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Fish Ecology Division

Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

by
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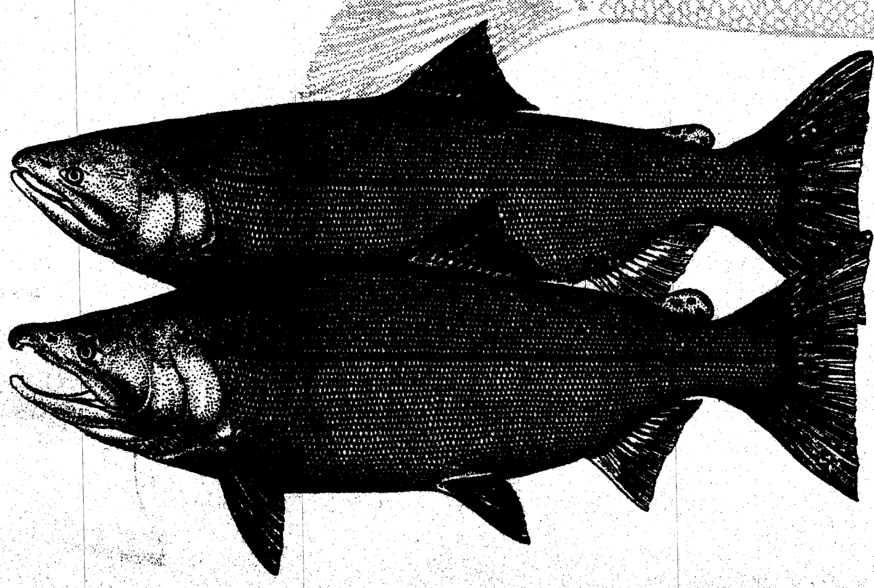

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Report of research by

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EXECUTIVE SUMMARY

In 2001, the U.S. Army Corps of Engineers (COE) asked the National Marine Fisheries Service (NMFS) to evaluate the technical feasibility of interrogating PIT-tagged fish in large-diameter juvenile fish bypass pipes (full-flow bypass system) at McNary Dam. Objectives of this evaluation were 1) to develop a PIT-tag interrogation system that would function year-round rather than only seasonally, as is presently the case, 2) to provide greater flexibility in the operation of the juvenile fish facility without disrupting operation of the present juvenile interrogation systems, and 3) to develop a system that could be used with the existing juvenile fish bypass pipe that leads from the powerhouse to the juvenile fish collection and monitoring facility. Information gained from the design of a full-flow system at McNary Dam will aid in the design of similar full-flow systems being proposed for Bonneville Dam, John Day Dam, and other federal hydroelectric dams of the Columbia River Basin.

The full-flow bypass system was installed in an area along the 91.4-cm-diameter steel bypass pipe. Initially, four antennas would be installed upstream from the diversion gate that directs flow either to the river or to the juvenile fish collection and monitoring facility. The extended-range PIT-tag electronic technology developed for adult salmonid fish ladders, in concert with the existing 12-mm-long PIT-tag, provided the framework from which this system was developed. Initial system concepts were evaluated at Digital Angel Corporation and NMFS electronic laboratories, and field tests were conducted at the NMFS field research station at Pasco, Washington.

A full-scale mock-up of a PIT-tag detection antenna and RF shield system was used for most field tests, with partial side walls on the shield for ease of access during testing. Specific issues addressed included antenna size, coil spacing, coil inductance, radio frequency (RF) electromagnetic noise susceptibility, vibration, multiple tags within the read window of an antenna, and shield design. Field tests were conducted during three periods: 30 July-2 August, 19-20 September, and 2-10 October 2001.

Field test results showed RF antenna shielding reduced ambient RF noise interference by a significant amount (~14% down to ~ 3%) and that the antenna shield could not be attached directly to the pipe. Achieving any RF noise reduction is important since there is an inverse relation between the amplitude of RF noise and the ability to read tags.

In addition, a means to shape the electromagnetic field generated by the antenna was developed. This shaping will enable a narrow tag-reading "window" to be formed, thus reducing the likelihood of more than one tag being read at any one time. Tests

showed that neither wide variations in water level and turbulence nor wave action within the test pipe caused significant change in excitation current, RF noise, or transceiver tuning.

An additional design concern for the full-flow bypass system at McNary Dam was the transfer of vibration from the pipe, water, and/or shield to the antenna. Vibration at certain frequencies can seriously degrade tag-reading ability. During testing, the PIT-tag system was shown to be highly sensitive to mechanical vibration from several sources. This mechanical vibration was eliminated by wrapping the antenna on a 2.5-cm-thick piece of foam. This method of controlling vibration will be used in the final design; however, the particular problems that may be encountered at the dam cannot be reliably predicted at off-site test locations and will have to be solved as they occur. We formed the following conclusions based on further tests.

1) Interference between the two transceivers can be eliminated by synchronizing the units to one another.

2) Changing water conditions within the pipe do not have a significant effect on tag-reading ability.

3) Tag-reading ability of the system appears to be adequate.

4) Antennas must be isolated from mechanical coupling of the fish transport pipe to control vibration.

Also, as a result of these findings, all four transceivers will be synchronized when installed at McNary Dam, and the antenna shield will be isolated from the fish-transport pipe. Final tests showed that the standard FS1001A transceiver could be used with a 112-cm-diameter antenna but with significantly reduced tag-reading distance from that achieved while using the 97-cm-diameter antenna. However, when a transceiver was equipped with an improved analog board, the reading range obtained approximated that achieved with the 97-cm-diameter pipe while using a non-modified transceiver.

