RESOURCE SOLUTIONS FOR RURAL COMMUNITIES

office 14 oak street, suite 302 . hood river . oregon . 97031 telephone 541.716.6085 website www.fcasolutions.org

fca

Bruce Suzumoto
Assistant Regional Administrator, Hydropower Division
National Marine Fisheries Service
1201 NE Lloyd Boulevard, Suite 1100
Portland, OR 97232-1274

Re: FCA Response to NMFS letter dated September 3, 2009

September 25, 2009

Dear Mr. Suzumoto:

The following document is Farmers Conservation Alliance's (FCA's) response to a letter provided by National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) on September 3, 2009. Both the response and NMFS' letter are in regards to FCA's request to amend the Farmers Screen criteria as well as accept the Farmers Screen as a NOAA Approved Technology.

For simplicity, FCA has copied the NMFS letter into this document and provided responses to each of the statements made therein. FCA has also provided this cover letter as a summary of our response.

FCA's Request

First Request: Through the information and studies already provided to NMFS, as well as the joint FCA/NMFS/USGS (U.S. Geological Survey) meeting on July 20, 2009, FCA has refined our request for Farmers Screen criteria changes to include:

- Change water depth to a minimum of 6 inches for Farmers Screen installations 0-20 cfs
- For screens larger than 20 cfs, FCA requests the criteria remain at the current 12 inch minimum water depth

FCA made the request for change of water depth on the smaller screens because current Farmers Screen criteria is based on the first, and very large (65 cfs), Farmers Screen installation in 2002. Since this time, FCA has installed 17 Farmers Screens in a variety of sizes, conditions, and locations. It was through these installations that FCA and Oregon Department of Fish and Wildlife passage engineers realized that the smaller screens tended to have higher sweeping velocities with water depths below 12 inches and, therefore, provided improved debris handling. By lowering the bypass flow to 6 inches, optimal sweeping velocity and approach velocities are achieved (a maximum of .25 feet/per/second (fps) for approach velocity and a minimum of 4 feet/per/second sweeping velocity).

These statements are supported by the recent research performed by Matt Mesa, Brien P.Rose, and Elizabeth S. Copeland of USGS and summarized in the document titled "Biological Evaluations of an Off-Stream Channel, Horizontal Flat-Plate Fish Screen—The Farmers Screen". The study states, "The ability of the Herman Creek screen to safely pass fish—at water depths ranging from 7-25 cm (3-10 inches)—was largely due to achieving a high ratio of SV to AV under a variety of diversion scenarios. The ratios of high sweeping velocity to approach velocity in our study ranged from about 30:1 to 60:1, which are substantially higher than the 2:1 sweeping velocity to approach velocity criteria established by NOAA-Fisheries for passive screens. The combination of high sweeping velocities and low approach velocities facilitated quick fish passage, eliminated impingements, and resulted in good self-cleaning. That most fish passed over the screen near the screen surface – regardless of water depth – suggests that water depth criteria previously established for larger versions of the Farmers Screen (i.e., 30 cm or 12 inches) could be relaxed for smaller screens like the one at Herman Creek." Hydraulic data from the study confirms improved sweeping velocity to approach velocity ratios at shallower depths."

Second Request: After working through NMFS Experimental Technology process for twelve years (first through the Farmers Irrigation District and now through FCA), FCA requests the Farmers Screen, at both the 6 inch and 12 inch water depths, be accepted as a NOAA Approved Technology.

Next Steps

Within the NMFS letter from September 3, 2009, recommendations were listed for a path forward. Stating specifically, "Our recommendation is that the current FCA criteria screens remain in experimental technology status until:…." Below are the NMFS recommendations as well as the FCA response to each:

1. **NMFS Recommendation:** Egress times for smolts placed in the canal are improved that such that 75 percent or more of the test fish released upstream of the screen volitionally exit the bypass within 24 hours, for the entire range of hydraulic conditions that could exist as a prototype screen site.

   FCA Response: While egress is a valid concern, the proposed testing would apply to all off-channel screen types, not just the Farmers Screen. As with any off-channel screen type, the diversion structure, the headgate type and configuration, the type and length of the conveyance to the screen, and the type and length of by-pass are site specific and vary greatly.

   As stated in Section 17.4.5 (Process for Developing Experimental Fish Passage Technology) of the Anadromous Salmonid Passage Facility Design published in 2007 by National Marine Fisheries Service, Northwest Region, "Results of both laboratory and field prototype evaluations must demonstrate a level of performance equal to or exceeding that of conventional fish passage devices before NOAA Fisheries will support permanent installations." FCA and collaborating agency partners have been unable to locate examples of the proposed testing for other off-channel screen technologies (other than testing at large facilities associated with a hydro-power project) with which the results of Farmers Screen testing could be compared to current technologies. Therefore, we feel the Farmers Screen is being held to a higher standard than other technologies.

However, what can be stated is that the sweeping velocities associated with the Farmers Screen are much higher than conventional technologies with a correlating lower approach velocity and, therefore, it is unlikely that the Farmers Screen would not perform at least as well as conventional technologies.

2. **NMFS Recommendation:** Debris testing should also be conducted to support the FCA assertion that cleaning can be accomplished with lower screen depths.

   FCA Response: Regardless of a 6 inch or 12 inch water depth, approach velocity and sweeping velocity are still meeting criteria requirements. This is supported by the USGS study statement, "The screen showed good self-cleaning performance and never had problems with debris loading." The hydraulic data gathered during the testing shows a very high ratio of sweeping velocity to approach velocity (30:1 to 60:1) throughout the range of water depths. In addition, hydraulic data from other Farmers Screen installations as well as observations by both FCA staff and agency representatives supports FCA's assertion as to the cleaning capabilities of the Farmers Screen at shallower depths when the screen is operating under heavy debris and sediment loads.

   Furthermore, it is unclear as to how one would quantify results regarding debris load testing. There are issues associated with releasing sediment into a diversion where it can affect downstream water quality.

3. **NMFS Recommendation:** The Fish Screen Oversight Committee (including NMFS) agrees that the current design criteria for FCA screens are acceptable for inclusion in regional juvenile fish screen criteria.

   FCA Response: FCA appreciates the consideration of the Fish Screen Oversight Committee (including NMFS) to determine Farmers Screen criteria. FCA hopes the FSOC committee will consider both 12 inches and 6 inches of bypass flow to be included in this criteria.

Conclusion

FCA understands that dealing with new technologies can be very difficult and time consuming for all involved. Unlike the standard protocols for currently used technologies, new installation, operations, systems, and habits must be developed. However, opportunities must be made available to test and refine the process of a new technology's parameters in order for the technology to succeed. Such is the case with the Farmers Screen. Through 17 installations, 6 biological and hydraulic tests, extensive post-installation monitoring, and commitment to ensure projects succeed, FCA has learned what makes a Farmers Screen project successful and what does not.

As with all screen technologies, a few Farmers Screen projects have had problems. However, the vast majority have operated as expected. Yet, it is the challenging projects that have allowed FCA and other project partners to learn the most about optimal Farmers Screen processes, site selection, screen operation, and technology performance. Having an open forum to share these lessons learned, and provide opportunities for improvement, is what will allow the Farmers Screen to succeed.

FCA appreciates the time NMFS has already taken to review our previous and current documentation. However, based upon this response to the NMFS September 3, 2009 letter, the full USGS study (as opposed to the draft executive summary cited in the NMFS letter), and clarification of actual events at the Lower Widows Creek Site, FCA expects that the issues raised by NMFS will be addressed and resolved..

FCA requests that this clarifying information be used for re-consideration of our request for change of water depth and for the Farmers Screen to be a NOAA Approved Technology.

If you have additional questions or clarification is needed, please feel free to contact Les Perkins at les.perkins@fcasolutions.org or Julie O'Shea at julie.oshea@fcasolutions.org. You can also reach us by phone at 541.716.6085. We appreciate your time and consideration.

Sincerely,

Julie O'Shea

Julie Davies O'Shea	Les Perkins
Executive Director	Business Development Director
Farmers Conservation Alliance	Farmers Conservation Alliance

Enclosures.

Bryan Nordlund, NMFS, Fish Screen Oversight Committee Chair
Dave Ward, Fish Screen Oversight Committee
Ray Hartlerode, Oregon Department of Fish and Wildlife
Matt Mesa, U.S. Geological Survey
Mary Gautreaux, Office of Senator Ron Wyden

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

September 3, 2009

Les Perkins
Farmers Conservation Alliance
14 Oak Street, Suite 302
Hood River, Oregon 97031

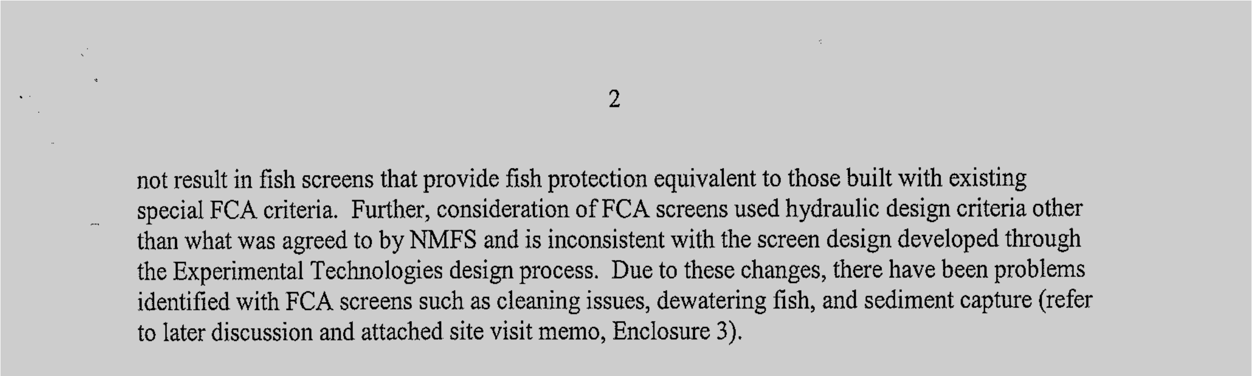
Re: Assessment of status of Farmers Conservation Alliance (FCA) Horizontal Screens as an Experimental Fish passage Technology

Dear Mr. Perkins:

In recent meetings and through correspondence with National Marine Fisheries Service (NMFS) staff, the FCA has requested assessment of the FCA screen as "conventional" fish passage technology. FCA has provided several documents for our consideration. The documents include; 1) undated document entitled The History and Development of the Farmers Screen, 2) an executive summary of a study conducted in 2009 by Matt Mesa and Liz Copeland of the United States Geological Survey (USGS), 3) some proposed criteria changes via e-mail and enclosed to this letter (Enclosure 1). We previously reviewed and responded by letter to the document entitled The History and Development of the Farmers Screen. This letter provides the results of our review of the executive summary and Enclosure 1. Our comments follow.

Acceptance of FCA screens as conventional technology
FCA request: A statement was made in a previous FCA submittal regarding the desire for a global approval letter for FCA screens similar to the one written for approval of the Intralox screen mesh.

NMFS reply: A key difference in these two situations is that Intralox Corporation developed a product that achieved criteria known to provide protection for fish. In contrast, FCA has developed a product that was outside known criteria that protect fish. In particular, the non-automated cleaning or cleaning through passive hydraulic action (a feature of the FCA screen), has caused fish to be killed and compromised screen protection at numerous sites throughout the Northwest. FCA seemed to have a good idea (based on boundary layer theory and demonstrated mathematically) that given the right combination of hydraulics on a horizontal screen, cleaning could be achieved through hydraulic action. This was further demonstrated in prototype construction, hydraulic lab study and in the Davenport Screen Facility installation, the initial horizontal screen constructed to special fish screen criteria (Enclosure 2, special criteria for FCA screens) collaboratively developed between many parties with considerable time and funding commitments from the Federal government. FCA's proposal to revise the collaboratively developed criteria would mean a repeat of this effort and expense, and, in our perspective, would



not result in fish screens that provide fish protection equivalent to those built with existing special FCA criteria. Further, consideration of FCA screens used hydraulic design criteria other than what was agreed to by NMFS and is inconsistent with the screen design developed through the Experimental Technologies design process. Due to these changes, there have been problems identified with FCA screens such as cleaning issues, dewatering fish, and sediment capture (refer to later discussion and attached site visit memo, Enclosure 3).

FCA Response:

FCA request for global approval letter:

During the July 20, 2009 meeting at the Portland NOAA Fisheries office, the nature of this request was clarified by FCA staff to NMFS staff. FCA did not expect nor request a global approval letter. FCA further clarified that the request for a letter similar to the Intralox letter was to be taken off the table.

> **"In particular, the non-automated cleaning or cleaning through passive hydraulic action (a feature of the FCA screen), has caused fish to be killed and comprised screen protection at numerous sites throughout the Northwest."**

There have been two instances of fish kill, one each at two different screen installations. The two installations that have had problems are Lower Widows Creek and Berry Creek. Both sites are located in the John Day basin and were installed in conjunction with the Oregon Department of Fish and Wildlife (ODFW) John Day Screen Shop.

In the case of Berry Creek, an improperly sealed weir wall caused screen de-watering to occur (documentation can be provided upon request). FCA did not fabricate or install the weir wall at Berry Creek. The problem has since been resolved. ODFW poured a solid concrete weir wall. Since this modification, the screen has been working properly—even during low water flows with no instance of fish kill. (This is due to the fact that as flows drop, a larger percentage of flow goes to the by-pass until 100% of flow is going to the by-pass and the approach velocity is 0.)

In the case of Lower Widows Creek, two issues occurred that led to fish being killed. First, the solid weir wall was damaged when ODFW removed it, and upon re-installation was never properly re-sealed. Due to this damage, water flowed under the weir wall making it possible to dewater the screen. Second, the screen was being operated by the multiple landowners with the weir wall flush gate left open continuously which is specifically prohibited in the operation manual (see attachment 1). This information was provided at the landowner owner training and later re-affirmed with the Farmers Screen operation manual. However, several landowners/screen operators were not identified until after operational problems had occurred which may have contributed to the operational issues. These landowners were trained and provided with an operation manual once FCA and ODFW became aware of their ownership.

FCA is currently working with ODFW staff to apply screen modifications to the Lower Widows Creek screen that would resolve both of these issues. Once the weir wall is sealed properly and the flush gate is bolted shut, screen dewatering will no longer occur, and therefore, this Farmers Screen installation will ensure safe fish protection. See FCA's response to Enclosure 3 for further explanation of the screen installations, the project challenges, lessons learned, and the pending changes.

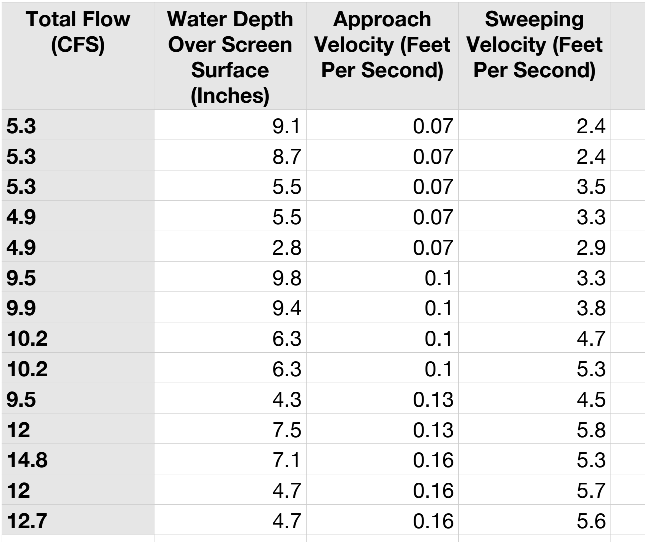
> **“FCA’s proposal to revise the collaboratively developed criteria would mean a repeat of this effort and expense, and in our perspective, would not result in fish screens that provide fish protection equivalent to those built with existing special FCA criteria”**

FCA recognizes the importance of the existing Farmers Screen criteria. After all, this criteria is the foundation for the Farmers Screen’s success. Rather than discard the criteria, FCA is requesting that one change be made to the Farmers Screen criteria: the request is for a minimum of 6 inches of water depth for bypass water on 0-20 cfs screens. Smaller screens work better at depths between 6 and 12 inches. Cleaning dynamics are improved as noted by operators of screens under 20 CFS including ODFW Hatchery Manager Duane Banks at the Herman Creek screen at the Oxbow Hatchery and ODFW Fish Passage Engineer Joel Watts at multiple Farmers Screen installations.

Matt Mesa of the USGS stated (in his testing report titled, “Biological Evaluations of an Off-Stream Channel, Horizontal Flat-Plate Fish Screen-The Farmers Screen”) that,

> *“The ability of the Herman Creek screen to safely pass fish – at water depths ranging from 7 – 25 cm (3 – 10 inches) – was largely due to achieving a high ratio of SV to AV under a variety of diversion scenarios. The ratios of SV to AV in our study ranged from about 30:1 – 60:1, which are substantially higher than the 2:1 SV: AV criteria established by NOAA – Fisheries for passive screens. The combination of high SV’s and low AV’s facilitated quick fish passage, eliminated impingements, and resulted in good self-cleaning. That most fish passed over the screen near the screen surface – regardless of water depth – suggests that water depth criteria previously established for larger versions of the Farmers Screen (i.e., 30 cm or 12 inches) could be relaxed for smaller screens like the one at Herman Creek.”*

Further more, the data regarding depth, sweeping velocity, and approach velocity from the USGS testing supports the request for a shallower depth based on screen hydraulics.



Total Flow (CFS)	Water Depth Over Screen Surface (Inches)	Approach Velocity (Feet Per Second)	Sweeping Velocity (Feet Per Second)
5.3	9.1	0.07	2.4
5.3	8.7	0.07	2.4
5.3	5.5	0.07	3.5
4.9	5.5	0.07	3.3
4.9	2.8	0.07	2.9
9.5	9.8	0.1	3.3
9.9	9.4	0.1	3.8
10.2	6.3	0.1	4.7
10.2	6.3	0.1	5.3
9.5	4.3	0.13	4.5
12	7.5	0.13	5.8
14.8	7.1	0.16	5.3
12	4.7	0.16	5.7
12.7	4.7	0.16	5.6

As the data shows, the best combination of approach velocity and sweeping velocity occur at shallower depths, generally near the 6 inch water depth. This is corroborated by hydraulic data from other small Farmers Screen installations.

This request is based on the continuation of the collaborative process that first made the Farmers Screen a reality. This collaborative process includes: FCA, federal and state agency staff, landowners, The Confederated Tribes of the Warm Springs, Jerry Bryan, Farmers Irrigation District, and USGS researchers. A list of these collaborators and their efforts can be provided upon request.

The current Farmers Screen criteria are based on one screen installation located near Hood River, Oregon. Over the last 10 years of the Farmers Screen's evolution, seven biological and hydraulic tests have been conducted as well as seventeen installations. In addition, current modifications made to the Farmers Screen were the result of working with ODFW engineering staff as well as working with NMFS staff (most recently Larry Swenson and Michelle Day.)

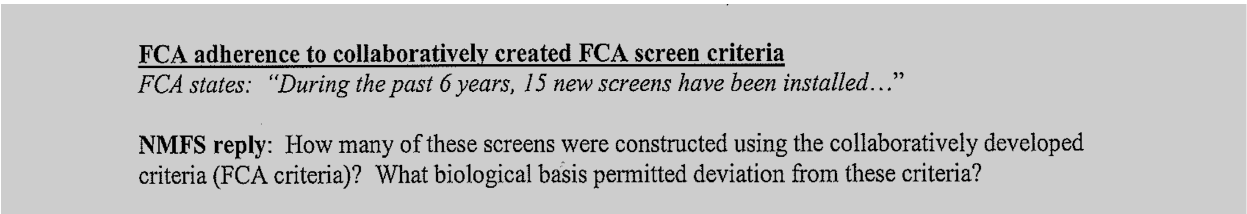
FCA has no interest in discarding the collaboratively developed criteria; rather, FCA is requesting an amendment to the Farmers Screen criteria that reflects the many findings from current screen installations, biological and hydraulic tests, Jerry Bryan's research, and input received from engineers and biologist from both state and federal agencies.

> **"FCA screens used hydraulic design criteria other than what was agreed to by NMFS" and "…inconsistent with the screen design developed through the Experiment Technologies design process."**

All 17 Farmers Screen installations were reviewed by Melissa Jundt, Larry Swenson, or Michelle Day of NMFS or were installed in non-anadromous systems where NMFS does not have jurisdiction. In addition, for all screens installed in Oregon, ODFW fish passage engineers have reviewed and approved projects and observed screen performance after installation. The additional screens installed outside of Oregon went through each state's approval process.

