A STUDY TO DETERMINE THE BIOLOGICAL FEASIBILITY OF A NEW FISH-TAGGING SYSTEM, PART II:

Development of an Extended-range PIT-tag Interrogation System for Adult Salmon

ANNUAL REPORT 1994-1996

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EXECUTIVE SUMMARY

This report covers work performed by the National Marine Fisheries Service (NMFS) between 1994 and 1996 to develop a passive integrated transponder tag (PIT-tag) system to interrogate volitionally migrating adult salmon. A phased approach was adopted to realize this goal. The plan was to address basic electronic, mechanical, and hydraulic engineering questions in Phase I. In addition, several biological studies were initiated to provide basic information needed to design interrogation systems that minimize the potential risks to migrating adult salmon. The results obtained in Phase I will provide direction for the Phase II work involving the actual design and development of the extended-range PIT-tag interrogation system. Finally, Phase III will evaluate the biological responses of fish to the final design(s).

Phase I of the project encompassed six work elements, four of which our are covered in this report. These four elements were:

1) Evaluation of alternative electronic equipment to improve operational performance of the existing 400-kHz PIT-tag system.

2) Evaluation of 125- to 135-kHz PIT tags to determine if they had improved sufficiently to satisfy the longer read distance needed for an extended-range interrogation system.

3) Evaluation of how fish-ladder interrogation units could be designed to satisfy engineering and biological concerns.

4) Evaluation of fish behavior at three potential interrogation locations in a fish ladder using video cameras.

NMFS contracted RF Engineering to evaluate alternative electronic equipment to improve the operational performance of the existing 400-kHz PIT-tag system. They recommended using Helmholtz coils and more efficient C-Class signal amplifiers. NMFS concluded that even with the suggested modifications, the overall limitations of the 400-kHz system, especially its allowable radio-frequency (RF) emissions level, make it less likely to work for interrogating adult salmon than interrogating systems operating at lower frequencies (125- to 135 kHz).

A requirements document was prepared that described basic attributes and performance criteria of PIT tags needed for monitoring adult salmon within the Columbia River Basin (CRB). The evaluation of 125-to 135-kHz tags yielded some that met the performance criteria.

Simultaneous to NMFS' tag evaluation, a technical committee was formed within the International Standards Organization (ISO) to develop ISO standards for small implantable transponders and related transceivers. One of the tags that had satisfied the CRB performance criteria also fundamentally met the proposed ISO standard according to the manufacturer. This factor, in addition to the inherent advantages that an established standard normally brings such as product compatibility, competitive pricing, and multiple product sources led NMFS and others to recommend that the ISO standard be considered for the CRB. NMFS also recommended that the initial focus of the ISO-based system for the CRB should be on the development of an interrogation system for juvenile salmon. The knowledge gained from this development could then be applied to development of an adult system.

NMFS contracted the engineering firm Summit Technology to design several types of PIT-tag interrogation-coil housings that could be installed in select areas of fish ladders and specifically in the Fisheries Research Engineering Laboratory fish ladder at Bonneville Dam. This laboratory could then be used in the future to test the coil housings and the other components of an extended-range system. The engineers had to take biological, structural, hydraulic, and operation and maintenance concerns into account in their designs.

NMFS contracted the U.S. Army Corps of Engineers (COE) to use video cameras to monitor fish behavior in the Washington fish ladder at Bonneville Dam. Video equipment was deployed in an underwater orifice, in an overflow weir, and in a vertical slot. An informational baseline was created on behavior, swimming velocity, and orientation of fish passing through these three potential interrogation points. This information will permit a before and after comparison if PIT-tag interrogation equipment is installed in the ladder.

Data analysis of fish velocity showed that mean upstream velocity varied with species, within species, and by location. The mean upstream velocity ranged from 0.56 to 2.67 m/sec. Most fish swam directly through the three potential interrogation points and thus exposure to electromagnetic fields will likely be of short duration (seconds to minutes) for migrating adult salmon. The baseline information obtained will also aid in the design and development of extended-range PIT-tag interrogation systems to monitor adult salmon in CRB fish ladders.

CONTENTS

INTRODUCTION

In the late 1980s, fisheries agencies recommended that the Bonneville Power Administration (BPA) install passive integrated transponder-tag (PIT-tag) interrogation systems at dams to interrogate migrating adult salmon. Restricted fish passage points (i.e., submerged orifices, overflow weirs, and vertical slots) within fish ladders were identified as possible PIT-tag interrogation points. In 1990, National Marine Fisheries Service (NMFS), under contract to BPA, initiated a project to investigate the technical and biological requirements of these larger interrogation systems. The initial tests were conducted using 400-kHz transceivers with 91-cm by 61-cm rectangular coils (tag excitation/receive antennas)(Prentice et al. 1994). We believed a PIT-tag interrogation system of this size could monitor most areas of interest. However, results showed that radio frequency (RF) emissions from the equipment exceeded acceptable limits established by the Federal Communications Commission (FCC) and ambient electrical noise significantly interfered with tag detection.

Based on current technology, we concluded that the practical reading range of the 400-kHz interrogation system was approximately 30 cm for a pass-through (tunnel-type interrogation system). We further concluded that a 30-cm system was too restrictive for use with adult salmon passing volitionally through PIT-tag interrogation systems.

During 1992 and 1993, NMFS sought proposals from PIT-tag manufacturers to develop an extended-range interrogation system that could be installed in adult fish-ladders located within the Columbia River Basin (CRB). The systems proposed were all based on 125- to 135-kHz operating frequencies. Unfortunately, based on technical or cost considerations, none of the proposals was satisfactory. However, this time period did mark the beginning of some significant improvements to the 125- to 135-kHz PIT tags as manufacturers started to incorporate new technologies (e.g., improved computer chips and tag coils). Therefore, after consultation with BPA in 1994, NMFS started a phased approach toward developing an extended-range PIT-tag system using in-house and outside resources.

The plan was to address basic electronic, mechanical, and hydraulic engineering questions in Phase I. In addition, several biological studies were initiated to provide basic information needed to design interrogation systems that minimize potential risks to migrating adult salmon. For example long exposures to electromagnetic fields might be a risk and thus, one study examined how long fish were exposed in fish ladders and another whether long exposures were harmful. The results obtained in Phase I will provide direction for the Phase II work that will address the actual design and development of the extended range PIT-tag interrogation system. Phase III will evaluate the biological responses of fish to the final design(s).

Six work elements of Phase I were completed during 1994-1996:

1) Evaluation of alternative electronic equipment to improve operational performance of the existing 400-kHz PIT-tag system.
2) Evaluation of 125- to 135-kHz PIT tags to determine if they had improved sufficiently to satisfy the longer read distance needed for an extended-range interrogation system.
3) Evaluation of how fish-ladder interrogation units could be designed to satisfy engineering and biological concerns.
4) Evaluation of fish behavior at three potential interrogation locations in a fish ladder using video cameras.
5) Evaluation of potential effects of electromagnetic fields (EMF) on maturing fish.
6) Evaluation of different approaches to improve tag retention in maturing salmon.

A discussion of work elements 1-4 is presented in this report, while work elements 5 and 6 will be included in a separate report that covers the biological studies completed during 1994-1996.

EVALUATION OF ALTERNATIVE ELECTRONIC EQUIPMENT TO IMPROVE THE PERFORMANCE OF THE 400-kHz SYSTEM

In 1994, NMFS contracted RF Engineering to determine if alternative exciter and receive antenna designs were available that could overcome several performance limitations (e.g., limited read range, sensitivity to water-level changes by the antenna system) of the 400-kHz PIT-tag system used in the CRB. At the time of the contract, NMFS was reviewing whether the performance of the 400-kHz system could be improved sufficiently to meet the need for an interrogation system for volitionally migrating adult salmon.

Contract activities included:

1) measuring the excitation sensitivity of Destron-Fearing PIT tags.
2) measuring the H-field (the part of electromagnetic field that energizes the tag) of a standard 400-kHz antenna.
3) designing a Helmholtz coil (antenna) for a 30.5-cm-diameter pipe.
4) constructing and evaluating ferrite-based excite and receive antennas.
5) measuring the effects of PIT-tag orientation on reading range.

A 30.5-cm diameter pipe was used simply as a point of reference, as larger-diameter antennas are required for interrogation of volitionally migrating adult salmon. A full description of these activities is presented in Appendix A.

Below is a summary of the findings by RF Engineering:

1) The minimum excitation level for 400-kHz tags was approximately two times greater in air than in water.
2) Under the test conditions employed by RF Engineering, the standard 400-kHz antenna system produced a lower H-field than expected.
3) With both coils unshielded, a Helmholtz coil produced a near-field H-field which was double that produced by the standard 400-kHz antenna with similar far-field emissions. The Helmholtz coil also showed resistance to detuning from water agitation and nearby metal objects.
4) It was suggested that further improvements in system performance could be obtained by using more efficient C-Class signal amplifiers with the PIT-tag interrogation system.

5) Shielding the Helmholtz antenna significantly decreased its E-field emissions compared to standard 400-kHz antennas. Therefore, RF Engineering suggested several shield designs to further improve shielding efficiency.

6) Tag orientation caused fewer detection problems when using a Helmholtz antenna.

7) The addition of ferrites to the exciter antenna decreased H-field attenuation.

8) It was suggested that gains in tag reading performance could be expected by separating the excitation and receive antennas.

These preliminary results suggest that it would be possible to make some improvement to the operating performance of the 400-kHz PIT-tag system. However, the extent of a possible improvement is unknown at this time without further laboratory and field tests because most of RF Engineering's tests were conducted under conditions quite dissimilar to those in the field or at the dams. Furthermore, NMFS believes that even with the suggested modifications implemented, the overall limitations of the 400-kHz system, especially its allowable RF emissions level, make it less likely to successfully detect adult salmon than interrogation systems operating at lower frequencies (125- to 135 kHz). Finally, several of the suggestions offered (e.g., C-Class signal amplifier and Helmholtz antenna) in this report could potentially be applied to these other systems.

EVALUATION OF 125-135 kHz PIT TAGS

In January 1994, a requirements document was prepared by NMFS and other fisheries agencies that described basic attributes and performance criteria for PIT tags needed for monitoring adult salmon within the CRB. This document and a request for technical information was sent to all known manufacturers of 125-135-kHz PIT tags. These lower frequency tags require less energy to activate than 400-kHz tags and consequently have longer read ranges. The resulting technical information was evaluated by NMFS. Those manufacturers having PIT-tag technology that appeared to meet the performance criteria were asked to participate in a product evaluation. The PIT tags were evaluated on the basis of physical dimensions, read distance, read speed, code error rate, and level of electromagnetic energy required for activation. Initial product evaluations by NMFS personnel and an outside contractor were completed in June 1994. Details of the tag analyses are not presented here because they contain proprietary information. However, several of the tags satisfied the performance criteria.

During the period the tags were being evaluated, a committee from the International Standard Organization (ISO) was formed to develop standards for small implantable transponders (PIT tags) and related transceivers (tag energizing and receive equipment). An ISO standard (described in published documents ISO 11784 and ISO 11785) was ultimately approved by the committee in February 1995 and signed in 1996.

One of the tags that satisfied the performance criteria fundamentally met the proposed ISO standard according to the manufacturer. This factor, in addition to the advantages that a standard normally brings to a product (e.g., product compatibility, competitive pricing, multiple product sources) led NMFS and others to recommend that the ISO standard be considered for the CRB. In addition, several manufacturers indicated in 1994 that ISO-based portable transceivers and 12-mm tags suitable for fisheries applications would be available prior to or soon after the signing of the ISO standard.

Because of the interest and support shown by the international PIT-tag user community toward the formation of an ISO standard as well as the advantages that an ISO-based system could offer over the existing 400-kHz system used in the CRB, NMFS recommended to BPA that long-term efforts be directed toward the development of an extended-range PIT-tag system using a ISO-based system. This recommendation was made even though some non-ISO systems could also have been adapted for fisheries applications. Furthermore, it was jointly concluded by NMFS and BPA that if the ISO-based system were to be incorporated into the CRB, that efforts should first be focused on the evaluation and implementation of a juvenile system before undertaking the development of an adult system. We believed that much of the knowledge gained in development of a juvenile system would be applicable to the development of an adult system and that this course of action would result in reduced system development time and cost. In addition, this approach would provide time for manufacturers to develop new products that could perform under the more demanding conditions needed for interrogation of migrating adult salmon.

ENGINEERING DESIGNS FOR INSTALLING PIT-TAG INTERROGATION EQUIPMENT IN FISH LADDERS

The design of a PIT-tag interrogation unit for use in adult fish ladders requires that a number of factors be considered: hydraulics, structural integrity of the ladder, ladder maintenance, fish passage, expected PIT-tag interrogation equipment performance, equipment accessibility, and overall system operation and maintenance. In addition, any design would need to be evaluated before it could be installed into CRB fish ladders. A contract was issued in 1995 to a structural engineering firm, Summit Technology, to:

1) Design several extended-range PIT-tag interrogation coil housings that could be used in fish ladders.

