Merwin Tailrace Fish Behavior Study
Revised Study Plan
June 30, 2005

I. Introduction

The Merwin upstream fish passage facility was originally completed with construction of the Merwin Dam. This trapping facility historically operated with three entrances but was reconfigured to improve operation. The current facility is operated with one trap entrance located on the South side of the dam to the right of the discharge from turbine Unit 1. This trap operates effectively but questions have been raised as to how effective the trap is at various turbine operations and flow conditions, and in particular how effective the adult trap is when turbine Unit 1 is operational.

Section 4.3 of the Final Settlement Agreement for the Lewis River Hydroelectric Projects called for the construction and future operation of an adult trap and transport facility at the Merwin Project. Section 4.1.1 of the Agreement called for studies to inform design decisions regarding upstream and downstream fish passage facilities and indicated that the studies should include an evaluation of the movement of fish in the corresponding tailrace or forebay. A further requirement of the Settlement Agreement was development of an Adult Trap Efficiency performance standard. In developing such a standard the Agreement called for evaluation of entry rate, fallback, crowding at the entrance, delay and abandonment of the trap area.

To effectively meet the requirements identified in the Settlement Agreement and summarized above, the tailrace study will consider the following objectives: 1) to document operation of the current trap as defined by adult trap efficiency (ATE); 2) to determine if fish are able to locate, approach, and enter the current trap under varying flow conditions and turbine configurations, and 3) to confirm and test selected fish monitoring technology in considering future trap monitoring needs.

Numerous approaches are possible to evaluate fish behavior in the Merwin tailrace and address the above objectives. The best approach will be the one that provides the most critical information to the design in a timely manner and that will minimize impacts both operationally to PacifiCorp and to the listed fish populations. The following study plan describes PacifiCorp's proposed approach to evaluating the operation of the current trap and calculating ATE (Phase I) as well as an approach for identifying, installing, and operating the best long term monitoring system for the new trap facility (Phase II).

Within Phase I, researchers have identified four tasks that they think are essential for designing the most informative study. The tasks are:

- Develop a final study plan
- Implement study plan
- Analyze and present data
- Prepare report.

After the Phase I study is completed study results will be used in Phase II, helping PacifiCorp select the best technology available for long term monitoring of the new trap facility based on daily ATE.

II. Phase I – Evaluation of Fish Behavior at the Existing Trap

Methods

Objective 1 – Estimate the abundance of adult salmonids entering the tailrace daily.

Data on the number of fish entering and leaving the tailrace from downstream locations will be based on fish detections from a fixed split-beam hydroacoustic array located at the downstream entrance to the tailrace. The split beam hydroacoustic array would be designed to provide as complete coverage as possible across the selected location on the river (Figure 2). The array would be located downstream of the tailrace, just above the boat access buoy line. Target strength of the system is set to detect adult sized salmonids greater than approximately 200 mm length.

The split beam hydroacoustic array will be used to estimate the number of fish entering the tailrace daily, I_d. This number will include error associated with detection efficiency, expansion outside the area sampled, and double-counting. Researchers will evaluate and report on the error associated with these estimates as well as the resulting uncertainty surrounding the daily estimate of the tailrace population. Daily trap entries, C_d will be divided by I_d to generate an ATE_{pop}. ATE_{pop} will be used as an indicator as to how well fish move into the project area and locate the trap

There is possibility of fish spawning above the hydroacoustic array and below the Merwin tailrace proper. Spawning observation will be made two or three times each week during the spawning season to account for these fish. The numbers observed spawning will be subtracted from the population estimate for the tailrace.

An optical camera will be located above the mouth of the trap and will detect fish leaving the tailrace via the upstream fish trap (Figure 1). In addition, the trap will be checked daily during the study. Trap checks will be used to identify the proportions of different species and life stages in the trap catch. These proportions will be applied to the passive counts generated by the hydroacoustic array and camera.

Objective 2 – Estimate the number of trap entry attempts made by adult salmonids in the tailrace.

