

**Development and Evaluation of Passive Integrated Transponder Tag Technology
(December 2006-November 2007)**

Sandra L. Downing, Earl F. Prentice, Bruce F. Jonasson, and Gabriel T. Brooks

Report of research by

Fish Ecology Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112

for

Division of Fish and Wildlife
Bonneville Power Administration
U.S. Department of Energy
P.O. Box 3621
Portland, Oregon 97208-3621
Project 1983-319-00, Contract 30330

November 2008

EXECUTIVE SUMMARY

Since 1984, the National Marine Fisheries Service (NMFS or NOAA Fisheries) has conducted research in cooperation with the Bonneville Power Administration (BPA) to expand and improve technology for passive-integrated-transponder tags (PIT tags) throughout the Columbia River Basin. Timely and accurate information derived from PIT-tag technology is increasingly critical to resource stakeholders in developing recovery programs and in assessing the effectiveness of efforts to enhance survival of juvenile and adult salmonids.

This report covers research conducted from December 2006 through November 2007 (FY07). The continued development of PIT-tag technology will enable researchers and fisheries managers to address issues expressed in all of NMFS biological opinions and the *Final Updated Proposed Action for the FCRPS Biological Opinion Remand* (UPA), released in 2004 by the U.S. Army Corps of Engineers, Bureau of Reclamation, and BPA (action agencies). Research was divided into three work elements, which are reported separately and summarized below.

Development of Interrogation Systems for Spillways—Currently, the fish managers are using spillways and other surface-bypass systems (e.g., the corner collector or spillway weirs) as primary conduits for passing juvenile salmonid through federal hydroelectric facilities in the Columbia River Basin during their outmigration. The result is that significantly less data are being collected because the spillways do not have PIT-tag interrogation equipment. Consequently, models used to evaluate the effectiveness of current management actions and restoration strategies are weakened by having fewer data points. Therefore, NMFS initiated a project in 2006 to develop interrogation systems for detection of juvenile salmonids bypassing hydroelectric dams through the spillways.

Significantly more difficult operating conditions are encountered in spillways than in any previous location where PIT-tag interrogation systems have operated to date. For example, the metal in the area of the antenna cannot be removed for structural reasons (normally for PIT-tag systems, all metal in the immediate vicinity is removed). Along with a selection committee of representatives from the action agencies, we reviewed responses to a NMFS request for proposals to develop a spillway system. We subsequently issued a contract for development to the Digital Angel Corporation.[†] In June 2007, Digital Angel delivered a technical feasibility report for developing a PIT-tag

[†] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

system that would work in unmodified spillbays at Bonneville Dam. The report included a detailed development plan and concluded that two 25-ft long by 5-ft wide antennas could be used to span the 50-ft spillbay opening, and antennas could be attached to the tailrace side of the spillbay gate.

We distributed the Digital Angel report to the action agencies and other interested parties, and met with all parties in October 2007 to decide whether to proceed with the project. Response was overwhelmingly positive, and two long-term tasks were subsequently initiated: First, the grant process was initiated to obtain a new contract for Digital Angel to develop the spillway system. Because the amount of the contract exceeded \$500 K, time required for approvals will be approximately 6 to 9 months.

Second, we initiated the process of getting permission from the Corps to use the repair spillbay at Bonneville Dam. Use of the repair spillbay is critical to development of the spillway detection system. It would allow testing of alternative antenna configurations and transceiver settings and provide accurate evaluation of any modifications needed to the current development plan. Use of the site will enable us to determine if the preliminary findings by Digital Angel hold true, and therefore if the project is worth continuing, or if the spillbay environment will ultimately contain too many hurdles for designing an effective PIT-tag system at this time. In the latter case, this initial work may suggest new pathways for solving the developmental goal.

Detection system for the ice and trash sluiceway at The Dalles Dam—Fish managers have expressed the need for developing detection systems in additional locations; among these was the ice and trash sluiceway at The Dalles Dam. In FY07, we coordinated two site visits to define possible antenna locations and limitations. We discussed possible locations and other factors important to designing a PIT-tag monitoring system for this site with PSMFC, Digital Angel, and the Corps. After the site visits and discussions, fish managers decided to postpone this project indefinitely.

Continued development and evaluation of in-stream interrogation systems—NOAA Fisheries began developing in-stream interrogation systems in 2000, when we demonstrated the first prototype system. At present, further development of in-stream systems depends on continued development of technology in three areas. First, larger antenna systems need to be designed to enable researchers to investigate in larger streams. Second, a transceiver is needed that will meet the requirements of a stand-alone system that can be operated in remote locations. For such a system, the transceiver must be able to log data, auto-tune, and automatically switch among antennas (multiplexing). Third, cost-effective power systems need to be designed for off-grid locations and for converting grid-based power.

Significant progress was made during FY07 in all three of these areas and is summarized below. In addition to improving in-stream detection capability, we began modifications that can be extended to applications in estuaries.

Antenna Systems

- Large 20-ft long by 4-ft wide antennas were successfully deployed at several sites.
- A new coax antenna cable was tested. The new cable allowed stronger electromagnetic fields to be generated in larger antennas, allowed the maximum distance between the antenna and transceiver to be doubled from 100 to 200 ft in electronically quiet environments, and is available at less than half the cost of the cable used previously.
- A series of antenna construction workshops was conducted and a step-by-step instructional compact disk was produced to provide researchers the ability to design and construct their own in-stream interrogation systems.
- By replacing the wire normally used in antenna construction (10 AWG, 105 conductor wire) with Litz wire (40 AWG, 1,100 conductor wire), we were able to construct an unshielded 10- by 2-ft antenna that was tested successfully in 28 ppt salt water.

