Evaluation of Antenna Designs for a Spillway PIT-Tag Detection System at Bonneville Dam: Abridged Report

Roger Anderson[1] and Sandra L. Downing[2]

[1]Destron Fearing Corporation, Digital Angel Corporation
490 Villaume Ave
South St. Paul, Minnesota 55075-2445

[2]Fish Ecology Division, Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112-2097

Technical report prepared 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 35800

August 2009

Introduction

In order to improve survival of salmonids migrating through the federally operated hydroelectric dams within the Columbia River Basin, the fish managers have changed how water is managed at these facilities. In the 1990s, large numbers of juvenile salmonids bypassed the hydroelectric dams by being directed through the collection and monitoring facilities at the dams. Currently, the practice is to bypass more fish via the dam spillways. The result is that significantly less data are being collected from the migrants that are tagged with passive integrated transponder (PIT) tags because the collection and monitoring facilities have PIT-tag interrogation equipment, but the spillways do not. Consequently, models used 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, we need to develop systems that will interrogate tagged fish in spillways.

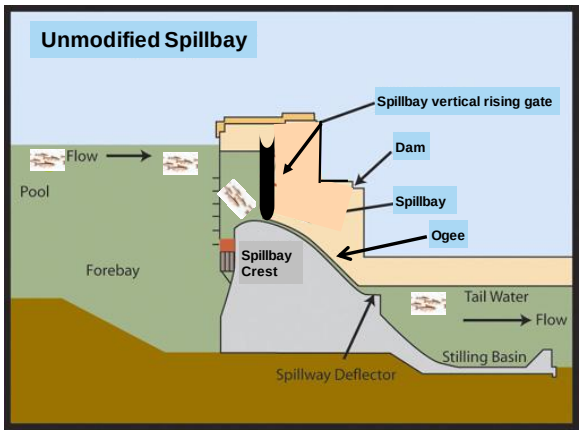


Figure 1. Photo of spillway at Bonneville Dam (top) and diagram showing the layout for one of its unmodified spillbays.

With the purpose of addressing the above fish data needs, The Fish Ecology Division of the Northwest Fisheries Science Center (National Marine Fisheries Service, NOAA) started a project in 2006 to investigate the development of a PIT-tag detection system to interrogate fish passing via spillways. The highest priority was the spillway at Bonneville Dam where each of the 18 spillbays is equipped with a vertical rising control gate (Figure 1). The goal was to develop a PIT-tag system for an unmodified individual spillbay. The second priority was to develop a

IT-tag system for spillbays equipped with RSWs (removable spillway weirs) or TSWs (temporary spillway weirs) (Figure 2).

In May 2008, NOAA Fisheries issued a contract to Destron Fearing for developing a PIT-tag detection system for spillways. The main task in the contract was to investigate development of a detection system for an unmodified spillbay at Bonneville Dam. For this task, Destron Fearing used the spillbay repair pit at Bonneville Dam, with the spare spillbay gate as a test facility. In this facility, they tested different antenna configurations, shielding materials and configurations, potential tag modifications, and transceiver settings.

Between July and December 2008, nearly 30 antenna configurations were tested to evaluate the effects of metal proximity and to determine the optimal antenna shielding arrangement for the spillway PIT-tag system. Basically, three different antenna designs that could be attached directly to a spillbay gate were evaluated:

1) A hugging design, wherein antennas that lay directly under the tailrace side of the spillbay gate (Figures 3A and 3B).
2) A vertical design (Figure 3C).
3) An intermediate angled design, where the antenna hung at a 30- or 52-degree angle (Figure 3D).

