Progress Report, Fourth Quarter 2002

Culvert Testing Program for Juvenile Salmonid Passage

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Abstract: The program addresses the testing and assessment of culvert designs, along with associated measurements of hydraulic conditions and fish behavior, occurring in full-scale physical models of culvert systems deployed in an experimental test bed. Experiments in the test bed will employ sophisticated instrumentation to measure the hydraulic conditions (velocity, turbulence, and water depth) associated with various culvert designs under various slopes and flow regimes and then relate these hydraulic results to repeatable, quantitative measurements of fish passage success. Major progress was made in the fourth quarter of 2002 on the fabrication and installation of the test bed at the Skookumchuck Hatchery near Tenino, Washington. The installation phase is now well advanced with about 80% of the fabrication and installation completed at the end of 2002. Baseline Construction of Portland, Oregon was the fabricator/installer selected and began work in August of 2002. As of December 30, 2002, the major system components had been fabricated and the head water and tail water tanks installed. An initial shakedown of the test bed is expected in late January 2003. Final installation is anticipated by mid February 2003. The flow meters are to be installed during an annual maintenance shutdown of hatchery water flow in late January or early February.

PURPOSE

The purpose of this document is to report progress on the culvert testing program for juvenile salmonid passage. This progress report contains three parts: 1. Review of the Program and 2. Work Accomplished Through the Fourth Quarter of CY 2002 and 3. Work Planned.

PART 1: REVIEW OF PROGRAM

PROBLEM STATEMENT

A fish passage research program using a specially fabricated test bed needs to be developed to identify the culvert designs and associated hydraulic conditions that allow successful upstream movement of juvenile salmonids at different life stages.

BACKGROUND

The Endangered Species Act (ESA) occasions the need to address situations that may affect salmon and salmon habitats. Culverts can block upstream passage of fish and other aquatic organisms, denying access to crucial habitat that fish need for rearing and feeding (National Research Council 1996, GAO 2001). Considerable effort is being undertaken by a variety of agencies and organizations at all levels to enhance fish passage through culverts. Extensive research and engineering to date has helped bring about enhancement of the passage of returning adult salmon (Copstead et al. 1998, Kahler and Quinn 1998, Moore et al. 1999, WDFW 1998). Mathematical models are used to guide culvert design for adult fish [e.g. FishXing from the U.S. Forest Service, (USFS 2000)]. However, recent research has revealed substantial upstream movement by juvenile salmonids (Kahler and Quinn 1998, Kahler et al. 2001), and the need to pass this life stage has made the problem even larger in scope.

The Washington State Department of Transportation (WSDOT) Workshop on Juvenile Fish Passage in 1997 called for a literature review on fish passage through culverts. The subsequent review by Kahler and Quinn (1998) reported on movements of juvenile and resident adult salmonids, salmonid passage abilities and swimming performance, and pertinent aspects of culvert hydraulics. The review concluded that upstream movement by juvenile salmonids is

substantial and was observed in nearly all studies designed to detect it. The cues and environmental factors associated with salmonid upstream movements are poorly understood. Kahler and Quinn (1998) concluded that the conditions optimal for culvert passage by juvenile salmonids are not well understood and must be determined.

The problem extends to tens of thousands of culverts in the State of Washington alone, and many are determined to be blocking juvenile salmonids from thousands of miles of habitat. The Washington State Department of Transportation (WSDOT) alone has over 500 barriers out of 1,585 culverts that block an estimated 3,000 linear miles of stream habitat. The U.S. Forest Service (USFS) in Washington and Oregon estimates there are between 6,000 and 9,000 culverts on their lands and 80% are barriers. Addressing the problem will be expensive. Completed retrofits to 36 WSDOT culverts cost approximately $5.7 million and increased access to about 212 linear km (132 linear miles) of habitat (Johnson et al. 2000). Therefore, determining appropriate hydraulic and fish passage designs for new and retrofitted culverts before installation is important. However, the effectiveness of current efforts to repair and retrofit culverts is simply not known because there is little or no monitoring (GAO 2001). Good understanding of the strengths and weaknesses of particular designs can support decisions related to cost and environmental implications for any institution involved in retrofitting culverts to enhance habitat access.