"Due to these changes, there have been problems identified with FCA screens such as cleaning issues, dewatering fish, and sediment capture."

Again, the problems referred to in this statement refer to isolated incidents at two aforementioned screen installations and not the performance of the Farmers Screen overall. In FCA's other 15 screen installations, screens have performed well. ODFW staff has been present to observe many of the other screen installations running under varying water quality and quantity conditions including extremely heavy sediment and organic debris loads.



FCA adherence to collaboratively created FCA screen criteria

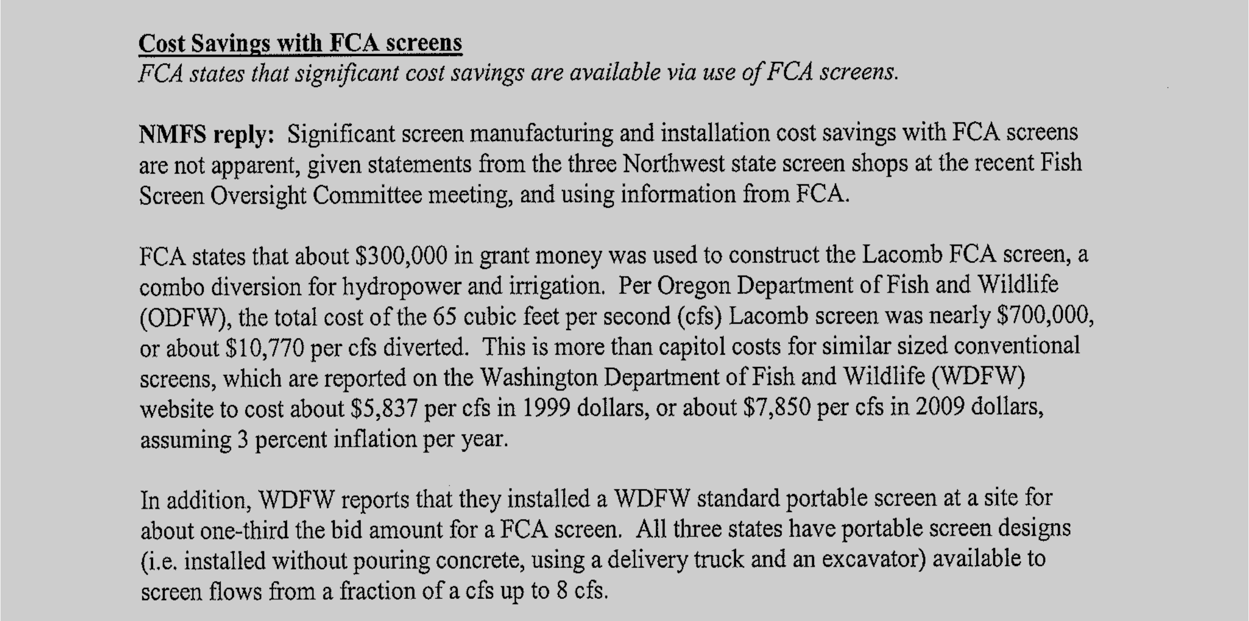
FCA states: "During the past 6 years, 15 new screens have been installed…"

NMFS reply: How many of these screens were constructed using the collaboratively developed criteria (FCA criteria)? What biological basis permitted deviation from these criteria?

FCA Response:
All of the screens were designed using the collaboratively developed criteria. Observations of screen performance at varying depths led to the request for a criteria amendment allowing a shallower operating

depth. In consideration of the request, Larry Swenson and Michelle Day of NMFS requested further biological testing be performed to determine how shallower depths may affect safe fish passage. USGS completed this research and submitted a draft report to NMFS engineer Melissa Jundt for review on August 28, 2009. The USGS biological testing report is meant to provide the biological basis for the requested amendment to that portion of the criteria.

Additionally, the Widows Creek Screens, currently being discussed in this document and more in-depth in Enclosure 3, were approved by NMFS and ODFW staff with knowledge that the screens would be operating at a 6 inch water depth. Documentation of this process can be provided upon request.



Cost Savings with FCA screens

FCA states that significant cost savings are available via use of FCA screens.

NMFS reply: Significant screen manufacturing and installation cost savings with FCA screens are not apparent, given statements from the three Northwest state screen shops at the recent Fish Screen Oversight Committee meeting, and using information from FCA.

FCA states that about $300,000 in grant money was used to construct the Lacomb FCA screen, a combo diversion for hydropower and irrigation. Per Oregon Department of Fish and Wildlife (ODFW), the total cost of the 65 cubic feet per second (cfs) Lacomb screen was nearly $700,000, or about $10,770 per cfs diverted. This is more than capitol costs for similar sized conventional screens, which are reported on the Washington Department of Fish and Wildlife (WDFW) website to cost about $5,837 per cfs in 1999 dollars, or about $7,850 per cfs in 2009 dollars, assuming 3 percent inflation per year.

In addition, WDFW reports that they installed a WDFW standard portable screen at a site for about one-third the bid amount for a FCA screen. All three states have portable screen designs (i.e. installed without pouring concrete, using a delivery truck and an excavator) available to screen flows from a fraction of a cfs up to 8 cfs.

FCA Response:

While lower screen cost is important to widespread screen installation, and therefore fish protection, FCA does not believe this discussion is pertinent to whether or not the Farmers Screen protects fish. However, FCA feels compelled to reply to the comments as they seem to question FCA's integrity.

FCA claims that significant cost savings are available, but does not claim that the Farmers Screen is always the least expensive option available. Screen costs are complicated and site dependent. It is difficult to compare screen project costs without detailed budgets and project information as each project has specific components that can drive up the project costs. There are three great discussions from a NOAA Science and Technology seminar by Darryl Hayes (private consultant), R. Dennis Hudson (U.S. Bureau of Reclamation), and Bernie Kepshire (ODFW) which describe screening costs and their drivers. The WDFW costing document mentioned by NMFS is the basis for R. Dennis Hudson's discussion about screening costs. These documents can be provided upon request.

Darryl Hayes says in his paper titled, "Fish Protection Facility Cost Drivers and Considerations: Why Are Costs All Over the Board": "It can be quite difficult to separate the cost of the screening portion of the project from the total project costs. For example, screen costs may only account for $5,000.00 of a $100,000.00 job. It is not easy to make general estimates that will hold true for a variety of projects."

Bernie Kepshire states in his paper titled, "Oregon Department of Fish and Wildlife Fish Screening Program: Fish Screen Types and Costs":

"Rotary Drum, prefabricated cost per CFS ranged from $3,859.00 to $9,358.00"

The WDFW costing document which NMFS cites gives a range of per CFS costs for conventional technologies of $606.00 to $17,790.00 in 1999 dollars. Using the average of these costs doesn't give a clear picture.

> **"FCA states that about $300,000 in grant money was used to construct the Lacomb Screen…"**

$300,000 in grant money was used for the Lacomb Screen. The remaining $412,000 was paid by Lacomb Irrigation District out-of-pocket. The full project costs are available in grant reports to Fish America Foundation, funded by NOAA Fisheries, ODFW FRIMA grant reports (which do not include grant writing, permitting, or project management and total $565,788.00) as well as in an article published in the Albany Democrat Herald newspaper (August 12, 2008.)

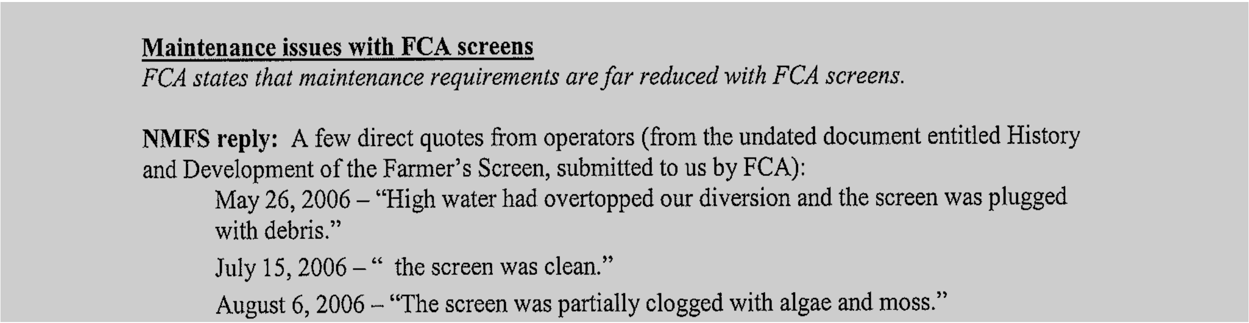
In 2007, because of the construction boom, projects around the Northwest saw big increases in labor and raw materials costs. Since the Lacomb project was built during this cost swell, it had significant cost increases. However, based on current contracts that are under construction, if the same project was built today, the total project cost would come in around $550,000.00 which is $8,461.00 per CFS. In this case, the higher per cfs cost was also due to a price that included grant writing, permitting services, as well as required an unusually significant amount of earthwork due to particular site conditions.

Where FCA does consistently provide significant cost savings is in long-term operation and maintenance. Cost savings with the Farmers Screen are due to the fact that there are no moving parts or power requirements.

As Darryl Hayes notes in his paper titled, "Fish Protection Facility Cost Drivers and Considerations: Why are Costs all over the Board?": "The costs associated with project operations and maintenance are usually significant and are often overlooked. It is rare for project planners to spend enough time considering who will operate and maintain the facilities. Most fish screen projects require control and cleaning systems that operate almost continually, especially during the irrigation season."

> **"In addition, WDFW reports that they installed……for about one-third the bid amount for a FCA screen."**

FCA has never bid on a project with WDFW. However, FCA learned at the Screening and Fish Passage Conference in Newport, OR in September 2009 that WDFW has a very innovative and cost effective modular that has been installed at several sites. This screen would be significantly less expensive than a Farmers Screen.

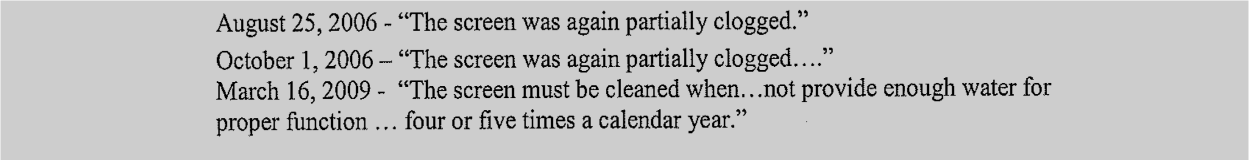


Maintenance issues with FCA screens

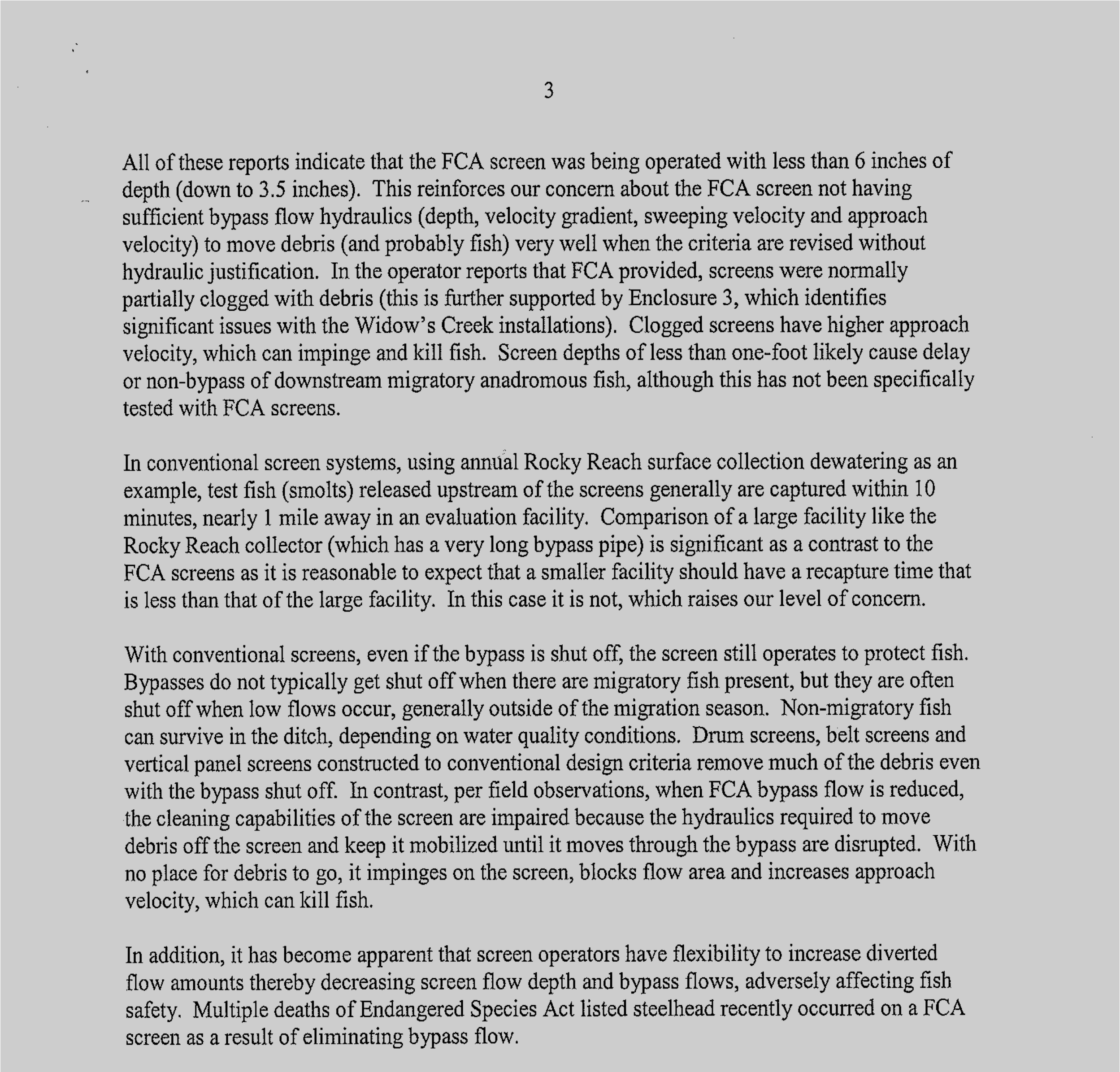
FCA states that maintenance requirements are far reduced with FCA screens.

NMFS reply: A few direct quotes from operators (from the undated document entitled History and Development of the Farmer's Screen, submitted to us by FCA):

> May 26, 2006 – "High water had overtopped our diversion and the screen was plugged with debris."
>
> July 15, 2006 – " the screen was clean."
>
> August 6, 2006 – "The screen was partially clogged with algae and moss."



August 25, 2006 - "The screen was again partially clogged."
October 1, 2006 – "The screen was again partially clogged…."
March 16, 2009 - "The screen must be cleaned when…not provide enough water for proper function … four or five times a calendar year."



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All of these reports indicate that the FCA screen was being operated with less than 6 inches of depth (down to 3.5 inches). This reinforces our concern about the FCA screen not having sufficient bypass flow hydraulics (depth, velocity gradient, sweeping velocity and approach velocity) to move debris (and probably fish) very well when the criteria are revised without hydraulic justification. In the operator reports that FCA provided, screens were normally partially clogged with debris (this is further supported by Enclosure 3, which identifies significant issues with the Widow's Creek installations). Clogged screens have higher approach velocity, which can impinge and kill fish. Screen depths of less than one-foot likely cause delay or non-bypass of downstream migratory anadromous fish, although this has not been specifically tested with FCA screens.

In conventional screen systems, using annual Rocky Reach surface collection dewatering as an example, test fish (smolts) released upstream of the screens generally are captured within 10 minutes, nearly 1 mile away in an evaluation facility. Comparison of a large facility like the Rocky Reach collector (which has a very long bypass pipe) is significant as a contrast to the FCA screens as it is reasonable to expect that a smaller facility should have a recapture time that is less than that of the large facility. In this case it is not, which raises our level of concern.

With conventional screens, even if the bypass is shut off, the screen still operates to protect fish. Bypasses do not typically get shut off when there are migratory fish present, but they are often shut off when low flows occur, generally outside of the migration season. Non-migratory fish can survive in the ditch, depending on water quality conditions. Drum screens, belt screens and vertical panel screens constructed to conventional design criteria remove much of the debris even with the bypass shut off. In contrast, per field observations, when FCA bypass flow is reduced, the cleaning capabilities of the screen are impaired because the hydraulics required to move debris off the screen and keep it mobilized until it moves through the bypass are disrupted. With no place for debris to go, it impinges on the screen, blocks flow area and increases approach velocity, which can kill fish.

In addition, it has become apparent that screen operators have flexibility to increase diverted flow amounts thereby decreasing screen flow depth and bypass flows, adversely affecting fish safety. Multiple deaths of Endangered Species Act listed steelhead recently occurred on a FCA screen as a result of eliminating bypass flow.

FCA Response:
The passages from operators cited above by NMFS are taken out of context and misrepresent screen performance. FCA feels that review of the operators' full quotes would be more helpful in understanding screen performance.

> **NMFS citation: May 26, 2006 – "High water had overtopped our diversion and the screen was plugged with debris."**

The complete May 26, 2006 entry from a screen on the East Fork of the Weiser River in Idaho actually says:

> *"On May 26, I visited the diversion and screen after winter snows had melted. High water had overtopped our diversion and the screen was loaded with debris. The debris was dry, but I left it there to see what would happen when we turned the water back in. I noticed that a breach had occurred between the canal delivery side and the fish return flow side as shown in the accompanying photograph. It appeared that turbulence set up by a eddy current was the cause. I returned the next day to instal a temporary fix consisting of 6 mil plastic, replace fill material, and rock armor for the canal side. The fix is shown in the accompanying photograph. The temporary fix held up well all season. Mike Kleinsmith of Farmers Irrigation came up with a fix that we will install this year. It consists of a small sheet of steel to shield the area from turbulence.*
>
> *Ken Ward, our corporation water master turned the ditch on and said that all of the debris lifted off when the pool under the screen filled."*
>
> **NMFS citation: August 6, 2006 – "The screen was partially clogged with algae and moss."**

The August 6th, 2006 entry, if cited in its entirety, would read as follows:

> *"I was contacted by our Area Watermaster, Bosko, early in June. He suggested that we were returning more water to the East Fork than we needed to. So I revisited the screen on August 6. There was six inches of water on top of the screen and a large amount of return flow to the East Fork. The temporary repair was holding up well. The screen was partially clogged with algae and moss. I theorized that the screen was not cleaning as well as it could because the water next to the screen appeared to be relatively free of turbulence. I made measurements of the screen height and the height of the weir wall. I then lowered the weir wall two inches resulting in four inches of water on top of the screen. This increased water delivery to our canal and decreased return flow to the East Fork. It appeared that there was plenty of water on top of the screen to permit fish passage over it."*
>
> **NMFS citation: August 25, 2006 – "The screen was again partially clogged."**

August 25th, 2006 complete statement:

> *"I revisited the screen on August 25. There was 4.75 inches of water on top of the screen and what appeared to be a sufficient amount of return flow to the East Fork. The temporary repair was holding up well. The screen was again partially clogged with algae and moss, but appeared to be cleaning better than before. The two attached photos show the screen's condition on August 25 before I cleaned it with a push broom."*
>
> **NMFS citation: October 1, 2006 – "The screen was again partially clogged…"**

October 1st, 2006 complete statement:

> "*I revisited the screen on October 1. There was 3.5 inches of water on top of the screen and what appeared to be a sufficient amount of return flow to the East Fork with good*

> *pools in the return flow channel. The temporary repair was holding up well. The screen was again partially clogged with alge and moss, but appeared to be cleaning fairly well. The two attached photos show the screen's condition on October 1 before I cleaned it with a push broom.*
>
> *I observed only one fish (species?) in the canal between the diversion and the screen and none in the canal. None of my observations showed any fish on the screen or in the return flow channel.*
>
> *As a summary of operations for 2005, I think the screen was a resounding success. We had no complaints from stockholders about low water. That is interesting because of the very low flow later in the season. An occasional cleaning with a push broom is minimal effort considering that required for other screens that Dave Hogen and I visited."*

NMFS citation: March 16, 2009 – "The screen must be cleaned when…..not provide enough water for proper function…four or five times a year."

