2003		June 2, 2003		June 2, 2003		June 2, 2003	
Time:	10:23 AM		10:23 AM		1:02 PM		1:02 PM	
Species:	Steelhead Fry		Steelhead Fry		Steelhead Fry		Steelhead Fry	
Test #:	Trial 4 PRE-TEST		Trial 4 POST-TEST		Trial 4 PRE-CONTROL		Trial 4 POST-CONTROL	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	*	*
50	0	0	0	0	0	0	*	*
Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

* -Not captured
0 -No Injury
1 -Eye Injury
2 -Fin Injury
3 -Gill Injury
4 -Bruise

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
SUMMER STEELHEAD FRY

Date:	June 2, 2003		June 2, 2003		June 2, 2003		June 2, 2003	
Time:	10:41 AM		10:41 AM		1:17 PM		1:17 PM	
Species:	Steelhead Fry		Steelhead Fry		Steelhead Fry		Steelhead Fry	
Test #:	Trial 5		Trial 5		Trial 5		Trial 5	
	PRE-TEST		POST-TEST		PRE-CONTROL		POST-CONTROL	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

* -Not captured
0 -No Injury
1 -Eye Injury
2 -Fin Injury
3 -Gill Injury
4 -Bruise

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
SUMMER STEELHEAD FRY

Date:	June 2, 2003		June 2, 2003		June 2, 2003		June 2, 2003	
Time:	10:56 AM		10:56 AM		1:33 PM		1:33 PM	
Species:	Steelhead Fry		Steelhead Fry		Steelhead Fry		Steelhead Fry	
Test #:	Trial 6		Trial 6		Trial 6		Trial 6	
	PRE-TEST		POST-TEST		PRE-CONTROL		POST-CONTROL	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	3	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
Average	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	3.00	0.00

* -Not captured
0 -No Injury
1 -Eye Injury
2 -Fin Injury
3 -Gill Injury
4 -Bruise

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
SUMMER STEELHEAD FRY

Date:	June 2, 2003		June 2, 2003		June 2, 2003		June 2, 2003	
Time:	11:11 AM		11:11 AM		1:55 PM		1:55 PM	
Species:	Steelhead Fry		Steelhead Fry		Steelhead Fry		Steelhead Fry	
Test #:	Trial 7 PRE-TEST		Trial 7 POST-TEST		Trial 8 PRE-TEST		Trial 8 POST-TEST	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	*	*
Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

* -Not captured
0 -No Injury
1 -Eye Injury
2 -Fin Injury
3 -Gill Injury
4 -Bruise

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
SUMMER STEELHEAD FRY

Date:	June 2, 2003		June 2, 2003		June 2, 2003		June 2, 2003	
Time:	2:15 PM		2:15 PM		2:32 PM		2:32 PM	
Species:	Steelhead Fry		Steelhead Fry		Steelhead Fry		Steelhead Fry	
Test #:	Trial 9		Trial 9		Trial 10		Trial 10	
	PRE-TEST		POST-TEST		PRE-TEST		POST-TEST	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	1	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	*	*
Average	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00

* -Not captured
0 -No Injury
1 -Eye Injury
2 -Fin Injury
3 -Gill Injury
4 -Bruise

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
SUMMER STEELHEAD FRY

Date:	June 2, 2003		June 2, 2003		June 2, 2003		June 2, 2003	
Time:	2:41 PM		2:41 PM		3:00 PM		3:00 PM	
Species:	Steelhead Fry		Steelhead Fry		Steelhead Fry		Steelhead Fry	
Test #:	Trial 11 PRE-TEST		Trial 11 POST-TEST		Trial 12 PRE-TEST		Trial 12 POST-TEST	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	3
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0
49	0	0	*	*	0	0	0	0
50	0	0	*	*	0	0	0	0
Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00

* -Not captured
0 -No Injury
1 -Eye Injury
2 -Fin Injury
3 -Gill Injury
4 -Bruise

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
SUMMER STEELHEAD FRY

Date:	June 2, 2003		June 2, 2003		June 2, 2003		June 2, 2003	
Time:	3:08 PM		3:08 PM		3:14 PM		3:14 PM	
Species:	Steelhead Fry		Steelhead Fry		Steelhead Fry		Steelhead Fry	
Test #:	Trial 13 PRE-TEST		Trial 13 POST-TEST		Trial 14 PRE-TEST		Trial 14 POST-TEST	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	1	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0
47	0	0	*	*	0	0	0	0
48	0	0	*	*	0	0	0	0
49	0	0	*	*	0	0	0	0
50	0	0	*	*	0	0	*	*
Average	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00

* -Not captured
0 -No Injury
1 -Eye Injury
2 -Fin Injury
3 -Gill Injury
4 -Bruise

HORIZONTAL FLAT PLATE FISH SCREEN TEST DATA - 2003
SUMMER STEELHEAD FRY

Date:	June 2, 2003		June 2, 2003	
Time:	3:25 PM		3:25 PM	
Species:	Steelhead Fry		Steelhead Fry	
Test #:	Trial 15		Trial 15	
	PRE-TEST		POST-TEST	
FISH	Lt side (%)	Rt side (%)	Lt side (%)	Rt side (%)
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0
14	0	0	0	0
15	0	0	0	0
16	0	0	0	0
17	0	0	0	0
18	0	0	0	0
19	0	0	0	0
20	0	0	0	0
21	0	0	0	0
22	0	0	0	0
23	0	0	0	0
24	0	0	0	0
25	0	0	0	0
26	0	0	0	0
27	0	0	0	0
28	0	0	0	0
29	0	0	0	0
30	0	0	0	0
31	0	0	0	0
32	0	0	0	0
33	0	0	0	0
34	0	0	0	0
35	0	0	0	0
36	0	0	0	0
37	0	0	0	0
38	0	0	0	0
39	0	0	0	0
40	0	0	0	0
41	0	0	0	0
42	0	0	0	0
43	0	0	0	0
44	0	0	0	0
45	0	0	0	0
46	0	0	0	0
47	0	0	*	*
48	0	0	*	*
49	0	0	*	*
50	0	0	*	*
Average	0.00	0.00	0.00	0.00
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00

* -Not captured
0 -No Injury
1 -Eye Injury
2 -Fin Injury
3 -Gill Injury
4 -Bruise

APPENDIX E

Length – Weight Data for Year 2003

FARMERS IRRIGATION DISTRICT FISH SCREEN TEST DATA - 2003

Overshot Horizontal Flat Plate Fish Screen - Farmers Canal

Date:	May 27, 2003 and May 28, 2003			June 2, 2003			June 3, 2003		
Race:	Winter			Summer			Spring		
Species:	Steelhead Smolt			Steelhead fry			Chinook fry		
	LENGTH AND WEIGHT			LENGTH AND WEIGHT			LENGTH AND WEIGHT		
FISH	Length (mm)	Weight (g)	Condition Factor	Length (mm)	Weight (g)	Condition Factor	Length (mm)	Weight (g)	Condition Factor
1	224	109.8	0.98	65	2.0	0.73	67	4.2	1.40
2	264	178.3	0.97	61	2.3	1.01	72	3.9	1.04
3	228	100.8	0.85	63	2.8	1.12	73	5.0	1.29
4	243	132.9	0.93	63	2.3	0.92	58	2.3	1.18
5	210	84.4	0.91	65	3.1	1.13	71	3.6	1.01
6	201	77.7	0.96	74	4.2	1.04	81	5.5	1.03
7	209	81.3	0.89	72	3.6	0.96	80	5.4	1.05
8	223	99.7	0.90	60	1.8	0.83	78	5.6	1.18
9	224	102.5	0.91	60	2.2	1.02	76	4.9	1.12
10	194	67.5	0.92	69	3.4	1.03	62	2.6	1.09
11	204	72.7	0.86	65	2.5	0.91	68	3.3	1.05
12	249	145.8	0.94	68	3.3	1.05	82	5.3	0.96
13	243	111.2	0.77	68	3.5	1.11	66	3.5	1.22
14	199	72.3	0.92	69	3.6	1.10	83	5.7	1.00
15	196	69.3	0.92	70	3.1	0.90	81	6.1	1.15
16	221	100.6	0.93	67	2.8	0.93	71	4.1	1.15
17	185	57.5	0.91	65	2.7	0.98	68	3.4	1.08
18	209	82.6	0.90	72	3.3	0.88	72	4.1	1.10
19	191	65.9	0.95	66	2.7	0.94	67	3.5	1.16
20	261	161.6	0.91	63	2.3	0.92	64	2.6	0.99
21	185	57.1	0.90	59	2.0	0.97	78	5.2	1.10
22	192	63.7	0.90	68	2.8	0.89	73	4.2	1.08
23	211	84.8	0.90	69	3.2	0.97	62	3.1	1.30
24	224	98.9	0.88	66	2.8	0.97	80	4.9	0.96
25	212	91.7	0.96	61	2.6	1.15	74	4.1	1.01
26	228	107.9	0.91	68	3.1	0.99	74	4.5	1.11
27	224	96.1	0.86	63	2.7	1.08	69	3.4	1.03
28	198	81.9	1.06	67	3.2	1.06	59	2.1	1.02
29	204	76.5	0.90	58	2.3	1.18	68	3.7	1.18
30	211	87.7	0.93	60	2.2	1.02	84	6.1	1.03
31	225	102.1	0.90	59	2.1	1.02	72	4.0	1.07
32	204	81.6	0.96	64	2.9	1.11	70	4.0	1.17
33	209	80.5	0.88	64	2.5	0.95	63	3.1	1.24
34	165	40.5	0.90	67	3.0	1.00	66	3.1	1.08
35	179	57.4	1.00	60	2.1	0.97	75	4.5	1.07
36	220	95.3	0.90	62	2.6	1.09	73	3.9	1.00
37	189	58.0	0.86	61	2.2	0.97	72	3.8	1.02
38	169	48.2	1.00	60	2.4	1.11	73	4.5	1.16
39	233	124.5	0.98	70	3.4	0.99	74	4.7	1.16
40	222	106.5	0.97	65	2.6	0.95	68	3.5	1.11
41	186	64.1	1.00	64	2.8	1.07	77	5.2	1.14
42	214	88.2	0.90	59	2.1	1.02	68	3.5	1.11
43	205	77.3	0.90	61	2.5	1.10	71	4.4	1.23
44	216	92.4	0.92	59	2.1	1.02	70	3.7	1.08
45	187	62.4	0.95	59	2.1	1.02	63	2.5	1.00
46	224	101.3	0.90	63	2.6	1.04	69	4.0	1.22

FARMERS IRRIGATION DISTRICT FISH SCREEN TEST DATA - 2003

Overshot Horizontal Flat Plate Fish Screen - Farmers Canal

Date:	May 27, 2003 and May 28, 2003			June 2, 2003			June 3, 2003		
Race:	Winter			Summer			Spring		
Species:	Steelhead Smolt			Steelhead fry			Chinook fry		
	LENGTH AND WEIGHT			LENGTH AND WEIGHT			LENGTH AND WEIGHT		
FISH	Length (mm)	Weight (g)	Condition Factor	Length (mm)	Weight (g)	Condition Factor	Length (mm)	Weight (g)	Condition Factor
47	187	56.5	0.86	65	2.9	1.06	65	3.2	1.17
48	190	59.0	0.86	63	2.7	1.08	73	4.9	1.26
49	190	57.6	0.84	64	3.1	1.18	78	5.5	1.16
50	179	52.3	0.91	64	3.0	1.14	76	4.9	1.12
51	191	57.5	0.83	64	2.6	0.99	73	3.9	1.00
52	181	57.0	0.96	66	3.0	1.04	74	4.9	1.21
53	210	83.4	0.90	56	1.9	1.08	71	3.7	1.03
54	208	74.2	0.82	64	2.6	0.99	68	3.6	1.14
55	242	113.8	0.80	56	1.9	1.08	66	2.9	1.01
56	199	74.1	0.94	66	3.0	1.04	75	4.3	1.02
57	237	122.3	0.92	55	1.9	1.14	70	3.5	1.02
58	186	59.2	0.92	63	2.6	1.04	68	3.8	1.21
59	205	82.9	0.96	68	3.2	1.02	68	3.8	1.21
60	231	120.5	0.98	67	3.0	1.00	71	4.0	1.12
61	206	79.5	0.91	56	1.9	1.08	66	3.4	1.18
62	196	79.7	1.06	61	2.1	0.93	67	3.1	1.03
63	211	87.5	0.93	64	2.8	1.07	64	2.8	1.07
64	233	108.3	0.86	65	3.0	1.09	66	2.9	1.01
65	237	114.8	0.86	62	2.6	1.09	60	2.6	1.20
66	233	102.5	0.81	59	2.1	1.02	62	2.9	1.22
67	252	152.3	0.95	64	2.7	1.03	75	4.1	0.97
68	223	91.3	0.82	55	1.6	0.96	62	2.3	0.97
69	197	75.8	0.99	65	2.8	1.02	63	2.9	1.16
70	194	63.7	0.87	60	2.9	1.34	69	3.7	1.13
71	219	88.9	0.85	63	2.6	1.04	60	2.5	1.16
72	219	89.3	0.85	68	3.1	0.99	59	2.6	1.27
73	207	79.7	0.90	65	2.8	1.02	72	4.0	1.07
74	206	81.8	0.94	65	2.7	0.98	70	3.9	1.14
75	221	104.4	0.97	64	2.8	1.07	63	2.7	1.08
76	249	133.4	0.86	67	2.9	0.96	64	2.8	1.07
77	202	79.6	0.97	62	2.2	0.92	63	3.0	1.20
78	186	63.5	0.99	63	2.4	0.96	59	2.4	1.17
79	242	143.1	1.01	63	2.6	1.04	71	4.2	1.17
80	225	105.3	0.92	69	3.3	1.00	68	2.9	0.92
81	213	88.9	0.92	68	3.6	1.14	72	4.2	1.13
82	208	76.4	0.85	64	2.5	0.95	80	5.4	1.05
83	229	111.7	0.93	63	3.1	1.24	66	3.1	1.08
84	194	68.8	0.94	63	2.7	1.08	75	4.1	0.97
85	206	95.5	1.09	64	3.0	1.14	72	4.3	1.15
86	210	81.0	0.87	67	3.4	1.13	72	4.0	1.07
87	230	103.6	0.85	66	3.3	1.15	77	3.2	0.70
88	186	62.2	0.97	66	2.9	1.01	74	4.3	1.06
89	209	82.9	0.91	65	2.8	1.02	76	4.3	0.98
90	239	134.5	0.99	62	2.6	1.09	58	2.3	1.18
91	208	83.4	0.93	68	3.5	1.11	66	2.9	1.01
92	185	56.7	0.90	67	3.1	1.03	67	3.0	1.00

FARMERS IRRIGATION DISTRICT FISH SCREEN TEST DATA - 2003

Overshot Horizontal Flat Plate Fish Screen - Farmers Canal

Date:	May 27, 2003 and May 28, 2003			June 2, 2003			June 3, 2003		
Race:	Winter			Summer			Spring		
Species:	Steelhead Smolt			Steelhead fry			Chinook fry		
	LENGTH AND WEIGHT			LENGTH AND WEIGHT			LENGTH AND WEIGHT		
FISH	Length (mm)	Weight (g)	Condition Factor	Length (mm)	Weight (g)	Condition Factor	Length (mm)	Weight (g)	Condition Factor
93	202	79.2	0.96	61	2.5	1.10	67	3.3	1.10
94	186	47.1	0.73	52	1.3	0.92	80	5.6	1.09
95	152	30.8	0.88	64	3.1	1.18	69	3.9	1.19
96	232	140.8	1.13	58	2.1	1.08	65	3.4	1.24
97	182	58.1	0.96	69	3.5	1.07	66	3.6	1.25
98	190	68.9	1.00	62	2.2	0.92	75	4.7	1.11
99	186	57.2	0.89	64	2.8	1.07	75	4.9	1.16
100	184	55.1	0.88	61	2.3	1.01	76	5.2	1.18
101	216	96.9	0.96	68	3.5	1.11	64	2.4	0.92
102	228	125.8	1.06	59	2.0	0.97	75	4.3	1.02
103	204	69.9	0.82	66	3.3	1.15	66	2.5	0.87
104	191	64.8	0.93	63	2.7	1.08	74	3.9	0.96
105	190	65.2	0.95	68	3.5	1.11	68	3.5	1.11
106	189	64.7	0.96	60	2.1	0.97	64	2.9	1.11
107	182	50.4	0.84	61	2.5	1.10	68	3.5	1.11
108	195	70.8	0.95	61	2.5	1.10	62	2.4	1.01
109	188	62.9	0.95	58	2.1	1.08	77	5.2	1.14
110	186	54.3	0.84	66	3.2	1.11	64	3.3	1.26
111	155	33.8	0.91	62	2.6	1.09	73	4.2	1.08
112	230	120.4	0.99	61	2.4	1.06	68	3.2	1.02
113	216	85.5	0.85	60	2.3	1.06	69	4.0	1.22
114	251	147.2	0.93	65	2.9	1.06	65	2.9	1.06
115	233	129.2	1.02	61	2.4	1.06	69	3.4	1.03
116	209	89.0	0.97	68	3.2	1.02	68	3.7	1.18
117	230	114.3	0.94	64	2.9	1.11	82	6.4	1.16
118	254	167.8	1.02	60	2.6	1.20	66	3.2	1.11
119	209	81.0	0.89	67	2.9	0.96	75	4.8	1.14
120	212	76.7	0.80	61	2.3	1.01	74	5.1	1.26
121	214	82.0	0.84	65	3.2	1.17	72	4.2	1.13
122	204	76.5	0.90	56	1.6	0.91	70	3.8	1.11
123	234	132.5	1.03	55	1.8	1.08	59	2.2	1.07
124	227	112.8	0.96	55	1.5	0.90	65	3.2	1.17
125	225	104.7	0.92	68	2.8	0.89	73	4.6	1.18
126	201	85.6	1.05	56	1.6	0.91	78	5.1	1.07
127	205	86.0	1.00	60	2.4	1.11	70	4.0	1.17
128	160	37.4	0.91	59	2.2	1.07	66	3.3	1.15
129	221	96.7	0.90	58	2.0	1.03	74	4.6	1.14
130	226	104.9	0.91	56	1.8	1.02	76	5.0	1.14
131	244	126.7	0.87	57	2.0	1.08	81	5.8	1.09
132	182	61.4	1.02	53	1.5	1.01	70	3.8	1.11
133	186	61.0	0.95	58	2.0	1.03	73	4.3	1.11
134	198	74.8	0.96	56	1.7	0.97	70	3.9	1.14
135	199	69.0	0.88	61	2.1	0.93	60	2.2	1.02
136	219	94.8	0.90	60	2.2	1.02	64	3.0	1.14
137	195	72.2	0.97	57	1.8	0.97	81	4.0	0.75
138	173	50.2	0.97	61	2.4	1.06	73	4.6	1.18

FARMERS IRRIGATION DISTRICT FISH SCREEN TEST DATA - 2003

Overshot Horizontal Flat Plate Fish Screen - Farmers Canal

Date:	May 27, 2003 and May 28, 2003			June 2, 2003			June 3, 2003		
Race:	Winter			Summer			Spring		
Species:	Steelhead Smolt			Steelhead fry			Chinook fry		
	LENGTH AND WEIGHT			LENGTH AND WEIGHT			LENGTH AND WEIGHT		
FISH	Length (mm)	Weight (g)	Condition Factor	Length (mm)	Weight (g)	Condition Factor	Length (mm)	Weight (g)	Condition Factor
139	183	54.4	0.89	56	1.9	1.08	76	5.0	1.14
140	187	51.6	0.79	56	1.9	1.08	73	4.9	1.26
141	205	77.7	0.90	61	2.3	1.01	71	4.0	1.12
142	196	69.2	0.92	60	2.1	0.97	72	4.2	1.13
143	181	55.9	0.94	52	1.3	0.92	61	2.6	1.15
144	226	101.3	0.88	54	1.7	1.08	68	3.2	1.02
145	223	103.4	0.93	57	1.8	0.97	69	3.6	1.10
146	212	89.7	0.94	51	1.4	1.06	69	3.5	1.07
147	152	32.6	0.93	57	2.4	1.30	72	4.0	1.07
148	235	112.8	0.87	58	1.8	0.92	74	4.5	1.11
149	239	120.6	0.88	61	2.1	0.93	68	3.6	1.14
150	186	58.2	0.90	75	4.1	0.97	70	3.6	1.05
151	191	69.9	1.00	69	2.8	0.85	82	5.9	1.07
152	148	28.3	0.87	65	3.2	1.17	68	3.6	1.14
153	199	74.6	0.95	62	2.5	1.05	80	5.2	1.02
154	204	80.0	0.94	68	3.6	1.14	74	4.5	1.11
155	206	86.1	0.98	65	2.8	1.02	73	5.0	1.29
156	186	61.7	0.96	65	2.9	1.06	77	5.1	1.12
157	203	78.1	0.93	67	2.9	0.96	78	5.6	1.18
158	241	125.6	0.90	65	2.7	0.98	60	2.5	1.16
159	211	92.3	0.98	61	2.2	0.97	60	2.3	1.06
160	209	71.8	0.79	62	2.5	1.05	71	3.9	1.09
161	200	72.5	0.91	75	3.7	0.88	70	3.9	1.14
162	174	50.6	0.96	70	3.1	0.90	75	5.1	1.21
163	219	111.1	1.06	69	3.6	1.10	65	3.2	1.17
164	159	36.5	0.91	63	2.6	1.04	68	4.2	1.34
165	188	55.7	0.84	57	1.6	0.86	77	5.5	1.20
166	214	90.3	0.92	64	2.6	0.99	82	5.4	0.98
167	180	54.3	0.93	66	3.2	1.11	73	4.2	1.08
168	183	57.8	0.94	66	3.3	1.15	79	5.3	1.07
169	172	50.2	0.99	67	3.8	1.26	62	2.6	1.09
170	189	65.8	0.97	58	2.1	1.08	65	2.6	0.95
171	190	64.5	0.94	59	2.2	1.07	64	2.5	0.95
172	169	44.7	0.93	67	2.9	0.96	75	4.7	1.11
173	184	57.2	0.92	68	2.7	0.86	64	3.1	1.18
174	251	176.7	1.12	61	2.6	1.15	73	4.6	1.18
175	207	85.3	0.96	68	3.1	0.99	73	4.5	1.16
176	221	104.5	0.97	63	2.6	1.04	78	4.8	1.01
177	182	61.9	1.03	60	2.5	1.16	65	3.2	1.17
178	220	85.2	0.80	66	3.2	1.11	66	3.5	1.22
179	218	79.5	0.77	57	1.8	0.97	74	4.8	1.18
180	202	74.1	0.90	66	3.0	1.04	67	2.5	0.83
181	240	143.4	1.04	68	3.5	1.11	57	2.2	1.19
182	235	119.2	0.92	56	1.8	1.02	63	2.3	0.92
183	227	110.5	0.94	63	2.3	0.92	66	3.2	1.11
184	236	130.3	0.99	67	3.1	1.03	69	3.1	0.94

FARMERS IRRIGATION DISTRICT FISH SCREEN TEST DATA - 2003

Overshot Horizontal Flat Plate Fish Screen - Farmers Canal

Date:	May 27, 2003 and May 28, 2003			June 2, 2003			June 3, 2003		
Race:	Winter			Summer			Spring		
Species:	Steelhead Smolt			Steelhead fry			Chinook fry		
	LENGTH AND WEIGHT			LENGTH AND WEIGHT			LENGTH AND WEIGHT		
FISH	Length (mm)	Weight (g)	Condition Factor	Length (mm)	Weight (g)	Condition Factor	Length (mm)	Weight (g)	Condition Factor
185	201	75.7	0.93	60	2.2	1.02	66	3.3	1.15
186	185	61.3	0.97	61	2.9	1.28	75	4.6	1.09
187	243	149.3	1.04	67	3.4	1.13	72	4.3	1.15
188	209	91.8	1.01	57	2.2	1.19	70	3.5	1.02
189	178	35.6	0.63	61	2.3	1.01	71	4.2	1.17
190	198	75.5	0.97	58	2.1	1.08	68	3.0	0.95
191	209	77.7	0.85	60	2.3	1.06	65	2.7	0.98
192	210	107.1	1.16	52	2.0	1.42	63	4.1	1.64
193	198	67.7	0.87	63	2.6	1.04	63	2.7	1.08
194	216	93.1	0.92	59	2.2	1.07	68	3.5	1.11
195	163	38.7	0.89	58	1.8	0.92	69	3.3	1.00
196	204	80.6	0.95	64	2.9	1.11	67	3.1	1.03
197	197	60.5	0.79	59	2.0	0.97	76	4.4	1.00
198	238	119.2	0.88	63	2.5	1.00	72	3.9	1.04
199	245	142.0	0.97	59	2.3	1.12	67	3.8	1.26
200	244	139.2	0.96	64	2.7	1.03	68	3.8	1.21
201	192	63.4	0.90	61	2.3	1.01	65	3.5	1.27
202	227	109.8	0.94	59	2.1	1.02	75	4.6	1.09
203	212	90.3	0.95	59	1.8	0.88	62	2.7	1.13
204	182	54.5	0.90	56	2.1	1.20	65	3.0	1.09
205	224	104.9	0.93	58	1.5	0.77	75	4.7	1.11
206	244	124.7	0.86	48	1.2	1.09	63	2.4	0.96
207	178	54.5	0.97				70	3.5	1.02
208	198	67.0	0.86				65	3.2	1.17
209	209	78.9	0.86				57	2.1	1.13
210	224	105.9	0.94				72	4.1	1.10
211	195	71.3	0.96				59	2.6	1.27
212	163	41.7	0.96				51	1.4	1.06
Average	207	85.1	0.92	63	2.6	1.04	70	3.8	1.11
Minimum	148	28.3	0.63	48	1.2	0.73	51	1.4	0.70
Maximum	264	178.3	1.16	75	4.2	1.42	84	6.4	1.64

APPENDIX F

Latent Mortality Data for Year 2003

Latent Mortality Data for Steelhead and Chinook Fry, and Steelhead Smolts for Spring 2003 Tests.

Holding Time (hrs)	Chinook Fry		Steelhead Fry		Steelhead Smolts	
	Test	Control	Test	Control	Test	Control
24	0	0	0	0	0	0
48	0	0	0	0	0	1
72	0	0	0	0	0	0
96	0	0	0	0	4	3
Total Count	**0**	**0**	**0**	**0**	**4**	**4**
Fish Held	**296**	**150**	**704**	**300**	**659**	**224**
% Mortality	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.6%**	**1.8%**

FARMERS IRRIGATION DISTRICT BETA FISH SCREEN TESTS - 2003

LATENT MORTALITY DATA -- STEELHEAD SMOLTS

	May 27 Tests		May 28 Tests		Combined Data	
Holding Time (hrs)	**Test Count**	**Control Count**	**Test Count**	**Control Count**	**Test Count**	**Control Count**
24	0	0	0	0	0	0
48	0	1	0	0	0	1
72	0	0	0	0	0	0
96	0	2	* 4	1	4	3
Total Count	**0**	**3**	4	**1**	**4**	4
Fish Held	183	167	476	57	659	224
% Mortality	**0.0%**	**1.8%**	**0.8%**	**1.8%**	**0.6%**	**1.8%**

* Note: Net pen very crowded. Net heavily occluded with algae. Flow through net was very low.

FARMERS IRRIGATION DISTRICT BETA FISH SCREEN TESTS - 2003

LATENT MORTALITY DATA -- FRY

Holding Time (hrs)	Steelhead Test Count	Steelhead Control Count	Chinook Test Count	Chinook Control Count	Combined Data Test Count	Combined Data Control Count
24	0	0	0	0	0	0
48	0	0	0	0	0	0
72	0	0	0	0	0	0
96	0	0	0	0	0	0
Total Count	**0**	**0**	**0**	**0**	**0**	**0**
Fish Held	704	300	296	150	1000	450
% Mortality	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

Appendix G - Mesa, M.G., Rose, B.P., and Copeland, E.S., 2010, Biological Evaluations of an Off-Stream Channel, Horizontal Flat-Plate Fish Screen – The Farmers Screen: U.S. Geological Survey Open-File Report 2010-1042

Biological Evaluations of an Off-Stream Channel, Horizontal Flat-Plate Fish Screen—The Farmers Screen

Open-File Report 2010–1042

U.S. Department of the Interior
U.S. Geological Survey

Biological Evaluations of an Off-Stream Channel, Horizontal Flat-Plate Fish Screen—The Farmers Screen

By Matthew G. Mesa, Brien P. Rose, and Elizabeth S. Copeland

Open-File Report 2010–1042

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2010

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Conversion Factors and Abbreviations and Symbols

Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
	Flow rate	
centimeter per second (cm/s)	0.0328	feet per second
cubic meter per second (m^3/s)	35.31	Cubic feet per second

Abbreviations and Symbols

Abbreviation and Symbol	Meaning
AV	approach velocity
CRRL	Columbia River Research Laboratory
FID	Farmers Irrigation District
FL	fork length
h	hour
mg/L	milligram per liter
NMFS	National Marine Fisheries Service
NV	normal velocity
s	second
SV	sweeping velocity
UV	ultraviolet
Z	water depth
<	less than
>	greater than

Biological Evaluations of an Off-Stream Channel, Horizontal Flat-Plate Fish Screen—The Farmers Screen

By Matthew G. Mesa, Brien P. Rose, and Elizabeth S. Copeland

Abstract

Screens commonly are installed at water diversion sites to reduce entrainment of fish. Recently, the Farmers Irrigation District (Oregon) developed a flat-plate screen design (that is, the Farmers Screen) that operates passively and may offer reduced installation and operation costs to irrigators. To evaluate the performance of this type of screen (its biological effect on fish), we conducted two separate field experiments in consecutive years. First, in 2009, two size classes of juvenile coho salmon (*Oncorhynchus kistuch*) were released over a small working version of this screen at Herman Creek, Oregon. The screen was evaluated over a range of inflow [0.02–0.42 cubic meters per second (m^3/s)] and diversion flows (0.02–0.34 m^3/s) at different weir wall heights. The mean approach velocities ranged from 0 to 5 centimeters per second and mean sweeping velocities ranged from 36 to 178 centimeters per second. Water depths over the screen surface ranged from 1 to 25 centimeters and were directly related to weir wall height and inflow. Passage of juvenile coho salmon over the screen under various hydraulic conditions did not severely injure the fish or cause delayed mortality. Injury or mortality did not occur even though many fish contacted the screen surface during passage. No fish were observed becoming impinged on the screen surface. Second, in 2010, we constructed a modular screen apparatus that had 34 meters of wooden flume connected to a 3.5-meter long section of the Farmers Screen to determine whether fish would refuse to pass over the screen and swim back upstream after encountering the leading edge of the screen under various hydraulic conditions. For these tests, smolting coho salmon and steelhead trout (*O. mykiss*) were released at the upstream end of the flume and allowed to volitionally move downstream and pass over the screen. Overall, 81 and 91 percent of the fish moved downstream through the entire apparatus within 5 and 25 minutes from their release and only 1 of the 275 fish released swam back upstream after encountering the screen. Collectively, our results indicate that when operated within its design criteria, the Farmers Screen provided safe and efficient downstream passage of juvenile salmonids under various hydraulic conditions. However, we do not recommend operating the Herman Creek screen at inflows less than 0.14 m^3/s because water depth can be quite shallow and the screen can completely dewater, particularly at low flows.

Introduction

Diversions from natural or manmade waterways are common in the United States and the water is used for many purposes. Many diversion structures are fitted with screens meant to prevent fishes and other aquatic life from becoming entrained in the diversion, injured, or killed. However, many thousands of water diversions remain unscreened. Some screening technology (for example, submersible traveling screens or rotary drum screens) and design criteria meant to protect fishes [National Marine Fisheries Service (NMFS), 2008] are relatively expensive and require frequent maintenance to operate properly (McMichael and others, 2004), which can limit the installation of screens in areas where screens are needed. Recently, the development of unique horizontal flat-plate fish screens offer designs that may be less expensive to install, offer simpler, more passive operation, and may have fewer detrimental effects on aquatic communities. Research on the hydraulic characteristics and biological effects of some flat-plate screens has been promising (Beyers and Bestgen, 2001; Frizell and Mefford, 2001; and Rose and others, 2008), but more work is needed to fully evaluate the performance of flat-plate screens. Evaluating different designs and sizes of horizontal flat-plate screens in the laboratory and in the field would allow further verification of screen performance, provide data for comparison with criteria for more traditional fish screens, and perhaps facilitate screen installation.

We evaluated the hydraulic and biological performance of a newly developed, off-stream channel horizontal flat-plate fish screen, also known as the Farmers Screen. These screens, designed over a 10-year period by personnel from the Farmers Irrigation District in Hood River, Oregon, have a higher rate of horizontal movement of water across the screen (sweeping velocity, SV) relative to the rate of movement of water through the screen (approach velocity, AV), good self-cleaning characteristics, the potential for reduced impingement, injury, and entrainment of fish, and may reduce installation and maintenance costs. The screens are manufactured in various sizes—a large version, designed to accommodate flows as large as 2.27 m^3/s, was subjected to hydraulic, debris-loading, and biological tests to evaluate injury and mortality to juvenile salmonids, including Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*). The test results showed that the large Farmers Screen did not cause injury or mortality to fish when operated in accordance with its design parameters **(**Craven Consulting Group, 2003). However, smaller versions of this screen have not been tested. Such evaluations would help to more fully evaluate the performance of these alternative technology screens.

The U.S. Geological Survey's Columbia River Research Laboratory (CRRL) conducted field experiments to assess the performance of this screen type during 2009 and 2010. The objectives of the study were to assess the hydraulic performance of the Farmers Screen and determine the effects of downstream passage of fish over the screen on their injury, delayed mortality, and behavior under various hydraulic conditions. This paper describes the study methods and results of those experiments.

Study Methods

Screen hydraulics and biological performance (2009)—The screen evaluated for its hydraulic and biological performance was located at the Oxbow Fish Hatchery in Cascade Locks, Oregon (fig. 1). The screen is on a side-channel of Herman Creek, a tributary of the Columbia River, and is designed to divert 0.28 m^3/s of water. The installation is similar to other Farmers Screens that have already been installed in the Pacific Northwest. For a complete description of this screen and of the Farmers Screen in general, see Farmers Conservation Alliance, 2006, *http://www.farmerscreen.org/*. For purposes of this report, we refer to this screen as the Herman Creek screen.

To assess the hydraulic performance of the Herman Creek screen, we adjusted the inflow entering the screen, measured the inflow and water depth (Z), diversion discharge, and bypass discharge, and calculated mean SV, AV, and normal velocity (NV, which is the AV multiplied by the percentage of open area of the screen, or AV × 0.5) under different weir wall heights. After most of these hydraulic conditions were measured, we experimentally released fish over the screen. We evaluated the screen under four weir wall heights (that is, 4, 11, 13, and 20 cm) and at inflows ranging from 0.02 to 0.42 m^3/s. We used multiple linear regression analysis to evaluate the influence of several continuous and discrete variables (for example, streamflow, weir wall height) on water depth over the screen, diversion discharge, and sweeping velocity. All coefficients are significant at the $P < 0.05$ level unless noted.

To assess the biological performance of the Herman Creek screen, we experimentally released groups of juvenile coho salmon (*O. kistuch*) over the screen under various hydraulic conditions and quantified any injuries to the integument of the fish and documented short-term delayed mortality. Our test fish were from the Oxbow Hatchery and we evaluated two size groups, large [85–145 mm FL (fork length)] and small (54–78 mm FL)], in two separate sets of trials. Fish that passed over the screen (treatment fish) were released in groups of 10, at a distance of 1–2 m above the upper edge of the screen, and were recaptured in a net beneath the bypass outfall. Control fish were released into the bypass outfall and captured in a net and held for several minutes to simulate the time it took most treatment fish to pass over the screen. We used a fluorescein dye method described by Noga and Udomkusonsri (2002) to determine the extent of ulceration on the skin, eyes, and fins of each fish. After capture, both groups of fish were euthanized in a lethal dose of MS-222 (200 mg/L), rinsed in a freshwater bath for 1 minute, and then placed in a solution of fluorescein dye (fluorescein disodium salt at 20 mg/L). After 6 minutes, fish were removed from the dye and rinsed in three separate freshwater baths over 3 minutes to remove excess dye. Images were taken of both sides of each fish in a dark box under ultraviolet (UV) light using a digital camera with a 200-mm macro lens. The UV lights were placed at 45° angles to the side of the fish and a yellow barrier filter was used to eliminate the blue auto-fluorescence. Images were imported into Adobe© Photoshop CS3 and the body surface area and area of fluorescence was measured on each side of a fish. The percentage of body surface area of a fish that was injured was derived by dividing the total area of fluorescence by the total body surface area. This included the two sides and most, but not all, of the dorsal and ventral surfaces of the fish. For each release group, we compared the percentage of body surface area of the fish that was injured for control and treatment fish using two-sample, Mann-Whitney *U* tests. We were interested in whether the levels of injury in treatment fish were significantly different than those of control fish. The level of significance was set at $P < 0.05$.

To assess delayed mortality after passage, additional fish were released in the same manner as described above but were transported to holding tanks after being collected in the bypass outfall. Fish were monitored for 24–48 h after passage and handling and the number of fish that died was compared between treatment and control groups. Mortality tests were conducted for most, but not all, of the same hydraulic conditions as injury tests.

To document the behavior of fish passing over the screen, treatment fish were videotaped using three underwater cameras mounted to one edge of the screen. The system was not designed to cover the entire screen area, and each camera provided only a partial, upstream view of the screen. Video files were reviewed in slow motion, and the approximate number of times fish contacted the screen, their orientation to the current during passage, and their general depth of passage were recorded. Control fish were not videotaped.

Behavioral responses of fish encountering the leading edge of a screen (2010)—To evaluate whether fish would refuse to pass over the screen after encountering the leading edge (a question we did not answer in 2009), we constructed a modular screen apparatus that had 34 m of wooden flume (46-cm wide by 36-cm deep) connected to a 3.1-m (long section of the Farmers Screen (fig. 2). The purpose of the long flume was to provide fish with plenty of distance between their release point (at the upstream end of the flume) and the upstream edge of the screen so the fish could orient themselves and move downstream somewhat naturally. The flume received water from the outflow of the Herman Creek Screen and was designed so that water velocities were slower in the upstream one-half of the flume than in the downstream one-half. We installed a trap on the downstream end of the screen to capture the fish.

We used yearling coho salmon (113–161 mm FL) from the Oxbow State Fish Hatchery (Oregon) and Skamania-stock steelhead (134–260 mm FL) from the Bonneville Fish Hatchery (Oregon) for tests. We used fish presumably undergoing the process of smoltification to maximize the probability that the fish would have a strong desire to migrate downstream. All the test fish were large and silvery with faint or non-existent parr marks. These fish should have had a relatively strong swimming ability (compared to smaller fish) and thus would be most likely to reject the screen if conditions posed a behavioral obstacle. Normally, these fish would have been released from the hatcheries during mid-April to early May. Prior to testing, all fish were held in large tanks at the Oxbow State Fish Hatchery and water temperatures were monitored daily.

On the day of testing, we first established the hydraulic conditions for the test, including inflow volume, water depth, AV, and SV over the screen, and water velocity and depths at several locations throughout the flume. Our intent was to test fish under various hydraulic conditions over the screen. We then removed 10 fish from their holding tank, placed them in a 19-L bucket with water, transported them from the hatchery to the test facility (about 2 km), and gently released them at the upstream end of the flume. Fish were allowed 20 minutes to volitionally migrate down the flume and pass over the screen. After 20 minutes, we gently prodded any fish that remained in the upper 3 m of the flume until the fish moved downstream. We conducted three to four releases of about 10 fish each, for a total release of 20–40 fish for each species under the various hydraulic conditions.

An observer was stationed on an elevated platform slightly upstream of the fish screen to record the behavior and passage timing of fish as they approached the screen. For each of five consecutive 5-minute periods, we recorded the number of fish that encountered the screen and whether the fish passed over the screen or refused to (that is, the fish turned and swam back upstream). For our analysis, we pooled data from the release groups for each species and hydraulic condition and determined the proportion of fish that passed over or rejected the screen for each time period. We also tallied data from each time period and determined the proportion of fish that passed over the screen within 25 minutes of their release.

Results of Field Experiments

Screen hydraulics and biological performance (2009)—Hydraulic conditions measured at the Herman Creek screen and the numbers of coho salmon released for injury and delayed mortality assessments are summarized in table 1. Diversion discharges (the volume of water collected from the screen and sent to the hatchery) comprised from 65 to 100 percent of the inflow rates. Mean AVs estimated for the entire screen ranged from 0 to 5 cm/s and for individual sections of the screen, mean AVs never exceeded 6 cm/s. Mean NVs ranged from 0 to 10 cm/s and varied along the length of the screen (fig. 3). Mean SVs ranged from 36 to 178 cm/s and generally were faster at the upstream edge and slower at the downstream edge of the screening panels. Mean SVs usually were at least 32 times higher than AVs for all conditions tested. The mean Z ranged from 1 to 25 cm and generally was deeper at the upstream end of the screen than at the downstream end. Mean depths were directly related to weir wall height and inflow and were inversely related to diversion discharge (R^2= 0.84; table 2), mean SVs were inversely related to weir wall height and diversion discharge and were directly related to inflow (R^2= 0.81; table 2), and diversion discharge was related to several variables (R^2= 0.99; table 2). "Hot spots" or localized areas of high AV with spiraling flow were not observed during any of our tests.

Overall, the injury rates of fish after passage over the Herman Creek screen were low, and severe injuries to the skin, eyes, and fins of both size cohorts were not observed. For large fish, the mean percentage of body surface area that was injured varied by release group and ranged from about 0.5 to 2.5 percent (fig. 4). The mean percentage of body surface area that was injured in treatment fish was significantly different than that of control fish for all test conditions (Mann-Whitney *U* tests, $P < 0.05$; fig. 4), but the magnitude of these differences was small (< 1 percent). For small fish, the mean percentage of body surface area that was injured ranged from about 0.4 to 3.0 percent (fig. 5). The mean percentage of body surface area that was injured in treatment fish was significantly different than that in control fish for three test conditions (fig. 5), but again, the magnitude of this difference was small (< 1 percent). One small fish, shown as an outlier in figure 5 with about 60 percent of its body surface area injured, probably was injured by something other than passage over the screen. For delayed mortality after passage, we tested 849 fish in total and none died within 24–48 h of passage or handling and only one control fish died.