The optimal conditions for culvert passage by juvenile salmonids are a key area upon which WSDOT has decided to focus its research efforts. To address this research area, WSDOT has enlisted several partners: Washington Department of Fish and Wildlife (WDFW), Alaska Department of Transportation (AlaskaDOT), Alaska Department of Fish and Game (ADFG), California Department of Transportation (CalTrans), Oregon Department of Transportation (ODOT), the Federal Highway Administration (FHWA) and the Pacific Northwest National Laboratory (PNNL). In this partnership, PNNL has undertaken the conduct of a phased program to address the hydraulic and behavioral issues associated with juvenile salmonid fish passage through culvert systems.

The program addresses the testing and assessment of culvert designs, along with associated measurements of hydraulic conditions and fish behavior, occurring in full-scale physical models of culvert systems deployed in an experimental test bed (Pearson et al. 2001) (Figure 1). Experiments in the test bed will employ sophisticated instrumentation to measure the hydraulic conditions (velocity, turbulence, and water depth) associated with various culvert designs under various slopes and flow regimes and then relate these hydraulic results to repeatable, quantitative measurements of fish passage success. In addition to direct turbulence measurements, the program will apply advanced, transient 3D computational fluid dynamics (CFD) models to simulate the turbulent flow conditions within the culvert environment. These simulations will be used in conjunction with the Acoustic Doppler Velocimeter (ADV) measurements to provide additional spatial and temporal details of the turbulent flow features near the corrugated boundary of the culvert (Figure 2). The program addresses the overall goal to develop new and retrofitted culvert designs and also sets the stage for development of innovative techniques for assessing culvert designs in the field.

OBJECTIVES

The overall goal of this research program is to identify culvert designs and associated hydraulic conditions that pass juvenile salmonids. This program goal is to be met by the development and use of a full-scale culvert test bed within which a systematically conducted program will evaluate

juvenile fish passage through various culvert designs under selected hydraulic conditions. The program addresses three main questions:

- What new culvert and retrofit designs pass juvenile salmonids?
- For such designs, how do hydraulic conditions and culvert characteristics influence the extent or degree of passage success?
- How does passage success vary with fish species and fish size?

The program can also provide information to develop field techniques to assess the effectiveness of installed culverts and retrofits. The program is intended to continue for five years after the test bed becomes operational in early 2003.

PHASES IN THE PROGRAM

The overall program has six phases: 1) Conceptual Design, 2) Draft Protocols, 3) Site Selection, 4) Design, Fabrication and Installation, 5) Behavioral and Hydraulic Testing, and 6) Final Reporting. As of the end of Fiscal Year 2002 (FY02), the first three phases have essentially been completed and the fourth phase, Fabrication and Installation, is well advanced. This document reports the overall progress through the end of FY02 and the month of October 2002.

PART 2: WORK ACCOMPLISHED BY PHASE

Phase 1. Conceptual Design. This phase was completed by Mid-2002. A conceptual model for passage of juvenile salmonids through culverts was developed and used in design of the test bed. The results of Kane et al. (2000) and Powers et al. (1997) were incorporated into the behavioral model. The latest version of the conceptual behavioral model (Pearson et al. 2002) will be used in development of the testing plan. The final design input sheet and program development plan have been submitted to WSDOT.

Phase 2. Draft Protocols. Two draft protocols were prepared. The first describes the procedures for Fish Handling during Behavioral Testing, and the second, procedures for Hydraulic Measurements during the culvert-testing program. A protocol on the behavioral observation procedures was drafted in later 2002. In the fourth Quarter 2002, the draft protocols were combined into a draft work plan with appendices. The work plan and protocols will be finalized after initial shakedown of the test bed.

Phase 3. Site Selection. The site selected for the test bed is the WDFW Skookumchuck Hatchery near Tenino, Washington. The hatchery can supply flows up to 20 cfs, has a ready supply of juvenile coho salmon, and can hold trout and other salmonids on a temporary basis. The necessary permits to use the site were secured in summer 2002.