NMFS discussed with the COE the results obtained with the 122-cm antenna and our concerns regarding possible fish behavior modification if pipes with dissimilar inside diameters were used on the project. As a result of these discussions, the COE is having fiberglass pipe fabricated that will have the same inside dimension as the exiting steel pipe. This pipe will also have an outside diameter similar to the 91.4-cm-diameter pipe tested. Based on this change and the positive test results obtained at Pasco, the prognosis for the successful installation of a full-flow PIT-tag detection system at McNary Dam appears to be favorable.

CONTENTS

INTRODUCTION

The National Marine Fisheries Service (NMFS) Biological Opinion for Operation of the Federal Columbia River Power System addresses the issue of increasing passage survival of juvenile salmonids at hydroelectric dams in the Columbia River Basin. One approach proposed includes bypassing fish under full-flow conditions and routing them directly back to the river rather than to the juvenile fish collection and monitoring facilities (NMFS 2000, Sections 9.6.1.4.2 and 9.6.1.4.6).

At present, when fish are bypassed and routed to the juvenile fish facilities at Columbia and Snake River hydroelectric dams, PIT-tagged fish are automatically detected and invaluable information regarding migrational behavior, timing, and survival is obtained (Prentice et al. 1990, Nunnallee et al. 1998, Downing et al. 2001). However, when juvenile fish are bypassed and routed under full-flow conditions directly back to the river rather than to the juvenile fish facilities, PIT-tag detection does not occur and the opportunity to obtain this information is lost. The collection of this information could greatly benefit many ongoing and future studies associated with salmonid recovery efforts in the Columbia River Basin.

In 2001, NMFS initiated an evaluation of the technical feasibility of developing a PIT-tag interrogation system for large-diameter juvenile fish bypass pipes (i.e., full-flow bypass system). Our effort was specifically directed at evaluating the conditions at McNary Dam. The objectives were to develop a PIT-tag system that would 1) enable PIT-tag interrogation year-round rather than only seasonally as is presently the case, 2) provide greater flexibility in the operation of the juvenile fish facility without precluding operation of the present juvenile interrogation systems, and 3) use the existing 91.4-cm-diameter juvenile fish bypass pipe that leads from the McNary Dam powerhouse to the juvenile fish collection and monitoring facility.

METHODS

A series of discussions were conducted with the COE and its contractors to obtain project-specific information required for a general appraisal of technical feasibility. A site visit to McNary Dam resulted in selecting an area along the 91.4-cm-diameter steel bypass pipe that runs from the dam's powerhouse to the juvenile fish collection and monitoring facility. It was decided that initially four antennas would be installed upstream from the diversion gate that directs flow to either the river or to the juvenile fish collection and monitoring facility.

Digital Angel Corporation (parent company of Destron Fearing, the PIT-tag equipment manufacturer) was contracted by NMFS to assist with antenna design and characterization. The general approach taken was to use the extended-range PIT-tag electronic technology developed for adult salmonid fish ladders and apply it to full-flow bypass pipes. This technology, in concert with the existing 12-mm-long PIT-tag, provided the framework from which the system was developed. Initial system concepts were evaluated at Digital Angel Corporation and NMFS electronic laboratories. Field testing was conducted at NMFS Pasco Field Station, where specific issues addressed included antenna size, coil spacing, coil inductance, radio frequency (RF) electromagnetic noise susceptibility, vibration, multiple tags within the read window of an antenna, and shield design. Field tests were conducted during three periods: 30 July-2 August, 19-20 September, and 10 October 2001.

Most tests at the NMFS Pasco facility were conducted using a full-scale but abbreviated mock-up of a PIT-tag detection antenna and RF shield system (partial side walls on the shield for ease of access during testing). The antenna and RF shield were installed around a section of high-density polyethylene (HDPE) pipe measuring 6.1-m long, 91.4-cm od (outside diameter) by 85.5-cm id (inside diameter), with a wall thickness of ~6 cm. This type of pipe material was used because steel or other metallic materials normally used with bypass pipes would create interference with the electrical fields produced by the PIT-tag system.

Both ends of the HDPE pipe were sealed, and two pipes with valves were attached at one end of the sealed pipe so that water could be introduced or drained from the pipe. The pipe was positioned on a fulcrum so that it could be tipped up and down. This enabled us to simulate water surging in the full-flow bypass pipe at McNary Dam during certain stages of operation and to determine the effect of water depth on tag-reading ability.

At the time of the July-August and September tests, the 91-cm-diameter HDPE pipe being evaluated was thought to be of the appropriate dimensions to be used with the existing steel pipe at McNary Dam. However, in late September we were notified that the inside dimension of the steel pipe, to which the HDPE pipe was to be mated, was 89.5 cm. This meant there was an inside dimension difference of ~4 cm between the pipes to be mated. The COE indicated that the next size HDPE pipe available had an outside diameter of 107-cm and an inside dimension of ~100 cm. With this new pipe dimension information available, a third series of tests was conducted in October to determine the effect of a larger-diameter pipe on tag-reading performance. In addition, this test series provided an opportunity to determine the technical feasibility of interrogating PIT-tagged fish using larger-diameter antennas.