March 16, 2009 complete statement (in this case the landowner states that the screen had to be cleaned when the grizzly at the intake fouled):

- *The types of sediments encountered in the diversion are pea gravel and large sand. Organic matter consists of fir needles, leaves, and woody debris.*
- *Personal observe the screen during irrigation season weekly. During the off season, personal observe the screen monthly or as weather permits.*
- *The screen requires rare cleanings. The screen must only be cleaned when the intake grizzly becomes fouled and does not provide enough water for proper funtion. The intake fouls approximately four or five times within a calendar year. This usually occurs during high water events.*
- *Aside from above the mentioned cleaning, the screen has required no further maintenance.*
- *The screen's impact to our operation and maintenance budget has resulted in savings of around 90%. The old screen required almost daily maintenance during irrigation season.*
- *The screen has proven to provide other positive impacts to the diversion. In contrast to the past, it is very user and fish friendly.*

All of the quotes except for the last one are from the same operator. As explained in the referenced document (History and Development of the Farmers Screen) provided to NMFS on April 3rd, 2009, the Idaho project from which the quotes were extracted by NMFS was the first project to be installed after the Davenport screen gained approval. It was installed on the National Forest with help from a Forest Service Biologist and was designed for a much greater flow than was actually used. The screen was designed for a water right of 16 CFS however it was later disclosed that the customer is only using about 8-9 CFS. The following quote could also have been included from that ditch operator:

> *"For performance and low maintenance, the screen has exceeded our expectations after three full seasons of operation. What little cleaning that is needed is done with a push broom on the screen a few times during the season. The folks at Farmers Conservation Alliance have been great to work with, and have provided us with the screen we needed."*

> **"All of these reports indicate that the FCA screen was being operated with less than 6 inches of water depth (down to 3.5 inches.)"**

The report from one screen in Idaho (which is not within NMFS jurisdiction) reported water depths to 3.5 inches, the rest of the screens have been operating between 6 and 12 inches of depth.

> **"In the operator reports that FCA provided, screens were normally partially clogged with debris…"**

Farmers Screens do not clog with debris when operated as they were designed and as prescribed in the operation manual. Clogging occurrences on Farmers Screens have been isolated events at specific locations with clear causes. The operation and maintenance logs support this statement. As demonstrated by the complete operator logs, as well as FCA's response to Enclosure 3 regarding Widows Creek, FCA's Farmers Screen does not normally clog with debris.

> **"Comparison of a large facility like Rocky Reach collector…it is reasonable to expect that a smaller facility should have a recapture time less than that of a larger facility."**

It is difficult to compare a facility like the Rocky Reach collector, a large dam with a hydroelectric facility, to a small agricultural diversion. Recapture time would be dependent on many factors outside of the screen itself such as diversion structure type, type of head-gate, type of conveyance to the screen, and fish return design. The Farmers Screen has significantly higher sweeping velocities than conventional technologies and therefore provides shorter exposure times to the screen. The biological testing by USGS provides data on length of time to recapture. It is consistently less than 10 minutes.

> **"…when FCA bypass flow is reduced, the cleaning capabilities of the screen are impaired…"**

FCA agrees that operation of the Farmers Screen without by-pass flow should not occur. Sites without suitable by-pass flow are not appropriate sites for the Farmers Screen.

> **"..it has become apparent that screen operators have flexibility to increase diverted flow amounts…."**

This incident of steelhead fish kill occurred on one of the Widows Creek screens as a result of operator error, coupled with structural damage to and improper sealing of its weir wall. (For more background information on this incident, see our response to the Widows Creek Site inspection.)

Screen operator manipulation is a potential problem with all currently available fish screening technologies. However, with the Farmers Screen, operator manipulation that could lead to screen dewatering is easily addressed by providing a <u>completely sealed weir wall.</u>

ODFW and FCA have together explored a new design change that would eliminate the flush mechanism in the weir wall. By using a fully sealed weir wall, with no option to manipulate the quantity of water diverted, the Farmers Screen slowly decreases the percentage of water going through the screen and sends an increasing percentage to the by-pass until 100% is going to the bypass and the approach velocity is 0. This design has been shown to work exactly as designed at the Berry Creek screen in the John Day basin and has been observed by ODFW staff during very low flows.

> *FCA states: "Experience from these projects has shown some obvious issues with the current criteria that negatively affect both screen function and fish protection and add significant cost to projects with no correlating improvement in fish protection or screen function."*
>
> **NMFS reply:** Assuming that this statement refers to current criteria for FCA screens, again, how many of these sites were constructed to current FCA criteria that were collaboratively developed with NMFS and other agencies? Of the sites constructed to FCA criteria, what issues negatively affect fish protection or screen function?

FCA Response:

The question could be restated as: How many of the FCA screens were constructed to the current NMFS criteria for the Farmers Screen? How many were constructed to the criteria requested by FCA? Therefore what issues negatively affect fish protection or screen function when they weren't constructed to NMFS standards?

The answer would be that all of the screens were constructed to the NMFS stated criteria for The Farmers Screen and when located in anadromous rivers or streams were reviewed by NMFS staff. Some of the screens have been operated at shallower depths which (along with biological testing, hydraulic testing, operation history, and input from other resource agency engineers and biologists) has led to the request by FCA to alter the criteria for the Farmers Screen.

Once again, FCA is simply requesting the following revision to The Farmers Screen criteria: Lower the operating depth of water over the screen from a minimum of 12 inches to a minimum of 6 inches for screens 0 to 20 CFS. Screens under 20 CFS simply perform better at depths less than 12 inches. The hydraulic cleaning function is enhanced with the shallower depths and less water must be removed from the river or stream which decreases the chance that fish will be entrained in the diversion in the first place. The USGS study included screen operation down to less than 3 inches of water depth over the screen surface and still USGS reported that, "The screen showed good self-cleaning characteristics and never had problems with debris loading".

> 4
>
> **<u>FCA suggestion for bypass flow</u>**
>
> *FCA suggested criterion change: "**Bypass Water:** Bypass flow must be available at all times for proper screen operation. Bypass flow must be sufficient to meet all other design criteria as bypass flow quantities are a function of screen design and operation."*
>
> **NMFS reply:** A generic statement such as "Bypass flow must be available…" does not mean that the bypass and screen facility is being properly operated. The statement that an operator cannot alter the flow without altering other hydraulic parameters is obvious. However, the bypass flow percentage is a <u>design criterion</u> that was developed via iterative prototype design to provide hydraulics conducive to fish bypass, and is <u>not an operational parameter</u>. As such, this is not acceptable as a criterion change

FCA Response:
FCA would agree that the generic statement does not mean that the facility is being properly operated. Therefore, FCA feels the statement should read, "For diversions 0-20 cfs, a minimum of 6 inches of by-pass flow is required. For diversions 20 cfs or greater, a minimum of 12 inches of bypass flow is required. For screen installations of 0 to 20 CFS, current installations greatly exceed the current NMFS criteria of 15% by-pass flow. Further, a reduced depth requirement for smaller screens leads to less water withdrawn from the river or stream. This leaves more water in stream for fish and wildlife and decreases the chance of entrainment in the first place.

FCA suggestion for approach velocity
FCA suggested criterion change: "***Approach Velocity:*** *The Farmers Screen is considered an active screen due to a hydraulic cleaning mechanism. The approach velocity must not exceed 0.40 ft/s. Using this approach velocity will minimize screen contact and/or impingement of juvenile fish. For screen design, approach velocity is calculated by dividing the maximum screened flow by the vertical projection of the effective screen area. For measurement of approach velocity, see Section 15.2."*

NMFS reply: The Farmers Screen is by definition, not an active screen. An active screen has an automatic mechanical cleaning system, while a passive screen does not. The Farmers screen has no automatic cleaning system and relies totally on hydraulic action to move debris. If the hydraulics change, cleaning is not assured. This is the reason why particular sideboards were placed on the design criteria for the Farmers screen, and numerous field reports indicate that in fact cleaning is not always achieved automatically. This indicates a design and/or operational flaw that may further limit NMFS acceptance of these screens. Debris accumulations increase screen approach velocity and increase the potential take of listed fish, if present at the site. This is not acceptable as a criterion change.

On another note, using a "vertical projection of the effective screen area," as proposed by FCA above, would result in a zero denominator in the proposed calculation, because a vertical projection of a horizontal surface is zero.

FCA Response:
Discussion of approach velocity has always been problematic when speaking about the Farmers Screen. Approach velocity is typically calculated by dividing the total flow through the screen by the total screen area (minus any supports that block screen area) regardless of the percentage of open area in the screen surface. The Farmers Screen criteria is very different in that the approach velocity is figured for net open area of the screen material. This effectively reduces the approach velocity for the Farmers Screen to nearly 1/4 of conventional active technologies and 1/2 of passive technologies.

> **"The Farmers Screen is by definition, not an active screen."**

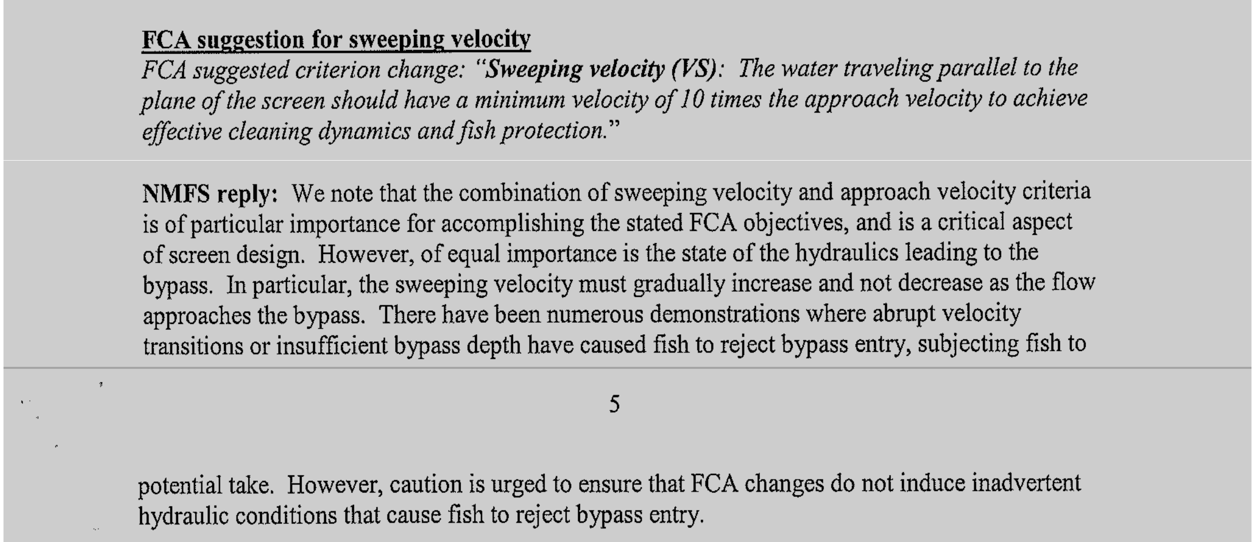
FCA would agree that the Farmers Screen does not fit the typical description of an active screen. However, the oscillating water velocity along the z axis actively lifts debris off of the surface of the screen. The hydraulics of the Farmers Screen actively cleans as long as it is operated as designed (just like mechanically cleaned screens).

> **"…numerous field reports indicate that in fact cleaning is not always achieved automatically."**

Cleaning has only been an issue at sites where screens are either operated improperly, the weir wall has been damaged or the weir wall was not installed properly. The discussion of what field reports documented has been previously discussed. More discussion of the field reports is provided in FCA's response to NMFS' Enclosure 3.

"…using a "vertical projection of the effective screen area," as proposed by FCA…"

The "vertical projection of the effective screen area" comes directly from the NOAA Fisheries criteria document regarding rotary drum, vertical panel, and incline screens. A clarification of the meaning of this phrase would be helpful.



FCA suggestion for sweeping velocity

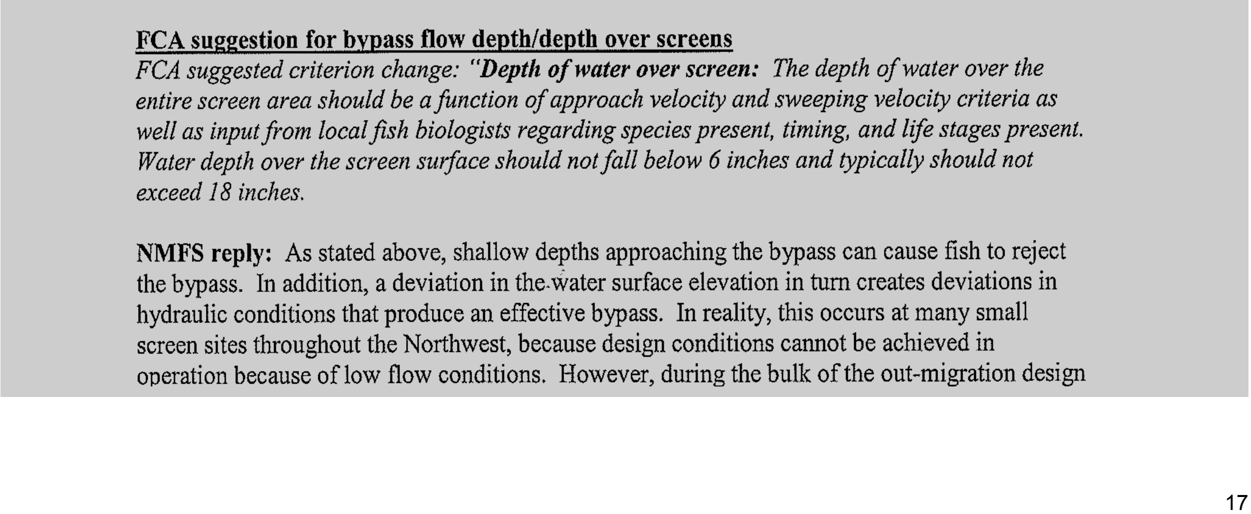
*FCA suggested criterion change: "**Sweeping velocity (VS):** The water traveling parallel to the plane of the screen should have a minimum velocity of 10 times the approach velocity to achieve effective cleaning dynamics and fish protection."*

NMFS reply: We note that the combination of sweeping velocity and approach velocity criteria is of particular importance for accomplishing the stated FCA objectives, and is a critical aspect of screen design. However, of equal importance is the state of the hydraulics leading to the bypass. In particular, the sweeping velocity must gradually increase and not decrease as the flow approaches the bypass. There have been numerous demonstrations where abrupt velocity transitions or insufficient bypass depth have caused fish to reject bypass entry, subjecting fish to potential take. However, caution is urged to ensure that FCA changes do not induce inadvertent hydraulic conditions that cause fish to reject bypass entry.

FCA Response:
Substantially uniform velocity sweeping across the screen without disruption in the average Froude number is necessary to ensure proper performance. The uniform sweeping velocity has been demonstrated down to 3 inches of bypass flow by the supporting USGS study.

"There have been numerous demonstrations where abrupt velocity transitions or insufficient bypass depth have caused fish to reject bypass entry…."

Velocities on the FCA Screen are quite consistent and any changes are very gradual. Depth does not change significantly for the entire length of the screen. The biological testing by USGS demonstrates the way fish react under varying hydraulic conditions, and, as well documented in the USGS report, fish are not harmed when passing over the FCA Screen.



FCA suggestion for bypass flow depth/depth over screens

*FCA suggested criterion change: "**Depth of water over screen:** The depth of water over the entire screen area should be a function of approach velocity and sweeping velocity criteria as well as input from local fish biologists regarding species present, timing, and life stages present. Water depth over the screen surface should not fall below 6 inches and typically should not exceed 18 inches.*

NMFS reply: As stated above, shallow depths approaching the bypass can cause fish to reject the bypass. In addition, a deviation in the water surface elevation in turn creates deviations in hydraulic conditions that produce an effective bypass. In reality, this occurs at many small screen sites throughout the Northwest, because design conditions cannot be achieved in operation because of low flow conditions. However, during the bulk of the out-migration design conditions are achieved because outmigration occurs during freshets and higher springtime flows. If this FCA design criterion is revised per the above suggestion, original design conditions may not ever be optimal for fish passage, because bypass operations have such a large design range and such a low minimum depth. Input from local fish biologists is of paramount importance for many aspects of general fish populations, but it is not clear how their input could affect screen design criteria.

FCA Response:

The water depth does not vary and so does not represent an abrupt transition that would cause fish to reject the bypass. In fact, once in the final reaches of the bypass chute, fish are typically "captured" and quickly flushed out of the system. The USGS data and video provide insights into this matter. Constant velocities and depths leading to the bypass provide at least comparable performance to conventional technologies. Furthermore, operating at shallower depths leads to less water being withdrawn from the river or stream which decreases the chance that fish will be drawn into the diversion in the first place.

FCA suggestion to change status of screen from experimental

FCA suggested criterion change (to NMFS design document): "The 2008 version currently reads: "11.6.1.7 ***Horizontal Screens:*** *Horizontal screens have been evaluated as an experimental technology, and may only be considered if the majority of flow passes over the end of the screen at a minimum depth of 1 foot…….." We request that this section be removed.*

NMFS reply: There has not been biological success demonstrated with bypass depths less than one- foot for FCA screens.

As reported in Bonneville Power Administration (BPA) Contract Report DE-AI79-86BP62611, marginal bypass conditions (2-inch bypass orifice, 6-inch bypass orifice and 4.5-inch deep bypass weir) were tested with conventional screens in the Battelle Lab in 1996 to determine which low flow bypass worked the best. The results were that 69 percent to 77 percent of the 45-60 mm Chinook fry moved from the screen forebay and were bypassed within 24 hours. Similarly, 57 percent to 76 percent of the 90-110 mm Chinook sub-yearlings moved from the screen forebay and were bypassed within 24 hours. No significant difference was reported for the three bypass types tested.

In annual testing (2003 through 2008) of the Rocky Reach bypass designed with conventional screen design criteria, and operated as designed, nearly all of the test fish released in the screen forebay make it into the bypass, transit nearly a mile and are returned to the river in an average of about 9 minutes. Also, in 2004 tests at the Walterville canal with conventional screens, total mortality ranged from 0.2 percent to 1.0 percent for Chinook fry, with the combined mortality for all fish (Chinook fry and smolt) only 0.6 percent. Over 93 percent of the fry and over

94 percent of the smolts released upstream of the screens were recovered below the screen in the 4 hour test period.

The FCA screens have not demonstrated this level of passage. In the Jim Buell test of the prototype FCA screen, only 46 percent of the steelhead smolt moved into the bypass during the 17-hour test period. After the initial 6.5 hours of test operations, only 1 percent more of the test fish moved into the bypass, potentially indicating rejection of the bypass conditions by the remainder of the test population.

As noted in the 2002 United States Bureau of Reclamation (USBR) bull trout tests on a FCA screen (that did not comply with the current FCA criteria), up to 3.5 percent of 28 mm bull trout

> were entrained when bypass depths were a little over five inches. There was also consistently lower survival (1.5 percent) for fish that passed over the screen in comparison to the control. This indicates a minimum fry mortality of 5 percent, higher than the maximum mortality generally seen in conventional screen designs tests (less than 4 percent, often less than 2 percent). Entrainment is a function of exposure time, mesh opening size and approach velocity.
>
> These comparisons of optimal conditions in the FCA screens (i.e. one foot bypass depth) versus the entire operational range of conditions (optimal and suboptimal) tested in a conventional screens suggests that current FCA screens do not exhibit equal performance to conventional screens.

FCA Response:

It is unclear how biological success has not been demonstrated with depth less than one foot. The USGS test gives very clear and positive results.