Phase 4. Design, Fabrication, and Installation. This phase is now well advanced with about 80% of the fabrication and installation completed at the end of 2002. Results of a competitive bid process for fabrication and installation conducted in the summer of 2001 indicated that the cost to build the test bed would be higher than the funding available at that time. The test bed design underwent a value engineering review in winter 2002. After WSDOT secured additional funding, PNNL issued a new request for proposals in late spring of 2002. For this rebid, a new set of the 100% design drawings completed by Mr. Harry Dunham, P.E., of Montgomery Watson Harza

(MWH) in April 2002 was used. Figure 1 shows one view of the Test Bed design accomplished by Mr. Dunham. Under a competitive bid process, the proposals for fabrication and installation were received July 2002. Baseline Construction of Portland, Oregon was the fabricator/installer selected and began work in August of 2002. An earlier installation of a butterfly value on the hatcheries head tank when the hatchery operations were down enabled the 2002 installation work to proceed without disrupting the water flows in the hatchery. As of December 30, 2002, progress on fabrication and installation included installation of the head water and tail water tanks (Figures 3, 4, 5). Progress on fabrication and installation and the schedule for remaining tasks appears in Table 1. An initial shakedown of the test bed is expected in late January 2003. Final installation is anticipated by mid February 2003. The flow meters are to be installed during a shutdown of hatchery water flow.

Phase 5. Behavioral and Hydraulic Testing. Specifications of the instruments for the hydraulic and behavioral observations have been developed. The ADV instrument has been received and was prepared for deployment in the fourth quarter 2002. Arrangements have been made for the loan of several video systems that will be used in the finalizing the protocols. The most appropriate system will be identified and purchased for long-term use. A testing plan detailing the initial tasks in the behavioral and hydraulic testing is to be submitted before the Steering Committed Meeting scheduled for March 2003.

Phase 6. Final Reporting. No final reporting activities were scheduled during FY01 and FY02. However, two presentations at scientific conferences (Pearson et al. 2001, 2002) have been made.

PART 3. PLANNED WORK

The major items scheduled for the first quarter 2003 include:

- Complete fabrication and installation of the test bed — Mid FEB 2003
- Conduct shakedown — Late JAN FEB 2003
- Initial behavioral and hydraulic testing — MAR 2003
- Conduct Steering Committee Meeting — MAR 2003

Table 1 provides a more detailed breakdown of the work scheduled for first quarter 2003. After completion of the shakedown and initial testing, the first year evaluations of proposed retrofit designs begins, probably about the first of April 2003.

REFERENCES

Copstead, R.L., K. Moore, T. Ledwith and M. Furniss. 1998. *Water/road interaction: An annotated bibliography*. Water/road interactions technology series. USDA Forest Service, Technology and Development Program. (http://www.stream.fs.fed.us/water-road)

GAO. 2001. Restoring Fish Passage Through Culverts on Forest Service and BLM Lands in Oregon and Washington Could Take Decades. U.S. General Accounting Office Report. GAO-02-136.

Johnson, G., S. Cierebel-Kanzler, and L. Cowan. 2000. *Fish Passage Program, WSDOT Fish Passage Barrier Removal Program, Progress Performance Report*. Submitted to Washington State Department of Transportation from the Habitat Program of the Washington Department of Fish and Wildlife. 49pp.

Kahler, Thomas M., and Thomas P. Quinn. 1998. *Juvenile and Resident Salmonid Movement and Passage through Culverts*. Final Report WA-RD 457.1 to the Washington State Department of Transportation, Olympia, Washington from The University of Washington, Seattle, Washington.

Kahler, T.M., P. Roni, and T.P. Quinn. 2001. Summer movement and growth of juvenile anadromous salmonids in small western Washington streams. Can. J. Fish Aquat. Sci. 58:1947-1956.

Kane, D.L., C.E. Belke, R.E. Gieck, and R.F. McLean. 2000. *Juvenile Fish Passage Through Culverts in Alaska: A Field Study*. Report Number INE/WERC 00.05. Water and Environmental Research Center, University of Alaska, Fairbanks, Alaska.