The aluminum RF shield mock-up used in the tests measured 2.4-m high by 2.4-m wide by 1.8-m long. The HDPE pipe ran horizontally through the center of the longitudinal axis of the shield. All parts of the shield were electrically connected using heavy-gauge copper wire. In addition to the shield, adjustable RF field clamps were constructed and evaluated in some of the tests. The clamps consisted of 31-cm wide by 5-mm-thick sheet aluminum cut to form a collar around the pipe and positioned on either side of an antenna coil. Clamps were not connected directly to the main shield box.

The final version of the shield box to be installed at McNary Dam in 2002 will be constructed with full aluminum walls on all sides. The mock-up shield was constructed with 61-cm separation between the central section of the shield and each end wall to provide access to the antenna. It was assumed that full RF shielding would be electrically similar to the partial shield mock-up. The test results reported below indicate that the assumption was appropriate.

All testing was performed using Destron Fearing FS1001A transceivers. Tag detection percentages reported were calculated from values produced directly by the transceivers. The detection values were obtained by placing a PIT tag into a 134.2-kHz electromagnetic field at various locations from the antenna. A tag that remains in a field of sufficient intensity to energize it will continuously transmit its code until it is removed from the field.

During this period the transceiver repeatedly calculates percent code detections as the ratio of valid code message strings received for a predetermined number of headers read. This measurement is not absolute because it is possible that some headers or message strings cannot be read due to RF noise or other causes. However, this procedure is more precise than comparing the expected vs. the observed number of code detections per unit time because it requires less time and thus encompasses less variation in the tag reading/detection process.

This method is reliable for evaluations of tag-reading ability within a particular environment or at a specific point in time. A number of reading-efficiency values can be obtained by placing tags at different stationary positions of interest within the antenna. The result is a range of tag-code detection reading efficiencies (%) for a large number of tag transmissions over a relatively short time. The extent size of this range will indicate the effects of noise or other interference.

The primary antenna configuration used in the tests was of a double/parallel coil design. This antenna was constructed using 16-gauge wire. The wire was wrapped in two sets or coils, each coil consisting of a single layer of closely spaced wire wraps around the pipe. The two coils of wire were separated by 3.8 cm. Each set of wire wraps was wound to attain an inductance of approximately twice that which has previously been found to work efficiently with an antenna series tuning capacitance of 4700 pF. The two coils were then connected in parallel, in phase, and in series with the tuning capacitors. After being adjusted to come to resonance at about the midpoint of the internal tuning range of the transceivers, the final number of wire wraps on each coil of the antenna was 13. The resultant total inductance was 303 μH.

The advantage of this antenna configuration is that for a similar inductance, the total number of turns is about twice what it would be for a single coil, and thus the configuration will have about twice the amp turns (exciter current (A) × number of turns) to produce the electromagnetic field intensity needed to interrogate PIT tags. Previous testing showed this type of antenna to have very good tag excitation and detection properties when the tag was at less than ideal orientation. In tests requiring a second antenna, an antenna of a single coil configuration was used. This type of antenna was close wound to 325 μH inductance and connected in phase with the first antenna. During the July-August tests, these antennas were wrapped directly around the 91-cm-diameter HDPE pipe.

The double/parallel antenna used during the September tests was not wrapped directly onto the HDPE pipe, but on a vibration dampener that was attached around the pipe. The vibration dampener was constructed by first securing a ring of 2.5-cm-thick by 25-cm-wide soft foam around the test pipe. On top of the foam were placed wooden slats measuring 31-cm long by 10-cm wide by 4-mm thick. The slats were located around the pipe at about a 60 degree spacing. The antenna wire was in turn wrapped over the wooden slats to form the antenna coils. This arrangement allowed the coils of the antenna to be adjusted after wrapping. The purpose of the foam was to reduce mechanical coupling of vibration from the transport pipe to the antenna and to eliminate the effects of shrinkage and expansion of the HDPE pipe with temperature changes.

RESULTS

Test Series 1, July-August 2001

1.1 Baseline Data

The first series of tests at the NMFS Pasco Field Station was conducted from 30 July through 2 August 2001. The first test was conducted without RF shielding installed to establish a baseline for comparison. In addition, all tests reported for this time period, with one minor exception to be detailed later, were made using a single antenna of the double/parallel coil design.

Although these measurements were made before the shield was installed, the adjustable RF field clamps were present but were spaced at about 64 cm from the upstream and downstream edges of the coils. Tightening screws were installed on the clamps to allow adjustment of their position on the pipe. The RF field clamps are used to load or reduce the longitudinal portion of the electromagnetic field produced by the antenna to limit the distance along the axis of the pipe where PIT tags can be excited and detected.

When the excitation field is too large, multiple tags within the field may interfere with one another and cause lost detections (similarly, if high volumes of fish pass through such a field, some tagged individuals can be missed due to tag transmission collisions). For this first set of measurements, the RF field clamps were adjusted to a range where they did not have much effect on the tuning and size of the tag interrogation field. Conditions of the test setup and measurements are shown in Table 1.

1.2 Radio Frequency Shield and Clamps

The second set of test measurements were made with the complete mock-up shield in place. The RF field clamps were maintained at 64 cm from either edge of the double/parallel antenna coils. The spacing between the two antenna coils was maintained at 3.8 cm. Test system setup and measurements are shown in Table 1.

Tag read range along the axis of the pipe was about 71-74 cm to first tag detection or 30.5 cm from either side of coil (30.5 cm upstream reading range added to the 11.4-cm coil width and the 30.5-cm downstream reading range). Tag-reading efficiency at the center of the coil was 100%

Table 1. Summary of test conditions for initial evaluations of the full-flow bypass system mock-up, Series 1, Tests 1-7, 30 July-2 August 2001.