2) Examine a facility for the purpose of installing and evaluating such antenna housings.

Summit Technology personnel visited Bonneville Dam and then designed coil housings that could be installed and evaluated in the Fisheries Engineering Research Laboratory (FERL), otherwise known as the Washington Shore Experimental Fish Ladder. The firm's report describing the design of the coil housings and necessary modifications to the FERL fish ladder is presented in Appendix B.

Below is a summary of the findings by Summit Technology:

1) Coil housings could be manufactured that take into account the biological, structural, hydraulic, and operation and maintenance concerns.

2) Necessary modifications to the FERL could be made without jeopardizing the ladder's integrity.

3) Coil housings similar in design to those described could be deployed in the vertical slots, underwater orifices, and overfall weirs at other CRB fish ladders.

VIDEO DOCUMENTATION OF FISH BEHAVIOR IN FISH LADDERS

Any PIT-tag interrogation system installed in fish ladders must be designed to minimize its impact on fish passage and ladder operation. To obtain needed design information, NMFS contracted the Portland District of the U.S. Army Corps of Engineers (COE) to use video cameras to monitor fish behavior in the Washington Shore Fish Ladder at Bonneville Dam. Video equipment was deployed in an underwater orifice, an overflow weir, and a vertical slot. The contract's objectives were as follows:

1) Document and establish fish behavior in a fish ladder before the installation of PIT-tag interrogation equipment.
2) Document orientation of fish (i.e., tag orientation) while passing through the three potential interrogation points;
3) Determine fish passage time (velocity) past the potential interrogation points; and
4) Estimate the potential time fish could be exposed to the electromagnetic field generated by the PIT-tag system.

The behavior of 728 salmon and other species (e.g., lamprey, shad) was recorded. Pacific lamprey (*Lampetra tridentata*) were of interest because their attaching behavior could potentially result in long exposure to the interrogation system's electromagnetic field. Furthermore, if lamprey were PIT tagged and they attached to the interrogation system, this would preclude other PIT-tagged fish from being read because two tags cannot be read simultaneously in the same electromagnetic field. The COE report for this study is presented in Appendix C. Below is a summary of the findings by the COE:

1) The video documentation successfully established a baseline that could be used to compare fish behavior before and after any fish ladder modifications.
2) Review of the video tapes showed that fish or tag orientation was satisfactory for PIT-tag interrogation at the three locations (underwater orifice, overflow weir, and vertical slot).
3) Results also showed that mean fish velocity varied greatly by species, for fish within species, and by location. Mean upstream fish velocities ranged from 56 cm to 267 cm/sec.
4) Finally, the data showed that exposure time to the electromagnetic field would be short for most fish (seconds to minutes). However, lamprey were seen attached to the sides of underwater, orifice overflow, and vertical slots. This potential problem would need to be addressed in the design of PIT-tag interrogation systems deployed in fish ladders where PIT-tagged lamprey were present.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

1) NMFS decided on a phased approach to develop an extended-range PIT-tag interrogation system using in-house and outside resources. In Phase I, basic electronic, mechanical, and hydraulic engineering questions were addressed. In addition, several biological studies were initiated to provide basic information for the design of interrogation systems that minimize potential risks to migrating adult salmon. Results from Phase I will provide direction for the Phase II work involving the actual design and development of an extended-range PIT-tag interrogation system. Phase III will then evaluate the biological responses of fish to this system.

2) The evaluation of alternative electronic equipment for the 400-kHz system resulted in several recommendations to improve operational performance (e.g., Helmholtz coil designs, C-class signal amplifiers). However, NMFS believes that even with the suggested modifications implemented, systems operating at lower frequencies (125-135 kHz) would be more likely to detect adult salmon. Some of the suggestions offered in the review could potentially be applied to other PIT-tag interrogation systems.

3) A requirements document was prepared that described basic attributes and performance criteria for PIT tags needed for monitoring adult salmon within the CRB. Evaluations of 125- to 135-kHz tags yielded some that met these performance criteria.

4) Simultaneous to NMFS' tag evaluation, a technical committee was formed to develop standards for small implantable transponders (PIT tags) and related transceivers. It appears the established standard will yield a system that will, in part, work for fisheries applications. Because of the advantages of a standardized product, NMFS recommended that the FDX-B ISO tag be considered for use in the CRB.

5) NMFS also recommended that the initial focus of the ISO-based system for the CRB should be on the development of an interrogation system for juvenile salmon. The knowledge gained from this effort could then be applied to development of an adult system.

6) NMFS issued a contract to the structural engineering firm Summit Technology to design PIT-tag coil housings that could be deployed and then evaluated in the FERL fish ladder at Bonneville Dam. The designed coil housings were for the underwater orifices, overfall weirs, and vertical slots of a fish ladder. The designs took into account biological, structural, hydraulic, and operation and maintenance concerns. Summit Technology's report indicated that the necessary modifications to the FERL could be made without jeopardizing ladder integrity. In addition, similar coil housings could be deployed in other CRB fish ladders.

7) NMFS contracted COE to use underwater video equipment to record fish behavior within the Washington shore fish ladder at Bonneville Dam. Video equipment was deployed in an underwater orifice, an overflow weir, and a vertical slot.

8) Fish velocity and orientation while passing through areas of interest were video recorded. Data analysis showed that mean swimming velocity varied with species, within species, and by location. Mean fish velocity ranged from 0.56 m to 2.67 m/sec. Neither fish orientation nor distance from potential antenna locations (as they passed through the various structures of interest) appeared to be outside the limits of possible PIT-tag detection. Further, the data indicated that exposure time to the PIT-tag interrogation system's electromagnetic field would be minimal for most species (lamprey being the potential exception).

Baseline fish behavior information obtained using video will be used in the design of PIT-tag interrogation systems for adult fish and for evaluating potential biological impact of systems deployed in the fish ladder.

ACKNOWLEDGMENTS

Support for this research came from the region's electrical rate payers through the Bonneville Power Administration.

APPENDIX A

Final Report: 400 kHz PIT Tag Antenna System

RF Engineering

FINAL REPORT

400 kHz PIT TAG Antenna System

March 15, 1995

WORK PERFORMED FOR:
NATIONAL MARINE FISHERIES SERVICE
MANCHESTER, WA 98353

REF: 43ABNF402429 I

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TABLE OF CONTENTS

WORK DESCRIPTION
(per PURCHASE ORDER)

Evaluate RF Engineering proprietary antenna and receive system in reference to the Destron/Fearing 400 kHz Pit Tag System used in the Columbia. River basin.

This Study was funded in two parts:

1. Initial Study: Statement of Work is attached as Appendix E

2. Extension: Statement of Work is attached as Appendix E1

OVERVIEW

This study was undertaken to determine if alternative exciter and receiver antenna designs were available which could improve the performance of the existing 400 kHz Pit tag antenna systems.

The present 400 kHz Pit tag tunnel (2U:3 by 61 cm) has several limitations:

1. Unit is difficult to tune and detunes easily due to:
    1. Amount of water in tunnel
    2. Water turbulence
    3. Metal in surrounding structure (i.e. concrete re-bar)

2. Maximum read range is 20.3 cm (8") and is heavily dependent on Pit tag orientation.
    (Read range limitation appears to be due to the receive sensitivity rather than the excite power)

3. Receiver is sensitive to external interference.

4. Tunnel must be made of non-conducting material.

5. Exciter loop must enclose the tunnel and cannot be used in a passby mode.

6. The driver circuitry requires high voltages and high current.

7. Exciter has high emission levels and is difficult to shield due to detuning effect.

An ideal Pit tag system would resolve the limitations discussed in the prior paragraph and would also satisfy the requirements listed below. These additional issues are not addressed in this study. They are presented here in order to provide a more complete list of the fisheries service requirements.

1. Able to read in both juvenile and adult measurement environments.

2. Able to read multiple fish (either by increasing range or read speed)

3. Able to read in less than 40 ms and a minimum speed of 20 fps.

4. Able to detect and read fish heart beat.

5. Able to detect presence and size of non tagged fish.

6. Meets regulatory and safety requirements
   - FCC emissions
   - ANSI Safety
   - Biologically Safe for animals
     (considerations are: Frequency, CW vs Pulse, Field Strength, etc)

7. Readers (including portable units) would be compatible with all Pit Tags, including future ISO Standards.

This study was undertaken to determine if new antenna/exciter designs would overcome same of the limitations of the present 400 kHz Pit tag tunnel. Two different antenna systems were studied and a review of other potential antennas was performed. These different systems and their primary benefits are listed below:

1. Ferrite based Exciter and Receive Antennas.
   1. Good passby candidate
   2. Can develop orthogonal H fields
   3. Can be used in conductive channels.

2. Helmholtz Coil Exciter and Ferrite Receive Antenna.
   1. Very uniform H field.
   2. Active length can be made any length (increases minimum read velocity).
   3. Insensitive to detuning
   4. Low exciter voltage.

3. Reviewed additional antenna types for possible exciter use.
(Review only - no analysis or measurements were performed)

1. Compact Loop antenna with integral ground plane.

2. Microstrip type launchers (with ground plane).

3. Solenoid structures.
Generally sate performance and magnetic field geometry as Helmholtz coil.

NOTE: Items 3.1 and 3.2 have potential for use in passby applications and for orthogonal H field excitation.

ACTIVITIES

1. MEASURED EXCITATION SENSITIVITY OF DESTRON/FEARING PIT TAG

DISCUSSION
Measurements were made of the minimum H field required to excite a Destron/Fearing Pit Tag over the frequency range 200 to 800 kHz. Results are for a single tag and are measured in water and air.

RESULTS are given in Appendix B.

COMMENTS
Selected results for a tag in water are:

13 Amp-T/meter at 400 kHz
8 Amp-T/meter at 600 and 800 kHz.

Minimum excitation levels in air are approximately two times greater than in water.

2. MEASURED H FIELD OF THE NMFS PROVIDED 400 KHZ TUNNEL

RESULTS are given in Appendix A.

1. Nominal H field: 30 Amp-Turns/meter.
2. H field ranges from 18 to 20 Amps-T/meter over the central plane of the antenna aperture.

COMMENTS
The above H field results are considered to be low compared to a properly tuned exciter coil and driver (per NMFS staff). Discussions during the October 27, 1994 meeting at RF Engineering suggested that desired excitation levels were 40 Amp-T/meter minimum. Whit Patton suggested that 80 Amp-T/meter would be a better value.

Proposed 1991 ANSI H field (and E field} safety guidelines are given in Appendix F1. They suggest an acceptable H field limit for human exposure at 400 kHz to be 40 Amp-T/meter.

3. DESIGNED HELMHOLTZ COIL EXCITER (for 12" PVC Pipe)

DISCUSSION

Magnetic coils (such as the Helmholtz and solenoid coils) provide a uniform H field over the entire interior region of the coil. This is in contrast with small antennas (such as ferrite coils) whose H field falls off inversely with the cube of range.

The physical operation at a magnetic coil requires that the magnetic flux flow inside and outside the coil. The need for this external flux path suggests that these coils are best used with non-conductive pipes and tunnels.

External metal shields can be used to reduce radiated emissions; however, they must be carefully designed in order to avoid detuning the coil.

ANTENNA/DRTVER DESCRIPTION

Antenna (Helmholtz Coil):

Two coils (2 turns each) spaced 6" apart.
Mounted an outside of 12" plastic bucket (simulated PVC pipe)

Antenna matching network:

Coils are connected in parallel and are driven from a capacitive step up network.
Antenna circuit is tuned to 400 kHz.
Coil voltages range from 60 to 200 volts peak to peak.

Exciter Driver #1:

Low impedance Class B Power Amplifier operating at 400 kHz.
Power supply: ± 20 Volts at 200 mA.
Amplifier schematic is given in Appendix C1.

Exciter Driver #2:

Goal was to provide a times 2 increase in H field compared to Driver #l and to determine if a balanced differential antenna drive would result in lower radiated emissions.

Design consisted of:

1. Redesigning the antenna matching network for a balanced input.
2. Use an input transformer and two Class B amplifiers to provide the required balanced output voltage.
3. Amplifier schematic is given in Appendix C3.

RESULTS:
Exciter #1: Measured H field measurements are given in Appendix C. H field ranges from 14 to 20; Amp-T/meter at the central plane of the antenna.
(See discussion on desired H field on page 6, section 2)

Exciter #2: See Appendix C2. H field has approximately doubled.

