Culvert Testing Program for Juvenile Salmonid Passage

Progress Report for January-June 2003

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ABSTRACT

The culvert test bed 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 at the Skookumchuck Rearing Facility near Tenino, Washington. This progress report covers the first and second quarters of calendar year (CY) 2003.

During the first quarter of CY2003, the installation phase was completed and a workshop and site visit for the steering committee was held. The steering committee provided guidance for next portion of the hydraulic and biological testing program. Plans for experimental work and water management were developed and coordinated with WSDOT and WDFW. The first quarter of CY2003 ended with a test bed that is fully functional structurally, mechanically, and hydraulically.

During the second quarter of CY2003, standard data collection protocols were established and hydraulic and biological data were collected on a baseline test bed configuration (6 ft round culvert, 40 ft long, 1.14% slope, bottom bare, spiraled corrugations 1 in high by 3 in peak-to-peak with a 5° right hand threaded pitch). Thorough hydraulic characterizations of 1, 2, 4, 8, and 16 cfs discharge rates were performed using a Sontek micro-acoustic Doppler velocimeter. The hydraulic data showed that (1) the velocity and turbulence intensity are reduced on the right side of the culvert as seen looking upstream (called the RVZ, reduced velocity zone) due to the orientation of the spiraled culvert corrugations; (2) the streamwise velocity in the RVZ is approximately 36% of the average velocity; (3) the lateral and vertical velocity components are very small relative to the streamwise velocity; (4) the lateral and vertical RMS velocities are comparable to those in the streamwise direction; (5) the RMS velocities in the RVZ show a minimal increase with increasing average velocity (proportional to discharge); (6) inlet losses were in the range of 0.32-0.42 velocity heads; and (7) velocity and RMS in the RVZ are higher near the culvert inlet due to flow separation and inlet drop. The key hydraulic feature in the culvert test bed is the RVZ.

Biological tests involved large (mean forklength 139 mm) juvenile coho salmon in April 2003 tests and small (mean forklength 55 mm) juvenile coho salmon in the remaining April and May tests. Large juvenile salmon were tested first because they were available at the hatchery; they were used in culvert tests until the WDFW had to release them. The tests with large juvenile salmon allowed us to establish fish handling and retrieval protocols. The following biological findings pertain to the tests with small juvenile salmon. The main biological metric was absolute passage success (APS is the number of fish in the headwater tank at the end of a test divided by the total number released into the tailwater tank at the beginning of that test). The experimental program called for the tests to start with volitional entry. Volitional entry means that a specific cue was not purposely used to elicit an upstream movement. The data indicated APS was 80% for large juveniles at night at 2 cfs; however, only eight tests with large juveniles could be completed. The small juvenile salmon had lower APS (0-23%) than the large juveniles (15-80%). APS was significantly ($P=0.038$) higher during night than day for small juvenile salmon; the result for large juveniles was nearly significant ($P=0.105$). The experiments indicated that time of day was more important for upstream movement than whether the whole system was darkened by covering the tanks with canvas during daylight. That is, shade over the tanks had no apparent

effect on APS. The biological tests fed development of standard protocols that were applied in subsequent tests.

Tests were performed to determine the relationship between discharge rate and APS for the baseline culvert test bed. The tests were sequential, 3 h long, at night with the discharge level randomized over 0.5-cfs increments between 1 and 4 cfs. APS was highest at 16% for 1.0 cfs, and fell to 3% at 1.5 cfs, 1.5% at 2.0 cfs, and was 0% by 4 cfs. Of the juveniles successfully passing upstream through the culvert and exiting into the headwater tank, passage from the RVZ was three times higher than from the left side of the culvert and two times higher than from the center portion of the barrel. Analysis of this limited data set suggests that the relatively low velocity and turbulence intensity in the RVZ may be an important factor determining success of upstream movement. This hypothesis should be investigated further with larger juvenile salmon later in CY2003.