Full-flow bypass system Test Series 1								
				Test 4				
	Test 1	Test 2	Test 3	Antenna 1	Antenna 2	Test 5	Test 6	Test 7
Antenna configuration								
DP = double/parallel, S = single	DP	DP	DP	DP	S	DP	DP	DP
Coil diameter (cm)	91.4	91.4	91.4	91.4	91.4	91.4	91.4	91.4
Number of wire wraps	13/13	13/14	13/15	13/15	13	13/15	13/15	13
Inductance (μH)	303	303	302	302	325	302	302	302
Spacing between coils (cm)	3.8	3.8	3.8	3.8	NA	3.8	12.7	12.7
Tuning capacitance (pF)	4700	4700	4700	4700	4700	4700	4700	4700
RF shield (mock-up)	No shield	√	√	√	No shield	√	√	√
RF field clamp spacing from coil (cm)	64	64	30.5	30.5	No clamps	30.5	25.4	25.4
RF noise (%)	6-7	-	3	2-5	12-14	3	3	
FS 1001A Transceiver	√	√	√	√	√	√	√	√
Total transceiver tuning capacitance (pF)	26,700	-	18,700	-	-	29,400	29,400	29,400
Fixed (× 1,000)	10	-	10	-	-	10	10	10
Variable (× 1,000)	10, 4.7, 2	-	4.7, 2, 1, 1	-	-	10, 4.7, 4.7	10, 4.7, 4.7	10, 4.7, 4.7
Phase (%)	0	-	1	0-2	-	1	1	1
Excitation current (amps peak-to-peak)	3.0 (3.6 max)	-	3.7 (3-4.3)	2.93-3.49 (±10%)	2.93-3.49 (±10%)	3.3 (2.7-4.0)	3.3 (2.7-4.0)	3.3 (2.7-4.0)
Cable length (m)	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5
HDPE Pipe	√	√	√	√	√	√	√	√
Outside diameter (cm)	91.4	91.4	91.4	91.4	91.4	91.4	91.4	91.4
Inside diameter (cm)	85.5	85.5	85.5	85.5	85.5	85.5	85.5	85.5
Water level*	varied	half full	half full	half full	half full	varied	half full	varied

* The effect on tuning of water level in the pipe varied between empty and full was < 2% phase difference.

1.3 Radio Frequency Field Clamp Placement

The third test consisted of positioning the antenna RF field clamps to within 30.5 cm of sides of the double/parallel antenna coils. The test setup and measurements are shown in Table 1, and tag-reading results are listed below.

Distance upstream from antenna (cm)	Tag detection (%)
22.9	5
17.8	55-60
12.7	94-95
7.6	100

1.4 Interference Between Antenna Systems

The fourth test in the series was conducted to determine the degree of interference between two adjacent antenna systems. The distance between the two antenna systems was 2.9 m, similar to that planned for final installation. The double/parallel and a single coil antenna (configuration previously described) were used in this test. No shielding or RF field clamps were installed around the second antenna. This configuration was used as a "worst case" scenario and it is expected that inter-unit interference in the final configuration will be somewhat less than this test indicates. A second FS1001A transceiver was attached to the unshielded antenna and tuned to resonance. The transceiver exciter current was adjusted to mid range.

When both transceivers were operated simultaneously, a beat frequency (difference between frequencies of the two units) was evident on both in terms of excitation current and RF noise level. Exciter current, phase variation, and RF noise displayed by the transceiver connected to the shielded antenna were as follows:

Excitation current:	2.93 to 3.49 amps peak-to-peak, about $\pm$ 10%
Phase:	beat frequency between detectors resulted in tuning changes of 0-2%
RF noise:	values ranged from 2 to 5% in step with beat frequency
RF noise:	RF noise from the coil outside the antenna shield box was 12-14% before the second antenna was excited

Tag-reading ability appeared to be at about normal when the exciter current approached the maximum and minimum values caused by the beat frequency. However, tag-reading sensitivity was considerably reduced during the more rapidly changing portions of the beat frequency cycle. Synchronization of the two transceivers was not tested during this test because the necessary cable was not available.

1.5 Hydraulic Conditions in the Pipe

The effect of water turbulence and wave action within the pipe on PIT-tag transceiver operation was evaluated during a fifth set of tests. This was accomplished by lifting and lowering one end of the pipe when half filled with water and measuring the resultant changes in tuning phase, exciter current, and RF noise. The second transceiver and antenna coil were disabled for this test and all subsequent tests in this series. Once started, the water surging in the pipe continued for 10 minutes or more, as evidenced by the water level in a sight tube installed at one end of the pipe. During these tests, the water level in the sight tube showed that the depth at the end of the pipe varied from less than quarter full to completely full. Throughout the period of surging, no indication of changes in tuning, noise, or exciter current level was seen; all values remained as steady as when the water within the pipe was still.