The optical camera located above the trap will allow for observation of fish behavior at the mouth of the trap. At this short range, the direction of individual fish will be evident and a total number of attempts and fallbacks at the trap can be determined. For this study, fallback is defined as when a fish swims into the fyke of the trap but is not captured by the weir and instead drops back into the tailrace. Obtaining counts of fish that successfully enter the trap and fallback will be completed by manual review and sorting of the optical camera images. In this way we will be able to generate fish counts in different behavior categories such as: approach, abort, enter, fallback. In addition, the sum of the number of successful entries and number of fallbacks provide a number of total trap attempts, A_d, that will be used to generate a second measure of ATE that is specific to attraction of active adult migrants, ATE $_{mig}$

Objective 3 – Estimate the number of adult fish that enter the trap and become captive.

Subtracting the total number of the fallbacks from the total number of trap attempts provides an estimate of daily successful entry to the trap. The number of successful trap entries each day should be identical to daily trap catch. Any discrepancies between these numbers will represent error in the camera detections. The camera error and absolute trap catch numbers will be monitored for a period of time and will be used to generate a camera efficiency rating that describes the percent of actual catch recorded as successful entries. Once derived, the camera efficiency rating will be applied to the number of successful camera entries to generate a daily catch estimate, C_d. This estimate reduces the need to operate and count the fish in the trap on a daily basis while enabling estimation of daily trap catch and operation. This estimate will be used in calculating the following two indices that will help evaluate daily efficiency of the Merwin upstream fish trap. The first index, ATE$_{pop}$ provides a means to monitor the efficiency with which fish, once in the project area, are locating and entering the trap. The second ATE$_{mig}$ gives an estimate of how efficient the existing trap configuration is at capturing fish. The equations for these ATEs follow:

$\text{ATE}_{pop} = C_d / I_d$

and

$\text{ATE}_{mig} = C_d / A_d$.