The results of our video analysis revealed that for large fish, the mean number of times fish contacted the screen surface ranged from 0.15 to 0.72 per fish observed (table 3). During passage, most fish remained low in the water column near the screen surface (table 3). Fish were oriented either upstream or downstream during passage, with no clear relation to the hydraulic conditions (table 3). For small fish, the mean number of times fish contacted the screen surface ranged from 0.26 to 0.62 per fish observed (table 4). Again, most fish remained low in the water column and near the screen surface during passage. Most fish were oriented upstream during passage.

Behavioral responses of fish encountering the leading edge of a screen (2010)—To evaluate the behavioral responses of juvenile salmonids approaching and passing over the screen, we released a total of 173 coho salmon and 102 steelhead trout in the modular screen apparatus under various hydraulic conditions (table 5). In general, the hydraulic conditions in the modular screen system were similar to those recorded in the Herman Creek screen. For example, mean AVs estimated for the entire screen ranged from 1 to 3 cm/s or 2 to 6 cm/s after correcting for net open area (50 percent) and Z ranged from 15 to 25 cm. Mean SVs ranged from 102 to 150 cm/s and were at least 32 times higher than AVs for all tests. In the flume, mean water velocities ranged from 60 to 79 cm/s in the upstream one-half of the flume and from 85 to 104 cm/s in the downstream one-half of the flume. Mean values of Z in the flume ranged from 23 to 31 cm. For coho salmon, from 75 to 95 percent of the fish approached and passed over the screen within 5 minutes of their release, depending on hydraulic conditions (table 5). Within 20 minutes, the percentages of fish that quickly passed over the screen increased to 82–98 percent. After 20 minutes, 12 fish remained upstream in the flume and were gently prodded to move downstream; all these fish passed over the screen without hesitation. For steelhead trout, from 47 to 90 percent of the fish approached and passed over the screen within 5 minutes of their release, depending on hydraulic conditions (table 5). Within 20 minutes, the percentages of fish that quickly passed over the screen increased to 79–95 percent. After 20 minutes, 11 fish (11 percent) were coerced downstream of the upper 3 m of the flume and one fish turned and swam back upstream after it encountered the screen. However, this fish returned to the screen within 10 minutes and successfully passed. Overall, 99.6 percent of the fish we observed passed over the screen without hesitation or delay.

Biological Evaluation of Experimental Results

The results of our experiments in 2009 indicate that passage of juvenile coho salmon over the Herman Creek screen under various hydraulic conditions did not severely injure the fish, cause delayed mortality, or delay fish migration. These results occurred even though most fish passed over the screen near the screen surface, many contacted the screen during passage, and fish were oriented to the current in various directions. However, we did not observe fish becoming impinged on the screen surface (that is, >1 second contact with the screen). The screen showed good self-cleaning performance and never had problems with debris loading. Our results are similar to those of Rose and others (2008), who also reported minimal injuries and low mortality of rainbow trout after passage over backwatered and inverted-weir horizontal flat-plate screens in Oregon. Other studies evaluated various designs of vertically oriented screens and reported results similar to ours (Danley and others, 2002; Zydlewski and Johnson, 2002).

The injuries observed in our fish—both treatment and control groups—were minor and indicate that fish had some trauma to the integument prior to testing and that our holding and handling procedures probably caused more trauma. The fluorescein dye method was effective for detecting injuries to the integument of fish and revealed that all fish had some level of injury after testing. As stated previously, however, all injuries were minor and any differences in mean injury rates between treatment and control groups were small, which makes it difficult to ascribe any biological significance to the injuries we observed. Furthermore, and perhaps more importantly, none of our test results would have exceeded the performance standards for safe passage of fish over conventional screen systems as established by NMFS. For example, performance standards set by NMFS include less than 0.5 percent mortality and 2 percent injury rate (that is, the percentage of a sample that is injured) for salmonid smolts, and that at least 90 percent of salmonids that encounter a screened water diversion are bypassed within 24 h (Bryan Nordlund, National Marine Fisheries Service, written commun., 2010). The agency defines injury as visual trauma (including but not limited to hemorrhaging, open wounds without fungus growth, gill damage, bruising greater than 0.5 cm in diameter), loss of equilibrium, or greater than 20 percent descaling on one side (Bryan Nordlund, National Marine Fisheries Service, written commun., 2009). Because none of our fish showed such injuries, mortality was less than 0.5 percent, and most fish traveled over the screen without hesitation or delay, the Herman Creek screen would surpass these NMFS standards. Although the performance standards discussed here are for other types of screens, the standards do indicate that screens like the one at Herman Creek probably would, at a minimum, meet federal regulatory standards.

The ability of the Herman Creek screen to safely and efficiently pass fish at water depths ranging from 7 to 25 cm was largely due to achieving a high ratio of SV to AV (30:1–60:1) under various diversion conditions. These ratios were substantially higher than the SV recommendations established by NMFS for horizontal screens, which only suggest that downstream SVs be higher than AVs for the entire length of the screen (National Marine Fisheries Service, 2008). The combination of high SVs and low AVs facilitated quick downstream fish passage and eliminated impingements; results are similar to Beyers and Bestgen (2001). Because most fish passed over the screen near the screen surface—regardless of water depth—indicates that the 30 cm water depth recommendation established for horizontal screens (National Marine Fisheries Service, 2008) could be relaxed for smaller screens like the one at Herman Creek. Although fish safely passed over the screen at a depth of only 7 cm, the number of screen contacts per fish increased at this shallow depth for large, but not small, fish. Even though the screen contact rate was not related to the extent or severity of injuries, operating the screen at water depths near 7 cm seems too shallow, particularly under high-flow conditions. Thus, although our results suggest that the Herman Creek screen can be operated effectively at water depths less than 30 cm, we cannot unequivocally recommend a single, specific minimum depth for this screen. Rather, a range of minimum depths, perhaps from 15 to 20 cm, probably would provide safe passage of fish under most circumstances.

Despite the advantages of the Herman Creek screen for protecting fish populations, there are some things to consider when interpreting our results. First, we were unable to evaluate all possible hydraulic conditions on screen performance, fish injury, and mortality. Although we believe our evaluations were realistic because they encompassed typical diversion conditions, there may be other flow conditions we missed that are relevant to fish passage and safety. Second, only two species of fish were tested for the screen evaluations and our results may not be applicable to other species. The fishes used in our experiments probably were good surrogates for other salmonids of similar size. Extrapolation of our results to other fishes, such as juvenile lampreys or endangered suckers in the Klamath Basin, seems inappropriate and would require further testing. Next, our video analyses were not rigorous and our camera installation was meant to provide qualitative information on the behavior of fish as they passed over the screen. Even though we used three cameras, we had limited fields of view and it was often difficult to see because of water turbidity, sunlight, or other factors. Although we are confident that the data we did collect were representative of fish behavior during passage, more detailed analyses will require further work. Finally, we evaluated only the effects of downstream passage on juvenile fish. Further testing would be required to assess the effects of this screen type on fish migrating upstream across the screen surface.

The purpose of our testing in 2010 was to determine whether fish would reject or refuse to pass over the screen after encountering its leading edge—a notion that was a concern to fishery managers and something we did not evaluate in 2009. The concern was related to the changing hydraulic conditions at the flume-screen interface and whether fish would sense this change, turn around, and refuse to pass. Extended delays in passage over the screen could lead to excessive energy use in fish and violation of the NMFS standard that fish must be bypassed within 24 h. Our results, however, clearly indicate that the flume-screen interface was not an obstacle to passage for fish moving volitionally downstream, because high percentages of fish passed within 20 minutes. Even the small number of fish we had to manually coerce to move downstream readily passed over the flume-screen interface. We cannot state whether all fish encountering and passing through small versions of the Farmers Screen would be bypassed within 24 h because none of our tests were designed to answer this question. However, we think the possibility of fish not passing over these screens within 24 h would be remote.

Conclusions

When operated within its design criteria—diversion flows of about 0.28 m^3/s—the Herman Creek screen provided safe and effective downstream passage of juvenile coho salmon under various hydraulic conditions. We do not recommend operating the Herman Creek screen at inflows less than about 0.14 m^3/s because water depth can be quite shallow due in part to a weir wall that was not sealed and the screen can completely dewater, particularly at low flows. If the screen is operated at inflows less than 0.14 m^3/s, caution must be used to avoid diverting an excessive amount of water, which can lead to shallow depths, insufficient bypass flow, and perhaps screen dewatering. Finally, we do not know the fate of fish that pass over the screen, enter the bypass channel, and are diverted back to the Columbia River. It is possible that passage through these areas is a stressful and disorienting event for fish, which could make them vulnerable to hazards that exist downstream, such as predation by fish or birds. This idea is not unique to the Herman Creek screen, but is relevant for many types of diversions and obstacles fish may encounter in the wild. Further research would be necessary to address this issue.

Acknowledgments

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References Cited

Beyers, D.W., and Bestgen, K.R., 2001, Bull trout performance in a horizontal flat plate screen: Final report to the Bureau of Reclamation, Water Resources Research Group, Denver, Colorado.

Craven Consulting Group, 2003, July 28, 2003 Memorandum and Draft Data Report—Evaluation of Overshot Horizontal Flat Plate Fish Screen: Farmers Canal, Hood River, Oregon. Prepared by Craven Consulting Group/Farmers Irrigation District.

Danley, M.L., Mayr, S.D., Young, P.S., and Cech, J.J., Jr., 2002, Swimming performance and physiological stress responses of split tail exposed to a fish screen: North American Journal of Fisheries Management, v. 22, p. 1241–1249.

Farmers Conservation Alliance, 2006, Resource solutions for rural communities: accessed November 12, 2010, at http://www.farmerscreen.org/.

Frizell, K., and Mefford, B., 2001, Hydraulic performance of a horizontal flat plate screen: Final report to the Bureau of Reclamation, Water Resources Research Group, Denver, Colorado.

McMichael, G.A., Vucelick, J.A., Albernathy, C.S., and Neitzel D.A., 2004, Comparing fish screen performance to physical design criteria: Fisheries, v. 29, chap. 7, p. 10–16.

National Marine Fisheries Service (NMFS), 2008, Anadromous salmonid passage facility design: NMFS, Northwest Region, Portland, Oregon.

Noga, E.J., and Udomkusonsri, P., 2002, Fluorescein: a rapid, sensitive, nonlethal method for detecting skin ulceration in fish: Veterinary Pathology, v. 39, p. 726–731.

Rose, B.P., Mesa M.G., and Zydlewski G.B., 2008, Field-base evaluations of horizontal flat plate fish screens: North American Journal of Fisheries Management, v. 28, p. 1702–1713.

Zydlewski, G.B., and Johnson, J.R., 2002, Response of bull trout fry to four types of water diversion screens: North American Journal of Fisheries Management, v. 22, p. 1276–1282.

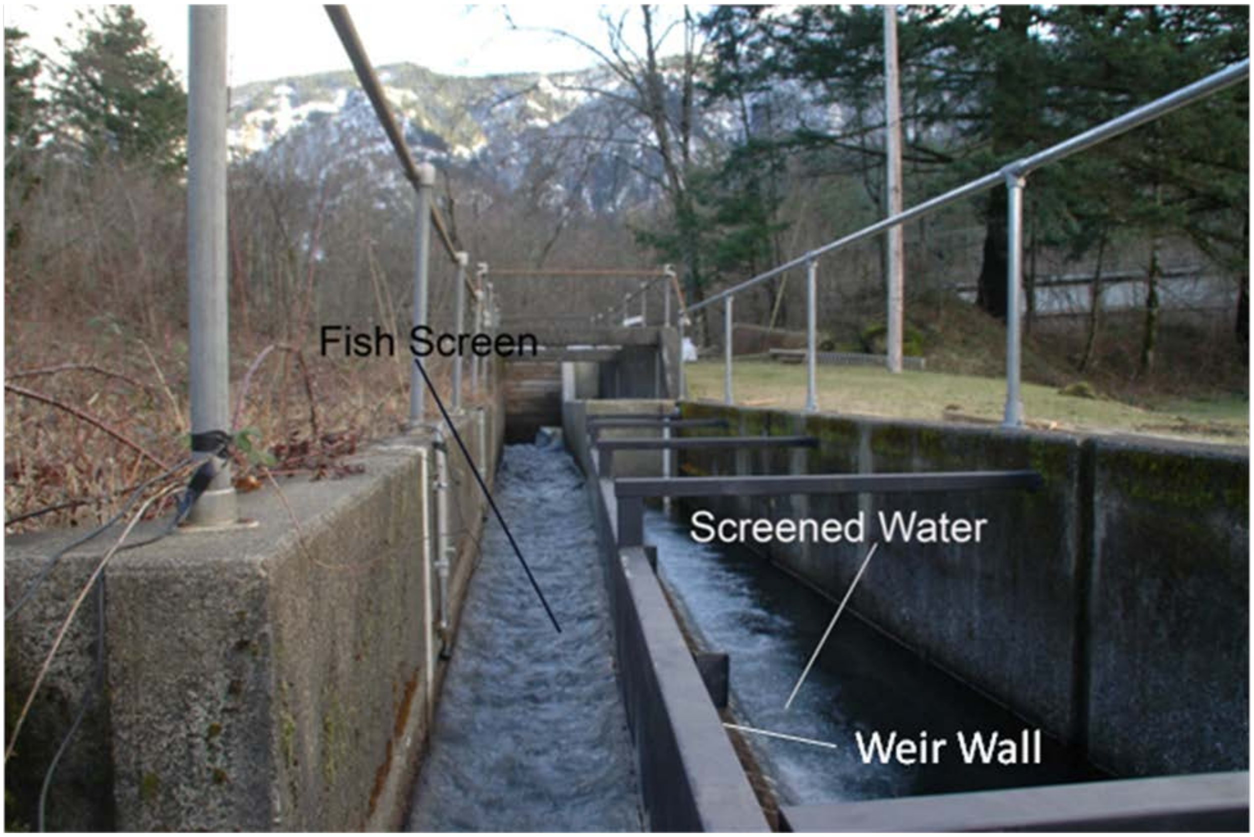

Figure 1. Photograph of the Herman Creek Screen, looking upstream, at the Oxbow Fish Hatchery, Cascade Locks, Oregon. Photograph taken by Brien P. Rose.

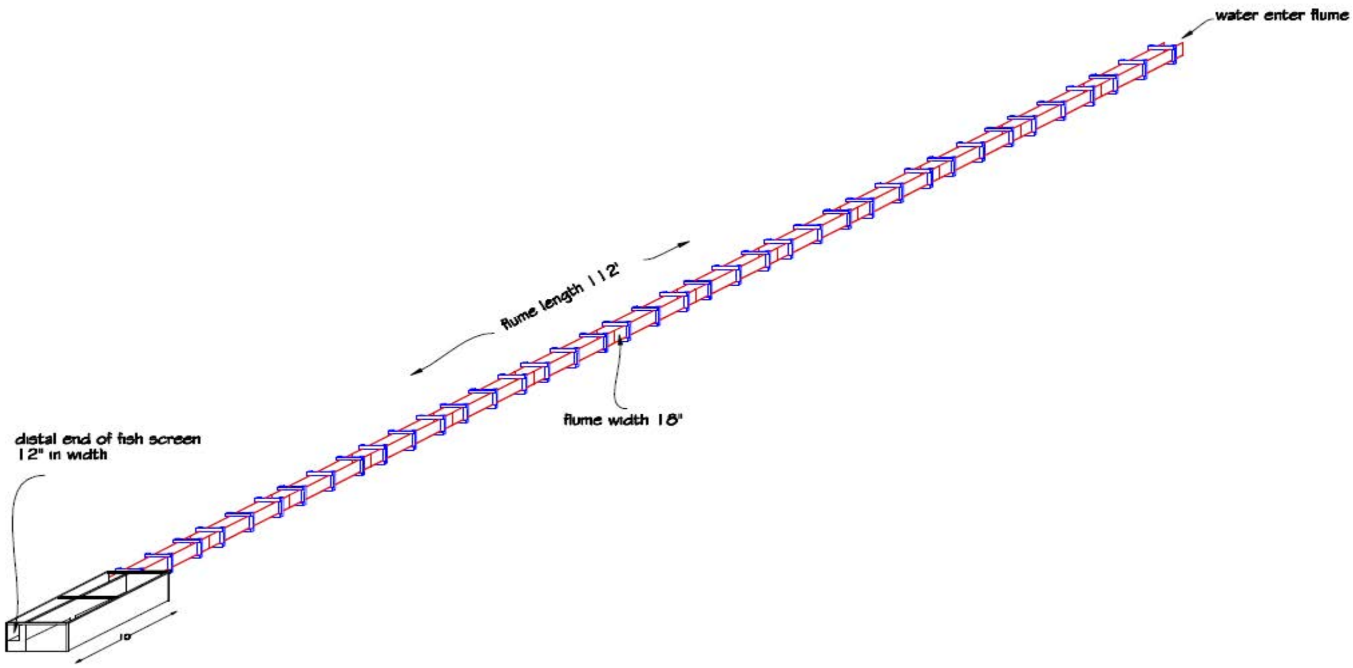

Figure 2. Schematic of the modular screen apparatus used to evaluate the behavioral responses of juvenile salmonids encountering the leading edge of the Farmers Screen, 2010. The modular screen apparatus consisted of a 34 m of wooden flume connected to a 3.1-m long section of the Farmers Screen.

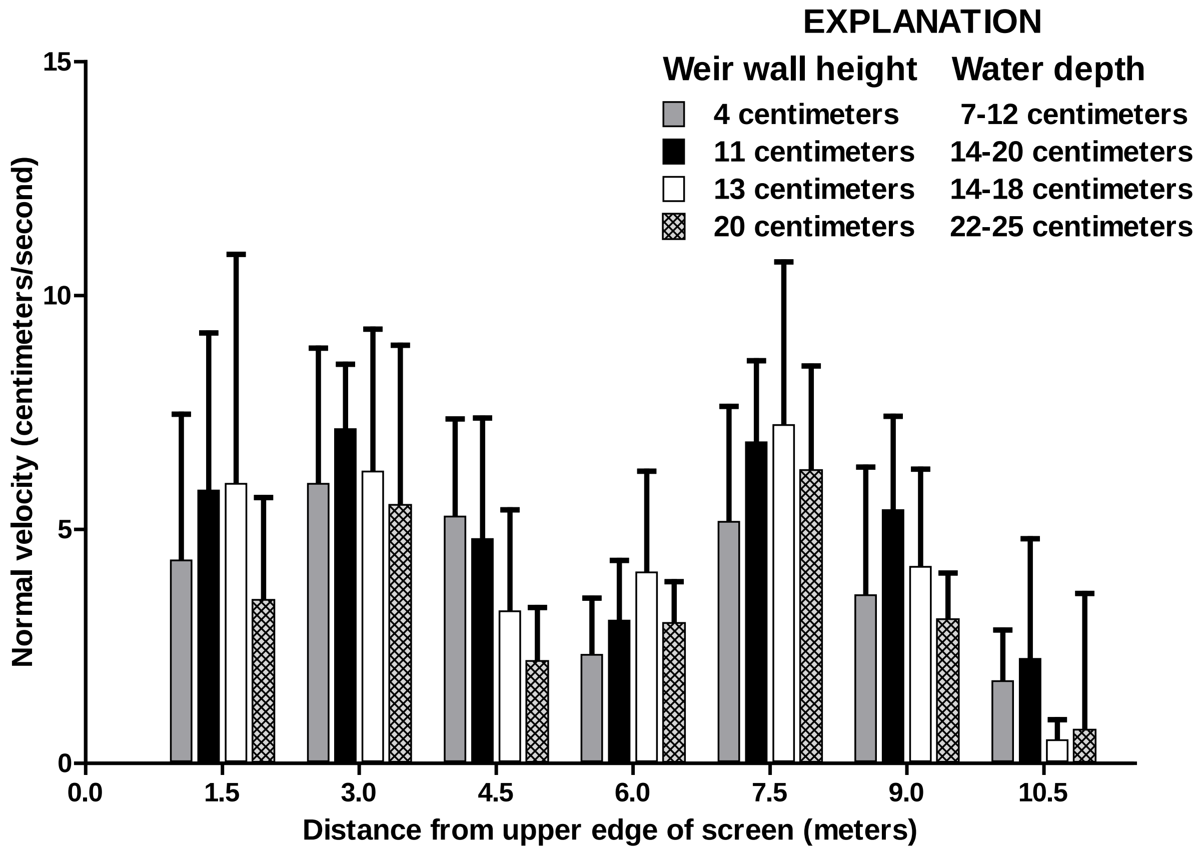

Figure 3. Mean normal velocities (approach velocities corrected for the net open area of the screen) estimated for different sections of the Herman Creek screen relative to weir wall height and water depth, 2009. The whiskers represent the standard deviations of the estimates.

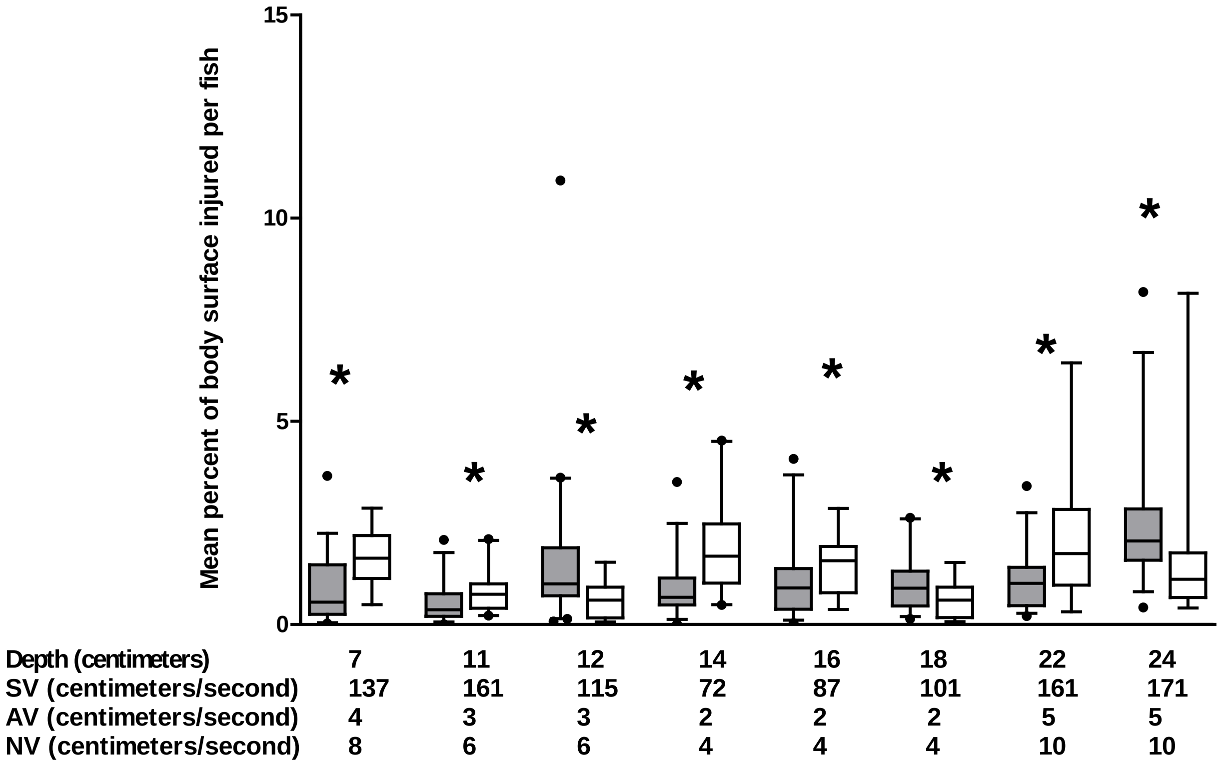

Figure 4. Distribution of the percentage of body surface area of large juvenile coho salmon injured when released over the Herman Creek screen (grey boxes) under various hydraulic conditions relative to control fish (white boxes). The upper and lower boundaries of the box represent the 25th and 75th quartiles, the line inside the box is the mean, the whiskers represent the 5- and 95-percent confidence intervals, and outliers are shown by solid points. The X-axis shows the water depth over the screen, the mean sweeping velocity (SV), the approach velocity (AV), and the normal velocity (NV) during each test. Asterisks denote a significant difference between medians within a group (Mann Whitney *U* test, $P < 0.05$).

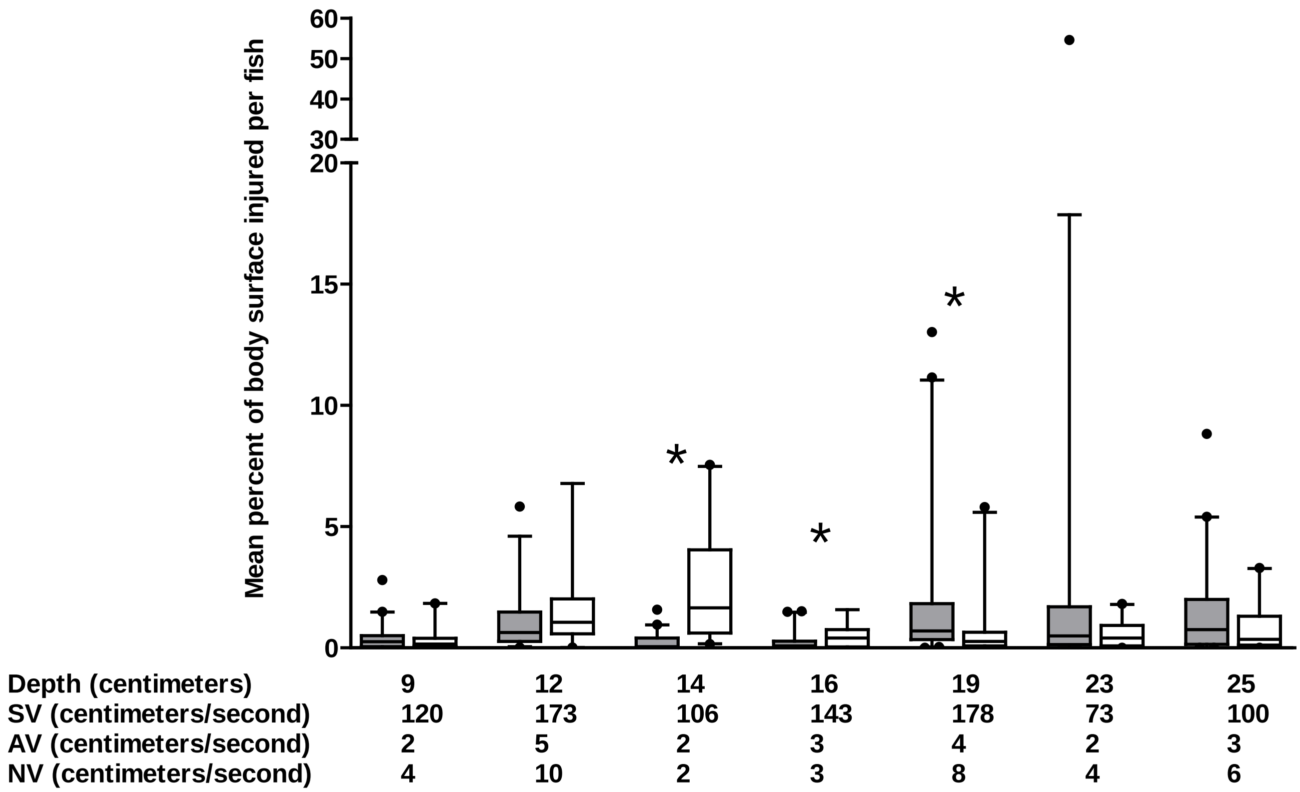

Figure 5. Distribution of the percentage of body surface area of small juvenile coho salmon injured when released over the Herman Creek screen (grey boxes) under different hydraulic conditions relative to control fish (white boxes). The upper and lower boundaries of the box represent the 25th and 75th quartiles, the line inside the box is the mean, the whiskers represent the 5- and 95-percent confidence intervals, and outliers are shown by solid points. The X-axis shows the water depth over the screen, the mean sweeping velocity (SV), the approach velocity (AV), and the normal velocity (NV) during each trial. Asterisks denote a significant difference between medians within a group (Mann Whitney *U* test, $P < 0.05$).

Table 1. Summary of hydraulic conditions at the Herman Creek screen and the numbers of two size groups of juvenile coho salmon used during injury and delayed mortality assessments.

[Trials were conducted on different days during February through May 2009. Q, discharge; SV, sweeping velocity; AV, approach velocity; Z, water depth over the screen; T, treatment fish; C, control fish. SD, standard deviation; cm, centimeters; cm/s, centimeters per second; m^3/s, cubic meters per second. Values in parentheses are data for delayed mortality tests. na, not available]

Inflow Q (m^3/s)	Diversion Q (m^3/s)	Bypass Q (m^3/s)	SV (cm/s; mean [SD])	AV (cm/s)	Z (cm; mean [SD])	Large fish		Small fish	
						T	C	T	C
4-cm weir wall height									
0.10	0.10	0.00	67 (34)	1	7 (1)				
0.14	0.13	0.01	87 (41)	2	7 (1)	37	17		
0.15	0.14	0.01	120 (50)	2	9 (1)			40 (44)	19 (15)
0.26	0.23	0.03	166 (52)	3	12 (1)				
0.27	0.25	0.02	137 (49)	4	11 (3)	38 (65)	20		
0.29	0.26	0.02	138 (73)	4	10 (1)				
0.31	0.28	0.02	130 (46)	4	12 (2)				
0.34	0.31	0.03	173 (45)	5	12 (1)			39 (51)	19 (17)
0.36	0.33	0.03	171 (41)	5	12 (1)	41 (60)	15 (30)		
11-cm weir wall height									
0.14	0.11	0.03	101 (30)	2	14 (1)	39	20		
0.15	0.12	0.03	106 (30)	2	14 (1)			40 (45)	20 (18)
0.29	0.23	0.05	161 (23)	3	16 (2)	40	20		
0.29	0.23	0.06	143 (30)	3	16 (1)			40 (45)	14 (15)
0.34	0.26	0.08	178 (32)	4	19 (1)			41 (36)	20 (15)
0.42	0.34	0.07	161 (30)	5	18 (1)	38 (61)	15 (42)		
13-cm weir wall height									
0.10	0.09	0.02	61 (20)	1	14 (0)				
0.20	0.13	0.07	170 (36)	2	16 (2)				
0.31	0.24	0.06	127 (25)	4	20 (1)				
20-cm weir wall height									
0.02	0.02	0.00	na	0	1 (1)				
0.04	0.03	0.01	36 (15)	0	8 (0)				
0.15	0.10	0.05	72 (12)	2	22 (1)	38	14		
0.15	0.10	0.05	73 (12)	2	23 (0)			36 (44)	20 (15)
0.27	0.20	0.07	100 (15)	3	25 (1)			35 (45)	20 (15)
0.28	0.22	0.06	115 (17)	3	24 (1)	39 (60)	15 (52)		
0.29	0.21	0.08	101 (25)	3	25 (1)				

Table 2. General linear models describing relation between hydraulic variables measured at the Herman Creek screen, 2009.

[All coefficients are significant (P < 0.05) unless noted. SV, sweeping velocity; Z, depth of water over screen; SQ, inflow discharge; DQ, diversion discharge; WW, weir wall height; *SEE*, standard error of estimate; cm, centimeters; m^3/s, cubic meters per second]

Dependent variable	Equation
Depth	Z = 2.592[1] + 0.572 (WW) + 89.673 (SQ) – 75.712 (DQ)
	$N = 24$, $R^2 = 0.84$, $SEE = 2.27$
Diversion discharge	WQ = 0.056 – 0.003 (WW) + 0.902 (SQ) + 0.000 (SV)
	$N = 24$, $R^2 = 0.99$, $SEE = 0.01$
Sweeping velocity	SV = 105.007 – 4.863 (WW) + 1,166.178 (SQ) - 1,063.394 (DQ)
	$N = 24$ $R^2 = 0.81$, $SEE = 17.82$

[1]P=0.25

Table 3. Mean number of fish contacts with the screen, their relative depth of travel during passage, and their general orientation to the water flow during passage for large juvenile coho salmon experimentally released over the Herman Creek screen, 2009.

[AV, approach velocity; SV, sweeping velocity; SD, standard deviation; cm, centimeter; cm/s, centimeter per second]

Date	Water depth (cm; mean [SD]))	AV (cm/s)	SV (cm/s; mean [SD])	Mean (SD) number of screen contacts per fish	Depth in water column (percentage of observed)			Orientation (percentage of observed)		
					low	mid	high	up stream	down stream	other
2/27	7	2	87 (41)	0.72 (0.58)	69	25	6	44	56	0
2/17	11	4	137 (49)	0.45 (0.23)	41	54	5	36	60	4
3/4	12	5	171 (41)	0.47(0.24)	53	35	12	55	45	0
3/2	14	2	101 (30)	0.26 (0.18)	58	35	6	35	65	0
2/18	16	3	161 (23)	0.41(0.23)	44	43	13	58	42	0
3/3	18	5	161 (30)	0.15 (0.18)	66	28	5	33	67	0
2/24	22	2	72 (12)	0.41 (0.34)	69	25	5	53	47	0
2/19	24	3	115 (17)	0.41 (0.33)	60	32	8	46	54	0

Table 4. Mean number of fish contacts with the screen, their relative depth of travel during passage, and their general orientation to the water flow during passage for small juvenile coho salmon experimentally released over the Herman Creek screen, 2009.

[AV, approach velocity; SV, sweeping velocity; SD, standard deviation; cm, centimeter; cm/s, centimeter per second]

Date	Water depth (cm; mean [SD])	*AV* (cm/s)	*SV* (cm/s; mean [SD])	Mean (SD) number of contact per fish	Depth in water column (percentage of observed)			Orientation (percentage of observed)		
					low	mid	high	up stream	down stream	other
5/19	9 (1)	2	120 (50)	0.32 (0.14)	57	40	3	56	40	4
5/20	12 (1)	5	173 (45)	0.50 (0.30)	63	33	4	61	15	24
5/15	14 (1)	2	106 (30)	0.56 (0.26)	58	32	10	55	41	4
5/13	16 (1)	3	143 (30)	0.42 (0.25)	49	37	14	44	38	18
5/14	19 (1)	4	178 (32)	0.62 (0.35)	65	23	12	53	35	12
5/8	23 (0)	2	73 (12)	0.26 (0.22)	69	24	7	70	30	0
5/12	25 (1)	3	100 (15)	0.35 (0.21)	53	28	19	61	37	2

Table 5. Summary of hydraulic conditions at the modular screen, the number and species of fish used for testing, and the percentage of fish that successfully passed over the screen during consecutive 5-minute periods, 2010. Only one steelhead refused to pass over the screen initially, but eventually did so within 10 minutes.

[Q, discharge; AV, approach velocity; SV, sweeping velocity; SD, standard deviation; cm, centimeter; cm/s, centimeter per second;

Inflow *Q* (m^3/s)	Water depth (cm; mean [SD])	AV (cm/s)	SV (cm/s; mean [SD])	Number of fish released	Percentage of observations where fish passed over the screen 0 – 5 min	5 – 10 min	10 – 15 min	15 – 20 min	>20[1] min
Coho Salmon									
0.06	15 (1)	2	111 (6)	40	91	0	0	0	9
0.09	15 (1)	3	150 (8)	20	75	10	10	0	5
0.09	19 (1)	2	132 (7)	33	82	0	0	0	18
0.07	20 (0)	1	102 (10)	40	88	0	0	0	12
0.08	25 (1)	1	102 (13)	40	95	3	0	0	3
Steelhead Trout									
0.06	15 (1)	2	111 (6)	40	90	3	0	0	8
0.09	15 (1)	3	150 (8)	22	62	5	0	29	5
0.08	25 (1)	1	102 (13)	40	47	12	0	21	21

[1]Values include fish that were prodded from the upper 3 m of the flume.

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Mesa and others— **Biological Evaluations of an Off-Stream Channel, Horizontal Flat-Plate Fish Screen—The Farmers Screen**—Open-File Report 2010–1042

Appendix H - Craven, 2001, Horizontal Flat Plate Fish Screen Project - Biological Assessment for Species under National Marine Fisheries Service Jurisdiction

Farmers Irrigation District
Hood River, Oregon

Horizontal Flat Plate Fish Screen Project

Biological Assessment for Species under National Marine Fisheries Service Jurisdiction

Prepared for

Farmers Irrigation District

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June 1, 2001

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1.0 INTRODUCTION

1.1 Purpose and Need

Farmers Irrigation District (FID) will be installing a new transmission water line, which will replace an old existing trestle and flume that presently links the irrigation district intake to a canal system that transports water into the low croplands of the Hood River Valley (Figure 1; Appendix A). In addition to the new transmission water line, a new fish screen will be constructed which necessitates the building of a fish bypass that delivers fish from the new screen back to Hood River (Figure 2). The existing fish screen is an older obsolete concept and the existing fish bypass consists of a small diameter flexible culvert. FID has chosen to undertake a bypass system that not only returns fish to the Hood River but also increases the rearing habitat available in the watershed. To accomplish this, a new channel will be created which will transfer water to Joe's Creek, an existing natural intermittent stream. The existing channel will be re-contoured to handle bypass predicted flows and enhanced to provide for fisheries habitat (Figure 3).

1.2 Species of Interest

Because work would occur adjacent to the Hood River, the project has the potential to affect chinook salmon (*Oncorhynchus tshawytscha*), chum salmon (*O. keta*), steelhead (*O. mykiss*), and their habitat (see Federal species list, Appendix B). The species populations addressed in this document are the Lower Columbia River chinook salmon evolutionarily significant unit (ESU), Columbia River chum salmon ESU, and Lower Columbia River steelhead ESU (Table 1). All fish species addressed in this document are under the jurisdiction of the National Marine Fisheries Service (NMFS). Recently, jurisdiction of coastal cutthroat trout (*O. clarki clarki*) has been transferred to the U.S. Fish and Wildlife Service (USFWS) and analysis of this fish species, as well as bull trout (*Salvelinus confluentus*) will be addressed in a similar document. While these are the only five federally listed fish species potentially occurring in the project area, Lower Columbia River coho salmon (*O. kisutch,* Candidate [final]) also occurs in the project area (Table 1). Although no protection is afforded this species under the Endangered Species Act (ESA), discussions of potential impacts, minimization and avoidance measures, and mitigation would generally apply to coho salmon, as they share similar habitats with federally listed salmon species addressed in this document. Consultation is accomplished in part, through this Biological Assessment (BA), which evaluates the potential effects the proposed project would have on fish species that are federally listed under the ESA.

Conservation measures are identified in this BA to avoid or minimize any adverse effects the proposed project would have on listed species or critical habitat. Critical Habitat has been designated for the three ESA listed fish species addressed in this document (Table 1). In the project area, Joe's Creek and the Hood River have been included as Critical Habitat for all three species. Designated critical habitat includes all waterways, substrate, and adjacent riparian zones below longstanding, naturally impassible barriers (i.e., natural waterfalls in existence for at least several hundred years). Riparian zones are defined as those areas within a horizontal distance of 300 feet from the normal high water level of a waterway or from the wetted edge of the waterway.

Table 1. Federally listed, Proposed, or Candidate Anadromous Fish Species and Evolutionary Significant Units (ESUs) Potentially Present at the Project Site - NMFS Jurisdiction

Common Name	Scientific Name	ESU	Federal Status	Critical Habitat Designated
Chinook Salmon	*Oncorhynchus tshawytscha*	Lower Columbia River	Threatened (3/99)	February 2000
Chum Salmon	*Oncorhynchus keta*	Columbia River	Proposed Threatened (3/99)	February 2000
Steelhead	*Oncorhynchus mykiss*	Lower Columbia River	Threatened (3/98)	March 1998
Coho Salmon	*Oncorhynchus kisutch*	Lower Columbia River	Candidate Final (7/95)	NA

The purpose of this BA is to address the effects of the proposed Joe's Creek bypass project on fish species listed as proposed, threatened, or endangered under the ESA This BA addresses the proposed action in compliance with Section 7(c) of the ESA of 1973, as amended. Section 7 of the ESA ensures that, through consultation (or conferencing for proposed species) with the USFWS and the NMFS, federal actions do not jeopardize the continued existence of any threatened, endangered, or proposed species, or result in the destruction or adverse modification of critical habitat.

1.3 Location and Habitat Description

The project area is located on the Hood River, near river-mile 11 (Township 2 North, Range 9 East, Section 29). The Hood River flows south to north, adjacent to the project area with Joe's Creek entering on the east bank. In this vicinity, the Hood River is a series of riffles, long runs and boulder cascades. River gradient averages 2-3 percent with several mainstem pools near the project areaa. Existing river conditions reveal high sediment levels associated with the Fall 2000 mud flow event that originated on Mt. Hood. Sediment deposition is apparent throughout the Hood River system with particularly large amounts found in pool tail-outs and along the banks of slower flow areas. Site visits revealed wetted widths in the Hood River ranging from 70-80 feet at Joe's Creek mouth. Limited amounts of large woody debris (LWD) were present during sight visits.

No spawning habitat exists near the Joe's Creek mouth. Lacking undercut banks, backwater channels, and other refuge areas, the Hood River at Joe's Creek offers little cover or protection for resident salmonid species, or rearing juveniles. Several mainstem pools may provide adequate spawning substrate for larger anadromous species such as chinook salmon. ODFW reports possible mainstem spawning of hatchery coho salmon and hatchery chinook salmon (S. Pribyl, pers. comm. 2001).

The vegetation community in the immediate floodplain near the diversion intake of the irrigation channel is not well vegetated due to slope and seasonal river level fluctuation. The species present are young and consist primarily of black cottonwood (*Populus balsamifera*), red alder (*Alnus rubra*), willow (*Salix sp.*), red-osier dogwood (*Cornus stolonifera*), Pacific ninebark (*Physocarpus capitatus*), and reed canary grass (*Phalaris arundinacea*). The banks of the Hood River are steep within the project area no adjacent wetland occur. There are no wetlands adjacent to the Hood River on the east bank where construction access will occur. Wetlands will be impacted by this project, and permit applications have been submitted to the Corps of Engineers and Oregon Division of State Lands.