1.6 Distance Between Coils

In the sixth set of tests the distance between the two coils of the double/parallel antenna was increased from 3.8 to 12.7 cm and the RF field clamps were moved to within 25 cm of the outside edges of the antenna coils. The transceiver was re-tuned to resonance and reading range was determined. The test setup is shown in Table 1, and reading measurements are listed below:

Total reading range along pipe axis (cm)	Tag detection (%)
20.3	5-8
15.2	50-58
10.2	79-82
5.1	95-96
0	99
antenna midpoint	100

1.7 Water Level in Pipe

The goal of the final test in this series was to retest the effect of water level in the pipe on the operation of the transceiver. The test configuration was as described for test series five and six. The transceiver was initially tuned with the test pipe half filled with water. The pipe was completely filled with water and then completely drained. Electrical observations were made during the filling and draining process.

It was shown that wide ranges in water level, water turbulence, and wave action in the test pipe did not significantly change excitation current, noise, or transceiver tuning. The measurements of tuning, noise, and current were as follows:

Water level in pipe	Δ tuning phase (%)	Δ RF noise (%)	Δ current
full	~0	~0	~0
half full	~0	~0	~0
quarter full	~0	~0	~0
empty*	0 to 4-5%	~0	~0

*Tuning phase returned to 0% after pipe was refilled to a quarter full.

Conclusions

RF shielding--RF shielding was shown to reduce ambient RF noise interference by a significant amount. During the dual transceiver test for inter-unit interference, the noise level was recorded as 12-14% before the shielded antenna was excited. In the first test series, which was conducted before the shield was installed, but which did have the RF field clamps in place, the recorded noise level was 6-7%. Finally, when all shielding and the RF field clamps were in place, the recorded noise level dropped to about 3%.

RF field clamps--RF field clamps, used in conjunction with coil spacing, provide the means to adjust and shape the effective electromagnetic field pattern within an antenna tunnel. This technique allows the electromagnetic field to be shaped such that the upstream and downstream reading range of the antenna can be adjusted to reduce the effect of tag-code transmission collisions and loss of detection when tag density is high. At the same time, a strong RF field intensity can be maintained within the central part of the antenna to ensure a high tag-reading probability.

Water level variation--The test pipe used in the Pasco mock-up was about 6-cm thick. Testing showed that wide ranges in water level, water turbulence, or wave action in the test pipe did not have a significant effect on excitation current, RF noise, or transceiver tuning.

Vibration sensitivity--High sensitivity to mechanical vibration from several sources proved to be important during the Pasco mock-up tests. High transceiver RF noise levels could be generated by gently drumming fingers on the RF shield, or by sliding a metal object gently over its surface. The detector, however, did not appear to be unduly sensitive to low-frequency movement of the RF shield. Rigorous shaking of the shield did not generate excessive noise, nor did it appear to have much effect on tuning.

Two factors that were present in the Pasco mock-up will not be present in the final installation. First, the Pasco mock-up RF shield rested directly on the test pipe and coupled all vibration from the pipe directly to the antenna. Second, the final version of the RF shield will have full shielding on all sides and will have reinforcement bracing for support and to reduce vibration. However, it is likely that the shield/antenna structure will still be sensitive to vibration.

One possible solution is to spray about 5 cm of foam insulation on all interior surfaces of the antenna shields to deaden the effects of vibration caused by rain, hail, wind, etc. Vibration is one of the problems that will have to be dealt with after installation of the McNary Dam full-flow bypass system. However, the particular problems to be encountered cannot be reliably predicted at this time, and will have to be solved as they occur.

Installation prognosis--The prognosis for the successful installation of a full-flow PIT-tag detection system at McNary Dam appears to be favorable.

Test Series 2, September 2001

Analyses of the data obtained during the 30 July-2 August test series revealed several aspects of the procedures and measurements that were not conclusive or pointed out problems that had to be addressed. A second series of tests were made during 19-20 September to better answer these questions and concerns (Table 2). The following six questions were addressed during this second series of tests:

1) Can inter-unit interference between adjacent PIT-tag transceivers be eliminated through synchronization of the transceiver units?

2) Will fluctuations in water depth within the full-flow transport pipe cause changes in system performance?

3) Can electrical noise in the PIT-tag transceiver generated by the mechanical coupling of vibration between the transport pipe and the antenna be reduced or eliminated?

4) Can vibration transmitted from the RF shield to the antenna be controlled or eliminated?

5) Will water discharging onto or from the full-flow transport pipe be a source of environmental RF noise for the PIT-tag system?

6) What PIT-tag reading range could be obtained with the system?

For this test series the setup was similar in most respects to that reported for test four of the first test series (i.e., the HDPE test pipe and the aluminum RF shield structure were unchanged with two antennas active) with the following two exceptions: the RF shield was separated from mechanical contact with the HDPE pipe, and the antenna was wound on a foam layer to reduce mechanical vibration coupling from the pipe to the antenna. Details of the test setup are shown in Table 2.

Table 2. Test conditions for tests of synchronization using a primary (double/parallel) and secondary (single) antenna configuration. This configuration was used for Series 2, Tests 1-6, 19-20 September 2001.