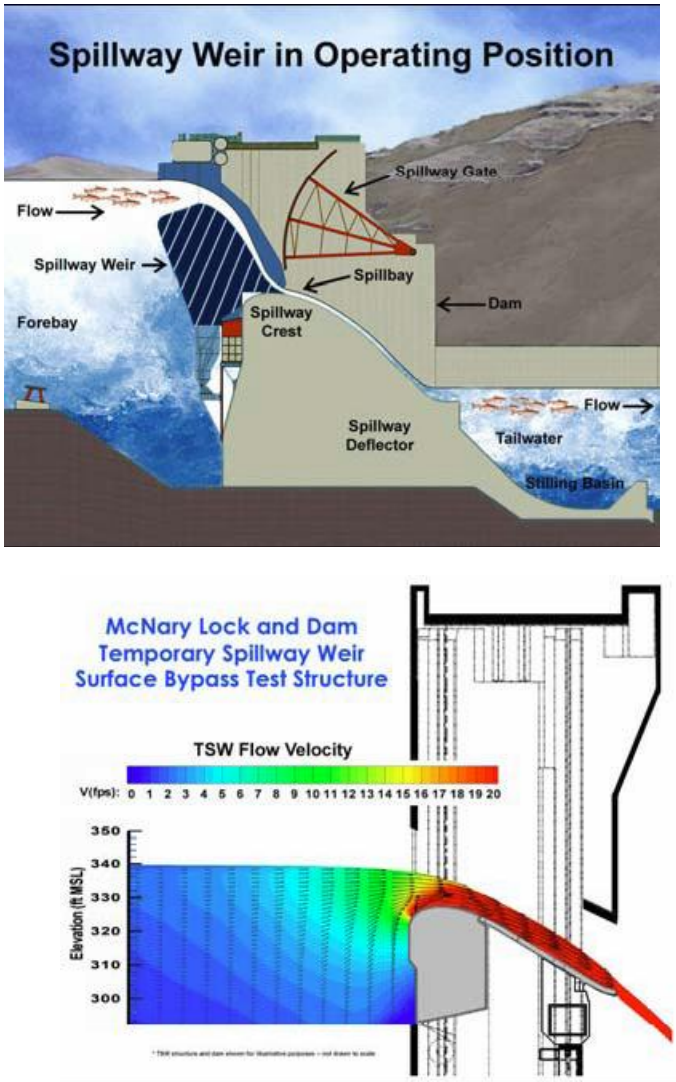


Figure 2. Drawings of reversible spillway weir (RSW) at top and temporary spillway weirs (TSW). Drawings courtesy of U.S. Army Corps of Engineers.

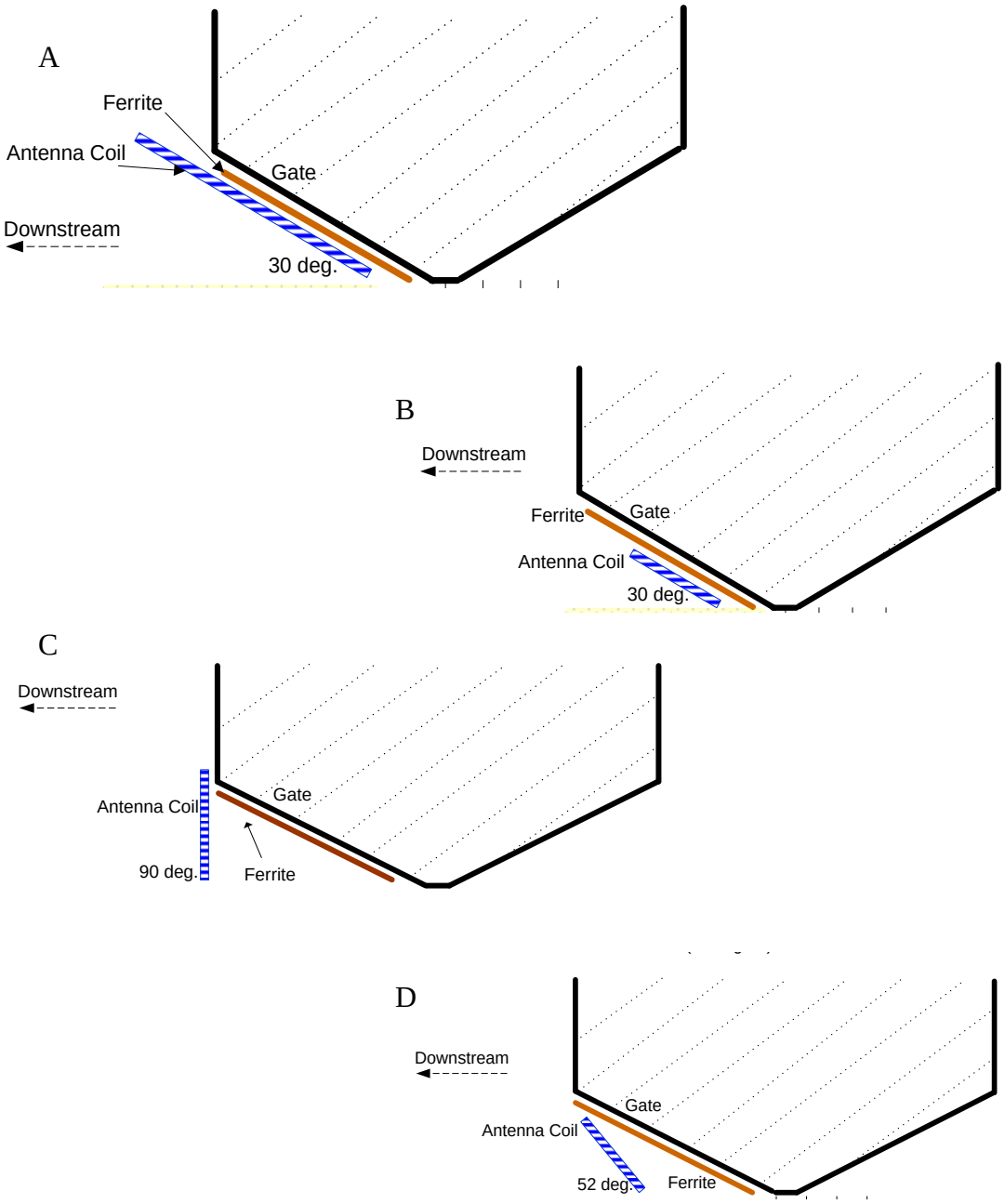


Figure 3. Side view of four antenna configurations tested in the repair bay at Bonneville Dam. Views A and B show hugging design with antennas of different sizes, view C is a vertical (90-degree) antenna, and view D is a 52-degree, intermediate angled antenna design.