COMMENTS
Exciter Driver #2 was designed as a balanced amplifier in order to decrease far field emissions and to double the output drive of Exciter Driver #1. Emission measurements did not show any improvement due to this balanced drive (see section 4) and increased drive capability could be more effectively achieved by paralleling the output of the drivers using a power tranformer. Paralleling the driver outputs provides a lower source impedance and simpler antenna matching network.

Exciter #1 and #2 were designed as class B amplifier stages in order to provide:

1. Good power amplifier efficiency
2. Low harmonic distortion
(in order to reduce radiated harmonics).

Emissions testing indicated very low harmonic radiation from the antenna matching networks and their associated Helmholtz coils. It is probable that Class C amplifiers may be used with this system and that amplifier operating efficiencies up to 50% may be achieved. This would allow several benefits such as lower drive voltages or larger coil diameters (up to 48").

The Helmholtz coil circuits showed good resistance to detuning due to water agitation or nearby metal objects.

4. MEASURED RADIATED E FIELD EMISSIONS

DISCUSSION

Measurements were made of the radiated emissions from the 400 kHz Pit tag tunnel and the Helmholtz coil at ranges of 30 and 100 feet using both E field and H field probes. The E field probes were 17" ground mounted monopoles, the H field probes were 8.25" diameter loops.

The E field measurements were erratic in signal level both inside and outside the building, results were location sensitive and did not behave well with range. H field measurements were in general far more consistent both inside and outside and behaved well with range. In addition H field measurements and calculations were in good agreement for the 12" Helmholtz coil (see Appendix G).

H field measurements were converted to E field equivalents before graphing in order to compare them with FCC emissions limits.

> NOTE: Measuring H field and then calculating E field from the measured H field value is a common practice in this frequency range and is an approved FCC technique.

RESULTS

Radiated E field emissions for the Pit Tag tunnel and the 12" Helmholtz coil with Driver #1 are given in Appendix G. Emissions are shown for the following Exciter configurations:

1. NOAA System - 400 kHz pit tag tunnel.
   (H field inside coil: 18 to 20 Amp-T/meter)

2. RFE System w/NO Shield - unshielded Helmholtz coil.
   (H field inside coil: 14 to 20 Amp-T/meter)

3. RFE System w/Open Shield - shielded Helmholtz coil.
   (Copper shield, 1 open turn, 14" wide, 8" separation from coil. Same H field as item 2 above)

4. RFE System w/Shorted Shield - shielded Helmholtz coil.
   (Copper shield, 1 shorted turn, 14" wide, 8" separation from coil. Same H field as item 2 above)

5. RFE System Calculated - calculated E field for unshielded Helmholtz coil.

No E field harmonics of the 400 kHz were observed from the RFE Exciters.

COMMENTS

The 400 kHz Pit tag tunnel and the unshielded Helmholtz coil generated similar internal H fields, but E field emissions from the tunnel were approximately 2 times greater than for the Helmholtz coil. This difference could be due to the larger size of the tunnel (197 sq in) compared to the coil (113 sq in) and is not deemed significant.

The calculated and measured values of E field emissions for the Helmholtz coil were consistent at the measured ranges of 30 and 100 feet. Extending this correlation to 300 meters allows a projection of E field emissions at the FCC specified measurement range for both the Pit tag tunnel and the various Helmholtz coil configurations.

The projected values of E field emissions at 300 meters are shown in Appendix G. The Pit Tag tunnel E field is projected to be 38 uV/meter versus an FCC limit of 6 uV/meter (see Appendix F). The various Helmholtz coil configurations give E field values ranging from 12 uV/meter to .23 uV/meter thus showing the benefits associated with shielding the coil.

HELMHOLTZ COIL SHIELDS

It is expected that an electrostatic shield or a shorted copper shield will be used to reduce far field emissions to FCC specified levels.

The shorted turn provides magnetic and electric shielding and reduces interactions with ferrous structural materials. It may require more space than an electrostatic shield.

5. BUILT FERRITE BASED EXCITER ANTENNAS

DISCUSSION

Ferrite based exciter antennas are expected to have the following benefits:

1. Exciter antennas can be placed at right angles to each other. This reduces the sensitivity to Pit tag orientation.
2. Ferrite antenna are not sensitive to detuninq or nearby non-ferrous conductive materials. They can be located inside a non-ferrous conductive tunnel.
3. May be used in passby mode.
4. Require low excitation voltage.

The primary concern with this type of exciter structure is that unlike the Helmholtz Coil or solenoid structures it does not produce a uniform H field. The H field of the ferrite antennas falls off as range cubed and to achieve acceptable H field levels in the center of the 400 kHz Pit tag tunnel requires very high H field levels at the tunnel walls.

RESULTS

Experiment #1

Measures the H field in a large tank of water far the following conditions: (see Appendix D1)

1. Single ferrite, 2.5" long
2. Single ferrite, 7.5" long
3. Two ferrites, spaced 8" apart
4. Single ferrite inside a conductive ring.

Results are given in Appendix D

Experiment #2

Measurements in the H field in a large tank of water for the following conditions: (see Appendix D3)

1. Single ferrite, 2.5" long
2. Two ferrites, one above the other
3. Two ferrites, spaced 8" apart
4. Four ferrites, two by two.

Results are given in Appendix D2

COMMENTS

A review of the data in Appendix D and D2 shows that the H field for a single ferrite exciter decreases roughly by a factor of 100:1 over a range of 0" to 4". This can be decreased to a factor of 40:1 when two ferrites are spaced 8" apart. The effect of the conductive Brass ring is seen to increase the overall H field by a factor of 2, but does not change the attenuation versus range profile.

It is expected that 4 ferrites in an 8" diameter round pipe would improve the attenuation ratio to 20:1. This would give an H field profile ranging from 20 Amp-T/meter at the center of the pipe to 400 Amp-T/meter at the pipe edge. This might be an effective arrangement inside non-ferrous metal pipe, particularly if a second set of ferrites were placed at right angles to the original set in order to reduce the sensitivity to Pit tag orientation.

6. BUILT FERRITE BASED RECEIVE ANTENNAS

DISCUSSION

The Destron/Fearing Pit tag is excited at 400 kHz and responds at 40/50 kHz. It is expected that separating the transmit and receive functions will allow optimization of each antenna and in particular it should allow an improvement in the read range.

HARDWARE DESCRIPTION

Exciter - operates at 400 kHz

Receiver - operates at 40/50 kHz

Antenna: Single 40 turn Ferrite antenna.
(Two may be required in final system)

Amplifier: Low noise amplifier with two 45 kHz bandpass filters (40 to 50 kHz) and a 400 kHz notch filter.
(Schematic is shown in Appendix H1)

RESULTS

Measurement were performed by mounting a Pit tag on a small ferrite exciter: the exciter signal level was set to a level just large enough to cause the Pit tag to respond with the normal FSK response signal (40 to 50 kHz).

The receive antenna was connected to the amplifier discussed above and measurements were made of relative signal response at the output of the amplifier. Results are shown in Appendix H for relative response in water and air versus distance from the receive antenna. Results were not highly dependent on Pit tag or receive antenna orientation.

A second set of tests were run with the ferrite based receive antennas in the 12" PVC pipe using the Helmholtz coil exciter. Return signals from the Pit tag in this test could be read up to a range of 6" from the receive antenna. The use of two (or three) receiving antennas spaced around the pipe would provide an adequate receiving antenna system.

COMMENTS

The primary restriction on receiver range in the measurements discussed above was an interfering 45 kHz signal in the middle of the receiver passband. The source of the spurious 45 kHz signal was not identified, but it was a stable signal which could be measured throughout the lab area. It is likely that this spurious signal would limit the overall system dynamic range even after installation of the normal emissions shield.

The signal strength and H field orientation of the spurious 45 kHz signal was measured and was found to be very consistent over the measurement area. It is projected that a second set of receive antennas placed 12" to 18" away from the Pit tag could be used to cancel the interfering signal in the primary receiving antennas without reducing the desired Pit tag return signal.

7. MEASURED READ DISTANCE VERSUS PIT TAG ORIENTATION

DISCUSSION

The Helmholtz coil exciter and ferrite based receive antennas discussed in Sections 3 and 6 were used to measure the effect of Pit tag orientation on system read range.

The measurements were performed at three different H fie1d levels, at varying ranges and at different locations inside the 12" diameter pipe.

RESULTS are given in Appendix 1

COMMENTS

The Pit tag could be rotated 50 degrees from the optimum orientation and still be read throughout the Helmholtz coil area when the H field was 30 Amp-T/meter. The minimum read angle decreased to 40 and 35 degrees when the H field strength was reduced to 22 and 16 Amp-T/meter respectively. These minimum readings occurred towards center of the pipe.

The above results could be improved by the following means:

1. Increase the H field to 40 Amp-T/meter as discussed in Section 3 of this report
2. Adjust the geometry of the Helmholtz coil in order to generate orthogonal H fields inside the pipe.

The following are alterations which could be made to the Helmholtz coil in order to generate orthogonal H fields inside the 12" PVC pipe.

1. Increase the number of coils and place them at 30 or 45 degree angles relative to the pipe axis.
2. Place additional coils on the outside surface of the pipe, this will create an H field transverse to the major axis of the pipe.

RECOMMENDATIONS

The present 400 kHz Pit tag tunnel uses a single solenoid type coil which serves as both a tuned 400 kHz exciter coil and a tuned 40 to 50 kHz receive coil. The system has several limitations which are discussed on page 3 of this report.

This study was undertaken to determine if alternative antenna designs were available which could improve the performance of the present 400 kHz system, particularly with respect to the following applications:

1. Circular Pipes (or Rectangular tunnels)
   (non conductive channel)

2. Rectangular Tunnels (maximum 8" wide)
   (conductive channel)

3. Passby Applications
   (both conductive and non-conductive channel)

1. Circular Pipes (or Rectangular tunnels) -non conductive channel

EXCITER
The Helmholtz coil described in this report has a number of benefits for an application with a non-conductive channel. Some of those benefits are listed below:

1. Uniform H field
2. Insensitive to detuning due to water level, shielding materials, etc.
3. Coil length can be increased for higher read velocity.
4. Coil geometry can be modified for orthogonal H fields.
5. Very large openings can be excited (up to 48" diameter) due to low coil impedance.
6. Simple excites amplifiers (low voltage and easy parallel operation).

RECEIVER
The ferrite based receive antennas discussed in section 6 can be integrated into very sensitive receiver systems. The ability to separate the excite and receive antennas allows this optimization to occur.

The receive system dynamic range can be increased by the use of a second set of interference sensing antennas:

2. Rectangular Tunnels (maximum 8" wide) -conductive channel

EXCITER
The ferrite based exciter antennas discussed in section 5 can be used in 8" wide conductive channels since the tails can be operated on top of a conductive ground plane. H field in this application would vary 40:1 (i.e. 20 to 800 Amp-T/meter). This type of exciter is best used in an area with high stream flow in order to limit animal H field exposure.

Alternative antennas (i.e. loop antenna or microstrip antenna with integral ground planes, see page 5) can also be considered as excites antennas for this application.

RECEIVER
The ferrite based receive antennas discussed above can be used as receivers in a conductive channel since they can be operated with a ground plane.

3. Passby Application (Shelf, 6 ft wide by 12" high) -

EXCITER
The ferrite base excites antennas discussed in item 2 above can be used in passby applications; however, they have a maximum range of approximately 4" with an expected H field variation of 100:1. The alternative antennas discussed above and on page 5 (i.e. loop antenna with integral ground plane or microstrip antenna with ground planes) offer ranges greater than 4" with a likely range of 12" and an H field variation of 20:1.

The performance of these antenna types can be evaluated experimentally or by computer simulation (CAE). The primary challenge for this application is the 12" read height and not the 6 ft shelf width.

RECEIVER
Same as item 2 above.

POTPOURRI
The following is a list of items which have been discussed during this study. No actions or recommendations are suggested here, they are listed as a reminder only.

1 Operating the Destron/Fearing Pit Tag at 125 kHz.

2. Receiving the Pit Tag return signal as RF Sidebands (350 to 450 kHz frequency range) rather than as 40 and 50 kHz law frequency signals.