PURPOSE

The purpose of this document is to report progress during the first and second quarters of CY2003 on the culvert testing program for juvenile salmonid passage. This progress report contains three main parts: (1) Program Review; (2) Work Accomplished; and (3) Work Planned. References and Table/Figure follow Part 3. Appendix A provides Notes from the Steering Committee Workshop. Work Accomplished references the report to be submitted under separate cover titled, "Evaluation of Juvenile Fish Passage Through an Experimental Culvert Test Bed: Standard Protocols and Baseline Characterization."

PART 1: PROGRAM REVIEW

PROBLEM STATEMENT

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

BACKGROUND

The Endangered Species Act (ESA) mandates that situations adversely affecting salmon and salmon habitats be addressed. 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, General Accounting Office 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 (FHA) 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.

Culvert Test Bed, Progress Report, First and Second Quarters CY2003

OBJECTIVES

The overall goal of this research program is to identify culvert designs and associated hydraulic conditions that juvenile salmonids can pass. 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) Biological and Hydraulic Testing; and (6) Final Reporting. As of the end of calendar year 2002 (CY02), the first three phases have been completed and the fourth phase, Fabrication and Installation, was well advanced. This document reports the overall progress through the first and second quarters of CY 2003. See table 1 for the program's schedule.

Table 1. Projected Schedule and Status for the Culvert Testing Program

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	Completed✓	31 Mar-03
5. Biological and Hydraulic Testing		
5a. Testing Plan	Completed✓	5 Apr-03
5b. Instrumentation specified	Completed✓	31 Jan-03
5c. Shakedown on instrumentation	Completed✓	15 Apr-03
5d. Draft Protocols	Completed✓	15 Mar-03
5e Steering Committee meeting	Completed✓	20 Mar-03
5f. First System Tested	Completed✓	30 Apr-03
5g Water Management Plan	Completed✓	5 Apr-03
5h Baseline Tests	50%	30 Jun-03
5i Tests of Various Retrofits	0%	30 Dec-03

6. Final Reporting		
6a CY 2003 Annual Report	0%	30 Jan-04

PART 2: WORK ACCOMPLISHED

PHASE 1. CONCEPTUAL DESIGN

This phase was completed in mid-CY2002. A conceptual model for behavior of juvenile salmonids passing upstream through culverts was developed and used in design of the test bed (Pearson et al. 2002). The model incorporated results from culvert passage studies by Kane et al. (2000) and Powers et al. (1997). The model was used to develop the work plan for hydraulic and biological testing. The final design input sheet and program development plan were submitted to WSDOT.

PHASE 2. DRAFT PROTOCOLS

Two draft protocols were prepared. The first describes the procedures for Fish Handling during Biological Testing, and the second, procedures for Hydraulic Measurements during the culvert-testing program. A protocol on the biological observation procedures was drafted in late 2002. In the fourth quarter of 2002, the draft protocols were melded into a draft work plan as appendices. The work plan and draft protocols were finalized in the first quarter of CY2003 after initial shakedown of the test bed and a meeting of the steering committee.

PHASE 3. SITE SELECTION

The site selected for the test bed is the WDFW Skookumchuck Rearing Facility near Tenino, Washington. The facility can supply discharges 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 the third quarter of CY2002.

PHASE 4. DESIGN, FABRICATION, AND INSTALLATION

This phase was completed in the first quarter of CY2003. It started in the third quarter of CY2001, when after a design was created, results of a competitive bid process for fabrication and installation conducted 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 the first quarter of CY2002. After WSDOT secured additional funding, PNNL issued a new request for proposals in the second quarter of CY2002. This re-bid used a new set of the 100% design drawings completed by Mr. Harry Dunham, P.E., of Montgomery Watson Harza (MWH) in April 2002. Figure 1 shows one view of the test bed design. Under a competitive bid process, the proposals for fabrication and installation were received July 2002. Baseline Construction, Inc. of Portland, Oregon was selected to fabricate and install the test bed and began work in August of 2002. Previously, a butterfly value on the hatchery site's head tank was installed during a break in hatchery operations. This enabled the CY2002 installation work to proceed without disrupting water flows in the hatchery. Flow meters were installed during another pre-arranged shutdown of hatchery water flow. An initial shakedown of the test bed was held in the first quarter of CY2003. Final installation was completed in March 2003.