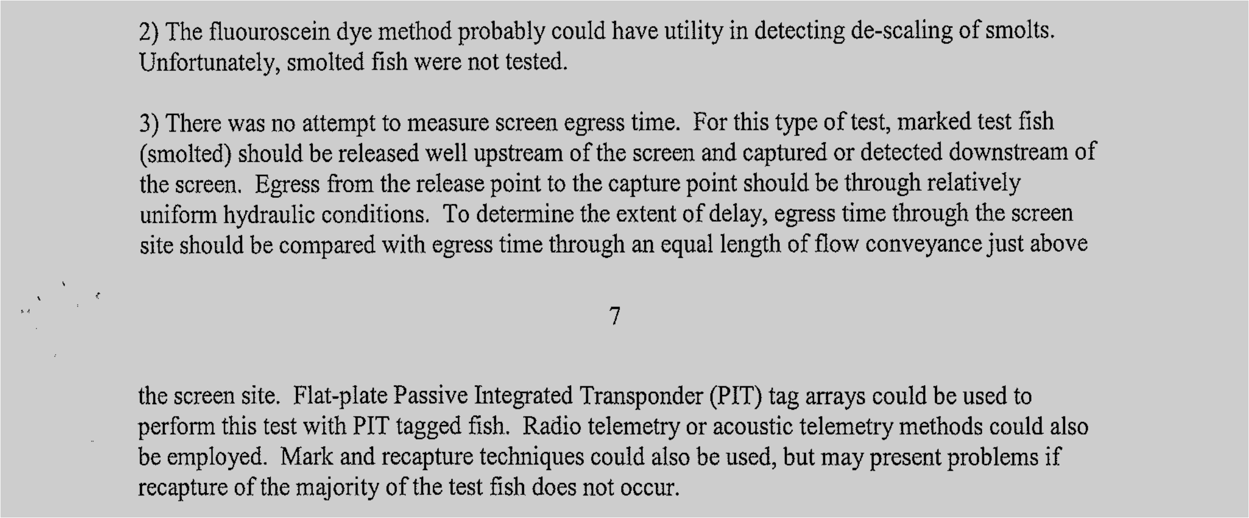
"In the Jim Buell test of the prototype FCA screen…"

In a letter to FCA dated January 27, 2006, Keith Kirkendall of NMFS described this same test this way, *"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."* The Buell tests were not performed on an FCA screen and did not have hydraulics conducive to effectively passing fish through a by-pass system. The prototypical screen upon which Buell performed his tests has little resemblance to an FCA screen. It was an early prototype upon which design changes were based due to inadequate protection for fish. Thus, this study was included in the history to demonstrate that even less than perfect screen embodiments still perform well with regard to fish protection. It is unclear as to why NMFS has changed its opinion regarding the results and meaning of this test.

"As noted in the 2002 United States Bureau of Reclamation (USBR) bull trout tests on a FCA screen…."

Again, the USBR bull trout tests were not performed on an FCA screen. The screen used was similar in many ways but lacks the refinements of the Farmers Screen. There were hydraulic inconsistencies and shadows that allowed fish to hold. This test also goes to illustrate how the technology has been refined but is not a fair characterization of how the current design passes fish. Again, this study was included in the history as an example of how testing results can lead to effective design change.

> **Recent Screen Tests**
>
> We recently received a draft Summary and verbal description of recent testing of FCA screens (Mesa and Copeland in 2009). We are willing to review the entire study report; herein we provide the following commentary based on our review of the executive summary of the report.
>
> 1) Use of flouroscein dye injury detection method as a metric for screen injury is not consistent with other screen evaluations done in the Northwest Region. It does not look at overall screen performance. This is because the magnitude of individual fish injury was recorded with the flouroscein dye method, as opposed a more conventional release and recapture evaluation, which provides migration rates, mortality rates and injury rates of the population at large. The flouroscein dye method revealed that nearly all fish were injured to some extent on the FCA screens, although some injuries were minor and probably negligible. However, this evaluation did not associate the degree of injury of an individual fish with its long-term survival. For example, a 1 percent injury of an individual fish could be negligible if it is a scale or two, but could cause eventual death if the injury was a distorted operculum.



2) The fluouroscein dye method probably could have utility in detecting de-scaling of smolts. Unfortunately, smolted fish were not tested.

3) There was no attempt to measure screen egress time. For this type of test, marked test fish (smolted) should be released well upstream of the screen and captured or detected downstream of the screen. Egress from the release point to the capture point should be through relatively uniform hydraulic conditions. To determine the extent of delay, egress time through the screen site should be compared with egress time through an equal length of flow conveyance just above the screen site. Flat-plate Passive Integrated Transponder (PIT) tag arrays could be used to perform this test with PIT tagged fish. Radio telemetry or acoustic telemetry methods could also be employed. Mark and recapture techniques could also be used, but may present problems if recapture of the majority of the test fish does not occur.

FCA Response:

FCA is pleased to learn that NMFS is willing to further discuss the USGS study and will defer to USGS for the technical discussion. What can be stated is that NMFS requested this testing. Larry Swenson and Michelle Day met with Les Perkins and Julie O'Shea of FCA, and Matt Mesa of the USGS on September 30th, 2008 to discuss how the testing would be conducted and what questions NMFS wanted to see answered. A draft copy of the study plan was sent to NMFS on November 4th, 2008. Mr. Mesa proposed the fluorescein dye method as the least subjective and most accurate method used today to assess fish injury. NOAA Fisheries staff presented no objections.

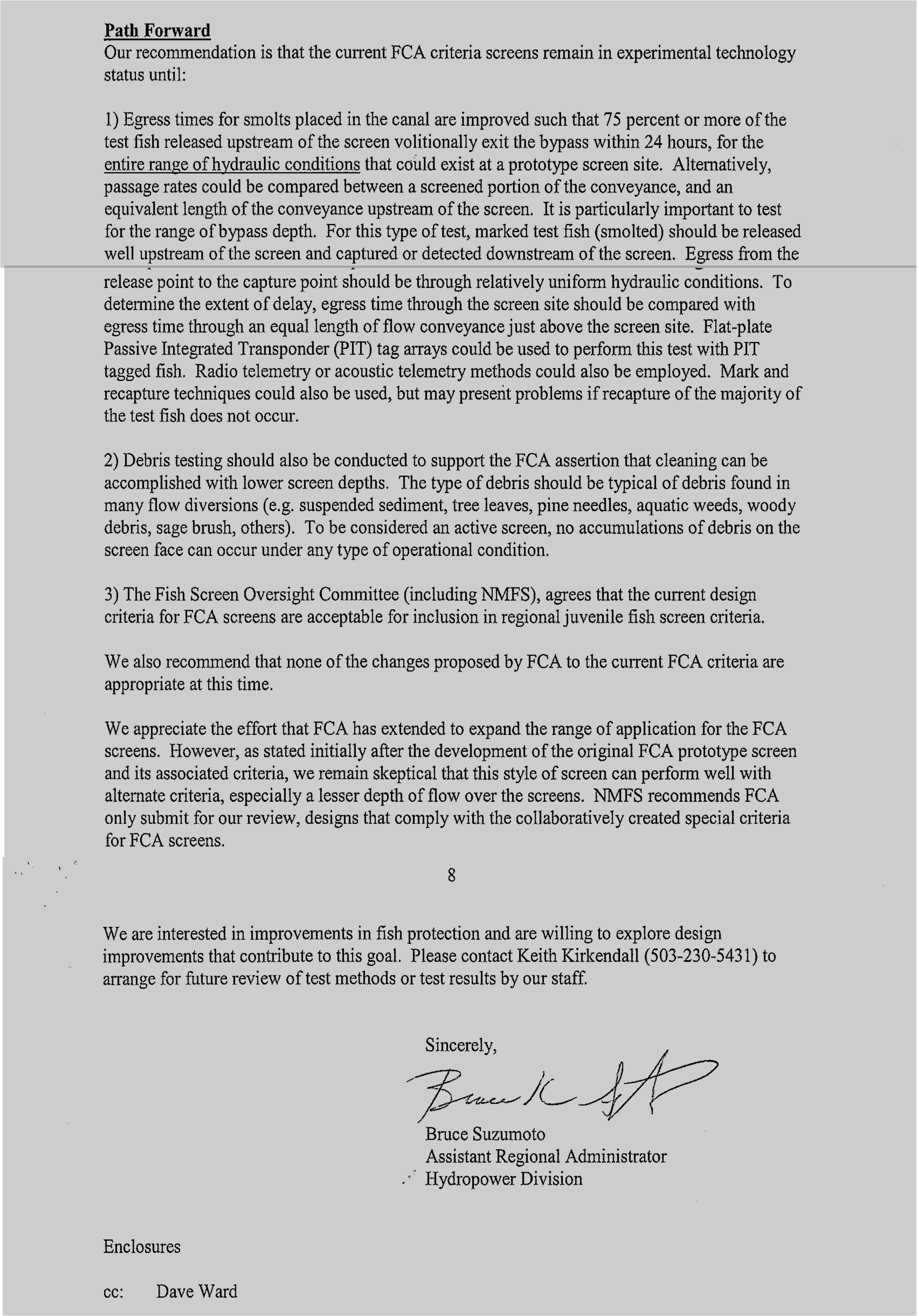
> **"The fluouroscein dye method revealed that nearly all fish were injured to some extent on the FCA screens…."**

No fish were injured when considered in terms of NOAA Fisheries injury criteria. There was no mortality and the injuries that were seen were no more significant than in the control population.

> **"There was no attempt to measure screen egress time. For this type of test, marked test fish (smolted) should be released well upstream…"**

There was no mention of needing to measure screen egress time during the test planning phases. However, USGS did capture limited data regarding egress time. The size of fish were discussed with NMFS and determined before the testing began. Smolted fish possibly could have been used if requested by NMFS, but no such request was made. In fact, Larry Swenson was scheduled to meet with FCA and USGS between testing of the two sizes of fish on the 17th of March 2009, to discuss any changes that might be necessary to the test design. Larry Swenson called Les Perkins on the 16th to say that he mentioned the March 17th meeting at a staff meeting and was informed by NMFS staff that he would not be allowed to attend.

The concern from NOAA Fisheries staff, and the reason for the test at NMFS' request, was not presented as delay, but purely the potential for injury to fish at shallower water depths.



Path Forward

Our recommendation is that the current FCA criteria screens remain in experimental technology status until:

1) Egress times for smolts placed in the canal are improved such that 75 percent or more of the test fish released upstream of the screen volitionally exit the bypass within 24 hours, for the <u>entire range of hydraulic conditions</u> that could exist at a prototype screen site. Alternatively, passage rates could be compared between a screened portion of the conveyance, and an equivalent length of the conveyance upstream of the screen. It is particularly important to test for the range of bypass depth. For this type of test, marked test fish (smolted) should be released well upstream of the screen and captured or detected downstream of the screen. Egress from the release point to the capture point should be through relatively uniform hydraulic conditions. To determine the extent of delay, egress time through the screen site should be compared with egress time through an equal length of flow conveyance just above the screen site. Flat-plate Passive Integrated Transponder (PIT) tag arrays could be used to perform this test with PIT tagged fish. Radio telemetry or acoustic telemetry methods could also be employed. Mark and recapture techniques could also be used, but may present problems if recapture of the majority of the test fish does not occur.

2) Debris testing should also be conducted to support the FCA assertion that cleaning can be accomplished with lower screen depths. The type of debris should be typical of debris found in many flow diversions (e.g. suspended sediment, tree leaves, pine needles, aquatic weeds, woody debris, sage brush, others). To be considered an active screen, no accumulations of debris on the screen face can occur under any type of operational condition.

3) The Fish Screen Oversight Committee (including NMFS), agrees that the current design criteria for FCA screens are acceptable for inclusion in regional juvenile fish screen criteria.

We also recommend that none of the changes proposed by FCA to the current FCA criteria are appropriate at this time.

We appreciate the effort that FCA has extended to expand the range of application for the FCA screens. However, as stated initially after the development of the original FCA prototype screen and its associated criteria, we remain skeptical that this style of screen can perform well with alternate criteria, especially a lesser depth of flow over the screens. NMFS recommends FCA only submit for our review, designs that comply with the collaboratively created special criteria for FCA screens.

We are interested in improvements in fish protection and are willing to explore design improvements that contribute to this goal. Please contact Keith Kirkendall (503-230-5431) to arrange for future review of test methods or test results by our staff.

Sincerely,

Bruce Suzumoto
Assistant Regional Administrator
Hydropower Division

Enclosures

cc: Dave Ward

FCA Response:

1. **NMFS Recommendation: Egress times for smolts placed in the canal are improved such that 75 percent or more of the test fish released upstream of the screen volitionally exit the bypass within 24 hours, for the entire range of hydraulic conditions that could exist as a prototype screen site**

FCA Response:
While egress is a valid concern, the proposed testing would apply to all off-channel screen types, not just the Farmers Screen. As with any off-channel screen type, the diversion structure, the headgate type and configuration, the type and length of the conveyance to the screen, and the type and length of by-pass are site specific and vary greatly.

As stated in Section 17.4.5 (Process for Developing Experimental Fish Passage Technology) of the Anadromous Salmonid Passage Facility Design published in 2007 by National Marine Fisheries Service, Northwest Region, “Results of both laboratory and field prototype evaluations must demonstrate a level of performance equal to or exceeding that of conventional fish passage devices before NOAA Fisheries will support permanent installations.” FCA and collaborating agency partners have been unable to locate examples of the proposed testing for other off-channel screen technologies (other than testing at large facilities associated with a hydro-power project) with which the results of Farmers Screen testing could be compared to current technologies. Therefore, we feel the Farmers Screen is being held to a higher standard than other technologies.

However, what can be stated is that the sweeping velocities associated with the Farmers Screen are much higher than conventional technologies with a correlating lower approach velocity and, therefore, it is unlikely that the Farmers Screen would not perform at least as well as conventional technologies.

2. **NMFS Recommendation: Debris testing should also be conducted to support the FCA assertion that cleaning can be accomplished with lower screen depths.**

FCA Response:
Regardless of a 6 inch or 12 inch water depth, approach velocity and sweeping velocity are still meeting criteria requirements. This is supported by the USGS study statement, “The screen showed good self-cleaning performance and never had problems with debris loading.” The hydraulic data gathered during the testing shows a very high ratio of sweeping velocity to approach velocity (30:1 to 60:1) throughout the range of water depths. In addition, hydraulic data from other Farmers Screen installations as well as observations by both FCA staff and agency representatives supports FCA’s assertion as to the cleaning capabilities of the Farmers Screen at shallower depths when the screen is operating under heavy debris and sediment loads.

Furthermore, it is unclear as to how one would quantify results regarding debris load testing. There are issues associated with releasing sediment into a diversion where it can affect downstream water quality.

3. **NMFS Recommendation: The Fish Screen Oversight Committee (including NMFS) agrees that the current design criteria for FCA screens are acceptable for inclusion in regional juvenile fish screen criteria.**

FCA Response:
FCA appreciates the consideration of the Fish Screen Oversight Committee (including NMFS) to determine Farmers Screen criteria. FCA hopes the FSOC committee will consider both 12 inches and 6 inches of bypass flow to be included in this criteria.

FCA Closing Statement
FCA is very disappointed with this response from NMFS. However, FCA feels confident that with clarification to many of the NMFS statements, review of the entire USGS study (as opposed to the draft study used for this letter) as well as an articulation of the many challenges that faced the Widows Creek site in question, many of the issues presented by NMFS will be resolved.

Additionally, FCA is expecting with this clarified information a reconsideration of FCA's request to modify the current Farmers Screen criteria to include:

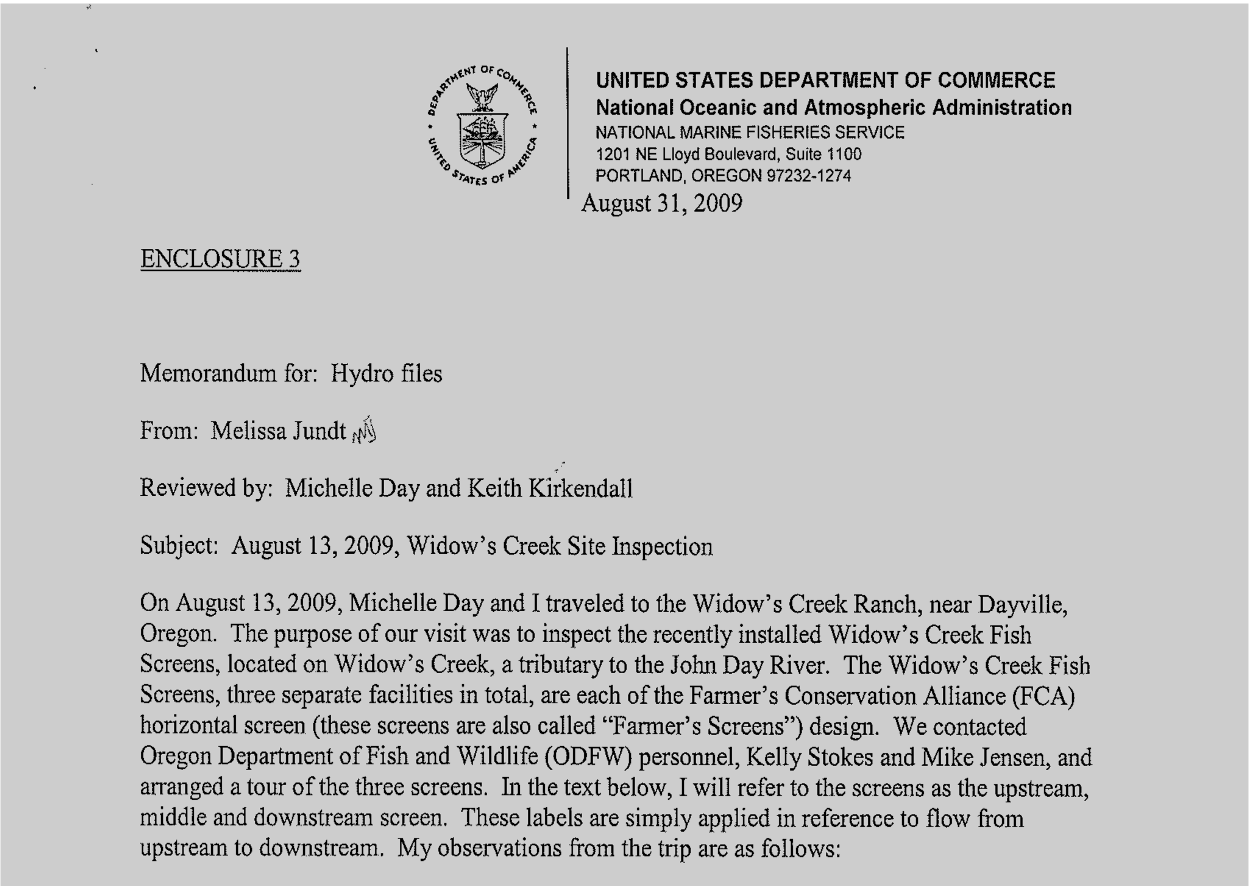
- Change water depth to a 6 inch minimum for Farmers Screen installations 0-20 cfs
- For screens larger than 20 cfs, FCA requests the criteria remain at the current 12 inch minimum water depth

In addition, because of the extensive supporting evidence, data resulting from subsequent research and testing, and operation experience from 17 total Farmers Screen installations in a wide variety of flow ranges and site conditions, FCA requests that the Farmers Screen be a NOAA Approved Technology.

We appreciate your time and consideration.

FCA Response to Enclosure 3
September 30, 2009

The following document is Farmers Conservation Alliance's (FCA's) response to the Widow's Creek Site Inspection performed by Melissa Jundt and Michelle Day of National Marine Fisheries Service (NMFS) on August 13, 2009.



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

August 31, 2009

ENCLOSURE 3

Memorandum for: Hydro files

From: Melissa Jundt

Reviewed by: Michelle Day and Keith Kirkendall

Subject: August 13, 2009, Widow's Creek Site Inspection

On August 13, 2009, Michelle Day and I traveled to the Widow's Creek Ranch, near Dayville, Oregon. The purpose of our visit was to inspect the recently installed Widow's Creek Fish Screens, located on Widow's Creek, a tributary to the John Day River. The Widow's Creek Fish Screens, three separate facilities in total, are each of the Farmer's Conservation Alliance (FCA) horizontal screen (these screens are also called "Farmer's Screens") design. We contacted Oregon Department of Fish and Wildlife (ODFW) personnel, Kelly Stokes and Mike Jensen, and arranged a tour of the three screens. In the text below, I will refer to the screens as the upstream, middle and downstream screen. These labels are simply applied in reference to flow from upstream to downstream. My observations from the trip are as follows:

Project History:

It is important to understand all of the information regarding the Widows Creek screen projects.

ODFW first contacted FCA regarding the three Widows Creek diversions in the spring of 2006. This had been a problematic site where two other screen types were previously installed, failed, and removed. Over the next two years, FCA visited the site several times with Kelly Stokes, Mike Jensen, and Steve Corwin (all from the John Day screen shop) and Joel Watts and Alan Ritchey of the Salem office of ODFW. The visits were performed to assess the site conditions and determine whether the Farmers Screen was an appropriate technology for the site. Considerations were: gradient, organic debris, sediment, available by-pass flow and landowner willingness to only operate when sufficient by-pass flow was available. Sediment was not characterized by FCA or ODFW as heavy on this system.