3. Plug and play packaging, software, etc.

Appendix A

H-Field Plot for NMFS 400 KHz Antenna System:

Top

-7	-10	-8
40	**28**	**36**
-12	-14	-10
22	**18**	**28**
-7	-9	-7
40	**32**	**40**

Bottom

Plane of 10 Turn Loop

Top

-8	-10	-8
36	**28**	**36**
-12	-14	-11
22	**18**	**25**
-8	-10	-8
36	**28**	**36**

Bottom

Plane of 8 Turn Loop

Top

-13	-12	-13
20	**22**	**20**
-14	-13	-14
18	**20**	**18**
-14	-13	-13
18	**20**	**20**

Bottom

Plane Between Loops

Top

-35	-34	-38
1.6	**1.8**	**1.1**
-32	-30	-32
2.2	**2.8**	**2.2**
-35	-33	-36
1.6	**2.0**	**1.4**

Bottom

12" in Front

Top

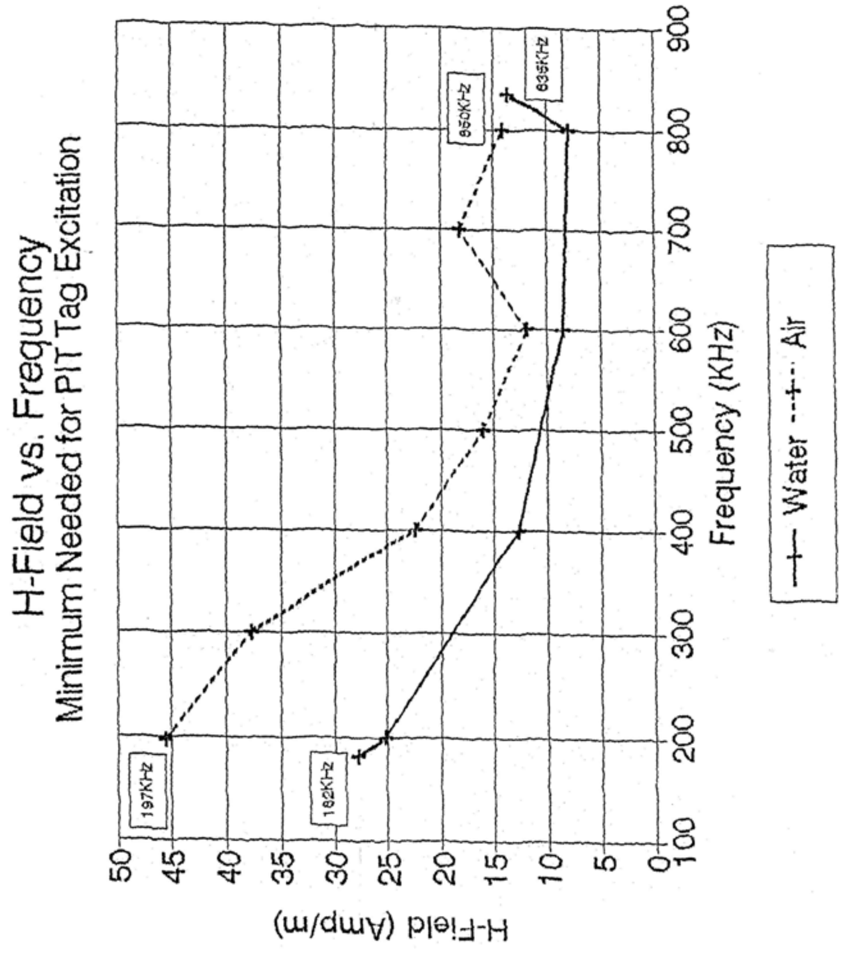
-37	-38	-38
1.3	**1.1**	**1.1**
-35	-34	-33
1.6	**1.8**	**2.0**
-38	-36	-38
1.1	**1.4**	**1.1**

Bottom

12" in Back

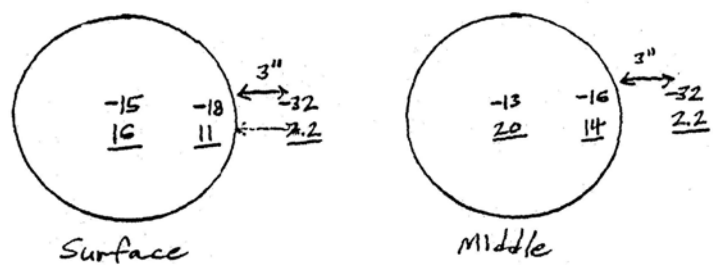
Note: Top numbers are signal level in dBm measured with Spectrum Analyzer.

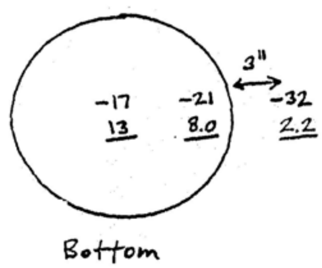
Underlined numbers are derived H-field levels in Amp/m.


H-Field vs. Frequency
Minimum Needed for PIT Tag Excitation
H-Field (Amp/m)
Frequency (KHz)
0
5
10
15
20
25
30
35
40
45
50
100
200
300
400
500
600
700
800
900
197KHz
182KHz
Water
Air

Appendix C

H-Field Plot for RFE 400 kHz Antenna System:

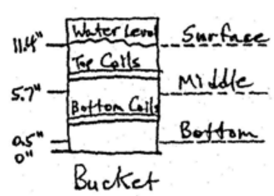




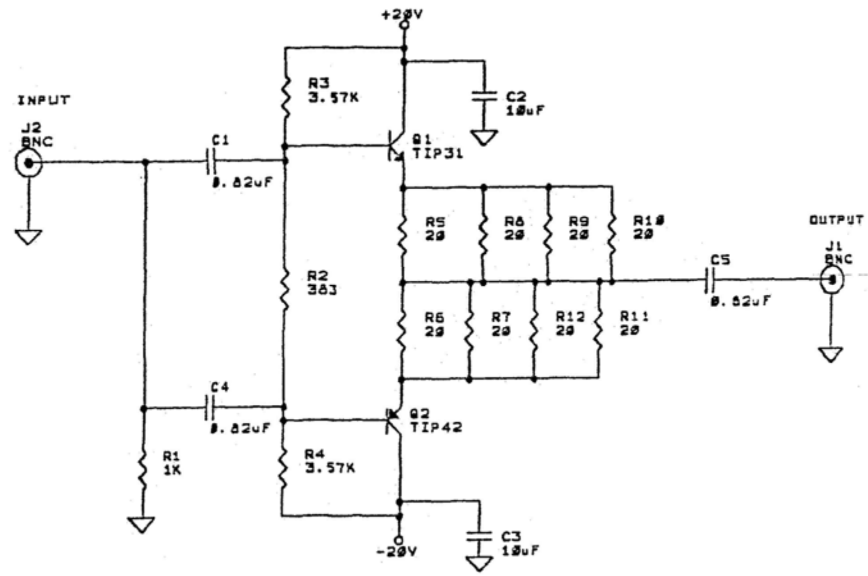
Note: Top numbers are signal level in dBm measured with Spectrum Analyzer.

Underlined numbers are derived H-field levels in Amp/m.

Profile:



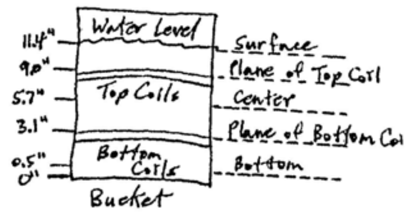
PUSH-PULL UNITY GAIN POWER AMPLIFIER

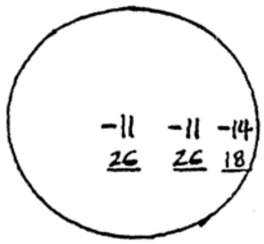


RF Engineering		
Title Exciter Power Amplifier for Fish Tag Project		
Size A	Document Number	REV 1
Date: October 27, 1994	Sheet 1 of 1	

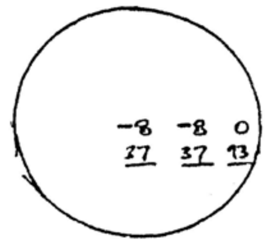
H-Field Mapping for RFE
400 KHz Antenna System:
$V_{coils} = 112\ V_{pp}$
$F_R = 386$ KHz

Profile:

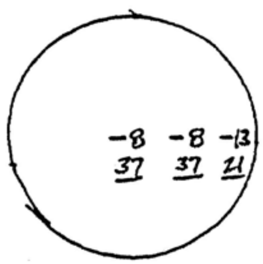




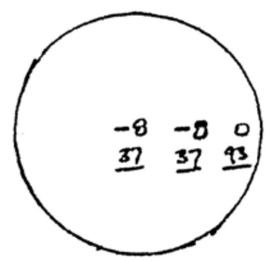
Surface



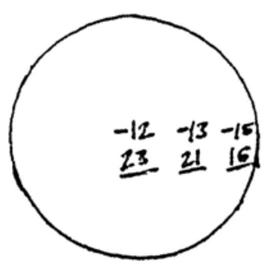
Plane of Top Coil



Center



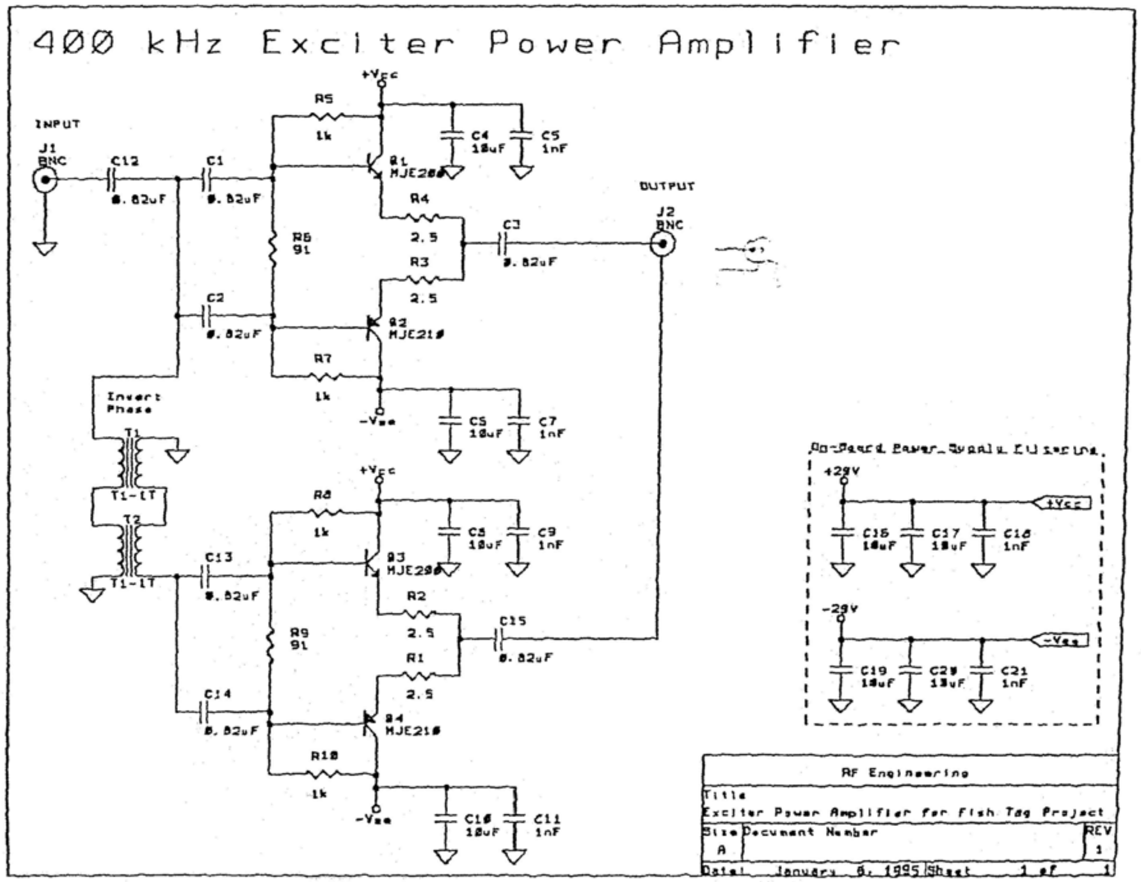
Plane of Bottom Coil

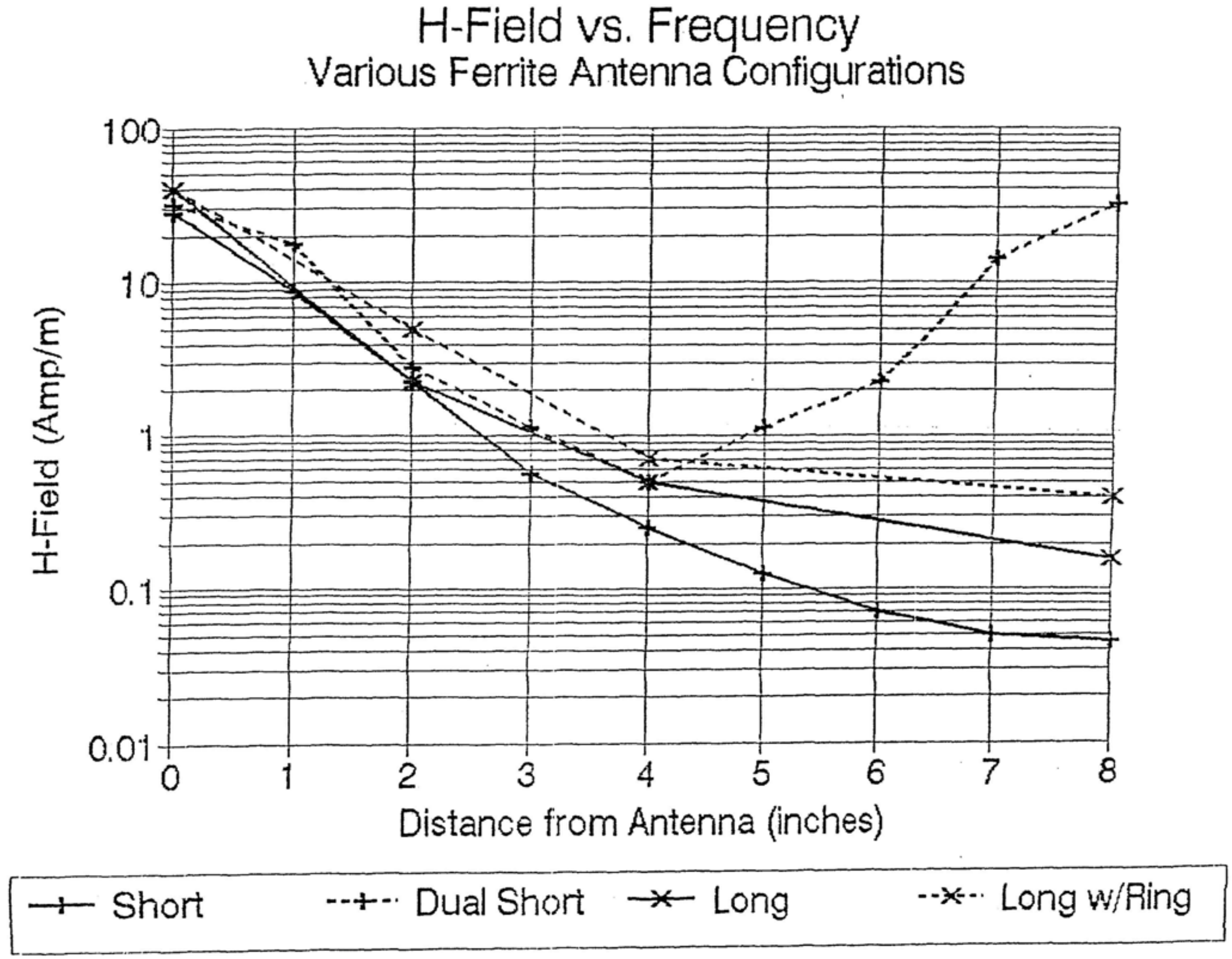


Bottom

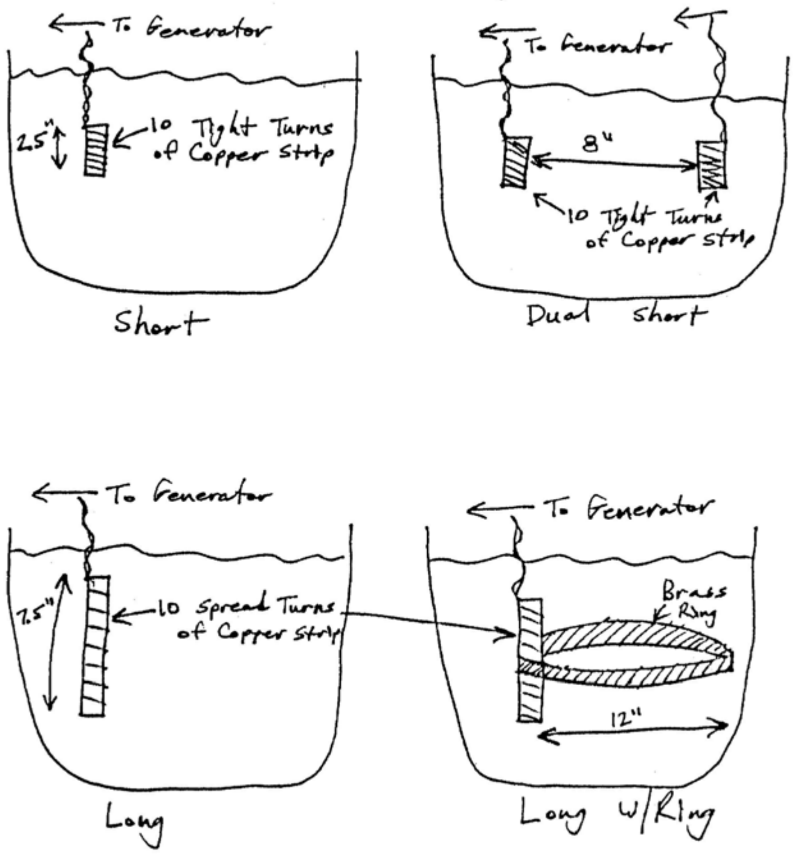
Note: Top numbers are signal level in dBm measured with Spec Analyzer.

Underlined numbers are derived H-Field levels in Amp/m


400 kHz Exciter Power Amplifier
INPUT
J1
BNC
C12
0.82uF
C1
0.82uF
C2
0.82uF
R5
1k
R6
91
R7
1k
+Vcc
-Vee
Q1
MJE200
Q2
MJE210
R4
2.5
R3
2.5
C3
0.82uF
C4
10uF
C5
1nF
C6
10uF
C7
1nF
OUTPUT
J2
BNC
Invert
Phase
T1
T1-1T
T2
T1-1T
C13
0.82uF
C14
0.82uF
R8
1k
R9
91
R10
1k
Q3
MJE200
Q4
MJE210
R2
2.5
R1
2.5
C15
0.82uF
C8
10uF
C9
1nF
C10
10uF
C11
1nF
On-Board Power Supply Filtering
+20V
-20V
+Vcc
-Vee
C16
10uF
C17
10uF
C18
1nF
C19
10uF
C20
10uF
C21
1nF
RF Engineering
Title
Exciter Power Amplifier for Fish Tag Project
Size
A
Document Number
REV
1
Date: January 6, 1995 Sheet 1 of 1


H-Field vs. Frequency
Various Ferrite Antenna Configurations
H-Field (Amp/m)
100
10
1
0.1
0.01
0
1
2
3
4
5
6
7
8
Distance from Antenna (inches)
Short
Dual Short
Long
Long w/Ring

Ferrite Antenna Configurations using Copper Strip Windings



Work Objectives and Specifications

Objective:

Determine if RF Engineering's proprietary antenna and receive design will excite a Destron/Fearing 400 kHz passive integrated transponder (PIT) tag and receive the return signal.

Work Description and Expected Products:

1) The work will be conducted with Destron/Fearing 400 kHz PIT tags. Tag excitation and receive equipment will be a combination of RF Engineering and Destron/Fearing excite and read equipment where appropriate. NMFS will Furnish all Destron/Fearing tags, exciter, and receive equipment to RF Engineering for the tests. This equipment and excess tags will be returned to NMFS in its original configuration and working condition unless specified by NMFS.

2) Read Distance:

a} Using RF Engineering's proprietary antenna design and Destron/Fearing receive equipment, determine the maximum read distance at three power levels of RF Engineering's choice when the tag is in its optimal orientation, Record both the excitation and return signal strengths under this condition.

b) Determine the maximum read distance when the tag is perpendicular, 45°, and parallel to the H field at one power level and provide an H field profile for each condition and estimated strength.

3) Determine the effect on both excitation and receive signal strength when grounded ferrous and non Ferrous metals are within 2.54 cm and 10 cm from the excitation and/or receive coil.

4) Destron\Fearing tags are reported to have a natural frequency around 900 kHz. Determine the upper frequency limit in which RF Engineering's proprietary antenna design can excite tags with performance greater than or equal to current technology.

5) Evaluate the present excitation and receive design of Destron/ Fearing excitation and receive circuitry. Provide a report detailing how this design and present equipment can be integrated into the RF Engineering proprietary antenna and reader system to enhance overall read performance of the existing PTT tag system used in the Columbia River Basin.

6) A report will be prepared that includes a methods and materials and a results and discussion section. All test results will be presented in the report.

RF Engineering
Amendment: Work objectives and specifications

Work Description and Expected Products:

1) The work will be conducted with Destron/Fearing 400 kHz PIT tags. Tag excitation and receive equipment will be a combination of RF Engineering and Destron/Fearing excite and read equipment where appropriate. NMFS will furnish all Destron/Fearing tags, exciter, and receive equipment to RF Engineering for the tests. This equipment and excess tags will be returned to NMF5 in its original configuration and working condition unless specified by NMFS.

2). Increase power:

Increase the power level from, 20 V to 40 + V to the Helmholtz coil and RF Engineering's proprietary antenna design. Determine H-field strength and maximum tag excitation/receive distance at the increased power levels.

3) Tag Read Range:

Determine the maximum excitation/receive distance underwater using multiple antenna (coil) configurations e.g., multiple excite coils with separate receive coils, multiple duel purpose coils, one large excite coil with multiple receive coils, etc.

4) RF Emissions:

Determine RF emissions for the 400 kHz 20.3 cm by 61 cm Pit tag tunnel (unshielded) when energized with RF Engineering's excitation/receive system. The measurements will be For the fundamental and harmonic frequencies and conducted in accordance to FCC requirements. The measurements will be made at a minimum of 30 meters from the radiating source using a H-field loop antenna and appropriate spectrum analyzer:

5) Report:

A report will be prepared that includes a methods and materials and a results and discussion section. All test results will be presented in the report.

§ 15.209 Radiated emission limits; general requirements.

(a) Except as provided elsewhere in this subpart, the emissions from an intentional radiator shall not exceed the field strength levels specified in the following table:

Frequency (MHz)	Field strength (microvolts/meter)	Measurement distance (meters)
0.009-0.490............	2400/F(kHz)	300
0.490-1.705............	24000/F(kHz)	30
1.705-30.0.............	30	30
30-88..................	100 **	3
88-216.................	150 **	3
216-960................	200 **	3
Above 960..............	500	3

** Except as provided in paragraph (g), fundamental emissions from intentional radiators operating under this section shall not be located in the frequency bands 54-72 MHz, 76-88 MHz, 174-216 MHz or 470-806 MHz. However, operation within these frequency bands is permitted under other sections of this part, e.g., Secs. 15.231 and 15.241.

(b) In the emission table above, the tighter limit applies at the band edges.
(c) The level of any unwanted emissions from an intentional radiator operating under these general provisions shall not exceed the level of the fundamental emission. For intentional radiators which operate under the provisions of other sections within this part and which are required to reduce their unwanted emissions to the limits specified in this table, the limits in this table are based on the frequency of the unwanted emission and not the fundamental frequency. However, the level of any unwanted emissions shall not exceed the level of the fundamental frequency.
(d) The emission limits shown in the above table are based on measurements employing a CISPR quasi-peak detector except for the frequency bands 9-90 kHz, 110-490 kHz and above 1000 MHz. Radiated emission limits in these three bands are based on measurements employing an average detector.
(e) The provisions in Secs. 15.31, 15.33, and 15.35 for measuring emissions at distances other than the distances specified in the above table, determining the frequency range over which radiated emissions are to be measured, and limiting peak emissions apply to all devices operated under this part.
(f) In accordance with Sec. 15.33(a), in some cases the emissions from an intentional radiator must be measured to beyond the tenth harmonic of the highest fundamental frequency designed to be emitted by the intentional radiator because of the incorporation of a digital device. If measurements above the tenth harmonic are so required, the radiated emissions above the tenth harmonic shall comply with the general radiated emission limits applicable to the incorporated digital device, as shown in Sec. 15.109 and as based on the frequency of the emission being measured, or, except for emissions contained in the restricted frequency bands shown in Sec. 15.205, the limit on spurious emissions specified for the intentional radiator, whichever is the higher limit. Emissions which must be measured above the tenth harmonic of the highest fundamental frequency designed to be emitted by the intentional radiator and which fall within the restricted bands shall comply with the general radiated emission limits in Sec. 15.109 that are applicable to the incorporated digital device.
(g) Perimeter protection systems may operate in the 54-72 MHz and 76-88 MHz bands under the provisions of this section. The use of such perimeter protection systems is limited to industrial, business and commercial applications.