Moore, K., M. Furniss, S. Firor, and M. Love. 1999. *Fish Passage Through Culverts: An Annotated Bibliography*. Six Rivers National Forest Watershed Interactions Team, Eureka, CA. http://www.stream.fs.fed.us/fishxing

National Research Council. 1996. *Upstream: Salmon and Society in the Pacific Northwest*. National Academy Press, Washington, D.C. 452pp.

Pearson, WH, MC Richmond, and J Schafer. 2001. "Culvert Testing Program for Juvenile Salmonid Passage." PNNL-SA-34744, Presented at International Conference on Ecology and Transportation, Keystone, Colorado, September 27-28, 2001. Prepared by Battelle Marine Sciences Laboratory, Sequim, Washington; Pacific Northwest National Laboratory, Richland, Washington; and Washington State Department of Transportation, Olympia, Washington.

Pearson, WH, M Richmond, J Schafer, and K Bates. 2002. "Behavioral Model of Juvenile Salmonid Passage for Assessment of Culvert Designs in an Experimental Test Bed." Presented at the 132nd American Fisheries Society Annual Meeting, Baltimore, MD, 18 AUG to 22 AUG 02. Invited Presentation in the Fisheries BioEngineering Symposium IV

Powers, P.D., K. Bates, T. Burns, B. Gowen, and R. Whitney. 1997. *Culvert hydraulics related to upstream juvenile salmon passage*. Technical Report, Washington Department of Fish and Wildlife. Olympia, Washington.

U.S. Forest Service. 2000. *FishXing.* http://www.strea.fs.fed.us/fishxing/index.html

WDFW (Washington Department of Fish and Wildlife). 1998. *Fish Passage Barrier Assessment and Prioritization Manual.* Washington Department of Fish and Wildlife, Habitat and Lands Service.

Table 1. Projected Schedule for the Culvert Testing Program FY02-FY03

Phase/Task	Status	Due Date
1. Conceptual Design	Completed	Spring 01
2. Draft Protocols	Completed	Spring 01
3. Site Selection	Completed	2-Jun-02
4. Design, Fabrication, Installation		
4a. Final Design	Completed	2-Apr-02
4b. Selection of Fabricator/Installer	Completed	2-Jul-02
4c. Fabrication/Installation		
Excavation	Completed	
Concrete Footings and Slabs	Completed	
Piping	Completed	
Fabrication of tanks	Completed	Dec-02
Installation of tanks	Completed	Dec-02
Shakedown (system integrity)	10%	Jan-02
Final installation - flow meters	0%	Mid-Jan-Feb-03
5. Behavioral and Hydraulic Testing		
5a. Testing Plan	50%	30 Jan-03
5a. Instrumentation	50%	Mid-Jan-03
5b. Shakedown on instrumentation	0%	End-Jan-Feb-03
5c. Final Protocols	10%	15-Mar-03
5d. First System Tested	0%	30-Apr-03