Joe's Creek is an intermittent stream approximately 1,000 feet long on a high alluvial terrace at the base of a talus slope. The creek was not flowing at the time of site visits in March, April and May. Joe's Creek relies on direct precipitation and seeps for a water source, and water likely quickly drains from the site. The site is relatively flat. Fish likely are not present in Joe's Creek because of the paucity of water most of the year, however during flood stage in the Hood River it is possible that fish could temporarily reside in Joe's Creek until flood waters recede.

There are three vegetation communities present within Joe's Creek: Conifer forest, deciduous forest and emergent seep communities. Areas with sufficient moisture support hydrophytes such as western red cedar, red alder, and skunk cabbage. Upland areas tended to support Douglas-fir and big leaf maple dominated native communities.

2.0 EVALUATION METHODS

The project site and surrounding area was visited numerous times between January and April 2001 to assess the potential presence of ESA listed species and determine habitat quantity and quality. The immediate vicinity near the project area was assessed, including the river channel and riparian area visible upstream and downstream from the project site. Presence potential was determined by the following means: A federal species request list (USFWS 1-7-00-SP-461, Appendix B), contact with Oregon Department of Fish and Wildlife (ODFW) biologists familiar with the area, and several field visits.

Factors considered in evaluating the project impacts included the species' dependence on specific habitat components that would be removed or modified, the abundance and distribution of habitat, habitat components in the project vicinity, distribution and population levels of the species (if known), the possibility of direct impacts on fish, the degree of impact on habitat, and the potential to mitigate the adverse effect. The methods outlined in *Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Watershed Scale* (NMFS, 1996) were used to analyze the potential for project impacts on water quality and in-stream and riparian habitat quality. The strategy outlined in this document is to determine the environmental baseline for the watershed, discuss how the proposed action would affect the environmental baseline, and then use that information in a dichotomous key to arrive at a determination of effect.

3.0 PROJECT DESCRIPTION

3.1 Proposed Project

Farmers Irrigation District (FID) will be installing a new transmission water line, which will replace an old existing trestle and flume that presently links the irrigation district intake to a canal system that transports water into the low croplands of the Hood River Valley (Figure 1; Appendix A). In addition to the new transmission water line, a new fish screen will be constructed which necessitates a fish bypass that will deliver fish from the new screen back to Hood River (Figure 2). The existing fish screen is an older obsolete concept and the existing fish bypass consists of a small diameter flexible culvert. FID has chosen to undertake a bypass system that not only returns fish to the Hood River but also increases the rearing habitat available in the watershed. To accomplish this, a new channel will be created which will transfer water to Joe's Creek, an existing natural intermittent stream. The existing channel will be re-contoured to handle bypass flows and enhanced to provide for fisheries habitat (Figure 3).

3.1.1 Fish Screen

The existing fish screen will be replaced with a new fish screen that will be placed in a new concrete flume along the existing pipeline alignment. There are no impacts to wetlands along the new pipeline, and the pipeline is not regulated by the Army Corps of Engineers or the Division of State Lands. The pipeline the project does not require a permit (COE – January 12, 2001, COE# 2001-64; DSL – March 05, 2001, DSL#23622; Appendix B).

The Farmers Canal Diversion fish screen will be a horizontally oriented, 160 foot long flat plate screen (Appendix D). The screen will be 10 feet wide at the screen entrance. Both of the screen sidewalls will taper evenly for 140 feet to an outlet transition throat, which will typically be set to 24 inches wide. The transition throat will be of equal width throughout its 20-foot length. One of the screen sidewalls will be adjustable in order to allow for fine-tuning of the screen hydraulics and the outlet transition throat width. Water passing through the outlet transition throat will flow with a short plunge of approximately 0.7 feet to the headwater pool at the beginning of Joe's Creek, which is the fish return bypass system.

The approximately 95 cubic feet per second (cfs) of water diverted from Hood River will flow through the Farmers Canal and be introduced to the fish screen approximately 1000 feet downstream from the point of diversion. The water will flow from the canal onto the flat plane of the screen, which is flush to and at the same elevation as the canal floor (Appendix D, Cross-section C). When the system flow is at steady state, the total diverted water (95 cfs) will be split between the water to be used for irrigation or hydroelectric purposes (about 80 cfs) and the water to be used for fish bypass purposes (up to 15 cfs). The irrigation and hydroelectric water will pass through the plane of the screen with a uniform approach velocity of less than 0.1 feet per second (fps). The water that passes through the plane of the screen will collect in a sub-screen chamber, which will be open to a collection bay (see Plan View and Cross-section A). Five feet away from the open, interior "wall" of the collection bay will be the interior, adjustable stop log weir. This weir will ensure a minimum water depth (0.9 feet) over the screen and a uniform approach velocity through the screen. Water in the collection bay will pass through two control gates to the forebay for the transmission pipes (see Cross-section E & D). The control gates will automatically maintain the upstream water depth to a pre-determined elevation. The gates are adjustable and require no power or telemetric control.

Water that does not pass through the screen (up to 15 cfs) will be conserved for fish bypass water, which will flow through the outlet transition throat to the Joe's Creek headwater pool. This bypass water will flow across the screen with an initial sweeping velocity of about 6 fps at the screen entrance. The sweeping velocity will gradually slow to about 5 fps and then smoothly accelerate to a final exit velocity of about 9 fps through the outlet transition throat and into the Joe's Creek headwater pool.

The design flow for the canal is 95 cfs. The range of flows expected is between 80 and 95 cfs indicating that the canal flows will be relatively constant. Constant flows will minimize the need to adjust the project facilities. Flows in the canal may be terminated at infrequent catastrophic events or for performance of maintenance. To continue to provide flows to Joe's Creek (See Section 3.1.2, below) a 12-inch diameter pipeline will run parallel and will be attached to the outside wall of the canal.

Fish passage across a similar prototype horizontal flat plate screen was evaluated (Data Report. Re-Evaluation of Farmers Irrigation District Protype Horizontal Flat Plate Fish Screen. Report prepared by Farmers Irrigation District, May 14, 2001). The results are summarized as follows:

- Steelhead Smolts

    1. No fish were descaled (20% or more loss in scales on either side)
    2. No injuries were recorded for 553 of 799 test fish recovered
    3. One injury (bruise) was recorded for 434 of 448 control fish recovered
    4. Fish not recovered were seen swimming upstream to the pool in front of the screen
    5. Scattered average scale loss reflected a 0.25% increase of the 553 test fish recovered
    6. Scattered average scale loss reflected a 0.10% increase of the 434 control fish recovered
    7. Latent mortality was 23 of 553 test fish recovered
    8. Latent mortality was 22 of 434 control fish recovered

- Steelhead Fry

    1. No injuries were recorded for 587 of 600 control fish recovered
    2. One bruise was recorded for 963 of 979 test fish recovered
    3. No latent mortality occurred in either the test or control fish

- Chinook Fry

1. Ten bruises were recorded in 987 of 1000 test fish recovered
2. Twelve bruises were recorded in 497 of 500 control fish recovered
3. No latent mortality occurred in either the test or control fish

The results of the tests suggest that the horizontal flat plate fish screen installed and operated according to strict criteria will provide safe passage for fish. In addition, the screen needs minimal maintenance to clean debris, however the proposed screen for Framers Canal will be fitted with a water burst cleaning system that will be used as required to ensure that the screen remains adequately debris-free.

3.1.2 Joe's Creek Bypass

Joe's Creek is approximately 900 feet long from its origin to the Hood River. It has a narrow channel from 1 to 5 feet wide and is intermittent except where small seeps and impoundments form forested wetlands within and adjacent to the channel. During a March 2001 delineation the creek did not flow but all wetland areas were ponded 2 to 3 inches. Joe's Creek can be separated into two distinct areas separated by an existing dirt access road. East of the access road Joe's Creek is a low gradient stream with loamy sand soils. West of the access road the stream channel has a 5 percent slope, is composed of cobbles and boulders from the adjacent slopes and no water was present except in one small wetland area.

The bypass flow for the new screen will be 10 to 15 cubic feet per second (CFS). The bypass flow will be directed to a new channel that flows into Joe's Creek and then to the Hood River. Because of the necessity to provide hydraulic capacity in case of an unlikely failure in the fish screen facility, the entire bypass route will be designed to convey up to 120 CFS. To prevent spillover from the new channel and Joe's Creek, a retention berm will be constructed running adjacent to the access road (Figure 3) to prevent water from eroding away at the pipeline infrastructure.

In order to utilize Joe's Creek as a fish bypass, 120 feet of new channel will be cut into the current grade from the new fish screen outlet to the intermittent channel (Figures 4 & 5). The new channel area is upland forest. Test pits indicate sand and cobble material is approximately 3 feet below current grade within the area where a new channel will be constructed. This material will be utilized to form a new streambed with the potential of cobble being imported if a large amount of sand and silt is encountered. Hydraulic analysis indicates cobble and small boulder material found in the test pits are of sufficient size to be retained in the return channel. Bypass flow is expected to be 10 to 15 CFS. The new channel will have a slope less than 1 percent, bottom width varying between 16 and 20 feet wide and top width of approximately 30 feet. Changes in screen location and bypass outlet elevations will result in some adjustments to the channel alignment and grade. Large wood material will be salvaged from the pipeline clearing and utilized to create habitat and form stream banks. Some erosion control fabric may be used if the volume of wood material is insufficient to ensure bank stabilization

Pools will be excavated in the existing channel and large wood will be placed in the channel for cover habitat (Figure 6). Most of the cover and rearing habitat will be in the upper 500 feet of channel. The lower segment of Joe's Creek has a steeper gradient and will primarily function as a natural downstream passage to the Hood River. Small boulder substrate exists within the steeper segment of Joe's Creek sufficient to resist design flows. A series of step pools will be constructed in the final 50 feet of channel, constructed from boulder material taken from within and adjacent to the Hood River. This work will provide a smooth transition for downstream migrating juvenile fish from this relatively steep portion of channel into the Hood River.

No culverts presently exist within this portion of Joe's Creek. As part of the stream re-construction one new 48-inch culvert will be installed (Figure 7). One 48 inch by 20 foot culvert will be located under the existing access road, which presently blocks the upper reaches of Joe's Creek from fish passage. Because no culvert exists under the access road, present high flows in Joe's Creek must breach the road to continue in its channel. A second 48 inch by 100 foot culvert will also be installed under the transmission pipeline structure to allow the pipeline to cross over Joe's Creek.

The retention berm is being constructed to prevent possible bypass channel overflow from eroding away at the transmission line footings. The berm will be constructed around the new fish screen outlet plunge pool and continue northeast along the existing access road for approximately 300 feet. The construction berm will then turn northwest and parallel Joe's Creek for another 200 feet. The berm will be approximately 4 feet high with 3:1 slopes and the footprint will be approximately 16 feet wide. The material used for constructing the berm will be a combination of onsite excavated material and imported clean fill.

3.2 Alternatives Considered but Rejected

Two alternatives were considered for the return bypass flow to the Hood River.

Alternative 1 – Pipe Outlet to River

This alternative is based upon the use of a piped outlet to return flows to Hood River. This method utilizes a pipe (approximately 48 inches in diameter) to direct water out of the irrigation canal at the point of the fish screen. A large diameter pipe is required to temporarily up to 80 CFS in case of canal failure near the fish screen. This type of bypass provides nothing more than a return to the original body of water. This alternative was not chosen because there was a desire to create a beneficial system bypass for fish, possibly providing potential rearing area. To reduce pipe velocities to acceptable limits, the pipe gradient needs to be 1.7% grade. To accomplish this, a large length of pipe would have to run upstream along the stream bank of the Hood River. The pipe would be very exposed during flood events on the Hood River. As a result, the risk of vandalism, failure, and damage is much greater with this alternative than Joe's Creek.

Alternative 2 – Joe's Creek Bypass

The Joe's Creek alternative will deliver bypass water to Joe's Creek and the return water to the Hood River. This alternative was chosen because of the natural habitat enhancement opportunities for salmon species and is discussed within this project description.

3.3 Proposed Project Schedule

The ODFW recommended in-water work period for the Hood River is July 15 through August 31. The fish screen will be constructed in the dry in an upland area. Joe's Creek bypass work will require minimal inwater work at the mouth of Joe's Creek. Work in Joe's Creek to enhance the existing channel will occur during the time of year when no water is flowing between Joe's Creek and Hood River.

4.0 NATURAL HISTORY AND SPECIES OCCURRENCE

Species: **Steelhead (*Oncorhynchus mykiss*)**
ESU: **Lower Columbia River**
Federal Status: **Listed Threatened**
Critical Habitat: **Designated February 16, 2000**

Migrating to spawning grounds and hatcheries, adult steelhead are found year-round in the Hood River. During spring and early summer, juveniles (smolts) migrate downstream on their way to the ocean. The Hood River hosts both winter and summer steelhead that return in overlapping runs throughout the year. Currently, steelhead research at Powerdale Dam aims to use offspring from wild adult steelhead to supplement and improve the Hood River's run of wild steelhead. Hatchery steelhead from several Columbia Basin hatcheries enter the Hood River throughout the year. These "stray" fish frequently enter the Hood River and are counted at Powerdale Dam (Table 2).

While juvenile steelhead likely would not be present in the project area during construction, adult steelhead may be migrating through the area and could occur in the immediate project area.

Summer-Run Steelhead

Both hatchery and wild summer steelhead are found in the Hood River. Hatchery supplementation is used for both runs, and Table 2 provides an estimate of recent escapement numbers. Summer steelhead spawn in the West Fork Hood River (S. Pribyl, pers. comm. 2001).

Winter-Run Steelhead

Currently the Hood River supports both a wild winter steelhead run and hatchery run as well. Some mainstem winter steelhead spawning has been reported (S. Pribyl, pers. comm. 2001).

For general information on the life/habitat requirements and life history of the Lower Columbia River steelhead, see the NMFS (www.nwr.noaa.gov) and the Federal Register notice published February 16, 2000. For general steelhead periodicity, see Appendix C.

Species: **Chinook Salmon (*Oncorhynchus tshawytscha*)**
ESU: **Lower Columbia River**
Federal Status: **Listed Threatened**
Critical Habitat: **Designated February 16, 2000**

Historically the Hood River hosted an abundant run of wild chinook salmon. Recent reports indicate that the run has been completely extirpated and is considered extinct (S. Pribyl, pers. comm. 2001). Since 1986 the Hood River has been stocked with a Deschutes River run of spring chinook salmon.

Adult hatchery spring chinook salmon are known to migrate up the Hood River from March through May on their way to spawning grounds. During spring, juveniles migrate downstream on their way to the ocean. While juvenile chinook salmon likely would not be present in the project area during construction, adults may be moving through the area on their way to spawning grounds and could occur in the immediate project area. Although no wild fall chinook run exists for the Hood River, hatchery and wild strays are often found in the lower river.

NMFS recognizes the original Hood River spring chinook run as extinct (Federal Register 1999). The current Hood River hatchery spring chinook run is not considered part of the Lower Columbia River chinook salmon ESU and is not protected under Section 7 of the ESA. To address wild stray chinook salmon that may enter the Hood River and the project area, and to satisfy ESA requirements, this report will evaluate potential project impacts to chinook salmon.

For general information on the life/habitat requirements and life history of the Lower Columbia River chinook salmon, see the NMFS (www.nwr.noaa.gov) and the Federal Register notice published February 16, 2000. For general chinook periodicity, see Appendix C.

Species: **Chum Salmon (*Oncorhynchus keta*)**
ESU: **Columbia River**
Federal Status: **Proposed Threatened**
Critical Habitat: **February 2000**

Chum salmon migrate up the Columbia River from October through January. Shortly after emergence, young chum salmon migrate downstream to the ocean. Although chum salmon are found in the Columbia River, they do not enter the Hood River. The project area is located approximately 8-miles upstream from the Columbia River. Downstream effects (sediment and turbidity) from project construction have been analyzed and, with proper minimization and avoidance measures in place, determined to be negligible. The project is expected to have no impact on Columbia River chum salmon or their designated critical habitat.

Species: **Coho Salmon (*Oncorhynchus kisutch*)**
ESU: **Lower Columbia River**
Federal Status: **Candidate**
Critical Habitat: **Not Applicable**

Adult coho salmon are known to migrate up the Hood River from October through January on their way to spawning grounds. During spring, juveniles migrate downstream on their way to the ocean. While juvenile coho salmon likely would not be present in the project area during construction, adult coho may be moving through the area on their way to spawning grounds and could occur in the immediate project area. Some reports of mainstem spawning by coho have been documented (S. Pribyl, pers. comm. 2001).

For general information on the life/habitat requirements and life history of the Lower Columbia River coho salmon, see the NMFS (www.nwr.noaa.gov) and the Federal Register notice published February 16, 2000. For general coho periodicity, see Appendix C.

Table 2. 1999-2000 Powerdale Dam Escapement - Hood River

Common Name	# of Fish (1999)			# of Fish (2000)		
	Wild	Hatchery	Unknown	Wild	Hatchery	Unknown
Winter Steelhead	909	290	28			
Summer Steelhead				198	1145	11
Coho Salmon	5	44	2			
Spring Chinook Salmon				64	87	5
Fall Chinook Salmon	16	4	3	18 (no breakdown)		

Source: ODFW 1999 and 2000 Approximate Escapement at Powerdale Dam (as of April 16, 2001), Steve Pribyl pers. comm. 2001

5.0 BASELINE CONDITIONS

The proposed project is located on the east bank of the Hood River, approximately 11 miles upstream from its confluence with the Columbia River. Land use in the surrounding area is primarily agricultural, with timber harvest occurring further upstream in the watershed. Land ownership in the surrounding areas consists of private, federal, state, and county owned forests. Baseline environmental conditions in the Hood River watershed are summarized in Table 3.

Numerous site visits revealed some degraded aquatic and riparian conditions throughout the project area. Because heavy land use (timber harvest, agriculture) occurs throughout the watershed, some baseline conditions have been degraded. Complex instream habitat is lacking in the Hood River near the project area. Limited amounts of LWD and several boulders provide only minimal cover for fish. The Hood River provides several pools and large boulders that may offer adequate cover, especially for smaller fish. Several pool tail-outs may be used for mainstem spawning by returning hatchery chinook and coho salmon (S. Pribyl, pers. comm. 2001).

5.1 Hood River Watershed

Flowing north from the base of Mt. Hood, the Hood River's main source of water is a glacier found along the mountains north and east slopes. The river has three major forks, the West Fork, Middle Fork, and the East Fork. All forks converge within 2 miles upstream from the project area and form the mainstem Hood River.

The Hood River flows through several different land use regions, including federal, state, and industrial timberlands, private agricultural land, and several small urban areas. Land use immediately surrounding the project site is predominantly agriculture with timber harvest occurring in the surrounding upland areas and upper watershed.

The Hood River from Powerdale Dam Powerhouse to the Diversion Dam is currently listed on the Oregon Department of Environmental Quality (DEQ) 303(d) List of Water Quality Limited Water Bodies for temperature and pH. From the mouth of the Hood River to Clear Creek is listed for temperature (303[d] list; DEQ, 2000).

The defined ODFW in-water work period for the Hood River, including the project site, is July 15 to August 31 (ODFW 2000).

5.2 Evaluation of Effects of the Proposed Project Using the NMFS Matrix

Potential risks to salmonids further evaluated using methods identified in *Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Watershed Scale* (NMFS, 1996), modified as necessary to reflect the site-specific nature of this project and the scope of the BA. Information regarding the environmental baseline conditions was obtained from the 303(d) list, direct observation, and information from ODFW personnel familiar with the area. Indicator values represent the best professional judgement based on the inventory data and qualitative observations of the project area. Many of the indicators are classified as "At Risk" or "Not Properly Functioning," because conditions in the project area appear degraded, and upstream forested areas have an extensive timber harvest history. The results of this analysis are summarized in Table 3, a Checklist for Documenting Environmental Baseline and Effects of Proposed Action(s) on Relevant Indicators.

"Properly Functioning" Indicators

None of the indicators are currently classified as "Properly Functioning." The Hood River suffers from timber harvest in its upper watershed and heavy agriculture use in its lower reaches. Dams, dikes, and channelization have altered the river and several of its native fish species no longer exist.

"At Risk" Indicators

Fourteen of the indicators are classified as "At Risk" for the Hood River watershed. The Sediment/Turbidity indicator is classified as "At Risk" due to the high level of timber harvest occurring within the watershed. The fall 2000 flood event exacerbated the sediment problem, at least on a short-term basis. The proposed project may cause a temporary increase in sediment delivery to the channel, and impacts may be seen during the initial introduction of water into Joe's Creek. Work would be isolated and short-term and would not degrade the indicator on a watershed scale.

The Chemical/Nutrient Contamination indicator is classified as "At Risk" for the Hood River watershed. The Hood River is classified on the DEQ's 303(d) list for temperature and pH. Although construction in the project area would increase the likelihood of hazardous material entering the river, risk will be minimized as described in the Minimization, Avoidance, and Compensation section of this report.

The Physical Barriers indicator is considered "At Risk" for the Hood River watershed due to the existence of several dams found along the river. This project, as proposed, would maintain this indicator.

The Substrate indicator is classified as "At Risk" because it is likely that the Hood River is affected by timber harvest and agriculture practices and therefore has increased levels of embeddedness due to sediment and turbidity. Embeddedness could increase locally because of sediment contributed from construction activities. However, project impacts would be temporary and minimal with best management practices in place.

The Large Woody Debris indicator is classified as "At Risk" due to lack of LWD observed throughout the project area. The watershed does not meet standards for LWD pieces/mile and lack of riparian vegetation limits LWD recruitment potential. The project will add LWD which should improve this indicator in the project area.

Off-Channel Habitat is classified as "At Risk" for the watershed due to the channelization and riparian zone encroachment through agriculture and timber harvest. Dam construction, irrigation, and channelization have likely led to the destruction of backwater areas important for salmonid rearing. This project will locally improve this indicator by providing rearing, and possible spawning habitat (depending on the species) for resident anadromous fish. Joe's Creek will also provide rearing habitat through the incorporation of pools, LWD, and boulders to increase and create complex cover.

The Refugia indicator has been classified as "At Risk" because of the degraded condition of the Hood River's riparian zone. Timber harvest, roads, and agriculture have all led to a decreased riparian zone and degraded aquatic conditions. Refugia habitat is expected to locally improve in the Joe's Creek area by planting the riparian area and creating aquatic habitat.

Streambank condition is considered "At Risk" for the Hood River watershed. Decreased riparian vegetation and channelization of the river has likely led to greater occurrences of active erosion and streambank sloughing. The proposed project will improve this indicator locally with a planting plan incorporated into the design.

The Floodplain Connectivity indicator is classified as "At Risk" due to high levels of floodplain encroachment from timber harvest and farming that has occurred in the Hood River watershed. Floodplain connectivity is anticipated to increase as a result of this project.

The Change in Peak/Base flows indicator is classified as "At Risk" because of past and existing levels of disturbance within the Hood River watershed. This project is expected to maintain this indicator.

The Drainage Network Increase indicator is classified as "At Risk" due to the high level of roads associated with the watershed. The proposed project will not result in any new roads and should maintain the indicator on a watershed scale.

The Road Density and Location indicator is classified as "Not Properly Functioning" due to the high level of urbanization associated with the watershed as well as the project area and its surroundings. This indicator will be maintained, as no new roads will be built as a result of this project.

The Disturbance History indicator is currently classified as "At Risk" due to the existing and historic timber harvest levels and limited riparian and refugia habitat. Boulder and LWD placement may cause a temporary disturbance within the project area. Disturbance will be minimized or avoided through the use of proper construction techniques.

The Riparian Reserves indicator is "At Risk" because existing riparian vegetation is sparse and provides little cover and function. The proposed project is expected to locally improve this indicator with a planting plan being incorporated into the design.

"Not Properly Functioning" Indicators

Only one of the indicators is considered to be "Not Properly Functioning" for the Hood River watershed. The Hood River is listed on the DEQ's 303(d) list for Temperature, with many days exceeding migration, spawning, and rearing temperature standard. A planting plan should maintain and locally improve this indicator.

"No Data" Indicators

Three of the indicators have been classified as "No Data" for the Hood River watershed. This classification is given to indicators that do not have adequate information to determine baseline conditions.

No data exists for Pool Frequency or Pool Quality for the Hood River. Currently, lack of LWD near the project area may decrease Pool Frequency and Pool Quality. The project is expected to maintain both indicators.

No data exists for Width to Depth Ratio for the Hood River. The project is expected to maintain this indicator.

Indicators Expected to be "Maintained"

All of the indicators are expected to be "Maintained" as a result of the proposed project. Limited construction activities and use of best management practices should minimize impacts on the watershed. Several indicators are expected to locally improve conditions within the project area. Impacts from construction of the Joe's Creek channel would be localized and temporary, and would not affect the Hood River on a watershed scale.

6.0 ANALYSIS OF EFFECT

This section addresses possible impacts caused by the proposed action.

6.1 Site-Specific Impacts

6.1.1 Water Quality

Proposed minimization and avoidance measures and best management practices should reduce any potential sediment transport to Joe's Creek and Hood River. The fish screen will be constructed in the dry in an upland area. No water quality impacts are anticipated. Joe's Creek construction activities also would occur in a dry channel, except for work on the step pools at the mouth. Limited work in this area would cause a local short-term increase in turbidity.

Water quality impacts during startup when flows will be bypassed to Joe's Creek for the first time will be minimized by slowly ramping the initial flows from the fish screen bypass into Joe's Creek to allow the channel to stabilize. Initial introduction of water into Joe's Creek may create a short-term increase in sediment to the Hood River. Sediment and turbidity impacts are expected to be limited, local, and of short duration of a few hours.

Requiring all machinery fueling and maintenance to occur over 150 feet away from the ordinary high water mark (OHWM) would minimize the hazardous material spill risk. Hazardous material containment systems would be ready for use, and trained personnel would be required to be on-site during any phase of construction in which hazardous material may come into contact with the river. The risk to fish and aquatic habitat would depend on the type of spill, time of year, spill amount, and success of containment. Equipment used below the OHWM would be cleaned and inspected daily to ensure hazardous materials (gas, oil, hydraulic fluid) from normal operation are not introduced. All in-water work would occur during the ODFW recommended in-water work period (July 15-August 31).

Vegetative plantings on the berm and along Joe's Creek following project completion should result in improved long-term riparian conditions and bank stability, at least locally. Water quality impacts from the project will be temporary and isolated through the use of minimization and avoidance measures described later in this report.

6.1.2 Habitat Alteration/In-water Work

Disturbance to critical habitat would include boulder and LWD placement. Evaluation of impacts on critical habitat are discussed in Section 5.2, Evaluation of Effects of the Proposed Project Using the NMFS Matrix (Table 3).

Work below the OHWM would occur during construction. All work within the OHWM would occur between July 15 and August 31. Minimal habitat alteration will occur in Hood River to create step pools at the mouth of Joe's Creek. The work will consist of importing boulders and other natural substrate materials to form step pools. Minimal excavation will be necessary near the confluence of Joe's Creek and Hood River. Only minor in-stream ground disturbing activities would occur below the OHWM as a result of the proposed project.

Construction impacts to Joe's Creek would be temporary and would not impact fish populations since no fish likely are present in Joe's Creek because there is no sustained flow (S. Pribyl, May 30, 2001). Minimization and avoidance measures described in this document would limit any excessive sediment delivery to Joe's Creek or Hood River resulting from this activity. In addition, construction would take place during the summer months, when spawning salmonid species would not occur in the project area.

6.1.3 Predation

Predation at the fish screen is not anticipated to be an issue (M. Jennings, CTWS; S. Pribyl, ODFW, pers. Comm. May 30, 2001). Based on comments from Jerry Bryan and Tod Hilsted, Farmers Irrigation District, there has not been any evidence of predation of fish from Farmers Canal. Although water depths in the canal will become shallower as the flow passes over the fish screen, depths of up to 0.9 feet will be maintained in the tapered fish bypass. In addition, velocities of up to 9 feet per second will allow quick passage of fish over the fish screen and minimize the opportunity for predation.

Joe's Creek is located in a highly shaded, dense canopied, forested area. In addition, the proposed placement of large woody debris (LWD), construction of undercut banks, and construction of pool areas would limit opportunities for predation. The small size of the creek would limit predatory bird from preying on fish potentially found in Joe's Creek. Any effects from predatory birds on fish species are expected to be minimal. Similarly, predatory mammals are not likely to have a significant impact on any fish found in Joe's Creek. Fish species that prey on salmonids have the potential to occur in Joe's Creek. However, the small size of Joe's Creek combined with low water temperatures would limit most fish species that prey on salmonids.

6.1.4 Fish Passage

The proposed horizontal plate fish screen is not expected to hinder passage of fish from the canal to the Joe's Creek bypass. The fish screen will be flush with the canal bottom at the upstream transition to minimize hydraulic changes as water flows down the system. In the event that the screen is dewatered, fish likely would continue to move down the screen to the bypass area to Joe's Creek. The downstream transition from the screen to Joe's Creek consists of a drop of approximately 0.7 of a foot. This would allow fish to easily pass upstream, however the velocity of up to 9 feet per second may discourage fish other than adults.

To address possible fish movement or migration through Joe's Creek, the system has been designed to pass fish safely both upstream and downstream. Jump pools have been incorporated into the Joe's Creek design to accommodate both juvenile and adult upstream passage. In addition the gradient of the culverts would be between 0-1 percent. Lack of significant attraction flows at Joe's Creek mouth would likely limit adult movement into the creek. However, Joe's Creek may provide a velocity refuge from mainstem high flow events for juvenile and adult salmonids.

6.1.5 Disturbance

Noise and vibration created during construction and heavy equipment operation within the project area have the potential to disturb resident and anadromous fish species. Any potential impacts would be minimized by timing of construction, location of work, small size of disturbance area, use of best management practices, and the fact that the level and duration of these activities are expected to be limited. Work on the fish screen will be confined to an area approximately 50 feet horizontal and 50 feet vertical from the Hood River. Noise and vibration that would impact fish in Hood River is expected to be minimal. Noise and vibration for work on Joe's Creek bypass also would be minimal because of the distance from Hood River, except for the construction of step pools near the mouth of Joe's Creek. In this area, although some noise and vibration can be expected during construction of step pools, the disturbance would be minimal and short-term.

6.2 Minimization and Avoidance Measures

The primary erosion control concern will be around disturbed areas following construction. These areas will be seeded and mulched to prevent erosion from occurring during winter rains. However, erosion control concerns are low because the construction will take place during the dry season.

Areas of soil disturbance requiring re-vegetation within the Joe's Creek project will occur along the stream banks of the new channel, all pool excavation areas within Joe's Creek, the two construction access routes, the berm fill areas, culvert installation area and the last 50 feet of stream channel where step pools will be constructed.

The existing wetlands presently located within the channel of Joe's Creek will be modified from shallow ponded areas to perennial stream with potential for salmonid rearing. Therefore, the hydrology regime will be changed. However, the finished stream channel will be re-vegetated similar to existing conditions so that the area will continue to be a forested riparian vegetation community maintaining and/or improving existing functions.

Conservation measures have been incorporated into the project design (Section 7.0) to minimize and avoid impacts on listed fish and their habitat. These measures address in-water work, erosion control, containment of construction materials, handling of hazardous materials, and disturbance of riparian vegetation. In addition, the project design has gone to great lengths to minimize impacts by using sediment control techniques and implementing a planting plan. Access to the site will be from an existing road found along the east bank.

The following describes precautions that will be taken in order to minimize project impacts on the Hood River and its fisheries.

- Equipment will be monitored for any hydraulic fluid or gas leaks during construction. All refueling will be completed 150 feet away from ordinary high water mark

- Construction will occur during the in-water work period of July 15 – August 31; therefore reducing potential harm to fish.

- Construction grading and willow plantings will minimize the amount of erosion and prevent fine material from entering the Hood River.

- A monitoring plan will be developed to evaluate the effectiveness of the fish screen to pass fish and of Joe's Creek to provide quality habitat for juvenile and/or adult salmonids

- A monitoring plan will be developed to assess the effectiveness of the fish screen and cleaning system to prevent debris buildup on the fish screen.

6.3 Impacts on Environmental Baseline

The evaluation of potential impacts for the proposed action on the Hood River watershed were conducted according to *Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Watershed Scale* (NMFS, 1996). The effect of the proposed project on the Hood River watershed environmental baseline are limited to temporary localized impacts that would result in no net change to watershed baseline values.

Although some clearing of vegetation will occur, the proposed planting plan should result in a local improvement in vegetation, erosion, and streambank stability. The use of natural boulders, instream LWD placement, and a planting plan will insure a long-term solution for the project area as well as the surrounding environment.

7.0 CONSERVATION MEASURES

Conservation measures are intended to minimize or avoid environmental impacts on listed species and Critical Habitat. The minimal work anticipated for the Joe's Creek project will require relatively few conservation measures to assure avoidance or minimization of impacts to fisheries resources and their habitat. Minimization and avoidance measures have been developed to remove, reduce, or compensate for adverse effects of the proposed project. The following measures have been incorporated into the contract document for the proposed project.

7.1 Sediment/Erosion Control

The design consultant and construction contractor will prepare a Sediment/Erosion Control Plan for the project. The plan will detail specifications for control devices and how they will be implemented for each activity that may contribute sediment to the river or result in erosion. The approved plan will be implemented fully and monitored by the contractor. Construction activities that may contribute sediment or result in erosion will not begin before control devices are in place.

All control devices will be inspected daily during rainy periods and weekly during dry periods. During all phases of construction, including no-work periods and other work stoppages, personnel will be available to make immediate repairs on control devices. All silt fences would be removed upon completion of the project. All disturbed slopes, including cut and fill slopes, would be hydroseeded or otherwise vegetated to minimize sediment runoff.

All cleared areas will be seeded and mulched as appropriate, before the fall rain period (jute mats may be used on steep slopes). Efforts will be made to implement seeding/mulching as soon as possible after exposure. Material removed during excavation will be stockpiled in areas where it cannot enter waterways. Measures will be taken to prevent construction debris from entering the river.

All equipment used for in-water work will be cleaned before use. External grease, oil, dirt, and mud will be removed. Water used for cleaning will not be discharged into the river. Following construction, all staging areas and other areas cleared by construction will be recontoured, as necessary, to prevent erosion and seeded with an approved erosion control mix. At the appropriate time of year, native tree and shrub species will be planted to stabilize banks and bind soil.

7.2 Hazardous Materials

The contractor will develop a Pollution Control Plan (including a spill response plan) and is responsible for containment and removal of any hazardous material released. The contractor would be responsible for containment and removal of any hazardous materials released.

In the event that hazardous material is encountered during the course of the work, regardless of whether or not the material was shown in the plans, the implementation of the contractor's plan would be included in the scope of the contract and would be carried out by the contractor. The contractor would maintain, at the job site, the applicable equipment and material designated in the plan.

The spill control plan would identify people responsible for implementing the plan if a spill of dangerous or hazardous waste should occur, and how the spill would be contained and cleaned up, including the removal of contaminated soil. Any spill that occurred, regardless of size and/or type of spill, would be reported to the County, which would then notify the appropriate agencies.

The construction area would be kept clean of all debris, litter, and garbage. Refuse containers would be kept under cover or equipped with a tight-fitting lid. All solid waste would be disposed of in accordance with County Ordinance.

7.3 Riparian Area

Impacts to the Hood River and Joe's Creek riparian areas would be limited and short-term. The planting plan is expected to locally improve the existing riparian conditions. Native plantings will increase shade, provide greater bank stability, and increase habitat conditions within the project area.

8.0 INTERRELATED AND INTERDEPENDENT EFFECTS

Interrelated actions include actions that are part of a larger action and depend on the larger action for justification. Interdependent actions are defined as actions with no independent utility apart from the proposed action. . This project is intended to return fish and flows back to the Hood River, and is an independent action that has no significant interrelated or interdependent effects. The project is designed to improve existing conditions and create a long-term solution for Farmers Irrigation District.

9.0 Cumulative Effects

Cumulative effects are defined as the effects of future state, local, or private activities that are reasonably certain to occur in the project's watershed. Additional projects within the watershed, especially industrial and residential development, are anticipated as population growth continues in the region. Associated roads and other types of development are therefore likely in the foreseeable future for the Hood River watershed. The influence of these activities cannot be quantified in this document, but have been incorporated qualitatively in the environmental baseline for the affected watershed.

10.0 COMPENSATORY MITIGATION

Compensatory mitigation is defined as efforts made to offset potential impacts to threatened or endangered species or significant natural resources that may occur during construction of a proposed project. Compensatory mitigation for the loss of wetland in Joe's Creek will be offset by the construction of the new channel and associated wetlands. Approximately 120 feet of new stream channel will be created within upland and covers an area of 0.08-acre. Additional habitat enhancements include providing year round hydrology to Joe's Creek and connectivity with Hood River. This permanent connection will provide needed salmonid rearing and refuge habitat. Also, pools will be created in the existing channel and large woody debris will be incorporated into the banks, diversifying the fisheries habitat over 600 linear feet. At a mitigation creation ratio of 1.5-acres of creation to 1-acre impact, the 0.025-acre wetland impact will be compensated for with 0.08-acre creation (credit of 0.05-acre) and riparian enhancement within Joe's Creek.

In addition to providing habitat during normal flow events, the Joe's Creek bypass would provide some refuge for fish during high flow events in the Hood River when sediment loads are high. In the bypass area, sediment loads are expected to be lower because of regulated sediment exclusion facilities

The vegetation-planting plan will consist of native plants described in the existing condition section above in order to restore the area to the same condition as prior to construction.

11.0 FINDING OF EFFECT

Although no spawning or rearing habitat occurs within the project area, in-water work has the potential to effect fish species that may be found in the project area. Effects are expected to be limited and minimized because of the small area of impact, through the use of sediment control techniques and the fact that all work would occur during the recommended in-water work period. On a watershed scale, the proposed action will not "hinder the attainment of relevant functioning indicators" as defined in *Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Watershed Scale* (NMFS 1996).

Based on an evaluation of the potential effects of the project (Table 3), the Joe's Creek bypass project **may affect, and is likely to adversely affect** Lower Columbia River steelhead. The proposed project is likely to result in the destruction or adverse modification of designated steelhead critical habitat.

Although the historic spring chinook salmon run of the Hood River is considered extinct (Federal Register 1999), an effect call of **may affect, and is likely to adversely affect** is appropriate to address possible wild stray chinook salmon that may occur in the project area. The proposed project is likely to result in the destruction or adverse modification of designated chinook critical habitat.

No Columbia River chum salmon are found in the Hood River, therefore the project is expected to have **no effect** on Columbia River chum salmon or their designated critical habitat.

With respect to candidate species, the proposed project is **likely to significantly impact** Lower Columbia River coho salmon populations, individuals or suitable habitat.

With conservation measures in place and all work occurring during the recommended in-water work period, the proposed project would limit the potential for adverse effects to the maximum extent possible. Proposed conservation measures would limit potential project-related effects to the project vicinity. Any impacts would be temporary and would not result in a long-term, net change in function of the existing riparian or aquatic habitat. The planting plan should result in a localized, long-term improvement in vegetation, erosion, and general riparian and aquatic conditions. The finished project would provide a long-term solution for maintenance issues faced by Farmers Irrigation District, result in improved fish screen facilities, provide creation of fisheries habitat, and the improve water quality conditions since existing frequent maintenance would reduce to occasional maintenance.

12.0 REFERENCES

Federal Register. Volume 64, No. 56. Wednesday, March 24, 1999

National Marine Fisheries Service. December 28, 1993. Endangered and Threatened Species, Federal Register. Vol. 58, No. 247, p. 68543 and 68543.

National Marine Fisheries Service. February 16, 1997. Endangered and Threatened Species, Federal Register. Vol. 65, No. 32, p. 7764 and 7819.

National Marine Fisheries Service. October 25, 1999. Endangered and Threatened Species, Federal Register. Vol. 64, No. 205, p. 57399.

National Marine Fisheries Service. 1996. Making Endangered Species Act determinations of effect for individual or grouped actions at the watershed scale. Environmental and Technical Services Division, Habitat Conservation Branch.

Oregon Department of Environmental Quality. 2001. DEQ's 1998 303(d) list of water quality limited waterbodies & Oregon's criteria used for listing waterbodies. Salem, Oregon. URL: <http://waterquality.deq.state.or.us >.

Oregon Department of Fish and Wildlife. 2001. Oregon guidelines for timing of in-water work to protect fish and wildlife resources.

Pribyl, S. April 16 and 26, 2001. Fisheries Biologist. Oregon Department of fish and Wildlife, The Dalles, OR. Personal Communication.

U.S. Fish and Wildlife Service. 2000. Federally listed and proposed endangered and threatened species, candidate species, and species of concern that may occur in the area of the proposed irrigation intake project. Reference number 1-7-00-SP-461, June 30, 2000. Oregon State Office, Portland, Oregon.

Appendix I - National Marine Fisheries Service, 2001, Endangered Species Act – Section 7 Consultation Biological Opinion & Magnuson-Stevens Act Essential Fish Habit Consultation – Replacement of an Existing Fish Screen, Construction of a New Bypass Flow Return System, and Modifications of the Diversion Intake in the Farmers Irrigation District Canal Hood River Watershed

Endangered Species Act - Section 7 Consultation
Biological Opinion
&
Magnuson-Stevens Act
Essential Fish Habitat Consultation

Replacement of an Existing Fish Screen, Construction of a New Bypass Flow Return System, and Modification of the Diversion Intake in the Farmers Irrigation District Canal
Hood River Watershed
Hood River County, Oregon

Agency: Bonneville Power Administration

Consultation Conducted By: National Marine Fisheries Service, Northwest Region

Date Issued: August 17, 2001

Refer to: OSB2001-0022-FEC

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1. ENDANGERED SPECIES ACT

1.1 Background

On June 27, 2001, the National Marine Fisheries Service (NMFS) received a letter and attached biological assessment (BA) from the Bonneville Power Administration (BPA) requesting formal consultation on a proposed fish screen replacement, bypass flow return system construction, and water intake modification project on the Farmers Irrigation District (FID) Canal in the Hood River watershed. The BPA is funding the proposed project through the Confederated Tribes of the Warm Springs Indian Reservation of Oregon (CTWSRO), and BPA has been designated as the lead agency for Section 7 consultation under the Endangered Species Act (ESA). The applicant is the Farmers Irrigation District in Hood River, Oregon. NMFS toured the project site with project personnel on June 21, 2001. In the June 2001 BA, the BPA determined that Lower Columbia River (LCR) steelhead (*Oncorhynchus mykiss*) may occur within the project area and that the proposed project is "likely to adversely affect" (LAA) LCR steelhead or their designated critical habitat. The historic run of wild LCR chinook salmon (*O. tshawytscha*) in Hood River is considered extinct. However, strays from other LCR chinook salmon populations may enter Hood River. Therefore, LCR chinook salmon will also be addressed in this Opinion.