[54 FR 17714, Apr. 25, 1989; 54 FR 32339, Aug. 7, 1989; 55 FR 18340, May 2, 1990; 62 FR 58658, Oct. 30, 1997]

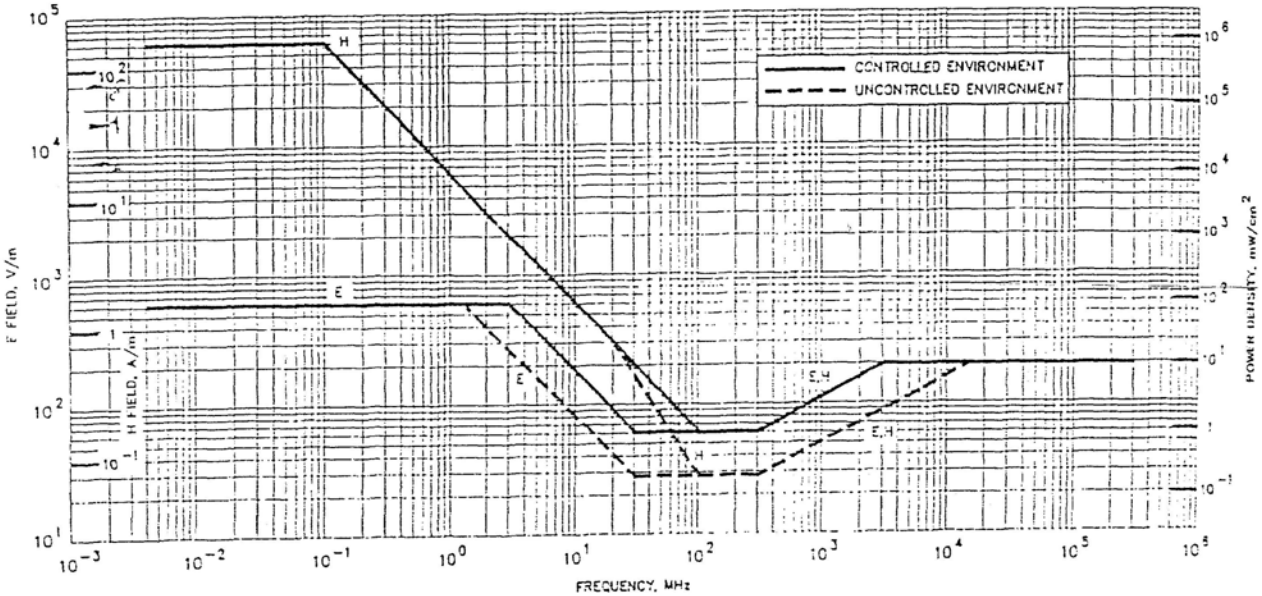
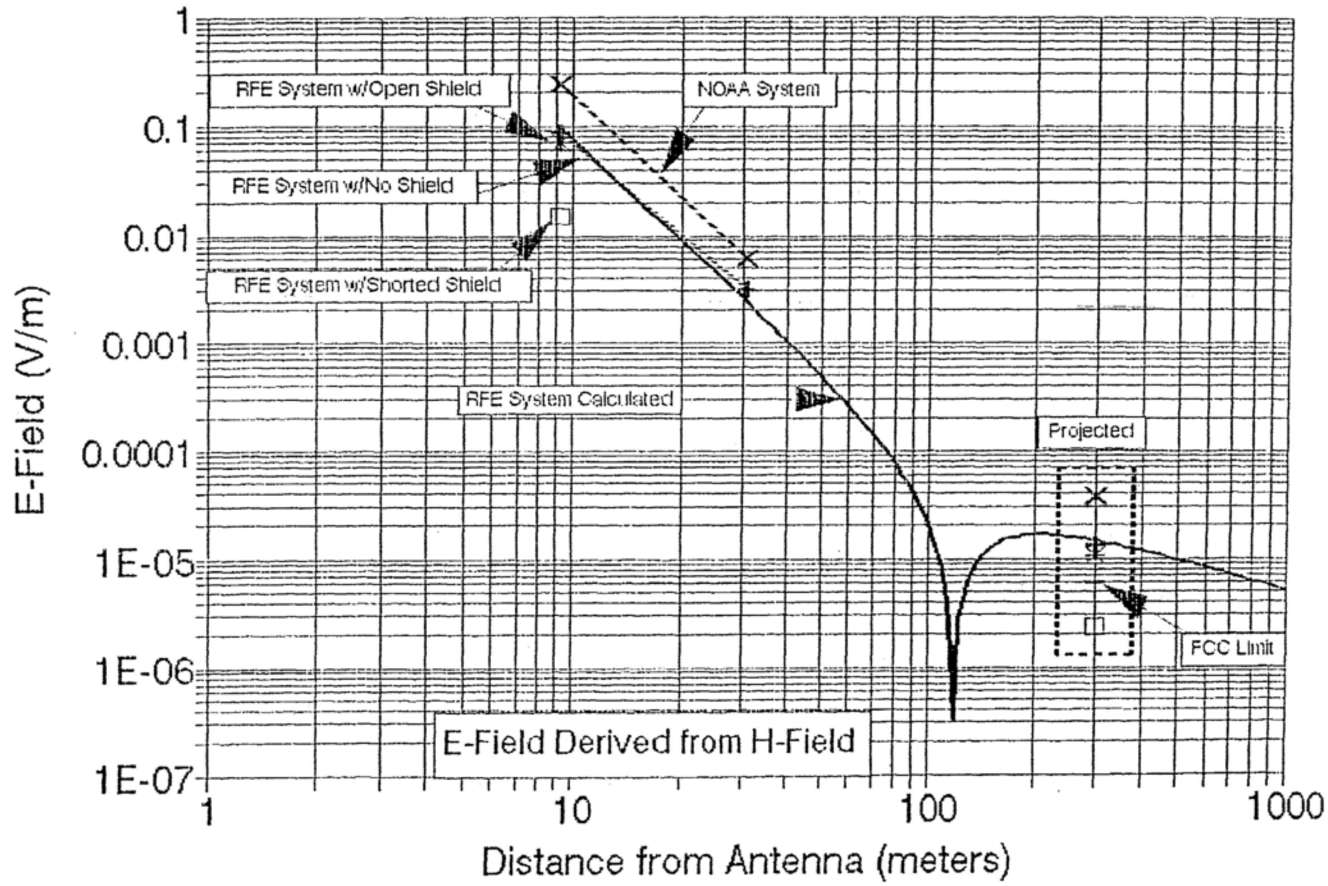


Fig. 4—Proposed 1991 ANSI RF protection guidelines for body exposure of humans.

FROM AARL Handbook

E-Field Strength vs. Distance
RFE and NOAA Systems at Fr=400KHz



PIT Tag Return Signal Read Distance vs. Tilt Angle 1/11/95

F(Tx)=400kHz F(Rx)=45kHz

V(Tx):	[Vpp]	112	81	58
h(Tx):	[A/m]	29.9	21.6	15.5

Position:	Maximum Tilt Angle (degrees):			
Edge:	Top Coils	60	60	50
	Center	55	50	40
	Low Coils	60	60	50
4" Inside	Top Coils	60	60	45
	Center	50	45	35
	Low Coils	60	60	45
6" Inside	Top Coils	60	60	45
	Center	55	40	35
	Low Coils	60	60	45

APPENDIX B

Predesign Report: Prototype Testing of Passive Integrated Transponder (PIT) Tag Monitors for Adult Salmon

Summit Technology

PREDESIGN REPORT

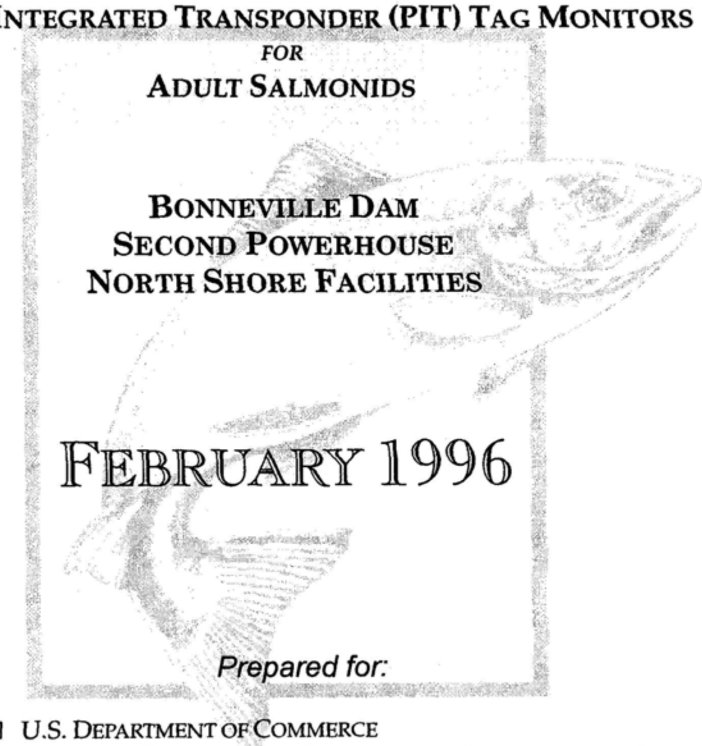
PROTOTYPE TESTING

OF

PASSIVE INTEGRATED TRANSPONDER (PIT) TAG MONITORS

FOR

ADULT SALMONIDS



BONNEVILLE DAM
SECOND POWERHOUSE
NORTH SHORE FACILITIES

FEBRUARY 1996

Prepared for:

- U.S. DEPARTMENT OF COMMERCE
- NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
- NATIONAL MARINE FISHERIES SERVICE
- COASTAL ZONE & ESTUARINE STUDIES DIVISION

Prepared by:

SUMMIT TECHNOLOGY
CONSULTING ENGINEERS, INC., P.S.
615 SECOND AVENUE, SUITE 580
SEATTLE, WASHINGTON 98104

TABLE OF CONTENTS

EXECUTIVE SUMMARY

National Marine Fisheries Service (NMFS), with support from Bonneville Power Administration (BPA), is investigating the technical feasibility of using Passive Integrated Transponder (PIT) tags to monitor the movement of adult salmonids passing through fish ladders. Although PIT tag transceivers are commonly used to track juvenile fish, this NMFS undertaking is unique in that it proposes to interrogate adult fish in fish ladders using a variety of PIT tag transceiver antenna sizes and geometries.

The program proposed by the NMFS includes several tasks. This design effort addresses two of those tasks.

- ❑ Evaluate the technical feasibility of using Bonneville Dam's Fisheries Engineering Laboratory fish ladder to study PIT tag transceivers and antenna designs for the interrogation of adult fish.

- ❑ Design PIT tag antenna housings that: a) enable a variety of antenna coil designs to be evaluated within a single housing, and b) can be deployed in an adult test facility without altering the facility's structural integrity, hydraulics, or modifying fish behavior.

Using engineering and hydraulic criteria, Bonneville Dam's Fisheries Engineering Laboratory (FEL) fish ladder was evaluated as to its suitability as a location to evaluate the proposed adult PIT-tag transceiver system.

Once the site is approved by all stakeholders, several modifications to the FEL fish ladder would be required to carry out the program. The ladder would be modified to emulate two fish passage areas, Vertical Slot and Orifice/Weir, of the Bonneville 2ND Powerhouse North Shore Fish Ladder. This ladder is considered typical of most ladder installations in the Columbia River Basin.

As part of this effort, antenna housings that emulate the Vertical Slot and Orifice/Weir area of a fish ladder are discussed. The antenna housings were designed to be installed and removed and not alter the ladder hydraulics or fish behavior. The design also enables various antenna configurations to be used within a housing for evaluation purposes.

The Vertical-Slot antenna housing was patterned after Baffles No. 15, 16, and 17 of the Bonneville 2ND Powerhouse, North Shore Fish Ladder, Exit Control Section. With similar opening width, opening height, and angle to flow, it is anticipated that the housing will not have fish passage and hydraulic performance different from the unmodified section of the existing North Shore Fish Ladder.

Upon completion of the adult PIT tag system evaluation by NMFS, anchor bolt sleeves that are installed in the floor and the sill will have plugs installed and left flush.

The Orifice/Weir antenna housings (based upon a combination of pass-through and pass-by concepts respectively) would be constructed as a full-scale model of Weirs 38 through 43 (of the Fisheries Engineering Laboratory Entrance Fish Ladder) and Weirs 44 through 48 (of the Fisheries Engineering Laboratory Exit Fish Ladder) (Fig. 2).

Conceptual designs have been prepared for two Orifice/Weir antenna housings, a Structural Fiberglass Orifice/Weir antenna housing constructed of fiberglass shapes and plates, and a Fiberglass Reinforced Concrete antenna housing. Of these two designs only one would be built.

A removable antenna housing would be installed as the top portion of the overflow weir; a second removable antenna housing, installed in a structural frame would serve as the orifice. Fish passage and hydraulic performance of the antenna housing should be similar to the existing Orifices/Weirs in the Fisheries Engineering Laboratory Entrance Fish Ladder and the North Shore Fish Ladder.

Upon completion of the test program, the Orifice/Weir antenna housings would be removed. The fiberglass anchor bolts would be cut off and reinforcing steel would be doweled into the walls and floor. Once the dowels are installed, the orifice/weir concrete would be replaced as shown in the original construction drawings, and any temporary bolt holes would be grouted flush.