ODFW contracted with FCA to purchase three Farmers Screens for the Widows Creek diversions and also contracted with FCA to install the screens. ODFW surveyed the sites and provided the site plans as well as providing an engineer on site during installation to determine screen location and by-pass layout. ODFW was responsible for all project development including permitting and obtaining information on water rights and access to the project sites. NOAA Fisheries staff members also reviewed and approved the project prior to installation.

FCA installed the three screens the week of April 20th, 2009. New head gates approved by ODFW were included in the contract. All screens were run and calibrated after installation and were inspected by ODFW personnel including a fish passage engineer.

The Widows Creek projects have provided great learning opportunities for all project partners. The primary lessons learned are:

1) Ensure the diversion does not dry up the stream at any time and that adequate by-pass flow is always available.
2) Identify all potential operators so that they can be properly trained.
3) A fully sealed weir wall is essential on small screens to ensure bypass flow.
4) Operation manuals and landowner training must be provided for all operators prior to screen operation.
5) Adequately assess sediment quantity and type. This can be difficult on small streams and is dependent primarily on anecdotal information. When possible try to corroborate information by gathering information from multiple sources.

> **<u>Fish presence on and near the screen</u>**
> During our tour of the downstream screen, I observed fish on the screen, maintaining location, which may indicate delay on top of the screen. In fact, my shadow caused these fish to move up and down the screen. The water surface was maintained between 0.4 feet (4.8 inches) and 0.55 feet (6.6 inches) (varying between the different screens, with the upstream screen operating at 0.4 foot (4.8 inches) and the middle screen at 0.4 foot (4.8 inches) and the lowest screen at 0.55 foot (6.6 inches, with the lowest screen operating in an unusual mode, see the discussion below). This illustrated an opportunity for fish to hold up on the screen. The fish were readily visible to and could be spotted by a predator.

FCA Response:

The Widows Creek screens are not operating in the manner that they were designed to operate. The reasons for improper operation will be addressed below.

> **<u>Sediment and debris conveyance</u>**
> Typical of most northwest stream and river systems, inflow from Widow's Creek conveys a significant sediment and debris load. During this visit I noted that each of the three screens had some degree of debris occlusion comprised of a mixture of inorganic and organic debris (Caddis Fly, organisms that may have been Western Brook Lamprey ammocoetes or aquatic insects, small gravels, algae, and various forms of other organic materials, see Image 1). Regular fouling occurs and is documented as significant at times (see Image 2). ODFW and the ranch manager stated that the screens require cleaning at least one time per day.

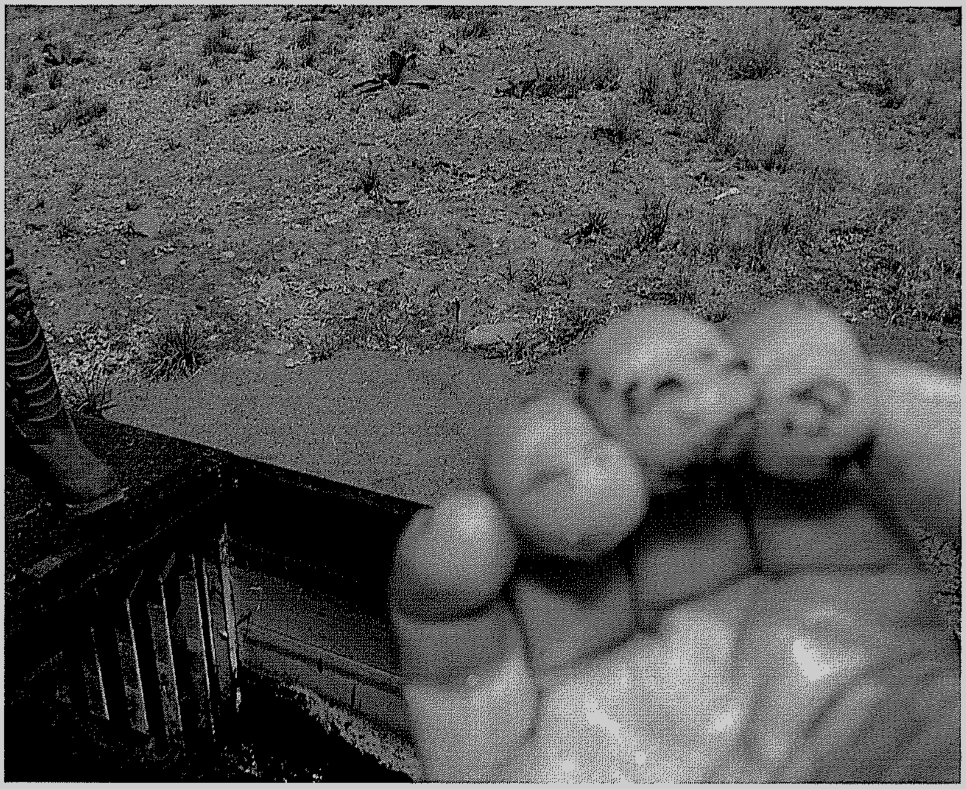
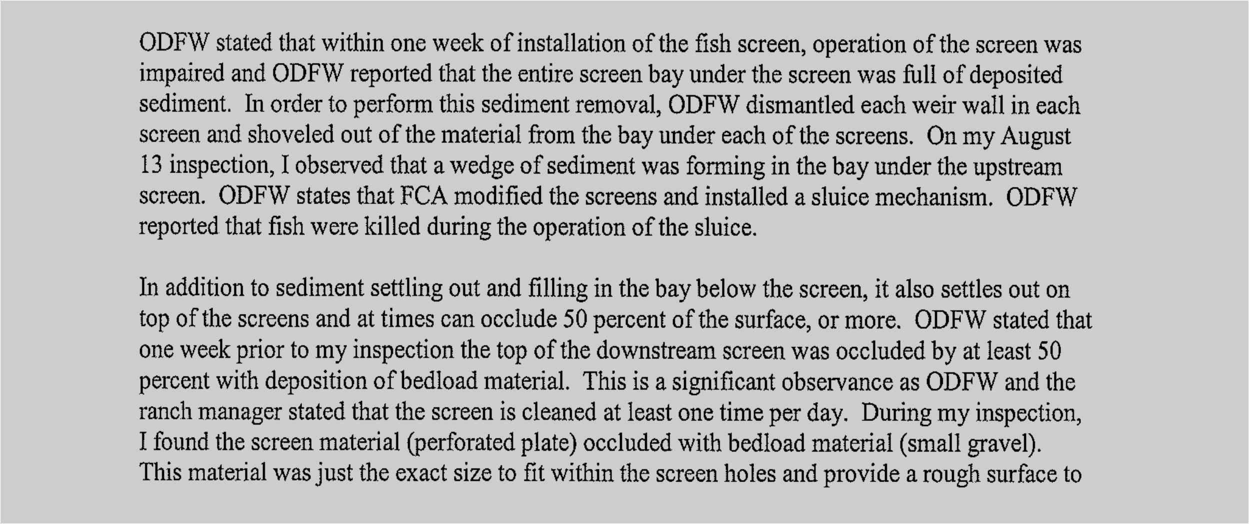


Image 1, organisms found on the screen

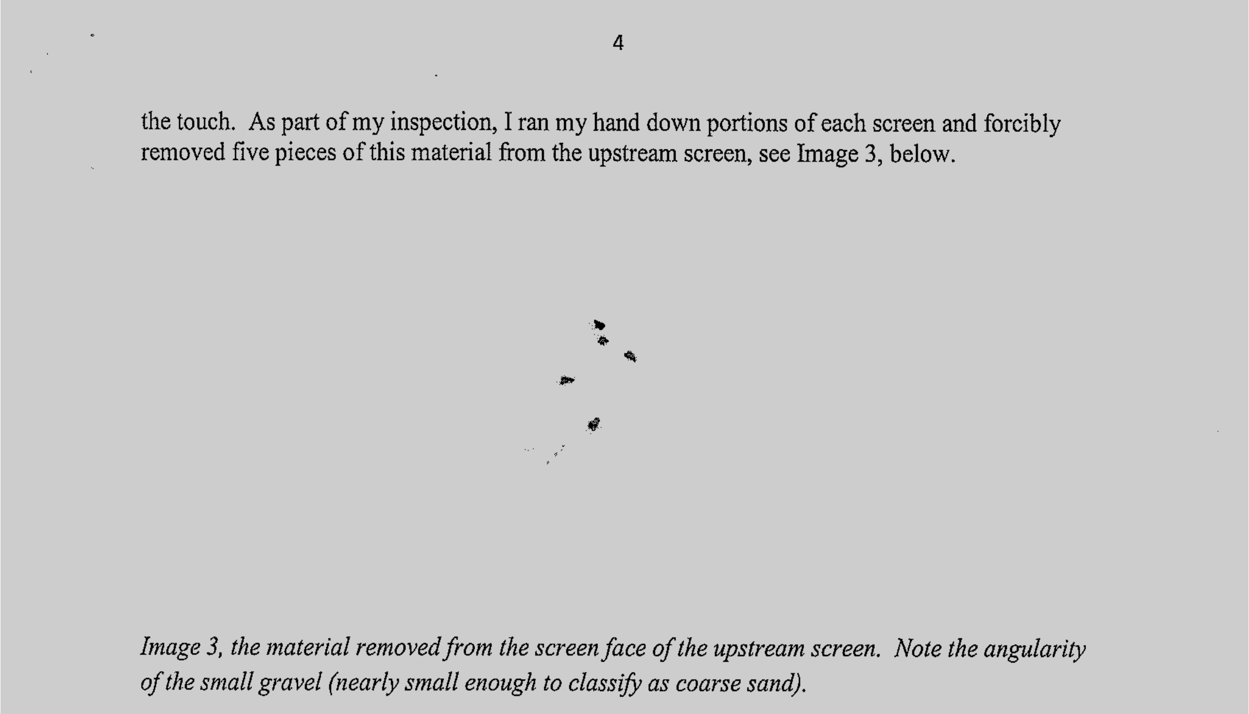
Image 2, fouling on the screens

3



ODFW stated that within one week of installation of the fish screen, operation of the screen was impaired and ODFW reported that the entire screen bay under the screen was full of deposited sediment. In order to perform this sediment removal, ODFW dismantled each weir wall in each screen and shoveled out of the material from the bay under each of the screens. On my August 13 inspection, I observed that a wedge of sediment was forming in the bay under the upstream screen. ODFW states that FCA modified the screens and installed a sluice mechanism. ODFW reported that fish were killed during the operation of the sluice.

In addition to sediment settling out and filling in the bay below the screen, it also settles out on top of the screens and at times can occlude 50 percent of the surface, or more. ODFW stated that one week prior to my inspection the top of the downstream screen was occluded by at least 50 percent with deposition of bedload material. This is a significant observance as ODFW and the ranch manager stated that the screen is cleaned at least one time per day. During my inspection, I found the screen material (perforated plate) occluded with bedload material (small gravel). This material was just the exact size to fit within the screen holes and provide a rough surface to



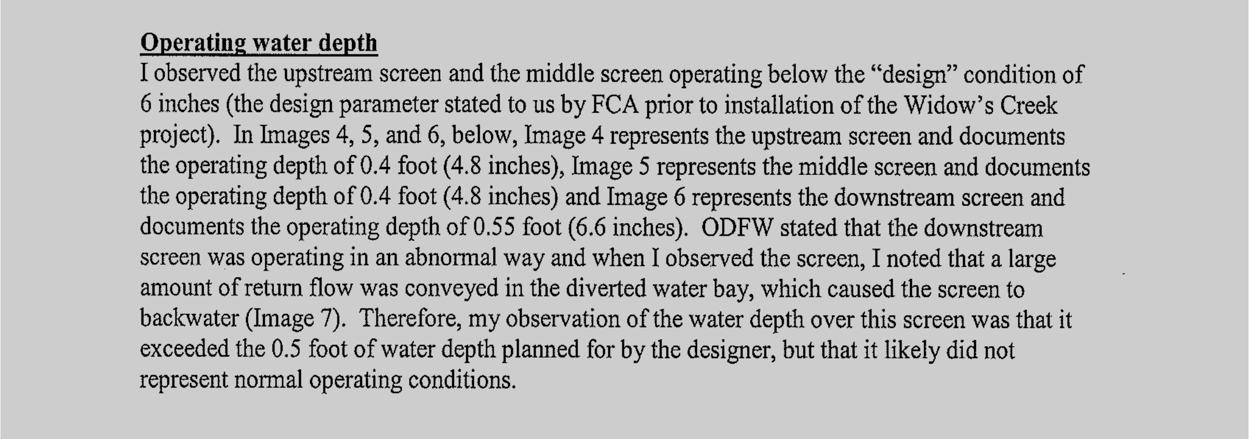
the touch. As part of my inspection, I ran my hand down portions of each screen and forcibly removed five pieces of this material from the upstream screen, see Image 3, below.

Image 3, the material removed from the screen face of the upstream screen. Note the angularity of the small gravel (nearly small enough to classify as coarse sand).

FCA Response:

The quantity of sediment during the spring run off was not anticipated by FCA or ODFW. During the first week of operation, the sediment did in fact overwhelm the screens. The screens have flush gates built into the solid weir walls, however, the landowner did not want the sediment flushed into his system. Therefore, ODFW removed the solid weir walls, which were sealed to the floor of the structure, in order to access the screen underbay to remove the accumulated sediment. During this process, the weir panels were damaged when they were removed. ODFW was not able to seal them properly upon re-installation. Water has been flowing under the weir walls since re-installation, contributing to improper operation.

In order to address the sediment issue, FCA, ODFW, and BPA representatives met on site to troubleshoot and come up with a solution. A sediment removal pipe and valve that returns water and sediment to the stream was agreed upon as the best solution. FCA and ODFW employees installed the sediment control valve and pipe. As stated in the operation manual and explained during the operator training, this sediment flush pipe is only to be used to flush sediment from under the screen when flows are sufficient to support it. This mechanism reduces the flow of water to the irrigator and therefore eliminates the incentive to improperly operate it. To FCA's knowledge, fish were not killed during operation of the sediment flush pipe. Instead, fish were killed at the site when the operator had the flush gates that are built into the weir walls operating continuously. Both FCA and ODFW agreed that the flush gates in the weir walls should be welded shut and will be replaced with external flush mechanisms for future projects. This will allow for sediment management without the opportunity to increase water flow to the landowner at the expense of fish protection and screen function.



Operating water depth

I observed the upstream screen and the middle screen operating below the "design" condition of 6 inches (the design parameter stated to us by FCA prior to installation of the Widow's Creek project). In Images 4, 5, and 6, below, Image 4 represents the upstream screen and documents the operating depth of 0.4 foot (4.8 inches), Image 5 represents the middle screen and documents the operating depth of 0.4 foot (4.8 inches) and Image 6 represents the downstream screen and documents the operating depth of 0.55 foot (6.6 inches). ODFW stated that the downstream screen was operating in an abnormal way and when I observed the screen, I noted that a large amount of return flow was conveyed in the diverted water bay, which caused the screen to backwater (Image 7). Therefore, my observation of the water depth over this screen was that it exceeded the 0.5 foot of water depth planned for by the designer, but that it likely did not represent normal operating conditions.

FCA Response:

As stated above, these screens are not being operated as designed which means that the water depth is not being maintained at the minimum 6 inch water depth. Until the weir walls are again removed, repaired, reinstalled, then resealed properly and the flush gates on the weir walls are permanently sealed, the screens will not be able to be operated properly. (FCA has no authority to perform this work independently and must coordinate with both the landowner and ODFW. FCA and ODFW are currently in process to make these screen adjustments.) When the screens were first installed and calibrated, the screens operated as they were designed (at a 6" minimum depth).

The pipe dumping water into the lower Widows Creek screen was the result of the rancher using water that had already passed through the middle Widows Creek screen. The rancher used an irrigation handline to pipe the screened water from the middle Widows Creek screen to the lower Widows Creek screen in order to increase the screened water flow at the lower screen site. Although this conveyance system looks odd, it does not alter screen performance. FCA believes a better solution would be to shut off the middle screen, leave the water in Widows Creek, then capture the water through the lower screen diversion.

