Feasibility Study for Evaluating Cumulative Exposure of Downstream Migrant Juvenile Salmonids to Total Dissolved Gas

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Executive Summary

We initiated a feasibility study in summer 1996 to determine if downstream migrant salmonids could be monitored to determine potential relationships between total dissolved gas (TDG) exposure and signs of gas bubble trauma (GBT). The primary objectives were to 1) establish logistical requirements for in-river monitoring of TDG exposure, including net pen design, deployment, and navigation constraints; 2) resolve uncertainties associated with effects of the net pen on fish behavior; 3) test the accuracy and precision of in-river monitoring equipment used to measure fish distribution and water quality; and 4) determine the application of hydrologic/flow models to predictions of TDG exposure. The study area extended from Levey Park, about 3 km upstream from Ice Harbor Dam, downstream to the forebay of McNary Dam.

A flow model, based on water particle travel time through the Ice Harbor Dam tailrace and McNary pool, was used to estimate trip duration for each test. A standard aquaculture net pen, 6.7 m in diameter and 5 m deep, was modified to suit our research needs. We used juvenile rainbow trout, *Oncorhynchus mykiss*, and fall chinook salmon, *O. tshawytscha*, as test species. In-river measurements included water velocity, boat position, and selected water quality parameters (temperature, dissolved oxygen, pH, depth, conductivity). Fish distribution within the net pen was monitored using scanning sonar, and a split-beam echo sounder was used to evaluate vertical distribution of fish in the river adjacent to the net pen.

Three test drifts were conducted from late July through late August. For the first test drift, efforts were mainly directed toward resolving uncertainties about logistics, including net pen assembly and deployment, and our ability to follow a prescribed float plan. We found that the net frame provided adequate support for pushing the net pen and that navigation at 2.4 km/hr was feasible under calm weather conditions. All fish were recovered at the end of the drift, and there were no signs of injury or stress. Primary objectives of the second drift were to successfully navigate through the lock system at Ice Harbor Dam and barge channel. Navigation was successful; however, "bottlenecks" existed within the channel immediately downstream of Ice Harbor Dam and locations where barge traffic could force the net pen into shallow depth. Turbulence from barge or boat traffic is likely to affect echo sounder signals for short periods of time. For our third drift, we added full deployment of monitoring systems and equipment (GPS, scanning sonar, split beam acoustic, water velocity, and water quality monitor). Our principal objectives for this drift were to describe fish behavior within the net pen with hydroacoustic equipment and determine the utility of other in-river monitoring equipment. The video display of the scanhead sonar image indicated that the lower portion of the net pen frame became distorted during tow. Acoustic monitoring provided valuable information on fish behavior and characteristics of the net during transit, and the rate of travel was consistent with our planned speed. For example, vertical distribution profiles showed that fish exhibited distinct diel movement patterns. Fish targets were detected in the river adjacent to the net pen using split-beam technology at depths to 10 m.

Our studies demonstrated that it was feasible to assemble and deploy a large net pen, using off-the-shelf equipment, for mobile monitoring of TDG exposure in the lower Snake and mid-Columbia river area. We were able to accurately monitor vertical and lateral distribution of smolts in the net pen and to document diel differences in their behavior. Further, we noted that fish sounded in response to researcher activity on the net pen perimeter platform. Thus, in-transit monitoring for GBT or mortality

would affect fish depth distribution and exposure to TDG. Our principal recommendations for future studies are directed at improving maneuverability of the net pen in adverse weather conditions, providing more vertical space for fish to distribute if they so choose, and applying new acoustics technology to simultaneously collect fish distribution data from within and outside of the net pen.

Acknowledgments

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Introduction

In their 1995 Federal Columbia River Power System Biological Opinion, the National Marine Fisheries Service (NMFS) specified a spill program at Snake and Columbia river projects. The hypothesis for the spill program was that specific amounts of prescribed spill would improve in-river survival of migrating juvenile salmonids while minimizing environmental hazards to salmonids and other aquatic biota. The NMFS also adopted an adaptive management strategy for the spill program. Under this strategy, NMFS must ensure that the biological effects of spill are monitored and that monitoring data acquired provide the necessary feedback to spill program managers to protect important aquatic resources from high levels of dissolved gas.

Review of the state of knowledge about the effects of high levels of dissolved gas on salmon and other river inhabitants has determined that several uncertainties exist about the effects of dissolved gas on fish and, as a consequence, on the ability of monitoring programs to provide adequate feedback for adaptive management of the spill program (Montgomery Watson, 1995a, 1995b; NMFS Panel on Gas Bubble Disease, 1994, 1995; NMFS/EPA Gas Bubble Disease Technical Work Group Inspection Team, 1995a, 1995b). This report describes a research project conducted by Pacific Northwest National Laboratory directed at resolving two uncertainties considered critical to validate the existing NMFS spill effects monitoring program: (1) Are current sampling designs and sites adequate for detecting mortality? and (2) Do signs of gas bubble trauma (GBT) accurately reflect biological effects?

We conducted a preliminary study to resolve uncertainties related to use of a mobile net pen to monitor fish and to determine if a more comprehensive study that monitors fish as they move downstream through the hydropower system is feasible. These kinds of field studies are needed to determine the appropriateness of laboratory findings to exposure scenarios in the field. For example, there has been considerable debate about how factors such as the condition and behavior of fish might influence their distribution in the water column and, as a consequence, modify their exposure history. Current in-river monitoring techniques do not include a means to relate symptoms of fish to actual conditions experienced during their downriver migration. New approaches are required to link exposure histories of fish with known operational scenarios and total dissolved gas (TDG) conditions in the Columbia and Snake rivers. One approach suggested by regional experts was a traveling pen concept where GBT and mortality in smolts is monitored as they migrate through the hydropower system. A traveling net pen study would complement the current monitoring program, including both direct capture observations and fixed location net pen studies. However, a traveling net pen study has many uncertainties associated with it, particularly related to validation of fish behavior in the net pen and accuracy of *in situ* measurement techniques.

Our overall research objective was to determine if fish with a known exposure history could be monitored during their freshwater migration interval through the federal hydropower system to establish a relationship between TDG exposure and symptoms of GBT. The primary objectives of the 1996 feasibility study were to:

- establish logistic requirements for in-river monitoring of TDG exposure, including net pen design, deployment, and navigation constraints

- resolve uncertainties associated with effects of the net pen on fish behavior, including effects of confined space on vertical distribution and activity patterns

- test the accuracy and precision in-river monitoring equipment used to measure fish distribution and water quality

- determine the application of hydrologic/flow models to predictions of TDG exposure.

To achieve these objectives we conducted three test net pen drifts (Drift 1, Drift 2, and Drift 3), which are described in the following sections. The tests helped us determine the feasibility of assembling and deploying a large net pen to monitor TDG exposure of juvenile salmonids to TDG in the lower Snake and Columbia rivers.

Study Area

The study area extended from Levey Park, about 3 km upstream from Ice Harbor Dam, downstream to the forebay of McNary Dam (Figure 1). Much of the route immediately downstream of Ice Harbor Dam was confined to the navigation channel because of depth constraints, i.e., much of the free-flowing section of the Snake River downstream of Ice Harbor Dam is <6.5 m deep. Principal reasons for selecting this area for study included: 1) TDG levels are typically highest there when compared to other lower Snake River reaches, 2) study results could be coordinated with other TDG monitoring studies conducted in the area (e.g., fixed location net pens, resident fish monitoring), 3) this reach provided for a test exposure interval of at least 24 hr, and 4) it was close enough to our laboratory that stress to test fish would be minimized during transport to the site.

Deployment locations were at the Port of Walla Walla facility on the south shore of the Snake River at RM 1.9 and at Levey Park, located on the north shore at RM 12.8. The retrieval location for all test drifts occurred immediately upstream of McNary Dam at the public boat launch area on the Oregon (south) side of the river.

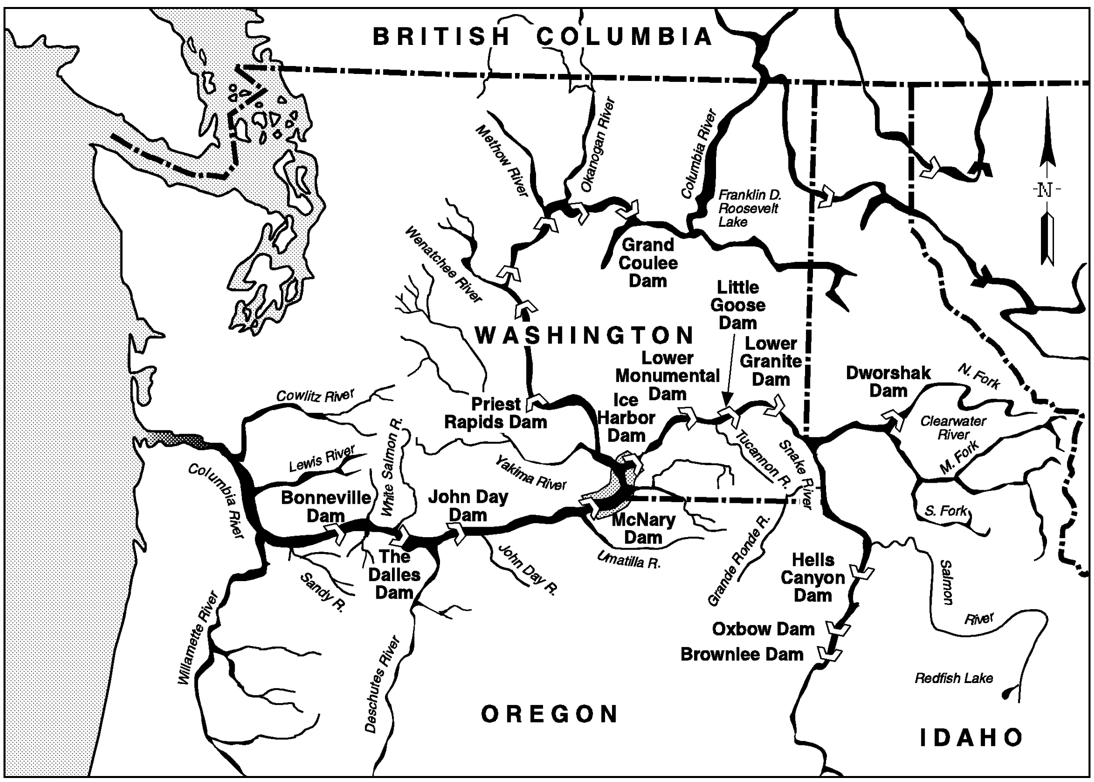

Figure 1. Location of Study Area (shaded portion) Within the Columbia River Watershed

Methods and Materials

This section outlines methods used to conduct the three drift tests and describes study materials, including the net pen selected for testing, test fish, and monitoring equipment.

Methods

The general methodology used to conduct the mobile net pen tests and specific objectives are described below for Drifts 1, 2, and 3.

Drift 1

The first test drift occurred July 30-31, 1996, from RK 3.0 (RM 1.9) of the Snake River to McNary Dam at RK 471 (RM 292.7) on the Columbia River, a total distance of 53 km (33 mi). Rainbow trout (250) were placed in the net. We directed our efforts for the first test mainly toward resolving uncertainties about logistics, including net pen assembly and deployment, and our ability to follow a prescribed float plan. Other concerns included our ability to maneuver the net pen around channel obstacles and river traffic, e.g., barges. We also addressed some aspects of the flow model and fish behavior.