Other parameters tested were antenna size (5 × 25 ft vs. 3 × 25 ft) and ferrite-tile shield configuration. Configurations tested included different space between tiles, different distance from the antenna wires, and a ferrite shield covering the entire gate bottom vs. a shield of strips covering only the metal ribs of the gate bottom.

Although the testing included both 12- and 23-mm tags, to expedite the reporting process, we include only results with 12-mm tags in this abridged report. In addition, the abridged report covers only the main results of this work. A proprietary report documenting all of the tests conducted has been submitted to NOAA Fisheries (Anderson et al. 2009)

The purpose of this report is to provide the fisheries community with a summary of the testing results, conclusions drawn, and recommendations as to the next steps needed in developing a PIT-tag detection system for the unmodified spillbays at Bonneville Dam. Toward this goal, we include a description of an alternative detection system wherein antennas could be installed into the ogee section of the spillbay rather attaching them to the spillbay gate (as was done here).

Results from R&D work

Hugging antennas

Destron Fearing tested three main types of hugging antennas. Initially, they tested a 5- by 25-ft antenna, which had performed well in preliminary tests conducted in Minnesota (Chan et al. 2007). This antenna was used to investigate ferrite-tile shielding configurations and to compare results for this antenna in an actual spillbay vs. results from preliminary work in the Minnesota test facility.

Ferrite-tile shielding—To test different ferrite-tile shield configurations, Destron tested the 5- by 25-ft antenna with no ferrite tiles and compared these results to the different shield configurations. Configurations tested were strips of ferrite tiles that covered the ribs of the spillbay gate, a full sheet of ferrite tiles (Figure 4), and a full sheet of tiles with an additional aluminum shield. These measurements were then repeated with the antenna away from the gate and then in position next to (under) the gate. From these tests, Destron concluded that the ferrite-tile shield with strips that covered the ribs of the gate was as effective as a ferrite-tile shield covering the entire bottom (Table 1).

Figure 4. Photos of the two tile shielding arrangements tested. Left: strips of ferrite tiles that match the ribs under the spillbay gate; right: full sheet of ferrite tiles.

Table 1. Measurements of current (in amps) needed to detect a 12-mm tag 33 inches below the lower end of hugging antenna with each shield design for an antenna both next to and away from the spillbay gate.

	Current (A) needed to detect a 12-mm tag 33" below the lower antenna end	
Shielding design with hugging antenna	Away from spillbay gate	Next to spillbay gate
No ferrite tiles	7.04	11.00
Strips of ferrite tile	6.56	9.12
Full sheet of ferrite tiles	6.40	8.85
Full sheet of ferrite tiles and aluminum shield	7.56	9.30

Results presented in Table 1 show that the least amount of current was needed for the antenna to read 12-mm tags using the full wall of ferrite tiles. However, the amount of current needed for the full wall of tiles was not significantly different from the amount needed for strips of tiles (Table 1). These results were promising because they suggest fewer tiles may be needed, and therefore it might be possible to design a circular (doughnut shaped) antenna housing, which would allow water to drain out through the middle.

Destron Fearing was reported that the 5 by 25-ft antenna performed as predicted based on what was learned in Minnesota during initial testing in 2007 (Chan et al. 2007). After the first round of testing in the repair bay, NOAA Fisheries was concerned that the 5-ft wide antenna would extended too far beyond the spillbay gate (Figure 5). This extension was of particular concern on the outer edge of the gate, where we know water will be cascading down from above as it spills around the spill gate. NOAA Fisheries then requested that Destron Fearing test two designs of 3- by 25-ft hugging antennas: one that was two-dimensional and a second that would be contoured to follow the curve of the spillbay gate.