Image 4, upstream screen operating water depth

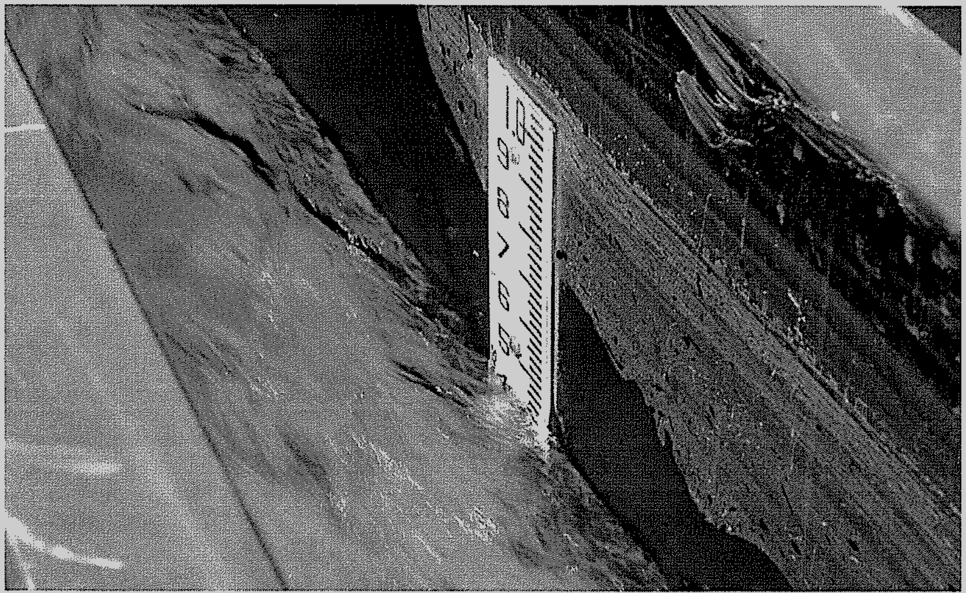


Image 5, middle screen operating water depth

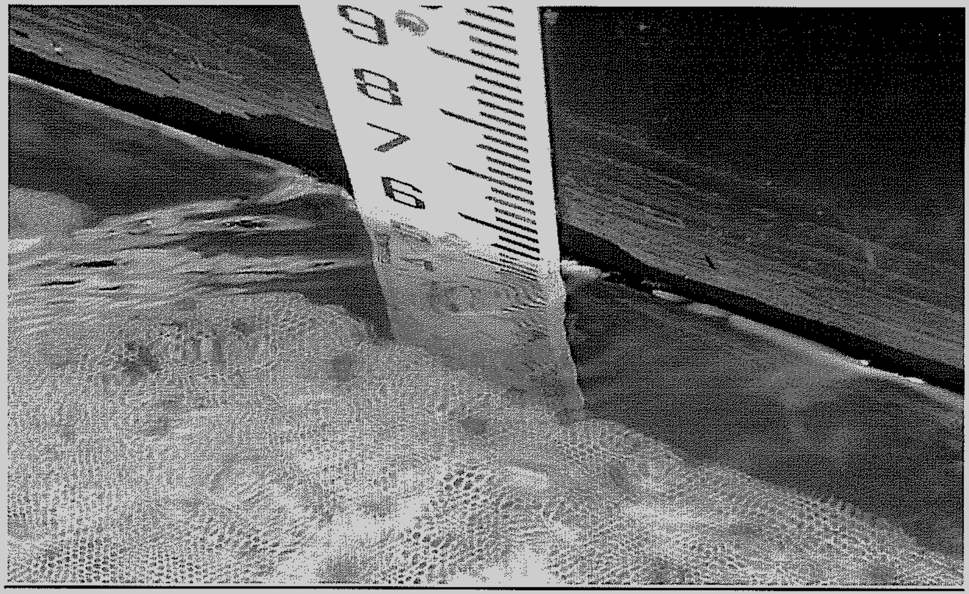


Image 6, downstream screen operating water depth

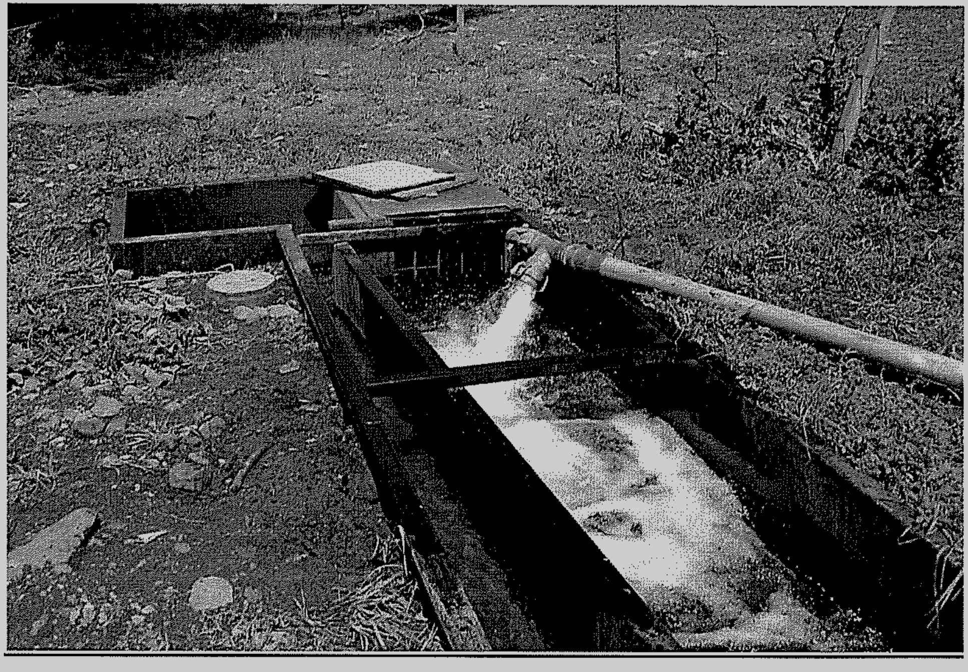
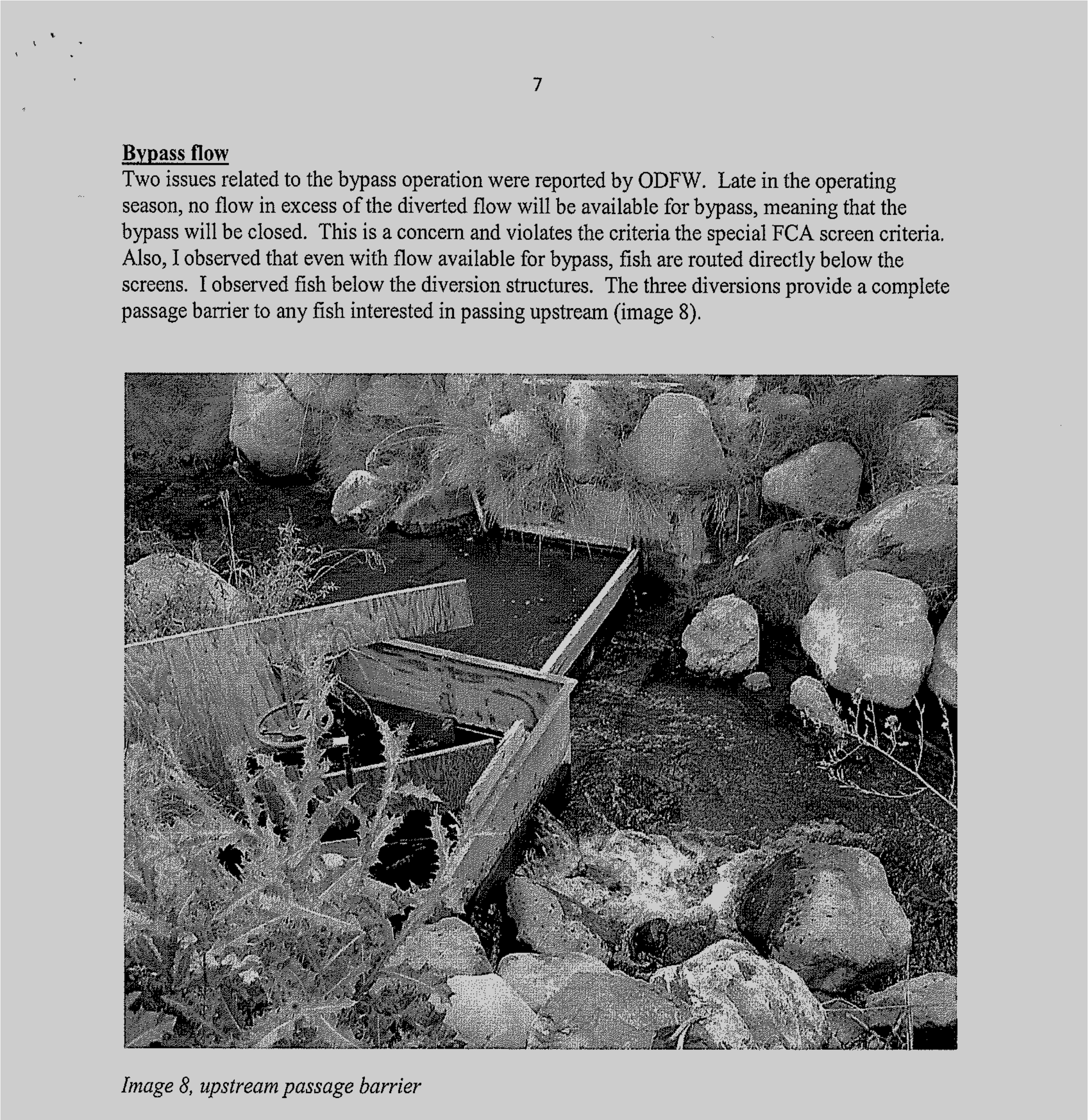


Image 7, downstream screen unusual operation with return flow to diverted water bay backwatering screen



Bypass flow

Two issues related to the bypass operation were reported by ODFW. Late in the operating season, no flow in excess of the diverted flow will be available for bypass, meaning that the bypass will be closed. This is a concern and violates the criteria the special FCA screen criteria. Also, I observed that even with flow available for bypass, fish are routed directly below the screens. I observed fish below the diversion structures. The three diversions provide a complete passage barrier to any fish interested in passing upstream (image 8).

Image 8, upstream passage barrier

FCA Response:

The necessity of by-pass flow has been of primary concern to all project partners throughout the duration of this project. FCA's understanding was that the diversions would be shut-off when flows dropped low enough to violate operating principles. FCA would agree that the screen should never be operated without adequate by-pass flow.

During low flows these diversion structures are passage barriers but they weren't addressed at the time of screen installation. The passage barriers existed prior to this project and were not addressed as part of this screen project.

Conclusion:

FCA is committed to working with all project partners to identify and implement solutions to the issues associated with the project. FCA has been performing regular monitoring throughout the irrigation season and has been meeting on site regularly with ODFW and BPA as well as the landowners. Solutions to the problems cited by NMFS have been identified and are being implemented by ODFW and FCA.

BIOLOGICAL EVALUATIONS OF AN OFF-STREAM CHANNEL, HORIZONTAL FLAT-PLATE FISH SCREEN—THE FARMERS SCREEN

Prepared by:
Matthew G. Mesa, Brien P. Rose, and Elizabeth S. Copeland
U. S. Geological Survey
Western Fisheries Research Center
Columbia River Research Laboratory
5501 Cook-Underwood Road
Cook, WA. 98605

Submitted to:
Farmers Conservation Alliance
14 Oak St, Suite 302
Hood River, OR 97031

Date submitted:
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Introduction

Diversions from natural or manmade waterways are common in the United States and used for many purposes. Many diversions are screened with devices meant to prevent fish and other aquatic life from becoming entrained, injured, or killed. However, many thousands of water diversions remain unscreened. Some screening technology (e.g., submersible traveling screens or rotary drum screens) and design criteria meant to protect fish (NOAA 2004) result in relatively expensive and high maintenance facilities (McMichael et al. 2004), which can limit the installation of screens in areas where they are needed. Recently, however, the development of unique horizontal flat plate fish screens offer designs that are 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; Rose and Mesa 2008), but more work is needed. Evaluating different designs and sizes of horizontal flat plate screens, both in the laboratory and in the field, would allow further verification of their performance, provide data for comparison with criteria for more traditional fish screens, and perhaps facilitate their installation. Also, evaluating the impacts of these screens on fishes besides salmonids—such as juvenile lampreys—would be informative.

We evaluated the hydraulic and biological performance of a new, off-stream channel horizontal flat plate fish screen, a.k.a. 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 provide lower installation and maintenance costs. The screens come in various sizes and a large, 2.3 m^3/s (80 cfs) version has been subjected to hydraulic, debris-loading, and biological tests to evaluate injury and mortality to juvenile and kelt salmonids, including Chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss*. The results showed that the large Farmers Screen did not cause injury or mortality to fish when operated in accordance with its design parameters (FID, 2003). However, smaller versions of this screen have not been tested. Evaluations of smaller versions of the Farmers Screen would help to more fully evaluate the performance of these alternative technology screens. Specifically, our objectives were to assess:

(1) the hydraulic performance of a small version of the Farmers Screen under different environmental conditions; and (2) the effects of passage over the screen on fish injury and delayed mortality.

Methods

The screen we evaluated was located at the Oxbow National Fish Hatchery in Cascade Locks, Oregon. 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 (10 cfs) of water. The installation is representative of 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 http://www.farmerscreen.org/. For purposes of this report, we refer to the screen as the Herman Creek screen.

To assess the hydraulic performance of the Herman Creek screen, we adjusted the inflow entering the screen, measured it 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 percent open area of the screen, or AV × 0.5) under different weir wall heights. After most of these measurements, we experimentally released fish over the screen (see below), but for some, we did not release fish. We evaluated the screen under four weir wall heights (i.e., 4, 11, 13, and 20 cm; or 1.6, 4.3, 5.1, and 7.8 inches) and at inflows ranging from 0.02 – 0.42 m^3/s (0.71 – 14.8 cfs).

To assess the biological performance of the Herman Creek screen, we experimentally released groups of juvenile coho salmon *O. kistuch* over the screen under different hydraulic conditions and quantified 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 FL) and small (54 – 78 mm), in two separate sets of trials. Fish that passed over the screen (treatment fish) were released in groups of 10, 1-2 m above the upper edge of the screen and recaptured in a net below 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 were euthanized in a lethal dose of MS-222 (200mg/L), rinsed in a fresh water bath for 1 min, and then placed in a solution of fluorescein dye (fluorescein disodium salt at 20mg/L). After 6 minutes, fish were removed from the dye and rinsed in three separate fresh water 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 we used a yellow barrier filter to eliminate the blue auto-fluorescence. Images were imported into Photoshop CS3 and we measured the body surface area and area of fluorescence for each side of a fish. The percent body surface area of a fish that was injured was derived by dividing the total area of fluorescence by the total body surface area. We calculated the mean (and SD) body surface area that was injured for each release group and compared control and treatment fish using two-sample, one-tailed *t*-tests. We were interested in whether the mean level of injury in treatment fish was significantly higher than background levels of control fish. The level of significance was set at $P < 0.05$. To assess delayed mortality after passage, 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.

We also videotaped the passage of treatment fish over the screen using three underwater cameras mounted to one edge of the screen. Each camera provided only a partial, upstream view of the screen and the system was not designed to cover the entire screen area. 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.

Results

A summary of hydraulic conditions measured at the Herman Creek screen and the numbers of coho salmon released for injury and delayed mortality assessments is shown in Table 1. Diversion discharges (the volume of water collected from the screen and sent to the hatchery) comprised from 65% to 100% of the inflow rates. Mean AVs estimated for the entire screen ranged from 0 to 5 cm/s (0 – 0.16 ft/s) and for individual sections of the screen never exceeded 6 cm/s (0.20 ft/s). Mean NVs ranged from 0 – 10 cm/s (0 – 0.33 ft/s) and varied along the length of the screen (Figure 1).. Mean SVs ranged from 36 to 178 cm/s (1.2 – 5.8 ft/s) and were generally faster at the upstream edge and slower at the downstream edge of the screening panels.

Mean SVs were usually at least 32 times higher than AVs for all conditions tested. The mean Z ranged from 1 to 25 cm (0.39 – 9.8 inches) and was generally deeper at the upstream than at the downstream end of the screen. Mean depths were directly related to weir wall height and inflow and were inversely related to diversion discharge, mean SVs were inversely related to weir wall height and diversion discharge and were directly related to inflow, and diversion discharge was related to several variables (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 – 2.5% (Figure 2). The mean percentage of body surface area that was injured in treatment fish was significantly higher than control fish for two test conditions (*t*-tests, $P<0.05$; Figure 2), but the magnitude of these differences was small (< 1%). For small fish, the mean percentage of body surface area that was injured ranged from about 0.4 – 3.0% (Figure 3). The mean percentage of body surface area that was injured in treatment fish was significantly higher than control fish for one test conditions (Figure 3), but again, the magnitude of this difference was small. One small fish, shown as an outlier in Figure 3 with about 60% of its body surface area injured, was probably injured by something other than passage over the screen. Individual injury rates for every fish in our tests are presented in Appendix A. 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.

For large fish, the mean number of times fish contacted the screen surface ranged from 0.15 – 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 up and 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 – 0.62 per fish observed (Table 4). Again, most fish remained low in the water column and near the screen surface during passage (Table 4). Most fish were oriented upstream during passage (Table 4).

Discussion

Our results indicate that passage of juvenile coho salmon over the Herman Creek screen under a variety of hydraulic conditions did not severely injure them or cause delayed mortality.

This occurred even though most fish passed over the screen near the screen surface, many contacted the screen during passage, and they were oriented to the current in a variety of directions. However, we never observed fish becoming impinged on the screen surface (i.e., >1 s 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 Mesa (2008), who reported minimal injuries to 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 (e.g., Danley et al. 2002; Zydlewski and Johnson 2002; Nobriga et al. 2004).

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 fluoroscein dye method was effective for detecting injuries to the integument and essentially resulted in all of our fish having some level of injury. However, as we stated previously, 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. Further, and perhaps more importantly, all of our fish would have far exceeded the performance standards for safe passage of fish over conventional screen systems as established by NOAA-Fisheries. For example, performance standards set by NOAA-Fisheries include less than 0.5% mortality and ≤ 2% injury rate (i.e., the percent of a sample that is injured) for salmonid smolts. 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, etc.), loss of equilibrium, or greater than 20% descaling on one side (Bryan Nordlund, NOAA-Fisheries, personal communication).. Because none of our fish showed such injuries and mortality was lower than 0.5%, the Herman Creek screen would surpass these NOAA-Fisheries standards. Although the performance standards discussed here are for other types of screens, they do indicate that screens like the one at Herman Creek would probably, at a minimum, meet federal regulatory standards.

The ability of the Herman Creek screen to safely pass fish—at water depths ranging from 7 – 25 cm (3 – 10 inches)—was largely due to achieving a high ratio of SV to AV under a variety of diversion scenarios. The ratios of SV to AV in our study ranged from about 30 – 60, which are substantially higher than the 2:1 SV: AV criteria established by NOAA-Fisheries for passive screens. The combination of high SVs and low AVs facilitated quick fish passage, eliminated impingements, and resulted in good self-cleaning. That most fish passed over the screen near the screen surface—regardless of water depth—suggests that water depth criteria previously established for larger versions of the Farmers Screen (i.e., 30 cm or 12 inches) could be relaxed for smaller screens like the one at Herman Creek. Although we safely passed fish over the screen at a depth of only 7 cm (2.8 inches), the number of screen contacts per fish was higher 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 (12 inches), we cannot unequivocally recommend a single, specific minimum depth for this screen. Rather, a range of minimum depths, perhaps from 15 – 20 cm (6 – 8 inches), would probably 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 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 two size groups of juvenile coho salmon we used were probably good surrogates for other salmonids of similar size. Extrapolation of our results to other fishes, such as juvenile lampreys, seems inappropriate and would require further testing. Finally, 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.

In summary, when operated within its design criteria (i.e., diversion flows of about 0.28 m^3/s or 10 cfs), the Herman Creek screen provided safe and effective passage of juvenile salmonids under a variety of hydraulic conditions. We do not recommend operating the Herman Creek screen at inflows lower than 5 cfs because water depth can get quite shallow and the screen can completely dewater, particularly at very low flows. If the screen is operated at inflows lower than 5 cfs, 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. Our research only provided crude estimates of the time it takes for fish pass over the screen under various hydraulic conditions. Future work, if necessary, should address this issue using more appropriate techniques (e.g., PIT tag studies). Finally, we do not know the fate of fish that pass over the screen, enter the bypass channel, and are diverted back to Herman Creek. 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 is not an idea 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.

Acknowledgements

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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 assessments (and delayed mortality tests). 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.

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[a])				
0.15	0.10	0.05	72 (12)	2	22 (1)	38	14		
0.15	0.10	0.05	73 (12)	2	23 (0[a])			40 (44)	20 (15)
0.27	0.20	0.07	100 (15)	3	25 (1)			40 (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 the relation between hydraulic variables measured at the Herman Creek screen, 2009. All coefficients are significant ($P < 0.05$) unless noted. AV = approach velocity (cm/s); SV = sweeping velocity (cm/s); Z = depth of water over screen (cm); SQ = inflow discharge (m^3/s); DQ = diversion discharge (m^3/s); WW = weir wall height (cm); SEE = standard error of estimate.

Dependent variable	Equation
Depth	$Z = 2.592^{a} + 0.572\ (WW) + 89.673\ (SQ) - 75.712\ (DQ)$
	$N = 24$, $R^2 = 0.84$, $SEE = 2.27$
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	$SV = 105.007 - 4.863\ (WW) + 1{,}166.178\ (SQ) - 1{,}063.394\ (\mathrm{DQ})$
	$N = 24$ $R^2 = 0.81$, $SEE = 17.82$

[a] 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.

Date	AV (cm/s)	SV (cm/s; mean [SD])	Water Depth (cm)	Mean (SD) number of screen contacts per fish	Depth in water column (% of observed)			Orientation (% of observed)		
					low	mid	high	up stream	down stream	other
2/27	2	87 (41)	7	0.72 (0.58)	50	23	4	41	59	0
2/17	4	137 (49)	11	0.45 (0.23)	41	54	5	36	60	4
3/4	5	171 (41)	12	0.47(0.24)	41	21	4	59	41	0
3/2	2	101 (30)	14	0.26 (0.18)	50	23	2	37	63	0
2/18	3	161 (23)	16	0.41(0.23)	35	34	13	60	40	0
3/3	5	161 (30)	18	0.15(0.18)	49	23	2	27	73	0
2/24	2	72 (12)	22	0.41 (0.34)	49	19	5	56	44	0
2/19	3	115 (17)	24	0.41 (0.33)	42	19	5	39	61	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.