The new horizontal flat plate (HFP) fish screen proposed for installation has been developed and evaluated by FID over several years. The FID has worked with NMFS, U.S. Fish and Wildlife Service (USFWS), Oregon Department of Fish and Wildlife (ODFW), and the CTWSRO personnel for the past two years in developing and testing the new screen design. In April 2001, the FID tested the screen by using steelhead fry and smolts and chinook fry (FID 2001). In a June 26, 2001, letter from NMFS to BPA, NMFS concurred that the HFP screen is worthy of further development, as biological testing appears promising and protective hydraulic conditions at the screen appear achievable through careful design. In that letter, NMFS also stated that "to achieve our acceptance of the facility for long-term use, the screen effectiveness must be gauged through post construction evaluation of: 1) Hydraulic conditions at the screen; and 2) biological evaluation of fish passing through the entire facility."

The LCR steelhead was listed as threatened under the Endangered Species Act (ESA) by NMFS on March 19, 1998 (63 FR 13347). The LCR chinook salmon was listed as threatened under the ESA on March 24, 1999 (64 FR 14308). The NMFS designated critical habitat for LCR steelhead and LCR chinook salmon on February 16, 2000 (65 FR 7764) and issued protective regulations under section 4(d) of the ESA on July 10, 2000 (65 FR 42422). The proposed action is within designated critical habitat for LCR steelhead and LCR chinook salmon.

The NMFS prepared this biological opinion (Opinion) to address affects of the proposed project on these species. The objective of this Opinion is to determine whether the subject action is likely to jeopardize the continued existence of the above listed species or destroy or adversely modify critical habitat.

1.2 Proposed Action

The proposed action consists of: 1) Replacement of an existing rotary fish screen in the FID Canal with a new HFP fish screen; 2) construction of a new bypass system to return fish that have been diverted into the FID Canal from Hood River back to Hood River; and 3) modification of the FID Canal water diversion intake. The project is on Hood River near River Mile 11 (T2N, R9E, Section 29). No new roads would be built in association with the proposed project. Conservation measures to minimize and avoid potential impacts to listed fish and their designated critical habitat are described in Sections 6.2 and 7.0 through 7.3 of the BA, and are incorporated herein by reference.

1.2.1 Fish Screen Replacement

The existing rotary drum fish screen in the FID Canal would be replaced by an HFP Screen. The existing fish screen is approximately 500 feet down the FID Canal from the diversion intake. The new screen would be placed in a new concrete flume within the existing FID Canal alignment approximately 1000 feet downstream from the point of diversion. Water to the FID Canal would be shut off during installation of the new screen, so that work would occur in the dry. Once the new screen is in place, the old screen would be removed. The new screen is intended to meet NMFS acceptance standards regarding mortality and injury of salmonid smolts and fry.

Approximately 95 cubic feet per second (cfs) of water are currently diverted from Hood River into the FID Canal. The FID has historic water rights for this water. No additional water would be diverted from Hood River into the FID Canal because of this project. When the system flow is at steady state, the total diverted water would be split between the water to be used for irrigation (about 80 cfs) and the water to be used for the fish bypass (10 to 15 cfs). The irrigation water would pass through the plane of the screen with a uniform approach velocity of less than 0.1 foot per second (fps). Water that does not pass through the screen would be used as fish bypass water and would flow through the outlet transition throat into the newly constructed bypass channel, then into Joe's Creek (an intermittent stream), before returning to Hood River.

The screen would be dewatered only if maintenance is necessary or a catastrophic event occurred. For maintenance, the flow through the FID Canal would be slowly and carefully reduced to avoid stranding of fish on the screen. Fish would likely move downstream to the bypass area and into Joe's Creek as flow is reduced in the canal. FID personnel would walk down the screen as the water is lowered to ensure that fish are not stranded on the screen. During a catastrophic high flow event, such as a total debris block of the canal intake (based on past history this is unlikely), the intake gates at the pipeline would close gradually as flow is reduced and eventually close completely. In this case, the screen would be dewatered and fish could be stranded. However, FID has never experienced such an event with the existing system[1].

1.2.2 Construction of a New Fish Bypass System

The existing fish bypass consists of a flexible culvert situated so that fish exiting the bypass culvert drop approximately 10 feet to the surface of the water in Hood River. A new bypass system will be constructed to return fish from the FID Canal to Hood River. The upstream end of the new bypass would leave the FID Canal approximately 1000 feet downstream from the canal intake. Normal bypass flow through the newly constructed channel and into Joe's Creek is expected to be a continuous 10 to 15 cfs. Flows in the FID Canal may be interrupted during infrequent catastrophic events (e.g., floods) or for performance of maintenance.

To provide water to Joe's Creek if flows through the FID Canal are shut off, a 12-inch diameter pipeline would run parallel to and would be attached to the outside wall of the canal. To create the new bypass, approximately 120 feet of new channel will be constructed to connect the screen bypass with Joe's Creek. The new channel would have a slope of less than 1 percent and a bottom width of 16 to 20 feet, and would pass through an upland, forested area. Material excavated to create the new channel connecting the bypass outlet to Joe's Creek and pools in Joe's Creek will be stockpiled in areas where it cannot enter waterways. The newly constructed channel will enter Joe's Creek approximately 900 feet upstream from the Joe's Creek-Hood River confluence. Large woody debris (LWD) will be placed in the newly constructed channel to aid in stabilizing banks and create pools, and in Joe's Creek to create pool habitat. Erosion control fabric will also be used in the newly constructed channel. In addition to LWD placement, three pools would be excavated in the upper 500 feet of the existing channel of Joe's Creek

An access road blocks Joe's Creek. A 20-foot long, 48-inch diameter culvert would be installed under this road so that Joe's Creek can serve as a fish bypass return system from the FID Canal to Hood River. In addition, a 100-foot long, 48-inch diameter culvert would be installed to pass the creek under the water transmission pipeline. Depending on the final angle of the 100-foot culvert, either a series of step pools will be created in the lower 50 feet of the existing channel or a new channel approximately 55 feet long will be built to connect the culvert to Hood River. The bypass system is designed to pass fish safely both upstream and downstream. Jump pools have been incorporated into the design to allow juvenile and adult passage upstream. Construction would occur in the dry, except at the confluence of the downstream end of Joe's Creek with Hood River. All areas disturbed by construction activities will be planted with native trees, shrubs, and grasses.

As a precautionary measure, the bypass system will be designed to convey up to 120 cfs. In addition, a rock berm four feet high will be constructed between the bypass channel and the

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[1] E-mail from Richard Craven, Craven Consulting Group, to Ron Lindland, National Marine Fisheries Service (July 9, 2001) discussing the potential for dewatering of the fish screen in the FID Canal.

pipeline route to prevent any potential bypass overflow from eroding the pipeline structure. Berm construction will not require any tree removal.

1.2.3 Modification of the Water Diversion Intake

The existing intake and upper part of the concrete flume presently fill with sediments from Hood River requiring periodic labor-intensive clean out. The proposed intake modification is designed to reduce sediment that enters the irrigation intake and eventually the FID Canal. The modification consists of redistributing boulders and stream bottom material to shift the existing thalweg of Hood River slightly toward the west, away from the canal intake, and installing two sediment excluder sills in the upper end of the FID Canal itself.

The thalweg shift in Hood River would be in area referred to as Area A in the BA, approximately 280-feet long by 25-feet wide. Boulders removed from this area would be placed along the west side of the river, away from the FID Canal intake. The river substrate would be moved using a large track hoe with a "thumb" attachment. The area (Area B) to which boulders from Area A would be relocated is approximately 200-feet long by 40-feet wide. LWD in 18 to 24-inch diameter logs and rootwads would also be placed in Area B. Near the downstream end of Area A, in Area C, several large (3 to 4 cubic yard) boulders, imported to the project site, would be placed in the river. Imported boulders placed in Area C would increase "roughness" in the stream channel and serve to increase the backwater effect at the FID Canal intake. Area C is approximately 90-feet long by 50-feet wide. Large boulders imported to the site would be collected from upland deposit areas within the Hood River watershed. LWD imported for use in the project would be collected from scrap piles at previously logged sites. Trucks used to haul equipment, LWD, and boulders would reach the diversion intake site on an existing access road. Gravel would be added to this existing road prior to implementation of the project. A track hoe would be used to move boulders and LWD from a temporary upland deposit area to the appropriate position in Hood River.

The existing diversion intake berm (Area D) and the area directly downstream along the outside edge of the concrete FID Canal structure (Area E) would be stabilized by placing imported boulders and LWD, and by planting native trees and shrubs. Species to be planted include Columbia River willow (*Salix fluviatilis*), Geyer willow (*S. geyeriana*), Pacific willow (*S. lucida var. lasiandra*), Sitka willow (*S. sitchensis*), and black cottonwood (*Populus balsamifera*). The willows and cottonwoods would be planted as stakes and in bundles of three to five on approximately 1-foot centers. Area D is approximately 260-feet long and varies in width from 10 to 50-feet; while Area E is approximately 100-feet long and 30-feet wide. An area (Area F) on the opposite side of the concrete FID Canal structure from Area E would be filled with pit run gravel to create better access to the canal. All in-water work in Areas A-E is expected to be completed within 15 days. Area F, which is approximately 100-feet long by 15-feet wide and is on the opposite side of the concrete FID Canal from the river, is currently a low area where fish can become stranded when high winter and spring flows recede. Area F would be filled with pit run gravel to eliminate the low area.

Two sediment excluder sills (Area G) and two sediment extractors (Area H) will be installed to eliminate sediment once it has entered the mouth of the diversion from Hood River, and to prevent the sediment from being transported further down the FID canal. One sediment excluder sill would be installed at the mouth (upstream end) of the diversion and the other 100-feet down the canal from the mouth of the diversion. The sediment excluder sills are precast concrete Jersey barriers,12-feet long by 2-feet high. The sediment excluders work by causing a re-circulating flow along the downstream face to keep sand-sized particles in suspension until they can be transported laterally and discharged into a sediment-flushing outlet back to the Hood River main channel. Besides the sediment excluder sills, two sediment extractor tubes would be installed in the canal. One sediment extractor would be at the mouth (upstream end) of the existing concrete canal, and the second would be approximately 500-feet down the canal. The tube sediment extractors consist of a pipe with a slot cut along one side parallel with the long axis of the pipe. The pipe is inset into the canal with the slot flush with the canal floor. The pipe has an open end at the side of the canal where discharge flows can return to the river. Water flow and sediment transported along the canal floor enters the pipe through the slot and exits the side of the canal. The momentum of flow entering from the canal induces a swirling flow along the circumference of the pipe. The swirling action will suspend captured particles permitting them to be transported laterally across the canal and discharged to the river.

1.3 Biological Information and Critical Habitat

The listing status and biological information for LCR steelhead are described in Busby et al. (1995, 1996). The listing status and biological information for LCR chinook salmon are described in Myers et al. (1998). The NMFS designated critical habitat for LCR steelhead and LCR chinook salmon on February 16, 2000 (65 FR 7764) and applied protective regulations under section 4(d) of the ESA on July 10, 2000 (65 FR 42422). The adjacent riparian zone is included in this critical habitat designation.

Critical habitat for LCR steelhead in Oregon includes all river reaches accessible to listed steelhead in the mainstem Columbia River from its mouth upstream to Hood River; in Columbia River tributaries from the Willamette River upstream to Hood River inclusive; and tributaries to the Willamette River downstream from Willamette Falls. Critical habitat for LCR chinook salmon in Oregon is similar, except it also include tributaries to the Columbia River downstream from the Willamette River. Freshwater critical habitat includes all waterways, substrates, and adjacent riparian areas – areas adjacent to a stream that provides the following functions: Shade, sediment, nutrient or chemical regulation, streambank stability, and input of LWD or organic matter – below longstanding, natural impassable barriers (i.e. natural waterfalls in existence for at least several hundred years) and several dams that block access to former LCR steelhead habitat. The proposed action in Hood River is within designated critical habitat for LCR steelhead and LCR chinook salmon.

Hood River serves as spawning, rearing, and migration habitat for LCR steelhead and LCR chinook salmon. Essential features of the area for these species are: (1) Substrate; (2) water quality; (3) water quantity; (4) water temperature; (5) water velocity; (6) cover/shelter; (7) food (juvenile only); (8) riparian vegetation; (9) space; and (10) safe passage conditions (50 CFR 226). The essential features this proposed project may affect are substrate, water quality (turbidity), cover/shelter, and safe passage conditions.

According to the BA, migrating adult LCR steelhead are present in the mainstem of Hood River year-round. Hood River supports both winter and summer steelhead that return in overlapping runs throughout the year. Hatchery steelhead from several Columbia River hatcheries are known to "stray" into Hood River. Wild steelhead destined for other Columbia River tributaries may do the same. Juvenile LCR steelhead are not likely to be present in the project area during the ODFW preferred in-water work period between July 15 and August 31. However, adult steelhead may be migrating through the area. The BA, citing S. Pribyl of ODFW, states that summer steelhead spawn in the West Fork of Hood River upstream from the project site, and that some spawning by winter steelhead is known to occur in the mainstem of Hood River. Winter steelhead spawn mainly in March and April, and would not be spawning, nor would eggs or alevins be present in the gravels, in the mainstem of Hood River during the preferred in-water work period between July 15 and August 31.

As stated above, wild chinook salmon in Hood River are considered extinct. Hatchery spring chinook spawn, rear, and migrate in Hood River and its tributaries, but these hatchery fish are not considered part of the LCR chinook salmon ESU. Hatchery chinook from several Columbia River hatcheries are known to "stray" into Hood River. Wild LCR chinook salmon destined for other Columbia River tributaries may do the same. Juvenile LCR chinook salmon are not likely to be present in the project area during the ODFW preferred in-water work period between July 15 and August 31. Chinook salmon are known to spawn in the mainstem of Hood River.

1.4 Evaluating Proposed Actions

The standards for determining jeopardy are set forth in Section 7(a)(2) of the ESA as defined by 50 CFR 402 (the consultation regulations). NMFS must determine whether the action is likely to jeopardize the listed species and/or whether the action is likely to destroy or adversely modify critical habitat. This analysis involves the initial steps of: (1) Defining the biological requirements of the listed species, and (2) evaluating the relevance of the environmental baseline to the species' current status.

Subsequently, NMFS evaluates whether the action is likely to jeopardize the listed species by determining if the species can be expected to survive with an adequate potential for recovery. In making this determination, NMFS must consider the estimated level of mortality attributable to: 1) Collective effects of the proposed or continuing action; 2) the environmental baseline; and 3) any cumulative effects. This evaluation must take into account measures for survival and recovery specific to the listed salmon's life stages that occur beyond the action area. If NMFS finds that the action is likely to jeopardize the continued existence of the listed species, NMFS must identify reasonable and prudent alternatives for the action.

Furthermore, NMFS evaluates whether the action, directly or indirectly, is likely to destroy or adversely modify the listed species' critical habitat. The NMFS must determine whether habitat modifications appreciably diminish the value of critical habitat for both survival and recovery of the listed species. The NMFS identifies those effects of the action that impair the function of any essential feature of critical habitat. The NMFS then considers whether such impairment appreciably diminishes the habitat's value for the species' survival and recovery. If NMFS concludes that the action will adversely modify critical habitat, it must identify any reasonable and prudent measures available.

For the proposed action, NMFS' jeopardy analysis considers direct or indirect mortality of fish attributable to the action. NMFS' critical habitat analysis considers the extent to which the proposed action impairs the function of essential biological elements necessary for juvenile and adult migration, spawning, and rearing of the listed and proposed species under the existing environmental baseline.

1.4.1 Biological Requirements

The first step in the methods NMFS uses for applying the ESA section 7(a)(2) to listed salmonids is to define the species' biological requirements that are most relevant to each consultation. The NMFS also considers the current status of the listed species taking into account population size, trends, distribution and genetic diversity. To assess to the current status of the listed species, NMFS starts with the determinations made in its decision to list LCR steelhead and LCR chinook salmon for ESA protection and also considers new data available that is relevant to the determination.

The relevant biological requirements are those necessary for LCR steelhead and LCR chinook salmon to survive and recover to a naturally reproducing population level at which protection under the ESA would become unnecessary. Adequate population levels must safeguard the genetic diversity of the listed stock, enhance its capacity to adapt to various environmental conditions, and allow it to become self-sustaining in the natural environment.

For this consultation, the biological requirements are improved habitat characteristics that function to support successful rearing and migration. The current status of the listed species, based upon their risk of extinction, has not significantly improved since the species were listed.

1.4.2 Environmental Baseline

The environmental baseline is an analysis of the effects of past and ongoing human-caused and natural factors leading to the current status of the species or its habitat and ecosystem within the action area. The action area is defined as, "all areas to be affected directly or indirectly by the Federal action and not merely the immediate area involved in the action" (50 CFR 402.02). The action area for this consultation, therefore, includes the streambed and streambank of the mainstem of Hood River within the area of disturbance at the FID Canal diversion intake and downstream to approximately 300 feet below its confluence with Joe's Creek and the streambed and streambank of Joe's Creek from the point of entry of the newly constructed bypass channel downstream to the mouth of Joe's Creek.

The current population status and trends for LCR steelhead are described in Busby et al. (1996), while those for LCR chinook salmon are described in Myers et al. (1998). In general, the current status of LCR steelhead and LCR chinook salmon populations is the result of several long-term, human-induced factors (e.g., habitat degradation, water diversions, hydropower dams) that serve to exacerbate the adverse effects of natural environmental variability from such factors as drought, floods, and poor ocean conditions.

Environmental baseline conditions within the action area were evaluated for the subject action at the project site and watershed scales. The results of this evaluation, based on the "matrix of pathways and indicators" (MPI) described in NMFS (1996), follow. This method assesses the current condition of instream, riparian, and watershed factors that collectively provide properly functioning aquatic habitat essential for the survival and recovery of the species. An assessment of the essential features of LCR steelhead and LCR chinook salmon critical habitat is obtained by using the MPI process to evaluate whether aquatic habitats are properly functioning. In the mainstem of Hood River, 15 of the 18 habitat indicators were rated as functioning "at risk," based on thresholds presented in the MPI. Water temperature, LWD, and width to depth ratio were rated as not properly functioning. None of the 18 MPI parameters were rated as properly functioning. The condition of each indicator is described in Sections 5.1 and 5.2 of the BA, and those descriptions are incorporated herein by reference. Hood River, from its mouth to Clear Creek (including the action area) is on the Oregon Department of Environmental Quality (ODEQ) Clean Water Act Section 303(d) list because of high water temperature.

According to the BA, the Newton-Clark Glacier slope failure several miles upstream from the FID Canal project site deposited millions of cubic yards of material in the Hood River watershed during the fall of 2000. Turbidity and sediment loads in Hood River are generally high during the preferred in-water work period (July 15 to August 31) because of glacial runoff. Dominant substrate material in Hood River at the project site is boulders and large cobble. Little, if any, suitable spawning habitat for LCR steelhead or LCR chinook salmon is present in Hood River near the proposed project.

1.5 Analysis of Effects

1.5.1 Effects of Proposed Action

1.5.1.1 Fish Screen Replacement

Installation of the new HFP fish screen would occur in the dry. No impacts to water quality in Hood River are expected. Installation of the new screen is expected to minimize or eliminate the danger that LCR steelhead and LCR chinook salmon will be entrained into the FID Canal, where they would become stranded and die.

Once the new screen is in place, a slight potential exists for fish to become stranded on the screen if a catastrophic event plugs the FID Canal intake with debris. If flow into the canal intake is blocked during a major catastrophic event, the screen would be dewatered and fish could potentially be stranded. The FID has never experienced such an event with the existing system. Since the thalweg of Hood River will be shifted slightly away from the FID Canal intake as part of the proposed project, the potential for blockage of the canal intake should be reduced even further from present conditions.

1.5.1.2 Construction of a New Fish Bypass System

The excavation of pools, placement of boulders, and placement of LWD in the newly constructed portion of the bypass system and in Joe's Creek, and installation of culverts in Joe's Creek will result in disturbance of the stream substrate. These activities will occur in the dry and no impacts to water quality in Hood River are expected. The initial introduction of water through the new bypass system may result in a temporary increase in turbidity in Hood River downstream from Joe's Creek. Potential turbidity increases would be minimized by slowly ramping the initial flows from the fish screen bypass into Joe's Creek to allow the channel to stabilize. Creation of step pools at the downstream end of the bypass, where it enters Hood River, could also result in some minimal amount of sediment entering Hood River. The temporary increase in stream turbidity in Hood River could result in temporarily reduced feeding efficiency for juvenile salmonids that may be present in the area. However, since turbidity in Hood River is usually high during summer months because of glacial runoff from Mt. Hood, any additional turbidity resulting from work in Joe's Creek may not be detectable in Hood River. Because Joe's Creek is an intermittent stream in the project area, no juvenile salmonids are expected to be present where excavation will occur. Therefore, operation of the excavator is not expected to kill or injure any juvenile salmonids in Joe's Creek.

The bypass system is designed to provide both upstream and downstream passage for juvenile and adult salmonids. The lack of significant attraction flows at the mouth of Joe's Creek would likely limit the number of adult LCR steelhead or LCR chinook salmon entering the creek from Hood River. Joe's Creek may provide a refuge from high flow events in the mainstem of Hood River for juvenile and adult salmonids, and is expected to provide rearing habitat for juvenile salmonids.

1.5.1.3 Modification of the Water Diversion Intake

Movement of boulders and placement of LWD in Areas A and B to shift the thalweg of Hood River away from the water diversion intake on the FID Canal and placement of imported boulders in Area C require operation of a track hoe below the ordinary high water mark (OHWM) and within the wetted width of Hood River. Placement of boulders and LWD on the existing diversion intake berm in Area D and along the existing concrete canal edge in Area E, and placement of the sediment excluder sills within the FID Canal also require use of a track hoe within the OHWM of Hood River, but little if any work within the wetted width of Hood River. Disturbance of substrate in Hood River would result in a short-term increase in the turbidity of Hood River at the project site and downstream. However, as stated above, turbidity levels and sediment loads in Hood River during the in-water work period (July 15- August 31) are generally quite high due to glacial runoff from Mt. Hood. The temporary increase in turbidity in Hood River, though it is expected to be a slight increase over baseline levels for that time of year, could result in temporarily reduced feeding efficiency for juvenile LCR steelhead or LCR chinook salmon that may be present in the project area. It is also possible that in moving boulders and placing LWD, the track hoe may kill or injure listed juvenile salmonids. Direct mortality is expected to be minimal, because juvenile fish will likely avoid the equipment and can move freely upstream or downstream from the project site. Because little, if any, spawning habitats for LCR steelhead or LCR chinook salmon spawning habitat are present in Hood River near the proposed project, spawning habitat for these species will not be adversely affected by the in-stream work.

Besides temporary increases of turbidity, movement of boulders and placement of LWD (Areas A and B) to shift the thalweg of Hood River away from the water diversion intake on the FID Canal and placement of imported boulders in Area C could result in some change of stream hydraulics at the water intake site and downstream. Movement of boulders would not result in increased water velocities that would impede fish passage, and no barriers to fish passage would be created. Substrates in Hood River at the water intake site and downstream are dominated by boulders and streambanks are well armored. Therefore, any change in stream hydraulics resulting from the slight shift of the thalweg at the water intake site is not expected to result in any streambank erosion downstream.

1.5.2 Effects on Critical Habitat

NMFS designates critical habitat based on physical and biological features that are essential to the listed species. Essential features for designated critical habitat include substrate, water quality, water quantity, water temperature, food, riparian vegetation, access, water velocity, space and safe passage. Those essential features which may be affected by this project in Hood River are substrate, water quality, and safe passage. For the proposed action, NMFS expects that the long-term effects will tend to improve current baseline conditions and increase available salmonid rearing habitat in Joe's Creek over the long term.

1.5.3 Cumulative Effects

Cumulative effects are defined in 50 CFR 402.02 as "those effects of future State or private activities, not involving Federal activities, that are reasonably certain to occur within the action area of the Federal action subject to consultation." For the purposes of this analysis, the action area for this consultation, therefore, includes the streambed and streambank of the mainstem of

Hood River within the area of disturbance at the FID Canal diversion intake and downstream to approximately 300 feet below its confluence with Joe's Creek and the streambed and streambank of Joe's Creek, from the point of entry of the newly constructed bypass channel downstream to the mouth of Joe's Creek. Other activities within the Hood River watershed have the potential to adversely affect fish and habitat within the action area. Future Federal actions, including the ongoing operation of hydropower systems, hatcheries, fisheries, and land management activities will be reviewed through separate section 7 consultation processes. NMFS is not aware of any significant change in non-Federal activities that are reasonably certain to occur. NMFS assumes that future private and State actions will continue at similar intensities as in recent years.

1.6 Conclusion

NMFS has determined that, when the effects of the FID Canal project addressed in this Opinion are added to the environmental baseline and cumulative effects occurring in the action area, it is not likely to jeopardize the continued existence of LCR steelhead or LCR chinook salmon. Additionally, NMFS concludes that the subject action would not cause adverse modification or destruction of designated critical habitat for LCR steelhead or LCR chinook salmon. NMFS believes that the proposed actions would cause a minor, short-term increase in stream turbidity in the mainstem of Hood River downstream from the project area. Turbidity levels during the July 15 to August 31 in-water work window are normally high in Hood River because of glacial runoff from Mt. Hood. Long-term effects will include improved fish survival due to improvements in the diversion intake, fish screen, and fish bypass system. Although direct mortality of adult or juvenile LCR steelhead and LCR chinook salmon from this project could occur during in-water work, it is not expected, and potential mortality would be minimal and would not result in jeopardy.

These conclusions are based on the following considerations: 1) All in-water work will be completed during the ODFW preferred in-water work period between July 15 and August 31 when listed salmonids are least likely to be present; 2) the amount of water diverted from Hood River into the FID Canal will not be changed by this project; 3) replacement of the obsolete rotary drum fish screen with the new HFP screen is expected to minimize or eliminate the potential for LCR steelhead and LCR chinook salmon to pass the screen and enter the FID Canal; 4) replacement of the existing flexible culvert fish bypass system with the new bypass system will result in a more natural, gentler means of returning fish from the FID Canal to Hood River and will create additional salmonid rearing habitat in Joe's Creek; 5) modification of the FID Canal diversion intake is expected to reduce the sediment entering the canal and thus, reduce the need for sediment removal from the canal and improve the functionality of the new fish screen; and 6) NMFS expects that the net effect of the proposed action will be to maintain or help restore properly functioning habitat conditions in the project area of the mainstem of Hood River and Joe's Creek.

1.7 Reinitiation of Consultation

Consultation must be reinitiated, if the newly installed HFP screen does not meet NMFS acceptance standards for mortality and injury of salmonid smolts and fry listed below in Section 2.3. Consultation must also be reinitiated if: 1) The amount or extent of taking specified in the Incidental Take Statement is exceeded, or is expected to be exceeded; 2) new information reveals effects of the action may affect listed species in a way not previously considered; 3) the action is modified in a way that causes an effect on listed species that was not previously considered; or 4) a new species is listed or critical habitat is designated that may be affected by the action (50 CFR 402.16). To reinitiate consultation, the BPA should contact the Habitat Conservation Division (Oregon Branch Office) of NMFS.

2. INCIDENTAL TAKE STATEMENT

Section 4 (d) and Section 9 of the ESA prohibit any taking (harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, collect, or attempt to engage in any such conduct) of listed species without a specific permit or exemption. Harm is further defined to include significant habitat modification or degradation that results in death or injury to listed species by significantly impairing behavioral patterns such as breeding, feeding, and sheltering (64 FR 60727; November 8, 1999). Harass is defined as actions that create the likelihood of injuring listed species to such an extent as to significantly alter normal behavior patterns which include, but are not limited to, breeding, feeding, and sheltering. Incidental take is take of listed animal species that results from, but is not the purpose of, the Federal agency or the applicant carrying out an otherwise lawful activity. Under the terms of section 7(b)(4) and section 7(o)(2), taking that is incidental to, and not intended as part of, the agency action is not considered prohibited taking provided that such taking is in compliance with the terms and conditions of this incidental take statement. An incidental take statement specifies the impact of any incidental taking of threatened species. It also provides reasonable and prudent measures that are necessary to minimize impacts and sets forth terms and conditions with which the action agency must comply in order to implement the reasonable and prudent measures.

2.1 Amount or Extent of the Take

The NMFS anticipates that the action covered by this Opinion has more than a negligible likelihood of resulting in incidental take of listed salmonids because of detrimental effects from increased turbidity levels (non-lethal), and the potential for direct incidental take during in-water work (lethal and non-lethal). Effects of actions such as the one covered by this Opinion are largely unquantifiable in the short term, and are not expected to be measurable as long-term effects on habitat or population levels. Therefore, even though NMFS expects some low level incidental take to occur due to the action covered by this Opinion, the best scientific and commercial data available are not sufficient to enable NMFS to estimate a specific amount of incidental take to the species itself. In instances such as these, the NMFS designates the expected level of take as "unquantifiable." Based on the information provided by the BPA and other available information, NMFS anticipates that an unquantifiable amount of incidental take could occur as a result of the action covered by this Opinion. The extent of the take is limited to the project area.

2.2 Reasonable and Prudent Measures

The NMFS believes that the following reasonable and prudent measures are necessary and appropriate to avoid or minimize take of listed salmonid species resulting from the action covered by this Opinion. The BPA shall:

1. Minimize the amount and extent of incidental take resulting from in-water work required to complete the project addressed in this Opinion by implementing measures to limit the duration and extent of in-water work.

2. Minimize the amount and extent of take and impacts on critical habitat resulting from erosion and chemical pollution associated with this project by implementing measures that minimize the movement of soils and sediment both into, and within, the river and minimize or avoid the potential for chemical pollution.

3. Minimize the potential for take associated with installation and operation of the FID Canal fish screen.

4. Complete a comprehensive monitoring and reporting program to ensure this Opinion is meeting its objective of minimizing the likelihood of take from permitted activities.

2.3 Terms and Conditions

To be exempt from the prohibitions of section 9 of the ESA, the BPA must comply with the following terms and conditions, which implement the reasonable and prudent measures described above. These terms and conditions are non-discretionary.

1. To implement reasonable and prudent measure #1 (in-water work), above, the BPA shall ensure that:

    a. All work within the active channels of Hood River and Joe's Creek will be completed within the ODFW approved in-water work period (July 15 to August 31).[2]

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[2] Oregon Department of Fish and Wildlife, *Guidelines for Timing of In-Water Work to Protect Fish and Wildlife Resources*, 12 pp. (June 2000) (identifying work periods with the least impact to fish) (http://www.dfw.state.or.us/ODFW html/InfoCntrHbt/0600_inwtrguide.pdf)

b. Extension of the in-water work period, including those for work outside the wetted perimeter of the stream but below the ordinary high water mark must be approved by biologists from NMFS.

c. In-water work will not inhibit passage of any adult or juvenile salmonid species throughout the construction period or after project completion.

2. To implement reasonable and prudent measure # 2 (erosion and pollution), above, the BPA shall ensure that:

a. All equipment that is used for instream work will be cleaned before entering the job site. External oil and grease will be removed, along with dirt and mud. Wash and rinse water will not be discharged into streams and rivers without adequate treatment. Areas for fuel storage and servicing of construction equipment and vehicles will be at least 150-feet away from any water body.

b. A spill containment and control plan with notification procedures, specific clean up and disposal instructions for different products, quick response containment and clean up measures that will be available on site, proposed methods for disposal of spilled materials, and employee training for spill containment has been developed and can be carried out at the project site.

c. Material removed or excavated from the river bottom (Area A), that will not be moved to another location in project Areas B-F as described in Section 1.2.3 above, will be placed in locations where it cannot enter streams or other water bodies.

d. Appropriate erosion control devices (e.g., silt fencing or straw bales) will be placed to prevent turbid water from entering Hood River or other water bodies from the project access road, when excavated material is loaded into trucks for removal from the project site, and during transportation to the final upland disposal site.

3. To implement reasonable and prudent measure #3 (fish screen installation and operation), above, the BPA shall ensure that:

a. The FID continues to work with NMFS, USFWS, CTWSRO, and ODFW to verify that the completed screen design is equivalent to conventional screens in minimizing and avoiding take of listed salmonid species and meets NMFS acceptance standards for mortality or injury of juvenile salmonids. Those acceptance standards are as follows[3]:

i. Smolt (greater than 60 mm in length) mortality: Design performance objective of less than 0.5% mortality; actual mortality greater than 0.5%, but less than 2.0% would require additional work to lessen mortality; actual mortality of greater than 2.0% would require abandonment of experimental HFP screen and installation of conventional screen.

ii. Smolt (greater than 60 mm in length) injury: Design performance objective of less than 2.0% injury; actual injury greater than 2.0%, but less than 4.0% would require additional work to lessen injury; actual injury of greater than 4.0% would require abandonment of experimental HFP screen and installation of conventional screen.

iii. Fry (less than 60 mm in length) mortality: Design performance objective of less than 2.0% mortality; actual mortality greater than 2.0%, but less than 4.0% would require additional work to lessen mortality; actual mortality of greater than 4.0% would require abandonment of experimental HFP screen and installation of conventional screen.

iv. Fry (less than 60 mm in length) injury: Design performance objective of less than 4.0% injury; actual injury greater than 4.0%, but less than 6.0% would require additional work to lessen injury; actual injury of greater than 6.0% would require abandonment of experimental HFP screen and installation of conventional screen.

b. FID personnel are on-site during high flow events in Hood River which have the potential to plug the FID Canal water intake with debris.

c. During such an event, FID personnel would close the pipeline intake, if possible, and check the fish screen periodically for stranded fish.

4. To implement reasonable and prudent measure #4 (monitoring and reporting), above, the BPA shall ensure that:

a. Within 30 days of completing the project, the BPA will submit a monitoring report to NMFS describing their success at meeting these terms and conditions. This report will consist of the following information:

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[3] E-mail from Melissa Jundt, National Marine Fisheries Service, to Ron Lindland, National Marine Fisheries Service (July 30, 2001) listing NMFS acceptance standards for mortality or injury of juvenile salmonids at fish screens.

i. Project identification.
   (1) Project name;
   (2) starting and ending dates of work completed for this project; and
   (3) the name and address of the construction supervisor.

ii. A narrative assessment of the project's effects on natural stream function.

iii. Photographic documentation of environmental conditions at the project site before, during and after project completion.
   (1) Photographs will include general project location views and close-ups showing details of the project area and project, including pre and post construction.
   (2) Each photograph will be labeled with the date, time, photo point, project name, the name of the photographer, and a comment describing the photograph's subject.
   (3) Relevant habitat conditions include characteristics of channels, streambanks, riparian vegetation, flows, water quality, and other visually discernable environmental conditions at the project area, and upstream and downstream of the project.

b. If a dead, injured, or sick endangered or threatened species specimen is located, initial notification must be made to the National Marine Fishery Service Law Enforcement Office, located at Vancouver Field Office, 600 Maritime, Suite 130, Vancouver, Washington 98661; telephone: 360/418-4246. Care should be taken in handling sick or injured specimens to ensure effective treatment and care or the handling of dead specimens to preserve biological material in the best possible state for later analysis of cause of death. In conjunction with the care of sick or injured endangered and threatened species or preservation of biological materials from a dead animal, the finder has the responsibility to carry out instructions provided by Law Enforcement to ensure that evidence intrinsic to the specimen is not unnecessarily disturbed.

c. Within one year of completion of all phases of the project (new screen installation, new bypass construction, water intake modification), BPA will submit a report to NMFS describing:

   i. Effectiveness of the new HFP screen in passing listed salmonids, uninjured, through the FID Canal bypass facility and back into Hood River.

   ii. Use of the newly created rearing habitat in Joe's Creek by juvenile salmonids.

d. Monitoring reports will be submitted to:

National Marine Fisheries Service
Oregon Habitat Branch
Attn: OSB2001-0022
525 NE Oregon Street, Suite 500
Portland, OR 97232-2778

3. MAGNUSON-STEVENS ACT

3.1 Background

The objective of the Essential Fish Habitat (EFH) consultation is to determine whether the proposed action described above may adversely affect designated EFH for relevant species, and to recommend conservation measures to avoid, minimize, or otherwise offset potential adverse effects to EFH resulting from the proposed action.

3.2 Magnuson-Stevens Fishery Conservation and Management Act

The Magnuson-Stevens Fishery Conservation and Management Act (MSA), as amended by the Sustainable Fisheries Act of 1996 (Public Law 104-267), requires the inclusion of EFH descriptions in Federal fishery management plans. In addition, the MSA requires Federal agencies to consult with NMFS on activities that may adversely affect EFH.

EFH means those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity (MSA §3). For the purpose of interpreting the definition of essential fish habitat: Waters include aquatic areas and their associated physical, chemical, and biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate; substrate includes sediment, hard bottom, structures underlying the waters, and associated biological communities; necessary means the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem; and ``spawning, breeding, feeding, or growth to maturity" covers a species' full life cycle (50CFR600.110).

Section 305(b) of the MSA (16 U.S.C. 1855(b)) requires that:

- Federal agencies must consult with NMFS on all actions, or proposed actions, authorized, funded, or undertaken by the agency, that may adversely affect EFH;
- NMFS shall provide conservation recommendations for any Federal or State activity that may adversely affect EFH;
- Federal agencies shall within 30 days after receiving conservation recommendations from NMFS provide a detailed response in writing to NMFS regarding the conservation recommendations. The response shall include a description of measures proposed by the

agency for avoiding, mitigating, or offsetting the impact of the activity on EFH. In the case of a response that is inconsistent with the conservation recommendations of NMFS, the Federal agency shall explain its reasons for not following the recommendations.

The MSA requires consultation for all actions that may adversely affect EFH, and does not distinguish between actions within EFH and actions outside EFH. Any reasonable attempt to encourage the conservation of EFH must take into account actions that occur outside EFH, such as upstream and upslope activities, that may have an adverse effect on EFH. Therefore, EFH consultation with NMFS is required by Federal agencies undertaking, permitting or funding activities that may adversely affect EFH, regardless of its location.

3.3 Identification of EFH

The Pacific Fisheries Management Council (PFMC) has designated EFH for federally-managed fisheries within the waters of Washington, Oregon, and California. The designated EFH for groundfish and coastal pelagic species encompasses all waters from the mean high water line, and upriver extent of saltwater intrusion in river mouths, along the coasts of Washington, Oregon, and California, seaward to the boundary of the U.S. exclusive economic zone (370.4 km) (PFMC 1998a, 1998b). Freshwater EFH for Pacific salmon includes all those streams, lakes, ponds, wetlands, and other water bodies currently, or historically accessible to salmon in Washington, Oregon, Idaho, and California, except areas upstream of certain impassable man-made barriers (as identified by the PFMC), and longstanding, naturally-impassable barriers (i.e. natural waterfalls in existence for several hundred years)(PFMC 1999). In estuarine and marine areas, designated salmon EFH extends from the nearshore and tidal submerged environments within state territorial waters out to the full extent of the exclusive economic zone (370.4 km) offshore of Washington, Oregon, and California north of Point Conception to the Canadian border.

The Pacific Fisheries Management Council (PFMC) has designated EFH for three species of Pacific salmon: chinook (*Oncorhynchus tshawytscha*); coho (*O. kisutch*); and Puget Sound pink salmon (*O. gorbuscha*)(PFMC 1999). Freshwater EFH for Pacific salmon includes all those streams, lakes, ponds, wetlands, and other water bodies currently, or historically accessible to salmon in Washington, Oregon, Idaho, and California, except areas upstream of certain impassable man-made barriers (as identified by the PFMC), and longstanding, naturally-impassable barriers (i.e., natural waterfalls in existence for several hundred years). Detailed descriptions and identifications of EFH for salmon are found in Appendix A to Amendment 14 to the Pacific Coast Salmon Plan (PFMC 1999). Assessment of potential adverse effects to these species' EFH from the proposed action is based on this information.

3.4 Proposed Action

The proposed action is detailed above in Section 1.2. The action area includes the streambed and streambank of the mainstem of Hood River within the area of disturbance at the FID Canal diversion intake and downstream to approximately 300 feet below its confluence with Joe's Creek and the streambed and streambank of Joe's Creek from the point of entry of the newly constructed bypass channel downstream to the mouth of Joe's Creek. This area has been designated as EFH for various life stages of chinook salmon (*O. tshawytscha*) and coho salmon (*O. kisutch*).

3.5 Effects of Proposed Action

As described in detail in Section 1.5.1, the proposed activity may result in detrimental short-term effects to water quality (turbidity) and disturbance of stream substrate. The temporary increase in stream turbidity could result in temporarily reduced feeding efficiency for juvenile salmonids which may be present in the area. The movement and relocation of boulders in Hood River would not result in increased water velocities that would impede fish passage, and no barriers to fish passage would be created. Substrate in Hood River at the water intake site and downstream is dominated by boulders and streambanks are well armored. Therefore, any change in stream hydraulics resulting from the slight shift of the thalweg at the FID Canal water intake site is not expected to result in any streambank erosion downstream.

3.6 Conclusion

NMFS believes that the proposed action may adversely affect the EFH for chinook salmon and coho salmon.