Transceiver Systems

During FY07, we continued the process started in 2006 to develop a new multiplexing transceiver. The first step of this process was to coordinate among government, tribal, and private entities to develop a requirements document. The requirements document was sent to Digital Angel for them to submit a proposal to develop a multiplexing transceiver that would meet the specified requirements. We obtained funding for transceiver development from BPA, the Corps, and NOAA Fisheries and then issued a contract to Digital Angel. Delivery of a prototype antenna-controller node is scheduled for February 2008, and delivery of a prototype master controller is scheduled for November 2008.

Power Systems

The FS1001M transceivers were designed to operate on 24-V DC because they are mostly deployed in areas where grid power is unavailable. However, when grid power is available, it is preferred because it is cheaper and more reliable. Unfortunately, grid power at times can interfere with the operation of the transceiver via inline electromagnetic interference (EMI); if EMI is at or near the operating frequency of the PIT-tag system (i.e., 134.2 kHz) and is of sufficient strength, it can significantly reduce or even prevent the reading of tags.

In order to power the FS1001M transceivers, the 110-V AC grid power must be converted to 24-V DC. Furthermore, a backup power system is needed to prevent loss of data during temporary grid power failures. Unfortunately, components of the conversion and backup systems can also produce EMI. Thus, finding a suitable power system design has required testing of numerous component products (e.g., chargers and timers).

During FY07, we successfully completed development of an inexpensive power system design, which consists of four batteries, a battery charger, and a timer-relay system. At all times, one pair of batteries is being charged while the alternate pair powers the transceiver. This eliminated problems with EMI from grid power. The timer switching circuit transfers transceiver duty to the alternate set of batteries every 2 or 4 h. If grid power fails, the timer will continue to transfer the transceiver power load back and forth between the two sets of batteries. Running on batteries alone, the transceiver should be able to operate normally for 5-7 d (much longer than any outage should last).

CONTENTS

EXECUTIVE SUMMARY	iii
INTRODUCTION	1
DEVELOPMENT OF 134.2-kHz ISO-BASED INTERROGATION SYSTEMS FOR SPILLWAYS	3
Introduction.....	3
Progress During Fiscal Year 2007	5
SUPPORT FOR DESIGNING A DETECTION SYSTEM FOR THE ICE AND TRASH SLUICeway AT THE DALLES DAM	8
CONTINUED DEVELOPMENT AND EVALUATION OF IN-STREAM INTERROGATION SYSTEMS	9
Introduction.....	9
Progress During Fiscal-Year 2007	10
Antenna Systems.....	10
Transceiver Systems	13
Power Systems	15
Conclusions and Recommendations	16
ACKNOWLEDGEMENTS	17
REFERENCES	18

INTRODUCTION

Since 1984, the National Marine Fisheries Service (NMFS or NOAA Fisheries) in cooperation with the Bonneville Power Administration (BPA) has conducted research to develop and evaluate technology for passive-integrated-transponder tags (PIT tags) throughout the Columbia River Basin. Research conducted as part of this project between December 2006 and December 2007 (FY07) was divided into three individual work elements, which are covered separately in this report.

The efforts by personnel associated with this project have produced and will continue to produce products that aid resource stakeholders in assessing the effectiveness of actions taken to enhance the survival of juvenile and adult salmonids. These products and their uses include:

- Survival and migration timing information on stocks to evaluate water management strategies and fish passage/collection facilities
- Data needed for the management and restoration of salmonids and other fish stocks listed under the Endangered Species Act (ESA)
- Information required for the management of multiple species in a variety of habitats
- Tools that enable fisheries researchers and managers to address previously unanswerable questions and critical uncertainties

These products are also used in genetic, physiology, behavior, and captive broodstock research on endangered species. The continued development of PIT-tag technology will enable researchers and fisheries managers to address issues expressed in all of NMFS biological opinions (BiOp) for operation of the Federal Columbia River Power System (FCRPS)(NMFS 1995a, 2000, 2004) and the proposed Snake River Recovery Plan (NMFS 1995b; tasks 2.1.d, 2.3.b.4, 2.4.a, 2.6.c.2, and 2.9.d). The technology is also essential to goals stated in the *Final Updated Proposed Action for the FCRPS Biological Opinion Remand* (UPA), which was released in 2004 by the U.S. Army Corps of Engineers (Corps), Bureau of Reclamation, and BPA (action agencies). In the UPA, these action agencies outline measures they plan to undertake to meet the performance standards described in the NOAA Fisheries 2000 BiOp for the FCRPS and to meet the new jeopardy analyses proscribed by the court after reviewing the 2004 BiOp (USACE et al. 2004).

DEVELOPMENT OF INTERROGATION SYSTEMS FOR SPILLWAYS

Introduction

In order to improve survival of salmonids migrating through federally operated hydroelectric dams within the Columbia River Basin, managers have changed how water is managed at these facilities. In the 1990s, large numbers of juvenile salmonids were diverted at the dams through collection and bypass facilities, which are equipped with PIT-tag monitors. More recently, managers have been using spillways and other surface bypass systems (e.g., the corner collector or spillway weirs) as primary conduits for passing salmonids through federal hydroelectric facilities during the juvenile migration. The result is that significantly less data are being collected from PIT-tagged migrants because there is no PIT-tag interrogation equipment at the spillways. Consequently, efforts to evaluate the effectiveness of current management actions and restoration strategies are weakened by having fewer data points. To avoid the loss of these data used to inform critical management decisions for ESA-listed salmonid stocks, interrogation systems are needed that will track PIT-tagged fish in spillways and other pathways that lack detection systems.