Drift 2

For Drift 2, from Levey Park (RK 19.1 [RM 11.8]) to RK 3.0 (RM 1.9) on the Snake River, we wanted to determine if our improvements to the net pen made assembly and deployment more efficient and to resolve uncertainties associated with logistics of navigation through the Ice Harbor locks and barge lane downstream of the dam. Thus, the primary objectives of the drift were to successfully navigate through the lock system and barge channel and to track our drift rate and location using GPS equipment. The drift took place August 22, 1996. Because of restrictions on our fish use permit, no fish were placed in our net.

Drift 3

For Drift 3, which began near mid-day August 28, 1996, and ended at 0800H on August 29, we repeated the navigation route taken during Drift 1, but fully deployed monitoring systems and equipment (GPS, scanning sonar, split-beam acoustic, water velocity, and water quality). A total of 200 fish (100 rainbow trout and 100 chinook salmon) were placed in the net. Our principal objectives were to describe fish behavior within the net pen with hydroacoustic equipment and to determine the utility of other in-river monitoring equipment.

Materials

Materials used to conduct the 1996 feasibility study are described below. The flow model used to estimate trip duration for each drift also is described.

Floating Net Pen

A primary objective of this study was to monitor the behavior of fish inside the net pen and compare it to the behavior of free-swimming fish in the adjacent river environment. Because ambient light, presence of food organisms, and other environmental conditions may affect fish behavior, the size of the net pen needed to be large enough to allow "free" movement of fish within the net. However, the use of a large net pen made some aspects of monitoring and sampling fish more difficult.

A standard aquaculture net pen[(a)] (Figure 2) was modified to suit our research needs. The net designed for the pen was about 6.7 m in diameter and 3 m deep. The net material was black braided nylon, 95 mm (3/8-in.) mesh, 1.9 cm (3/4-in.) stretch that was reinforced on three horizontal and six vertical seams. The flotation ring was constructed from four sections of high-density polyethylene pipe (0.3 m diameter, 1.6 cm thick) bolted together with bulkhead flanges. When assembled, the frame was hexagonal in shape, with each side being about 3 m long. The gross buoyancy of the ring was 1270 kg. The top of the flotation ring had a wooden walkway (~0.3 m wide). Twelve metal stantions attached to the walkway and flotation ring supported a 7.6 cm diameter PVC hand rail that also acted as the frame for a 1-m-high jump net extension. Volume within the net was approximately 140 m^3.

We added a 2-m drop extension to the standard net to attain the planned depth of 5 m. We also added a support frame for the net pen made from 7.6 cm (3 in.) diameter aluminum pipe (Figure 3). Six vertical upright pipes (4.3 m long, with cross bars near the bottom and ~1.2 m from the top) were secured to the flotation ring walkway and to a spreader hoop made from 5 cm (2 in.) iron pipe (hexagonal in shape, 18.3 m perimeter) using nylon rope lashings and stainless steel hose clamps. This arrangement provided a rigid "cage" around the upper 3.3 m of the net. The hoop and frame were outside the net, and the net was fastened to the spreader hoop with cable ties at a reinforced seam 3.3 m below the water surface. The weight of the spreader hoop and the rigidity of the aluminum pipes kept the netting taut. A second hoop made from 4 cm (1 1/2 in. ID) PVC pipe was attached inside the net bottom to support the bottom 2 m net extension. Six 4- to 5-kg anchors were attached to loops at the bottom of the net to add weight to stretch and maintain the shape of the extension.

Test Fish

We used fish reared at our aquatic research hatchery for the study. Juvenile rainbow trout *Oncorhynchus mykiss*, (12-15 cm fork length [FL]) were reared from brood stock. Fall chinook salmon, *O. tshawytscha*, (10-12 cm FL) came from eggs obtained from the Washington Department of Fish and

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(a) Ocean Circle™ Enhancement Cage. Ocean Spar Technologies, LLC, Bainbridge Island, Washington.

Wildlife's Priest Rapids Hatchery. Test fish were transported to the site in an insulated fish transport tank supplied with oxygen and placed in the net pen on the day before each drift.

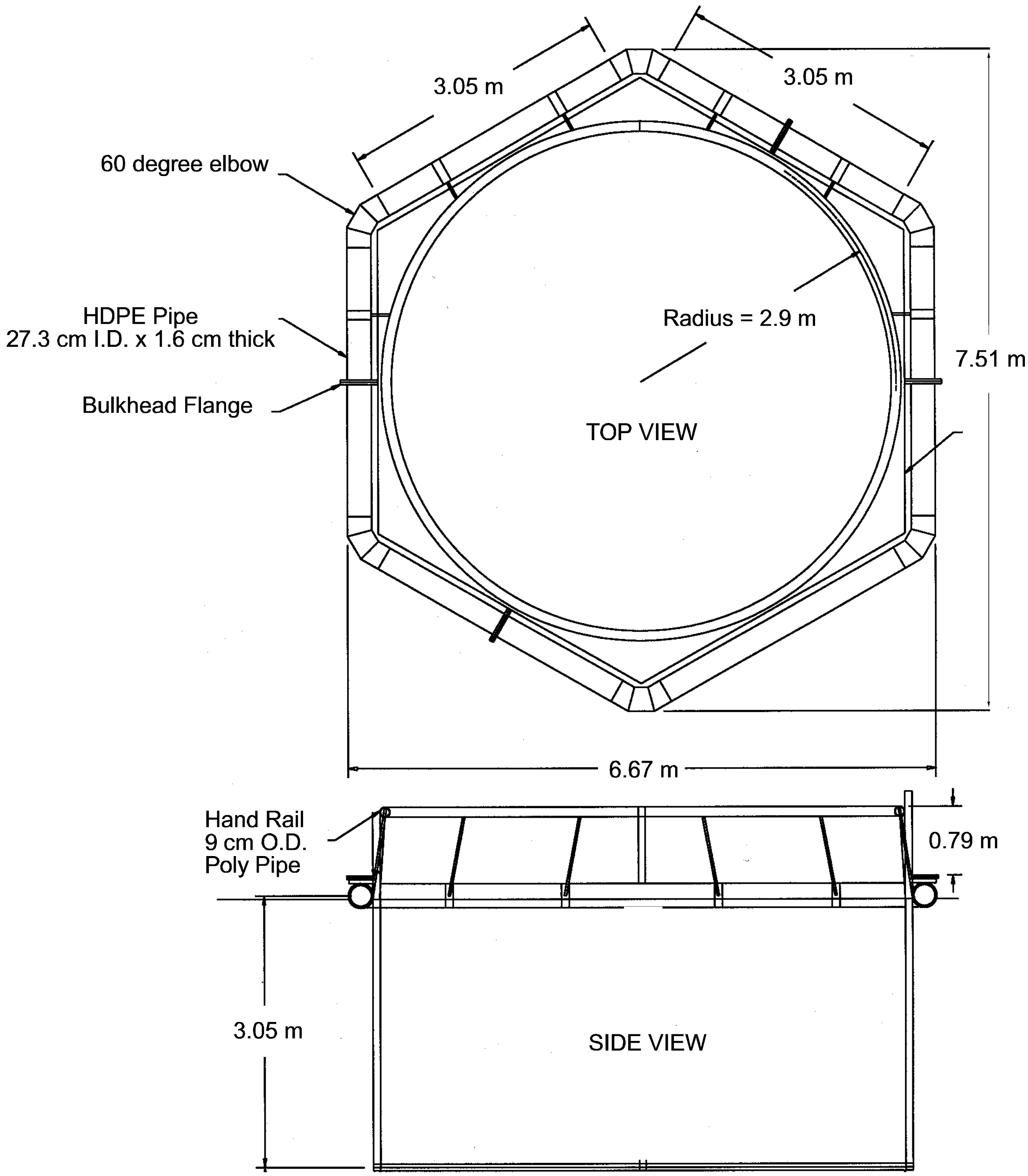

Figure 2. Commercial Floating Net Pen Before Modifications to Meet Research Needs

In-River Monitoring

One goal of this study was to determine the feasibility of deploying sophisticated electronic equipment to monitor fish behavior within and adjacent to the mobile net pen. Primary considerations for the boat included adequate deck space, cover for equipment, sufficient power to maneuver the pen, and low fuel requirements. The boat used for these studies was a 5.1-m (17-ft) Monarch with twin 75 hp outboard engines. Its bow shape was suitable for pushing the net pen, space for equipment and personnel was adequate, and fuel efficiency was better than the 6.3-m (21-ft) jet sled that was also tested. Electrical power requirements for equipment also was a major consideration for planning monitoring activities. We used a 1750-watt generator to operate all AC equipment, and 12-volt marine deep cycle batteries were used to operate DC equipment. All equipment was operated continuously except for brief maintenance and refueling periods.

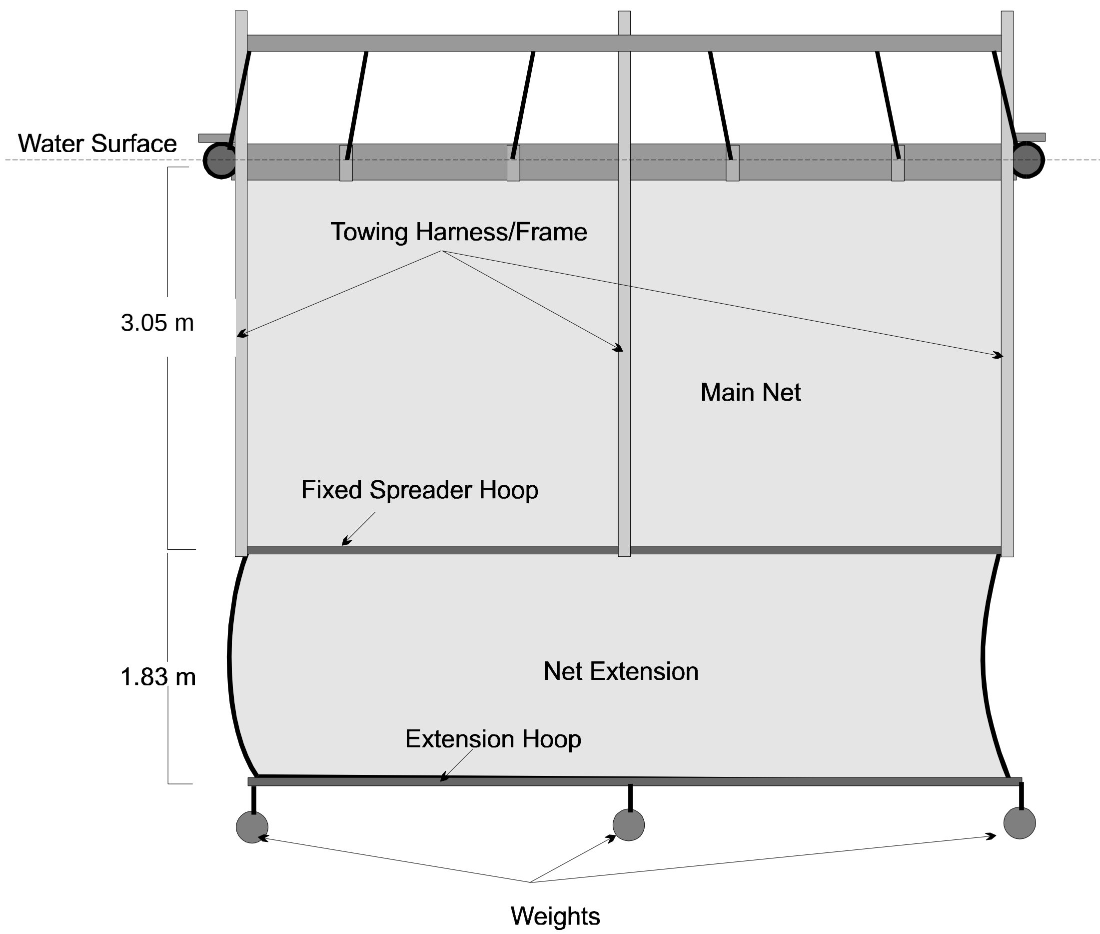

Figure 3. Towing Harness, Supports, and Drop Extension Added to Net to Meet Research Needs