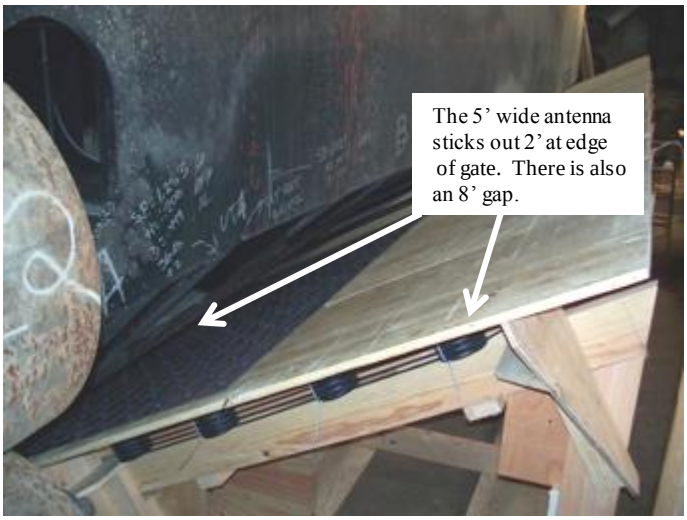
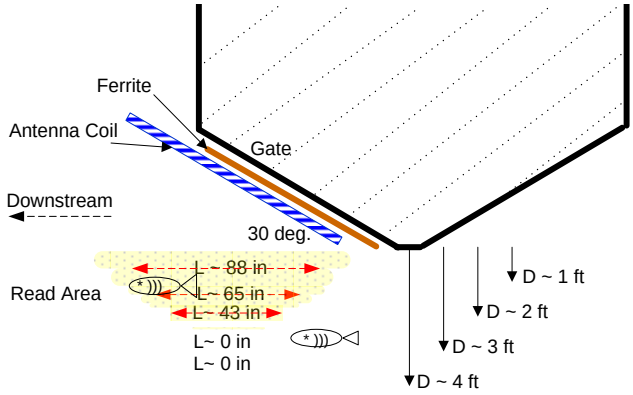


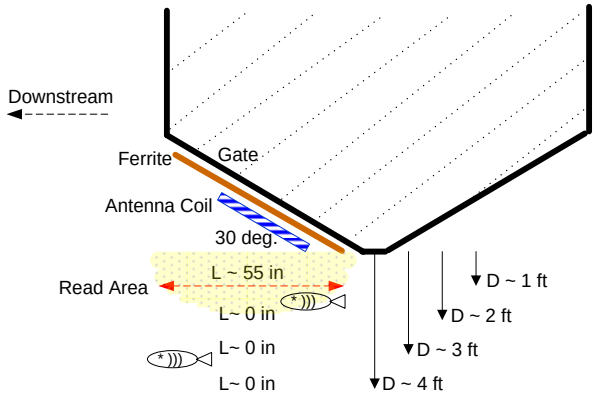
Figure 5. Photo shows the 5-ft-wide antenna at the edge of the gate. It shows how far out it extends and the gap.

Narrower antenna tests—Destron Fearing agreed to would test a 3- by 25-ft antenna that was narrow enough to fit under the spillbay gate; however, they cautioned that the narrow antenna would be unable to detect a 12-mm PIT tag with a 5-ft spillbay gate opening. Read-area patterns were derived for the area directly under each antenna and not at the opening of the gate. This is because that is where the electromagnetic field is generated. It is important to realize that the ogee drops approximately one foot from the gate opening to the outer edge of spillbay gate. Therefore, if the gate is open 1 ft, then the read area under the antenna must reach a depth of approximately 2 ft to cover the entire water column where tagged fish might be passing.

The 3-ft wide hugging antenna definitely did not detect as well as the 5-ft wide antenna had (Figure 6). Results showed that the 3-ft wide antenna would produce a tag-reading area that would be effective only if the gate were open 1 ft. By comparison, the 5-ft wide antenna could detct fish with the gate open 2.5-ft. These tests were run with the shield composed of stripes of ferrite-tiles.



Gate open at a distance D (ft)	Horizontal activation distance L (in)	# of telegrams broadcasted for a regular tag
1	88	3.9
2	65	2.9
2 ½	43	1.9
3	0	0



Gate open at a distance D (ft)	Horizontal activation distance L (in)	# of telegrams broadcasted for a regular tag
1	55	2.4
2	0	0
3	0	0
4	0	0

Figure 6. Tag-reading ranges (yellow dotted area) for the 5-ft wide antenna (top) and 3-ft wide hugging antennas. Tables below the diagram show the effective gate openings of each antenna.

Next, a contoured antenna was tested. This antenna was difficult to construct because the spillway gate surface changes in multiple directions over its 25-ft span. The contoured antenna definitely reduced the gap between the gate and the antenna at the outer edge (Figures 5 and 7).

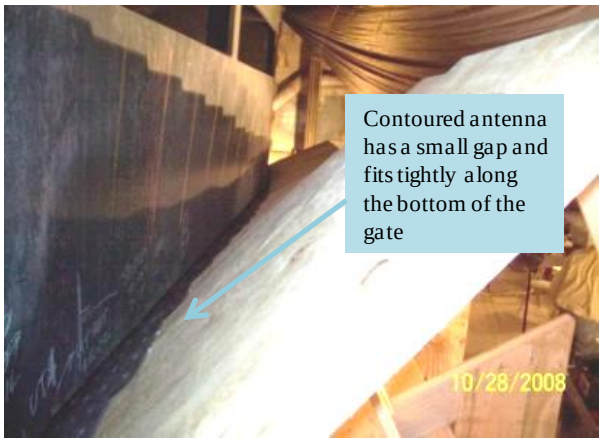


Figure 7. Photo of contoured antenna showing smaller gap at the spillbay gate edge, as well its tight fit along the bottom of the spillbay gate.