Estimates suggest that at least 50% of salmonids use the spillway to pass Bonneville Dam during their juvenile migration (Figure 1). The NMFS Northwest Regional Office wants to collect more data at Bonneville Dam to reduce the standard errors surrounding the reach survival rates calculated for salmonids, especially steelhead. If possible, they want to know the pathways that individual fish take through Bonneville Dam to determine whether it is possible to calculate survival rates for the different pathways. Results would be used to try to manage salmonids to encourage them to use the passage route with the highest survival rate.



Figure 1. Photo of the spillway at Bonneville Dam that contains 18 individual spillbays.

To address these fish data needs, the Fish Ecology Division of the Northwest Fisheries Science Center started a project in 2006 to investigate development of a PIT-tag detection system for spillways. The priority for this research was the spillway at Bonneville Dam, where each of the 18 spillbays is equipped with a vertical rising control gate (Figure 2). The goal was to develop a PIT-tag system for an unmodified individual spillbay. BPA would also like NMFS to investigate developing a PIT-tag system for spillbays equipped with temporary spillway weirs.

Developing PIT-tag systems for spillbays will require a system that must overcome significantly more difficult operating conditions than any previous PIT-tag system has to date. For example, each spillbay opening is 50 ft wide, which may well require antennas that are significantly larger than those currently being deployed. To further complicate matters, metal in the area of spillway antennas cannot be removed for structural reasons. Normally, all metal in the immediate vicinity of a PIT-tag interrogation system is removed to minimize RF interference. In other words, the PIT-tag system will need to deal with metal spillbay gates, temporary spillway weirs, and rebar in the floors and walls of spillbays. The system will also need to work with tags currently in use by researchers in the Columbia River Basin (the 12.5- × 2.1-mm Digital Angel[‡] model TX1400SST tag). Other significant challenges to successfully designing and deploying a spillway PIT-tag system include overcoming facility vibration, potentially tons of turbulent water contacting the antenna housing, high water velocities (over 60 ft/s), and wind.

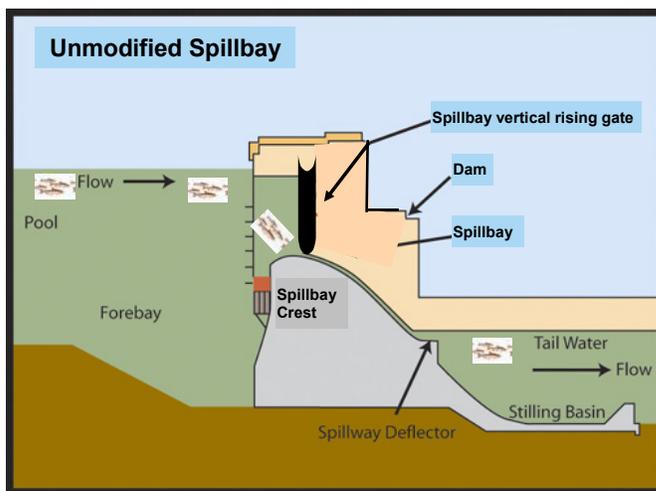


Figure 2. Diagram of an unmodified spillbay with a vertical rising gate at Bonneville Dam. The vertical gate gets raised to create a passageway for migrating juvenile salmonids that is located 50-60 ft below the water surface of the forebay.

There is a difference in how fish pass dams with different types of spillbays. Juvenile salmonids typically swim in the upper 10-20 ft of the water column within the river as they migrate downstream to the ocean. In unmodified spillbays, the opening of a spillbay gate is 50-60 ft below the water surface at the face of the dam (Figure 2). Consequently, juvenile fish must dive to depths of 50-60 ft to enter passage routes through individual spillbays. While passing through these unmodified spillbays, juvenile fish are exposed to high pressures and velocities (>60 ft/s).

[‡] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

In fiscal year 2006, NOAA Fisheries issued a request for proposals to begin the process of finding solutions for PIT-tag monitoring of the spillway at Bonneville Dam. Proposals were reviewed by a committee of individuals from NMFS, BPA, and the Corps. The proposal from Digital Angel (DA) was chosen, and a contract was issued in August 2006 to investigate the technical feasibility of developing a system for the unmodified spillbays at Bonneville Dam. We formed a multi-agency team to follow the progress of the development.

Progress During Fiscal Year 2007

The contract issued to Digital Angel in August 2006 continued until June 2007. During that time, DA conducted both theoretical and laboratory investigations to determine if it would be technically feasible to develop a detection system for unmodified spillbays at Bonneville Dam.

In June, DA delivered the final report on technical feasibility (Chan et al. 2007). The report concluded that a PIT-tag system could be developed for spillways, and it included a detailed development plan using two 25-ft long by 5-ft wide antennas to span the 50-ft opening of an individual spillbay at Bonneville Dam. These antennas would be attached to the tailrace side of the spillbay gate (Figure 3). This location was chosen partially to minimize installation and maintenance risks that would have resulted from using alternative locations in the forebay. Location of antennas on the spillbay gate would also place them as close as possible to the gate opening.

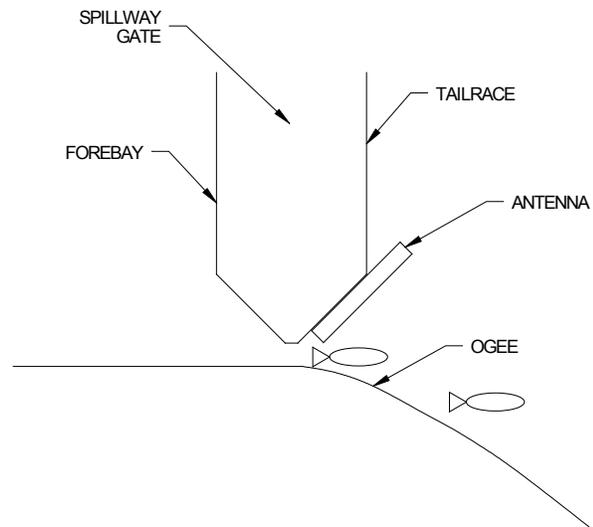


Figure 3. Sketch of an individual spillbay that shows where Digital Angel would attach their PIT-tag antenna as part of a PIT-tag detection system for the unmodified spillbays at Bonneville Dam.