Scanning Sonar

A scanning sonar system was used to monitor fish distribution within the net pen (Figure 4). The system operated at a frequency of 675 kHz, well into the ultrasound range, which would not be discernible by the fish under test. The scanhead was supported on a vertical pole attached to the railing and submerged about 0.3 m below the surface in the center of the net pen. Both the processor/ controller and monitor were located inside the tow boat. The monitor display was video taped continuously during the daytime and periodically during the night. An antenna type rotator was used to rotate the scanhead on the horizontal axis. The scanhead was tilted 15° from horizontal to compensate for the tilt angle of this particular scanhead. The transducer beam was fan-shaped (1.7° x 30°) and was scanned orthogonal to the long axis of the scanhead. The scan sector was set at 240° to provide good definition of the surface in addition to the entire sweep of the net pen. The optimum orientation would be in a normal configuration with the axis orthogonal to the long axis of the scanhead. This would result in a scan track that would follow the centerline from side to side with the approximate coverage (Figure 5). Thus, the plan and side view of the net pen shows the predicted coverage using side scanning sonar. The darkened area represented in the plan view is the area covered parallel to the surface at the depth of the scanhead deployment. The light area is an approximation of the area covered at the net pen bottom. In the side view, the shaded area is an approximation of the area covered on the sides of the net pen.

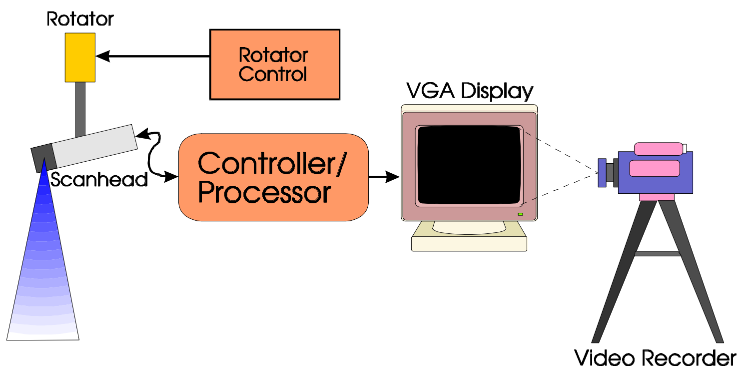

Figure 4. Scanning Sonar System Configuration Used to Monitor Fish Behavior Within the Net Pen

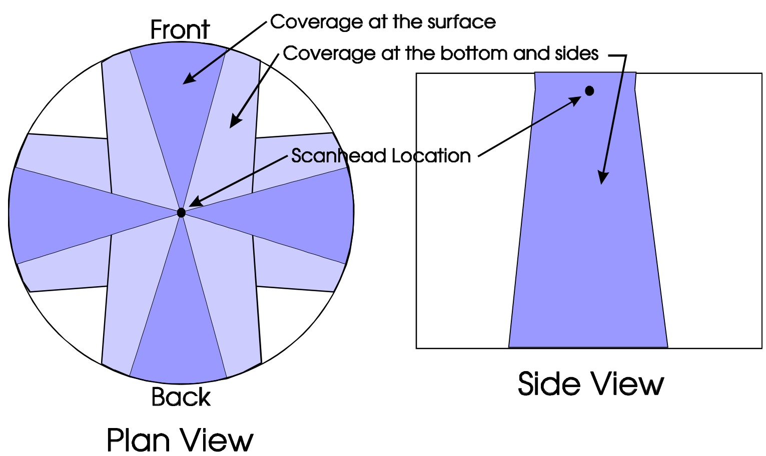

Figure 5. Plan and Side View of Net Pen Coverage Using Side Scanning Sonar

Split-Beam Echo Sounder

A split-beam echo sounder (420 kHz) was used to evaluate vertical distribution of fish in the river adjacent to the net pen. The configuration is shown in Figure 6. Split-beam tests were conducted on August 28-29, 1996, with a split-beam transducer attached to a rigid pole mount on the port side of the tow (push) boat. The transducer was angled up 45° from vertical and looking out away from the boat. This angle was chosen to provide reasonable coverage from near the surface to the maximum depth of the net pen (approximately 5 m) and beyond to approximately 27 m. Data files were collected approximately every 5 min throughout the survey period.

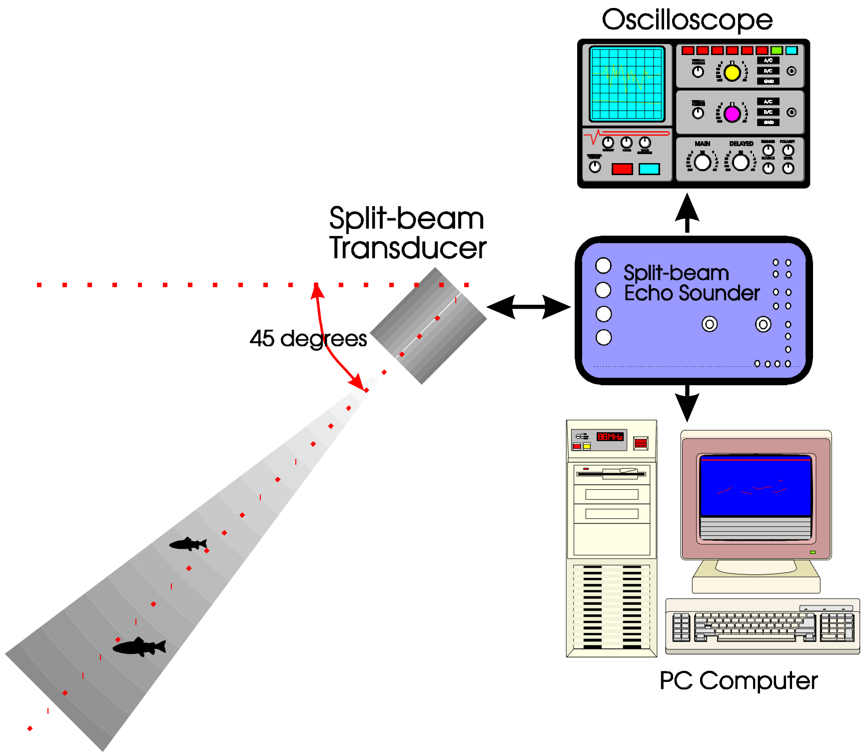

Figure 6. Split-Beam Echo Sounder Configuration Used to Monitor Depth Distribution of In-River Fish

We conducted additional tests in September to assess the suitability of the split-beam hydroacoustic technique to operate very near-surface during net pen drifts. The transducer was characterized by a split 6^{o} beam with first side lobes down approximately -30 dB and deployed from a pole mount attached to the bow of the boat. A ping-pong ball target (approximately -40 dB target strength) was suspended from a surface float on a weighted monofilament fishing line suspended at the same or slightly deeper depth as the transducer (approximately 1 m). The boat was then positioned at various ranges from the target to determine its detectability.

Water Quality Monitoring System

A YSI Model 6000 Environmental Monitoring System™ was used to monitor selected water quality parameters (temperature, dissolved oxygen, pH, depth, conductivity). A Sweeney Model DS1-A saturometer™ was used to monitor TDG levels. The system was suspended from a line at about mid-depth in the net pen (2.5 m). Data were recorded at 10-min intervals throughout Drift 3 from the mouth of the Snake River to the forebay of McNary Dam.

Exposure Modeling

Another project goal was to link hydrologic flow models to possible exposure scenarios related to TDG concentrations in the study reach. We developed an approach to track net pen locations relative to modeled flow regimes.

A flow model, based on water particle travel time through the Ice Harbor Dam tailrace and McNary pool, was used to estimate trip duration for each test (Table 1) In addition, information from the 1995 PIT-tag data base indicated that smolt migration rates through this section of the river were approximately 0.8 km/hr (0.5 mi/hr). Thus, our rates of travel were adjusted accordingly during the test drifts.

Water velocity measurements were made with a Marsh McBirney Model 2000™ water current meter. The probe was positioned about ~0.3 m below the water surface immediately in front of the leading edge of the net pen. These measurements were compared to readings inside the net pen to monitor effects of the net on velocity and ensure that conditions inside the net pen were not detrimental to the fish stocks.

A Trimble Pro XL™ Global Positioning System (GPS) was used to record boat position during the second and third net pen drifts. The GPS system provided accuracy of about ±2 m following differential correction using a base station located on the Hanford Site. The GPS antenna was mounted on top of the boat cabin. Data was recorded at 1-min intervals on Drift 2 and at 10-min intervals during Drift 3. The GPS data were differentially corrected and processed using PFINDER™ software. Corrected data were then imported into ARC/INFO, a geographical information system (GIS) software. Positional data were integrated with existing GIS databases showing the shoreline of the Snake and Columbia rivers to produce a graphic representation of net pen location during the drift. From this data set, we could determine our exact location at any given time during a trip.

Table 1. Estimated Trip Time from Ice Harbor Dam to McNary Dam and Water-Particle Travel Times (WPTT) under Different Discharge Regimes (combined totals from Priest Rapids and Ice Harbor dams)

Columbia River Discharge (Qc)	Snake River Discharge (Qs)	Total Time (hr)	WPTT (ft/sec)
50	25	156	0.18
100	50	78	0.35
200	100	40	0.71
300	150	27	1.06

Results and Discussion

This section summarizes results of the 1996 feasibility study as they relate to specific study objectives.

Drift 1

Study objectives for Drift 1 focused on logistical requirements, fish behavior, and exposure modeling. Results are described below for these areas.

Logistical Requirements

We overcame several logistical challenges during our first attempt to assemble the net pen. Because the ends of each of the four sections of the flotation ring were open (not sealed), sections were bolted together at the water's edge to prevent water from entering the pipe. Because of the slope of the bank, we experienced some difficulty aligning sections, but we were able to bolt the four sections into a water-tight flotation ring. Once the ring was floating, the remainder of the assembly process went relatively smoothly. We found it difficult to secure vertical poles to the spreader hoop with rope lashings as suggested by the vendor because it was difficult to hold the pieces in place and make tight wraps under water. Instead, we used stainless steel hose clamps as fasteners. This joint was much more rigid than lashings and could be easily loosened for disassembly. It was not possible to lift the spreader hoop manually, because of the overall weight and drag. Therefore, we added three boat winches to the metal stantions supporting the hand railing to raise and lower the spreader hoop during assembly and disassembly. The entire assembly process required approximately 4-6 man-days of effort.