The contoured antenna induced a larger loading effect because more surface area of the antenna was in contact with metal in the spillbay gate. Consequently, the read area was reduced slightly near the center of the gate and significantly toward the outer edge of the gate. Overall, nearly one ampere more was required for the contoured antenna than for the hugging antenna to activate a 12-mm tag located 28 inches below the gate end (Table 2). Thus the contoured design would be effective at detecting fish only if the gate were open no more than 1 foot.

Table 2. Amps required to detect 12 mm tag from tests comparing the contoured and two-dimensional 3- by 25-ft antennas.

3 × 25 ft antenna	Trial number	L_{100KHz}	Q_{100KHz}	Current (A) needed to detect a 12 mm tag 28" below the lower antenna end – next to gate
Contoured	19	381 uH	216	11.80
Hugging	20	381 uH	202	11.00

Since both 3-ft wide antenna designs performed significantly worse than the 5-ft wide antenna, the 5-ft wide hugging antenna design is recommended. To address the issue of water on the overhanging portion of the antenna, Scott Bettin (Project Manager at BPA) and others suggested that Destron use a sloping cap over the antenna to protect it from cascading water. The Corps may recommend alternative housing designs if the fisheries community decides to proceed with this design.

Vertical and intermediate angled antenna designs

During construction of the contoured antenna, the Destron Fearing lead engineer experimented with performance of a vertical antenna. Using the flat, two-dimensional, 3- by 25-ft antenna, he hung the antenna vertically from the spillbay gate. He then measured read-area with the antenna it hung vertically and again with the antenna tilted inward (Figure 8).

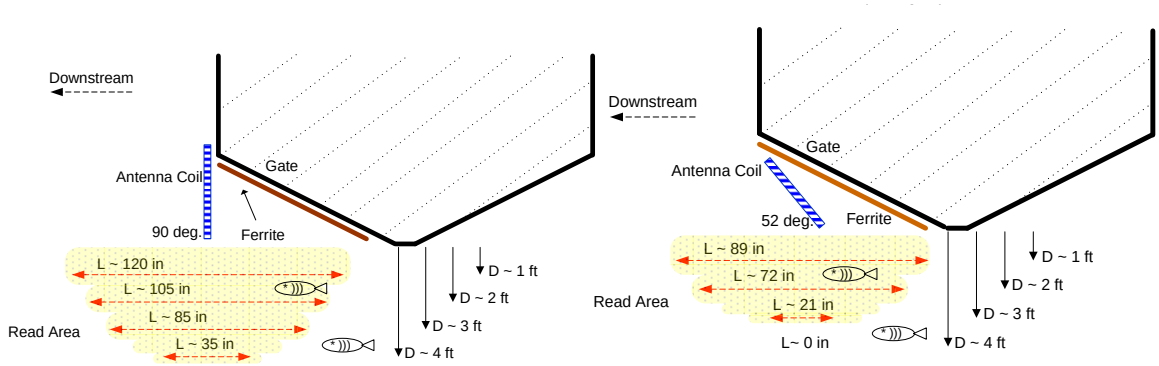
Figure 8. Photos of the hanging vertical (left) and 52-degree intermediate angled antennas.

Because the initial measurements of the vertical configuration looked promising, Destron Fearing conducted a series of tests to investigate the vertical and 52-degree angled antenna design. For the first set of these tests, a full ferrite-tile shield was attached along the bottom of the spillbay gate (Figure 9). The vertical antenna was hung against the front of the spillbay gate, and tag reading measurements were taken. Measurements were also taken with the antenna at 30- and 52-degree intermediate angles. The vertical antenna configuration (90°) had significantly longer read distances than either the 30- or 52-degree angle configuration (Table 3).

Table 3. Maximum vertical read distances for the different antenna designs. At each maximum vertical distance, the horizontal read distances were measured.

Antenna design (3- × 25-ft)	Vertical read distance (ft)	Horizontal read distance (ft)
Vertical (90°)	4	2.92
Intermediate angle (52°)	3	1.75
Intermediate angle (30°)	2	0.0
Hugging	1	4.6

Destron Fearing then determined the read area for the vertical and 52-degree intermediate angled antennas. The vertical design produced the largest read area of any antenna design tested (Figure 9; see Figures 5 and 6 for the hugging design). Testing of the vertical design antenna showed that this antenna could detect a tagged fish with a spillbay gate open to ~4 ft (remember that at this location below the antenna, the ogee is 1 ft lower than the gate opening). This 4-ft gate opening could not be tested empirically because the gate in the repair bay is fixed with a 3-ft opening. The 52-degree intermediate angled antenna would be able to detect fish with a gate opening of 2.5-3 ft, which is better than the 1 ft range of the hugging 3-ft wide antenna and about the same as the 5-ft wide hugging antenna.