Full-flow bypass system Test Series 2		
	Primary antenna	Secondary antenna
Antenna configuration	double/parallel	single
Coil diameter (cm)	97 (w/ 2.5-cm foam)	91.4
Number of wire wraps per coil	15/16	12
Spacing between coils (cm)	15 (inside edges)	NA
Coil width (cm)	3.8	3.8
Inductance (μH)	327	325
Tuning capacitance w/ 2×2 configuration (pF)	4,700	4,700
RF shield (mechanically isolated from pipe)	√	no shield
RF field clamp width (cm)	30.5	NA
RF field clamp spacing (cm)	69	NA
RF noise (%)	0-2	12-14
RF field clamp distance from coil edge (cm)	23	NA
FS 1001A Transceiver	Master	Secondary
Total transceiver tuning capacitance (pF)	-	26,700
Fixed (× 1,000)	-	10
Variable (× 1,000)	-	10,4.7,2
Phase (%)	0-2	-
Excitation current (amps peak-to-peak)	2.93-3.49	4.5
Cable length (m)	30.5	17.1
HDPE Pipe	√	√
Outside diameter (cm)	91.4	91.4
Inside diameter (cm)	85.5	85.5
Water level inside pipe	varied	varied

2.1 Synchronization

The first test in this series explored the inter-antenna interference under two conditions: when the two adjacent PIT-tag transceivers were synchronized and when they were not. The results again showed unsynchronized transceivers affect system performance. These results are similar to those obtained in the first test series and agree with our past experience. The measurements were as follows for the primary transceiver (master transceiver) connected to a double/parallel coil antenna:

Excitation current:	varied only slightly (about 2%)
Tuning phase:	no significant effect, no obvious beat frequency
RF noise:	Values ranged from 0-2%; no obvious beat frequency

2.2 Water Level Effect on Tuning

The second test in this series addressed the effect of water level in the test pipe on system tuning. Results showed that the tuning phase increased about 2% from dry to full conditions. The electrical current to the antenna and RF noise level was unchanged in both states after re-tuning. Finally, no change was noted in tuning phase, noise, or current as water level was lowered from full to a half full condition.

Based on these results we believe water level fluctuation within the pipe will be a non-issue from an electronics standpoint. It should be noted that changing water levels within the pipe might affect fish orientation and thus the angle of the tag within the reading window of the antenna system. This in turn may affect tag-reading ability. We will not know the effect of fish orientation on tag-reading ability at McNary Dam until after system installation and evaluation.

2.3 Effect of Vibration on Pipe

The third test addressed the question of vibration on system performance. During the first test series it was found that high transceiver RF noise levels could be generated by gently drumming fingers on the RF shield, or by sliding a metal object gently over its surface. Unlike the July-August test series, the antenna RF shield for this test series was isolated from the pipe. In addition, the antenna coils were wrapped on a 2.5-cm-thick layer of soft foam.

Test conditions and results were as follows while vibrating the pipe:

Conditions on pipe	Δ RF noise
Screwdriver tapping on pipe	none
Hard, repeated rapping with screwdriver handle	no RF noise effect
Moderate pounding with hammer	no RF noise effect
Hard pounding with hammer	very slight increase in RF noise level

These results show that the vibration dampening system used during this test series effectively solved the RF noise problem produced during our testing. In addition, when the antenna was wrapped directly onto the pipe, as during the July-August test series, expansion/shrinkage caused the antenna to loosen and move enough to affect its inductance, and hence tuning. During this test series, with the foam layer under the antenna, no temperature-related effects were observed.

2.4 Effect of Vibration on Radio Frequency Shield

The same procedures used to create vibration on the pipe were repeated on the RF shield with the following general results:

Conditions on shield	Δ RF noise
Screwdriver tapping or scraping	none
Moderate tapping with hammer	no RF noise effect
Hard pounding with hammer	increase 9-10% to 20-30%

The data did show that some areas of the RF shield were more sensitive to vibration than others. The portion of the RF shield immediately surrounding the antenna was the most sensitive, while the end walls were very insensitive. Results above were for the area immediately surrounding the antenna.

2.5 Noise Effect of External Water

Sensitivity to RF noise generated by running water was addressed in the fifth test of this test series. The setup and results were as follows:

Condition on transport pipe	Δ RF noise
Ambient PIT-tag detector RF noise level	9-10%
Water dripping or being poured onto pipe	9-10%
Uninterrupted stream of water flowing from pipe drain onto gravel	25-50%
Uninterrupted stream flowing from pipe drain onto 2.5-cm-thick foam	9-12%

The sensitivity of the PIT-tag transceiver to RF noise caused by a steady stream of water falling onto gravel was significant even with the antenna separated from the test pipe with 2.5 cm of soft foam. However, the overall sensitivity of the antenna to RF noise was considerably reduced from when the antenna was wrapped directly onto the pipe as during the July-August test series (RF noise approached 100%). The mechanism of how electrical interference can be generated by water falling onto gravel while the same antenna is very insensitive to other types of mechanical vibration is not understood. However, we do not believe that this phenomenon will be a problem at McNary Dam.

2.6 Tag Reading Range

The final test of this test series addressed tag reading range. Reading range measurements were made using a double/parallel coil antenna wound on 2.5-cm-thick foam. RF field clamps were in position as previously described. Tag reading-range measurements were made along the long axis of the pipe and from the center of the antenna. Results were as follows:

Total reading range (cm)	Tag detection (%)
30.5	0
27.9	1-2
25.4	20-50
22.9	20-50
20.3	80-100
17.8	90-100
15.2	97-100
<15.2	100

The reading distance and percent of tags read is satisfactory for this size antenna. Tapping and pounding on pipe during any reading range measurement had no effect on either the distance at which a tag could be read or the percent of tags read. We concluded that if similar system performance can be obtained at McNary Dam, the full-flow bypass system will meet the needs of the fisheries community.

Conclusions

Based on results of the second series of mock-up tests for the McNary Dam full-flow bypass system, we made the following conclusions:

1) Interference between the two transceivers can be eliminated by synchronizing the units to one another.