3.7 EFH Conservation Recommendations

Pursuant to section 305(b)(4)(A) of the Magnuson-Stevens Act, NMFS is required to provide EFH conservation recommendations for any Federal or state agency action that would adversely affect EFH. The conservation measures that the BPA has built into the project are generally applicable to EFH for the designated species, and are intended minimize the potential adverse effects to EFH. However, these measures do not address the potential impacts described above. Consequently, the NMFS incorporates the reasonable and prudent measures and associated terms and conditions of this incidental take statement as EFH conservation recommendations.

3.8 Statutory Response Requirement

Please note that the Magnuson-Stevens Act (section 305(b)) and 50 CFR 600.920(j) requires the BPA to provide a written response to NMFS' EFH conservation recommendations within 30 days of its receipt of this letter. The response must include a description of measures proposed to avoid, mitigate, or offset the adverse impacts of the activity on EFH. If the response is inconsistent with NMFS' conservation recommendations, the reasons for not implementing the BPA shall explain its reasons for not following the recommendations.

3.9 Consultation Renewal

The BPA must reinitiate EFH consultation with NMFS if either action is substantially revised or new information becomes available that affects the basis for NMFS' EFH conservation recommendations (50 CFR 600.920).

4. LITERATURE CITED

Busby, P., S. Grabowski, R. Iwamoto, C. Mahnken, G. Matthews, M. Schiewe, T. Wainwright, R. Waples, J. Williams, C. Wingert, and R. Reisenbichler. 1995. Review of the status of steelhead (*Oncorhynchus mykiss*) from Washington, Idaho, Oregon, and California under the U.S. Endangered Species Act. 102 p. plus 3 appendices.

Busby, P.J., T.C. Wainwright, G.J. Bryant, L.J. Lierheimer, R.S. Waples, F.W. Waknitz, and I.V. Lagomarsino. 1996. Status review of west coast steelhead from Washington, Idaho, Oregon, and California. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-27, 261p.

FID (Farmers Irrigation District). 2001. Re-evaluation of Farmers Irrigation District Prototype Horizontal Flat Plate Fish Screen. May 14.

Myers, J.M., R.G. Kope, G.J. Bryant, D. Teel, L.J. Lierheimer, T.C. Wainwright, W.S. Grant, F.W. Waknitz, K. Neely, S.T. Lindley, and R.S. Waples. 1998. Status review of chinook salmon from Washington, Idaho, Oregon, and California. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-35, 443 p.

NMFS (National Marine Fisheries Service). 1996. Making ESA Determinations of Effect for Individual or Grouped Actions at the Watershed Scale. NMFS Environmental and Technical Services Division, Habitat Conservation Branch, 525 NE Oregon Street, Portland, Oregon. 28 p. (Available @ www.nwr.noaa.gov under Habitat Conservation Division, Habitat Guidance Documents).

NMFS (National Marine Fisheries Service) 1999. The Habitat Approach: Implementation of Section 7 of the Endangered Species Act for Actions Affecting the Habitat of Pacific Anadromous Salmonids, 13 pages. NMFS, Portland, Oregon (August 26, 1999)

ODFW (Oregon Department of Fish and Wildlife) 2000. *Guidelines for Timing of In-Water Work to Protect Fish and Wildlife Resources*, 12 pp (June 2000)(identifying work periods with the least impact on fish) (http://www.dfw.state.or.us/ODFWhtml/InfoCntrHbt/0600_inwtrguide.pdf).

PFMC (Pacific Fishery Management Council). 1998a. Amendment 8 to coastal pelagic species fishery management plan. PFMC, Portland, Oregon. December.

PFMC (Pacific Fishery Management Council). 1998b. Final environmental assessment: regulatory review for Amendment 11 to Pacific Coast groundfish fishery management plan. PFMC, Portland, Oregon.

PFMC (Pacific Fishery Management Council). 1999. Amendment 14 to the Pacific Coast Salmon Plan. Appendix A: Description and Identification of Essential Fish Habitat, Adverse Impacts and Recommended Conservation Measures for Salmon. Portland, Oregon.

Appendix J - Craven, 2003, Monitoring Plan for Farmers Canal Overshot Horizontal Flat Plate Fish Screen Hood River, Oregon

Monitoring Plan for Farmers Canal

Overshot Horizontal Flat Plate Fish Screen

Hood River, Oregon

Prepared by:

Farmers Irrigation District
Hood River, Oregon

February 11, 2003

Table of Contents

1.0 INTRODUCTION

Farmers Irrigation District (FID) operates the Farmers Canal on the Hood River, Oregon (Figure 1). The canal intake diverts approximately 95 cubic feet of water per second (cfs) from the Hood River. Water is conveyed through this diversion to various locations in the Hood River Valley for irrigation and to generate hydroelectric power to the Pacific Northwest energy grid.

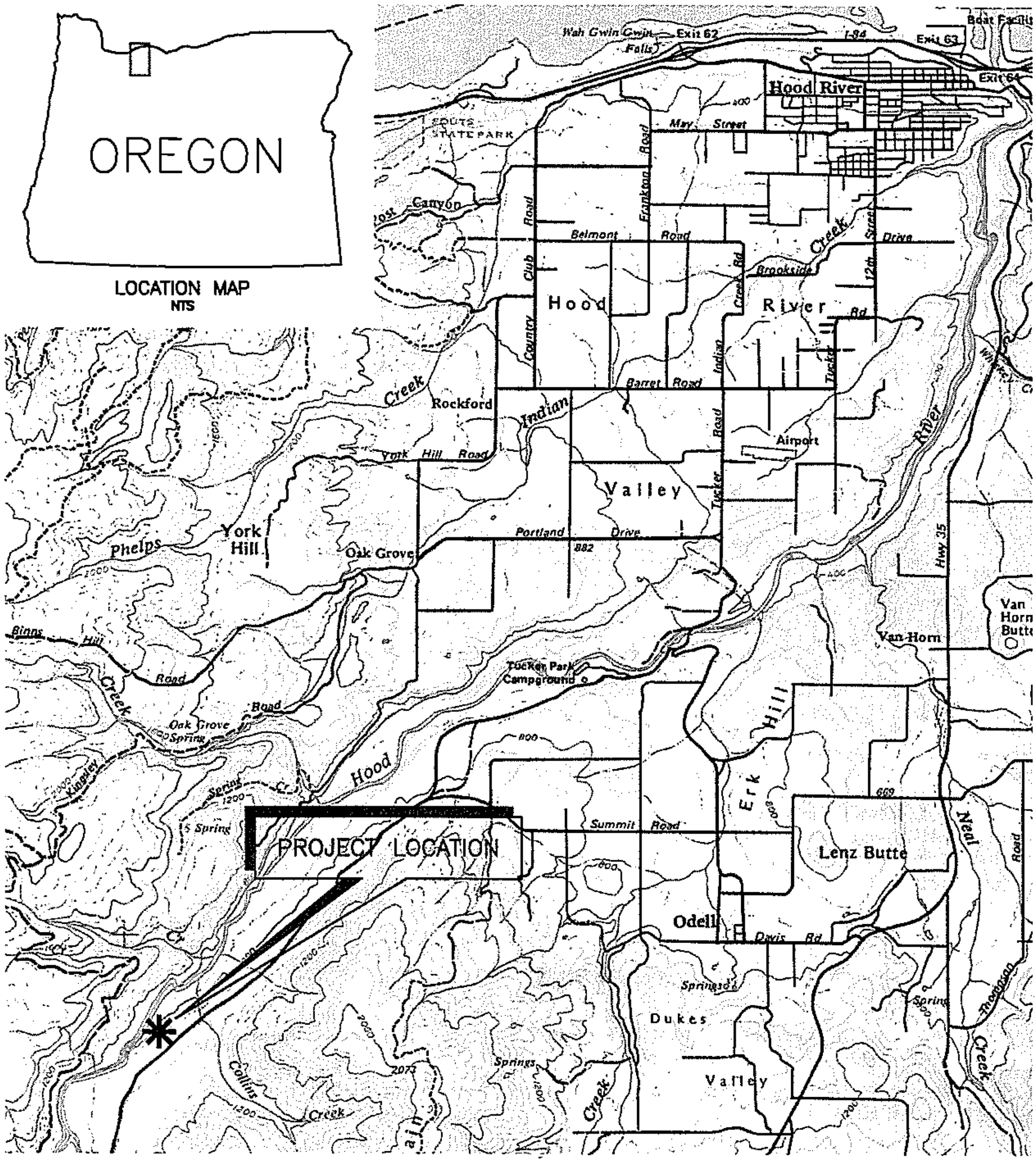
An outdated fish screening system near the head of the canal provides fish protection (Figure 2). The system consists of a rotating drum screen and a fish bypass back to the river. FID has attempted to update and improve the existing fish screen system, but the outdated equipment and fish protection screens require a substantial investment in time and funding to upgrade to an acceptable rotating drum screen. In addition, one of the main concerns of the existing system has been the high maintenance required to prevent buildup of debris and sediments from the river. Because of the high costs and maintenance issues, FID initiated studies several years ago to evaluate alternatives to the existing system.

These studies resulted in a new design and operation concept for a horizontal flat plate fish screen to replace the existing rotary drum screen. Based on a new concept in design and hydraulic control, FID designed and tested a prototype overshot horizontal flat plate fish screen on the Farmers Canal several miles downstream from the intake on the Hood River. Based on biological and hydraulic analyses of the performance of the prototype in 2000 and 2001, FID decided to design an overshot horizontal flat plate fish screen to replace the outdated rotary drum screen.

The overshot horizontal flat plate screen has been designed by FID and approvals received from the Oregon Department of Fish and Wildlife (ODFW), National Oceanic Atmospheric Administration (NOAA) Fisheries, and U. S. Fish and Wildlife Service (USFWS). Permits also were received from the U.S. Army Corps of Engineers and Oregon Division of State Lands. Construction was started in the fall of 2001, with completion scheduled for the fall of 2002/winter 2003 (Figure 2).

The location selected for the new screen also will allow a portion of an intermittent stream (Joe's Creek) to be enhanced. Joe's Creek is a small, approximately 900-foot long tributary of the Hood River and only flows intermittently during high precipitation (Figure 2). Enhancement will be provided by additional habitat in the creek in the form of pools and large woody debris and by providing bypass water from the screen to enter the normally dry creek. This additional habitat will provide refugia habitat for juvenile fish diverted with the bypass flow and allow fish to access the Hood River.

A sediment management facility for this screen will be installed near the inlet of the canal. Sediment management techniques include the use of two jersey barriers and two vortex tubes that will provide for continuous sluicing of sediment and bedload from the diverted flow and back to the river (Figure 2). Pinch valves will be installed to shut off flow out of vortex tubes during low flow periods.



SCALE: 1 INCH = APPROXIMATELY 1 MILE

LATITUDE: 45° 37' 00"
LONGITUDE: 21° 37' 00"

SOURCE: HOOD RIVER, OREGON (#430)
GREEN TRAILS - 15 MINUTE SERIES

FIGURE 1

VICINITY MAP

Farmers Irrigation District
Overshot Horizontal Flat Plate
Fish Screen Project

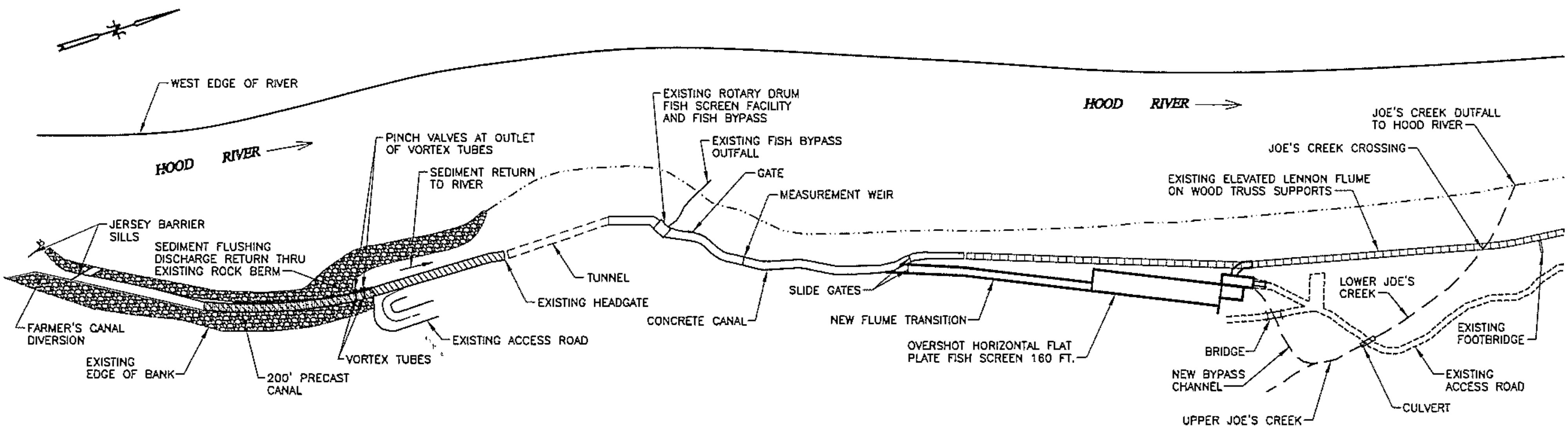


FIGURE 2

FISH SCREEN AND CANAL FACILITIES

Farmers Irrigation District
Overshot Horizontal Flat Plate
Fish Screen Project
2/11/03

2.0 FUNDING ENTITIES

A number of agencies have contributed to the success of the project to date. Since the inception of this fish screening concept, ODFW and Confederated Tribes of Warm Springs (CFTWS) representatives have worked directly with FID staff to continually refine the evaluation process. Once these local resource managers felt the concepts were sound, ODFW, CFTWS, and FID made presentations to regional NOAA Fisheries and USFWS representatives. NOAA Fisheries and USFWS representatives encouraged FID, CFTWS, and ODFW to complete two biological tests across the prototype screen installed at one of FID's hydropower facilities. The results from these tests are very positive.

Furthermore, the United States Bureau of Reclamation (USBR) has historically shown a strong interest in FID screen concepts and conducted additional hydraulic and biological testing in its Denver, Colorado hydraulics laboratory with the support of Colorado State University. Very favorable results also were obtained in these tests and, consequently, approval to proceed with construction of a full-scale version of the screen (called the "beta site") was received from NOAA Fisheries, USFWS, ODFW, and CFTWS. FID began design and construction of a beta site on FID's Farmers Canal diversion from the Hood River in the fall of 2001.

With the strong support of the Hood River Watershed Group, CFTWS, USFWS, and NOAA Fisheries, FID has received grant funding from Bonneville Power Administration (BPA), CFTWS, Oregon Watershed Enhancement Board (OWEB), National Fish and Wildlife Foundation (NFWF), United States Department of Agriculture (USDA), and Pacific Coastal Salmon Recovery Fund (through Columbia River Intertribal Fish Commission). Without the support and thinking of all of the representatives of the aforementioned agencies, this project would never have moved ahead. The dedicated consultants and agency personnel associated with this project have helped to develop what appears to be a very promising alternative technology to address fish screen and passage issues throughout the northwest and beyond.

3.0 GOAL OF MONITORING PLAN

The goal of this monitoring plan is to provide sufficient information to determine if the overshot horizontal flat plate fish screen is an acceptable fish protection device, provides design and operational characteristics equivalent to or superior to other systems in similar field conditions, provides self-cleaning characteristics, and is economically feasible. Based on the results of evaluations, changes in operation or design configuration may be recommended to minimize impacts on fish resources in Farmers Canal. The applicability of the design and operation of the system for other similar diversions also will be determined.

In addition to the evaluation of the operation of the overshot horizontal flat plate screen on the Farmers Canal diversion, the use of Jersey Barriers and vortex tubes for sediment management and the use of an ephemeral stream, Joe's Creek, as a suitable bypass area for flows and fish will be determined. Based on the results, modifications of habitat characteristics may be necessary to improve rearing or passage for juvenile or adult fish.

The results of the monitoring plan will be used in an adaptive management program that adjusts the fish screen structural and hydraulic components, the sediment management strategies, and the habitat components in Joe's Creek to improve overall performance and ensure survival of fish resources.

4.0 PROJECT REVIEW TEAM

The evaluation of the effectiveness of the FID Overshot Horizontal Flat Plate Screen is an experimental evaluation under the auspices of the ODFW, USFWS, NOAA Fisheries, CFTWS, and BPA. A project review team from these respective agencies will participate in studies and/or review all documentation concerning the performance of the fish screen and make recommendations concerning the effectiveness of the fish screen to protect fish resources.

Evaluation of the screen will be performed by FID, ODFW, and the CFTWS.

5.0 PROJECT FACILITIES CALIBRATION ACTIVITIES

Once the canal, fish screen, cleaning system, Waterman gates, telemetry system, fish bypass system, and connections to the existing flume have been installed, activities will be undertaken to observe and calibrate the system. The system will be calibrated by temporarily diverting flows from the old canal to the new canal. The existing rotary drum screen is anticipated to remain in place during calibration activities unless head losses impact the calibration. If the rotary drum screen needs to be removed, concurrence for removal will be secured from the ODFW, NOAA Fisheries, and USFWS. The following activities will occur:

- Inspect the surface of the new screen to ensure there are no openings where fish could hide or escape to the irrigation system.
- Observe and measure flows over the fish screen.
- Observe natural cleaning capability of the fish screen.
- Test the automated cleaning capability of the water spray system to ensure that adequate coverage is provided.
- Observe ramping of flows through the fish bypass to Joe's Creek, and impact on fish habitat.
- Observe turbidity changes in Joe's Creek as flows are ramped.
- Observe flow characteristics in the vicinity of where the flume passes over Joe's Creek

6.0 EVALUATION OF FISH SCREEN

The overshot horizontal flat plate fish screen will be evaluated for hydraulic characteristics, cleaning capabilities, and fish injury and/or mortality.

6.1 HYDRAULIC CHARACTERISTICS

Hydraulic characteristics (depths/velocities) of the fish screen were predicted based on hydraulic modeling and tests at the prototype fish screen. The operating fish screen will be evaluated to determine if the predicted and operational characteristics are similar. Particular attention will be given to water depths across the screen. Parallel and orthogonal velocities at the plane of the screen also will be carefully studied. Attention will be given to the relative uniformity of water depth, orthogonal velocity, and parallel velocity across the entire plane of the screen. In the instance that the operational characteristics are not similar to the predicted characteristics, the impact on cleaning capabilities and fish injury and mortality will be evaluated. Operational characteristics will be modified as necessary to provide the best balance that achieves no fish injury or mortality.

6.1.1 Activity 1 – Compare Predicted and Actual Depths and Velocities

Location

The evaluations will be performed in the Farmers Canal at the overshot horizontal flat plate fish screen.

Methods

Water depth and parallel velocity measurements will be collected at 3-inches off the plane of the screen using the ODFW acoustic Doppler meter. The approach velocity will be measured directly using the ODFW acoustic Doppler velocity meter at 3-inches off the plane of the screen. Measurements will be taken at 1-foot intervals across the screen every 10 feet along its length. Total flow will be calculated from these velocity measurements at each transect. Data will be collected at 65, 80, and 95 cfs, which are the flow ranges typically found at the Farmers Canal diversion. The results will be compared against the predicted depths and velocities.

Schedule

Depths and velocity measurements as well as data compilation and analysis will be completed in fall 2002/winter 2003.

Periodic Reports

Periodic reports will be prepared using template tables, calculations, and graphics. Text describing and discussing the data and results will be included in the reports and the characteristics of screen performance will be discussed in detail. Expected and unexpected results will be addressed and further studies, as needed, will be identified and delineated.

Annual Report

An annual report will be prepared summarizing the periodic reports and discussing future studies including recommendations regarding system configuration and operation parameters necessary to achieve optimal depths and velocities required to ensure safe fish passage and efficient debris and sediment management.

6.1.2 Activity 2 – Modify Configuration to Evaluate Sensitivity of Configuration to Changes that May Affect Depths and Velocities across Screen

Location

The evaluations will be performed in the Farmers Canal at the overshot horizontal flat plate fish screen.

Methods

The screen's two primary hydraulic control devices -- the taper wall and stop log weir -- will be tested at their full range of settings. Water depth and parallel velocity measurements (at 3-inches off the plane of the screen) will be collected using the ODFW acoustic Doppler meter. The approach velocity will be measured directly using the ODFW acoustic Doppler meter at 3-inches off the plane of the screen. Measurements will be taken at 1-foot intervals across the screen every 10 feet along its length. Total flow will be calculated from these velocity measurements at each transect. Data will be collected at 80 cfs, which is the standard flow at the Farmers Canal diversion. Each taper wall and stop log weir setting will be compared against all other settings to evaluate the sensitivity of configuration changes. From this analysis, a proper operational configuration will be determined for the typically expected flow.

Schedule

Depths and velocity measurements as well as data compilation and analysis will be completed in fall 2002/winter 2003.

Periodic Reports

Periodic reports will be prepared using template tables, calculations, and graphics. Text describing and discussing the data and results will be included in the reports and the characteristics of the screen performance will be discussed in detail. Expected and unexpected results will be addressed and further studies, as needed, will be identified.

Annual Report

An annual report will be prepared summarizing the periodic reports and discussing future studies including recommendations regarding system configuration and operation parameters necessary to achieve optimal depths and velocities required to ensure safe fish passage and efficient debris and sediment management.

6.1.3 Activity 3 – Evaluate Screen Operational Characteristics as a Function of Changes in Flow

Location

The evaluations will be performed in the Farmers Canal at the overshot horizontal flat plate fish screen.

Methods

After a proper operational configuration at 80 cfs has been determined, the screen system will be operated through a wide range of flow settings from 10 to 100 cfs in 10-cfs increments. Water depth and parallel velocity measurements will be collected using at 3-inches off the plane of the screen using the ODFW acoustic Doppler meter. The approach velocity will be measured directly. Measurements will be taken at 1-foot intervals across the screen every 10 feet along its length. Each flow setting will be compared against all others to evaluate screen sensitivity to a wide range of changes in flow.

Schedule

Depths and velocity measurements as well as data compilation and analysis will be completed in fall 2002/winter 2003.

Periodic Reports

Periodic reports will be prepared using template tables, calculations, and graphics. Text describing and discussing the data and results will be included in the reports and the characteristics of the screen performance will be discussed in detail. Expected and unexpected results will be addressed and further studies, as needed, will be identified.

Annual Report

An annual report will be prepared summarizing the periodic reports and discussing future studies including recommendations regarding system configuration and operation parameters necessary to achieve optimal depths and velocities required to ensure safe fish passage and efficient debris and sediment management.

6.2 CLEANING CAPABILITIES

Proper cleaning of the screen will depend on maintaining a proper configuration. The self-cleaning characteristics of the screen will be evaluated by direct observation of debris loading on the screen and recording the frequency of cleaning necessary by manual cleaning and water burst cleaning. Observations will be made during various times of the year to have a range of conditions that could cause low loading to high loading. Conditions will include low flow and high flows in the Hood River.

6.2.1 Activity 1 - Observe Water Burst and Self-Cleaning Capabilities of the Screen

Location

Observations will be performed at the Farmers Canal on the overshot horizontal flat plate fish screen.

Methods

Daily inspections will be made of the total surface area of the overshot horizontal flat plate fish screen looking for evidence of debris and sediment impingement. Observation platforms will be placed across the top of the support wall of the screen structure. Platforms will be spaced to allow inspection of the screen for debris and sediment impingement. The plane of the screen will be delineated as a numbered grid system for observation purposes. A data form will be prepared to allow recording of data based on the grid system. Each location of debris and sediment impingement, if any, will be characterized on the data form as sediment, debris, or both. The amount and rate of debris accumulation will be calculated as the percent coverage per unit area as a function of time.

The greatest area of potential debris impingement on the installed screen is at the bypass throat. System configuration changes may be necessary in order to mitigate this effect. The screen will be characterized in terms of the ratios Vs/Va and Qb/Qd. The Froude number will be calculated at each transect and flow. The system may be shutdown briefly for adjustments to the screen system.

Schedule

Observations of the screen's self-cleaning capabilities will be conducted throughout the year from winter 2003 through summer 2003.

Periodic Reports

Periodic reports will be prepared using daily field observations. The reports will compile debris and sediment observation data and will discuss the efficacy of the screen's self-cleaning capabilities. The data sheets will be discussed with ODFW and the CFTWS on a daily, or weekly, basis depending on the nature of the results.

Annual Report

An annual report will be prepared summarizing the periodic reports and discussing recommendations regarding system configuration and operation parameters necessary to achieve optimal cleaning characteristics required to ensure safe fish passage and efficient debris and sediment management.

6.2.2 Activity 2 – Observe Frequency and Effectiveness of Water Burst Cleaner

Location

Observations will be performed at the Farmers Canal on the overshot horizontal flat plate fish screen.

Methods

Following each daily inspection of the total area of the overshot horizontal flat plate fish screen for evidence of debris and sediment impingement, the water burst cleaner will be activated, if necessary. Observation platforms will be placed across the top of the support wall of the screen structure. Platforms will be spaced to allow observation of the screen for debris and sediment impingement following the water burst cleaning process. The plane of the screen will be delineated as a numbered grid system for observation purposes using the grid data form. Each location of impingement following the water burst cleaning process will be characterized on the data form as sediment, debris, or both. Cleaning frequency and duration will be recorded. The water burst cleaner will be adjusted and refined as necessary to remove debris and sediment from the screen to minimize changes in hydraulics that may impact screen efficiency.

The greatest area of potential debris impingement is the leading edge. System configuration changes may be necessary in order to mitigate this effect. The system may be shutdown briefly for adjustments to the water burst cleaning system.

Schedule

Observations of the frequency of use and effectiveness of the water burst cleaning system will be conducted beginning winter 2003 and continuing through summer 2003.

Periodic Reports

Periodic reports will be prepared based on daily field observations and data forms. The reports will be a compilation of the data including discussions and conclusions. The reports will be discussed with ODFW and the CFTWS on a daily, or weekly, basis, depending on the nature of the results. In the event there appears to be a problem in performance, the Project Review Team will be notified.

Annual Report

An annual report will be prepared summarizing the periodic reports regarding the water burst cleaning system configuration and operation parameters necessary to achieve optimal cleaning characteristics required to ensure safe fish passage and efficient debris and sediment management.

6.2.3 Activity 3 – Observe Sediment Accumulation under the Screen

Location

Observations will be performed at the Farmers Canal on the overshot horizontal flat plate fish screen.

Methods

Once every quarter, or once a month during heavy suspended and bed load sediment times of year, the screen system will be briefly shutdown to inspect beneath the plane of the overshot horizontal flat plate fish screen for sediment accumulation. The plane of the screen will be delineated as a numbered grid system for observation purposes. A sediment accumulation data form will be prepared that allows data to be recorded based on the grid system. The depth and location of sediment accumulation will be identified on the data form.

Schedule

Observations of the sediment accumulation under the screen will be conducted from winter 2003 through summer 2003.

Periodic Reports

Periodic reports will be prepared based on field observations of sediment accumulation. The reports will present data and discuss the nature of sediment accumulation beneath the plane of the screen. Any changes in sediment deposition beneath the plane of the screen over time will be discussed as will necessary corrective action and operation considerations, if any. The reports will be discussed with ODFW and the CFTWS, depending on the nature of the results. In the event there appears to be a problem in performance, the Project Review Team will be notified.

Annual Report

An annual report will be prepared summarizing the periodic reports and discussing recommendations regarding system configuration and operation parameters necessary to minimize sediment beneath the plane of the screen.

6.2.4 Activity 4 - Evaluate Sediment/Debris Transport

Location

The evaluation will be performed in the Farmers Canal at the overshot horizontal flat plate fish screen.

Methods

Specific types of debris will be introduced in the canal upstream of the fish screen in pre-determined amounts. Visual observation of the effectiveness of the parallel velocity for the type and quantity of debris will be recorded. Effectiveness of the parallel velocity will be based upon degree of debris impingement. The incoming flow rate to the screen will be set at 80 cfs for the evaluation. The parallel velocity, flow depth, and resulting flow rate will be recorded. Flow measurements will be taken at 1-foot intervals across the screen every 10 feet along its length. Debris observation will be taken at each 10-foot length. The same procedure will be performed for specific types and gradations of sediment introduced upstream of the fish screen. Additionally, the accumulated sediment beneath the plane of the screen will be quantified and characterized using the methods and data form described in Section 6.2.3.

Schedule

Evaluation of debris and sediment transport will be performed during winter 2002 and fall 2003.

Periodic Reports

A report will be prepared describing the findings and summarizing the effectiveness of the overshot horizontal flat plate fish screen to transport various types of debris and sediment for each evaluation period.

Annual Report

An annual report will be prepared summarizing the periodic reports and discussing recommendations regarding system configuration and operation parameters necessary to minimize debris buildup on the screen.

6.3 IMPINGEMENT, FISH INJURY AND/OR MORTALITY, AND PREDATION

Impingement (fish trapped against the fish screen because of excess approach velocities) will be evaluated. Fish injury and/or mortality of fish passing over the screen will be evaluated. Predation on the fish screen and in Joe's Creek will be evaluated.

6.3.1 Activity 1- Observe Screen for Evidence of Impingement of Fish on the Fish Screen

Location

The existing rotary drum screen will not be removed from the canal for evaluation of natural downstream migrating fish that enter the canal. This activity will not be conducted until approval has been received from NOAA Fisheries, ODFW, and USFWS to remove the rotary drum screen to allow natural downstream migrating fish to be subjected to the fish screen. Tests with hatchery fish (with the rotary drum screen in place) are scheduled for April 2003. Approval for the removal of the rotary drum screen may occur during fall 2003 after appropriate evaluations, report review and discussions with agencies. At that time, this activity will be implemented.

Methods

The total area on the fish screen will be observed for evidence of impingement of juvenile/smolt/adult fish. Observation platforms will be placed across the top of the support walls for the fish screen. Platforms will be spaced to allow observation of the plane of the screen for evaluation of fish impingement. Areas of potential impingement include the plane of the fish screen, attachment points between screens, and at the interface of the fish screen and the canal walls.

The plane of the screen will be delineated as a numbered grid system (the size of each grid to be determined later) for observation purposes. A data form will be prepared that allows data (number, species, and location of impingement) to be recorded based on the grid system. The location of fish that are characterized as impinged or "resting" on the screen will be recorded on the data form.

Schedule

The schedule for the observations will depend on the removal of the rotary drum screen.

Periodic Reports

Weekly or more frequent field reports will be prepared based on the observations. The reports will be a compilation of daily observations in a summary form to allow an expedited decision to determine if the fish screen is performing adequately. The reports will be discussed with ODFW and the CFTWS on a daily or weekly basis, depending on the nature of the results. In the event there appears to be a problem in performance, the Project Review Team will be notified.

Annual Report

An annual report will be prepared that documents the objectives, methods, and results of the evaluation. The report will provide all observation data as appendices. The report will provide a conclusion based on analysis of the data. Recommendations will be made concerning the adequacy of fish protection provided by the fish screen as well as ways to improve fish screen performance to avoid or minimize injury to fish resources.

6.3.2 Activity 2 – Evaluate Injury to Downstream Migrating Wild Fish Passing the Screen

A proposal was made by FID to evaluate downstream migrating wild fish passing over the fish screen. Based on comments received from ODFW and Confederated Tribes of the Warm Springs Reservation that wild fish should not be subjected to handling and other processing associated with these types of tests, the scope of work for this activity has been eliminated.

6.3.3 Activity 3 – Evaluate Injury to Hatchery Test Fish Passing the Screen in Spring 2003

Location

Evaluations will be performed during spring 2003 in the Farmers Canal and at the horizontal flat plate fish screen using hatchery fish provided by ODFW and the CFTWS. One test flow will be evaluated during spring 2003. The normal flow expected in the canal, between 80 and 90 cfs will be the test flow.

Methods

The methods used will be similar to those used during the evaluations of the Farmers Prototype Horizontal Plate Fish Screen conducted in 2000 and 2001. In those studies, hatchery Chinook fry (Parkdale Fish Facility), steelhead fry (Oak Springs Hatchery), and steelhead smolts (Oak Springs Hatchery) were tested during spring months. The fish were transported to the site, acclimated for 48 hours in net pens, and experimental and control groups of fish tested. Prior to tests, fish were anesthetized, measured, evaluated for injury types, allowed to recover and then subjected to passage over the screens. Control fish were treated in the same manner except that they were not subjected to passage over the screen. Control fish were subjected to the catch net to attempt to normalize the results for both test and control fish. After the tests, both control and test fish were re-evaluated for injury, allowed to recover, and then placed in a net pen to evaluate delayed mortality for 96-hours.

Injuries will be characterized as bruises, gill/eye, fin, scale loss or other categories as defined by observation. Scale loss will be characterized by evaluating scattered scale loss on each side of the fish and recording results for each side separately. The methods for characterizing scale loss will be developed during winter/early spring 2003. The method of characterization will be similar to those used in the 2000 and 2001 evaluations of the prototype.

The tests evaluated the injury/mortality of experimental fish that passed over the screen to control fish that did not pass over the fish screen. Adult fish were not subjected to the prototype fish screen in 2000 and 2001. Since ODFW has expressed an interest in impact on steelhead kelts (Steve Pribyl, January 28, 2002), ODFW may be able to supply hatchery kelts from the Powerdale facility for test purposes.

The tests proposed for the horizontal flat screen in Farmers Canal are as follows:

Species to be Tested during Spring 2003:
Spring Chinook fry
Steelhead fry
Steelhead smolts
Adult steelhead (kelts)

Pre-Test Acclimation:
Fish will be transported from the rearing facility to the site and acclimated in net pens for 96 hours prior to tests.

Pre-Test Analysis:
Prior to each experimental or control release of fish, each fish will be examined for evidence of injury (fin, gill, eyes, bruises, and scale loss). Scale loss will be estimated based on an examination of each side of the fish and recorded on standard forms. The test characteristics for steelhead kelts will be determined in consultation with ODFW during spring 2003.

Test Characteristics:

	Chinook Fry	Steelhead Fry	Steelhead Smolts	Adult Steelhead (kelts)
Number of Experimental Tests per Species:	15	15	15	
Number of Control Tests per Species:	5	5	5	to be
Number of Fish per Test:	50	50	50	determined
Total Fish:	1,000	1,000	1,000	
Method of Release:	Poured from 5-gallon buckets			
Method of Capture:	Net pen in the receiving pool			

Injury Analysis:
Fish will be anesthetized, evaluated for injuries (fin, gill, eye, bruises, and scale loss). Scale loss will be evaluated in a manner similar to methods used for prototype tests in 2000 and 2001. For these tests, a single observer was trained to evaluate the percent of scale loss on test and control fish before and after the tests. Fish used in the test and control releases will be evaluated and observed at the hatchery to develop a standard method of evaluation for the 2003 tests.

Delayed Mortality Analysis:
Delayed mortality as a result of passing experimental fish over the fish screen or subjecting control fish to the catch net pen will be evaluated by returning test and control fish to separate net pens to observe survival for 96-hours.

Schedule

Chinook fry, steelhead fry, and steelhead smolts will be available in spring 2003. Tests will be conducted on these species at that time.

Periodic Reports

Field reports will be prepared after each series of tests are completed. The reports will be a compilation of test results in summary form to allow an expedited decision to determine if the fish screen is performing adequately under test conditions. The reports will be discussed with ODFW and the CFTWS on a daily or weekly basis, depending on the nature of the results. In the event there appears to be a problem in performance, the Project Review Team will be notified.

Annual Report

An annual report will be prepared that documents the objectives, methods, and results of the evaluation. The report will provide all observation data as appendices. The report will provide a conclusion based on analysis of the data. Recommendations will be made concerning the adequacy of fish protection provided by the fish screen as well as ways to improve fish screen performance to avoid or minimize injury to fish resources.

6.3.4 Activity 4 – Survey Fish Screen/Joe's Creek for Evidence of Predation

Location

Evidence of predation on fish will be documented between the mouth of Joe's Creek and the entrance of the fish bypass flows from the fish screen.

Methods

Evidence of predation will be documented by walking each side of Joe's Creek (as necessary) to observe any predatory animal use along side the creek. Evidence of potential predatory animal use will include animal tracks and presence of fish remains in the creek or along the creek. Evidence will be documented by preparation of a template graphic of Joe's Creek to record data for each field visit.

Schedule

Biweekly field visits will occur during late fall, winter, and early spring months and weekly field visits will occur during late spring, summer, and early fall. Based on comments from ODFW, survey activity may need to occur over several seasons to characterize predation as predators become aware of the potential prey source and to evaluate predation seasonally as fish abundance fluctuate.

Periodic Reports

Weekly or biweekly reports will be prepared using a template graphic to record data. In the event that evidence suggests a predation problem, consultation will be initiated with ODFW to discuss the potential significance of the predation and measures to reduce or minimize it.

Annual Report

An annual report will be prepared that summarizes the weekly or biweekly reports. The information will be tabulated to demonstrate any trends in increase in predation and the locations of predation. The report will include an evaluation of the value of continuing the monitoring as well as any measures to reduce or minimize it.

6.4 MIGRATION DELAY

The impact of the screen on fish movement over the screen will be evaluated by direct observation, and if necessary by release of hatchery fish (if feasible and acceptable by ODFW in this reach of the river). Juvenile fish, smolts, and adult fish (steelhead kelts) will be evaluated.

6.4.1 Activity 1 – Evaluate Delay by Experimental Releases of Hatchery Pre-Smolts

Location

The canal system provides a confined area where fish can be released a considerable distance upstream of the fish screen and captured downstream of the fish screen. The only difficulty is the assumption that fish must move down the canal rather than swim upstream and out of the canal or residualize in the canal for long periods of time before moving downstream. If fish do not move downstream, the validity of the test will be in question, depending on the number of "missing" fish. In the event that all fish are not recaptured, discussions with ODFW, NOAA Fisheries, and USFWS will occur to determine the significance of missing fish and to develop a course of action for future tests.

Methods

An attempt will be made to test delay in front of the fish screen by releasing experimental groups of Chinook and steelhead (pre-smolts, fry, and smolts) approximately 50 to 100 feet upstream of the fish screen. A block net will be temporarily installed in the canal to attempt to prevent fish from swimming upstream rather than downstream. After the block net is installed, fish will be released. Released fish will be observed between the release point and the fish bypass. A net pen or other similar capture devise will be used to capture fish that pass from the fish bypass to the pool below the bypass.

The following numbers of fish will be released:

	Chinook Fry	Chinook Pre-Smolts	Steelhead Smolts
Number of Releases:	5	5	5
Number of Fish per Release:	100	100	100 ? 25 in prototype
Total Fish:	500	500	500

The fish will be allowed 30 minutes to travel to the fish bypass capture net. After 30 minutes, the number of fish captured will be determined and a decision made to start the next test. The tests will occur sequentially for each species so that the total time for 5 releases, observations, and capture will be approximately 3 to 4 hours. At the end of the testing period for all 5 releases, the total fish released will be compared to the number captured. Depending on the difference in numbers, a decision will be made to remove or leave the capture net and block net in place for another 1 to 2 hours to attempt to capture all fish that were released for the tests. After several tests, the results will be discussed with ODFW and CTWSR to determine if this is an acceptable way to evaluate delay.

Schedule

Schedules for releases and release details will be determined during spring 2003 as the availability of fish for each species is determined.

Periodic Report

A weekly or biweekly report will be prepared that documents any fish delay on the fish screen and/or at the upstream end of the screen. The report will document the numbers of each species and size of fish captured in the net. The report will document any anomalies and injuries as described in Section 6.3.3.

Annual Report

An annual report will be prepared. It will present the objectives, methods, results, and recommendations for minimizing delay. The report will focus on the effectiveness of the screen to pass fish without delay. Recommendations will be made to improve effectiveness, as appropriate.

6.4.2 Activity 2 – Evaluate Changes in Screen Configuration to Minimize Delay

This activity is undefined. If Activity 1 demonstrates a migration delay problem, consultation will be initiated with ODFW and NOAA Fisheries to discuss the problem and the next steps to evaluate the problem.

Weekly or Biweekly Reports

A weekly or biweekly report will be prepared that documents any fish delay on the fish screen and/or at the upstream end of the screen. The report will document the numbers of each species and size of fish captured in the net. The report will document any anomalies and injuries.

Annual Report

An annual report will be prepared that summarizes the weekly or biweekly reports. The report will present the objectives, methods, results, and recommendations for minimizing delay. The report will focus on the effectiveness of the screen to pass fish without delay. Recommendations will be made to improve effectives, as appropriate.

6.5 ATTRACTION OF FISH TO THE SEDIMENT CONTROL STRUCTURES IN THE FARMERS CANAL

The placement of jersey barriers in the canal and vortex tubes in the floor of the canal is expected to reduce sediment accumulations in the canal system. These structures have the potential to attract fish that are entrained in the flow of the canal. The potential of the jersey barriers and vortex tubes to attract fish, and for the vortex tubes to injure fish will be evaluated.

6.5.1 Activity 1 – Evaluate Jersey Barriers

Location

Jersey barriers are located at two locations in the canal. Both locations will be evaluated.

Methods

The attraction of fish to the jersey barriers will be determined by direct observations of fish schooling or individual fish presence around the barriers. Observations will be made by viewing through the water column from the shore or by placing a fish viewing chamber in the water for closer observations. FID also will determine if observations around the barriers can be safely made by snorkel surveys. The velocity of the canal flow may be too great to permit this method of observation.

Schedule

During winter months (December, 2003; January and February, 2004) and spring months (March, April, May, and June, 2003) when most downstream migration is expected, observations will occur three times per week at each barrier. In the instance where fish are found to be present around the jersey barriers, ODFW will be notified to determine if the frequency of observations should be increased, or to determine if measures should occur to attempt to prevent fish presence.

Periodic Reports

Field reports will be prepared on a weekly basis to document observation results. The reports will be sent to ODFW and discussed as necessary.

Annual Report

An annual report will be prepared that documents the objectives, methods, results, and recommendations. The report will document the approximate number and species of fish, whether the results are a problem for migration, and recommendations to avoid or minimize the problem.

6.5.2 Activity 2 – Evaluate Vortex Tubes

Location

Vortex tubes are located at two locations in the canal. Both locations will be evaluated.

Methods

The attraction of juvenile or adult fish to the vortex tubes will be determined by direct observations of fish schooling or individual fish presence around the tubes. Observations will be made by viewing through the water column from the canal or by placing a fish viewing chamber in the water for closer observations.