Date	AV (cm/s)	SV (cm/s; mean [SD])	Water Depth (cm)	Mean (SD) number of contact per fish	Depth in water column (% of observed)			Orientation (% of observed)		
					low	mid	high	up stream	down stream	other
5/19	2	120 (50)	9 (1)	0.32 (0.14)	57	40	3	56	40	4
5/20	5	173 (45)	12 (1)	0.50 (0.30)	63	33	4	61	15	24
5/15	2	106 (30)	14 (1)	0.56 (0.26)	58	32	10	55	41	4
5/13	3	143 (30)	16 (1)	0.42 (0.25)	49	37	14	44	38	18
5/14	4	178 (32)	19 (1)	0.62 (0.35)	65	23	12	53	35	12
5/8	2	73 (12)	23 (0)	0.26 (0.22)	69	23	7	70	30	0
5/12	3	100 (15)	25 (1)	0.35 (0.21)	55	29	20	61	36	2

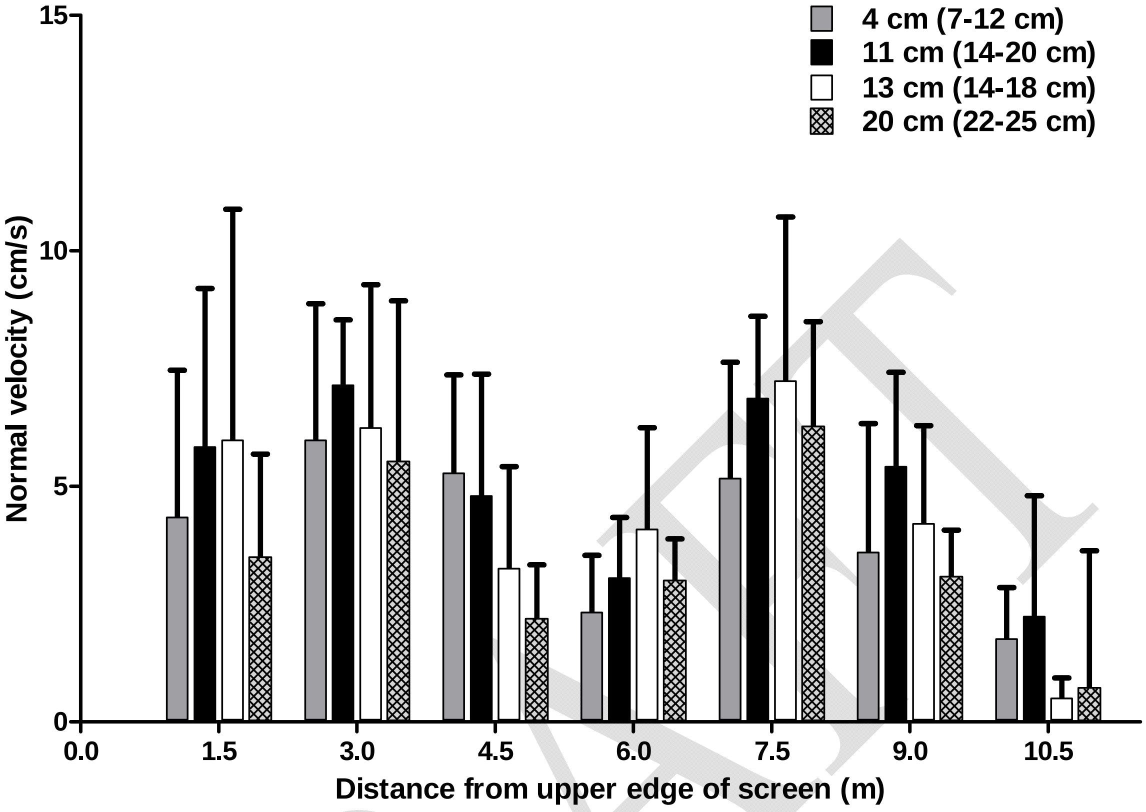

Figure 1.—Mean (and SD) normal velocities (approach velocities corrected for the net open area of the screen) estimated for different sections of the Herman Creek screen relative to weir wall height and water depth (in parentheses), 2009.

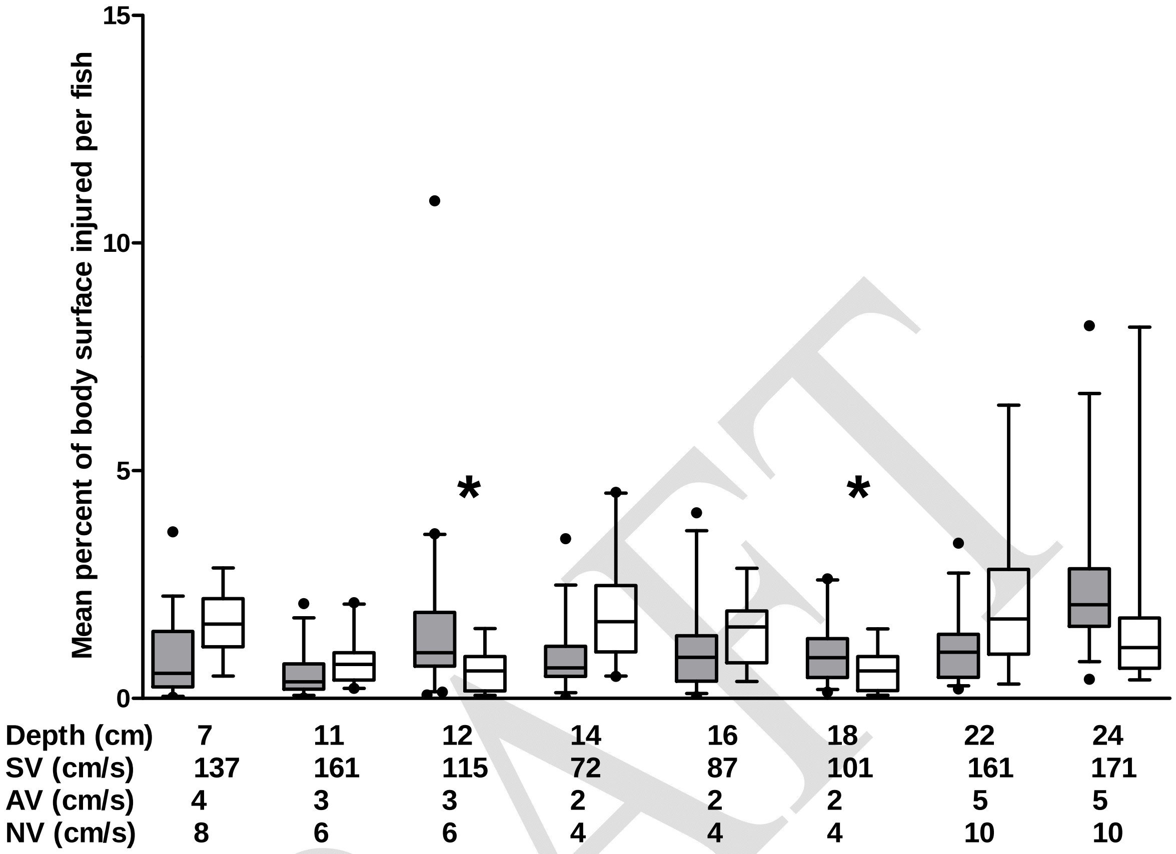

Figure 2.—Box and whisker plots of the percent body surface area injured in large juvenile coho salmon released over the Herman Creek screen (grey boxes) under different hydraulic conditions relative to control fish (white boxes). The upper and lower boundaries of the box represent the 25th and 75th quartiles, the 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, the mean sweeping velocity (SV), the approach velocity (AV), and the normal velocity (NV) during each trial. Asterisks denote a significant difference between means within a group (one-tailed *t*-test, $P < 0.05$).

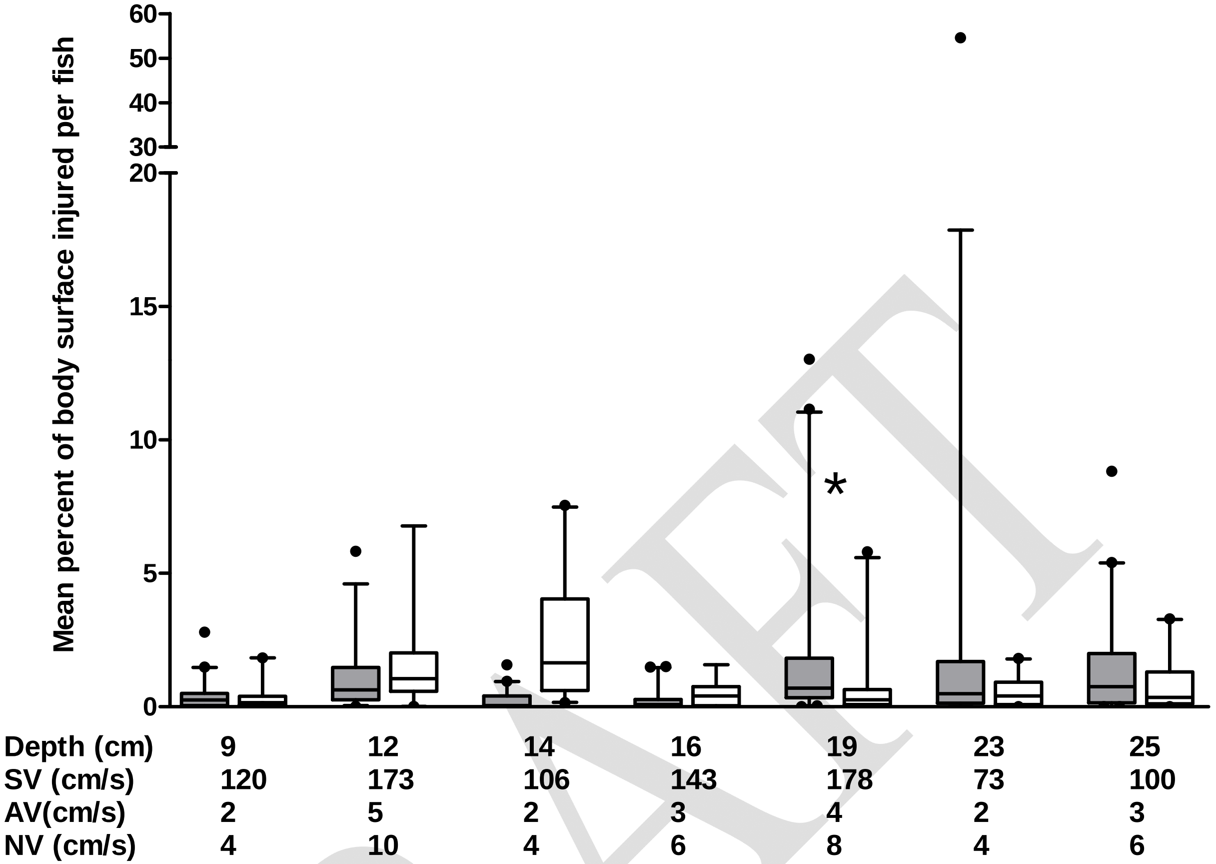

Figure 3.—Box and whisker plots of the percent body surface area injured in small juvenile coho salmon released over the Herman Creek screen (grey boxes) under different hydraulic conditions relative to control fish (white boxes). The upper and lower boundaries of the box represent the 25th and 75th quartiles, the 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, the mean sweeping velocity (SV), the approach velocity (AV), and the normal velocity (NV) during each trial. Asterisks denote a significant difference between means within a group (one-tailed *t*-test, $P < 0.05$).

Appendix A. *Size and body surface area injured of large-sized juvenile coho salmon tested under differing suites of hydraulic conditions at the Herman Creek Screen.*

Table A.1. Fork length (mm), weight (g), and mean percent of body surface area injured for large-sized individual juvenile coho salmon that passed over the Herman Creek Screen (treatment fish) or did not (control fish). This test was done on 17 February 2009 and used a weir wall height of 4 cm (2 inches), inflow discharge of 0.27 m^3/s (9.5 cfs), diversion discharge of 0.25 m^3/s (8.8 cfs), bypass discharge of 0.02 m^3/s (0.7 cfs), SV of 137 cm/s (4.5 ft/s), AV of 4 cm/s (0.13 ft/s), NV of 8 cm/s (0.26 ft/s) and Z of 11 cm (4.3 inches).

Treatment			Treatment			Control		
FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury
125	18.5	0.3	120	17.7	0.3	122	19.3	2.1
129	21.7	0.2	133	23.5	0.7	115	15.5	0.6
109	11.8	0.3	131	22.3	0.5	128	21.7	0.8
113	15.3	0.2	108	12.5	0.6	121	18.2	0.9
120	18.0	0.2	132	22.0	0.1	129	22.6	0.8
119	17.2	0.1	113	14.6	0.7	110	14.4	1.1
124	20.3	0.3	120	18.1	0.8	130	23.0	1.0
120	19.4	0.2	120	17.5	0.3	120	17.0	0.2
124	18.6	0.1	126	21.1	1.1	123	20.2	0.4
110	12.5	2.1	124	19.2	1.8	120	18.9	0.8
123	18.7	0.4	127	21.1	0.3	127	21.8	0.2
122	19.4	1.5	115	15.3	0.1	119	16.0	0.4
115	17.8	1.5	109	12.9	0.2	119	18.0	0.5
115	16.0	0.8	125	22.3	0.4	120	19.1	0.7
126	20.8	0.2	124	19.0	0.4	125	19.7	0.3
120	17.7	0.0	110	13.2	0.5	126	21.4	0.2
110	14.4	1.1	123	18.7	1.4	117	17.5	1.1
123	19.0	0.4				109	13.5	0.8
123	20.0	0.4				119	16.2	0.7
108	11.6	0.3				115	15.3	1.5
105	10.9	0.6						

Table A.2. Fork length (mm), weight (g), and mean percent of body surface area injured for large-sized individual juvenile coho salmon that passed over the Herman Creek Screen (treatment fish) or did not (control fish). This test was done on 18 February 2009 and used a weir wall height of 11 cm (4 inches), inflow discharge of 0.29 m^3/s (10.2 cfs), diversion discharge of 0.23 m^3/s (8.1 cfs), bypass discharge of 0.05 m^3/s (1.8 cfs), SV of 161 cm/s (5.3 ft/s), AV of 3 cm/s (0.10ft/s), NV of 6 cm/s (0.20ft/s) and Z of 16 cm (6.3 inches).

Treatment			**Treatment**			**Control**		
FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury
85	6.2	1.1	120	18.3	0.4	136	29.9	0.5
128	16.7	0.8	124	21.4	0.1	126	23.1	1.3
123	17.5	0.5	104	9.3	0.4	130	22.3	0.7
117	17.3	2.2	135	23	4.1	114	15.3	0.5
114	15.2	1.0	130	22.7	1.2	120	19.7	0.9
127	20.7	2.2	120	18.5	2.0	122	20.6	1.6
115	15.5	1.5	122	17.7	2.4	125	22.0	1.5
109	12.8	0.8	130	21.8	0.6	126	21.4	1.7
129	20.6	1.6	129	21.6	1.0	122	17.8	2.9
126	20	1.2	107	12	1.3	116	16.8	2.4
119	13.9	2.2	113	13	1.2	121	21.4	2.1
117	17.1	0.0	126	21.3	0.7	120	18.7	1.6
121	19.5	1.3	118	17.3	3.7	103	10.4	0.4
121	19.1	0.1	118	17.5	0.4	132	23.2	1.6
109	12.5	0.3	124	20.4	1.0	110	14.2	1.4
122	18.3	1.1	109	14.3	0.5	124	20.4	2.5
115	16.3	0.3	114	14.5	0.8	119	17.2	1.7
120	19.5	0.2						
129	22.5	0.3						
115	16.4	0.3						
120	19.0	0.2						

Table A.3. Fork length (mm), weight (g), and mean percent of body surface area injured for large-sized individual juvenile coho salmon that passed over the Herman Creek Screen (treatment fish) or did not (control fish). This test was done on 19 February 2009 and used a weir wall height of 20 cm (8 inches), inflow discharge of 0.28 m^3/s (9.9 cfs), diversion discharge of 0.22 m^3/s (7.8 cfs), bypass discharge of 0.06 m^3/s (2.1 cfs), SV of 115 cm/s (3.8 ft/s), AV of 3 cm/s (0.10ft/s), NV of 6 cm/s (0.20ft/s) and Z of 24 cm (9.4 inches).

Treatment			**Treatment**			**Control**		
FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury
125	20.2	2.0	118	16.5	0.4	108	10.0	8.2
125	19.2	2.5	125	20.5	1.6	117	17.2	0.5
112	13.8	2.4	130	22.9	1.8	121	17.6	1.3
111	13.2	6.7	136	25.4	2.2	122	8.9	0.5
122	20.0	3.8	130	23.3	0.8	122	17.9	0.7
134	23.4	4.1	113	14	2.1	123	19.2	1.8
117	15.5	3.6	140	23.7	2.2	120	16.5	1.3
121	18.1	1.4	124	19.4	1.1	122	19.5	2.8
120	18.6	0.9	120	17.2	2.1	124	18.3	1.5
116	16.0	3.9	115	16.3	1.7	113	14.1	0.7
113	14.3	1.8	134	23.1	1.4	118	17.2	0.8
115	16.0	2.5	122	17	1.9	116	15.7	1.0
116	15.1	1.0	119	16.2	2.3	112	15.3	0.4
116	16.7	1.7	126	19.4	1.9	126	20.0	1.1
114	14.3	5.5	130	21.8	0.9	103	11.0	1.8
119	16.1	2.1	109	12.8	2.4			
123	19.8	1.6	135	24.9	1.1			
130	21.9	2.8	125	19.8	1.6			
127	20.2	3.1						
120	16.6	6.3						
120	16.3	8.2						

Table A.4. Fork length (mm), weight (g), and mean percent of body surface area injured for large-sized individual juvenile coho salmon that passed over the Herman Creek Screen (treatment fish) or did not (control fish). This test was done on 24 February 2009 and used a weir wall height of 20 cm (8 inches), inflow discharge of 0.15 m^3/s (5.3 cfs), diversion discharge of 0.10 m^3/s (3.5 cfs), bypass discharge of 0.05 m^3/s (1.8 cfs), SV of 72 cm/s (2.4 ft/s), AV of 2 cm/s (0.07 ft/s), NV of 4 cm/s (0.13ft/s) and Z of 22 cm (8.7 inches).

Treatment			**Treatment**			**Control**		
FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury
121	20.2	1.9	119	16.5	0.3	121	20.2	2.5
117	16.1	0.6	120	18.5	2.4	110	14.2	3.4
118	17.8	1.7	125	22.8	1.2	126	20.5	0.3
119	17.6	1.4	125	18.8	1.3	125	20.6	0.7
114	17.8	0.4	139	25.3	1.7	120	16.4	1.5
132	24.4	1.1	120	19.3	1.4	117	16.7	1.0
120	18.3	2.4	128	21.5	1.2	110	14.4	2.1
123	25	0.6	115	14.9	0.6	117	16.9	6.4
112	14.5	0.6	132	23.7	1.3	94	8	3.6
119	18.7	1.0	123	18.8	1.2	134	26.7	1.7
127	23	1.0	122	18.6	1.2	117	16.3	1.6
138	29.6	2.4	121	15.4	3.4	132	23.9	1.8
129	23.1	0.4	109	12.8	0.9	130	22	0.8
140	28.8	0.3	132	25	0.8	122	19.6	2.6
128	22	0.3	126	21.6	0.5			
119	17.7	0.2	105	12.1	0.7			
125	18.2	1.0	127	20.9	2.7			
123	18.7	1.2						
120	18.7	0.4						
124	20.3	0.3						
125	18.4	0.4						

Table A.5. Fork length (mm), weight (g), and mean percent of body surface area injured for large-sized individual juvenile coho salmon that passed over the Herman Creek Screen (treatment fish) or did not (control fish). This test was done on 27 February 2009 and used a weir wall height of 4 cm (2 inches), inflow discharge of 0.14 m^3/s (4.9 cfs), diversion discharge of 0.13 m^3/s (4.6 cfs), bypass discharge of 0.01 m^3/s (0.4 cfs), SV of 87 cm/s (2.9 ft/s), AV of 2 cm/s (0.07 ft/s), NV of 4 cm/s (0.13ft/s) and Z of 7cm (2.8 inches).

Treatment			**Treatment**			**Control**		
FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury
130	22.6	0.9	120	17.1	0.8	113	12.8	2.2
120	18.4	1.2	117	16.0	0.1	120	16.6	1.1
132	22.7	1.6	129	19.5	0.4	115	12.7	1.4
113	13.4	1.8	118	15.8	0.1	124	19.7	1.1
125	18.5	1.2	132	22.0	1.7	131	22.6	1.8
116	14.7	1.8	114	14.3	0.1	112	14.5	1.6
130	23.8	1.6	123	17.5	0.0	127	19.2	2.9
120	16.8	0.5	114	13.8	0.6	115	15.1	2.6
120	16.7	0.4	113	13.1	0.3	114	14.1	1.2
121	18.5	0.4	130	22.0	1.1	122	17.5	0.5
127	19.0	1.2	122	18.8	0.3	115	14.3	2.1
113	14.0	0.1	113	14.0	0.4	125	18.5	1.3
120	17.8	0.2	138	26.3	0.2	121	18.5	1.7
124	20.0	1.2	128	20.9	0.0	117	15.2	1.6
117	16.5	1.9	121	18.8	0.3	115	15.3	1.3
119	15.5	1.4	133	25.2	0.2	127	20.2	2.6
118	15.4	2.1				122	16.8	0.8
126	18.2	3.7						
118	17.1	1.8						
123	18.6	0.9						
120	16.3	0.5						

Table A.6. Fork length (mm), weight (g), and mean percent of body surface area injured for large-sized individual juvenile coho salmon that passed over the Herman Creek Screen (treatment fish) or did not (control fish). This test was done on 2 March 2009 and used a weir wall height of 11 cm (4 inches), inflow discharge of 0.14 m^3/s (4.9 cfs), diversion discharge of 0.11 m^3/s (3.9 cfs), bypass discharge of 0.03 m^3/s (1.1 cfs), SV of 101 cm/s (3.3 ft/s), AV of 2 cm/s (0.07 ft/s), NV of 4 cm/s (0.13 ft/s) and Z of 14 cm (5.5 inches).