Additional advantages of this plan were that the antennas would be attached to a known loading structure (the gate), where the unknown and variable loading effects of the ogee would be minimized, and where overall mechanical risk would be reduced by minimizing contact with water flow.

Digital Angel utilized a software simulation tool to evaluate different antenna designs. The software enabled them to determine magnetic flux densities for different antenna designs, which provided them with theoretical antenna performances and corresponding tag-activation ranges. Once they determined promising antenna designs based on the simulation tool, they constructed prototype antennas. They then investigated different antenna shielding options with the different prototype antennas. They tested over 40 designs and compared the empirical results with the theoretical results derived with the simulation software. The two matched well.

Two variables needed to be evaluated during the feasibility study: 1) whether the detection system could detect PIT tags moving at 60 ft/s and faster, and 2) whether it could detect tags when a vertical spillbay gate was open 2-5 ft. To test these variables, DA designed and built a pneumatic tester, which enabled the PIT tag to travel at a high speed and at the same time accurately recorded tag speed. The prototype antenna was tested with both 12.5-mm and 20-mm PIT tags. The 12.5-mm tags were detected around 2 ft below the antenna at 60 ft/s when in optimal orientation and could be detected farther away when stationary. Based on these results, one conclusion was that the tag-code message might need to be shortened to get more reads when many tagged fish are being detected.

The final prototype antenna design used a layer of ferrite tiles to protect antennas from interference by the metal spillbay gates. However, since an actual spillbay gate was not available for DA laboratory trials in Minnesota, this approach still needs to be field tested with an actual spillbay gate. Fortunately, at Bonneville Dam, a test facility exists that basically matches most characteristics of the site where the permanent system will be installed: a spare spillbay gate is maintained at the dam for use as a repair facility. Traditionally, this has been used for spillbay gates that need repairing and painting, but for this project it means that we have a test facility where different parameters can be investigated such as different test antenna configurations, transceiver settings, whether modifications are needed to the current 12.5-mm tag, and whether the ferrite tiles work with an actual spillbay gate.

As soon as NOAA Fisheries received the condensed final report from Digital Angel, we distributed it to the action agencies and other interested parties. A meeting was held in October 2007, where a summary of the findings was presented by NOAA Fisheries and Digital Angel, and where a decision could be made on whether the fisheries community wanted the action agencies to proceed with this project. The response from the data managers was overwhelmingly positive in favor of proceeding.

After the October meeting, we initiated two long-term tasks. The first was to start the process of granting a new contract to Digital Angel, and the second, to begin the process of obtaining permission from the Corps to use the repair spillbay as a test facility.

Because the contract to DA was more than \$500 K, the time required was approximately 6-9 months to obtain the necessary approvals from NOAA. This contract will cover investigative work that needs to be done in the repair spillbay, the design and fabrication of antennas that will be installed into an operational spillbay, and testing in the operational spillbay. The contract would include a schedule based on positive results for each task and obtaining assistance from the Corps for completing the tasks. Furthermore, each task would include milestones where the team would make “go or no go” recommendations on whether to continue with the project.

Utilizing the repair spillbay is a critical step in the development of this detection system. However, this site has not been used by the Corps for at least 2 years because lead paint was used in the facility. They have removed most of the paint, but are unable to guarantee that all of it has been removed. This is one reason it will take time for approval, although a Corps safety officer at Bonneville Dam has detailed what procedures would need to be followed for the researchers to safely use the facility.

Testing in the repair spillbay will enable us to determine if the preliminary findings by Digital Angel hold true, and if development is therefore worth continuing, or if the spillbay environment contains too many hurdles to design an effective PIT-tag system at this time. Alternatively, this initial work may suggest new pathways for solving the developmental goal. Given that the work in the repair spillbay will include experimentation, it makes economical sense to test initially with only one 25-ft-long test antenna instead of with two test antennas. Then when the Contractor and NOAA Fisheries are satisfied with the performance of the single antenna, a second antenna can be constructed to test whether there are any problems associated with a two-antenna system.

Hopefully, by the end of the next contract (November 2008), we will have collected enough data from the work in the repair spillbay to have learned whether the spillbay environment contains too many hurdles or if we should continue with the development of the detection system for the unmodified spillbays at Bonneville Dam.

A DETECTION SYSTEM FOR THE DALLES DAM ICE AND TRASH SLUICeway

Based on the success of the detection system developed for the corner-collector at Bonneville Dam, fish managers in 2006 discussed additional locations where PIT-tag detection systems were needed. Some of these locations can easily be accommodated using systems adapted from established technologies; others cannot be. The latter category includes the ice and trash sluiceway at The Dalles Dam. This site potentially could require an antenna even larger than the corner collector, and it appears to have more turbulent water conditions. Since we need to find out how well the corner-collector detection system operates and how well the new PIT tag model performs, we proposed moving slowly on this work element. For that reason, in FY07 we proposed conducting two site visits to define possible antenna locations and limitations.

The site visits occurred in conjunction with the discussion of installing PIT-tag systems into the fish ladders at The Dalles Dam. During the site visits, NOAA Fisheries, PSMFC, and Digital Angel discussed possible antenna locations and other factors important to designing PIT-tag systems for these locations with the Corps. Soon after these site visits, the fish managers decided to postpone this project indefinitely.