The PIT-tag system operates using a strong electromagnetic field. If during the operation of either the Vertical-Slot or Orifice/Weir antenna system it is found the radio frequency (RF) emissions of the system exceed federal standards, an RF shield may be required. A conceptual design for this shield is provided.

Although this design report addresses the feasibility of producing a test facility and antenna housings for an extended-range PIT tag transceiver system, the ultimate goal of the NMFS program is to interrogate adult salmon ascending fish ladders. To that end, procedures were explored and are presented to install, maintain, and remove extendedrange PIT tag transceivers in main ladders.

AUTHORIZATION

This Predesign report was prepared in accordance with the contract between the Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Coastal Zone & Estuarine Studies Division, and Summit Technology dated February 17, 1995.

INTRODUCTION

National Marine Fisheries Service (NMFS), with Bonneville Power Administration (BPA) support, is investigating the technical feasibility of using Passive Integrated Transponder (PIT) tags to monitor the movement of adult salmonids ascending fish ladders. This requires antennas and associated antenna housings to be designed, fabricated, and evaluated that are several times larger than presently used in the Columbia River Basin (CRB). In addition, these antennas must be of various geometries, completely waterproof, accessible for maintenance, and not alter the hydraulics of the fish ladder.

Two general categories of extended-range PIT tag antenna housings are required, passby and pass-through. The first approach would be used in connection with the VerticalSlot and Overfall-weir fish passage areas of a fish ladder. In the pass-by concept, PIT tag interrogation takes place while fish pass by a flat-plate antenna housing placed in a vertical or horizontal position. The second approach is used with orifices located within a fish ladder. Here fish being interrogated for PIT tags, pass through an opening within the antenna housing. In either case, the antenna housings must accommodate a range of antenna coil designs and be easily installed, removed, and adjusted for various testing conditions.

Once fabricated, the antenna housings, antennas, and associated PIT-tag transceiver electronics must be evaluated. To minimize impact and maximize flexibility in testing, NMFS sought a test fish ladder that could be altered to emulate existing fish ladders in the Columbia River Basin. The final selection of such a facility would be dependent upon agreement and cooperation from all stakeholders.

Working toward this goal, NMFS proposed to contract an independent structural engineering firm to:

- ❑ Evaluate the technical feasibility of using Bonneville Dam's Fisheries Engineering Laboratory fish ladder to study PIT tag transceivers and antenna designs for the interrogation of adult fish.
- ❑ Design PIT tag antenna housings that: a) enable a variety of antenna coil designs to be evaluated within a single housing, and b) can be deployed in an adult test facility without altering the facility's structural integrity, hydraulics, or modifying fish behavior.

TEST FACILITY LOCATION AND DESCRIPTION

The first goal of this design effort was to evaluate the technical feasibility of using Bonneville Dam's Fisheries Engineering Laboratory (FEL) fish ladder to study PIT-tag transceivers and antenna designs for the interrogation of adult fish. This ladder is located adjacent to the North Shore Fish Ladder at the Bonneville Dam's 2ND Powerhouse. Plans, sections, and details of the existing North Shore Fish Ladder and Fisheries Engineering Laboratory fish ladders are shown in Figs. 1 through 7. The question as to the ladder's availability for such a program was not part of this effort.

The antenna housings to be evaluated at the facility are designed to emulate the VerticalSlot and Orifice/Weir portions of a fish ladder. The antenna housings thus were designed as replacement sections for the areas of interest. For the Vertical-Slot area, a sectional vertical flat-plate or pass-by antenna housing was designed. A similar pass-by antenna housing placed horizontally is suggested for the weir portion of the Orifice/ Weir area, while a pass-through antenna housing is used with the orifice. Details of these housings are described elsewhere in this document.

For the FEL fish ladder to be considered as a PIT tag systems evaluation site, the ladder had to meet several criteria:

1. The weir and orifice geometries in the test ladder must be representative of the weir and orifice geometries in operating fish ladders within the CRB (e.g., North Shore Fish Ladder at the Bonneville 2ND Powerhouse).
2. The test ladder must be operable at various controllable water flow rates; it also must be able to be dewatered on demand.
3. The test ladder should be readily accessible by equipment needed to install and remove the antenna housings.
4. The test ladder must be capable of being altered without jeopardizing its integrity or functionality now or in the future.

The FEL's facility meets all of the above criteria.

At this time, it is understood that during the antenna evaluation period at the FEL fish ladder that both antenna areas, Vertical-Slot and Orifice/Weir, will not be operate simultaneously. All hydraulic calculations and conclusions are based on this assumption.

Figures showing the general arrangement and existing conditions at the proposed test ladder are provided at the end of this report. Fig. 1 shows the general arrangement plan of the North Shore features at Bonneville 2ND Powerhouse. Fig. 2 shows the Entrance and Exit Fish Ladders in plan view. Fig. 3 shows a plan detail of the Entrance Fish Ladder with the proposed locations for the test antennas highlighted. Partial sections of the Entrance Fish Ladder are shown in Fig. 4. Also in Fig. 4 the proposed locations for the test antennas are highlighted.

Figures showing existing conditions at a representative main ladder are also provided. These figures are provided for comparison to the proposed antenna housing drawings. This comparison illustrates that the test antenna housings should not have fish passage or hydraulic performance different from the existing North Shore Fish Ladder. Fig. 5 shows a plan view of the vertical slots. A test antenna housing is being proposed which emulates these vertical slots. The proposed vertical slot antenna housing is described in this report in the section titled "Vertical-Slot Antenna Housing" and is shown in engineering drawings (Figs. 15 through 19). Fig. 6 shows a plan view of the orifice/weir section of the North Shore Fish Ladder. Fig. 7 shows the details of the orifice and weir geometries of the existing North Shore ladders. A test antenna housing is being proposed which emulates these orifice/weir sections. The proposed orifice/weir antenna housings are described in this report under the title "Orifice/Weir Antenna Housing" and are shown in engineering drawings (Figs. 20 through 24).

Isometric renderings of the antenna housing installation in the Entrance Ladder to the FEL have been prepared to illustrate the relationship between the antenna housing and existing ladder construction. These are Figs. 8 through 14.

Fig. 8 shows a view of the antenna housing installation looking down and toward the southwest. Fig. 9 shows the antenna housings in the Entrance Ladder looking east from above Entrance Weir 43.

Figs. 10 and 11 are looking through the north wall of the Entrance Fish Ladder at the Vertical Slot antenna housing installation. In Fig. 10 the preferred Vertical Slot antenna housing is illustrated. Fig. 11 illustrates the alternate Vertical Slot antenna housing.

The downstream face of the Orifice/Weir antenna housing is shown in Fig. 12. Fig. 13 shows the upstream face of the Orifice/Weir antenna housing. The final isometric rendering is Fig. 14, showing an exploded view of the Orifice/Weir antenna housing and structural frame.

ANTENNA HOUSINGS

The second task of this effort was to design antenna housings that: a) enable a variety of antenna coil designs to be evaluated within a single housing, and b) can be deployed in an adult test facility without altering the facility's structural integrity, hydraulics, or modifying fish behavior. The general location and approach taken for the housing are described in the previous section. A detailed description of the antenna housings designed for use in the Vertical-Slot and Orifice/Weir area of the fish ladder follows.

VERTICAL SLOT ANTENNA HOUSING

Description

The Vertical-Slot antenna housing is patterned after Baffles No. 15, 16, and 17 of the Bonneville 2ND Powerhouse, North Shore Fish Ladder, Exit Control section. For the geometry of these orifices, see Fig. 5 (Vertical Slot Orifice Plan).

Two proposed designs have been prepared to model these orifices in the test ladder: a Preferred Vertical Slot antenna housing, and an Alternate Vertical Slot antenna housing. The Preferred Vertical Slot has been so designated because the geometry of its proposed installation allows greater flexibility in modeling the actual ladder hydraulic conditions. Of the two alternative designs prepared for consideration, only one will be selected and constructed.

The term Vertical-Slot antenna housing is used when characteristics common to both the Preferred and Alternate antenna housings are discussed in this section.

The Vertical-Slot antenna housing consists of a guide wall and the slot walls. The guide wall will be installed on the upstream side of the antenna housing. The slot walls consist of two portions: a fixed portion, and an adjustable portion. Both the guide wall and the slot walls will be fabricated of Series 500/525 structural fiberglass shapes and plates. All framing members will be 8-inch channels covered with 0.5-inch-thick fiberglass skin plate. Although the antenna housing is constructed primarily with adhesive-bonded connections, the design allows for bolted connections. This will permit the antenna housing to be modified independent of the unit's structural frame. The Preferred Vertical Slot antenna housing drawings are shown as Fig. 15 (Plan) and Fig. 16 (Elevations). The Alternate Vertical Slot antenna housing drawings are shown as Fig. 17 (Plan), Fig. 18 (Elevations), and Fig. 19 (Sections and Details).

Antenna housings will be enclosed in the downstream end of the fixed portion and the upstream end of the vertical slot's adjustable portion. The unused portion of the housing is currently shown on Fig. 17 to be filled with closed cell polystyrene foam. The unused portion could also be left as an air void. Filler materials will be selected based on their dielectric characteristics and their stability in a moist environment. To ensure negative buoyancy, water will be allowed to enter compartments of the antenna housing or portions of the antenna housing will be ballasted.

To install the antenna housings, they will be slid vertically down into compartments within the Vertical Slot antenna housing (Figs. 15 and 17). Because the antenna housings will be positively buoyant, it will be necessary to force them down into the compartments. A cover plate and retainer will be installed to secure the housings. For tests that utilize less than the full-height antennas, the unused portion will be replaced by an antenna-shaped spacer.

Although not shown on the sketches, there will be provisions to connect the antenna leads to the PIT tag detection system. If required, provisions for a metal RF shield would be included above the antenna.

Preferred Location

The guide wall of the Preferred Vertical Slot antenna housing will consist of a wall perpendicular to the test fish ladder's longitudinal axis. This wall will be fabricated in three, full-height sections.

The full-height sections will be bolted to the floor using inserts with a spacing of 3 inches. This configuration-two 2-foot sections, one 1-foot section, and bolt inserts on 3inch spacing-allows the fixed portion of be adjustable from 1 foot to 5 feet wide, and on either side of the test ladder.

This adjustability allows the tests to be conducted with arrangements which best initiate parallel flow lines through the antennas and minimize the potential for short-circuiting the flow.

The slot walls of the Preferred Vertical Slot antenna housing will consist of two portions, each containing an antenna housing oriented parallel to the other, forming the slot. These portions will be installed at a slope of 0.25:1.00 from perpendicular to the fish ladder's longitudinal axis. The portions will be bolted to the floor and each wall of the test ladder. The right-hand portion of the slot wall (looking downstream) will be bolted in a fixed location. The left-hand section provides adjustability.

A false floor will be installed to raise the floor elevation to 42.0 feet. This floor will be sloped on the downstream face to minimize the locations where fish could hold up.

Provisions will be made for a partial-height, adjustable, vertical barrier on the downstream edge of the vertical slot. This vertical barrier has been proposed to facilitate testing of the antennas. With the barrier removed, full-depth tests can be run to prove antenna performance at hydraulic pressure heads of up to 12 feet. The vertical barrier can then be installed and tests run at varying flow velocities. The velocity of the water through the slot is dependent upon the height and placement of the vertical barrier.

In the North Shore Fish Ladder, Exit Control section, feet-per-second (fps) slot velocities, including carryover, have been observed to be approximately 3.5 fps to 6.0 fps. The FEL Entrance Fish Ladder design flow is 33 cubic feet per second (cfs). To representatively model slot velocity and the ladder flow rate concurrently, it will be necessary to adjust the slot's width and the vertical barrier's height.

Alternate Location

The guide wall of the Alternate Vertical Slot antenna housing also will consist of a wall perpendicular to the longitudinal axis of the fish ladder. As currently proposed, the guide wall is joined to the fixed portion of the slot walls.

The fixed portion of the slot walls will consist of a stem wall extending downstream at a slope of 0.25:1.00 from parallel to the longitudinal axis of the fish ladder. This portion will be fabricated in one section; the panel is then bolted to the floor of the fish ladder.

The adjustable portion o tl~,e st alls will also be installed at a slope of 0.25:1.00 from parallel to the longitudinal axis of the fish ladder, constructed in one section, and bolted to the floor. The bolts will be provided with a spacing of 3 inches. This spacing, along with oversized holes in the adjustable portion, will allow the vertical slot to be set at openings of 1 foot to 2 feet, in 3-inch increments. One upstream and one downstream closure plate will be provided for each opening increment, for a total of five sets of plates.

A false floor will be installed to preclude the fish avoiding detection by swimming below the antennas. The false floor is sloped on the downstream face to help minimize the tendency for fish to hold up in front of the raised floor.