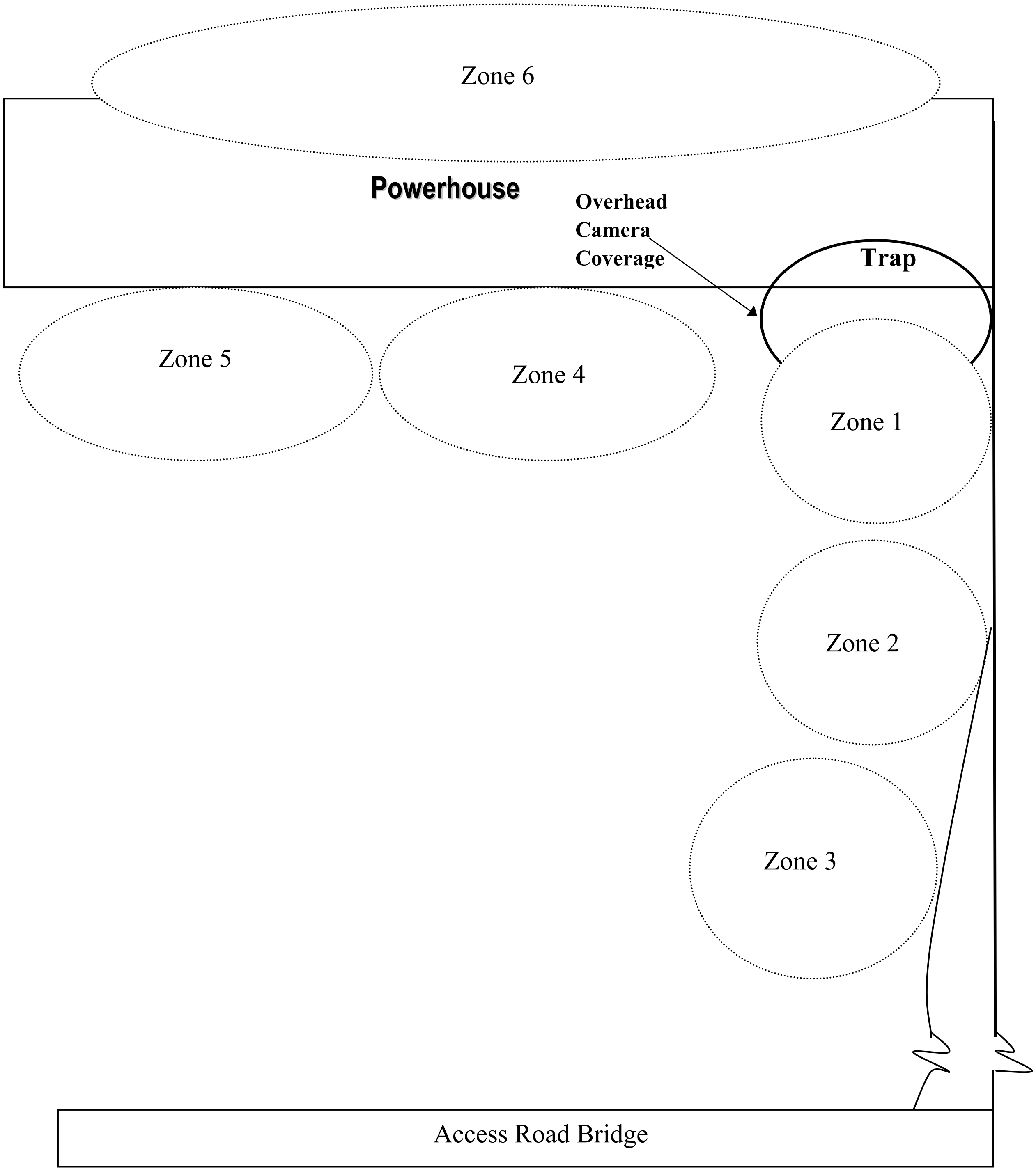

Figure 1. The fixed radio telemetry array proposed to monitor fish distributions and movements in the tailrace. Drawing not to scale.