CONTINUED DEVELOPMENT AND EVALUATION OF IN-STREAM INTERROGATION SYSTEMS

Introduction

PIT-tag users from numerous agencies have indicated the need for both "stand-alone" (i.e., system that could be located in a remote area without access to the power grid) and power-grid supported interrogation systems to monitor juvenile and adult fish in remote locations, especially small streams. In-stream interrogation systems would, among other objectives, enable PIT-tag users to obtain information on overwinter stream survival, migration timing, and recruitment success with minimal human involvement. Many juvenile salmon are presently being captured, PIT-tagged, and released in small streams, in part to determine the effectiveness of stock restoration efforts. Until 2004 when the first multiplexing transceiver (FS1001M where the M stands for multiplexing) became available, the only existing means of obtaining movement information on tagged fish was to recapture them, install a trap, or wait until they passed a dam where PIT-tag interrogation systems were installed. These methods provided valuable information, but left large voids in our understanding of fish biology and ecology.

NMFS personnel have been working on the development of PIT-tag interrogation systems for remote locations since 2000, when they demonstrated a prototype in-stream detection system at the NMFS Manchester Research Station to show proof of concept (Downing et al. 2004). In August 2001, we deployed a prototype in-stream interrogation system in Rattlesnake Creek, a tributary of the Little White Salmon River. This work was done in cooperation with the U.S. Geological Survey (USGS) Columbia River Research Laboratory and local landowners adjacent to the creek.

In 2002, we established a second test location in Valley Creek near Stanley, Idaho. This second location presented environmental and logistical challenges that dramatically differed from the Rattlesnake Creek site. In addition to providing field locations for the evaluation of PIT-tag technology as it is developed, the interrogation of PIT-tagged resident fish from both of these locations is providing needed early life history information to both USGS (Allen et. al 2003; Jezorek and Connolly 2003, Connolly et al. 2005) and NOAA Fisheries investigators (Achord et al. 2004).

The development of a stand-alone interrogation system is a dynamic process that depends on the continued development of technology in three areas. First, larger antenna systems need to be designed to enable researchers to investigate in larger streams. Second, cost-effective power systems need to be designed for remote locations and for

converting grid-based power. Once available, these power systems will need to be evaluated to determine how effective the power systems are under different site conditions. The transceiver is the third area that needs additional development to meet the requirements of a stand-alone system. For such a system, the transceiver must be able to log data, auto-tune, and automatically switch among antennas (multiplexing). Besides stream applications, NOAA Fisheries investigators want to start utilizing these detection systems for research in estuaries where there is a similar void in our understanding of fish biology and ecology.

This report describes the efforts of NOAA Fisheries towards addressing the above tasks from December 2006 through November 2007 while aiding investigators in their efforts to obtain biological information for addressing stock restoration efforts.

Progress During Fiscal-Year 2007

Antenna Systems

During FY07, the size of antennas for use in freshwater was significantly increased, as was the maximum distance the antenna could be located from the transceiver. The change in antenna size was both due to use of the TX1400SST tag, introduced by Digital Angel in 2006, and changes in antenna construction methods. The increase in distance from the antenna to the transceiver was achieved after NMFS tested a new coax antenna cable. Lower resistance in this cable allows higher electrical currents to be accessible in the antennas. The current is used to generate the electromagnetic field that energizes the tag. Therefore with more current, we were able to fabricate significantly larger antennas that could still produced the electromagnetic field required to energize the more sensitive SST tags. During FY07, antennas measuring 20-ft long by 4-ft wide were deployed at several sites (Figure 4).

We actually successfully tested 25-ft long by 4-ft wide antennas, but antenna structural integrity, installation, and handling difficulties mounted as antennas longer than 20 ft were constructed using the existing methods. The next large change in antenna design and size will hopefully come as a result of the development of a new multiplexing transceiver, which will offer greater functionality than the FS1001M transceiver presently available (see below). Larger antennas are still needed to expand stream research into larger and deeper rivers.



Figure 4. Photo showing six 20-ft long by 4-ft wide antennas installed in the Cedar River near Landsburg Dam in February 2007. Two antenna arrays that spanned the width of the river were installed.

Until this year, the distance between the antenna and transceiver was limited to 100 ft. This limitation was in part related to the type of cable used to connect the transceiver to the antenna. In 2007, we investigated using Belden 8214 RG-8 coax cable to connect the antenna and transceiver together. The new cable was less than half the cost of the cable used previously, which had been the standard since 2004. More importantly, it provided better performance with its lower resistance. The new cable had an impedance of 50 ohms and an inductance of $0.065 \mu\text{H}$. In electromagnetically quiet environments, the new cable allows the distance between transceiver and antenna to be doubled from 100 to 200 ft.

Antenna construction was also simplified in FY07. Improvements in construction method resulted in PVC-pipe antennas being produced in about one-third less time and at a lower materials cost than previous versions, with no decrease in performance. The most significant change was adapting polycarbonate grid sheets developed for greenhouses to construct the backbone for holding the antenna wires (Figure 5). The