We attempted to pull the net pen into deeper water to extend the net to its full depth. However, we quickly discovered that we could neither move the boat upstream (even in slack water) or maneuver it when towing the net behind the boat. As we pulled harder with the boat, the increased prop wash negated our thrust. In contrast, the net pen could be maneuvered easily when it was pushed. Thus, we built a small docking platform on one side of the net pen to help secure the boat in a fixed position for pushing (Figure 7).

A crew consisted of three people, two on the boat and a third person with a vehicle on the shore to provide support as needed. Although there were reports of high winds in the late afternoon on July 30, the first test day, the weather was warm and sunny with no wind throughout the day. The night crew experienced upriver winds (10-20 mph) for about 4 hr in the middle of the night.

The net pen was easy to maneuver in calm water. If course correction was necessary, the boat pivoted around the net pen and could then be pushed on the desired course. Barge wakes presented no problems. Approaching barges were visible for several miles, and we could easily steer clear of barge traffic. Wakes from barges were negligible and did not affect our ability to navigate.

Figure 7. Fully Assembled Net Pen with Push Boat

Fuel consumption was monitored closely during the first trip. Our internal gas tanks held 36 gal and we had an extra 10 gal onboard. Because there was no monitoring equipment onboard during the first drift, the boat was detached from the net pen and taken to shore for shift change and refueling, and the net pen was set adrift. At shift change, another 10 gal was added to the tanks. The night crew had to make one additional fuel stop enroute to the study area with the aid of the shoreline support staff. Total gas consumption for the trip was ~66 gal, or about 3.3 gal/hr.

Fish Behavior

The net pen was stocked with 250 rainbow trout on July 29. The first fish observations were made about 2 hr after the drift was underway. Fish were visible swimming about 3 ft below the water. They generally swam in the downstream direction, maintaining their position in the middle of the net pen. Some lateral movement of fish was observed as well. Fish responded by sounding if approached by staff. By mid-afternoon, fish were no longer visible near the surface. No observations were made at night. All fish were recovered when the net pen was dismantled at the end of the drift and there were no mortalities or noticeable injuries.

Exposure Modeling

The initial float plan was based on estimated travel times of juvenile migrant salmonids (based on PIT tag data), river flows, and a model that predicted water particle movement rate. Average daily flows at Priest Rapids and Ice Harbor Dams were ~150 kcfs and ~40 kcfs, respectively in late July. Based on this information, we chose 2.4 km/hr (1.5 mph) as the target speed for the first drift. Therefore, we anticipated that it would take ~20 hr to reach McNary Dam from the mouth of the Snake River.

We monitored our position using river navigation charts, channel marker buoys, and shoreline structures and features. Engine speed (~1200 rpm in calm water) was adjusted to maintain a speed of ~2.4 km/hr. When moderate upriver winds were present, engine speed was increased to as much as ~2000 rpm. We covered the 50-km (31 mi) reach through McNary pool in 20 hr, or almost exactly at our desired target speed (Figure 8). Drift rate was faster than our desired speed at the beginning of the drift and somewhat slower at the end of the drift. Our observations were consistent with water particle movement rates predicted in the flow model for the river flows present during our drift.

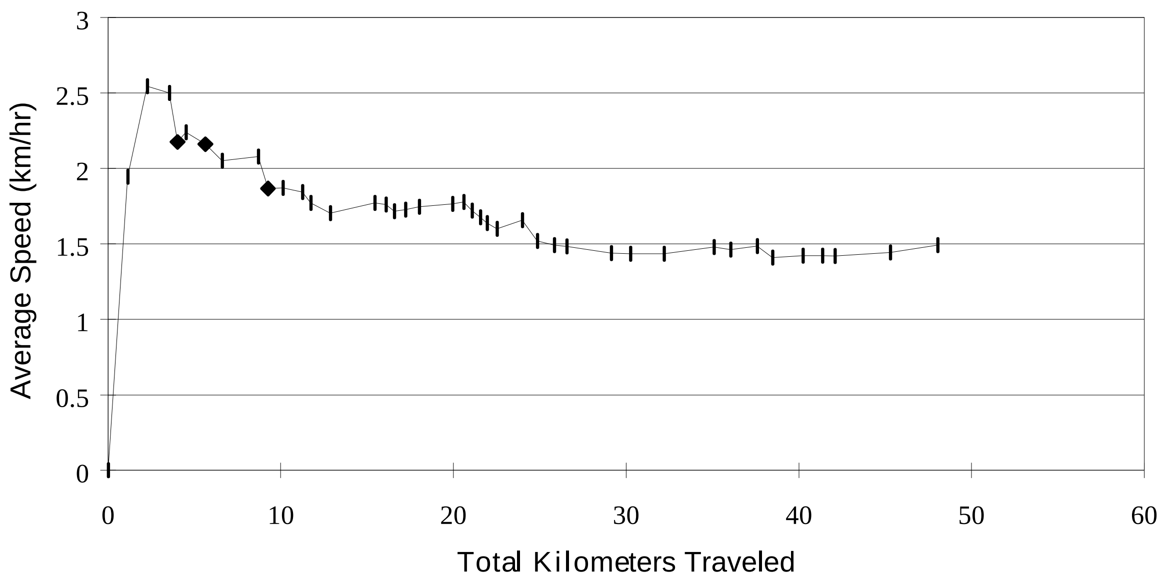

Figure 8. Estimated Drift Rate Using Navigation Charts and Channel Marker Buoys to Monitor Location During Drift 1, July 30-31, 1996

Summary

The following observations relative to study objectives were made during the first drift:

- The net frame, although designed to tow the net pen, provided adequate support for pushing the net pen at a speed of 2.4 km/hr.

- Solid plates were sealed to the ends of each of the four segments of the flotation ring. This modification allowed for individual pieces to be floated on the water for alignment and assembly without the risk of water entering the sections. This modification also made it possible for two people (rather than four) to move and assemble the flotation ring.

- When fully assembled, the flotation ring was about half submerged. Therefore, the walkway around the net pen was only about 0.25 m above the water line. Any chop or wave action resulted in water going over the walkway. Thus, any monitoring equipment mounted on the net pen required protection from the elements.

- Fish responded to a noticeable water velocity within the net pen. Fish oriented into the velocity (the direction the net pen was traveling) and maintained their position during the drift.

- Limited visual observations of fish (i.e., coloration, position in the net pen, swimming behavior) indicated that they were not stressed during the drift. However, they responded by sounding when approached by staff.

- All fish were recovered at the end of the drift, and there were no signs of injury or stress to the fish.

- Water velocity within the net pen was estimated at ~0.23 m/sec at an estimated travel speed of 2.4 km/hr or 0.67 m/sec (1.5 mph).

- Barge wakes and traffic did not interfere with our float plan.

- Movement and navigation of a net pen following a predetermined float plan was feasible under calm weather conditions.

Drift 2

For Drift 2, results are summarized below for related logistical requirements and exposure modeling.

Logistical Requirements

Based on our experience during net pen assembly for Drift 1, several modifications were made to make deployment easier, to strengthen the frame, and to enhance our control of the net pen during the drift for sampling and disassembly. For example, end plates were welded to the end of each section of the flotation ring, creating four independent floating sections. This allowed for individual sections to be floated, aligned, and loosely bolted together during assembly. When all four sections were attached, all bolts were tightened to complete the flotation ring assembly. A fourth winch was added to the metal stantions supporting the hand railing to assist in raising and lowering the spreader hoop. The winches also helped to center and support the spreader hoop for installing stainless steel hose clamps to hold the vertical aluminum poles in place. The entire assembly for Drift 2 took less than 3 man-days of effort.

Conditions were calm throughout the day. In addition, there were no barges or other boat traffic in the locks during the lock-through. Because of uncertainties about water depth in certain areas downstream of Ice Harbor dam, we used a pilot boat to search for trouble areas as we proceeded downstream. We monitored water depth with a depth finder during the drift but did not continuously record depth.

Based on average daily flows at Ice Harbor Dam in the day preceding our drift (40 kcfs), we estimated that it would take about 5-6 hours to reach the mouth of the Snake River. However, flow at Ice Harbor Dam increased from ~40 kcfs to about 60 kcfs during our drift. For the first 6.4 km downstream of the dam (RK 15.6 to RK 8.9 [RM 9.7 to RM 5.5]), we navigated in the barge channel that runs along the north shoreline. We stayed near the red buoy line (left side of the channel when facing downstream) so that we could move into shallower water to avoid barge traffic if necessary. At about RK 8.9 (RM 5.5), the channel switched from the north to the south shoreline. We followed the channel and proceeded down the south shore for the remainder of the drift (~RK 3.0 [RM 1.9]). We encountered only one barge traveling downstream during the trip. The barge was visible from several miles away and we easily avoided it by maneuvering across channel to the red buoy line marking the south boundary of the navigation channel. However, we observed that the turbulence from the tugboat prop showed up on our echo sounder depth chart for a few minutes after the barge passed.

Exposure Modeling

To get to the Ice Harbor locks in time to meet the lock-through schedule, the net pen was pushed the 3.5 km from Levey Park to Ice Harbor Dam forebay in the “up” position, i.e., only the bottom and about 0.5 m of the net and lower end of the frame were in the water. We were able to easily push the net pen in this configuration at the rate of about 3-5 km/hr without stressing the frame. When we arrived at the dam forebay, we lowered the net frame until the spreader hoop was about 3 m below the water surface. The 2-m drop section of the net was not lowered in anticipation of shallow water downstream of Ice Harbor Dam. We established radio contact with the lock operator and proceeded with the drift. The entire lock-through process took less than an hour, and we encountered no logistical problems.

We had minor problems activating the GPS system and did not log positional data from Levey Park to about 1.5 km downstream of Ice Harbor Dam (RK 14.5 [RM 9.0]). From that point on, data were recorded at 1-min intervals. Positional data for the net pen during the second drift are shown in Figure 9.

Water velocity within the net pen, as measured with a velocity meter, varied from 0.34 m/sec to 0.20 m/sec (1.1 to 0.67 fps) and were related to engine revolutions per minute (rpm). When engine speed was raised to ~1900 rpms in slack water areas, velocities within the net pen were about 0.32 m/sec (1.0 fps). When engine speed was maintained at ~1200 rpm, velocity within the net pen was about 0.2 m/sec (0.65 fps). Our drift from Ice Harbor Dam to the Port of Walla Walla took approximately 3 hr or 2-3 hr less than we predicted.

Summary

No logistical problems were encountered during Drift 2. However, we found a few "bottlenecks" within the channel immediately downstream of Ice Harbor Dam, locations where barge traffic potentially could force the net pen into depths <6.5 m. Specific observations related to in-river monitoring and exposure modeling objectives included:

- Turbulence from barge or boat traffic is likely to affect fish observations (echo sounder signals) for short periods of time.