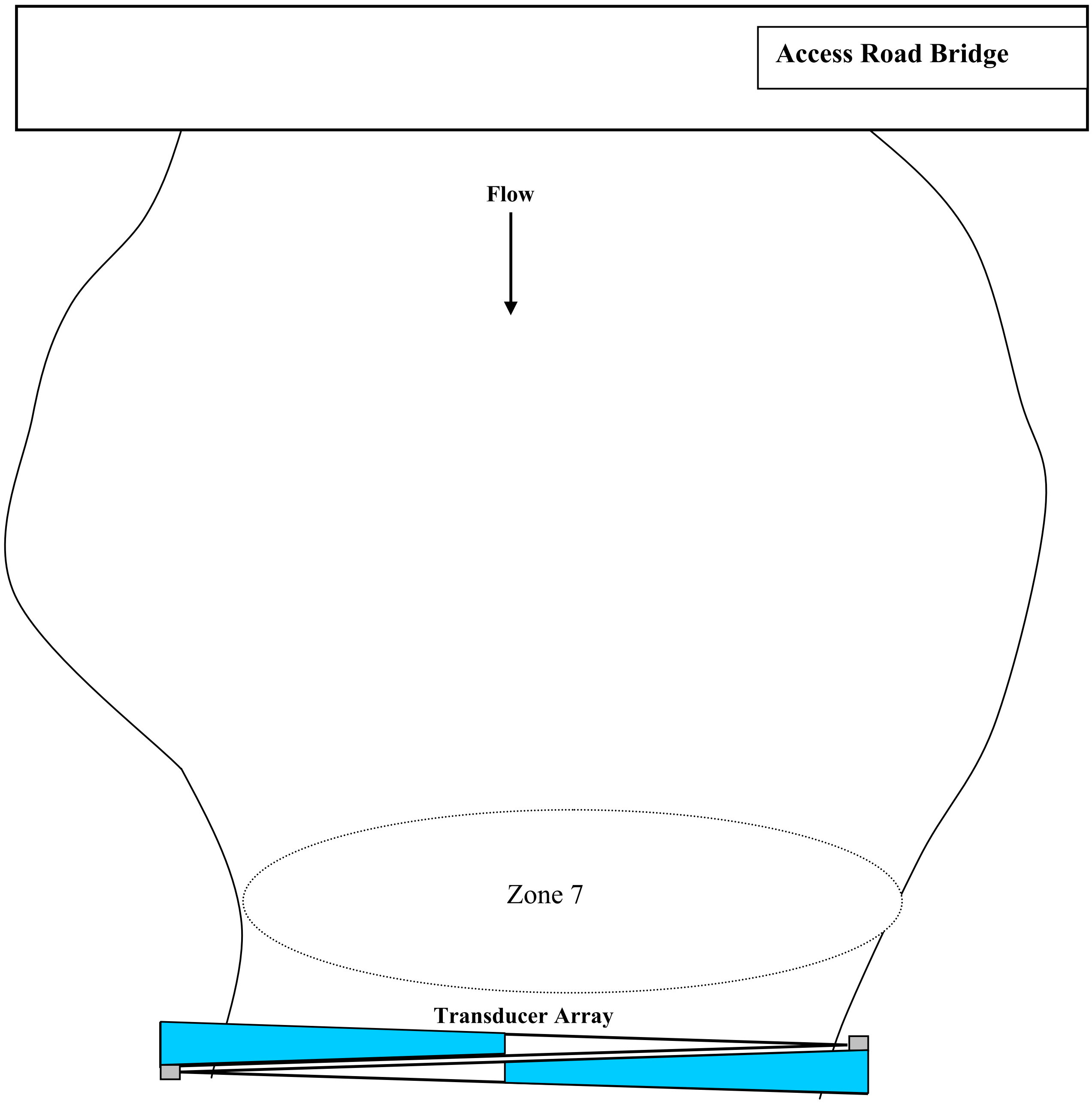

Figure 2. Conceptual plan view of proposed fixed hydroacoustic and radiotelemetry arrays to detect adult salmonids entering the Project Area. Drawing not to scale.

Objective 4 – Determine what (if any) tailrace conditions impede fish movement into the trap.

At Merwin Dam, there are at least seven possible operating scenarios when considering only turning turbines off and on and assuming shut down of all three turbines is not to be considered. If variable flow rates are added, the number of potential scenarios increases exponentially. In addition other tailrace conditions (tailrace elevation, spill, trap entrance head, trap gate opening dimension) may possibly influence fish behavior and trap efficiency. Given time constraints and migration windows for fish species, controlled testing to evaluate fish reaction to all possible perturbations of tailrace conditions would likely be difficult or logistically infeasible.

Given the proximity of Unit 1 to the trap entrance, researchers propose to conduct a controlled test to determine and compare ATEs when Unit 1 is operating (Unit 1 ON) and when it is shut down (Unit 1 OFF). Treatments will be applied systematically to capture early, peak and late migration timing, but the order of treatments will vary randomly to prevent possible conditioning.

Tests of ATE

Researchers will test the null hypothesis that the operating condition (Unit 1 ON or Unit 1 OFF) has no impact on either ATE_{pop} or ATE_{mig}. To test the null hypothesis, an experiment will be constructed that applies a treatment effect (Unit 1 ON) versus a control (Unit 1 OFF). There may be other factors that influence both ATEs, such as climatic conditions (e.g., precipitation, barometric pressure, cloud cover); therefore, researchers will pair control and treatment units. Each treatment will last a several days, thus paired treatments may take as long as two weeks to complete.

Observational Tests

Fish behavior as observed with the optical camera will also be used to evaluate the effects of operating conditions. The number of fish that approach, abort, enter, and fallback will be compared between the Unit 1 OFF and Unit 1 ON treatments using a statistical approach. The paired counts of fish in each of these categories can be used to evaluate how behavior of fish may change in relation to each operational treatment. For example, the number of attempts and fallbacks per fish trapped may be different between control and treatment even if ATE does not differ. This result might suggest that fish may need to expend more energy to make it into the trap under a particular operating treatment. These analyses can be completed in a similar pair-wise method as will be used to test the effect of treatment on ATE. To minimize variability between treatments the differential between the bottom of the trap entrance and the tailrace surface elevation must be maintained at a constant of 1 ft.

Normal hydroelectric operations will occur during periods outside of test conditions. During these times the fish trap is scheduled to be sampled 5 days a week, Monday through Friday.

Data collected during the non-test periods will be used to assess the relationship between the 4 fish behaviors and ATE and other operational parameters. Because there are multiple environmental and operational changes that may occur during the non-test periods, researchers will use a retrospective approach to this analysis. A generalized linear modeling approach to evaluate the contribution of possible predictor variables will be used to evaluate ATE. A separate analysis will be conducted for the mutually exclusive categories of fallbacks, aborts, approaches, and successful entries.

Radiotelemetry Study

We are proposing a radio-telemetry study to monitor the behavior of adult fish in the tailrace. Specifically, we will compare the distribution and movement of tagged fish in the tailrace under the different operating scenarios of Unit 1 on and off. This study will involve tagging returning coho and Chinook salmon and winter and summer steelhead and monitoring their behavior with fixed radio array in the Project Area. The data from tagged fish will be assumed to be representative of the corresponding fish populations and as such will help us understand the behavior of the fish in the tailrace both prior to and after they first locate the trap entrance.