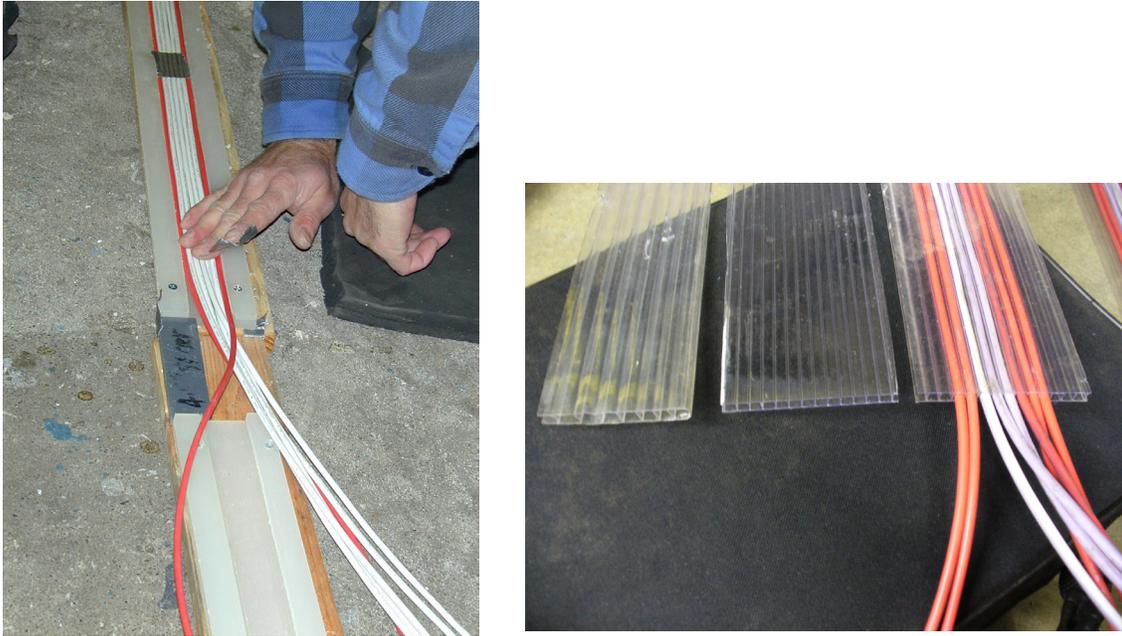


Figure 5. Photos showing the old construction method and the polycarbonate grid sheets that are now used to construct the backbone that holds the antenna wires in place in the middle of the PVC pipes to maintain a 2-in air gap needed for optimal antenna performance.

polycarbonate grid sheets already contained 6- or 8-mm channels, and wire for the antenna could be pushed through the channels. This kept the wire wraps in defined spaces and prevented them from overlapping. Inserting wire into channels was significantly faster than the previous method of having to cut large sheets of wood and plastic to different sizes. The plastic pieces were then used to define the gap with another sheet fastened over to keep the wires in place (Figure 5).

In an effort to enable individuals to have the maximum flexibility in designing their own in-stream interrogation systems and reduce system costs, we also conducted a series of antenna construction workshops during FY07. The objective was to teach interested parties how to construct their own antennas and cables so that they could match the properties of a given antenna to their needs at a reasonable cost and in a timely manner. Antenna construction workshops were provided to individuals from the U.S. Geological Survey, Fish and Wildlife Service, and National Marine Fisheries Service, as well as the Oregon Department of Fish and Wildlife. The antenna construction process relies on common shop tools, limited shop skills, a very basic understanding of electronics, and off-the-shelf components. We produced a compact disk that provides step-by-step instructions, with photographs of the antenna construction process. The CD was furnished to workshop participants and is available to any interested parties.

In 2007, NOAA Fisheries continued to investigate designing antennas for estuarine environments, which are critical habitats for juvenile salmonids. Like streams, estuaries are habitats that in the past have lacked PIT-tag interrogation systems. Previous attempts to operate unshielded FDX PIT-tag antennas in saltwater (conductivity measurements of 28-31 ppt) were unsuccessful because the saltwater caused a significant drop in antenna current. The drop in current resulted in tags not being able to be read in the middle of unshielded antennas that measured over 30 by 30 inches. In 2005, antenna size was successfully increased to 5-ft long by 2-ft wide by incorporating an RF shield. The shield preloaded the antennas, which helped to reduce the drop in antenna current. However, the addition of the shield significantly increased antenna weight, overall size, and cost.

We investigated two variables in 2007 to try to increase the size of antennas that could be used in saltwater and to overcome the disadvantages presented by a shielded antenna. The first change was to replace the wire normally used in antenna construction (10 AWG, 105 conductor wire) with Litz wire (40 AWG, 1,100 conductor wire) from Kerrigan-Lewis Wire. The second change was to use the coax cable described above. We successfully constructed an unshielded 10-ft long by 2-ft wide antenna that produced an overall tag-reading window in the center of 16 inches when it was tested in 28 ppt saltwater. This antenna range was measured using the FS1001M because it is the quietest transceiver available at this time. We are looking forward to testing whether the new multiplexing transceiver (see below) will enable larger antennas to be constructed for use in saltwater.

Transceiver Systems

Starting in 2001, NOAA Fisheries managed the efforts by DA to modify their FS1001A transceiver to work as an interim product for in-stream research (Downing et al. 2004). For this research, the interim transceiver needed to be able to auto-tune as water conditions changed and to operate multiple antennas. In 2004, the first production models of the FS1001M transceiver were available for researchers to purchase, and by 2007, over 25 projects were using the interim FS1001M. As more transceivers were used, a problem emerged with the CPU board, a critical component of the transceiver. Without warning, the CPU board would fail to operate when the transceiver was cycled on and off; this failure caused all stored data to be lost. This was a serious problem if it occurred when study fish were passing the antennas. Digital Angel was finally able to identify the problem: it appeared that the SRAM chip U4 degraded, possibly due to damage caused by electrostatic discharge (failures were most prominent under cold weather conditions). Digital Angel found an alternative chip and replaced the chips.

Since the FS1001M was based on a transceiver design that included parts over 10 years old, NOAA Fisheries began to develop a new multiplexing transceiver in 2006. We worked with the different governmental, tribal, and private entities to write a requirements document (Downing 2006). In order for the new multiplexing transceiver to have the flexibility to work well for future known and unknown applications, researchers and managers wanted to separate the transceiver electronics into multiple enclosures based on function. These and other features are described in detail in the requirements document.