The vortex tubes transport approximately 5 cfs back to the Hood River. Adult fish potentially could be attracted to the outfall of the vortex tube. Observations will occur to determine if adult fish are present.

Schedule

Observations will occur three times per week during winter months (December, January, and February) and spring months (March, April, May, and June). In the instance where fish are present, ODFW will be notified to determine if the frequency of observations should be increased for more detailed observations, and to determine a course of action to minimize attraction.

Periodic Reports

Field reports will be prepared on a weekly basis to document observation results. The reports will be sent to ODFW and discussed as necessary.

Annual Report

An annual report will be prepared that documents the objectives, methods, results, and recommendations. The report will document the approximate number and species of fish, whether the results suggest an entrainment or injury problem, and recommendations to avoid or minimize the problem.

7.0 EVALUATION OF JOE'S CREEK

Joe's Creek will be evaluated to determine the impact of the estimated 5 to 15 cfs on riparian and wetland development and fish habitat. Fish sampling of Joe's Creek is not proposed because of the potential impact of handling activities on wild fish, however snorkel surveys will be conducted.

7.1 WETLANDS

The minimal wetlands in the vicinity are expected to increase as a result of the additional water flow from the fish screen bypass. The influence of additional flows on wetland development (hydrophytic plants and wetland hydrology) will be documented.

7.1.1 Activity 1 – Observe Wetland Species and Areas of Development in Joe's Creek

Location

Wetlands are likely to emerge in the upper portions of Joe's Creek above the culvert and along the new excavation route that connect the fish screen bypass to Joe's Creek. These areas are mostly composed of a soil medium. The condition of Joe's Creek below the culvert is mostly rocky talus slope, and not conducive to wetland emergence. However, the entire length of the new bypass and Joe's Creek should be observed.

Methods

Wetland monitoring will require a site walk-though with a close focus on emergence of wetland plant communities dominated by hydrophytic species near the high water mark of the new bypass channel and Joe's Creek. If such communities are documented, then wetlands monitoring stations will be established to representatively document conditions.

Monitoring of wetlands will include:

- Vegetation community analysis of species present and percent cover;
- Hydrology analysis to place a Cowardin classification to the wetland; and
- Photo-documentation.

Schedule

Wetland monitoring should occur mid to late May 2003 and 2004 when ambient air temperatures have warmed sufficiently to allow perennial vegetation to emerge and hydrology levels can be documented during the early part of the growing season.

Periodic Reports

A field report will be drafted at the completion of the wetland site visit. This report will include data sheets of wetland plots if wetlands are encountered, and discuss existing conditions on the day of the visit. This information will be used later in the year for composing the annual report on riparian conditions within the project area.

Annual Report

Wetlands will be included in the annual report that discusses riparian conditions within the project area. The wetland section will cover any emergence of wetlands, including species present, percent coverage per stratum, native versus non-native vegetation ratios, and approximate area. Further discussion will include problem areas if any occur and recommendations for the problems as well as a conclusion that references the newly emerging community to other common wetland types in the vicinity.

7.2 RIPARIAN HABITAT

The additional flow of water to Joe's Creek as well as riparian plantings may affect riparian habitat. Observations will be made on riparian changes along Joe's Creek.

7.2.1 Activity 1 – Observe Changes in Riparian Species and Densities

Location

Present riparian conditions along Joe's Creek are well vegetated, especially in the canopy stratum. The upper limits of the creek and the proposed bypass route are forested with Douglas-fir (*Pseudotsuga menziesii*) and western red cedar (*Thuja plicata*). The lower portion of the creek is composed of a thick stand of young red alder (*Alnus rubra*) and big-leaf maple (*Acer macrophyllum*). A portion of these trees will be removed for the construction of the bypass channel and for stream modification for proposed flows. A planting plan has been proposed to replace and improve riparian conditions especially in the most disturbed areas. The areas where trees are removed will be the focus of the riparian monitoring. However, the entire length of the project area will be observed to note changes that may occur.

Methods

The purpose of the riparian monitoring will be to ensure that the replacement planting plan is successful and that there are only short-term adverse effects from the selective tree removal. Monitoring will focus on canopy cover recovery and non-native species introduction.

Riparian monitoring will include the following:

- Site walk-though to monitor success of new plantings, including species list, percent canopy cover, and vigor of the species; and
- Photo-documentation to document riparian cover and progression of growth from year to year.

Schedule

Monitoring of riparian conditions should occur in August 2003 and 2004. This time of year is ideal because the plantings would all be identifiable and the dry weather conditions of late summer would show potential negative effects on planted species that may need watering in the first couple seasons to become established.

Periodic Reports

A field report will be drafted at the completion of the riparian site visit. This report will document survival rate of planted species and indicate any volunteer species that may have emerged. Documentation of vigor and/or death of planted species will be discussed. This information will be used later in the year for composing the annual report on riparian conditions within the project area.

Annual Report

The annual report will discusses riparian conditions both upland and wetland, planted and volunteer within the project area. The report will state the objectives, methods, results, and recommendations (if any) to improve riparian vegetation establishment. The report will document representative species communities present, percent coverage per stratum, and native versus non-native vegetation ratios. Further discussion will include problem areas if any occur and potential remedy for the problems as well as a conclusion that references the newly emerging community to other common riparian types in the vicinity.

7.3 Stream Channel and Snorkel Surveys

The channel of Joe's Creek will be modified to accommodate additional flows and channel configurations. The impact of these changes on pools, riffles, and backwater areas will be evaluated. In addition, the potential for flow changes in Joe's Creek (15 to 5 cfs) to strand fish will be evaluated. Since fish will not be captured by netting/sieves/electrofishing to evaluate fish use of Joe's Creek, snorkel surveys at several locations will occur.

7.3.1 Activity 1 – Observe and Measure changes in Riffle and Pool Width and Depth and Conduct Snorkel Surveys

<u>Location</u>

The project area should be separated into three observation categories. The new bypass channel, upper Joe's Creek (above culvert), and lower Joe's Creek (below culvert). These categories are representative of significant differences in the local ecosystem. The bypass is presently upland, upper Joe's Creek is coniferous forest, and lower Joe's Creek is deciduous forest. The entire area will be observed and documented for monitoring purposes.

<u>Methods</u>

Pool and riffle widths and depths will be monitored by establishing transects at up to four pools and four riffle areas between the bypass outfall and the mouth of Joe's Creek. These transects will be staked with anchor rebar and numbered to allow return to the exact location. A transect will be established at the head end, the middle area, and at the lower area of a pool or riffle. At each transect the following measurements will be made:

- Water depth (referenced to a bench mark) at intervals across the transect; and
- Distance upstream or downstream (measured from the upstream and downstream transects at a pool or riffle) that the riffle or pool has migrated.

The baseline conditions of the riffle widths, water depths, and substrate composition will be documented after initial operation of the bypass for a few days. The initial conditions will form the basis for comparison to subsequent observations.

Changes in the substrate composition will be documented from photo-documentation points along each of the pools and riffle areas and visual descriptions of the substrate. Wolman Pebble Counts may be used to supplement the information on changes observed in substrate composition.

Snorkel surveys will be conducted in the bypass channel, upper Joe's Creek and lower Joe's Creek to document use of these areas by adult and juvenile fish. Transect locations will be established during the spring and summer of 2003.

Schedule

Baseline characteristics will be determined during spring and summer 2003. Subsequent visual observations will occur weekly, but data collection will occur during September of each year. Snorkel surveys will be conducted during September of 2003.

Periodic Reports

Field reports will be drafted at the conclusion of any observational or data collection field visit. The reports will document the above monitoring results based on each of the areas. This information will be combined together for the annual report.

Annual Report

The annual report will discuss conditions within the new channel and Joe's Creek. The changes in the system channel will be qualitatively and quantitatively compared (as possible) with a focus on long-term trends that may develop as a result of the increased flows. The results of snorkel surveys will document number and species of fish and locations of fish use, need for additional large woody debris or other types of habitat elements, and adequacy of the pools for fish. The report will state the objectives, methods, results, and recommendations (if any) to improve stream channel and fish habitat conditions.

7.4 WATER QUALITY (TURBIDITY, SEDIMENT, WATER TEMP)

Water quality will be evaluated in Joe's Creek. Dissolved oxygen, water temperature, turbidity, and sedimentation will be measured. Particular attention will be given to dissolved oxygen and water temperature during summer months. In addition, the potential build up of glacial materials in the receiving pool for the bypass flow and Joe's Creek could adversely affect the habitat quality designed into the system.

7.4.1 Activity 1 – Measure Water Quality Parameters (turbidity, dissolved oxygen, and water temperature)

Location

Turbidity, water temperature, and dissolved oxygen will be measured in the following locations:

- Receiving pool downstream of the fish screen;
- Joe's Creek between the ~~culvert~~ bridge under the access road and the newly constructed connection between the fish screen; and
- Joe's Creek pool upstream of the existing pipeline trestle crossing.

Methods

Turbidity will be measured by a field portable Hach 2100P Turbidimeter. Dissolved oxygen will be measured using a portable dissolved oxygen meter. Water temperature will be measured with a continuous data logger (Hobo Water Temperature Pro Logger) and downloaded on a weekly basis.

Schedule

Turbidity and dissolved oxygen will be measured biweekly during winter and spring months and weekly during summer and early fall months. Water temperature will be continuously monitored.

Periodic Reports

Weekly or biweekly field reports will be prepared by recording the data on standard forms that state the measurement(s) sampling location, results, and trends since the last measurement, and anomalies noted during field visits.

Annual Report

An annual report will be prepared that summarizes the weekly or biweekly measurements of turbidity and dissolved oxygen in tabular and graphic format. Water temperature measurements will be summarized as daily mean values and/or minimum-maximum values. The report will state the objectives, methods, results, and recommendations (if any) to improve water quality conditions.

7.4.2 Activity 2 – Estimate Sediment Build-up

Location

Sediment build up will be measured in the following locations:

- Receiving pool downstream of the fish screen;
- Joe's Creek between the culvert under the access road and the newly constructed connection between the fish screen; and
- Joe's Creek pool upstream of the existing pipeline trestle crossing.

Methods

Sediment buildup will be estimated by changes in bottom elevation and Wolman Pebble Counts. To determine changes in bottom elevation, a baseline elevation will be measured by rod and level in each location. In the case of the pool below the fish bypass return, two cross sections and a longitudinal section will be profiled to allow changes in elevation to be determined. For the other two areas, only cross sections will be measured.

Wolman Pebble Counts will be performed in each location to document changes in substrate composition. One count will be performed in each location.

Schedule

Baseline elevations will be measured and Wolman Pebble Counts will be made immediately after construction. Approximately one to two weeks after flows have been introduced to Joe's Creek, the measurements and counts will be repeated. Yearly (2003 and 2004) measurements and counts will be performed during fall of each year.

Annual Report

An annual report will be prepared that describes the changes in elevation and surface substrate composition. The report will present the objectives, methods, results, and recommendations for maintaining or improving habitat conditions in Joe's Creek.

8.0 RECOMMENDATIONS

The goal of this monitoring plan is to provide sufficient information to determine if the overshot horizontal flat plate fish screen is an acceptable fish protection device, provides design and operational characteristics equivalent to or superior to other systems in similar field conditions, provides self-cleaning characteristics, and is economically feasible. Based on the results of evaluations, changes in operation or design configuration may be recommended to minimize impacts on fish resources. In addition, the applicability of the design and operation of the system for other similar diversions will be determined.

In addition to the evaluation of the operation of the overshot horizontal flat plate screen on Farmers Canal, the use of Joe's Creek as a suitable bypass area for flows and fish will be determined. Based on the results, modifications of habitat characteristics may be necessary to improve rearing or passage for juvenile or adult fish.

9.0 PROJECT SCHEDULE

The project evaluation schedule based on a construction completion date of November 1, 2002, is shown in the attached figure. The initial evaluation of the Overshot Horizontal Fish Screen will occur between late fall 2002 through August 2003. At the end of the evaluation, a Draft Final Report will be prepared in anticipation of a meeting with the Project Review Team to discuss the results and recommendations for additional study. Although the evaluations are scheduled only through summer 2003 for the report, evaluations as shown in the schedule are expected to continue beyond that date. The scope of work will be revised to reflect modification of tasks and schedule during fall 2003.

Farmers Irrigation District
Monitoring Schedule for Overshot Horizontal Flat Plate Fish Screen

TASK NAME	2003 (Oct – Oct)
5.0 PROJECT FACILITIES CALIBRATION	3/21
6.0 EVALUATION OF FISH SCREEN	
6.1 Hydraulic Characteristics	
6.1.1 Activity 1 – Compare Predicted and Actual Depths and Velocities	2/28
6.1.2 Activity 2 – Modify Configuration to Evaluate Sensitivity of Configuration of Screen	3/7
6.1.3 Activity 3 – Evaluate Screen Operational Charact.	3/28
6.2 Cleaning Capabilities	
6.2.1 Activity 1 – Observe Water Burst and Self-Cleaning Capabilities of the Screen	5/30
6.2.2 Activity 2 – Observe Frequency and Effectiveness of Water Burst Cleaner	7/15
6.2.3 Activity 3 – Observe Sediment Accumulation under the Screen	8/8
6.2.4 Activity 4 – Evaluate Sediment/Debris Transport	5/21
6.3 Impingement, Fish Injury and/or Mortality, and Predation	
6.3.1 Activity 1 - Observe Screen for Impingement	9/15
6.3.2 Activity 2 - Evaluate Injury to Wild Fish Passing the Screen	9/15
6.3.3 Activity 3 - Evaluate Injury to Hatchery Fish Passing Screen in Srping 2003	4/30
6.3.4 Activity 4 - Survey Fish Screen/Joe's Creek for Predation	4/30
6.4 Migration Delay	
6.4.1 Activity 2 – Evaluate Delay by Experimental Releases of Hatchery Pre-Smolts	6/30
6.4.2 Activity 3 – Evaluate Changes in Screen Configuration to Minimize Delay	6/20
6.5 Attraction of Fish to the Sediment Control Structures in the Farmers Canal	
6.5.1 Activity 1 – Evaluate Jersey Barriers	7/31
6.5.2 Activity 2 – Evaluate Vortex Tubes	7/31
7.0 EVALUATION OF JOE'S CREEK	
7.1 Wetlands	
7.1.1 Activity 1 – Observe Wetland Species and Areas of Development in Joe's Creek	5/16
7.2 Riparian Habitat	
7.2.1 Activity 1 – Observe Changes in Riparian Species and Densities	8/14
7.3 Stream Channel and Snorkel Surveys	
7.3.1 Activity 1 – Observe and Measure changes in Riffle and Pool Width and Depth	9/19
7.4 Water quality (turbidity, sediment, water temp)	
7.4.1 Activity 1 – Measure Water Quality Parameters	8/29
7.4.2 Activity 2 – Estimate Sediment Build-up	8/29
INTERIM REPORT AND MEETING NO. 1	3/16
INTERIM REPORT AND MEETING NO. 2	6/1
FINAL REPORT AND MEETING NO. 3	8/17
6.3.1 Activity 1 – Observe Screen for Impingement (ON HOLD)	

Project Schedule
February 11, 2003

Task — Milestone — Summary

Appendix K - Mesa, M., Rose, B., Zydlewski, G., 2005, Evaluation and Development of hydraulic and biological criteria for two unique horizontal flat plate fish screens Final Report 2005: U.S. Geological Survey, and University of Maine

Evaluation and development of hydraulic and biological criteria for two unique horizontal flat plate fish screens

Final Report 2005

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Executive summary

We used a field approach to evaluate the performance of two types of uniquely-designed horizontal flat plate fish screens (inverted weir and backwatered) for water diversion structures. Because fish can be entrained into water diversion structures or harmed by contact with screens, NOAA-Fisheries has designated specific operational criteria for them (e.g., approach velocities not to exceed 6 cm/s). However, such criteria were developed for screens positioned vertical to water flow, not horizontal. For this reason, we measured selected hydraulic variables and released more than 2,000 juvenile and adult redband rainbow trout *Oncorhynchus mykiss* over two types of horizontal flat plate fish screens in Oregon. Our goal was to develop criteria for the placement and operation of these types of screens that ensures the safe passage of fish over them.

The inverted weir screens were all located on tributaries of the Crooked River near Prineville, Oregon, and the single backwatered screen was located on a diversion of the Donner und Blitzen River in the Malheur National Wildlife Refuge. For all screens, we measured stream discharge, diversion discharge, approach velocity (AV), sweeping velocity (SV), and water depth over the screen surface several times in 2004 and 2005. We evaluated inverted weir screens over a range of stream flows 0.24 to 1.77 m^3/s and diversion flows 0.10 to 0.31 m^3/s. The diversion rates comprised from 23% to 56% of the stream flow. Approach velocities ranged from 3 to 8 cm/s and SV's ranged from 0.69 to 1.43 m/s. The mean depth of water over the screens ranged from 5 to 16 cm. We evaluated the backwatered screen over stream flows ranging from 0.23 to 0.79 m^3/s and diversion flows from 0.08 to 0.32 m^3/s. The diversion rates comprised from 23% to 62% of the stream flow. Mean SV's for this screen ranged from 0.15 to 0.66 m/s and AV's over the entire screen area ranged from 1 to 5 cm/s. The mean depth of water over this screen ranged from 6 to 34 cm.

To assess the effects of downstream passage over the screens on mortality, injury, and behavior, we released juvenile and adult fish under the variety of hydraulic conditions described. For most of our tests, survival 24 h after passing over the screens of juvenile and adult fish was greater than 98%. In most cases, injury rates were low and severe injuries were almost nonexistent. The majority of injuries were minor splits of the skin in between the fin rays. The number of times fish contacted or were impinged on the screen surface was low and dependent on water depth and formation of hot spots, or vortices that developed on the backwatered screen. Based on our results, screens of this type for streams of the size we worked on can be effective at diversions approaching 0.30 m^3/s. Current NOAA-Fisheries AV criteria for passive, vertical

screens (≈6 cm/s) would provide adequate protection for fish traveling over the inverted weir screen design. In fact, we noticed no problems for fish passing over these screens at AV's up to 8 cm/s. For backwatered flat plate screens, like the one we tested at Malheur, fish injury, screen contacts, and impingements increased when AV's exceeded 3 cm/s, thus the current NOAA criterion of 6 cm/s seems too high for adequate fish passage and protection. We suggest that AV's of about 2 cm/s (calculated by dividing screen area by the discharge rate) will provide efficient and safe passage of fish over this type of screen. Although this criterion seems low, it accounts for variation in AV over the entire surface area of the screen and provides irrigators and fishery managers a simple, cost effective method to set discharge rates that minimize harm to fishes. This AV criterion could be increased to 3 cm/s, or perhaps higher, if SV's can be maintained at 20 cm/s or higher. For horizontal flat plate screens, SV and water depth over the screen are important factors to consider. We documented increased rates of fish injury, contact with the screen, and impingements when SV was near 10 cm/s. These effects were reduced or eliminated when SV's were increased to about 20 cm/s. Thus, we recommend that SV's be maintained near 20 cm/s for screens similar to the backwatered screen we evaluated. Additional design modifications, such as concentrating water over or lowering the water depths above the screening panels, may be necessary to meet our SV criterion. The water depth necessary to safely pass fish over these horizontal flat plate screens varies and depends largely on the size of the fish. Our results suggest that water depths greater than 7 cm would likely provide adequate protection for juvenile anadromous salmonids up to about 20 cm fork length for the inverted weir design. Additional research is needed to determine whether depth criteria could be established for backwatered flat plate screens. Finally, as we mentioned earlier, the backwatered flat plate design seems prone to the development of hot spots, or downward, spiraling flow through the screen. We consider such conditions unsafe for fish passage and recommend that managers and engineers identify the cause and remedy for such conditions.

Introduction

Diversions from natural or manmade waterways are common in the United States and are used for many purposes. For example, diversions from the Sacramento-San Joaquin Delta provide water for about 18 million people and about 1 million hectares of farmland in California (Danley et al. 2003). Many diversions are screened with various devices meant to prevent fish and other aquatic life from becoming entrained, injured, or killed. However, many thousands of water diversions remain unscreened. Unscreened diversions have been identified as a contributing factor in the decline of salmonid runs over the past few decades (USFWS 1995) and are considered stressors on aquatic resources (Dadswell and Rulifson 1994; Kingsford 2000). Despite current listings of Pacific salmon *Oncorhynchus* spp., steelhead *O. mykiss*, and bull trout *Salvelinus confluentus* under the Endangered Species Act and millions of dollars directed towards screening (see McMichael et al. 2004), many diversions in the western U. S. remain unscreened or screened insufficiently.

Current water diversion screening technology and design criteria meant to protect fish (developed by NOAA-Fisheries) results in relatively expensive and high maintenance facilities (e.g., more than $9,000 per cfs withdrawal for small diversions; see http://wdfw.wa.gov/hab/engineer/scrnunit.htm for examples). Despite state and federal cost share programs, the high cost of these traditional fish screens limits the participation and support of private landowners with water rights, thus limiting the geographic expansion of fish screen installations throughout the West. In recent years, however, many new screen designs have been developed that are potentially less expensive to install, offer simpler, more passive operation, and may have fewer detrimental effects on local fish communities. These new screen designs could offer attractive alternatives to private landowners interested in screening their diversions.

Horizontal flat plate fish screens are an example of a recent alternative technology that potentially provides lower installation and maintenance costs. Because of this, many screens of this type have been installed in the field. However, little is known about their hydraulic performance and biological impacts. Recently, Beyers and Bestgen (2001) used a working horizontal flat plate screen model in a laboratory setting to investigate the effects of passage of bull trout over the screen. Also, Frizell and Mefford (2001) provided a detailed description of the hydraulic performance of this model. In a series of experiments under a variety of hydraulic conditions, Beyers and Bestgen (2001) reported few consistent negative effects on bull trout passing over the screen. Evaluating field sites with screens of this type would allow further verification of their performance, provide data for comparison with criteria for more traditional fish screens, and perhaps facilitate their installation.

Historically, the development of criteria for the installation and operation of fish screens has come primarily from laboratory studies on the swimming capabilities of relevant species (e.g., juvenile anadromous salmonids). Such criteria are regulated by NOAA-Fisheries for new and existing traditional screen installations. The idea underlying such criteria is that designers, engineers, and biologists have assumed that if the swimming abilities of a fish are greater than the approach velocities (AV; the velocity of water actually passing through the screen surface) of the withdrawal intake, then the fish are protected (Clay 1995). However, some research suggests that contacts with a screen and impingement can occur at AV's far below the swimming capabilities of fish (Hanson and Li 1978; Swanson et al. 1998), suggesting that the swimming performance approach to development of criteria for screens may be inadequate (Swanson 2004).

The goal of our study was to evaluate the performance of some uniquely-designed horizontal flat plate fish screens at selected locations in the field. Specifically, our objectives were to: (1) document the hydraulic performance of some screens in the field under a variety of discharge and withdrawal conditions; and (2) evaluate delayed mortality and the rate and severity of injury of fish experimentally passed over the surface of screens in the field. Our results should be useful for the development of guidelines for future screen installations, and for hydraulic and biological performance criteria for two flat plate screen designs already being used at water diversion structures.

Study sites

We chose several previously established horizontal flat-plate fish screen installations in Oregon to evaluate. They were selected based on the following criteria: (1) the installations were representative of horizontal flat-plate technology; (2) there have been no previous hydraulic or biological assessments of these screens; (3) fish species of concern were located in the area; and (4) the sites had good access and offered potential for experimental manipulation.

The study sites included the Smith and Cook screens on McKay Creek, and the Rye Grass screen on Ochoco Creek (Figure 1). McKay Creek is a tributary of the Crooked River located near Prineville, Oregon. This creek drains 256-km^2 and provides more than 80 km of fish habitat. The upper reaches of McKay Creek and its tributaries flow through public forest lands used primarily for timber harvest, cattle grazing, recreation, and irrigation. The lower reaches flow through agricultural areas used primarily for crop production, cattle grazing, and irrigation. During summer, flows in McKay Creek can get quite low, and often the lower section does not meet the 0.60-m^3 in-stream water right at the confluence of the Crooked River. Also, the stream can exceed state water temperature criteria for rearing and spawning of salmonids. Ochoco Creek is also a tributary of the Crooked River near Prineville that drains about 925-km^2. The upper reaches of Ochoco Creek flow through the forested hills and steep canyons of the Ochoco National Forest. The lower reaches flow through agricultural and urban areas. Ochoco Dam, located at river km16, provides irrigation water during the summer months.

The Smith, Cook, and Rye Grass screens were inverted weir horizontal flat plate screens constructed of 0.91-m steel pipe inverted upstream and cemented into the river bottom. Screen to weir ratios (the linear length of screen/linear length of the in-stream portion of the weir) were 23% for the Smith, 41% for the Cook, and 57% for the Rye Grass screen. These facilities had three (Smith), five (Cook), and seven (Rye Grass) screening panels. The panels were 0.61-m long and 1.22-m wide and constructed of 0.175-cm profile bar screen positioned perpendicular to river flow. The screening panels had 17%, 16%, and 4% (Smith, Cook, and Rye Grass) gradients and the head differentials were approximately 0.25-m, 0.08-m, and 0.38-m at the three sites. All screens were equipped with a v-notched slot to facilitate fish passage that did not require fish to traverse the screen surface and to eliminate the potential dewatering of stream areas below the screens during extreme environmental conditions, such as severe drought. The bottom of the v-notch slot was positioned 0.25-m above the downstream water at the Smith screen and below the downstream water surface at the Cook screen. The Rye Grass screen used a three tier v-notch system with a maximum head differential between tiers of 0.18-m.

We also evaluated one screen located on the east canal of the Donner und Blitzen River (the Malheur screen; Figure 2). The east canal of the Donner und Blitzen River, located on the Malheur National Wildlife Refuge near Frenchglen, Oregon, is a manmade channel designed to provide irrigation water and connectivity between tributary streams and the mainstem river. The Donner und Blitzen River drains approximately 515-km^2 of glaciated canyons and the Steens Mountain. The Malheur screen was a simple backwatered horizontal flat plate fish screen constructed of 1.2-m-diameter steel pipe with two 1.2-m x 2.4-m profile bar screening panels (0.175-cm mesh) oriented parallel to flow. This screen was also equipped with a v-notch slot to facilitate fish passage and eliminate the potential for downstream dewatering. Water level over the screen surface was manipulated with an inverted rock weir positioned approximately 10-m downstream.

Methods

Hydraulic assessments

At each screen and during different times of the year, we measured several hydraulic variables, including: (1) approach and sweeping (SV; the velocity of water flowing parallel to the screen surface) velocities; (2) water depth over the screen; (3) river discharge; and (4) diversion discharge. Approach velocities (AV) at all screens were estimated by dividing the screen area by the diversion rate. We chose this estimation method for AV (which assumes equal flows through all screening panels), because it required no special equipment, was the method most likely to be used in the field, and could be easily done by irrigators or fishery managers that monitor the screens. At the Malheur screen, we also evaluated the extent of variation in AV over the screen surface by measuring three dimensional velocities in the center of every 30-cm^2 section using an Acoustic Doppler Velocimeter (ADV). For each section, we collected 15 measurements at 2.5-cm above the screen surface that lasted 1 s each and derived a mean. We did this nine times at different SV and AV scenarios. On one occasion, to examine the variation in AV's over a longer period, we collected 180 one second measurements over every 60 x 40 cm section of the screen. To eliminate extreme values, we excluded the top and bottom 10^{th} percentile measurements from our analysis. Sweeping velocity (SV) measurements were generally taken over every 30-cm^2 section of screen surface area using a Marsh-McBirney electronic velocity meter. These measurements were collected at 7.6 cm above the screen surface or at 0.6(depth) in shallower water. Water depth over the screen was measured using a depth gauge. Stream discharge was measured from the first suitable location upstream of the screen following the protocol of Bain and Stevenson (1999). When possible, diversion rates were estimated from screen outflow pipes and irrigation canals, again following the protocol of Bain and Stevenson (1999). We measured these variables at each site under natural conditions several times during the irrigation season. Sometimes, we experimentally manipulated diversion rates and depth of water at certain screens to assess hydraulic characteristics not observed during irrigation season. Such conditions could occur in the field and allowed us to evaluate the screens under the widest possible range of scenarios. During our assessments, screens were visually examined for hot spots (i.e., vortices, or spiraling, downward flow through the screen). The hydraulic data was summarized and served as baseline information for the selected screens and established the context for the fish passage studies. We also compared our data to established NOAA-Fisheries screening criteria.

Biological assessments

To evaluate the impact of screens in the field, we released fish over each screen and documented immediate and delayed (24 h) mortality, and the rate and severity of injuries sustained after passage. The following sections detail the various aspects of our experimental releases.

Fish collection.—Test fish were wild redband rainbow trout (*O. mykiss*) collected using a backpack electrofisher in stream sections adjacent to the fish screens. Fish were placed in 19-L buckets and transferred to live cages near the screen for processing. When fish collection occurred away from the immediate area of the fish screen, they were transferred to the screen site in a 1.0 x 0.5 x 0.6-m insulated plastic transport container. Water temperature in all holding vessels was monitored and held at ambient during fish collections.

Pre-passage fish processing and holding.—When all the fish for a test were at the screen site, they were anesthetized in either 50 mg/L buffered MS-222 or a solution of carbon dioxide (one tablet of Alka-Seltzer Gold© per 2.5 L of water), measured (fork length, FL, to the nearest mm), weighed (to the nearest g), and given a comprehensive examination for injuries to the body. We modified criteria outlined by Beyers and Bestgen (2001) to assess fish condition prior to passage over a screen. The examinations included visual inspections of the skin (noting any abrasions, hemorrhages, or cuts), scales (estimating the percent body area descaled), fins (recording trace fin splits, fin splits, frayed fins, broken fins, or missing fins), and eyes (noting abrasions, exophthalmia, hemorrhages or missing eyes). During some tests, and to facilitate individual identification, fish of suitable size (weight > 3.0 g) were implanted with a 12 mm Passive Integrated Transponder tag (PIT tag; 134.2 kHz) injected into the body cavity using a 12 gauge hypodermic needle as described by Prentice et al. (1990). After all fish had been examined, they were randomly divided into two groups, treatment and control, for testing the next day. Age classes of the test groups were estimated by length frequency analysis.

Experimental apparatus.—On the day of a test, a device to experimentally release fish over the screens was installed on the upstream and downstream sides of the fish screens (Figure 3). The device allowed fish to be released on the upstream side of the screen and recaptured on the downstream side. It consisted of two boxes, each constructed of aluminum, measuring 1.0 x 1.0 x 0.5-m and all sides covered with a 6.35 mm plastic mesh. One box was placed on the upstream side of the screen so the bottom was aligned with the screen surface. The second box was placed similarly on the downstream side of the screen and was equipped with a fyke to facilitate quick capture of fish after passage. Plexiglas or plastic mesh guide walls were installed perpendicular to the screen surface to ensure that fish traveled over the screen surface and were recaptured. The distances between guide walls were adjusted to facilitate visibility of our underwater camera observations (see below).

Releases of fish over the screens.—After the overnight holding period, groups of fish were released over the screen. We usually released fish under conditions where water was flowing straight and uniformly over the screen surface (laminar flow). At the Malheur screen, we also conducted some releases over a section of the screen that had hot spots. A group of 10-25 fish, either treatment or control, were removed from the holding cages and placed into the upstream box. Each group was allowed at least 10 minutes to volitionally leave the box and pass downstream over the screen. After 10 minutes, we prodded the remaining fish and forced them to move downstream. Fish that passed over the screen were captured in the downstream box and immediately examined (see below). For control fish, a Plexiglas sheet was placed over the screen before passage. Control and treatment fish releases were usually alternated until a sample ranging from 35-70 fish from each group were tested. Several under and above water video cameras were used to record the behavior of fish during passage. All video tapes were reviewed at our laboratory and we recorded the time required for fish to pass over the screen, general orientation to the current, how often fish contacted the screen, how often they were impinged (i.e., stuck on the screen for more than one second), and their general depth of travel. Fish contact and impingement rates were derived by dividing the total number of occurrences by the number of fish viewed per release event.

Post-passage fish examinations and survival.—After passage, fish were immediately removed from the downstream box and placed in 19-L buckets. For each group, we recorded the elapsed time for each fish to pass over the screen and the number of fish that died immediately after passage. After a group of fish passed, they were anesthetized, measured, scanned for PIT tags, and examined for injuries using the criteria described above. Immediately after the post-passage examinations, fish were placed in live cages positioned in the stream and held for 24 h to assess the extent of delayed mortality. After 24 h, we returned live fish to their original capture location.

Statistical analysis—Fish that died immediately after passage or after 24 h were tallied. For each fish, we recorded whether it was injured (yes or no) after passage over the screen and what type of injuries it sustained. Prior to analysis, we accounted for the injuries fish had prior to releases, by either deducting the pre-existing injury rate from the post-passage injury rate (untagged fish), or by counting the number of new injuries fish had after screen passage (PIT-tagged fish). We compared the proportion of fish injured between treatment and control groups using Fisher's Exact Test (Zar 1984). We examined the relations between rate of injury, number of times fish contacted the screen, impingement rate, AV, SV, water depth, and diversion rate using simple and multiple regression analysis. Comparisons between two variables were conducted using two-tailed *t*-tests. For all tests, the level of statistical significance was $\alpha = 0.05$.

Other observations.—To provide some indication of the "self-cleaning" capabilities of each screen design, we occasionally estimated the percent of screen area covered by debris (fine sediments, algae, aquatic and terrestrial vegetation, and woody debris). These were casual observations done in between routine cleaning operations. Daily accumulation rates of debris were calculated by dividing the percent of screen area covered at observation by days between observations and cleaning. In addition, estimates of diversion rates and cleaning schedules were recorded.

Results

Hydraulic assessments

We evaluated inverted weir screens over a range of stream flows (0.24 to 1.77 m^3/s) and diversion flows (0.10 to 0.31 m^3/s; Table 1). The diversion rates comprised from 23% to 56% of the stream flow. Approach velocities ranged from 3 to 8 cm/s and SV's ranged from 0.69 to 1.43 m/s and were slower along the upstream edge (0.48 to 0.94 m/s) and faster at the downstream edge of the screening panels (0.79 to 1.85 m/s). Sweeping velocities were generally at least ten times higher than AV's for most of the conditions we evaluated. The magnitude of increase in SV from the upstream to the downstream edge of a panel was greatest at the Smith and Cook screens (16-17% gradient) and lowest at the Rye Grass screen (5% gradient). The mean depth of water over the screens ranged from 5 to 16 cm and was generally deeper at the upstream end (5 to 19 cm) compared to the downstream end (0 to 12 cm). Mean SV's for all inverted weir screens were directly related to stream discharge and inversely related to the screen:weir ratio ($R^2 = 0.84$, $P < 0.05$; Table 2). Also, the mean depths of water at the downstream side of the screen were related to several hydraulic variables ($R^2 = 0.78$, $P < 0.05$; Table 2). Screens with relatively high screen to weir ratios (the Cook and Rye Grass screens) had significantly lower mean SV's than the Smith screen (two sample *t*-test, $P < 0.05$) despite the Smith screen being in an area with lower stream discharge.

We evaluated the Malheur screen over stream flows ranging from 0.23 to 0.79 m^3/s and diversion flows from 0.08 to 0.32 m^3/s. The diversion rates comprised from 23% to 62% of the stream flow. Mean SV's for the Malheur screen ranged from 0.15 to 0.66 m/s and, in contrast to the inverted weir screens, were faster along the upstream edge (0.17 to 0.68 m/s) and slower at downstream edge of the screening panels (0.07 to 0.51 m/s). Calculated AV's over the entire screen area ranged from 1 to 5 cm/s. The mean depth of water over the screen ranged from 6 to 34 cm and was slightly shallower at the upstream end (7 to 32 cm) compared to the downstream end (6 to 37 cm).

Variation in AV over the screen surface, as estimated by the ADV, was substantial. Further, use of the ADV revealed that water was pulsing through the screen in two dimensions, up and down, at least on the micro scale of the ADV. On average, 70% (range 64-74%) of all 30 cm^2 sections showed a net downward velocity through the screen. Many sections, up to 36%, actually showed a net water velocity flowing up through the screen. Overall, mean AV's exceeded 12, 6, and 3 cm/s at 10, 35, and 53% of all sections.

Results of our longer (180 s) assessments of variation in AV were similar to those just described (Figure 4). For example, when we used the ADV for 180 s, 69% of the sections we evaluated showed a mean downward AV. Also, mean AV's exceeded 12, 6, and 3 cm/s at 21, 42, and 50% of all individual sections that were examined. The variation (*SD*) in AV was related to the mean and *SD* of sweeping velocity for each individual section (R^2 =0.87; $P < 0.05$; Table 2; Figure 5).

Hot spots, or vortices, were observed during our Malheur screen investigations when approach velocities exceeded 2 cm/s (Figure 6). These hot spots covered approximately 20% of the total screen area and were located on the screening panel proximal to the diversion outflow.

Biological assessments

Hydraulic conditions present during our experimental releases generally fell within the range of values seen during our hydraulic investigations. For all of our tests, the survival rates of fish held for 24-h after passage were high. During releases of fish over the inverted weir screens, survival rate was 99.9% for treatment fish and 99.1% for control fish. Fish released over the screen at Malheur showed 98% (those released over hot spots) to 99% (those released over laminar conditions) survival for treatment fish and 100% survival for control fish. Only one out of over 1400 fish released died immediately after passage.

Detection of injuries in our fish due to screen passage was difficult because fish had natural injuries and perhaps incurred more injuries during capture, handling, and holding. Thus, injuries that fish had prior to passage over the screens were recorded and subtracted from our experimental groups before analysis. Overall, injury rates related to passage over the screen were very low and consisted primarily of minor fin injuries. Injuries to the skin, eyes, scales or severely frayed or broken fins were rare. Injuries related to passage over the screen were somewhat more common in Age-1 than in Age-0 fish.

For fish released over the inverted weir screens, there were no significant differences in injury rates between the treatment and control fish (Table 3). Injuries associated with screen passage were more common in Age-1 fish and were due to the occurrence of minor fin injuries ("trace fin splits").

Significant differences in injury rates between treatment and control groups were detected in 23% of our laminar flow test conditions at the Malheur screen (Table 4). All significant differences in injury rates between groups occurred when AV's equaled or exceeded 4 cm/s and SV's were less than 10cm/s. Again, the differences were due primarily to differences in the number of trace fin splits observed in each group after passage. For our releases of fish over hot spots, 16% of our comparisons indicated a significant difference in injury rate between treatment and control fish (Table 4). In these cases, injuries other than trace fin splits contributed to the differences in injury rates between treatment and control fish.

Fish injury rate was positively related to AV only during our low SV, backwatered tests at the Malheur site ($r^2 = 0.77$, $P = 0.052$; Figure 7). Injury rates (including control releases) generally increased during testing at higher SV's.

Video observations.

During our releases of fish over the inverted weir screens, the number of times that fish contacted the screen was higher during low water conditions and for Age-1 and older fishes. During two evaluations at the Cook screen, very shallow water caused all fish to contact the screen. All contacts with the screen were of very short duration and no fish became impinged on the inverted weir screens. The number of times that fish contacted an inverted weir screen was inversely related to depth ($r^2 = 0.67$, $P < 0.0001$; Figure 8) and not related to SV or AV. The time required for fish to travel over the screen was always less than or equal to 1 s and fish generally traveled no greater than 8 cm of the screen surface.

When fish were released over the Malheur screen under laminar flow conditions, the number of times fish contacted or were impinged on the screen was low (mean $\pm$ SD contacts = 0.6 ± 0.7). When fish were released over hot spots, the number of times fish contacted the screen increased significantly relative to laminar flow conditions (mean $\pm$ *SD* = 3.0 ± 1.8; *t*-test, $P < 0.001$). Under laminar conditions, the number of times fish contacted the screen was positively related to AV only when SV's were 10 cm/s or less. The number of times fish contacted the screen decreased and fish impingements were eliminated when SV's exceeded 20 cm/s (i.e., when the SV:AV ratio > 5). The time required for fish to travel over the screen generally decreased with increased SV and fish generally traveled within 8 cm of the screen surface.

Debris on the screens.

Despite the lack of mechanical cleaning devices, the inverted weir screens remained relatively free of debris when maintained with an established cleaning schedule (every 1-6 days depending on the amount of debris in the stream). All of the inverted weir screens accumulated debris at about 5% of the screen area per day, despite differences in hydraulic conditions and design. The backwatered screen at Malheur had higher debris accumulations rates (up to 16%). When the backwatered screen had perforated plate screen material and was operated at an AV of about 1 cm/s, it accumulated half the debris load per day (8%) compared with a screen that had profile bar screen material and AV's of around 2 cm/s (16%).

Discussion

Our results indicate that horizontal flat plate screens of the types we tested have great potential as safe and effective fish screens for irrigation and other diversions. The designs were relatively simple, had no moving parts, and had SV's and AV's under a variety of hydraulic conditions that rarely injured or killed fish after passage and allowed easy maintenance and cleaning. The screen structures were relatively inexpensive to install when compared to drum or other mechanically operated screens and can be designed for a variety of diversion rates. Thus, these horizontal flat plate screens offer private landowners and irrigators a low cost, effective alternative for screening diversions that appear to be harmless to fish based on the tests conducted.

Despite the potential advantages of horizontal flat plate screens for protecting fish populations, several caveats need to be considered when interpreting our results. First, because our experiments were conducted in the field, we were unable to evaluate all possible hydraulic conditions on screen performance, fish injury, and mortality. Basically, we had no control over stream flows and only minor control over diversion rates, so we often evaluated what nature and the irrigators provided at the time. Although we believe our evaluations were realistic because they encompassed typical irrigation scenarios, there may be other flow conditions we missed that are relevant to fish passage and safety. Second, only one species of fish was tested for the screen evaluations and our results may not be applicable to other species. The juvenile, wild Redband rainbow trout we used were probably good surrogates for other salmonids such as cutthroat trout *O. clarki* and other forms of rainbow trout, such as steelhead. Extrapolation of our results to other fishes, such as, juvenile lampreys, or endangered suckers in the Klamath basin, seems inappropriate and would require further testing. Finally, there are many design variations within the category of horizontal flat plate screens and our tests represented only some of these. Evaluating screens with different screen materials (e.g., perforated plate vs. vertical bar screen), screen panel angles, weir configurations, screen panel sizes, and other design elements would provide a more thorough understanding of flat plate screens in general.