We will attempt to collect 100 adult, hatchery-reared fish for each of four species/stocks (summer steelhead, coho salmon, winter steelhead, spring Chinook salmon) by using a drifting gill net or hook and line sampling. The drifting gill net technique has been used for years to collect adult bull trout in Swift reservoir and in Yale tailrace for tagging and transporting. The method is quick and efficient thereby minimizing stress on the fish. We believe drift gill netting is far less stressful than hook-and-line capture. If our target sample sizes cannot be met with these methods we can also collect hatchery reared adults at the Lewis River Hatchery. Any supplemental fish collected at the hatchery ladder would be tagged and transport to the Study Area for release.

Up to 100 fish per species/stock will be tagged with Lotek MCFT-3A coded fish transmitters. These tags are 16 mm in diameter, 41 mm in length and weigh 16 g in air. With burst rates of 1.5 to 2 seconds these tags should last as long as 380 days. Tags will be gastrically implanted into fish covered in a nylon sock. This method has been used successfully to mark adult fish at PacifiCorp's Powerdale Hydroelectric Facility. If fish do not become sufficiently sedate for gastric implantation we will resort to use of CO2 as a backup to calm the fish for tagging. Individual fish will then be allowed to recover in isolated cells of a covered, aerated recovery tank. Once fully recovered, fish will be released in the pool just below the tail race, where many fish are known to hold during their upstream migration.

We will attempt to tag the fish in four batches of 25 spread over the early and peak portions of each fish run. Early in a run, the first group of 25 fish will be collected, tagged, and released with Unit 1 off. We are assuming that 20 % of our tagged fish will be lost from the study due to tag regurgitation or fish leaving the project area. Thus once 75 % of the first tag group has entered the trap we will end the first replicate of 1OFF. Beginning early the next morning we will commence operation of Unit 1 and will begin tagging a group of 25 fish for the 1ON treatment. The 1ON treatment will run for the same number of days required for the first 1OFF treatment. This tagging and treatment pattern will be replicated again during the peak of the run. Using this design, if we are unable to collect and tag our goal of 50 fish per treatment we will attempt a third replicate during the latter portion of a run.

Fixed Array

A total of 7 fixed detections zones will be established for this study (Figures 1 and 2). This will include 6 underwater antennae with 2 receivers and 1 DSP/receiver units located in the tailrace proper (Zones 1-6) and one aerial antenna with a single receiver located downstream of the tailrace (Zone 7). We also will use a mobile antenna to daily verify the presence of tagged fish in the trap.

Zone 7 is the most downstream detection zone and will be used to indicate that a tagged fish has entered the Project Area. An aerial antenna and a receiver will be placed just upstream of the existing hydroacoustic array (Figure 2). The antenna will be deployed to cover across the river capturing the entire water column. Detection zones 1 through 6 will be located in the tailrace. They will use underwater antennae, which limit the area covered, so movement in front of the trap, along the rock wall on the south side of the tailrace, along the face of the dam, and in the entry to the underwater gallery located behind the Powerhouse can be isolated (Figure 1). These antennae will be fabricated by PacifiCorp and are based on a design developed and tested by Chelan PUD. The ability of the antennae to detect the radio signal will be attenuated tightly enough to allow for deployment of 6 non-intersecting zones as generally depicted in Figure 1.

Treatment Groups

For analysis, fish will be classified into a treatment group based on the operating condition that occurs at the time of the initial detection presumably in Zone 7. Thus a fish that enters the Project Area for the first time while Unit 1 is on will be categorized as in the Unit 1 On treatment group, 1OnA. This classification assumes that once the fish enter they remain in the Project Area. Some fish may choose to leave the Project Area after initial entry. These fish will be monitored separately throughout the course of the study and the sequence of their subsequent detections will be used to determine our ability to classify them to a treatment group. For example a fish that enters the Project Area when Unit 1 is off and immediately leaves the area but returns a day later when Unit 1 is off will be classified into the same Unit 1 off treatment group, 1OffA. However, a fish that enters the Project Area when Unit 1 is off and returns a week later when Unit 1 is on will be classified into a distinct Unit 1 on treatment group, 1OnB. Likewise a fish that enters the Project Area with Unit 1 on and subsequently with Unit 1 off would be classified into treatment group 1OffB. Given the possible scenarios we are assuming that the 100 fish per species/stock will be classified into one of four treatment groups, 1OnA, 1OnB, 1OffA, 1OffB.