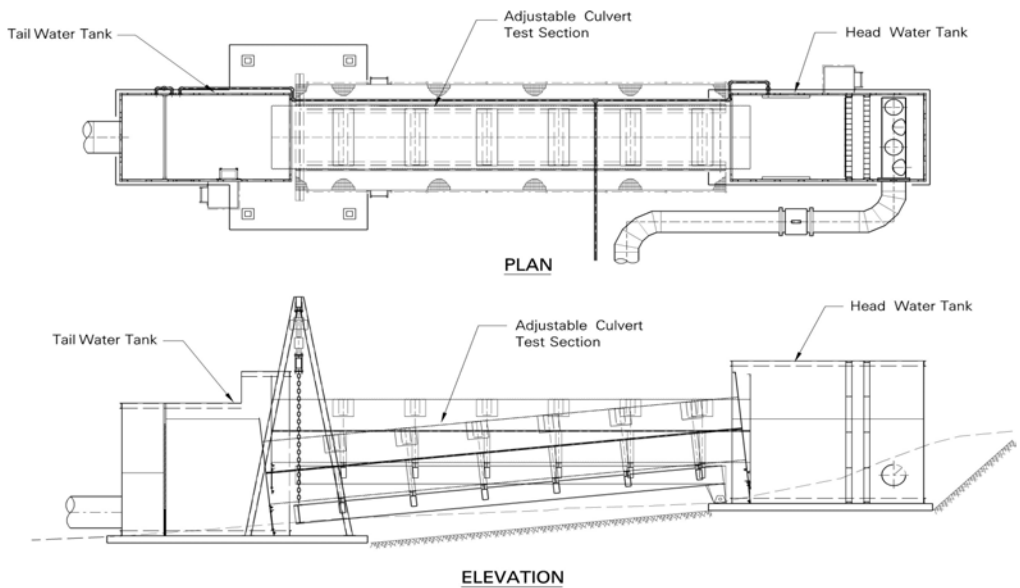

Figure 1. Test Bed for Evaluation of Passage of Juvenile Salmon through Culverts Designed by Montgomery Watson Harza for the Pacific Northwest National Laboratory and the Washington State Department of Transportation.

PHASE 5. BIOLOGICAL AND HYDRAULIC TESTING

This phase started in the second quarter of CY2003. Objectives for testing during this quarter were to: (1) establish standard protocols for biological and hydraulic data collection; and (2) assess the baseline culvert test bed. The instruments for the hydraulic and biological observations were obtained using specifications developed previously and installed and tested at the test bed. An experimental work plan was developed and discussed at a meeting of the steering committee in March 2003 (see Appendix A for notes from the steering committee meeting). The steering committee provided guidance for next portion of the hydraulic and biological testing program. Water management and safety plans were also drafted and coordinated with WSDOT and WDFW. Biological and hydraulic tests have been completed and standard data collection protocols were established based on these results. Using the standard protocols, the baseline culvert test bed (6 ft round culvert, 40 ft long, 1.14% slope, bottom bare, spiraled corrugations 1” high by 3” peak-to-peak with a 5° right hand threaded pitch) was thoroughly characterized hydraulically for 1, 2, 4, 8, and 16 cfs discharges. In addition, the relationship between fish passage success (number of fish in the HW tank at the conclusion of the test divided by the number originally released into the TW tank) and discharge rate was determined under volitional entry conditions. A report will be submitted to WSDOT in early third quarter of CY2003 titled, “Evaluation of Juvenile Fish Passage Through an Experimental Culvert Test Bed: Standard Protocols and Baseline Characterization.” Important findings in this report include:

- Preliminary hydraulic results show there is a “reduced velocity zone” (RVZ) near the right hand wall of the culvert (looking upstream). This skewed velocity distribution is likely due to a flow deflection caused by the spiraling in the corrugations.
- Underwater video of fish exiting the culvert into the headwater tank shows that passage from the RVZ was three times higher than passage from the left side of the culvert and two times higher than passage from the center portion.
- Both large and small juvenile salmon had higher passage rates during night than day, but no differences in passage were observed when the head- and tailwater tanks were shaded with canvas than when they were not.. Thus, time of day appears to be more of a determining factor for upstream movement than shade or light level.
- Preliminary observations indicate that the large juvenile had higher passage success than the small juveniles; maximum passage was 80% for large and 23% for small juveniles.
- Tests were performed to determine the relationship between discharge rate and APS for the baseline culvert test bed. The tests were sequential, 3 h long, at night with the discharge level randomized over 0.5-cfs increments between 1 and 4 cfs. APS was highest at 16% for 1.0 cfs, and fell to 3% at 1.5 cfs, 1.5% at 2.0 cfs, and was 0% by 4 cfs.
- Analysis of this limited data set suggests that the relatively low velocity and turbulence intensity in the RVZ may be an important factor determining success of upstream movement. This hypothesis should be investigated further with larger juvenile salmon later in the year.

PHASE 6. FINAL REPORTING

No final reporting activities have been scheduled as of the end of the second quarter in CY2003. However, three presentations at scientific conferences have been made (Pearson et al. 2001; 2002; 2003). In addition, Dr. Pearson gave seminars at the U.S. Fish and Wildlife Service offices in Olympia, Washington and the U.S. Forest Research Laboratory in Corvallis, Oregon.

PART 3. WORK PLANNED

Table 1 provides a detailed breakdown of the work scheduled for the third quarter of CY2003. The major items scheduled for the third quarter of CY2003 include:

1. Submit report for standard protocols and baseline characterization.
2. Finish hydraulics – get missing flow levels for the relationship (1.5, 2.5, 3.0, and 3.5 cfs)
3. Perform baseline tests with new size group of fish available in September 2003.
4. Put in retrofit (to be decided) and test at current slope (1.14%)
5. Change slope (to be determined) and test retrofit.
6. Replace retrofit with baseline culvert and test at the second slope.
7. Re-evaluate results whether another slope is necessary or go to another retrofit.

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APPENDIX A

Steering Committee Site Visit and Meeting in March 2003

A steering committee was formed to provide guidance to the culvert test bed program. The steering committee is comprised of PNNL and agencies funding the program, including WSDOT, ODOT, AlaskaDOT, CalTrans, and the Federal Highway Administration. In addition, participants in the steering committee meeting include representatives of fisheries resource agencies and other interested parties, such as ADFG, CDFG, NMFS, USFWS, and WDFW. On March 18, 2003, the steering committee and interested parties visited and inspected the test bed site at the Skookumchuck Rearing Facility near Tenino, Washington. On March 19, 2003, a meeting was held at the Seatac Doubletree Hotel in Seattle, Washington (see agenda below). The objectives of the site visit and meeting were to (1) familiarize the steering committee with the test bed and its capabilities; (2) establish test priorities for 2003; and (3) identify possible avenues for future work. The site visit was well attended (~25 people) and resulted in many complimentary comments about the quality of the design, fabrication, and installation of the test bed. At the meeting the next day, the steering committee noted that

<u>March 18 – Site Visit</u>

- Tour of site with staff at duty stations at the head- and tailwater tanks, culvert test bed, and trailer for video monitoring.
- Question and answer period.