- Movement rate of the net pen and boat was much faster while we were in the barge channel than predicted rates based on the water particle velocity model and discharge at Ice Harbor Dam.

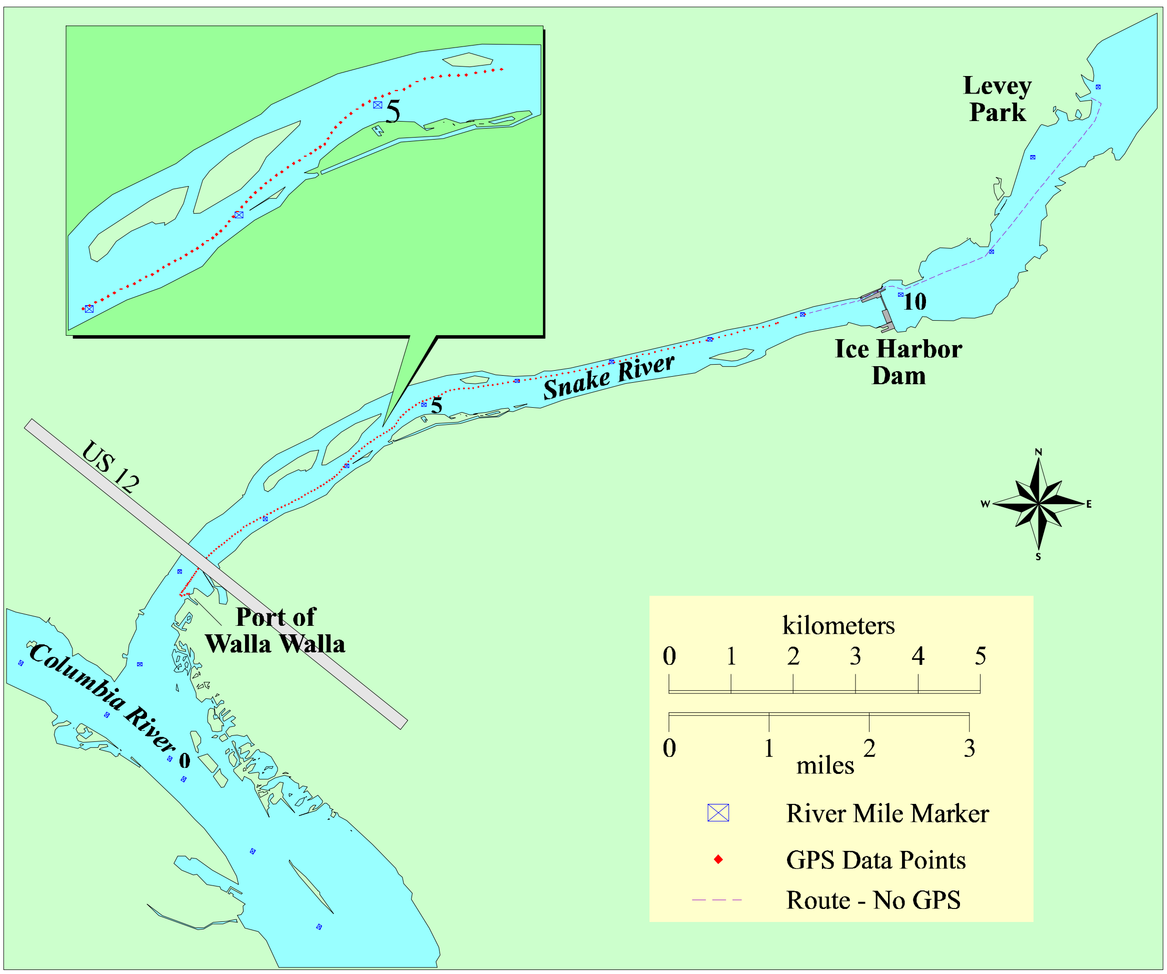

Figure 9. GPS Positional Data for Drift 2, August 2, 1996

Drift 3

Results for Drift 3 are summarized below related to logistical requirements and fish behavior objectives. In-river monitoring results also are reported.

Logistical Requirements

Monitoring equipment was set up and tested the day before the drift (August 27). However, because of the lack of security at the deployment site, all equipment had to be dismantled and reassembled in the morning. The day crew consisted of two people on the boat. One shift change occurred roughly at the midpoint of the trip. Two people were on the boat during the night, and a third person followed in a vehicle on shore for additional support. Extra fuel was added at shift change to eliminate the need for refueling in the middle of the night. No modifications were made to the net pen for Drift 3 except for adding and setting up monitoring equipment.

Weather was warm and calm throughout the day (August 28). However, the night crew again experienced mild upriver winds at night (5-10 mph). Engine speed was increased to ~1800 rpm to maintain forward progress into the wind. Winds were calm in the early morning. However, when the net pen and boat reached the boat launch on the Oregon side of McNary Dam (August 29), high winds (≥50 km/hr) made it difficult to bring the net pen ashore.

Fish Behavior

The net pen was stocked with 100 rainbow trout and 100 fall chinook salmon smolts on the day before the drift. During Drift 3 we kept the scanhead sonar primarily in a "front to back" orientation (front being the left side of the video display and the back being the right side of the display). We periodically rotated the head to look across the net pen in a side-to-side fashion with the port side on the left side of the screen and the starboard side on the right side of the display. The sonar display indicated that there was considerable distortion of the net pen during tow (Figure 10).

The solid structure (aluminum pipes) of the net pen appeared to be hanging nearly vertical during the tow; however, the net showed a large distortion as illustrated in Figure 10, particularly at the bottom. The bottom of the net, which hung freely below the vertical supports was pushed back about 1 m from the vertical position. This created a noticeable pocket at the back of the net that may have provided a refuge for fish. All of the fish observed near the surface during water velocity measurements were chinook salmon, leading us to surmise that the rainbow trout were seeking shelter somewhere within the pen confines. For the most part, the chinook salmon appeared to be located high in the water column and toward the front or leading edge of the pen, and quite often at or very near the billowed net.

When the net pen drifted under conditions of no power (Figure 11), the sides hung nearly vertical, and the pen extended to its full depth (approximately 5 m). At this time, the fish distribution changed, i.e., fish appeared to aggregate within different parts of the pen. We also noted under these conditions that fish scattered more throughout the pen rather than schooling toward one side or the other.