2) Changing water conditions within the pipe does not have a significant effect on tag-reading ability.

3) The antennas must be isolated from mechanical coupling of vibration from the fish transport pipe.

4) The RF shield structure must be mechanically isolated from the transport pipe to reduce the effects of vibration caused by wind, rain, etc.

5) Water discharge onto the transport pipe had no effect on the system.

6) Tag-reading ability of the system appears to be adequate.

Test Series 3, October 2001

Considerable system testing was conducted using a 91.4-cm-diameter HDPE pipe during the first two test series with very favorable results. However, in late September we were notified by the COE that the pipe dimensions with which we were working did not match those of the steel pipe to which the PIT-tag system was to be mated nor to the HDPE pipe which they selected. The pipe they selected measured 107-cm outside diameter by 95.9-cm inside diameter, with about a 5-cm wall thickness. This size HDPE pipe was the closest match the COE could find to the inside dimension (89.5 cm) of the existing steel pipe at McNary Dam.

This larger pipe size presented several problems. First, the transitions between the upstream and downstream ends of the replacement pipe section, if not matched in dimension, will result in some turbulence and a change in water-flow velocity. It is known that such a change in velocity can cause a behavioral response in fish as they enter a transition zone. It is possible that if fish hesitate, accelerate, or alter their orientation in the pipe as they pass the pipe transition area, PIT-tag detection efficiency may be reduced.

The second problem is that the increase in the outside diameter of the pipe necessitates the use of larger antenna coils. The consequence of this increase in coil size is that the electromagnetic field generated by the system must be of a much greater volume yet still be sufficiently intense to energize PIT tags. Furthermore, a larger antenna will be more affected by ambient RF noise.

3.1 Repeat Tests with Antenna Coil Diameter at 112 cm

The effect on PIT-tag detection due to an increase in antenna diameter from 97 cm (91.4-cm-diameter pipe plus 2.5-cm layer of foam wrapped on pipe) to 112 cm (107-cm-diameter pipe plus 2.5-cm layer of foam) was tested using a mock-up of the full-flow system at Pasco on 2 October. Earlier testing had shown that the 2.5-cm-thick layer of soft foam was required between the pipe and the antenna to eliminate the effects of RF noise caused by mechanical vibration and to compensate for thermal expansion and contraction of the pipe.

Two tests were conducted using a mock-up of a 107-cm-diameter pipe (112-cm-diameter antenna). RF field clamps were not used during either of the two tests. For the first test, each coil consisted of 16 wraps of wire to approximate the same Amp-turn ratio as used during previous testing. The test setup is shown in Table 3.

Tag-reading range for this antenna configuration was 71 cm (total reading distance measuring both upstream and downstream) with about a 5% tag-reading efficiency. A 50% or greater reading efficiency occurred within a 20-25 cm (total reading distance) path along the axis of the antenna. These results are significantly lower than those obtained in the previous test series (i.e., tag-reading efficiency of 50% or greater was measured over a 51-cm distance for the 97-cm-diameter antenna).

The reading range of that antenna would probably have been somewhat larger but still reduced if the RF field clamps had not been present. The RF field clamps were used to purposely compress the tag-reading volume within the antenna coil to reduce the effects of code collisions when high densities of tagged fish occur. Higher and lower exciter current settings were also tested for effects on tag readability; higher current (4.4 A peak-to-peak max) had no effect, lower current slightly reduced tag readability

3.2 Inductance with Coil Diameter at 112 cm

The procedures and setup used in Test 1 were repeated for Test 2 except the number of wire wraps on each antenna coil was reduced to 12 to make the antenna similar in inductance to that used in the September test series.

Higher and lower exciter current settings were tested; higher current (4.8 A peak-to-peak max) had no effect, lower current slightly reduced tag readability. In addition, when test results from tests with the 2 October system configuration were compared to previous tests conducted using a 97-cm antenna, it was obvious that considerable reading efficiency was lost with the larger 112-cm-diameter antenna. The reason is that the volume that must be excited with an electromagnetic field of sufficient intensity to energize tags is roughly equivalent to the cube of the antenna radius (the volume of a sphere = $4/3\pi r^3$). The increase in necessary detection volume from a 97-cm coil to a 112-cm coil is about 150%.

Table 3. System configuration for Tests 1-2 (2 October) and 3-5 (10 October). An improved analog board was evaluated during Test 3. The board was upgraded with an additional RF noise-filtering circuit and increased gain. Configuration B evaluated the upgraded board, and Configuration C evaluated the upgraded board with a 24-V exciter module.