Hydraulic characteristics of flat plate screens

Although inverted weir and simple, backwatered screens are both examples of the horizontal flat plate design, variation in the design and structural components created unique hydraulic properties at each. For example, the hydraulic properties of the inverted weir screens were in large part created by using a weir that directed stream discharge over the screen surface area. This typically resulted in high SV's that quickly passed both fish and debris downstream. One potential drawback of this design, which we observed on several occasions, is that water depths over the screens can often be shallow, which can leave insufficient water for fish passage. For example, during our 2005 investigations at the Rye Grass screen, the downstream third of the two screens nearest the diversion outflow were dewatered; potentially exposing fish attempting to pass over the screen to harmful situations. This dewatering was apparently caused by a combination of factors, including low stream discharge, high diversion rates, and excessive growth of aquatic vegetation near the screen that restricted stream flow near the dewatered area. Operators of such screens should be aware of factors that lead to poor performances of inverted weir screens. The performance of these screens could be enhanced (e.g., maintaining high SV's, sufficient depths; and decreasing the risk of dewatering) by decreasing the screen:weir ratio and by installing screens at steeper gradients relative to the stream surface. Although shallow water and other limitations prevented us from measuring AV's using an ADV, there were no visual indications (i.e., vertical, downward flows) that hotspots were created during normal operation of the inverted weir screens.

Contrary to the inverted weir design, the hydraulic conditions of the backwatered screen at Malheur were primarily controlled by a rock weir structure located downstream of the device. This structure could be used to manipulate water depth over the screen, thus providing some direct control over SV's. On average, when calculated by dividing the screen area by the diversion rate, AV's at the Malheur screen ranged from 1-5 cm/s, which are below current NOAA-Fisheries passive screen criteria (6 cm/s). However, when measured using the ADV, we noted that the AV's of this design were highly variable and constantly changing. Use of the ADV revealed a cyclical pattern of water velocities downward and upward through the screen, i.e., the water seems to be "pulsing" through the screen in different directions. Finally, during the majority of the hydraulic conditions tested at the Malheur screen, we observed the development of hot spots or areas of vortical, non-uniform flow. These always occurred on the side of the screen proximal to the diversion. The exact cause of such hot spots is unknown but provides a subject for further study.

The variation we saw in AV's when measured with an ADV suggest some relations that might warrant further examination. Within each section we measured AV for 180 s, we noted that the variation in AV (as indicated by the SD) was inversely related to the mean SV and positively related to the variation in SV. These relations suggest that the variability in AV could be reduced by modifying the design to achieve higher and less variable SV's. How this could be accomplished is within the realm of the hydraulic engineer, but suggestions include concentrating stream discharge over the screening panels, gradually reducing the downstream screen width, adjusting the spacing of any internal baffles, or controlling the porosity of the screen in different sections or areas.

Fish passage over flat plate screens

In the majority of cases, survival of fish was high (>98%) 24 h after passing over the inverted weir screens and the Malheur screen; and injury rates of fish passing over these screens were low and severe injuries were almost nonexistent. Basically, the inverted weir designs performed flawlessly, at least under the conditions we tested. For the Malheur screen, which was a relatively simple, backwatered design, we noted that rate of injury increased when AV's exceeded 3 cm/s and SV's were low. We should note, however, that the majority of these injuries were minor and apparently non-lethal. Increased rates of injury under such conditions seem to result from fish spending relatively long periods over the screen surface. Minor increases in SV (10 cm/s) reduced this effect and improved passage conditions. When we forced fish to pass over hot spots on the Malheur screen, delayed mortality rates as high as 10% occurred and the rate of injury was increased.

Although we were successful, assessment of injury rates of fish after passage over the screens was difficult and time consuming. As such, there are several caveats to consider when interpreting our injury results. First, a high percentage of fish used in our experiments (especially Age-1 or older fish) had many pre-existing minor injuries. These pre-existing injuries were very time consuming to quantify and had to be taken into account prior to our releases. Secondly, we noted that the injuries sustained by fish after passage over the screens were not related to the number of screen contacts or impingements, which surprised us. For example, when we released fish over hot spots at the Malheur screen, we saw that fish were experiencing relatively turbulent environments that caused high rates of screen contacts and prolonged impingements. However, although we might interpret such conditions as unsuitable for safe fish passage, injury rates of fish during these tests were generally low. This suggests that assessing the biological performance of screens in the wild based solely on examinations of fish for post-passage injury may be inappropriate. In fact, because examining fish for injury after passage over the screens was so time consuming, had inherent sources of measurement error, and may not be indicative of poor passage conditions, we cannot recommend this method for future screen evaluations in the field. Other methods, such as the use of dyes for assessing injuries to the skin or scales (Noga and Udomkusonsri 2002) or the use of improved procedures for evaluating delayed mortality, would be simpler and probably just as effective.

The use of underwater video provided useful information for a more thorough evaluation of screen performance during our fish releases. We documented the number of times fish contacted or were impinged on the screen and could assess the relative severity of such events. Further, we tried to relate contacts and impingement events with hydraulic conditions and note that such observations were not influenced by capture, handling, and holding like our injury assessments were.

Our video observations of the releases of fish over the inverted weir screens indicated that this design provided mostly safe and efficient passage conditions for fish. The hydraulic variable that was most strongly related to the number of screen contacts was water depth. During some releases, many fish contacted the screen simply because there was shallow water over the screen surface. During these shallow water releases, fish often glided upright on their ventral side over the screen and, on occasion, with the dorsal portion of their body out of the water. The influence of shallow water on contact with the screen was greater for larger fish. Thus, although many fish contacted the screen during our releases over the inverted weir design, none of these events resulted in serious injury or death. The high SV's associated with this design effectively prevented any impingement of fish.

Both AV's and SV's influenced the number of times fish contacted the screen at the Malheur backwatered design. Under normal, laminar flow conditions, the majority of contacts with the screen were minor and on the ventral side of the fish. During our low SV test at this screen, the number of contacts increased at higher AV's. When SV's were increased by about 10 cm/s, the number of contacts with the screen decreased, impingement was virtually eliminated, and fish did not spend a prolonged time over the screen. Thus, even minor increases in SV can increase the performance of this design considerably. When we released fish over hot spots on this screen, the number of times fish contacted and were impinged on the screen increased considerably. Further, we think the severity of such events was relatively high. Thus, as we mentioned previously, irrigators, engineers, and fish managers should do all they can to understand the development of hot spots and take corrective measures.

Operation and design recommendations

Based on our results, we hoped to develop hydraulic and biological performance criteria for the two designs of flat plate screens addressed in this study and provide guidelines for future screen installations. Our recommendations, as outlined below, are based on our hydraulic evaluations of these screens, injury assessments of fish after passage over these screens, and underwater video observations of fish passing over the screens. Although we conducted many tests in the field, we did not cover all conditions that fish might experience in the field. In particular, we did not conduct any tests that resulted in severe rates of injury, severe injuries, or death of fish. Thus, we did not explore the extremes of hydraulic conditions that fish may encounter. Overall, our tests indicated that passage of fish over these types of screens under a wide variety of conditions was very safe. As such, our suggestions for the operation of these types of screens should be considered conservative and not universally applicable.

Current NOAA-Fisheries criteria (NOAA 2004; Ray Hartlerode, Oregon Fish Passage and Screening Director, personal communication) limits typical passive screen diversions to 0.03 m^3/s (with a few potential exceptions) and sets a maximum AV limit of 6 cm/s for the protection of juvenile anadromous salmonids. Our results indicate that, for streams of the size we worked on, both types of screen—inverted weir and backwatered—safely and effectively diverted water up to, and far beyond this 0.03 m^3/s criterion without affecting screen performance or increasing risk to fish passing over the screen. In fact, we tested the performance of inverted weir screens at discharge flows of 0.10 to 0.31 m^3/s and they performed admirably. At the Malheur screen, we evaluated screen performance at diversion flows from 0.08 to 0.32 m^3/s, and again, this screen performed well. Thus, we suggest that screens of this type can be effective at diversions approaching 0.30 m^3/s. However, we remind the reader that diversion flows, stream discharge, water depth over the screen, SV, and AV are all interrelated and all factors must be considered when deciding how best to operate a screen.

Our results indicate that the current NOAA-Fisheries AV criterion of 6 cm/s will provide adequate protection for fish at the inverted weir screens, at least for salmonids similar to those we tested. In fact on one occasion, we tested AV's up to 8 cm/s and encountered no serious problems. For backwatered flat plate screens, like the one we tested at Malheur, the AV criterion of 6 cm/s seems too high for adequate fish passage and protection. Based on our results, we suggest that AV's of about 2 cm/s (calculated by dividing screen area by the discharge rate) will provide efficient and safe passage of fish over this type of screen. This AV criterion could be increased to 3 cm/s, or perhaps higher, if SV's can be maintained at 20 cm/s or higher.

The NOAA-Fisheries passive screen criteria have no sweeping velocity requirements (for screens less than 6 feet in length) and provide no water depth requirements for flat plate screens. For horizontal flat plate screens, SV and water depth over the screen are important factors to consider. We documented increased rates of fish injury, contact with the screen, and impingements when SV was near 10 cm/s. These effects were reduced or eliminated when SV's were increased to about 20 cm/s. Thus, we recommend SV's greater than 20 cm/s for the types of screens we evaluated. The water depth necessary to safely pass fish over these horizontal flat plate screens varies and depends largely on the size of fish and anticipated debris load. Our results suggest that water depths greater than 7 cm would likely provide adequate protection for anadromous salmonids up to about 200 mm fork length for the inverted weir design. By using appropriate screen to weir ratios, engineers should be able to design these screens to meet this recommendation. Additional research is needed to determine minimum depth requirements for the simpler backwatered design. Finally, as we mentioned earlier, the backwatered flat plate design seems prone to the development of hot spots, or downward, spiraling flow through the screen. We consider such conditions unsafe for fish passage and recommend that managers and engineers identify the cause of and remedy for such conditions.

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Literature Cited

Bain, M. B., and N. J. Stevenson, editors. 1999. Aquatic habitat assessment: common methods. American Fisheries Society, Bethesda, Maryland.

Beyers, D. W., and K. R. Bestgen. 2001. Bull trout performance in a horizontal flat plate screen. Larval Fish Laboratory Contribution Number 128. Larval Fish Laboratory, Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins, CO

Clay, C. H. 1995. Design of fishways and other fish facilities. Lewis Publishers, Boca Raton, Florida.

Dadswell, M. J., and R. A. Rulifson. 1994. Microtidal Estuaries: a region of collision between migratory marine animals and tidal power development. Biological Journal of the Limnaean Society. 51:93-113

Danley, M. L., S. D. Mayr, P. S. Young, and J. J. Cech, Jr. 2002. Swimming performance and physiological stress responses of splittail exposed to a fish screen. North American Journal of Fisheries Management 22:1241-1249.

Frizell, K., and B. Mefford. 2001. Hydraulic performance of a horizontal flat plate screen. Final report. U. S. Bureau of Reclamation, Water Resources Research Laboratory, Denver, Colorado.

Hanson, C. H., and H. W. Li. 1978. A research program to examine fish behavior in response to hydraulic flow fields: development of biological design criteria for proposed water diversions. Office of Water Research and Technology, U.S. Department of the Interior, Completion Report for Project C-7679, Sacramento, California.

Kingsford, R.T. 2000. Ecological impacts of dams, water diversions, and river management on floodplain wetlands in Australia. Australia Ecology 25:109-127

McMichael, G. A., J. A. Vucelick, C.S. Albernathy, and D. A. Neitzel. 2004. Comparing fish screen performance to physical design criteria. Fisheries 29(7):10-16

National Oceanic and Atmospheric Administration. 2004. Draft anadromous salmonid passage facility guidelines and criteria. National Marine Fisheries Service, Northwest Region, Portland, Oregon.

Noga, E.J. and P. Udomkusonsri. 2002. Fluorescein: A rapid, sensitive, nonlethal method for detecting skin ulceration in fish. Veterinary Pathology 39:726-731.

Prentice, E., T. Flagg, and C. McCutcheon. 1990. Feasibility of using Passive Integrated Transponder (PIT) tags in salmonids. American Fisheries Society Symposium 7:317-322.

Swanson, C., P. S. Young, and J. J. Cech, Jr. 1998. Swimming performance of delta smelt: maximum performance and behavioral and kinematic limitations of swimming at submaximal velocities. Journal of Experimental Biology 201:333–345.

Swanson, C., P.S. Young, and J.J. Cech Jr. 2004. Swimming in a two vector flows: performance and behavior of juvenile Chinook salmon near a simulated screened water diversion. Transactions of the American Fisheries Society 133:265-278.

USFWS (U.S. Fish and Wildlife Service). 1995. Working paper on restoration needs: habitat restoration actions to double natural production of anadromous fish in the Central Valley of California, volume 2. Prepared for the U.S. Fish and Wildlife Services under the direction of the Anadromous Fish Restoration Program Core Group, Stockton, California.

Zar, J. H. 1984. Biostatistical analysis, second edition. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

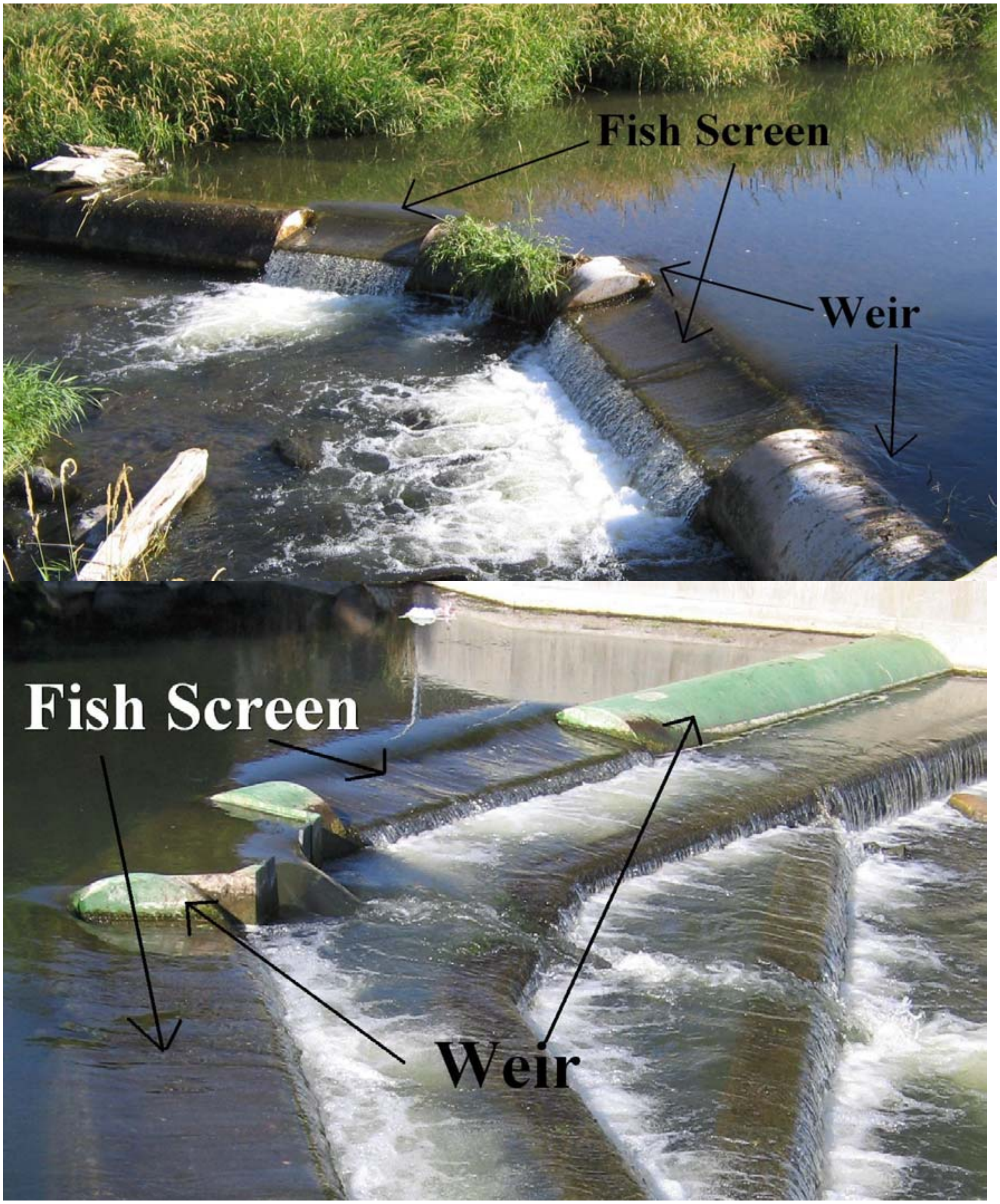


Figure 1. Photographs of the Smith (top) and Rye Grass (bottom) inverted weir flat plate fish screens located on Mckay and Ochoco Creeks near Prineville, Oregon. The screening panels are located in the cut-out areas of steel pipe. Note the V-notch passage structure in the middle of each screen.

Figure 2. Photograph of the backwatered horizontal flat plate fish screen (the Malheur screen) and the rock weir flow control structure located in the East canal of the Donner und Blitzen River, Oregon

Figure 3. Apparatus used to experimentally release juvenile rainbow trout over selected horizontal flat plate screens in the field. The device is shown here attached to the Malheur screen. Each site required modifications to account for differences in water turbidity and structural variations of the
screens.

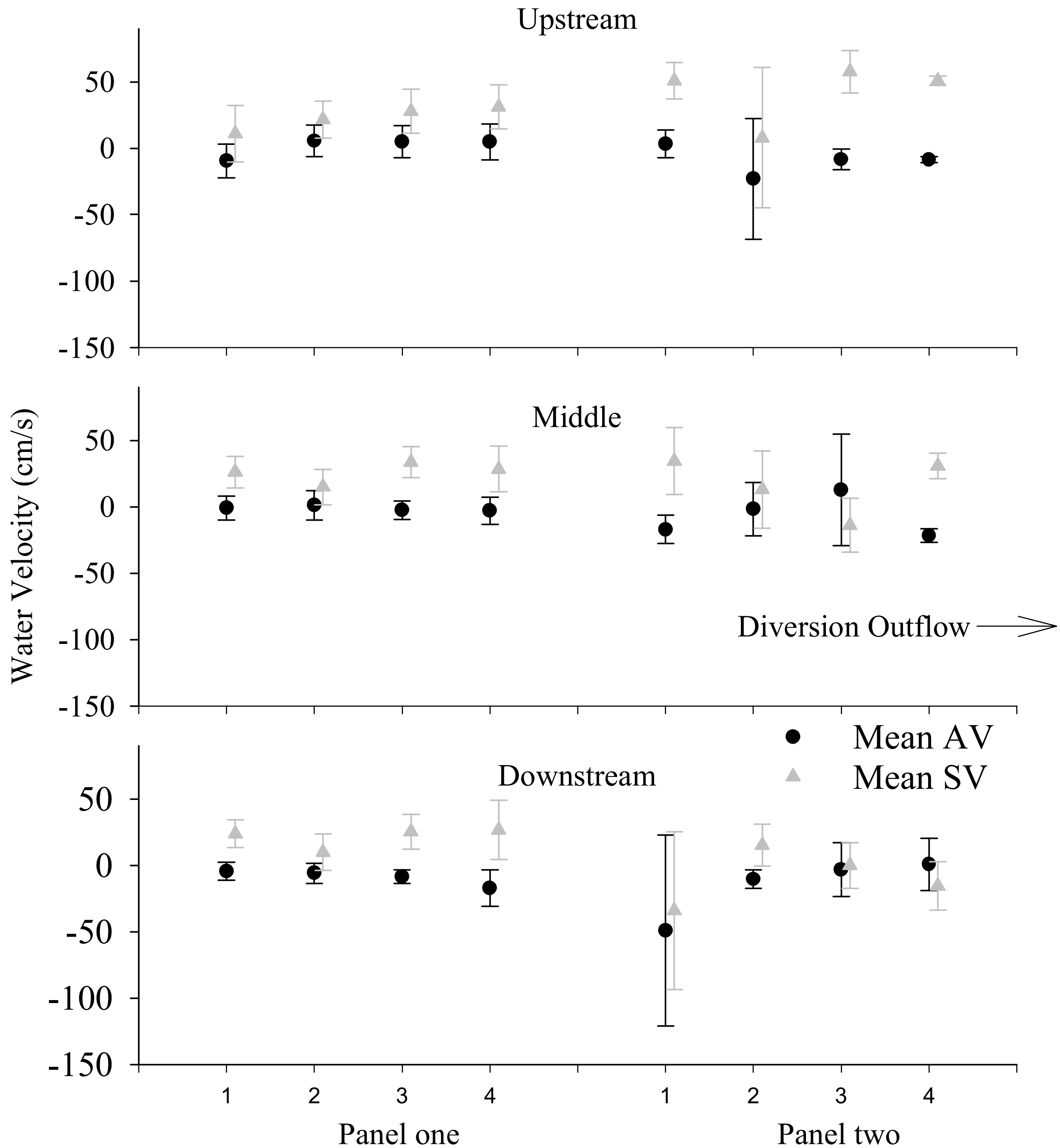
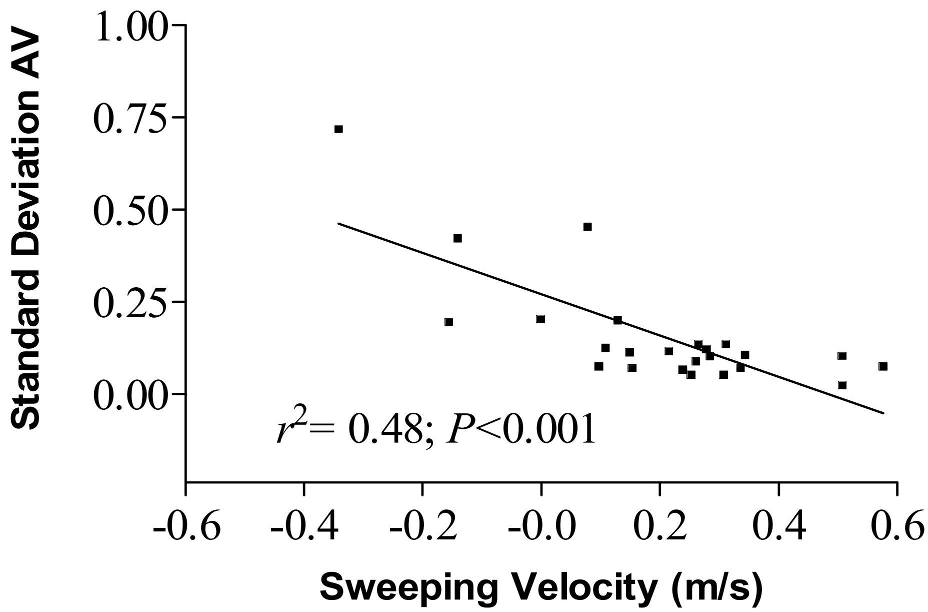


Figure 4. Mean (and SD) approach and sweeping velocities from the Malheur screen, a backwatered horizontal flat plate fish screen. Data were collected with an Acoustic Doppler Velocimeter from the front (upstream), middle, and rear (downstream) of two screen panels. Means were derived from 180 one second velocity measurements in the center of every 0.60 x 0.40 m section of screen area. All velocities on the left side of the graph came from one panel, those on the right came from the other. Withdrawal outflow was to the right of the graph.



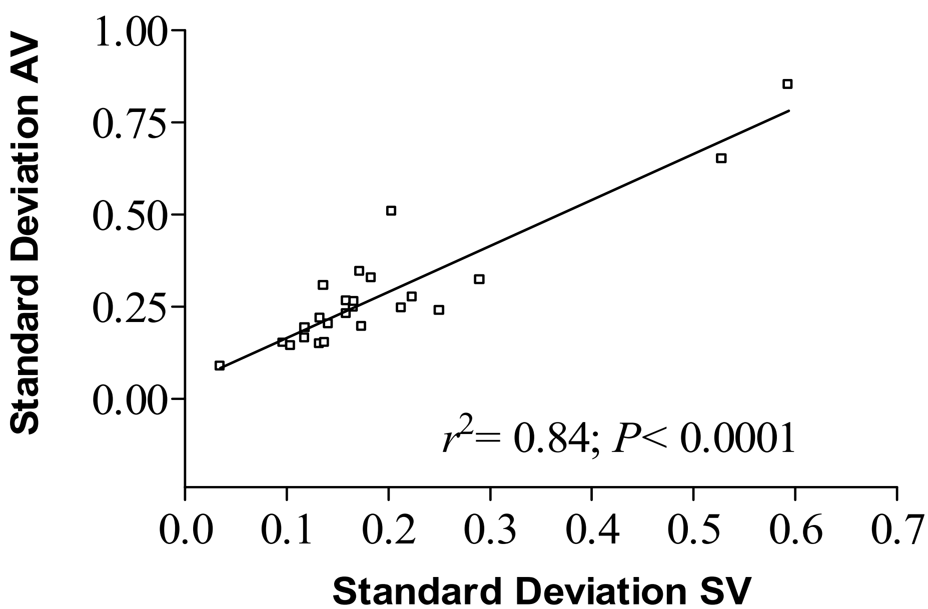


Figure 5. Simple linear regression of the standard deviation of approach velocity and the sweeping velocity in the center of several sections of the Malheur screen (top graph) and standard deviation of AV and SV (bottom graph). Data were derived by calculating descriptive statistics from 180 s of measurements from an Acoustic Doppler Velocimeter.

Figure 6. Photograph of a hot spot, or vortex, on the Malheur screen.

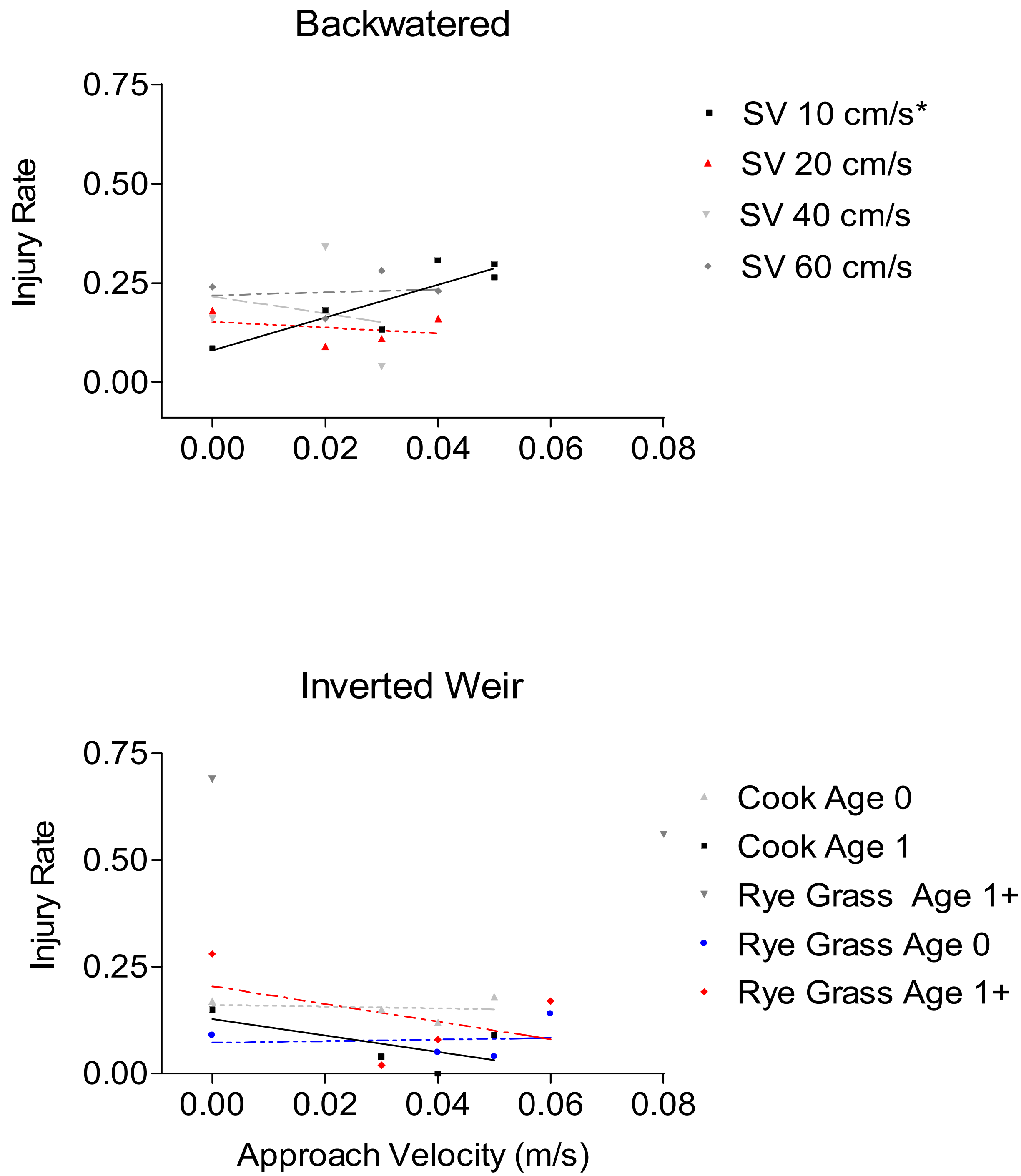


Figure 7. Relations between rate of injury and approach velocity for juvenile Redband rainbow trout experimentally released over two types of horizontal flat plate fish screens. Injury rate includes all injuries to the skin, eyes, and fins. Lines indicate the linear regression for various tests at different screens. An asterisk denotes a regression line that differed significantly from zero. SV = sweeping velocity. Approach velocities of zero were our control releases.

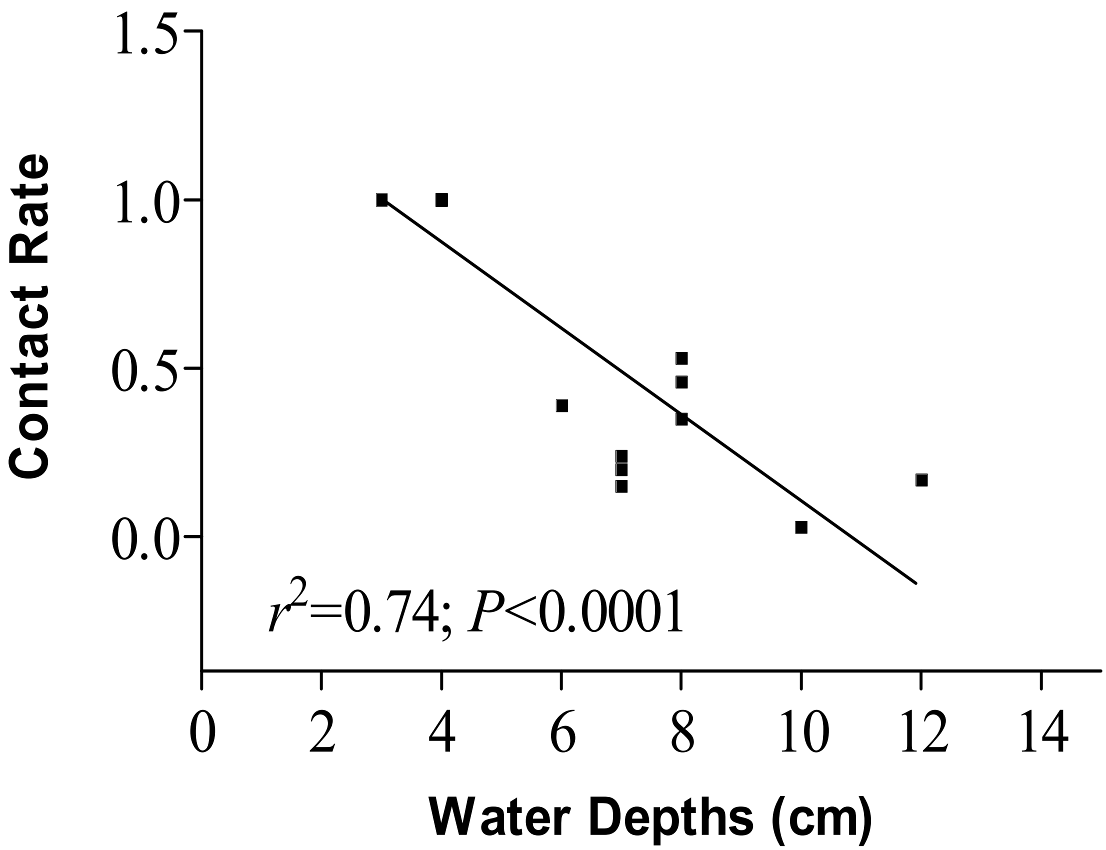


Figure 8. Relation between contact rate and water depth for fish released over inverted weir horizontal flat plate screens. Contact rates were derived by dividing the total number of times fish touched the screen by the number of fish viewed on underwater video tapes.

Table 1. Summary of hydraulic conditions for two styles of horizontal flat plate fish screens during field work in 2004 and 2005. Q = discharge, SV = sweeping velocity, AV = approach velocity. Bold dates indicate days when fish releases occurred; na = not available.

Design Style Screen	Date	Stream Q (m^3/s)	Diversion Q (m^3/s)	Mean SV (SD) (m/s)	AV (m/s)	Mean Depth (SD) (m)
Inverted Weir						
Cook	**6/04/2004**	1.26	na	1.43 (0.45)	na	0.12 (0.02)
	8/11/2004	0.47	0.20	1.04 (0.24)	0.05	0.05 (0.03)
	8/13/2004	0.31	0.11	0.72 (0.12)	0.03	0.04 (0.01)
	8/13/2004	0.31	0.16	0.70 (0.04)	0.04	0.05 (0.04)
	7/06/2005	0.43	0.10	0.90 (0.31)	0.03	0.06 (0.01)
	7/08/2005	0.42	0.16	0.88 (0.18)	0.04	0.05 (0.02)
	8/13/2005	0.55	na	1.08 (0.30)	na	0.06 (0.02)
	8/24/2005	0.39	na	1.12 (0.24)	na	0.05 (0.02)
Rye Grass	**6/17/2004**	1.77	0.39	1.14 (0.34)	0.08	0.15 (0.03)
	6/09/2005	na	0.20	0.99 (0.37)	0.04	0.13 (0.05)
	6/09/2005	na	0.26	0.93 (0.46)	0.05	0.10 (0.05)
	6/09/2005	na	0.27	1.01 (0.38)	0.05	0.12 (0.04)
	7/15/2005	0.54	0.30	0.78 (0.26)	0.06	0.06 (0.09)
	7/17/2005	0.58	0.18	0.77 (0.26)	0.03	0.07 (0.03)
	7/17/2005	0.58	0.23	0.69 (0.21)	0.04	0.06 (0.02)
	8/09/2005	0.55	0.31	0.73 (0.20)	0.06	0.05 (0.02)
	8/11/2005	0.55	0.19	0.78 (0.21)	0.04	0.06 (0.02)
	8/11/2005	0.55	0.27	0.85 (0.21)	0.05	0.06 (0.02)
	8/11/2005	0.55	0.31	0.73 (0.20)	na	0.05 (0.02)
	8/26/2005	0.62	na	0.85 (0.18)	na	0.08 (0.09)
Smith	**6/27/2004**	0.47	na	1.32 (0.32)	na	0.09 (0.03)
	6/09/2005	na	na	1.42 (0.44)	na	0.12 (0.03)
	7/13/2005	0.33	na	1.17 (0.38)	na	0.07 (0.03)
	8/12/2005	0.31	na	1.14 (0.37)	na	0.06 (0.02)
	8/24/2005	0.24	na	0.98 (0.31)	na	0.05 (0.02)
Backwatered						
Malheur	**7/12/2004**	0.79	0.17	0.29 (0.08)	0.03	0.34 (0.02)
	7/14/2004	0.75	0.32	0.32 (0.10)	0.05	0.32 (0.01)
	8/01/2004	0.33	0.13	0.15 (0.06)	0.02	0.31 (0.01)
	8/01/2004	0.33	0.17	0.15 (0.12)	0.03	0.30 (0.01)
	8/03/2004	0.32	na	0.16 (0.08)	0.05	0.23 (0.01)
	7/22/2005	0.23	0.11	0.22 (0.07)	0.02	0.12 (0.01)
	7/24/2005	0.34	0.21	0.22 (0.09)	0.04	0.22 (0.01)
	7/27/2005	0.30	0.10	0.47 (0.11)	0.02	0.11 (0.01)
	7/29/2005	0.32	0.11	0.49 (0.19)	0.03	0.06 (0.01)
	7/16/2004	0.61	0.14	0.57 (0.08)	0.02	0.18 (0.01)
	7/18/2004	0.69	0.21	0.66 (0.08)	0.04	0.16 (0.01)
	7/28/2004	na	0.08	0.52 (0.19)	0.01	0.12 (0.01)
	7/30/2004	0.46	0.19	0.57 (0.24)	0.03	0.10 (0.01)

Table 2. General linear models that describe screen hydraulics and behavior of juvenile redband trout exposed to two design styles of horizontal flat plate fish screens. All values are significant (P<0.05) unless specifically noted. Abbreviations are as followed: AV = approach velocity (cm/s); SD_{AV} = standard deviation of AV; SV sweeping velocity (cm/s) ; SD_{SV} = standard deviation of SV; SC = Screen contact rate (contacts per fish viewed); Z = depth of water over screen (cm); SQ = Stream discharge (m^3/s); WQ = withdrawal discharge (m^3/s); SW = screen length/weir length *100; G = screen gradient (%); SEE = standard error of estimate.

Type	Equations
A) Models that describe the effects of stream discharge, withdrawal discharge, screen gradient and screen/weir ratio on the hydraulic properties of inverted weir screens.	
Depths	$Z = 9.291 + 9.668\ (SQ) - 6.913\ (WQ^{a}) - 0.115(SW) - 0.156(G)$ *Observations* = 18, R^2 = 0.78, SEE = 0.60
Sweeping Velocity	$SV = 118.33 - 2.03(SW) + 133.87(SQ)$ *Observations* = 18 R^2 = 0.84, SEE = 8.24
B) Models that describe the relationship of the variability of approach velocities to mean and average sweeping velocities on backwatered horizontal flat plate fish screens.	
SD_{AV}	$SD_{AV} = 11.399 - 0.1896(SV) + 1.063(SD_{SV})$ *Observations=24,* R^2 = 0.87., SEE =6.44
c) Models to describe the effects of hydraulic and biological variables on screen contact rates at two design styles of horizontal flat plate fish screens.	
Inverted weir	$SC = 1.354 - 0.131(Z)$ *Observations* = 22, r^2 = 0.67, SEE= 0.25
Backwatered	$SC = -0.152 + 0.258(AV)$ *Observations* = 17, r^2 = 0.50, SEE= 0.45

[a] *P*=0.06

Table 3. Hydraulic conditions and injury rates of juvenile Redband rainbow trout that were experimentally released over inverted weir fish screens during 2004-05. Sweeping velocities in italic print were derived from measurements at the front and middle of the screen only due to insufficient water depth at the rear of the screen. A single release of control fish was conducted for each set of releases of treatment fish. No injury rates between treatment and control fish differed significantly. AV = approach velocity (m/s); SV = sweeping velocity (m/s); D = water depth over the screen (cm); C = control fish; T = treatment fish; NA = data not available.

				Age of fish	No. released		% injured	
Screen	AV	SV	D	tested	C	T	C	T
Cook								
	0.03	0.91	4	1+	33	26	15	4
	0.04	*0.97*	4	1+	33	31	15	0
	0.05	*0.95*	4	1+	33	30	15	9
	0.03	*0.66*	4	0	47	50	17	15
	0.04	*0.68*	3	0	47	49	17	12
	0.05	*1.04*	4	0	47	47	17	18
Rye Grass								
	0.08	1.36	12	1+	80	77	69	79
	0.03	0.79	8	1+	32	39	28	2
	0.04	0.82	8	1+	32	38	28	8
	0.06	0.99	8	1+	32	30	28	17
	0.04	0.78	7	0	49	44	9	5
	0.05	0.85	7	0	49	43	9	4
	0.06	0.81	7	0	49	52	9	14
	a	*0.61*	3	0	49	39	9	3
Smith								
	NA	1.28	6	1+	39	40	85	83

[a]Screen was about 33% dewatered during these releases.

Table 4. Hydraulic conditions and injury rates of juvenile Redband rainbow trout that were experimentally released over the Malheur fish screen during 2004-05. A single release of control fish was conducted for each set of releases of treatment fish. Injury rates in bold print differed significantly. AV = approach velocity (m/s); SV = sweeping velocity (m/s); D = water depth over the screen (cm); C = control fish; T = treatment fish; NA = data not available.