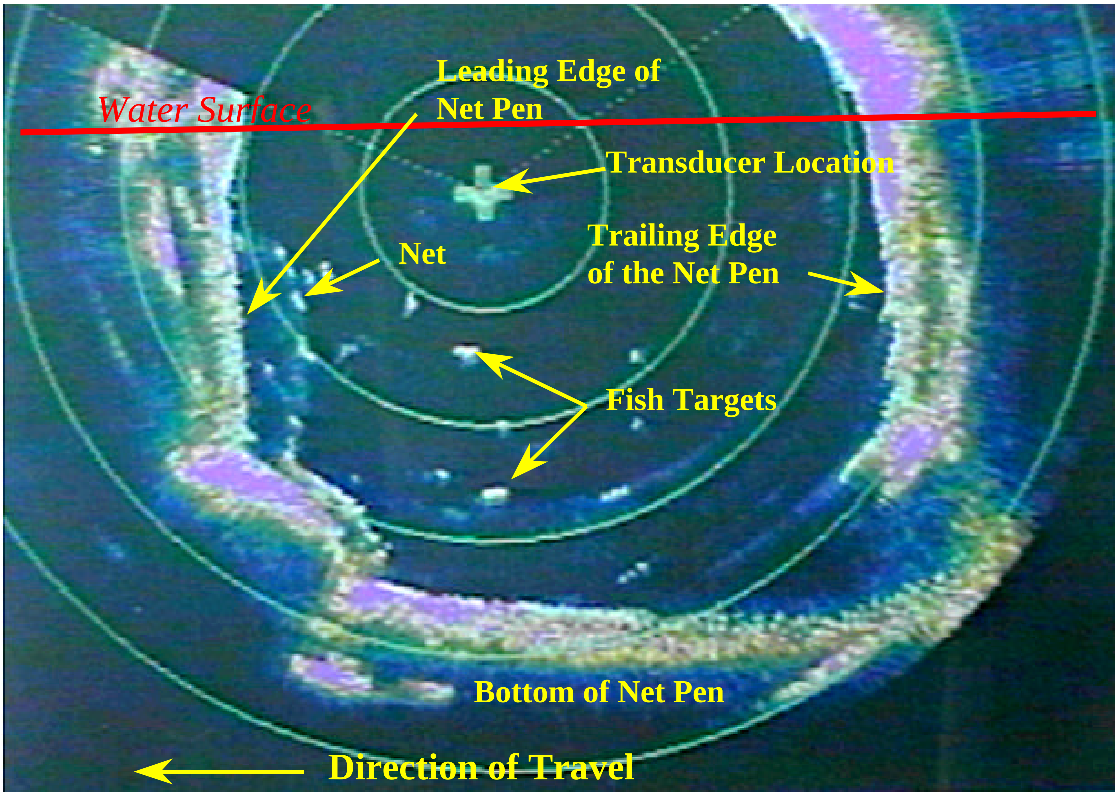

Figure 10. Example of Net Pen Distortion While Under Typical Drift Conditions

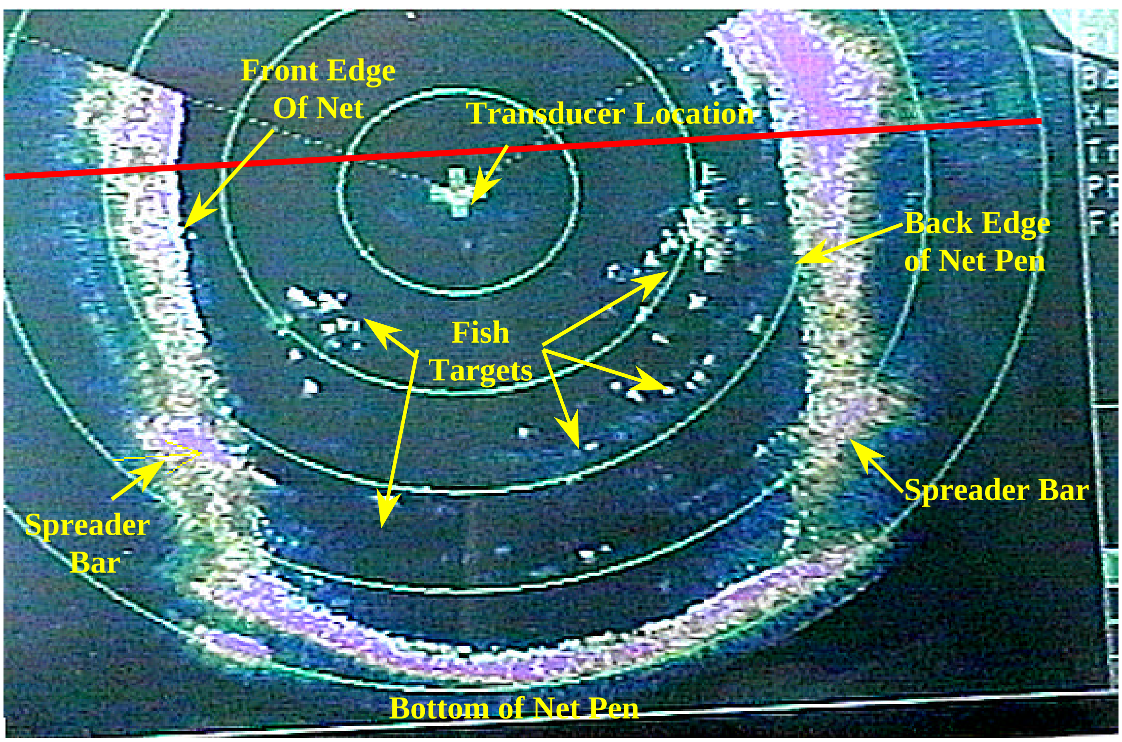

Figure 11. Net Pen Profile Under Stationary (no power) Drift

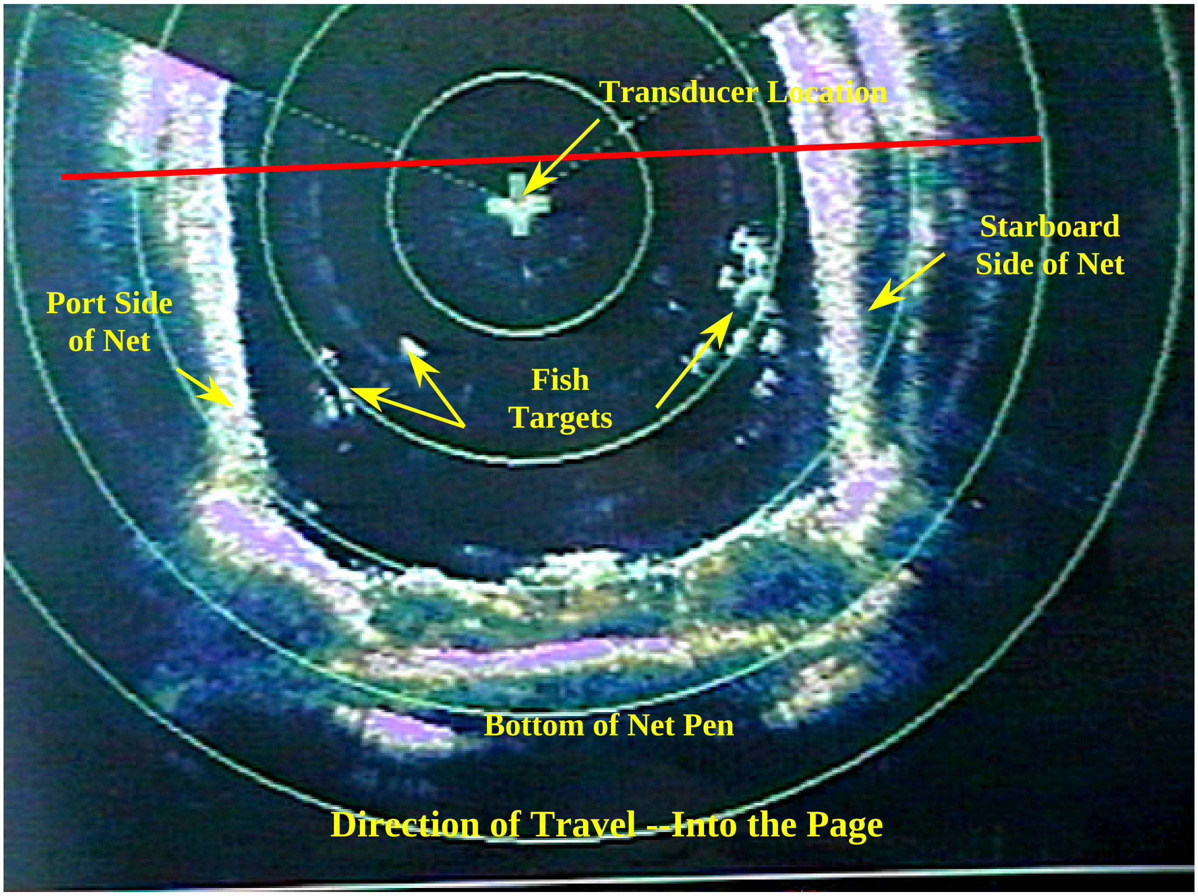

Figure 12. Side-to-Side Scan of the Net Pen While Under Typical Drift Conditions

We also conducted a side-to-side scan of the net pen to evaluate the distribution of fish across the width of the pen relative to the direction of travel. The side-to-side scan provided the display illustrated in Figure 12.

Video tapes of the screen display were reviewed to evaluate fish position within the net pen. Front-to-back net pen profile "snapshots" were obtained every half hour from 1000H on August 28 through 0800H on August 29. Optimas™ software was used to trace the net shape relative to the scanhead sonar position in the center of the net. Targets (fish) were counted, and their positions were overlaid onto the net shape for each "snapshot".” Optimas files were saved to a spread sheet where they were converted into a graphic format. The profiles were grouped into four temporal intervals: day(1000-1600 H), dusk (1600-2200H), night (2200-0400H), and dawn (0400-0800H). Depth distribution of fish targets was analyzed at 1-m depth intervals for each scan. Resultant data were summarized as the percentage of fish targets in each 1-m depth interval for each of the four temporal intervals.

Vertical distribution of fish within the net pen changed during the 22 hr testing period (Table 2). For example, during the daytime (1000-1600H) and dusk (1600-2200H) intervals, over 70% of the fish were found at depths between 1 and 3 m. In contrast, fish were more uniformly distributed across all available depths during the all-dark period (2200-0400H). During the dawn and early daylight period, fish moved up in the water column and were primarily surface oriented. For the most part, the bottom 1 m of the net pen was not available to fish because it bunched up during the drift, especially during the night when we increased engine power to compensate for upriver wind.

We also made periodic visual observations of fish activity in the net pen to evaluate their orientation, behavior, and to confirm observations made on the scanning sonar monitor. Fish in the upper 1 m of the water column were visible during daylight hours. Virtually all fish we observed at the surface were chinook salmon. As we moved around the net pen to make observations, the salmon would sound until they were not visible. This response was confirmed on the scanning sonar monitor. Although we never saw a school of rainbow trout near the surface, individual rainbow trout occasionally would come to the surface, but would quickly sound.

Of the 100 rainbow trout and 100 chinook salmon placed in the net pen, all but two of the salmon were recovered at the end of the drift. There were no signs of injury or stress to the rainbow trout. However, many salmon were badly descaled. The descaling may have been due to fish getting trapped in the bag of the net while powering into an upriver wind at night. Descaling may also have occurred as we attempted to recover fish from the net in extremely high winds after our arrival at McNary Dam. In addition, we found two dead salmon in the net pen before the drift began.

Table 2. Depth Distribution of Fish (%) During Selected Time Intervals

Depth (m)	1000H to 1600H[(a)]	1600H to 2200H[(a)]	2200H to 0400 H[(b)]	0400H to 0800H[(b)]
0 to 1	14.7	7.6	29.3	76.4
1 to 2	49.2	42.4	26.8	18.1
2 to 3	27.4	32.6	24.4	5.6
3 to 4	8.6	17.4	19.5	0

(a) Based on 11 samples per time period (subset of continuous recording).
(b) Based on 5 samples per time period because video was not continuously recorded.

In-River Monitoring

The purpose of this part of the study was to demonstrate the ability to collect data on fish location using hydroacoustic tools, and to monitor water quality conditions. In-river monitoring included measures of vertical fish distribution using split-beam acoustic techniques and water quality measurements. Because Drift 3 occurred in late August, most salmonid species were not present, although some targets we observed may have been salmonids.

Fish Distribution - Vertical distribution of fish (species unknown) was recorded in the river cross-section adjacent to the net pen during the drift. A total of 240 files, each containing about 5 minutes of data, were collected during Drift 3. Data files were processed using HARP-SB™ software and were grouped in to 6-hr time blocks representing day, dusk, night, and dawn. Random files were selected for each 6-hr period. Fish target strength was dependent on the size of fish, where the fish passes through the field, and the aspect angle of fish detected by the transducer. Many files contained few or no fish targets. Target strength varied from -46.8 to -28.2.

Examples of fish distribution at four representative time intervals/locations in McNary Pool are shown in Figures 13 a-d. Targets were readily identified at depths to 10 m. The setup used during this study (transducer aimed at a 45° angle) resulted a limited coverage in the region close to the transducer (i.e., near the surface). A different aiming angle would be required to provide a better comparison of vertical distribution between in-river and net pen fish.

Water Quality - Dissolved oxygen, pH, and conductivity data were collected continuously during Drift 3 and are shown in Figures 14-16. Data collected before the net pen was underway may be erroneous because water was not actively passing over the instrument sensors. Dissolved oxygen measurements (Figure 14) show levels exceeding 100% during most of the drift. The accuracy of these readings was not verified. However, the data collected were similar to TDG levels reported at gas monitoring sites at Ice Harbor and McNary dams.

At the confluence of the Snake and Columbia rivers, pH values changed from ~7.5 to ~8.05 (Figure 15). Both the pH and dissolved oxygen graphs indicated a marked change (erratic readings followed by a gradual decline) at about 1800H. This time coincided with our crossing of the channel from the west (right) to the east (left) shore of the Columbia River, just downstream of the mouth of the Walla Walla River and the Boise Cascade plant at Wallula. The readings may have been related to any or all of these changes.

Conductivity (Figure 16) was markedly different as we moved from the Snake River into Columbia River water (~135 and 105 μS/cm, respectively). However, once in the Columbia River, the conductivity remained relatively constant and did not show the fluctuations at 1800H as with the pH and dissolved oxygen readings.

We were unable to collect gas supersaturation (TDG) data during Drift 3 because of an instrument malfunction that occurred in transit. Based on data available on the Internet from monitoring stations at Ice Harbor and McNary dams, TDG levels during this period were 100-115%, which are believed to be safe for fish and not likely to affect their behavior.