Gate open at a distance D (ft)	Horizontal activation distance L (in)	# of telegrams broadcasted for a regular tag
1	120	5.3
2	105	4.6
3	85	3.7
4	35	1.5

Gate open at a distance D (ft)	Horizontal activation distance L (in)	# of telegrams broadcasted for a regular tag
1	89	3.9
2	72	3.2
3	21	0.9
4	0	0

Figure 9. Tag-reading range (dotted area) for the vertical (90-degree) and angled (52-degree) antenna configurations.

Destron Fearing also tested whether it would be possible to change the shape of the ferrite tiles. For example, using the 52-degree intermediate angled antenna, they tested the difference between activating the 12-mm tag with strips of ferrite tile vs. the full sheet of tiles (Table 4). They determined that there was difference in tag activation distance of only 1-ft between the two types of shielding.

For future development, Destron-Fearing proposed testing the effectiveness of a small ferrite shield attached to the downstream face of the gate using the vertical antenna design (Figure 10). They also propose testing of a 5- by 25-ft vertical antenna design.

Table 4. Results from test to determine the effect of fully-covered or strips of ferrite-tile shields on the distance measure for activating the 12-mm tag.

Shield configuration (52° intermediate angled antenna)	Distance of activation with 12-mm tag (inches)
Fully covered ferrite tile shield	29
Strips of ferrite tile shield	28

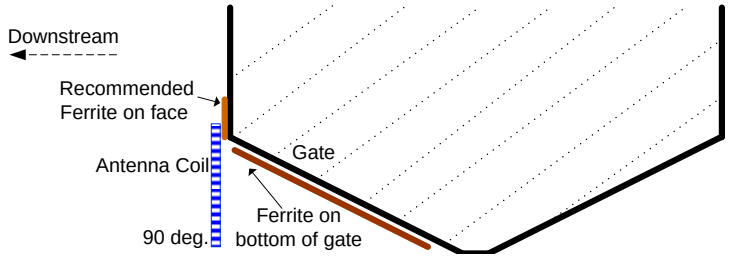


Figure 10. Locations of antenna shield recommended for face of a spillbay gate (shown with a vertical antenna). Also shown is the location of the shield that was tested.

Conclusions

Destron Fearing was able to demonstrate successful reading of the 12-mm tag at around 4 ft below the bottom of the antenna using the vertical (90°) configuration with part of the antenna placed against the upper portion of the metal spillbay gate (Figure 4C). Since the read-area patterns are located directly under the antenna, not at the opening of the gate, this 4-ft distance means fish would be detected when the gate was open 3 ft. We could not test the full read range of the vertical antenna configuration because the gate in the repair bay is fixed with a 3-ft opening.

Based on trial data, the best design is the 3- by 25-ft antenna configured vertically (90° perpendicular to the ogee floor). The worst design was the hugging antenna; the two intermediate-angle antennas yielded in-between reading results. If the hugging antenna design is preferred, then the 5-ft wide antenna performed significantly better than the 3-ft wide one.

The shielding tests suggest that using strips of ferrite tiles was as effective as using a full sheet of ferrite tiles that covered the entire bottom. This is important because water does need to pass through the bottom of the gate. In the future, Destron Fearing wants to test a shield that just covers the face of the gate with the vertical antenna design.

Recommendations

Antenna Design

Recommended antenna design—Based on the tests conducted, Destron Fearing recommends the vertical antenna configuration. We further recommend testing of a shield attached to the face of the spillway gate instead of the bottom of the gate (Figure 15). We believe this will be effective based on tests demonstrating that a partial ferrite shield was as effective as a full ferrite shield. This would greatly simplify the overall shielding design and allow water to flow freely down through the spillbay gate.

We also recommend testing a larger, 5- by 25-ft vertical gate to determine whether it would permit detection of fish when the gate was opened the maximum of 5 ft.
After these tests, if the fisheries community chooses to go forward with this design, the mechanical attachment and design of the antenna assembly would be evaluated.

Antenna housing—We recommend the use of pipe-style housing for the antenna housing enclosures (Figure 11). This would permit water to mostly go through the antenna instead of hitting a solid structure.

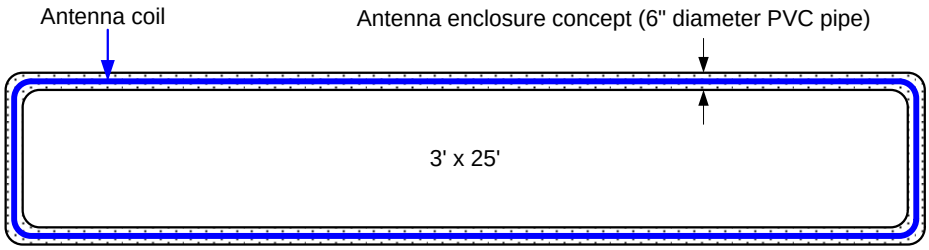


Figure 11. Diagram of a pipe style antenna housing.