				Age of fish	No. released		% Injured	
Conditions	AV	SV	D	tested	C	T	C	T
Laminar								
SV 10 cm/s								
	0.02	0.15	34		39	35	9	18
	0.03	0.13	31		39	38	9	13
	0.04	0.17	34		39	39	**9**	**31**
	0.05	0.21	30		39	40	**9**	**30**
	0.05	0.23	30		39	38	**9**	**26**
SV 20 cm/s								
	0.02	0.26	13		43	21	18	9
	0.03	0.23	26		43	29	18	11
	0.04	0.23	24		43	32	18	16
SV 40 cm/s								
	0.02	0.48	8		39	38	16	34
	0.03	0.46	5		39	33	16	4
SV 60 cm/s								
	0.01	0.59	12		38	37	24	16
	0.03	0.63	11		38	32	24	28
	0.03	0.66	8		38	39	24	23
Non-laminar								
SV 10 cm/s								
	0.03	0.22	34		24	21	13	17
	0.05	0.17	30		24	32	13	18
	0.07	NA	NA		24	35	13	31
SV 60 cm/s								
	0.02	0.52	17		40	38	18	19
	0.03	0.58	15		40	43	18	21
	0.04	0.47	15		40	42	18	29

Appendix L - Mesa, M.G., Rose, B.P., and Copeland, E.S., 2012, North American Journal of Fisheries Management, Field-Based Evaluations of Horizontal Flat-Plate Fish Screens, II: Testing of a Unique Off-Stream Channel Device-the Farmers Screen: U.S. Geological Survey

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Field-Based Evaluations of Horizontal Flat-Plate Fish Screens, II: Testing of a Unique Off-Stream Channel Device—the Farmers Screen

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ARTICLE

Field-Based Evaluations of Horizontal Flat-Plate Fish Screens, II: Testing of a Unique Off-Stream Channel Device—the Farmers Screen

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Abstract
Screens are installed at water diversion sites to reduce entrainment of fish. Recently, the Farmers Irrigation District (Oregon) developed a unique flat-plate screen (the "Farmers Screen") that operates passively and may offer reduced installation and operating costs. To evaluate the effectiveness of this screen on fish, we conducted two separate field experiments. First, juvenile coho salmon *Oncorhynchus kisutch* were released over a working version of this screen under a range of inflows (0.02–0.42 m^3/s) and diversion flows (0.02–0.34 m^3/s) at different water depths. Mean approach velocities ranged from 0 to 5 cm/s and sweeping velocities ranged from 36 to 178 cm/s. Water depths over the screen surface ranged from 1 to 25 cm and were directly related to inflow. Passage of fish over the screen under these conditions did not severely injure them or cause delayed mortality, and no fish were observed becoming impinged on the screen surface. Second, juvenile coho salmon and steelhead *O. mykiss* were released at the upstream end of a 34-m flume and allowed to volitionally move downstream and pass over a 3.5-m section of the Farmers Screen to determine whether fish would refuse to pass over the screen after encountering its leading edge. For coho salmon, 75–95% of the fish passed over the screen within 5 min and 82–98% passed within 20 min, depending on hydraulic conditions. For steelhead, 47–90% of the fish passed over the screen within 5 min and 79–95% passed within 20 min. Our results indicate that when operated within its design criteria, the Farmers Screen provides safe and efficient downstream passage of juvenile salmonids under a variety of hydraulic conditions.

There are many kinds of irrigation diversion screens in the USA, and all are designed to prevent fishes and other aquatic life from becoming entrained, injured, or killed by the diversion. The most common are vertically oriented screens, such as panel, traveling-belt, and rotary drum screens. Although these types of screens have been extensively studied and have design and operating criteria meant to protect fish (NMFS 2008), they can be relatively expensive and require frequent maintenance to operate properly (McMichael et al. 2004), which can limit the installation of screens in areas where they are needed. Recently, the development of unique horizontal flat-plate fish screens offer designs that may be less expensive to install and offer simpler, more passive (i.e., no moving parts) operation than other screens. Research on the hydraulic characteristics and biological effects of some flat-plate screens has resulted in a greater understanding of how they work (Frizell and Mefford 2001) and shown few negative effects (e.g., injury or mortality) on juvenile bull trout *Salvelinus confluentus* or rainbow trout *Oncorhynchus mykiss* that passed over such screens (Beyers and Bestgen 2001; Rose et al. 2008). However, more work is needed to fully evaluate their performance. Evaluating different designs and sizes of horizontal flat-plate screens in the laboratory and in the field would allow further verification of screen performance, provide data for comparison with more traditional fish screens, and perhaps facilitate screen installation.

For this work, we evaluated the hydraulic and biological performance of a newly developed horizontal flat-plate fish screen, also known as the Farmers Screen (Figures 1, 2), for use in an

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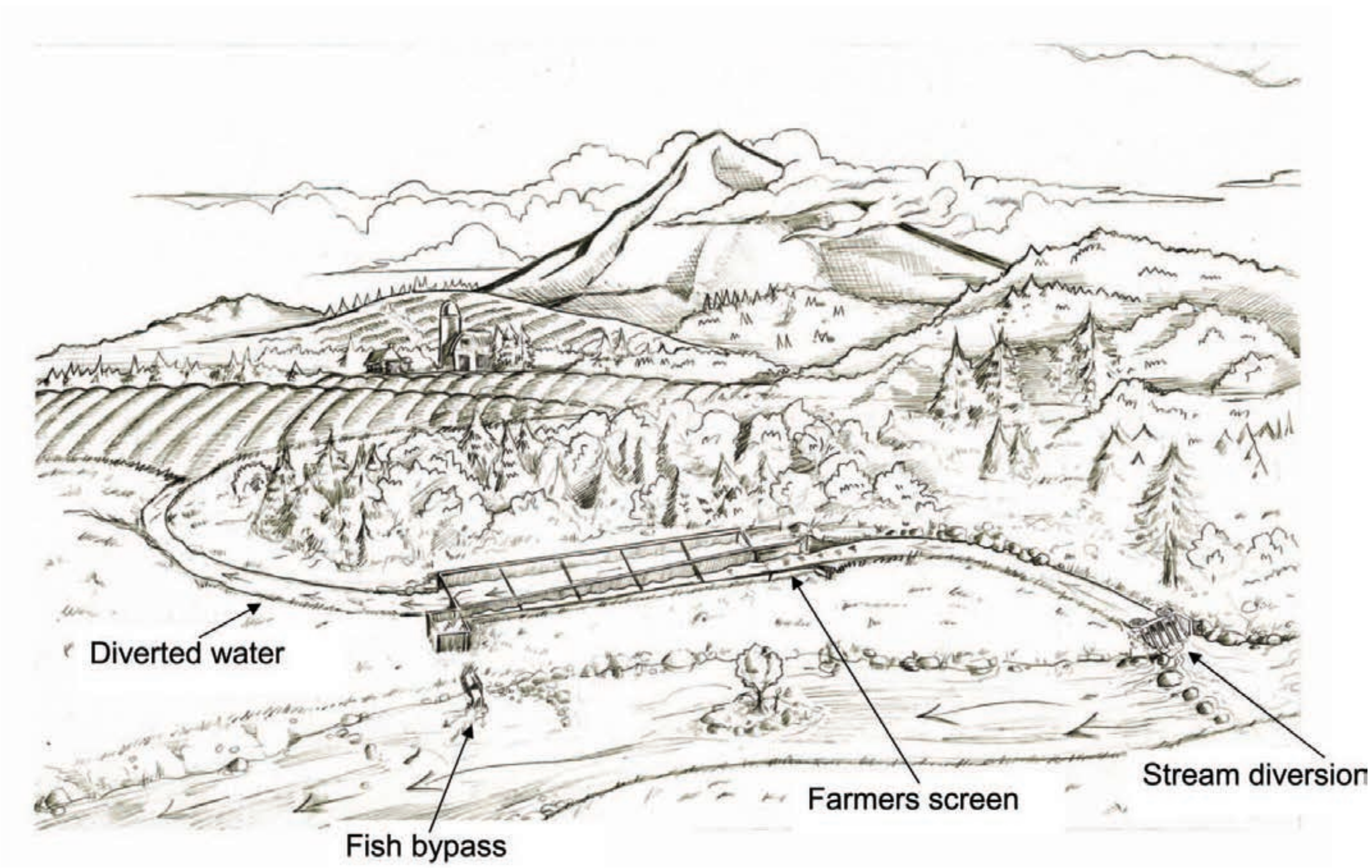


FIGURE 1. Conceptual drawing of a typical Farmers Screen installation (courtesy of the Farmers Conservation Alliance, Hood River, Oregon).

off-stream channel. These screens, designed over a 10-year period by personnel from the Farmers Irrigation District in Hood River, Oregon, have a high ratio of sweeping velocity (the velocity of water flowing parallel to the screen surface) to approach velocity (the velocity of water actually passing through the screen surface) and a 50% open surface area with relatively small screen pore sizes. These characteristics provide good self-cleaning; reduce the potential for fish impingement, injury, and entrainment; and may afford lower installation and maintenance costs (see www.farmerscreen.org for detailed information). The screens are manufactured in various sizes and can accommodate flows ranging from 0.01 to over 4.5 m^3/s (0.5–160 ft^3/s). There are many small unscreened or insufficiently screened diversions with flow less than 1.4 m^3/s (50 ft^3/s) in the western USA, and small diversions can take a high percentage of the flow from small streams; most larger diversions have already been screened (Moyle and Israel 2005; Rose et al. 2008). We therefore decided to test a small version of the Farmers Screen because of the great potential for installing these devices in many areas. Our objectives were to (1) assess the hydraulic performance of a Farmers Screen designed to divert only 0.28 m^3/s of water; (2) determine the extent of injury and delayed mortality in fish that have been experimentally released over the screen under various hydraulic conditions; and (3) evaluate whether fish would refuse to pass over the screen upon encountering its leading edge, again under a variety of hydraulic conditions.

METHODS

Study site and hydraulic assessments.—We evaluated a small Farmers Screen located at the Oxbow Fish Hatchery in Cascade Locks, Oregon (Figure 3). The screen is on a side-channel of Herman Creek, a tributary of the Columbia River, and was designed to divert 0.28 m^3/s of water. The screen was similar to other Farmers Screens that have already been installed in the Pacific Northwest. The Herman Creek screen site allowed us to create various test conditions.

For hydraulic assessments of the Herman Creek screen, we first adjusted the inflow entering the screen and measured it in the flume just upstream of the screen surface with a Marsh–McBirney electronic velocity meter following the protocol of Gallagher and Stevenson (1999). We also measured discharge at the very downstream end of the screen (i.e., the bypass flow) and estimated diversion discharge as the difference between the entrance and bypass flows. We then calculated mean approach velocity by dividing the effective screen surface area by the diversion discharge. Sweeping velocities and water depth were measured at 28 evenly spaced positions across seven transects

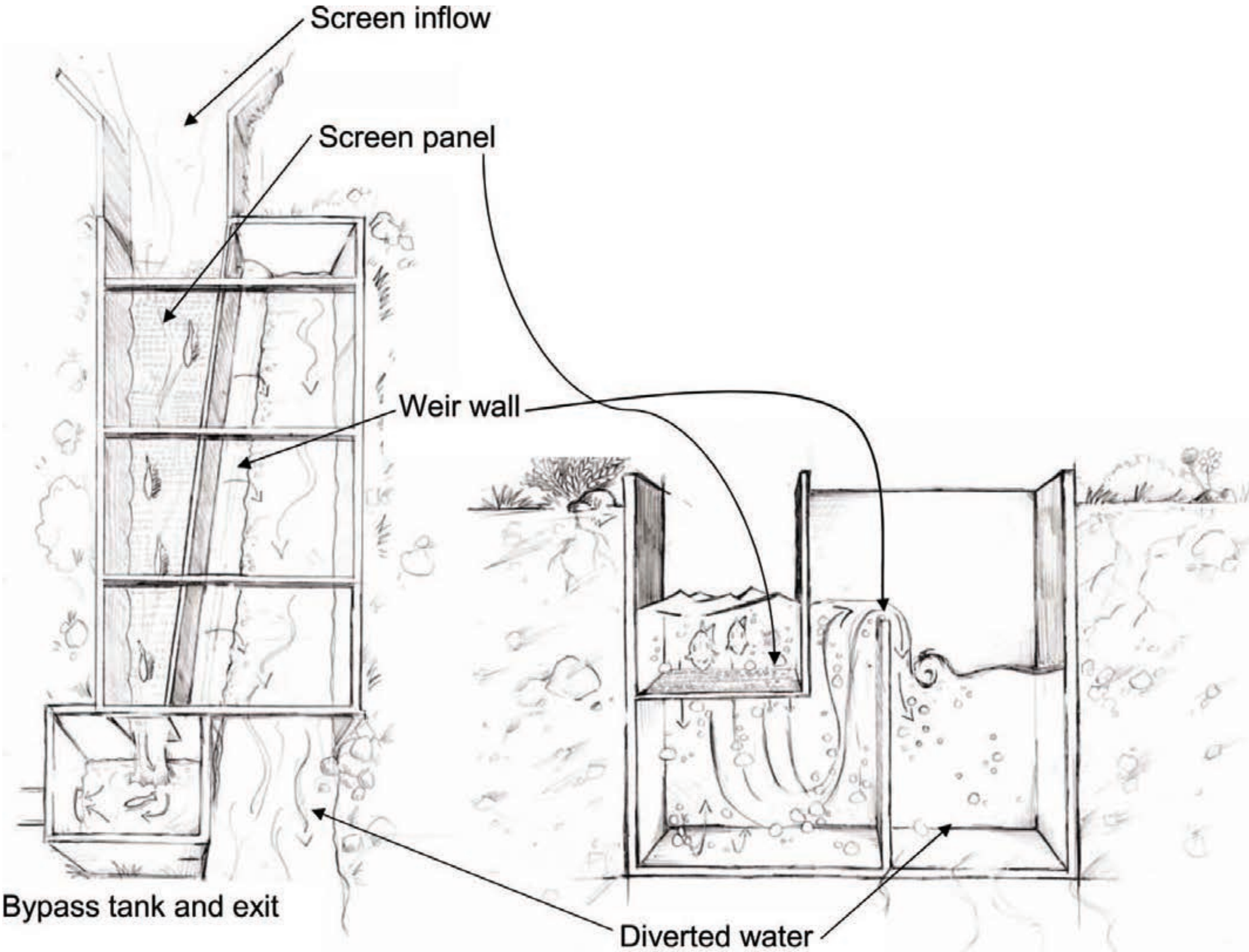


FIGURE 2. Conceptual overhead and frontal views of a typical Farmers Screen showing design details (courtesy of the Farmers Conservation Alliance, Hood River, Oregon).

on the fish screen perpendicular to the flow. Water velocities were measured at 7.6 cm above the screen surface or at 0.6 × water depth in shallow water. The diversion discharge was the volume of screened water going to the hatchery, and the bypass flow was the water returning fish and debris back to the stream. We recorded the diversion flow, and the sweeping velocity, approach velocity, and depth relative to the inflow and weir wall height.

Biological assessments.—To assess the biological performance of the Herman Creek screen, we experimentally released groups of juvenile coho salmon *O. kisutch* over the screen under various hydraulic conditions (as determined above) and quantified any injuries to the integument and documented short-term delayed mortality. Our test fish were from the Oxbow Hatchery, and we evaluated two size groups, large (85–145 mm fork length) and small (54–78 mm), in two separate sets of trials from 17 February to 20 May 2009. Prior to testing, fish were netted from their hatchery rearing ponds, examined for trauma or abnormalities (e.g., body deformities, missing fins, >20% descaling, etc.), and healthy fish were divided into groups that were held separately for up to a week in net pens placed within a large hatchery pond. On the day of testing, the hydraulic conditions for the screen were set, and several samples of 8–10 fish each were removed from the net pens and placed in 19-L buckets that received a constant inflow of river water. Groups impartially selected to pass over the screen (treatment fish) were released 1–2 m upstream of the upper edge of the screen and recaptured in a sanctuary net (45 cm wide, 35 cm long, and 100 cm deep with 0.3-cm nylon mesh) positioned beneath the bypass outfall. Groups selected as control fish were released directly into the sanctuary net and held for 2 min to simulate the time it took most groups of treatment fish to pass over the screen. After each test, the cod end of the sanctuary net containing the recaptured fish was quickly lifted and immersed in a bucket containing a lethal

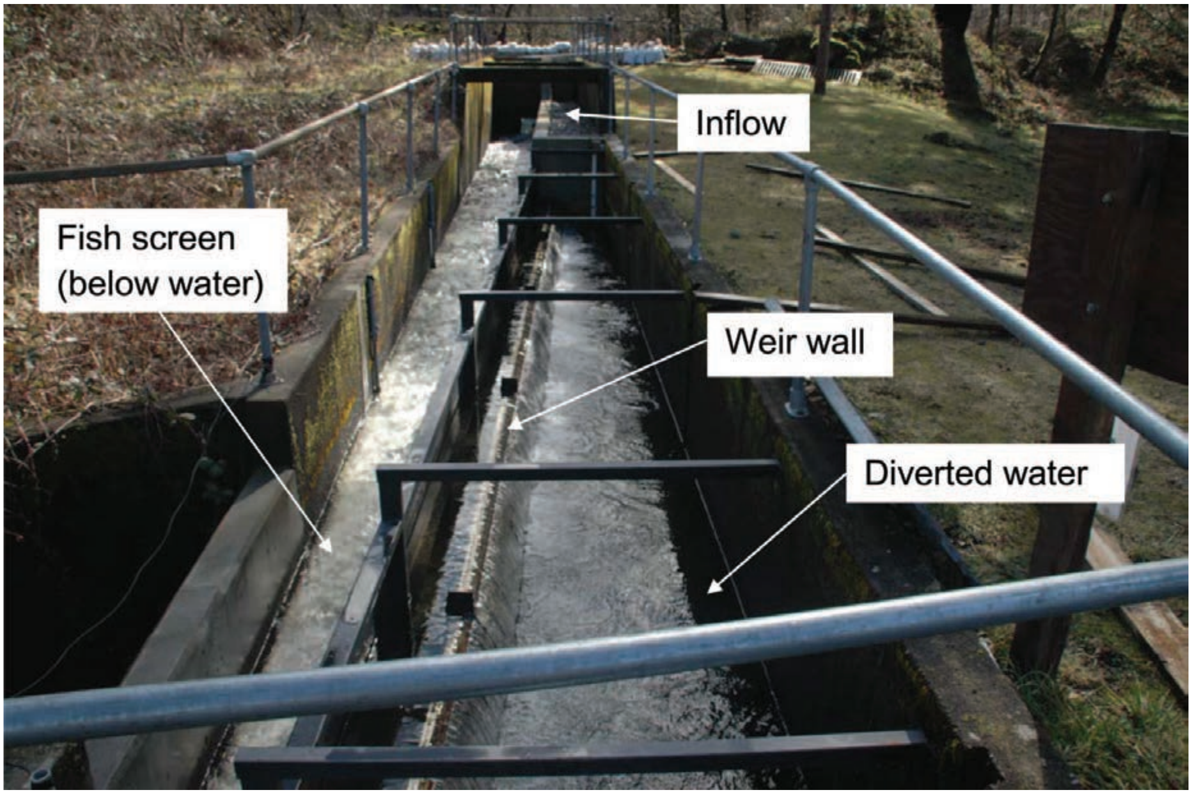


FIGURE 3. Photograph of the Herman Creek Screen, looking upstream, at the Oxbow Fish Hatchery, Cascade Locks, Oregon. Photograph by Brien P. Rose. [Figure available in color online.]

dose of MS-222 at 200 mg/L of water. Tests were conducted during daylight hours and water temperatures of 5–7°C.

We used a fluorescein dye method described by Noga and Udomkusonsri (2002) to determine the extent of ulceration on the skin, eyes, and fins of each fish. After fish were euthanized, they were rinsed in a freshwater bath for 1 min and then placed in a solution of fluorescein dye (fluorescein disodium salt at 200 mg/L). After 6 min, fish were removed from the dye and rinsed in three separate freshwater baths over 3 min to remove excess dye. Images were taken of both sides of each fish in a dark box under ultraviolet (UV) light using a digital camera with a 200-mm macro lens. The UV lights were placed at 45° angles to the side of the fish, and a yellow barrier filter was used to eliminate the blue auto-fluorescence. Images were imported into Adobe Photoshop CS3, and the body surface area and area of fluorescence were measured on each side of a fish. The percentage of body surface area of a fish that was injured was derived by dividing the total area of fluorescence by the total body surface area. This included the two sides and most, but not all, of the dorsal and ventral surfaces of the fish. For each release group, we compared the median percentage of body surface area that was injured between control and treatment fish using Mann–Whitney *U*-tests.

To assess delayed mortality after passage, additional fish were released in the same manner as described above but were transferred to 76-L holding tanks adjacent to the screen after being collected in the bypass outfall. The tanks received flow-through water from Herman Creek via a pump submerged in a nearby hatchery pond. Fish were monitored for 24–48 h after passage, and the number of fish that died was tallied for treatment and control groups. Mortality tests were conducted for most, but not all, of the same hydraulic conditions as injury tests.

Behavior of fish at the leading edge of a screen.—To evaluate whether fish would refuse to pass over a small Farmers Screen after encountering the leading edge, we constructed a 34-m wooden flume (46 cm wide × 36 cm deep) and connected it to a 3.1-m-long modular section of a Farmers Screen. The modular Farmers Screen is a prefabricated, 3.0-m-long section of screen designed for inflows ranging from 0.01 to 0.42 m^3/s (0.5–15 ft^3/s) that requires minimal site preparation, is easy to transport, and can be installed at remote locations. The purpose of the flume was to provide fish with plenty of distance between their release point (at the upstream end of the flume) and the upstream edge of the screen so they could orient themselves and move downstream somewhat naturally. The flume received water from the outflow of the Herman Creek screen and was designed so that water velocities were slower in the upstream half of the flume than in the downstream half. We installed a trap on the downstream end of the screen to capture the fish.

We used yearling coho salmon (113–161 mm) from the Oxbow Hatchery and Skamania steelhead (anadromous rainbow trout; 134–260 mm) from the Bonneville Fish Hatchery (Oregon) for these tests. All the fish were large and silvery with faint or nonexistent parr marks; they normally would have been released from the hatcheries during mid April to early May. Prior to testing, all fish were held in large tanks at the Oxbow Hatchery and water temperatures during holding and testing ranged from 6–9°C.

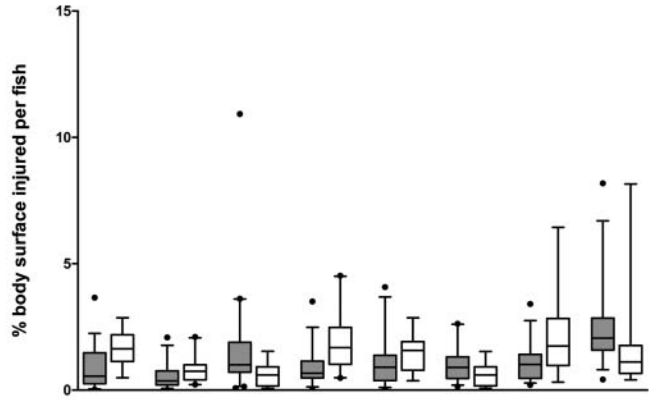
Prior to releasing fish, we first established the hydraulic conditions for the test, as described above, and also measured water velocities and depths at several locations throughout the flume. Our intent was to test fish under various hydraulic conditions over the screen, similar to those that we tested at the Herman Creek screen. We then removed 7–10 fish from their holding tank, placed them in a 19-L bucket with water, transported them from the hatchery to the test facility (about 2 km), and gently released them at the upstream end of the flume. Fish were allowed 20 min to volitionally migrate down the flume and pass over the screen. After 20 min, we gently prodded any fish that remained in the upper 3 m of the flume until they moved downstream. Under the various hydraulic conditions, we conducted three to four releases of 7–10 fish each, for a total release of 20–40 fish for each species.

An observer was stationed on an elevated platform slightly upstream of the fish screen to record the behavior and passage timing of fish as they approached the screen. For each of five consecutive 5-min periods, we recorded the number of fish that encountered the screen and whether the fish passed over the screen or refused to (e.g., the fish turned and swam back upstream). For analysis, we pooled data from the release groups for each species and hydraulic conditions and determined the cumulative proportions of fish that passed over or rejected the screen for each 5-min period.

RESULTS

Hydraulic Assessments

Inflows established at the Herman Creek screen ranged from 0.02 to 0.42 m^3/s, depending on water depth (Table 1). Diversion discharges ranged from 0.02 to 0.34 m^3/s, comprised 65–100% of the inflow rates, and were always higher than bypass flows. Mean approach velocities estimated for the entire screen ranged from 0 to 5 cm/s and never exceeded 6 cm/s for individual sections of the screen. Mean sweeping velocities ranged from 36 to 178 cm/s and were faster at the upstream edge and slower at the downstream edge of the screening panels. Mean sweeping velocities were at least 32 times higher than approach velocities for all conditions tested. The mean water depth ranged from 1 to 25 cm and generally was deeper at the upstream end of the screen than at the downstream end (Table 1). Hot spots (i.e., localized areas of high approach velocity with spiraling flow) were not observed during any of our tests.



Water depth	7	11	12	14	16	18	22	24
Sweeping velocity	137	161	115	72	87	101	161	171
Approach velocity	4	3	3	2	2	2	5	5
N tmt	37	38	41	39	40	38	38	39
N cont	17	20	15	20	20	15	14	15

FIGURE 4. Box plots of percent body surface area injured for large (85–145 mm) juvenile coho salmon released over the Herman Creek screen (grey boxes) under different hydraulic conditions relative to control fish (white boxes). The upper and lower boundaries of the box represent the 25th and 75th quartiles, the horizontal line inside the box is the mean, the whiskers represent the 5% and 95% confidence intervals, and outliers are shown by solid points. The *x*-axis shows the water depth over the screen (cm), the mean sweeping velocity (cm/s), the approach velocity (cm/s), and the number of treatment (tmt) and control (cont) fish tested during each trial. Differences between medians within a group were significant for all tests (Mann–Whitney *U*-tests, $P < 0.05$).

Biological Assessments

Overall, the injury rates of fish after passage over the Herman Creek screen were low, and severe injuries to the skin, eyes, and fins of both size cohorts were not observed. For large fish, the percentage of body surface area that was injured varied by release group and ranged from about 0.5% to 2.5% (Figure 4). Median values were significantly different between treatment and control fish for all test conditions (Mann–Whitney *U*-tests: $P < 0.05$; Figure 4), but the magnitude of these differences was small (<1%). For small fish, the percentage of body surface area that was injured ranged from about 0.4% to 3.0% (Figure 5). The medians for treatment and control fish differed significantly for three test conditions (Figure 5), but again, the magnitude of these differences was small (<1%). For delayed mortality after passage, we tested 849 fish in total; no treatment fish died within 24–48 h of passage, and only one control fish died.

Behavior of Fish at the Leading Edge of a Screen

To evaluate the behavioral responses of juvenile salmonids approaching and passing over a modular Farmers Screen, we released a total of 173 coho salmon and 102 steelhead under various hydraulic conditions (Table 2). In the flume, mean water velocities ranged from 60 to 79 cm/s in the upstream half and from 85 to 104 cm/s in the downstream half. Mean water depths

TABLE 1. Summary of hydraulic conditions measured at the Herman Creek screen, February through May 2009. Single asterisks denote the hydraulic conditions under which fish were released for injury tests only, double asterisks those for injury and delayed mortality tests; NA = not available.

Inflow (m^3/s)	Diversion (m^3/s)	Bypass discharge (m^3/s)	Mean (SD) sweeping velocity (cm/s)	Approach velocity (cm/s)	Mean (SD) depth over screen (cm)
			Weir wall height: 4 cm		
0.10	0.10	0.00	67 (34)	1	7 (1)
0.14*	0.13	0.01	87 (41)	2	7 (1)
0.15**	0.14	0.01	120 (50)	2	9 (1)
0.26	0.23	0.03	166 (52)	3	12 (1)
0.27**	0.25	0.02	137 (49)	4	11 (3)
0.29	0.26	0.02	138 (73)	4	10 (1)
0.31	0.28	0.02	130 (46)	4	12 (2)
0.34**	0.31	0.03	173 (45)	5	12 (1)
0.36**	0.33	0.03	171 (41)	5	12 (1)
			Weir wall height: 11 cm		
0.14*	0.11	0.03	101 (30)	2	14 (1)
0.15**	0.12	0.03	106 (30)	2	14 (1)
0.29*	0.23	0.05	161 (23)	3	16 (2)
0.29**	0.23	0.06	143 (30)	3	16 (1)
0.34**	0.26	0.08	178 (32)	4	19 (1)
0.42**	0.34	0.07	161 (30)	5	18 (1)
			Weir wall height: 13 cm		
0.10	0.09	0.02	61 (20)	1	14 (0)
0.20	0.13	0.07	170 (36)	2	16 (2)
0.31	0.24	0.06	127 (25)	4	20 (1)
			Weir wall height: 20 cm		
0.02	0.02	0.00	NA	0	1 (1)
0.04	0.03	0.01	36 (15)	0	8 (0)
0.15*	0.10	0.05	72 (12)	2	22 (1)
0.15**	0.10	0.05	73 (12)	2	23 (0)
0.27**	0.20	0.07	100 (15)	3	25 (1)
0.28**	0.22	0.06	115 (17)	3	24 (1)
0.29	0.21	0.08	101 (25)	3	25 (1)

TABLE 2. The number of coho salmon and steelhead released (*N*) over the modular Farmers Screen in 2010, and the cumulative percentage of fish that successfully passed over the screen in consecutive 5-min periods. After 20 min had passed the remaining fish were coerced from the upper 3 m of the flume; only one steelhead refused to pass over the screen initially but eventually did so within 10 min.

					Percent of fish passing over screen				
Inflow discharge (m^3/s)	Depth (cm)	Approach velocity (cm/s)	Sweeping velocity (cm/s)	*N*	5 min	10 min	15 min	20 min	>20 min
			Coho salmon						
0.06	15 (1)	2	111 (6)	40	91	91	91	91	9
0.09	15 (1)	3	150 (8)	20	75	85	95	95	5
0.09	19 (1)	2	132 (7)	33	82	82	82	82	18
0.07	20 (0)	1	102 (10)	40	88	88	88	88	12
0.08	25 (1)	1	102 (13)	40	95	98	98	98	2
			Steelhead						
0.06	15 (1)	2	111 (6)	40	90	93	93	93	7
0.09	15 (1)	3	150 (8)	22	62	67	67	96	4
0.08	25 (1)	1	102 (13)	40	47	59	59	80	20

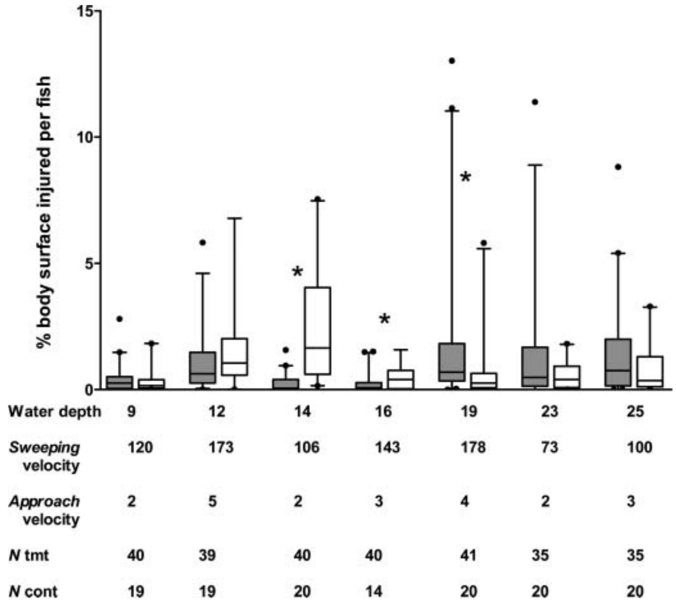


FIGURE 5. Box plots of percent body surface area injured for small (54–78 mm) juvenile coho salmon released over the Herman Creek screen (grey boxes) under different hydraulic conditions relative to control fish (white boxes). Box plot descriptions and *x*-axis labels are as defined in the caption for Figure 4. Differences between medians within a group are denoted by an asterisk (Mann–Whitney *U*-tests, $P < 0.05$).

in the flume ranged from 23 to 31 cm. For coho salmon, 75–95% of the fish approached and passed over the screen within 5 min of their release, depending on hydraulic conditions (Table 2). Within 20 min, the percentages of fish passing over the screen increased to 82–98%. After 20 min, 3–18% of the fish (12 total) remained upstream in the flume and were gently prodded to move downstream; all of these fish passed over the screen without delay.

For steelhead, 47–90% of the fish approached and passed over the screen within 5 min of their release, again depending on hydraulic conditions (Table 2). Within 20 min, the percentages of fish passing over the screen increased to 79–95%. After 20 min, 5–21% of the fish (11 total) were coerced downstream from the upper 3 m of the flume, and one fish turned and swam back upstream after it encountered the edge of the screen. However, this fish returned to the screen within 10 min and successfully passed. Overall, 99.6% of the fish we observed passed over the screen without delay.

DISCUSSION

The Farmers Screen is a unique type of horizontal flat-plate fish screen that may offer substantial benefits to irrigators and fish alike. Although there are several Farmers Screens currently operating in the Pacific Northwest, they have not received enough biological testing to evaluate their potential impacts on fish. As such, these screens are still considered experimental technology by the National Marine Fisheries Service (NMFS) and considerable debate has ensued regarding their hydraulic and biological criteria and operation. Our results indicate that passage of juvenile coho salmon over the Herman Creek screen under various hydraulic conditions did not severely injure them, cause delayed mortality, or delay migration. These results occurred even though most fish passed over the screen near the screen surface, many contacted the screen during passage, and fish were oriented to the current in various directions (based on video observations by us; data not shown here). However, we did not observe fish becoming impinged on the screen surface (i.e., >1 s contact with the screen). We also never had problems with debris loading on the screen, although our tests were done at times when the amount of debris was sparse. Our results were similar to those of Rose et al. (2008), who reported minimal injuries and low mortality of rainbow trout (45–250 mm) after passage over backwatered and inverted-weir horizontal flat-plate screens in Oregon. Rose et al. (2008) evaluated ranges of sweeping (15–143 cm/s) and approach (1–8 cm/s) velocities that were similar to ours. Other studies evaluated various designs of vertically oriented screens and reported results similar to ours for juvenile splittail *Pogonichthys macrolepidotus* (mean length of about 6 cm; Danley et al. 2002), bull trout (median length, 25 mm; Zydlewski and Johnson 2002), and juvenile Chinook salmon *O. tshawytscha* (4.4–7.9 cm; Swanson et al. 2004).

The injuries observed in our fish among both treatment and control groups were minor and indicate that fish had some trauma to the integument prior to testing and that our holding and handling procedures probably caused slightly more trauma. Compared with visual observations and quantification (see Rose et al. 2008), the fluorescein dye method was effective for detecting injuries to the integument of fish and revealed that all fish had some level of injury after testing. Again, however, all injuries were minor and any differences in injury rates between treatment and control groups were small, which makes it difficult to ascribe any biological significance to the injuries we observed. Further, and perhaps more importantly, none of our injury results would have exceeded the criteria for safe passage of fish over conventional screen systems, as established by NMFS (2008). For example, criteria specify a less than 0.5% mortality and 2% injury rate (i.e., the percentage of a sample that is injured) for salmonid smolts and that at least 90% of salmonids that encounter a screened water diversion should be bypassed within 24 h (Bryan Nordlund, NMFS, personal communication). The agency defines injury as visual trauma (including, but not limited to, hemorrhaging, open wounds without fungal growth, gill damage, bruising >0.5 cm in diameter), loss of equilibrium, or greater than 20% descaling on one side (Bryan Nordlund, NMFS, personal communication). Because none of our fish showed such injuries, mortality was less than 0.5% and most fish traveled over the screen without delay, the Herman Creek screen would easily surpass these NMFS standards. Although the criteria discussed here are for other types of screens, they do indicate that screens like the one at Herman Creek probably would, at a minimum, meet federal regulatory standards.

The ability of the Herman Creek screen to safely and efficiently pass fish at water depths ranging from 7 to 25 cm was largely due to achieving a high ratio of sweeping velocity to approach velocity (range = 30:1 to 54:1) under various hydraulic conditions. These ratios were substantially higher than initial recommendations for sweeping velocity established by NMFS for horizontal screens, which only suggest that downstream sweeping velocities be higher than approach velocities for the entire length of the screen (NMFS 2008). The combination of high sweeping velocities and low approach velocities facilitated quick downstream fish passage and eliminated impingements, which was similar to the results of Beyers and Bestgen (2001). That most fish passed over the screen near the screen surface, regardless of water depth, indicates that the 30-cm water depth recommendation established for horizontal screens (NMFS 2008) could be relaxed for smaller screens like the one at Herman Creek. Although fish safely passed over the screen at a depth of only 7 cm, the number of screen contacts per fish increased at this shallow depth for large (85–145 mm) but not small (54–78 mm) fish (based on video data not shown here). Even though the screen contact rate was not related to the extent or severity of injuries, operating the screen at water depths near 7 cm seems too shallow, particularly under high-flow conditions. Thus, although our results suggest that the Herman Creek screen can be operated effectively at water depths less than 30 cm, we cannot unequivocally recommend a single, specific minimum depth for this screen. Rather, a range of minimum depths, perhaps from 15 to 20 cm, would probably provide safe passage of fish under most circumstances.

Despite the success of the Herman Creek screen in safely and effectively passing fish, there are some things to consider when interpreting our results. First, we were unable to evaluate all possible hydraulic conditions on screen performance, fish injury, and mortality. Although we believe our evaluations were realistic because they encompassed typical diversion conditions, there may be other flow conditions we missed that are relevant to fish passage and safety. Second, we only tested two species of fish and our results may not be applicable to other species. The fishes used in our tests were probably good surrogates for other salmonids of similar size, but extrapolation of our results to other fishes, such as juvenile lampreys or endangered suckers in the Klamath Basin, seems inappropriate and would require further testing. Finally, we evaluated only the effects of downstream passage on juvenile fish. Further testing would be required to assess the effects of this screen type on fish migrating upstream across the screen surface, although such behavior would probably be rare.

The purpose of evaluating the reactions of fish approaching a Farmers Screen was to determine whether fish would reject or refuse to pass over the screen after encountering its leading edge, a notion that was a concern to fishery managers and something we did not evaluate specifically at the Herman Creek screen. The concern was related to the changing hydraulic conditions at the flume-screen interface and whether fish would sense this change, turn around, and refuse to pass. Extended delays in passage over the screen could lead to excessive energy use in fish and violation of the NMFS standard that fish must be bypassed within 24 h. Our results, however, clearly indicate that the flume–screen interface was not an obstacle to passage for fish moving volitionally downstream because high percentages of fish passed within 20 min. Even the small number of fish we had to manually coerce to move downstream readily passed over the flume–screen interface. We cannot state whether all fish encountering and passing through small versions of the Farmers Screen would be bypassed within 24 h because none of our tests were designed to answer this question. However, we think the possibility of fish not passing over these screens within 24 h is remote.

MANAGEMENT RECOMMENDATIONS

When provided with an adequate inflow and configured to maintain a water depth of near 10 cm, the Herman Creek screen provided safe and effective downstream passage of juvenile coho salmon under a variety of hydraulic conditions. As such, given proper site conditions, the Farmers Screen may offer a useful alternative to irrigators, fisheries agencies, and others contemplating a fish screen installation. With their off-channel installation, no moving parts, the potential for good self-cleaning ability, and safe and effective passage of juvenile salmonids under a variety of conditions, the Farmers Screen would appear to be a welcome addition to the arsenal of fish screening devices currently available. However, to achieve the full benefits of the Farmers Screen, they must be operated within their design criteria. This stipulation cannot be emphasized enough because these screens, like all horizontal flat-plate screens, can completely dewater under certain aberrant conditions, which could leave fish stranded on the screen surface. This is a problem unique to horizontal screens and requires that operators pay close attention to design criteria, particularly inflow rates, water depth over the screen, and sweeping velocity to approach velocity ratios. For example, we would not recommend operating the Herman Creek screen at inflows less than about 0.14 m^3/s (about half of what it was designed for) because water depth can become quite shallow if the weir wall is not fully sealed or the screen can completely dewater, particularly at very low flows. If the screen is operated at inflows near or slightly less than 0.14 m^3/s, caution must be used to avoid diverting an excessive amount of water, which can lead to shallow depths, insufficient bypass flow, and perhaps screen dewatering. In the end, however, a complete dewatering of the Farmers Screen would require significant deviations from design, installation, or operating criteria and can be easily avoided. Finally, for the Herman Creek screen, we do not know the fate of fish that pass over the screen, enter the bypass channel, and are diverted back to the Columbia River. It is possible that passage through these areas is a stressful and disorienting event for fish, which could make them vulnerable to hazards that exist downstream, such as predation by fish or birds. This idea is not unique to the Herman Creek screen, but is relevant for many types of diversions and obstacles fish may encounter in the wild. Further research would be necessary to address this issue.

ACKNOWLEDGMENTS

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REFERENCES

Beyers, D. W., and K. R. Bestgen. 2001. Bull trout performance in a horizontal flat plate screen. Final report to the U. S. Bureau of Reclamation, Water Resources Research Group, Denver.

Danley, M. L., S. D. Mayr, P. S. Young, and J. J. Cech. 2002. Swimming performance and physiological stress responses of split tail exposed to a fish screen. North American Journal of Fisheries Management 22:1241–1249.

Frizell, K., and B. Mefford. 2001. Hydraulic performance of a horizontal flat plate screen. Final report to the U. S. Bureau of Reclamation, Water Resources Research Group, Denver.

Gallagher, A. S., and N. J. Stevenson. 1999. Streamflow. Pages 149–157 *in* M. B. Bain and N. J. Stevenson, editors. Aquatic habitat assessment: common methods. American Fisheries Society, Bethesda, Maryland.

McMichael, G. A., J. A. Vucelick, C. S. Albernathy, and D. A. Neitzel. 2004. Comparing fish screen performance to physical design criteria. Fisheries 29(7):10–16.

Moyle, P. B., and J. A. Israel. 2005. Untested assumptions: effectiveness of screening diversions for conservation of fish populations. Fisheries 30(5):20–28.

NMFS (National Marine Fisheries Service). 2008. Anadromous salmonid passage facility design. NMFS, Northwest Region, Portland, Oregon.

Noga, E. J., and P. Udomkusonsri. 2002. Fluorescein: a rapid, sensitive, nonlethal method for detecting skin ulceration in fish. Veterinary Pathology 39:726–731.

Rose, B. P., M. G. Mesa, and G. B. Zydlewski. 2008. Field-based evaluations of horizontal flat plate fish screens. North American Journal of Fisheries Management 28:1702–1713.

Swanson, C., P. S. Young, and J. J. Cech Jr. 2004. Swimming in two-vector flows: performance and behavior of juvenile Chinook salmon near a simulated screened water diversion. Transactions of the American Fisheries Society 133:265–278.

Zydlewski, G. B., and J. R. Johnson. 2002. Response of bull trout fry to four types of water diversion screens. North American Journal of Fisheries Management 22:1276–1282.