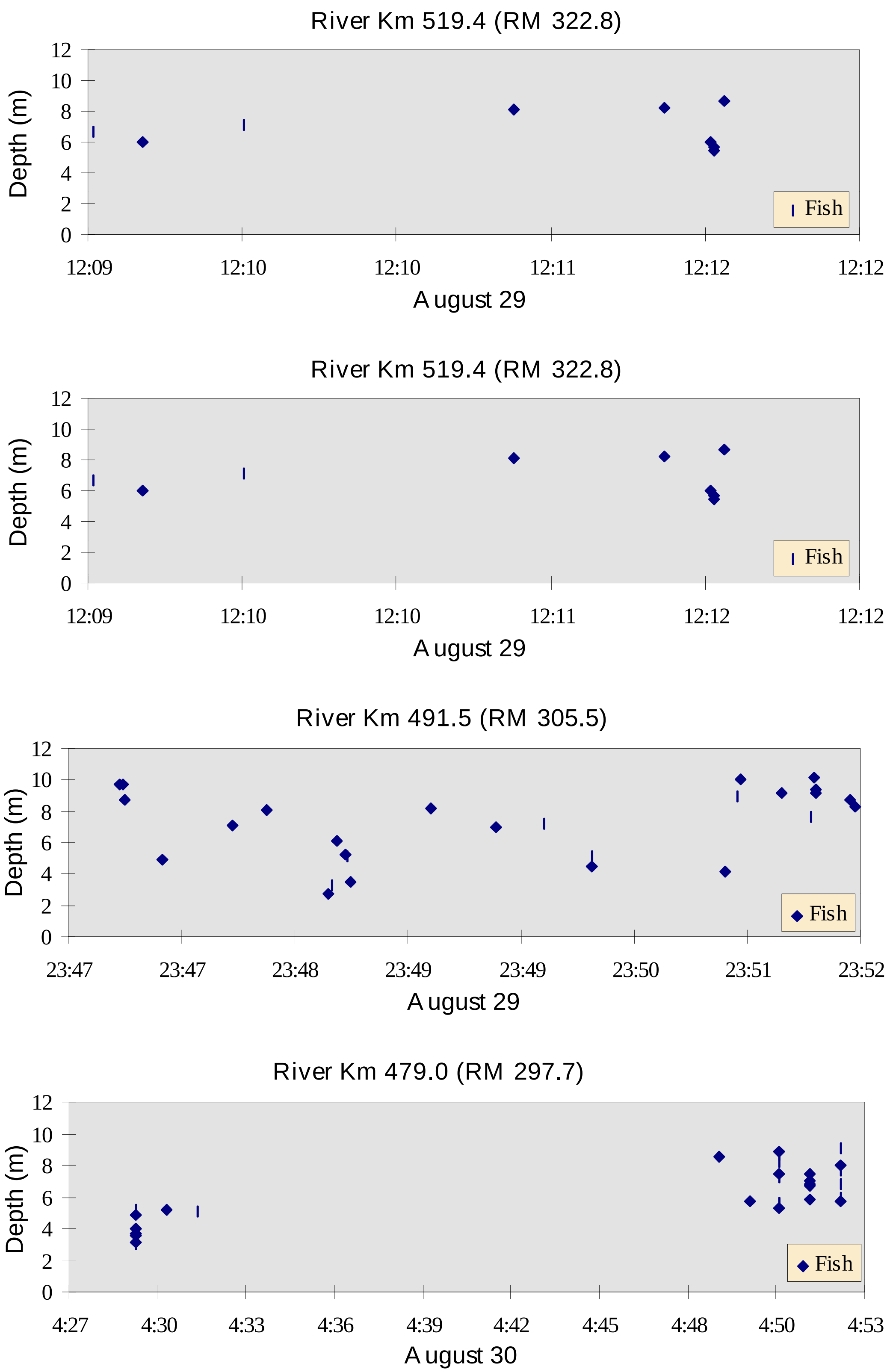

Figure 13. Vertical Distribution of Fish Outside the Net Pen Using Split-Beam Acoustic Technique

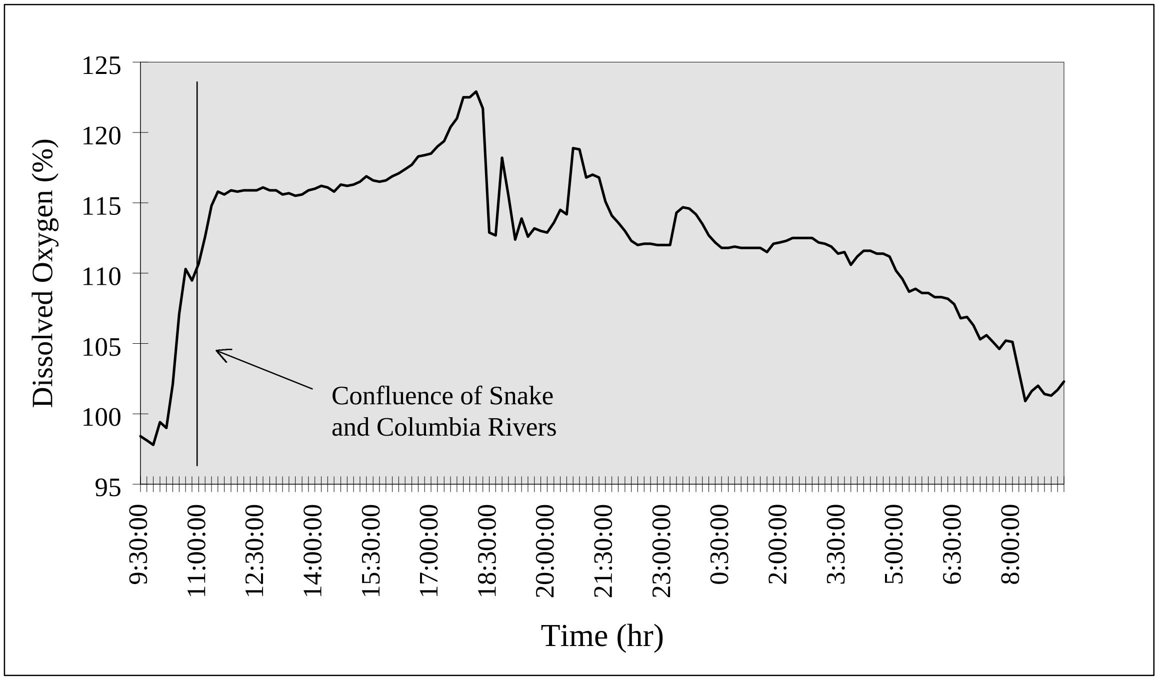

Figure 14. Dissolved Oxygen Levels (%) During Drift 3, August 28-29, 1996

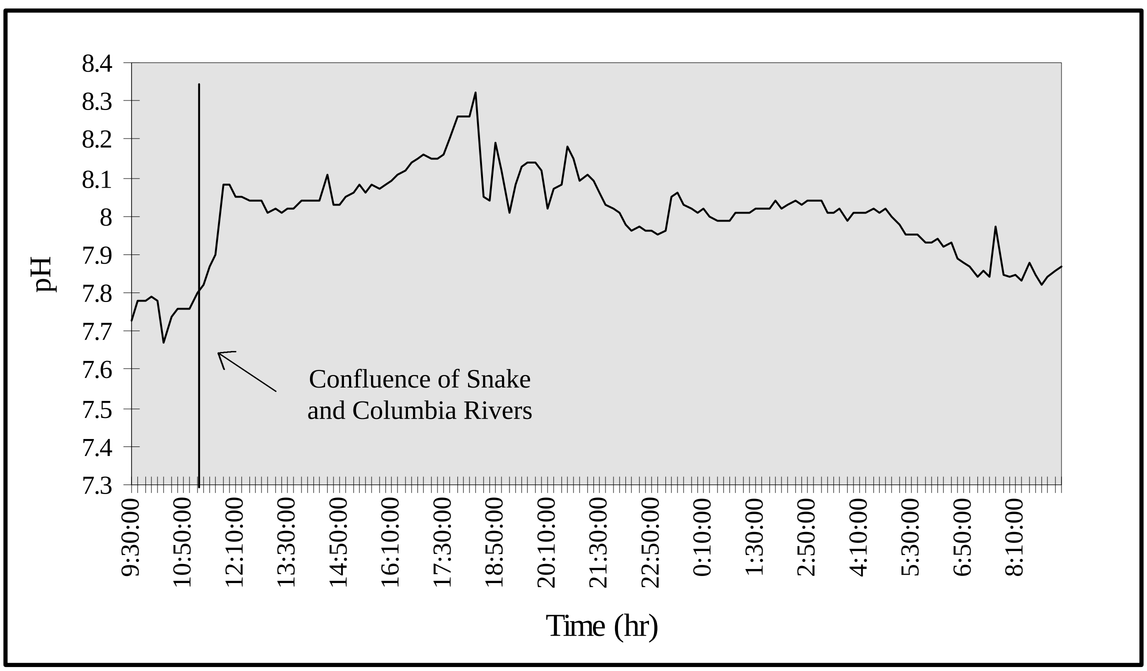

Figure 15. pH Measurements During Drift 3, August 28-29, 1996

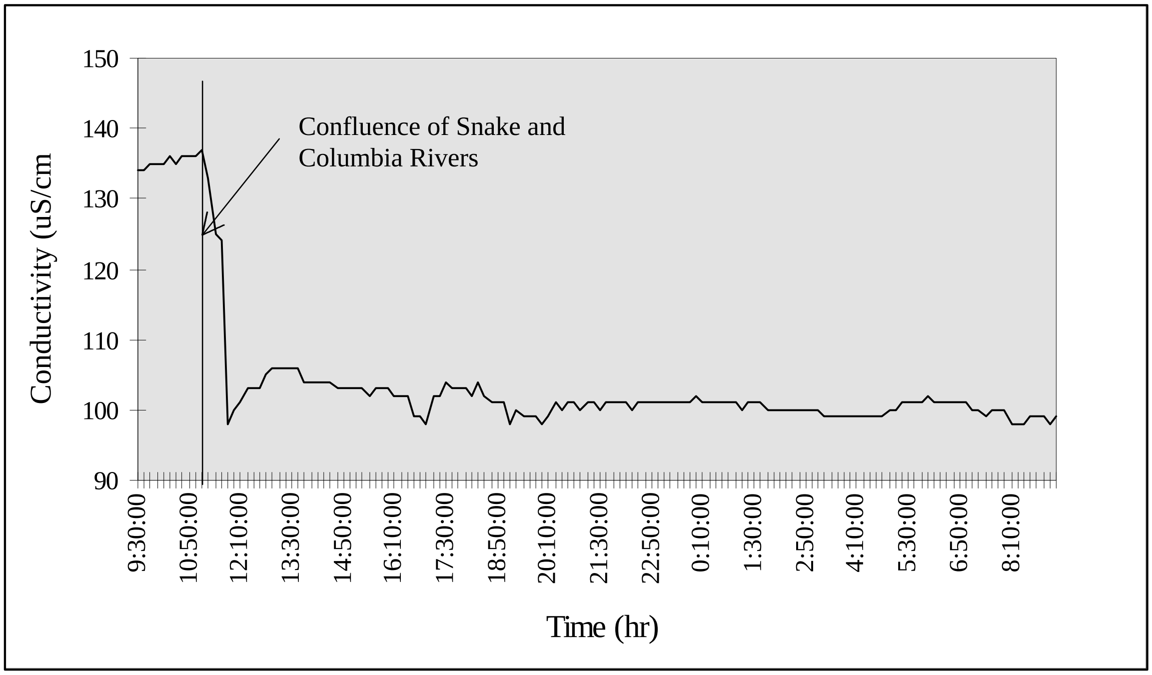

Figure 16. Specific Conductivity Levels During Drift 3, August 28-29, 1996

Exposure Modeling

Flows at Priest Rapids and Ice Harbor Dams were approximately 140 and 40 kcfs, respectively. Again, we estimated the trip from the mouth of the Snake River to McNary Dam to take ~20 hours. Our planned drift rate was the same as for Drift 1, a target speed of 2.4 km/hr (1.5 mph). Location was recorded at 3-min intervals using GPS (Figure 17). Data collection was interrupted twice during the drift, apparently because of poor satellite reception when passing through the narrow steep canyon walls at Wallula Gap. Our rate of travel (as shown by the spacing of red dots in Figure 16) was relatively uniform with two exceptions. At about RK 521.6 (RM 324), just downstream of the confluence of the Snake and Columbia rivers, our speed was faster than during the remainder of the drift. The other noticeably different drift rate occurred at Port Kelly (RK 502 [RM 312]) when downstream progress was slowed during shift change and refueling. The night crew increased engine speed to compensate for upriver winds that affected the desired drift speed.