Alternative antenna location—An alternative option to attaching an antenna to the spillbay gate would be to install an antenna system in the ogee area (Figures 1 and 12). In this location, the water depth is shallower (1-3 ft, depending on gate opening), and water velocity is faster (65-90 ft/s) than at the gate location, but the antennas would be more protected.

The ogee area is the location that has been accepted for the PIT-tag system scheduled to be installed for the TSW spillbay at Ice Harbor Dam. The ogee location is attractive for several reasons:

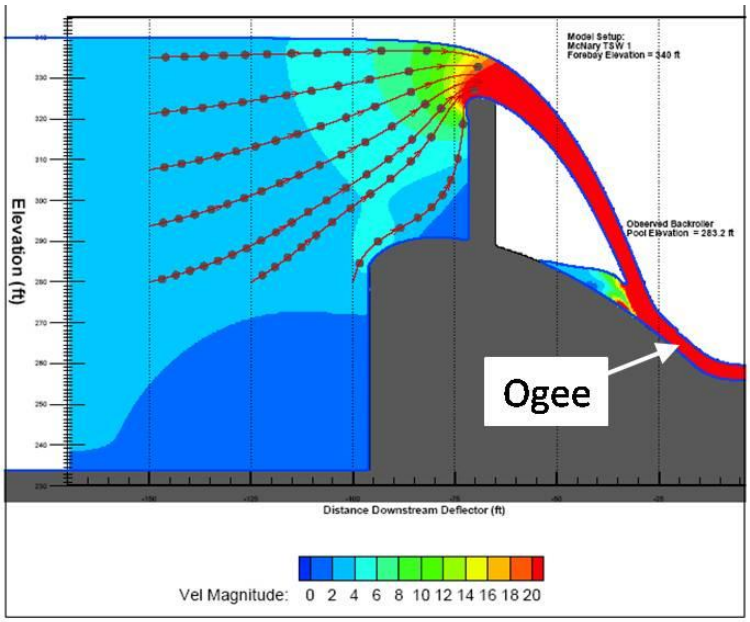


Figure 12. Diagram from USACE showing water velocities for a TSW system and general location and water conditions in site where ogee system would be located. USACE estimates water velocities of ~65-90 ft/s.

- A system in the ogee area would not affect hydraulics;
- There are no debris issues in the ogee area;

- The ogee area design would permit multiple antennas to be installed across the length of the ogee, and therefore reduce the impact of tag collisions;
- If the area where antennas were to be installed was large enough, then multiple antenna arrays could be installed, which is important from an operations and management perspective;
- Water depth is lower in the ogee area than near the gate opening;
- The ogee system could potentially worked for all styles of spillbays

We have developed two potential antenna designs for an ogee location (Figure 13):