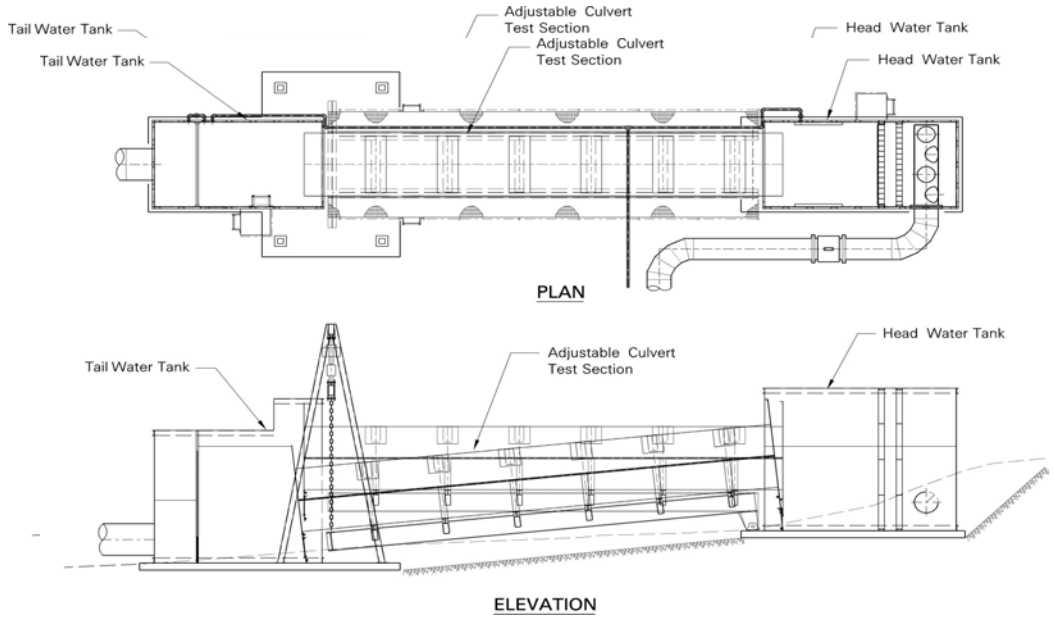

Figure 1. Test Bed for Evaluation of Passage of Juvenile Salmon through Culverts Designed by Montgomery Watson Harza for the Pacific Northwest National Laboratory and the Washington State Department of Transportation.

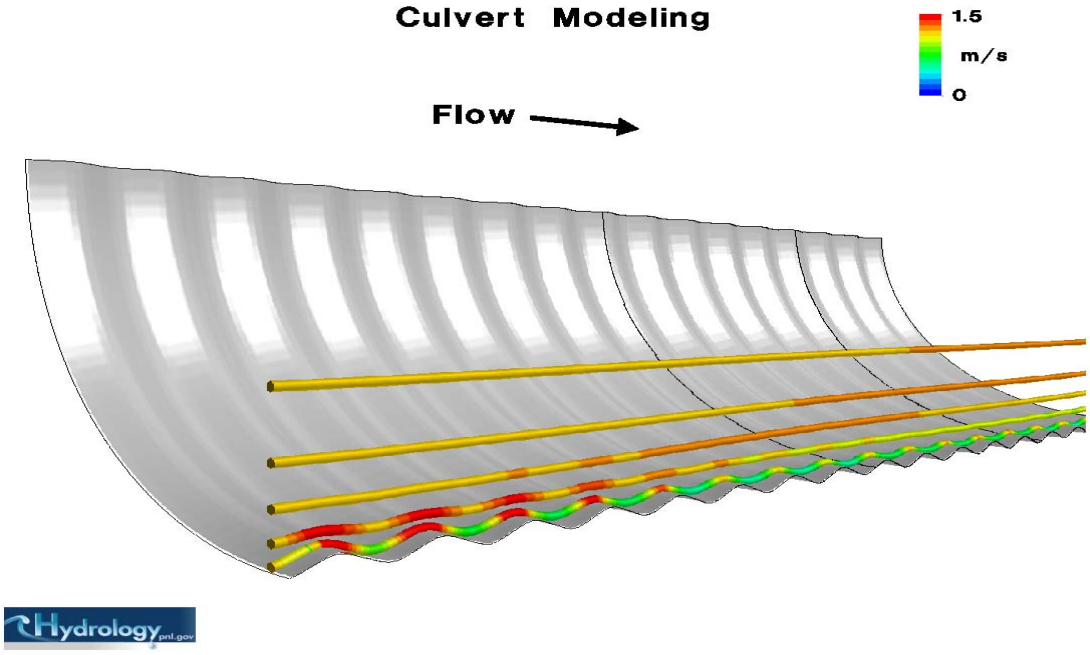

Figure 2. An Example Visualization of Output from a Computational Fluid Dynamics Model for Water Flow in a Corrugated Steel Culvert.

Figure 3. Photograph of Head Water and Tail Water Tanks, December 2002. The test be support and culverts to be tested will be installed between the two tanks. Skookumchuck Hatchery is in the background.

Figure 4. Photograph of the TailWater Tank of the Culvert Test Bed, December 2002.

Figure 5. Photograph of Discharge Piping from Culvert Test Bed, December 2002.