<u>March 19 – Meeting at Seatac Doubletree Hotel</u>

- Review of site visit and objectives – W. Pearson (Battelle) and J. Toohey (WSDOT)
- Introductions - All
- Overview of culvert test bed program – W Pearson
- Test bed design, installation, and operation – H. Dunham (Montgomery Watson Harza)
- Break
- Culvert test bed hydraulics – M. Richmond (Battelle)
- FY03 work plan – G. Johnson (Battelle)
- Perspective on culvert studies – M. Furniss (USFS)
- Strawman list of priorities – W Pearson
- Lunch

- Discussion and decision on work plan and priorities – All
- Wrap-up – W. Pearson and J. Toohey

A. Review, Introductions, and Overview (Pearson)

Powers (WDFW) suggested that a video of the test bed would be useful to show interested parties. **Pearson** said Battelle would pursue this.

Whitman (CDFG) wondered how the test bed fit into the larger scheme-of-things for WSDOT. **Wagner** (WSDOT) answered that WSDOT has been working toward an overall research strategy for about six years. The research has included two tracts, biology/behavior and hydrologic. The test bed brings the two together, but is not the "be all, end all." One expectation WSDOT has is that the results from test bed research will allow them to check design standards currently in use for retrofits. **Whitman** asked for more details on how they intend to use the results. **Wagner** responded that one could look at different stream gradients with different physical approaches. It is also possible that the WDFW standards for fish passage might need to be revisited.

Miles (ADOT) noted a benefit of the test bed is the capability to move to study of full-scale culverts designs and to be able to test the assumptions we're using today. He noted the test bed would not provide all of the answers.

Nordlund (NOAA Fisheries) asked if WDFW and WSDOT design standards were the same. **Powers** and **Wagner** responded, yes.

Pearson mentioned he attended a workshop in Ketchikan, AK last year and one of the main topics of concern was the relationship between fish passage and turbulence in a culvert. This issue will be important here too.

Powers pointed out that stream simulation was important in culvert design these days. The goal is to make the culvert big enough to maintain stream flow. **Miles** added that stream simulation does NOT tell us entrance and exit losses although, as **Powers** noted, if steam simulation is done right then hydraulics are less of an issue.

Jones (ODOT) asked how we planned to account for the possibility that adaptive behavior by the test fish is presumably acquired over time. **Pearson** responded that the test protocol now incorporates the "hard-wired" behavior in the animals. We haven't designed the study to address learning. We'll use naïve fish and use them only once. The protocol will be simple to start. **Whitman** suggested then that we are testing response. **Pearson** said yes, although adaptive behavior could be studied down the road.

DeHart (USFWS) cautioned that this study will be using hatchery fish that have spent their entire lives in ponds and raceways. Wild fish would be much more "experienced." This is a weakness or drawback that we simply have to accept for now. **Pearson** commented the WDFW might allow wild fish for testing from the same drainage, but that work with the hatchery fish is a logical starting point to develop protocols, minimizing impacts to wild fish. This may be an issue for later in the program.

B. Design and Construction (Dunham)

Dauble (Battelle) noted the need for a fish friendly release and recapture system. **Johnson** said that this would be explained during the work plan presentation.

Nordlund asked how we planned to get the gravel substrate into the culvert. **Dunham** answered that they were working on a method; might shovel in real gravel, or could possibly install a simulated gravel bed load. Also, working on the baffling. Final details of the methods to include bed load and baffles are being considered.

Wagner wondered if we'd come across any other test beds like this one. **Pearson** replied, no, this is pretty much one-of-a-kind. Dunham said there'd been some full-sized test beds but for much smaller culverts in diameter, flow, slopes, length, etc.

C. Hydraulics (Richmond)

Whitman asked if we could do a velocity profile for the baffle condition in the CFD run. **Richmond** replied, yes, eventually.

Powers asked about the dimensions of the ADV sample volume, sampling rate, and the ability to focus measurements in certain areas. Volume is about 1 cm3, sampling rate is 50 times per second, and yes measurements can be focused.