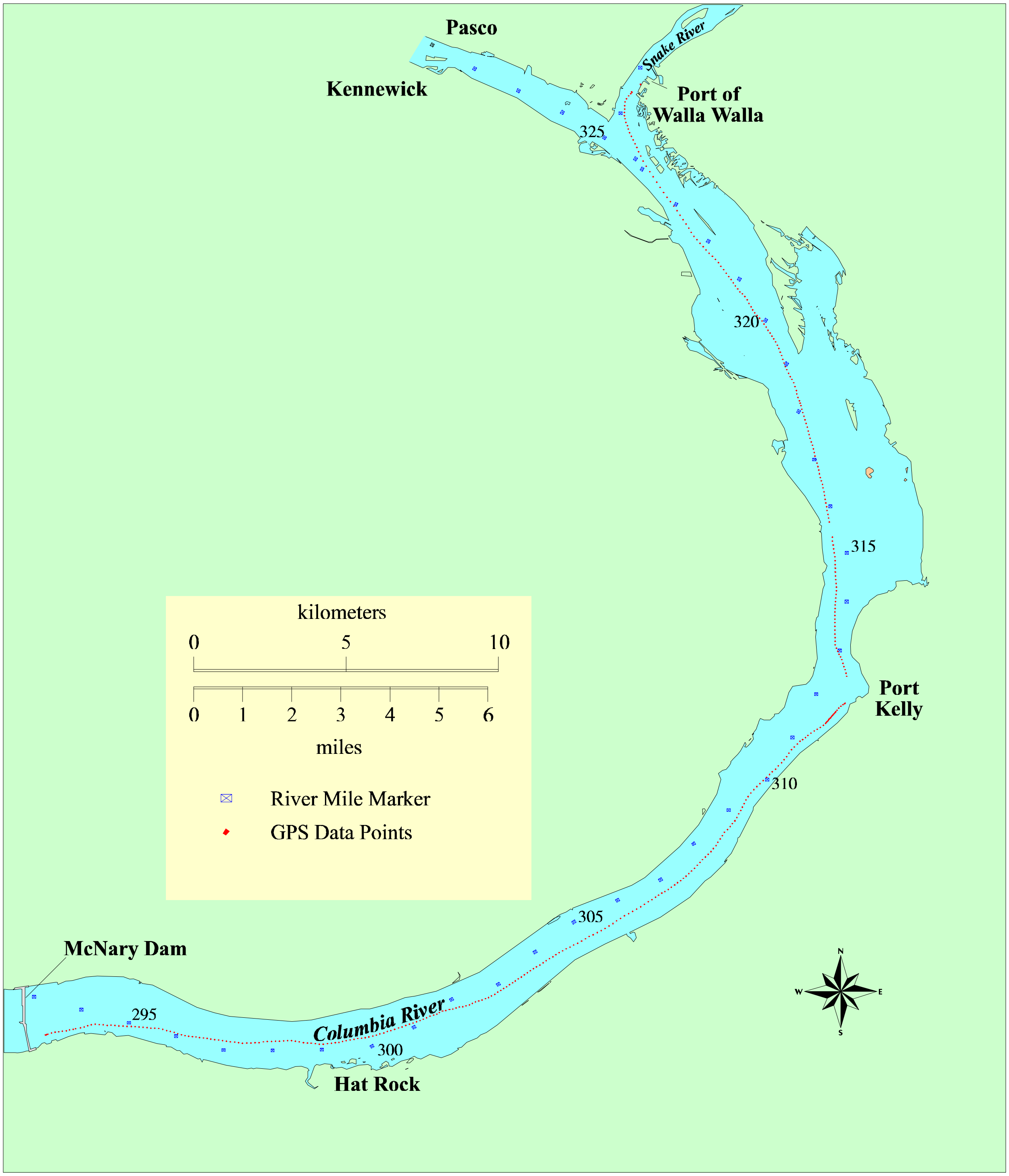

Figure 17. GPS Positional Data for Drift 3, August 28-29, 1996

Summary

We met all objectives for the third drift except that some water quality monitoring equipment did not perform as expected. Acoustic monitoring provided valuable information on fish behavior and characteristics of the net during transit, and the rate of travel was consistent with our planned speed. Other more specific observations related to future monitoring included:

- High winds at the end of the drift influenced maneuverability of the net pen.

- Our video display of the scanhead sonar image indicated that (under conditions of no power), the sides of the net pen hung vertical under conditions of no power, and the pen extended to the full 5 m depth. However, the lower portion of the net pen frame became distorted during tow.

- Vertical distribution profiles showed that fish exhibited distinct diel patterns.

- There appeared to be segregation between the chinook salmon and rainbow trout during the drift.

- Fish targets were detected in the river adjacent to the net pen using split-beam technology at depths to 10 m. However, the setup used did not evaluate the upper water column (<4 m depth) adequately (see other testing below).

- Marked differences in water quality were noted between the Snake and Columbia rivers.

Other Testing

Initial efforts directed at monitoring in-river fish distribution during Drift 3 provided good coverage of both near-surface and deep areas. However, additional testing was conducted in September 1996 using a standard target to refine our monitoring techniques, particularly to assess the ability of the system to operate very near surface during net pen drifts. During testing with different split-beam configurations, we found that the standard ping-pong ball target could easily be detected at up to 20 m distance and to within 1 m of the surface. Thus, we concluded fish readily could be detected at this range under perfectly calm conditions. The range increased substantially to over 40 m with very low noise both in listening only and active modes of operation when we tilted the transducer slightly downward. We believe that potential effects of the boat on the vertical distribution of fish would be minimal at these tested distances. A preferred deployment might include mounting the transducer on the bow of the net pen, either as a front- or side-looking arrangement. A simple rotator device would permit sampling of a full range of depths in the river cross-section adjacent to the net pen.

Conclusions and Recommendations

We determined that it was feasible to assemble and deploy a large net pen, using off-the-shelf equipment, for mobile monitoring of TDG exposure in the lower Snake and mid-Columbia rivers. Mobility and maneuverability of the net pen, and its rigidity, were adequate when the net was pushed. Further, the designed frame was strong enough that it remained rigid during pushing. However, towing the net pen was next to impossible. This configuration also resulted in prop wash that would create "noise" for acoustic monitoring conducted in the net pen and adjacent areas. Modifications to the manufacturers design, such as capping the flotation ring section, using stainless steel hose clamps instead of rope lashings, and adding boat winches to manipulate and support the weight of the spreader hoop and towing frame, improved the stability of the net pen and made deployment much more manageable.

We identified some constraints for future use of the net pen concept for monitoring fish. For example, the amount of freeboard and flotation restricted the types of monitoring equipment that could be mounted on the walkway. Because of the potential risk for expensive instruments to be lost or damaged, they had to be housed in a sheltered area, either on the push boat or another floating platform/boat attached along the side of the net pen.

We were able to accurately monitor vertical and lateral distribution of smolts in the net pen and to document that diel differences in their behavior occurred. Further, we noted that fish sounded in response to researcher activity on the net pen perimeter platform, at least during the daytime. Thus, any such activity (including enroute mortality or GBT monitoring) could alter fish behavior enough to potentially affect their depth distribution. This indicates that equipment deployment and operation should be scheduled to minimize disturbances to fish. Another concern regarding fish behavior for Drift 3 was species interaction. We noted that aggression and/or dominance by one species over another could affect the behavior, and ultimately, the TDG exposure of the other species. Thus, future tests should be conducted with one species and or size group at a time.

Our principal recommendations for future studies, as described below, are directed at improving maneuverability of the net pen in adverse weather conditions, higher flows, or faster push rates, providing more vertical space for fish to distribute if they so choose, coordinating efforts with other studies of fish distribution, and using new acoustics technology to be more efficient in collecting fish distribution data both within and outside of the net pen.

Improved Maneuverability

The boat and engine size used were sufficient to maneuver the net pen in calm water and at low speeds (i.e., <2.5 fps). However, rough water conditions, which would occur often during the spring or major outmigration period of smolts, would require the use of a larger vessel with more freeboard and power. The integrity of the net pen itself has not been tested in rough water. Thus, there is some concern that a heavy chop with whitecaps could affect the structural integrity of a net pen. For safety reasons, any research float plan should include delays for inclement weather. Another safety-related prerequisite would be the contingency to release the push boat from the net pen in an emergency situation to minimize loss of equipment.

Increased Net Size

Additional tests are needed, using a deeper net pen, to resolve uncertainties associated with the effect of the net pen on fish behavior (i.e., vertical distribution and potential TDG exposure). The drop section (i.e., lower 2 m) of the net needs to be strengthened to prevent distortion when the net pen is being pushed. Distortion of the frame was noticeable at low speeds and very apparent when engine speed (rpm) was increased to make headway into the wind. Lengthening the overall net depth to at least 6 m would likely provide the minimum 5 m depth desired for fish exposure monitoring.

Acoustics Technology

The acoustic technology selected for any future studies must be able to monitor vertical fish distribution in the upper 5-6 meters of the water column, as well as deeper water. The split-beam sonar technique used for monitoring juvenile salmonid behavior in the net pen had limited sample volume. This volume limitation could be resolved using a new technology called multibeam sonar. A multibeam sonar is a device made up of many receiving elements that sends sound in all directions (typically over 120 to 180^o) then receives sound on at individual locations where the beam is formed. The receiving beam is typically 2^o x 20^o. The multibeam technique, coupled with a second proprietary receiver, permits sensing in fine three-dimensional resolution and over a large volume of water equivalent to that inside of the net pen. Because the sound is sent and received over up to 180^o, the same transducer could also be used to “look” out in front or to the side of the net pen. The high repetition rate (ping rate) of these devices would permit real time tracking and behavioral evaluations of targets both inside and outside of the net pen. The system would provide an acoustically diced volume within the net pen and broad coverage in front of, below, and to the sides of the net pen. The acoustically diced volume would be analyzed to provide information on fish behavior within the net pen in three dimensions. Thus, all regions of interest could be monitored with a single piece of equipment. We recommend this technology be tested and any limitations described before further development of the mobile net pen concept.

Fish Distribution Monitoring

The most critical area to monitor when addressing the effect of fish sounding or depth compensation on TDG exposure in smolts is the upper 3-4 m of the water column. Because each additional meter of depth negates the equivalent of about 10% supersaturation, the relative amount of time a smolt spends in the upper 4 m of the water column largely determines its potential risk or exposure history. Given an effective net pen depth of 5 m, it should be possible for fish to avoid the effects of elevated TDG (e.g. $\leq$ 150%) by sounding to the bottom of the net pen. However, fish outside the net pen have more choices than fish confined within the net pen. For example, they may enter shallow backwater or shoreline areas to feed. Conversely, fish in reservoirs may spend much of their time in deeper water. Thus, it is essential that net pen distribution estimates be coupled (in time and near-space) with measures of in-river smolt distribution. Also, future research should consider the influence of people on fish behavior.

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