The time individual fish spend in each zone will be tallied for fish in different treatment groups and used to generate distributions of habitat use with in the tailrace for each fish and total time individual fish are in the tailrace. The hypothesis to be tested is that fish time distributions are not significantly different for treatment groups 1OnA and 1OffA and for 1OnB and 1OffB. We will also count the number of zonal transitions, movements from one zone to the next, to assess individual fish movement and will compare these counts under the different operating scenarios. The distribution of transition counts will be compared between treatment groups. The hypothesis to be tested is that transition count distributions are not significantly different for treatment groups 1OnA and 1OffA and for 1OnB and 1OffB.

Statistical Analyses
Each fish will be analyzed for the time spent in each of the 7 zones. The fish are the unit of replication for several reasons: 1) if we analyze the number of locations aggregated across all fish, a few frequently observed fish could dominate the analysis; 2) there may be individual behavioral differences among fish, and we want to account for this variability; 3) our analysis will be completed on the data as it was measured, rather than on an average or summed quantity that may obscure the individual fish behavior; and 4) if we analyze each fish individually, we have additional flexibility about the treatment conditions. The treatment does not have to span the duration of initial tagging through capture in the trap or loss from the system. Because the 7 zones are mutually exclusive, a generalized linear model for proportions (multinomial regression) will be used. The analysis will determine if the proportional use of the zones differs between treatments. For example, we will be able to test if the use of Zone 1 is greater under 1OnA versus 1OffA.

Objective 5 – If tailrace conditions preclude trap entry or cause migration delay what locations would be preferred for a new trap entrance?

Monitoring the daily influx of fish in the tailrace population will allow researchers to determine if the trap catch changes concomitantly with fluctuations in the tailrace population and will provide a numerical assessment of fish movement through the tailrace. Researchers will be able to determine if fish move through the tailrace at a constant pace, or if the pace changes as operating conditions change and over the migration period. In addition, the radio telemetry study will provide data on the total time that tagged fish spend in the Project Area, the number of times fish travel into and out of the Project Area, and the total time fish spend in each of the detection zones. The data collected for the different treatment groups also will be used to compare time spent in the Project Area under different operating conditions. The hypothesis to be tested is that total time spent in the project area is not significantly different for fish in Off and On treatment groups. We will address this hypothesis by comparing the time between detection at Zone 7 and capture in the trap (the project area) under Off and under On treatments using a hypothesis testing framework such as analysis of variance (ANOVA). In addition, the number on times that individual fish enter and exit the Project Area under different operating scenarios will be calculated and statistically compared to evaluate any possible far field effect of Unit 1 operations. The null hypothesis to be tested is that the number of fish exiting the Project Area is not significantly different between On and Off treatment groups. We will test the number of times fish exit the project again using ANOVA.

Data collected on the total time fish spend in each of the detection zones will provide for a descriptive analysis of possible locations for alternative trap entrances. In addition, we can test whether there are statistical differences between zones for each operational scenario (On versus Off). These data can be summarized for Off and On treatments to account for behavioral changes associated with project operations to suggest alternative locations that increase the probability of fish encountering the trap. If no differences are evident between treatment groups the data will be pooled for presentation.

III. Phase 2 – Long Term Monitoring the New Trap

The goal of this Phase is to develop a long-term monitoring system that will provide sufficient detailed information to identify and hopefully eliminate any operational constraints on the Merwin Project. To reach this goal, the 2005 test study will be critiqued. In addition to just looking at data results, it will be important to consider information gathered during the study on ease of equipment operation, labor requirements, Project operational constraints, and overall cost. This information should be incorporated into the decision on the best technologies for permanent installation. It is possible that equipment not selected for the study will be more desirable for permanent installation. For example, due to a lack of availability in 2005 and high cost researchers have opted not to use the newly developed long term DIDSON camera for the study and instead have proposed a hydroacoustic array at the mouth of the tailrace. However, when considering year round use of a permanent detection system, the initial high capital cost of the DIDSON may be countered by the reduction in savings associated with automated data processing. With use of any remote monitoring equipment researchers would recommend periodic verification of the daily estimates.