The requirements document was forwarded to DA in order for them to submit a proposal for development of a multiplexing transceiver that met the requirements. Digital Angel submitted their proposal to NOAA Fisheries in January 2007 (Figure 6). The proposal described a system that would place the electronics necessary for antenna performance in an enclosure, which would be installed near or in the stream. Electronics for transceiver control and data collection would be placed in another enclosure, which

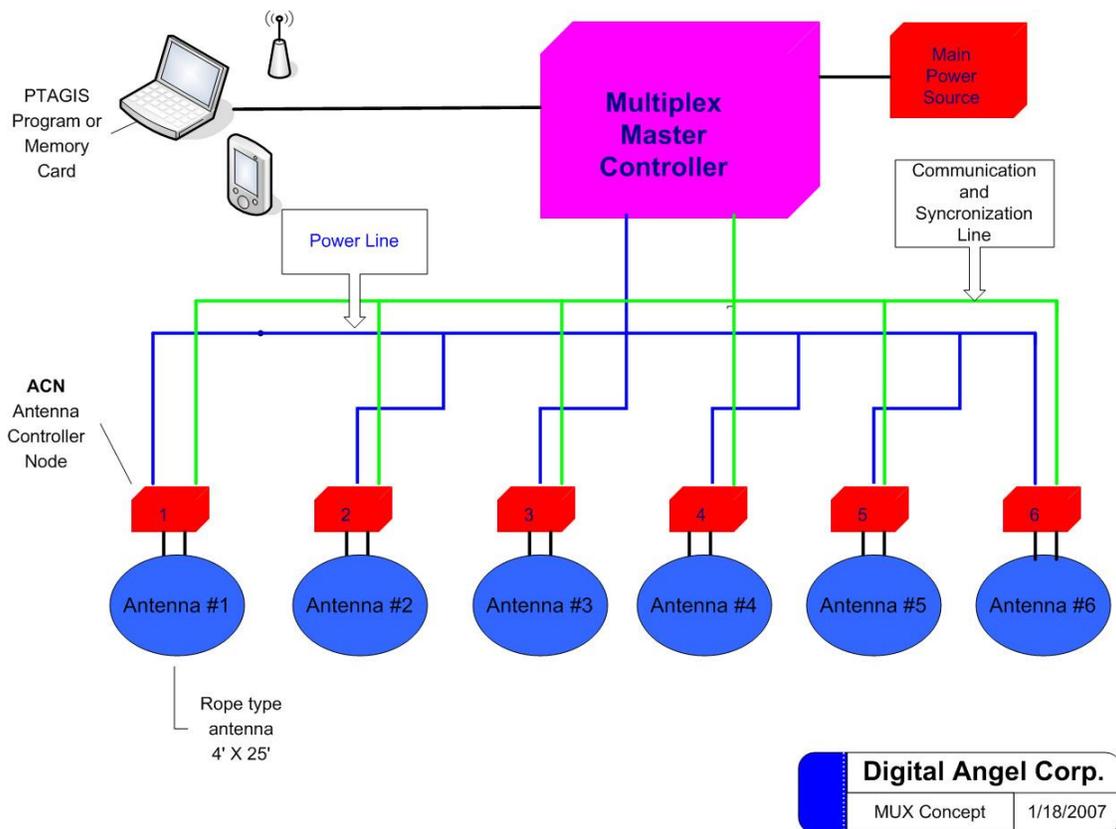


Figure 6. Diagram of the new multiplexing transceiver proposed by Digital Angel. It enables the master controller to be separated from the satellite antenna controller nodes by 500-1,000 ft.

could be installed farther away from the stream (e.g., 500-1000 ft away). In this transceiver concept, there would be one satellite antenna-controller node (ACN) for each antenna. Each antenna-controller node would communicate with a master controller (MC), where the data would be stored.

Funding for the transceiver development was obtained from BPA, the Corps, and NOAA. NOAA issued a contract to Digital Angel in August 2007. The development will take approximately 2 years to complete. Digital Angel is scheduled to deliver a prototype antenna-controller node in February 2008 and prototype master controller in November 2008.

Power Systems

The FS1001M transceivers were designed to operate on 24-V DC because they are mostly deployed in areas where grid power is unavailable. However, when grid power is available, it is preferred because it is cheaper and more reliable. Unfortunately, grid power at times can interfere with the operation of the transceiver via inline electromagnetic interference (EMI). If this interference is at or near the operating frequency of the PIT-tag system (i.e., 134.2 kHz) and is of sufficient strength, it can significantly reduce or even prevent the reading of tags.

To operate the transceiver using grid power, the 110-V AC power must be converted to 24-V DC. Furthermore, a backup power system is typically installed to avoid losing data during temporary grid power failures. Unfortunately, the conversion and backup systems can also be sources of EMI. Therefore, the process of developing a solid power system design has taken time and required testing of numerous products, as often the electronic products (e.g., chargers and timers) produced RF noise instead of helping to eliminate it. During 2007, we successfully finished developing an inexpensive power system design that included backup capability and was electronically quiet.

The final grid-based power system design consisted of four 12-V batteries (Battery Council International group-31), a battery charger (e.g., Interacter model PS 2408), and a timer-relay system (Figure 7). The batteries are divided into two sets. Each set of batteries is connected in series to provide the required 24-V DC. One set of batteries is always being charged, while the other set powers the transceiver. This eliminates any EMI from grid power, which may interfere with transceiver operation. The timer switching circuit is set to transfer charging duty to a new set of batteries every 2 or 4 h (the electronic design for the switcher is available from the authors). If grid power fails, the timer switching circuit will continue to operate, transferring the transceiver power load back and forth between the two sets of batteries until the 18-V operating threshold of the transceiver is reached and the transceiver stops operating. Running on batteries alone, the transceiver should be able to operate normally for 5-7 d.