	Full-flow bypass system Test Series 3				
	Test 1	Test 2	Test 3		
			A	B	C
Antenna configuration					
DP = double/parallel	DP	DP	DP	DP	DP
Coil diameter (cm)	112 (2.5-cm foam)	112 (2.5-cm foam)	112 (2.5-cm foam)	112 (2.5-cm foam)	112 (2.5-cm foam)
Number of wire wraps per coil	16/16	12/12	12/12	12/12	12/12
Spacing between coils (cm)	15	15	15	15	15
Coil width (cm)	3.8	3.8	3.8	3.8	3.8
Inductance (μH)	496	322	322	322	322
Tuning capacitance (pF)	783.3	4,700	4,700	4,700	4,700
RF shield (isolated from pipe)	√	√	√	√	√
RF field clamp width (cm)	NA	NA	30.5	30.5	30.5
RF field clamp spacing (cm)	NA	NA	69	69	69
RF noise (%)	1-2	2	1-2	1-2	6
Clamp distance from coil edge (cm)	NA	NA	23	23	23
FS 1001A Transceiver	√	√	√	√	√
Total tuning capacitance (pF)	68,000	24,000	23,000	23,000	23,000
Fixed (× 1,000)	-	-	10	10	10
Variable (× 1,000)	-	-	10, 2, 1	10, 2, 1	10, 2, 1
Phase	-	-	-	-	-
Excitation current (A peak-to-peak)	4.1	4.5	4.5	4.5	5.0
Cable length (m)	17.1	17.1	17.1	17.1	17.1
Analog board with additional RF noise-filtering circuit, increased gain	No	No	No	√	√
24-V exciter module	No	No	No	No	√
HDPE Pipe	√	√	√	√	√
Outside diameter (cm)	107	107	107	107	107
Inside diameter (cm)	95.7	95.7	95.7	95.7	95.7
Water level					

Since the standard FS1001A PIT-tag transceiver was observed at, or a little beyond, its limit of optimal efficiency, only two factors can be changed to improve the proposed PIT-tag system performance: 1) the excited volume must be reduced, or 2) the electromagnetic field strength must be increased.

The PIT-tag detection volume can be reduced by reducing the outside diameter and wall thickness of the pipe. A custom fiberglass pipe could be constructed that matches the inside diameter of the existing pipe (89.5 cm) but has a thinner wall thickness. If this were done, then the result of the first two series of tests would be applicable and the prospects for project success would be high.

A second option that may increase the reading efficiency of the system is to use transceivers that the manufacturer developed for small stream application. These transceivers became available after the 2 October test series and incorporated a number of changes over the transceiver used in all tests up to this point.

3.3 Transceiver Configuration

The final test series was conducted on 10 October 2001. The objective was to determine relative tag-reading efficiency using three configurations of the FS1001A transceiver. All tests were conducted using a mock-up of a 112-cm-diameter pipe. The three transceiver configurations are shown in Table 3; reading range data for each transceiver configuration is summarized below.

	Total reading range (cm)	Tag detection (%)
Configuration A	78	~5
	66	50
	64	75
	51	95
	*46	100
Configuration B	84	~5
	76	50
	69	75
	*56	100
Configuration C	86	~5
	71	50
	69	75
	*56	100

* coil center

When the current was set to greater than 5.0 A peak-to-peak, the RF noise increased. At 5.4 A peak-to-peak, RF noise was ~24%. A point was found at 6.1 A peak-to-peak where the RF noise decreased to12-13% (higher RF noise to either side of the adjustment) but reading range was not improved.

It appears that when the FS1001A transceiver is equipped with the improved analog board, an acceptable reading range can be obtained with a 112-cm-diameter antenna. The 56-cm total reading range (28 cm either side of the antenna's center) showed a 100% reading efficiency for tags at ideal orientation along the axis of the antenna. This finding suggests that the system should also read tags at less than ideal aspect, although at lower detection rates.

One of the problems associated with a large antenna is its correspondingly large reading volume, which results in an increased probability of tag collisions. If fish-passage velocity is assumed to be 3 m/sec, then a tag traveling along the axis of the antenna at ideal orientation should be detected 5-6 times within the 56-cm area of highest measured tag-reading rate. A fish passing along the edge of the pipe should be read at least 2-3 times, since the width of the antenna is 23 cm. These estimated numbers of detections per fish are conservative, since only the dimensions with 100% tag detection rates were included. Various environmental conditions can cause electronic RF noise which can reduce tag-reading efficiency. Testing of the system after final installation will be required before a reliable estimate of tag-reading efficiency can be calculated.

It should be noted that after the October tests were complete, a series of discussions took place with the COE and other agencies regarding the pipe dimensions and the possible effects of pipe size on project success and fish health. As a result of these discussions, the COE located a manufacturer of fiberglass pipe who could fabricate pipe to the same dimensions as the steel pipe it will replace. This change will result in little if any water turbulence in the area where the two types of pipe are mated, and will thus eliminate the concern regarding fish behavioral changes that could affect tag reading or cause stress to fish.

The smaller diameter pipe to be used on the project closely approximates that used in our July-August and September test series. This means that the test data gathered are directly applicable, and that the probability of detecting tags should be very high. Furthermore, the use of the smaller diameter pipe reduces the likelihood that any serious problems will be encountered during installation of the system at McNary Dam. This does not imply that the installation need not be undertaken in a complete and careful manner. The only implication is that the basic system, as described above, should perform satisfactorily if the listed precautions and techniques are employed.

Conclusions

The October tests showed that the standard FS1001A transceiver could be used with a 112-cm-diameter antenna but with reduced tag-reading distance from that achieved with the 97-cm-diameter antenna. Using a transceiver equipped with an improved analog board increased the reading range to that achieved for the 97-cm-diameter pipe. Higher and lower exciter current settings were tested; higher current (4.8 A peak-to-peak max) had no effect, lower current slightly reduced tag readability. A reduced reading range was observed when the number of wire wraps making up a coil was reduced to 12.

NMFS discussed with the COE the results obtained with the 122-cm antenna and our concerns regarding possible fish behavior modification if pipes with dissimilar inside diameters were used on the project. As a result of these discussions, the COE will have a fiberglass pipe fabricated that has the same inside dimension as the existing steel pipe and with an outside diameter that is near that tested in July-August and September test series.

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