Miles questioned if the definition of turbulence accounted for the duration of the ADV pulses. **Richmond** said, no, but the data can be analyzed to look for "pulsating" turbulence. **Miles** also pointed out that it would be useful to translate the hydraulic data into the traditional design parameters, e.g., inlet loss, outlet, loss, etc.

Whitman asked how the CFD results compared to the prototype (test bed). **Richmond** said they had not had a chance to do this yet, but would soon.

Dauble suggested it would probably be important to maximize the length of the flow into the tailwater tank, so minimize the backwater. This will be discussed further later.

D. Work Plan (Johnson)

Miles suggested we test a "controlled" situation, e.g., with all of the culvert hatch covers open.

DeHart noted the physical constraints of the test bed structure will restrict the simulation of realistic conditions. This is especially true in the head- and tailwater tanks.

Miles recommended we place some of the cameras close to the water to get fine-scale movements. Johnson noted that, based on comments at the site visit, we planned to add more cameras including underwater cameras in the head- and tailwater tanks.

The committee discussed PIT technology for the test bed. Johnson will follow-up with **Dr. Lang** at Humboldt State who ah apparently used PIT successfully near a culvert.

Someone asked how we planned to measure downstream passage. **Johnson** explained that the video records could be used to quantify downstream passage, in addition to qualitative observations at the tanks.

Jones commented that one trial per test set-up would not be enough. **Johnson** replied that two trials per day was our goal, and might even need to test the same set-up the next day and the day after that. **Jones** and **DeHart** also raised the issue of a physiological exam after a test. **Johnson** said that we were not planning to do anything more than a visual examination of each test fish, i.e., no blood work is planned.

Dauble commented that the motivation issue needs to be resolved. We assume fish will move, but how to separate the fish that are motivated to move upstream, but can't because of the conditions, from those not motivated at all. That is, is passage success/failure due to lack of motivation or bad passage conditions? **Johnson** replied that they would look into ways to observe, classify, and record the "level of motivation" in each fish. Motivation needs to be removed as a factor in determining passage success (=number successfully moving from the tailwater tank to the headwater tank as staying the divided by the total number motivated and available to move upstream from the tailwater tank). **Pearson** noted that we want the test bed to test capability, not motivation. **Powers** said that they forced their fish to try to swim upstream as they could not resolve the motivation issue.

Nordlund offered that understanding why fish do NOT pass is the key. He also asked how the results would be used to refine designs.

Wagner pointed out that there is a need to design road crossings that pass fish wanting to change positions in a stream.

Nordlund asked if one could extrapolate test results with one size of culvert and its associated turbulence to other sizes of culvert. **Richmond** responded that they should be able to scale-up the hydraulic model from one size to another; the issue will be the fish response.

Nordlund questioned the need to study the 2-foot or 3-foot diameter culverts, since the current criteria call for 6-foot. **Pearson** replied that one of the partners was interested in the smaller diameter culverts for application on high slopes.

Nordlund continued the discussion with an inquiry about whether we'd considered different corrugation spacings. **Pearson** said, yes. **Miles** noted that 3 X 1 inch were the most common, but 6 X 2 inch were also used. **Whitman** wondered what sort of spacings and depth modifications would be doable in retrofits.

E. Perspectives on Culvert Design (Furniss)

Quote from George **Peterson** (USFS), "Don't spend more on the analysis than the cost of being wrong."

A few notes from **Furniss'** talk follow. He presented the Fish Crossing Model. Average velocity doesn't really occur. Fish seem to exploit low velocity corridors. Explained velocity reduction values, which we should be able to derive from test bed data. Concerned about all organisms, not just salmon. Need to validate the CFD. Examine hydraulic heterogeneity and how fish deal with it. Look at the roughness coefficients. Note jumping ability in the test fish. Furniss noted that it's hard to design to simultaneously pass debris/flow downstream and fish upstream.