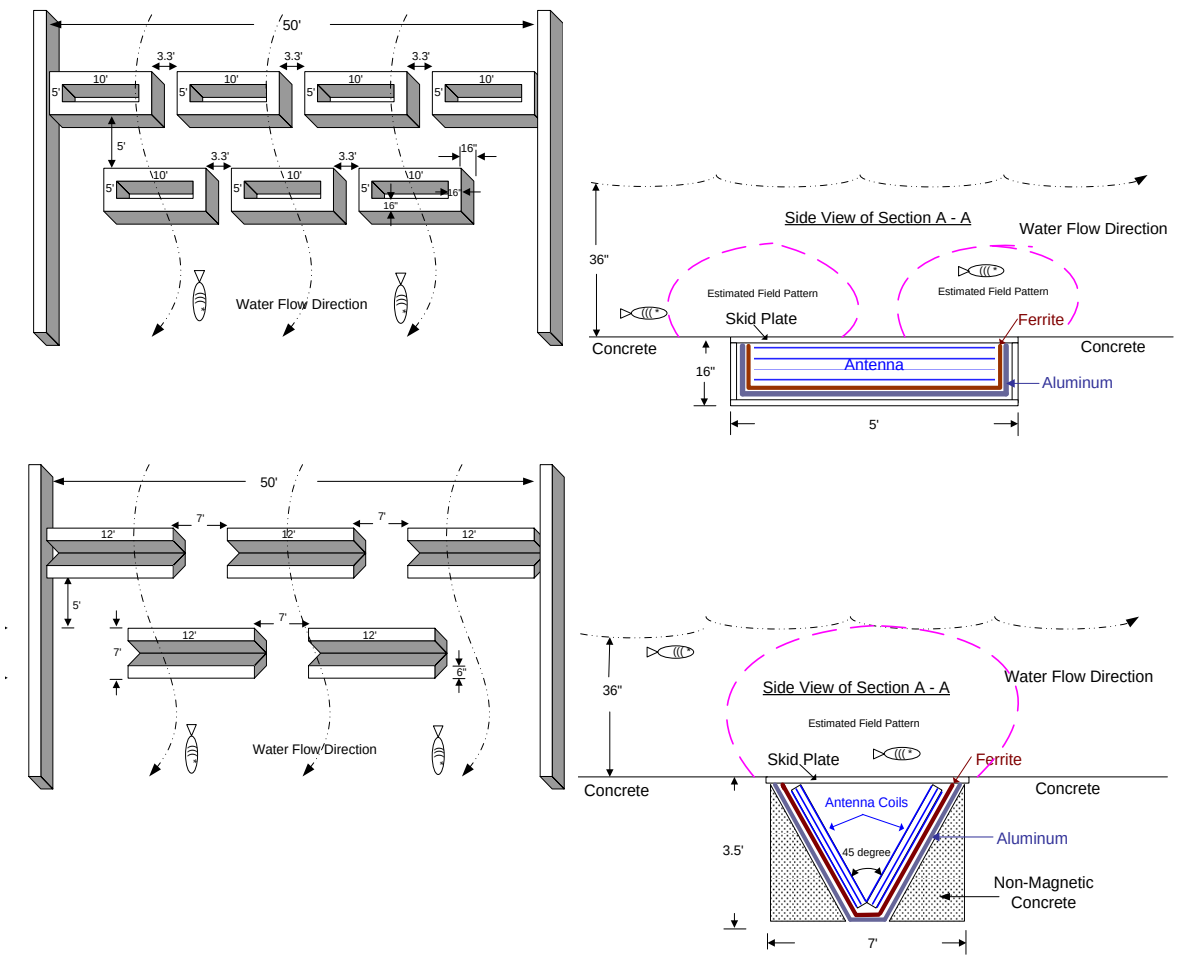


Figure 13. Plan and side views of potential PIT-tag detection systems that could be installed into the ogee areas of the spillbays. At left are plan views of a flat-plate (top) and V-shaped antenna configuration. Side views of each configuration are shown at left.

The flat-plate antenna system would require seven antennas while the V-shaped antenna system would require five antennas. The V-shaped antennas should be able to detect the 12.5-mm PIT tags in the full 36-inch water depth, while the flat-plate antennas would probably only detect all tags when water depth was 20 inches deep. Starting in August 2009, Destron Fearing will test antennas with these and additional shapes. One concern with any of the spillbay antenna designs is the impact of tag collisions. If an ogee-based PIT-tag system can be designed using smaller (and more) antennas (Figure 13), the impact of tag collisions could be reduced.

Tag modifications

Another way to improve the efficiency of a PIT-tag detection system for the spillway would be to shorten the tag telegram time by 50% to make the detection system more effective (Table 5). For a standard tag telegram (ISO FDX-B protocol), the total time required to broadcast one complete tag telegram is 30.5 ms; thus the total number of telegrams that can be broadcast per second is 32.8.

The advantage of a shorter tag-telegram time is that, as the read area narrows with distance from the antenna, faster reading time will enlarge the effective read area. Typically to be effective, we need a minimum of 1.0 telegram, but prefer an area that will cover 1.5 telegrams.

We also recommend that the faster tag be designed to utilize less activation current, which would provide longer read range.

Table 5. The table demonstrates how a tag with faster telegram timing would double the number of telegrams that could potentially be detected, which would enlarge the effective read area produced by an antenna. The example given is for the 3-ft wide vertical antenna.

	Vertical 3 × 25 ft antenna		
Gate opening distance (ft)	Horizontal activation distance (in)	Telegrams broadcast (n)	
		Regular tag	Fast tag
1	120	5.3	10.6
2	105	4.6	9.3
3	85	3.7	7.5
4	35	1.5	3.1

Transceiver modifications

Testing was done with the existing BCC transceiver. We recommend modifying this transceiver system with a receiver circuitry that has higher sensitivity and that can read the new faster tag. New and existing less expensive transceivers, such as the ACN and DF2020, may be utilized to drive spillway and ogee type antennas.

Next steps for this project

1. Meet with FFDRWG to discuss pros and cons of the different antenna designs and location.
2. Meet with Corps to discuss pros and cons in terms of attaching antenna housings.
3. Demonstrate the performance of one or all of the designs using a series of tests defined by NOAA.

References

Roger Anderson, Alex Artyukhov, Vincent Chan, Roger Clark, Keith Kuhnly, Marc LeMay, Zeke Mejia, Yuri Smirnov. 2009. Progress Report on Phase II of Developing a Spillway PIT-tag detection system. Confidential report submitted to NOAA Fisheries.

Vincent Chan, Alex Artyukhov, Yuri Smirnov, Roger Anderson, Roger Clark, Keith Kuhnly and Zeke Mejia. 2007. Spillway PIT-Tag Detection System Condensed Final Report. Confidential report submitted to NOAA Fisheries.