Figure 7. Photos showing the grid-based power system installed at a site and a close up of the timer switching circuit, which isolates batteries being charged from those being used to operate the transceiver. Batteries are in the box at the bottom of the phone-booth style instrument enclosure.

Conclusions and Recommendations

Significant progress was made toward the goal of developing a stand-alone in-stream interrogation system. By the end of 2007, the 20-ft long by 4-ft wide antennas had been deployed at several sites, and the new coax antenna cable enabled the antennas to be installed up to 200 ft away from the transceiver. Construction of stream antennas was streamlined, but the hope is that the new multiplexing transceiver that NOAA Fisheries has contracted Digital Angel to develop will enable larger and less complex antennas to be constructed in the future. We also recommend finding solutions that will enable large antennas to be designed for estuarine environments.

We are satisfied with the grid-based power system that we finished designing in 2007. The thermogenerators are working well for many off-grid sites, but we recommend that NOAA Fisheries continue to monitor progress in the development of alternative fuels, as one of these may produce a more appropriate power system for some remote applications.

ACKNOWLEDGEMENTS

Support for this research came from regional electric ratepayers through the Bonneville Power Administration. We are grateful to personnel from the Walla Walla and Portland Districts of the U.S. Army Corps of Engineers and to Pacific States Marine Fisheries Commission staff. Without their timely assistance, some of our field work could not have been completed.

We are also indebted to NMFS employee Gary Fredericks for his persuasive support for developing a detection system for the spillways. Finally, our field evaluations of the in-stream interrogation technology could not have been done without the assistance from researchers running different projects. These include sites operated by NOAA Fisheries and USGS.

REFERENCES

- Achord, S., R. A. McNatt, E. E. Hockersmith, B. P. Sandford, K. W. McIntyre, N. N. Paasch, J. G. Williams, and G. M. Matthews. 2004. Monitoring the migrations of wild Snake River spring/summer Chinook salmon smolts, 2002-2003. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon. Available at www.efw.bpa.gov/searchpublications/ (October 2008).
- Allen, B. M., P. J. Connolly, and K. Martens. 2003. Characterization of flow, temperature, habitat conditions, and fish populations in the Rattlesnake Creek watershed. Pages A1-A65 *in* Connolly, P. J. editor. Assess current and potential salmonid production in Rattlesnake Creek associated with restoration efforts, 2002-2003. Report of the U.S. Geological Survey to the Bonneville Power Administration, Portland, Oregon. Available at www.efw.bpa.gov/searchpublications/ (October 2008).
- Chan, V., A. Artyukhov, Y. Smirnov, R. Anderson, R. Clark, K. Kuhnly, and Z. Mejia. 2007. Spillway PIT-tag detection system. Report of the Digital Angel Corporation to the National Marine Fisheries Service, Seattle, Washington.
- Connolly, P. J., I. G. Jezorek, and E. F. Prentice. 2005. Development and use of in-stream PIT-tag detection systems to assess movement behavior of fish in tributaries of the Columbia River Basin, USA. Pages 217-220 *in* Noldus, L. P. J. J., F. Grieco, L. W. S. Loijens, and P. H. Zimmerman, editors. Proceedings of the measuring behavior, 2005: 5th international conference on methods and techniques in behavioral research. Noldus Information Technology, Wageningen, The Netherlands.
- Downing, S. L. 2006. Requirements document for multiplexing PIT-tag transceiver. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).
- Downing, S. L., E. F. Prentice, E. P. Nunnallee, and B. F. Jonasson. 2004. Development and evaluation of passive integrated transponder tag technology, 2000-2002. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

- Jezorek, I. G., and P. J. Connolly. 2003. Instream PIT-tag detection system. Pages B1-B15 in P. J. Connolly, editor. Assess current and potential salmonid production in Rattlesnake Creek associated with restoration efforts, 2002-2003. Report by the U.S. Geological Survey to the Bonneville Power Administration, Portland, Oregon. Available www.efw.bpa.gov/searchpublications/ (October 2008).
- NMFS (National Marine Fisheries Service). 1995a. Reinitiation of consultation on 1994-1998 operation of the federal Columbia River power system and juvenile transportation program in 1995 and future years. Endangered Species Act, Section 7 consultation, Biological Opinion. (Available from NMFS Northwest Regional Office, 7600 Sand Point Way NE, Seattle, WA 98115-0070)
- NMFS (National Marine Fisheries Service). 1995b. Proposed recovery plan for Snake River salmon. (Available from NMFS Northwest Regional Office, 7600 Sand Point Way NE, Seattle, WA 98115-0070)
- NMFS (National Marine Fisheries Service). 2000. Reinitiation of Consultation on Operation of the Federal Columbia River Power System, Including the Juvenile Fish Transportation Program and 19 Bureau of Reclamation Projects in the Columbia Basin. Endangered Species Act - Section 7 Consultation, Biological Opinion. Available at www.salmonrecovery.gov/Biological_Opinions/FCRPS/2000_biop/ (October 2008).
- NMFS (National Marine Fisheries Service). 2004. Reinitiation of Consultation on Operation of the Federal Columbia River Power System, Including the Juvenile Fish Transportation Program and 19 Bureau of Reclamation Projects in the Columbia Basin. Endangered Species Act - Section 7 Consultation, Biological Opinion. Available at www.salmonrecovery.gov/Biological_Opinions/FCRPS/biop_remand_2004/ (October 2008).
- USACE (U.S. Army Corps of Engineers), Bureau of Reclamation, and Bonneville Power Administration. 2004. Final Updated Proposed Action for the FCRPS Biological Opinion Remand. Available at www.salmonrecovery.gov/Biological_Opinions/FCRPS/biop_remand_2004/docs/upa_final/FinalUPANov242004.pdf (October 2008).