F. Testing Sequence (Pearson)

Pearson opened the topic of finalizing the hydraulics protocols. (Points were listed on a marking board.)

- **Miles** suggested that we need a method to measure velocity in the "upper corner" near the water surface and side of the culvert. **Guensch** replied that a pitot tube would work.
- It was also noted that we need a consistent method to measure or determine the boundary layer.
- **Whitman** commented that we should use the fish to determine the occupied zone.
- Calculate outlet and inlet losses.

- Focus on the shallower depths

Pearson moved the discussion to standard protocols.

- Collect data on where fish are to determine the occupied zone.
- **Whitman** pointed out the need to have agency buy-off. Also need to know what sizes of culverts agencies have to deal with.
- **Furniss** noted the need for economy of testing. Make best guess of a threshold using a model to get the starting point in a "stair-step" experimental design.
- **Miles** thought the protocol should include a beveled inlet.
- **Powers** said depth (water surface profile) and velocity are key variables, not discharge.

Pearson led discussion of the baseline (reference) culvert.

- Need a good definition of the culvert hydraulically and biologically.
- Minimize backwater and still maintain outlet control. Need to be able to apply this criterion to other situations.
- Dependent variables are fish passage success, efficiency. Independent variables are culvert type, bed slope.
- Characteristics of the reference culvert may change as we learn.
- **Wagner** suggested that we look at the reference culvert in relation to existing designs.
- **Powers** noted that the average culvert length is about 80 ft. We'll still apply the learning from the test bed to long culverts, but will need to do so carefully and examine hydraulics and fish swimming capability.
- **Wagner** questioned what the real purpose of the reference culvert was. **Pearson** explained that we something to compare to. The reference culvert does not have to be the "best." **Sargeant** noted that we need to know the motivation of the fish. **Miles** offered that knowing the variability [of fish response] will be important. Wagner said we need a hydrologic baseline, as well as a "normal" condition.
- **Nordlund** asked if there were field studies of passage rates, because we could compare culvert test results to these. The group agreed this was a good idea.

Moving the discussions along, **Pearson** broached the subject of retrofits, bed configurations, and corrugation size. The following items, not in prioritized order, were discussed.

- Baffles – notched and staggered; 30-45 deg relative to culvert wall; alternating
- Full width weirs across the culvert
- Try "adult" baffles on juvenile salmon
- Hydraulic head losses of submerged weirs
- Ramped baffles
- Horizontal angled corner baffle

- Hydraulic manual test "EDF"
- Test common types of baffles, then use CFD to investigate different shapes
- Bed material must stay in place
- Investigate the need for bed material
- Assess hydraulic conditions created by bed material
- Study bed conditions thought to be favorable to juveniles
- Corrugation size – 3 x 1 vs 6 x 2 inches

Miles asked if there was enough acceptance of the spacing and height of baffles that we don't have to test anymore. **Wagner** replied that may be the case for adults, but not juveniles. **Dauble** suggested starting with a baffle known to work on adults and apply it to juveniles. **Nordlund** agreed, but asked what's the accepted design, as there is not complete consensus.

Powers recommended using known data on fish passage success. **Furniss** said to focus on what the experts know works.

Pearson reminded everyone that this was a planning exercise for what to do after we have the standard protocols.

Dauble suggested we identify one or two standard baffles, one or two bed loads, then go testing. Also, he thought it would be good to test corrugation sizes greater than the height of the test fish.

Wagner mentioned the need to measure head loss for the gravel beds.

Pearson summarized the discussion saying first priority from the group is to emphasize retrofits as the next step after development of the standard protocol. And, retrofits already in place for adult salmon should be examined for passage of juvenile salmon.

G. Wrap-Up (Pearson and Toohey)

Toohey gave a brief summary of the funding situation. Battelle will be pursuing federal funding.

Toohey and **Pearson** thanked everyone for coming and the valuable comments they provided.

Pearson adjourned the meeting.