Treatment			**Treatment**			**Control**		
FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury
112	15.2	1.1	125	18.8	0.7	128	19.9	0.8
112	14.9	0.5	119	16.4	1.0	126	22.8	1.2
121	18.8	2.4	127	20.2	1.1	119	15.1	2.9
116	16.7	0.3	123	17.9	0.6	124	18.2	1.6
118	16.1	0.8	123	17.1	1.4	136	25.1	1.4
114	14.9	0.2	118	20.6	0.8	115	15.2	0.7
132	24.1	1.3	124	18.1	0.6	128	21.3	0.9
120	17.9	0.6	120	17.3	0.0	116	16.3	0.5
120	18.2	0.5	123	18.6	1.0	115	16.7	1.0
133	25.5	0.3	134	21.7	0.8	120	17.4	1.8
135	24.5	1.0	125	17.9	0.4	113	13.7	1.4
110	13.1	0.7	129	21.1	0.1	120	16.2	4.2
124	17.8	2.4	122	18.1	1.1	125	22	2.5
124	18.8	3.5	112	13.5	2.4	113	13.9	2.4
129	21.1	0.4	125	19.6	0.7	122	16.8	2.4
117	15.7	2.5	96	9.6	0.6	126	21.1	1.5
123	18.1	0.4	125	18.9	0.5	115	14.8	4.5
114	14.2	0.6	116	15.7	1.4	120	17.3	2.9
112	13.4	0.5				115	15.2	2.4
129	22.0	1.3				123	16.9	2.0
115	14.4	0.6						

Table A.7. Fork length (mm), weight (g), and mean percent of body surface area injured for large-sized individual juvenile coho salmon that passed over the Herman Creek Screen (treatment fish) or did not (control fish). This test was done on 3 March 2009 and used a weir wall height of 11 cm (4 inches), inflow discharge of 0.42 m^3/s (14.8 cfs), diversion discharge of 0.34 m^3/s (12.0 cfs), bypass discharge of 0.07 m^3/s (2.5 cfs), SV of 161 cm/s (5.3 ft/s), AV of 5 cm/s (0.16 ft/s), NV of 10 cm/s (0.33 ft/s) and Z of 18 cm (7.1 inches).

Treatment			**Treatment**			**Control**		
FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury
114	15.9	0.1	113	12.5	0.3	115	14.7	0.9
115	16.4	0.4	120	16	0.9	126	18.3	0.2
110	14.1	0.9	122	17.5	1.3	115	15.1	0.2
128	21.1	2.0	130	21.5	0.4	128	19.6	1.3
117	15.1	0.4	127	19.4	1.0	120	17.3	0.8
128	22.5	0.6	132	21.3	1.0	120	18.2	0.1
145	29.4	1.3	125	19.6	1.3	140	26.4	0.3
115	15	0.9	135	24.3	0.7	133	22	0.3
115	13.5	0.9	125	18.2	0.5	124	17.6	0.6
125	18.6	2.5	127	20	2.6	120	16.4	0.9
126	18.3	0.7	128	19.9	0.4	131	21.8	0.9
124	18	0.7	127	18.8	1.0	121	16.3	1.0
145	28.6	2.4	125	18.1	1.6	120	16.6	0.3
124	17.8	0.9	122	17.2	1.1	123	18.4	1.5
114	13.6	0.6	118	15.4	0.8	129	21.7	0.1
115	14.6	0.3	122	18.2	1.0			
127	20.1	0.8	133	20.6	2.6			
117	15.6	2.0						
124	19.7	0.7						
119	16.1	0.2						
123	18.6	0.2						

Table A.8. Fork length (mm), weight (g), and mean percent of body surface area injured for large-sized individual juvenile coho salmon that passed over the Herman Creek Screen (treatment fish) or did not (control fish). This test was done on 4 March 2009 and used a weir wall height of 4 cm (2 inches), inflow discharge of 0.36 m^3/s (12.7 cfs), diversion discharge of 0.33 m^3/s (11.7 cfs), bypass discharge of 0.03 m^3/s (1.1 cfs), SV of 171 cm/s (5.6 ft/s), AV of 5 cm/s (0.16 ft/s), NV of 10 cm/s (0.33 ft/s) and Z of 12 cm (4.7 inches).

Treatment			**Treatment**			**Control**		
FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury
115	15.2	1.0	121	15.2	0.8	121	16.3	1.0
128	20.0	0.9	127	17.4	0.1	120	16.6	0.3
119	16.0	0.9	120	16.7	0.1	126	18.3	0.2
115	14.9	1.1	125	18.1	1.9	129	21.7	0.1
128	20.7	0.8	119	15.3	1.0	115	15.1	0.2
124	19.6	3.4	128	20.5	10.9	128	19.6	1.3
132	23.1	0.7	120	16.6	0.5	120	17.3	0.8
116	15.7	0.3	125	17.5	3.4	120	18.2	0.1
132	24.4	0.8	118	14.7	0.9	123	18.4	1.5
134	22.2	0.4	123	19.0	2.2	133	22.0	0.3
130	23.6	0.8	129	19.5	2.2	115	14.7	0.9
118	17.1	0.7	128	22.7	2.1	124	17.6	0.6
125	19.6	1.1	125	19.4	3.5	131	21.8	0.9
122	18.6	1.9	125	20.0	1.2	120	16.4	0.9
124	18.5	2.2	130	23.5	0.6	140	26.4	0.3
117	15.5	1.4	130	23.9	1.4			
120	17.7	1.1	135	24.0	1.0			
130	21.4	3.6	138	24.8	1.5			
122	18.0	1.3	128	20.8	0.7			
126	19.5	0.2	130	21.2	1.4			
120	16.6	0.5						

Appendix B. *Size and body surface area injured of small-sized juvenile coho salmon tested under differing suites of hydraulic conditions at the Herman Creek Screen.*

Table B.1. Fork length (mm), weight (g), and mean percent of body surface area injured for small-sized individual juvenile coho salmon that passed over the Herman Creek Screen (treatment fish) or did not (control fish). This test was done on 8 May 2009 and used a weir wall height of 20 cm (8 inches), inflow discharge of 0.15 m^3/s (5.3 cfs), diversion discharge of 0.1 m^3/s (3.5 cfs), bypass discharge of 0.05 m^3/s (1.8 cfs), SV of 73 cm/s (2.4 ft/s), AV of 2 cm/s (0.07 ft/s), NV of 4 cm/s (0.13 ft/s) and Z of 23 cm (9.1 inches). A blank cell indicates data not available.

Treatment			**Treatment**			**Control**		
FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury
69		2.8	68	3.3	0.0	70		0.3
72		1.2	70	3.4	0.0	70		0.4
70		3.6	64	2.5	0.4	77		1.8
74		2.4	67		0.5	74		0.4
68		0.2	68		0.5	67		0.1
70		4.1	68		0.5	63		0.2
67		54.6	68	3.6	0.3	70		0.5
72		11.4	67		1.7	70		1.4
70	3.3	3.6	75		8.3	68		0.1
69	3.5	0.0	65		0.2	72		1.0
73	3.8	1.1	68		0.1	70		0.3
67	3.4	0.5	70		0.1	72		0.4
68	3.5	0.1	69	3.4	0.1	63		1.0
68	2.9	0.6	70		0.1	68		0.0
73	3.8	0.2	73	3.9	1.1	72		0.8
69	3.8	0.1	64		0.2	72		0.1
69		0.4				68		0.0
66	2.7	0.1				69		0.1
62	3.4	1.7				69		0.5
73	4.4	0.7				69		1.2

Table B.2. Fork length (mm), weight (g), and mean percent of body surface area injured for small-sized individual juvenile coho salmon that passed over the Herman Creek Screen (treatment fish) or did not (control fish). This test was done on 12 May 2009 and used a weir wall height of 20 cm (8 inches), inflow discharge of 0.27 m^3/s (9.5 cfs), diversion discharge of 0.20 m^3/s (7.1 cfs), bypass discharge of 0.07 m^3/s (2.5 cfs), SV of 100 cm/s (3.3 ft/s), AV of 3 cm/s (0.10 ft/s), NV of 6 cm/s (0.20 ft/s) and Z of 25 cm (9.8 inches).

Treatment			**Treatment**			**Control**		
FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	Mean injury	FL (mm)	WT (g)	% injury
70	3.3	0.2	72	4	5.4	78	4.6	0.4
70	3.7	5.2	68	3	1.1	72	3.4	0.6
74	4.3	3.1	66	3.8	1.1	69	3.3	0.8
58	1.9	0.0	73	4.1	0.0	72	3.8	0.2
63	2.5	0.1	69	3.2	1.1	71	3.6	0.9
69	3.6	0.2	62	3	2.2	74	3.7	1.5
68	2.9	0.1	69	4.1	0.0	69	2.6	3.3
70	3.6	0.4	62	3	0.0	70	3.3	0.0
69	3.6	0.3	64	2.8	1.2	59	1.9	2.2
65	2.8	2.0	73	3.9	0.3	69	3.3	0.1
73	3.8	3.3	71	3.5	0.5	69	3.2	0.1
67	3.2	0.8	66	2.7	4.7	66	3	0.3
71	3.5	0.0	54	1.4	1.7	71	3.6	1.0
69	3	0.5	69	3.1	0.7	71	3.6	2.8
82	5	0.0	68	3	0.2	73	3.8	0.3
64	2.7	2.0				74	4	1.4
73	4.1	0.5				71	3.5	0.3
76	4	8.8				67	2.8	0.1
68	3.2	0.8				70	3.6	0.0
75	4.1	2.8				67	3	0.0

Table B.3. Fork length (mm), weight (g), and mean percent of body surface area injured for small-sized individual juvenile coho salmon that passed over the Herman Creek Screen (treatment fish) or did not (control fish). This test was done on 13 May 2009 and used a weir wall height of 11 cm (4 inches), inflow discharge of 0.29 m^3/s (10.2 cfs), diversion discharge of 0.23 m^3/s (8.1 cfs), bypass discharge of 0.06 m^3/s (2.1 cfs), SV of 143 cm/s (4.7 ft/s), AV of 3 cm/s (0.10 ft/s), NV of 6 cm/s (0.20 ft/s) and Z of 16 cm (6.3 inches).

Treatment			**Treatment**			**Control**		
FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury
69	3.7	0.1	67	3.3	0.2	70	3.4	0.7
70	3.6	1.0	70	3.4	0.5	70	3.6	0.0
70	3.7	0.3	68	3.1	0.0	76	4.3	1.6
70	3.4	0.2	70	3.3	0.2	70	3.6	0.0
69	3.1	0.1	75	4.4	0.0	73	3.5	0.0
68	3.2	0.0	68	3.4	0.0	70	3.4	0.1
66	2.9	0.1	70	3.5	0.1	69	3.2	0.7
68	3.3	0.1	68	3.1	0.3	69	3.4	0.5
64	2.3	0.4	67	3	0.3	68	3.5	0.7
71	3.4	0.0	71	4.5	1.5	72	3.4	0.3
70	3.3	0.0	67	3.3	0.0	66	2.8	0.1
65	2.6	0.3	67	3.3	0.0	77	4.2	0.9
73	4.1	0.0	73	4.7	0.1	73	3.8	0.9
68	2.9	0.0	70	3.3	0.0	70	3.2	0.0
66	3.1	0.0	63	2.7	0.2			
73	3.8	0.0	65	2.8	0.0			
68	3.2	0.0	72	3.4	0.1			
76	4.3	0.3	55	1.7	0.0			
67	2.8	0.6	72	3.6	0.2			
73	3.9	0.0						
70	3.3	1.5						

Table B.4. Fork length (mm), weight (g), and mean percent of body surface area injured for small-sized individual juvenile coho salmon that passed over the Herman Creek Screen (treatment fish) or did not (control fish). This test was done on 14 May 2009 and used a weir wall height of 11 cm (4 inches), inflow discharge of 0.34 m^3/s (12 cfs), diversion discharge of 0.26 m^3/s (9.2 cfs), bypass discharge of 0.08 m^3/s (2.8 cfs), SV of 178 cm/s (5.8 ft/s), AV of 4 cm/s (0.13 ft/s), NV of 8 cm/s (0.26 ft/s) and Z of 19 cm (7.5 inches).

Treatment			**Treatment**			**Control**		
FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury
71	3.6	0.1	73	3.7	0.3	70	3.3	0.7
74	3.9	11.1	70	3.5	1.8	70	3.3	1.4
72	3.5	0.7	78	4.9	1.5	70	3	0.3
70	3.6	7.4	67	3.2	10.1	68	3	0.9
71	3.5	0.3	73	3.8	0.8	78	4.5	1.2
67	3	0.0	78	4.1	0.4	74	3.8	0.5
73	4	0.5	65	3	1.6	69	3	0.3
70	3.6	0.4	68	3.1	0.7	69	3.1	0.0
65	2.8	0.0	70	3	0.8	67	3.1	5.8
63	2.7	0.1	75	3.4	0.7	66	2.7	0.1
69	3.3	0.2	67	2.8	3.0	66	2.8	0.3
72	3.8	0.7	77	4.5	0.5	64	2.4	0.0
70	3.2	0.7	68	3.1	6.7	75	4.1	0.2
72	3.6	0.5	71	3.6	1.9	65	2.6	0.0
69	3.1	1.1	69	2.9	0.4	77	4.3	0.2
69	3.1	0.1	75	3.9	0.4	68	3.1	0.4
74	3.7	1.1	65	2.6	5.1	70	3.1	0.1
69	3.1	13.0	73	4.1	4.2	60	2.1	0.0
71	3.5	0.9	69	3.4	0.0	65	2.6	0.2
74	3.7	0.2	72	3.3	2.0	70	3.3	0.4
67	2.7	0.7						

Table B.5. Fork length (mm), weight (g), and mean percent of body surface area injured for small-sized individual juvenile coho salmon that passed over the Herman Creek Screen (treatment fish) or did not (control fish). This test was done on 15 May 2009 and used a weir wall height of 11 cm (4 inches), inflow discharge of 0.15 m^3/s (5.3 cfs), diversion discharge of 0.12 m^3/s (4.2 cfs), bypass discharge of 0.03 m^3/s (1.1 cfs), SV of 106 cm/s (3.5 ft/s), AV of 2 cm/s (0.07 ft/s), NV of 4 cm/s (0.13 ft/s) and Z of 14 cm (5.5 inches).

Treatment			**Treatment**			**Control**		
FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury
75	3.8	0.4	65	2.6	0.0	68	3.4	7.5
76	4.2	1.6	74	3.8	0.0	70	3.6	1.2
71	3.3	0.1	65	2.5	0.6	69	3.2	0.7
67	2.9	0.7	69	3.1	0.0	69	3.4	0.3
66	3	0.4	66	2.5	0.1	67	3	0.2
68	3	0.4	72	3.3	0.0	70	3.4	2.8
70	3.3	0.0	68	3.6	0.1	65	2.5	2.6
69	3.2	0.0	67	2.8	0.4	68	2.9	6.2
65	2.9	0.1	78	4	0.0	74	3.8	3.5
63	2.7	0.1	68	2.8	0.1	66	2.9	0.3
66	2.8	0.2	71	3.7	0.0	72	3.8	0.5
73	3.6	0.0	69	3	0.0	68	3.1	1.9
68	3	0.8	71	3.6	0.0	69	3.3	0.6
70	3.3	0.0	70	3.4	0.0	73	4	4.4
67	3.1	0.0	75	3.7	0.0	69	3.3	2.8
73	3.9	0.5	64	2.4	0.0	70	3.5	4.2
69	3.6	0.0	75	3.8	0.1	68	3	1.4
63	2.4	1.0	62	2.1	0.0	71	3.6	0.8
68	3.1	0.0	68	2.8	0.1	75	4.2	1.2
70	3.5	0.2				73	3.7	5.2
67	2.9	0.5						

Table B.6. Fork length (mm), weight (g), and mean percent of body surface area injured for small-sized individual juvenile coho salmon that passed over the Herman Creek Screen (treatment fish) or did not (control fish). This test was done on 19 May 2009 and used a weir wall height of 4 cm (1.6 inches), inflow discharge of 0.15 m^3/s (5.3 cfs), diversion discharge of 0.14 m^3/s (4.9 cfs), bypass discharge of 0.01 m^3/s (0.4 cfs), SV of 120 cm/s (3.9 ft/s), AV of 2 cm/s (0.07 ft/s), NV of 4 cm/s (0.13 ft/s) and Z of 9 cm (3.5 inches).

Treatment			**Treatment**			**Control**		
FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury
68	2.6	0.2	68	3	0.3	70	2.9	0.1
70	3.2	0.3	70	3.2	0.0	73	3.5	0.2
68	2.9	0.0	68	3	0.0	72	3.5	0.5
69	3.3	1.5	70	3.5	0.1	64	2.5	0.6
55	1.5	0.0	60	1.7	0.1	70	3.3	0.2
73	3.6	0.4	78	4.3	0.9	70	3.2	1.8
72	3.5	1.0	73	3.6	0.0	72	3.2	0.1
69	3.3	0.0	72	3.2	1.1	69	2.9	0.4
73	3.8	1.4	72	3.5	0.2	68	2.8	0.4
69	2.7	0.3	68	3	0.1	65	2.8	1.5
73	3.6	0.2	71	3.6	0.4	75	3.8	0.2
70	3.4	0.2	78	4.4	0.0	71	3.1	0.1
70	3.4	0.6	68	2.8	0.0	71	3.3	0.0
68	3.1	0.3	65	2.9	0.2	74	3.3	0.0
72	3.4	0.5	68	2.7	0.3	68	2.9	0.1
65	2.4	0.6	75	3.7	0.4	75	3.9	0.0
69	3	0.2	72	3.4	0.7	70	3.3	0.0
70	3.5	2.8	70	2.9	0.3	64	2.4	0.1
75	3.7	0.5	70	3.5	0.1	70	3.4	0.4
58	1.9	0.0						
71	3.6	0.0						

Table B.7. Fork length (mm), weight (g), and mean percent of body surface area injured for small-sized individual juvenile coho salmon that passed over the Herman Creek Screen (treatment fish) or did not (control fish). This test was done on 20 May 2009 and used a weir wall height of 4 cm (1.6 inches), inflow discharge of 0.34 m^3/s (12 cfs), diversion discharge of 0.31 m^3/s (10.9 cfs), bypass discharge of 0.03 m^3/s (1.1 cfs), SV of 173 cm/s (5.7 ft/s), AV of 5 cm/s (0.16 ft/s), NV of 10 cm/s (0.33 ft/s) and Z of 12 cm (4.7 inches).

Treatment			**Treatment**			**Control**		
FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury	FL (mm)	WT (g)	% injury
69	3.3	0.2	67	2.6	0.1	74	4.0	1.3
68	3.0	0.1	76	4.4	0.8	70	3.0	1.7
70	3.5	1.0	71	3.4	1.8	67	2.9	6.8
78	4.3	0.3	68	3.1	0.8	70	3.1	0.7
71	3.4	0.7	70	3.2	1.5	72	3.6	0.6
74	4.0	0.7	65	2.9	0.7	67	3.2	1.6
72	3.6	0.3	66	2.6	0.3	76	4.4	1.3
71	3.2	1.0	69	2.9	1.8	72	3.2	3.8
70	3.4	0.0	70	3.5	0.5	67	2.8	1.0
77	3.8	0.1	74	4.1	1.5	73	3.6	4.4
67	2.9	0.4	75	4.2	3.0	58	1.8	0.0
68	3.1	1.5	67	3	4.6	72	3.4	0.6
71	3.6	0.4	68	2.8	1.2	65	2.6	0.3
78	5.1	2.5	72	3.3	1.8	68	3.4	1.1
72	3.7	0.2	65	2.6	4.3	69	3.0	0.7
69	3.3	0.4	73	3.8	5.8	68	3.0	0.3
66	3	0.6	75	3.9	0.1	70	3.4	2.0
63	2.4	0.3	69	3.1	0.4	67	2.9	0.5
78	4.9	0.0				68	3.2	6.2
72	3.5	0.4						
72	3.7	0.5						