Installation

Vertical Slot antenna housings have been designed for two locations in the proposed test ladder. While only one will be installed, both alternates would be installed in a similar manner, by bolting to the existing walls and floor. Since installation of the Vertical Slot antenna housing will not require removal of concrete portions of the existing fish ladder, no concrete replacement will be required.

Preferred Location

The selected location for the Preferred Vertical Slot antenna housing is in the large pool upstream of Weir 53. (Refer to Fig. 3 for location.) This pool, the first downstream from the FEL, is 8 feet wide by approximately 26 feet long.

The large pool area allows flexibility in the alignment and placement of the antenna housing. This flexibility allows a design that models the water flow patterns of the North Shore Ladder, Exit Control section. It is this flow modeling which makes the large pool upstream of Weir 53 the preferred alternative location.

In the selected pool, the floor is level at El. 38.00, and there is no sill, orifice, or weir adjacent to the proposed antenna housing location.

Alternate Location

The selected ladder location for the Alternate Vertical Slot antenna housing is between Weir 51 and Weir 52 in the FEL Entrance Fish Ladder (Fig. 3). Each section of the fish ladder from Weir 46 through Weir 52 has a level floor with a sill at each weir which is 2.5 feet high. An orifice is formed in each sill. The top of the sill at Weir 52 is El. 40.50.

Installation of the adjustable portion of the Vertical Slot antenna housing will require that the weir gate and its appurtenances at Weir 51 are removed, and that the orifice in the sill is covered. Because of the number of anchor bolts to be installed, and the critical nature of their location, it is expected that the fiberglass fabricator will prepare a template to match the drilling of the members.

Operation

Both Vertical Slot antenna housings operate in similar fashion. 'The tests can be run at various flow rates, flow depths, and slot velocities that approximate that of the main fish ladder.

The proposed test ladder design flow is approximately 33 cfs. Supply flow is comprised of water diverted from the main ladder and water supplied by a floor diffuser in the FEL. The supply diffuser in the FEL has a maximum capacity of 60 cfs. For high-flowrate tests of the Vertical Slot antenna housings, it may be necessary to divert excess flow from the test ladder before it is discharged to (and disrupts flow in) the main ladder. This flow could be diverted by temporary pumping or by the installation of a screened and gated pipe that discharges into the existing storm drain manhole.

Preferred Location

The Preferred Vertical Slot antenna housing will be designed to operate with a maximum water depth of 13 feet and with a maximum width of 2 feet. The antenna housing would be operated to provide a range of test velocities and flow depths by varying the flow rate, slot area, and number of downstream weir gates open.

The slot area may be varied not only by adjusting the slot width, but by adjusting the height also. As a result, the partial-height, adjustable, vertical barrier is proposed. With a 2-foot slot width and a ladder flow rate of 35 cfs, all but approximately 3 to 4 feet of the slot would need to be blocked off to produce an average velocity of 6.O fps. This velocity, although representative of existing slot flow velocity, is perhaps somewhat excessive. However, the use of blocking to increase slot velocities could be used to some degree, with the open portion of the slot positioned at any desired elevation.

At full design depth and maximum slot width, the flow through the slot at a 1.0-foot drop will be approximately 144 cfs. For a slot width of 1.5 feet, the flow is approximately 108 cfs; for a slot width of 1.0 feet, the flow is approximately 72 cfs.

Alternate Location

The Vertical Slot antenna housing will be designed to operate with a maximum water depth of 13 feet and a width of 2 feet. This test would be operated to provide a range of test velocities by varying the ladder flow rate and the slot width. Additional operational flexibility is achieved by opening or closing the downstream weir gates.

The water surface upstream of Weir 52 will be at El. 52.50. With a 1-foot drop, the flow through a 2.0-foot slot will be approximately 144 cfs. For a slot 1.5 feet wide, the flow is approximately 108 cfs. For a slot 1.0 feet wide, the flow is approximately 72 cfs.

Performance

The Vertical Slot antenna housing is patterned after Baffles No. 15, 16, and 17 of the Bonneville 2ND Powerhouse, North Shore Fish Ladder, Exit Control Section. For the geometry of existing orifices, see Fig. 5 (Vertical Slot Orifice Plan). The existing slot is 1.969 feet wide in that set of baffles. The antenna housing opening will be nominally 2.0 feet wide and has approximately 0.375-inch adjustability. The antenna housing will have an adjustable opening width which will allow the modeling of additional sets of baffle. For example, Baffles No. 16 and 17, with an opening of 1.719 feet, could be modeled by setting the antenna housing at 1.75 feet and taking up all the slack in the hold-down bolts.

Both the antenna housing slot and the existing ladder slot are sloped 0.25:1.0 with respect to the longitudinal axis of the fish ladder.

With similar opening width, opening height, and angle to flow it is anticipated that the antenna housing will have fish passage and hydraulic performance similar to the existing North Shore Fish Ladder.

Removal

Upon completion of the tests, the anchor bolt sleeves installed in the existing ladder will have plugs installed and left flush.

ORIFICE /WEIR ANTENNA HOUSING

Description

The Orifice/Weir antenna housing will be constructed as a full-scale model, or prototype, of Entrance Weirs 38 through 43 and Exit Weirs 44 through 48 of the FEL fish ladder (see Figs. 1, 2, 3, and 7). Conceptual designs have been prepared for two Orifice/Weir antenna housings: a Structural Fiberglass Orifice/Weir antenna housing constructed of fiberglass shapes and plates, and a Fiberglass Reinforced Concrete antenna housing. Of these two designs only one will be built.

Two types of antenna will be tested in the Orifice/Weir unit. A flat antenna will be tested in the weir section, and a loop antenna will be tested in the orifice section. The antenna housing will be removable for modification or maintenance. If necessary, provisions for a metal RF shield will be made above the antenna housing to provide RF shielding.

Structural Fiberglass

A Structural Fiberglass Orifice/Weir antenna housing will be constructed of Series 500/525 structural shapes and plates. For the upstream elevation and sections pertaining to this antenna housing, see Fig. 20 (Elevation and Section) and Fig. 21 (Sections).

The frame will consist of 6-inch channel sections and will be covered with 0.5-inch-thick plate. This results in a total thickness of 7 inches for the structure. This is 1 inch less than the current Weir 42.

The antenna housing will be 8 inches thick and will have the upstream and downstream chamfer profiles similar to existing weirs. The unit's structural frame is constructed with adhesive bonded connections. Design of the antenna housings allows for removable and interchangeable antenna sections, which permits the antennas to be modified

independent of the unit's structural frame. The antennas are enclosed in annular portions of the antenna housing. This housing is currently shown to be filled with closed cell polystyrene foam or left as an air void. Filler materials will be selected based on their dielectric characteristics and their stability in a moist environment. To ensure negative buoyancy, water will be allowed to enter cells of the antenna housing or portions of the antenna housing will be ballasted.

Proposed construction of structural frames for the antenna housings is of structural fiberglass plates and shapes, with standard colors of olive green and haze gray. It is anticipated that these colors will not distract the fish and, therefore, will not disrupt fish passage. Proposed construction of antenna housings is of sheets of Lexan® plastic, which may be painted to match the structural frames.

Although not shown on the sketches, there will be provisions to connect the antenna leads to the RF generator and data collection system.

Fiberglass Reinforced Concrete

A fiberglass-reinforced, concrete Orifice/Weir antenna housing would be constructed using moderate-strength, 5,000-pounds-per-square-inch (psi), portland cement concrete. Structural reinforcing will be Thermal Cure® fiberglass rod and bar. Temperature reinforcing will be synthetic fiber reinforcement.

The antenna housing will have thickness, geometry, and surface material identical to the existing Weir 42. Antennas will be enclosed in housings fabricated of Lexan®, and will be removable. The profile of the overflow weir and the orifice chamfers will match existing profiles. For construction details of the antenna housing, see Fig. 22 (Elevation and Section) and Fig. 23 (Sections).

Although the sketches of this antenna housing show an unreinforced section, and preliminary design calculations indicate that lower strength concrete (as low as 1,000 psi) may be used without reinforcement, it is not recommended that the antenna housing be constructed without structural and temperature reinforcement. The concrete strength and reinforcing density will depend on the final design criteria selected and the desired "toughness" of the unit. For all selections of design criteria, concrete strength, and structural reinforcing density it is recommended that fibrous reinforcement be used for shrinkage and temperature crack control, and that fiberglass rod be used as structural reinforcement. Additionally, it is recommended that concrete used have a design compressive strength of 5,000 psi.

The antennas are shown as being enclosed in a housing, fabricated of Lexan®, similar to the Structural Fiberglass Orifice/Weir antenna housing. The housing will be filled with the same materials as the other antenna housings.

Although not shown on the sketches, there will be provisions to connect the antenna leads to the PIT tag detection system.

Installation

It is proposed that the orifice/weir antenna housing be installed at the Weir 421ocation in the FEL Entrance Fish Ladder (Fig. 3). This location was selected because it is in a location of established flow and is accessible. Weir 42 is nearly the middle weir on the south side of the ladder, is in the sloping floor portion of the ladder, and is bordered by fixed overflow weirs both upstream and downstream. (Weirs 44 through 53 have adjustable gates; Weirs 38 through 43 are fixed overflow sections.) Additionally, Weir 42 is not too deep in the ladder channel, and it does not have a strut above it as do Weirs 39 and 40. The only other weir to meet the same criteria, Weir 41, is in an equivalent location; however, Weir 42 was selected.

Removal of the existing overflow portion of the weir would be required, and this would entail cutting the concrete and reinforcing steel in the wall. In addition, a portion of the concrete beneath the weir must be removed to accommodate the loop antenna around the orifice at the weir bottom.

Construction drawings for the ladder specify a minimum cover of 4 inches for unformed surfaces. This should minimize the need to cut any reinforcing steel in the floor of the ladder.

Operation

A removable antenna housing will be installed as the top portion of the overflow weir. Another removable antenna housing, installed in the structural frame, will serve as the orifice. As fish swim through the orifice or over the weir, the PIT tag will be energized by an electromagnetic field originating in the antennas. The PIT tag then discharges and the signal is received by the antenna. Excess RF radiation will be trapped by the RF shield provided above and beside the antenna units.

Performance

Fish passage and hydraulic performance of the antenna housing should be similar to the existing weir/orifices in the FEL Entrance Fish Ladder and the North Shore Fish Ladder. Similar performance will be achieved with this antenna housing by fabricating it to the same geometry as the present Weir 42 of the FEL Entrance Fish Ladder. Weir 42 of the FEL Entrance Fish Ladder is hydraulically similar to one side of the weirs in the North Shore Fish Ladder of the 2ND Powerhouse. Consequently, the prototype installed in place of Weir 42 should also perform similarly to the weirs in the North Shore Fish Ladder of the 2ND Powerhouse. The geometry of Weir 42 is shown in Fig. 7 (Orifice and Weir, Details).

Removal

Upon completion of the test program, the Orifice/Weir antenna housings will be removed from the Entrance Weir. The fiberglass anchor bolts will be cut off and reinforcing steel will be doweled into the walls and floor. The dowels will be similar to those cut out during the installation of the antenna housing. They will be offset to avoid the cut-out reinforcing. Once the dowels are installed, the orifice/weir concrete will be replaced as shown in the original construction drawings. Any temporary bolt holes will be grouted flush.

RADIO FREQUENCY (RF) SHIELD

The PIT tag antenna is both an RF transmitter and receiver. To reduce the release of stray RF emissions, provisions for an RF shield will be made above the antenna housing and the adjacent bays of the ladder. One possible design is shown in Fig. 24 (Radio Frequency Shield - Plan and Section).

The RF shield would be configured as a modular, removable access platform with grounding capability. There would be three 8.0-foot panels marked Left, Center, and Right. The Left and Right panels would have a guardrail on one end; the center panel would not. This modular layout would allow the shield to cover beyond two pools of the ladder, or, with the center panel omitted, to cover only the antenna housing. If it is found necessary to extend the RF shield, additional center type panels could be fabricated and installed. In addition to the horizontal shielding provided by the grating, there would be adjustable wire fabric on the ends of the Left and Right panels to capture RF emissions traveling with a horizontal component.

APPLICATION TO MAIN LADDER OPERATION

OVERVIEW

This predesign report addresses the feasibility of producing a test facility for an extended-range PIT tag interrogation system. However, the goal of the NMFS program is to interrogate adult salmon in ascending fish ladders. To this end, procedures were investigated to install, maintain, and remove the extended-range PIT tag monitors in main ladders.

This section of the report will identify the concerns raised in translating the extendedrange PIT tag monitoring equipment from a test ladder to an operating main ladder. It will also propose ways in which this translation may be accomplished.

INSTALLATION

Installation in an operating ladder will be more constrained than installation in the test ladder. Initial installation will be limited to the period of scheduled ladder shutdown, and in-service repairs will need to be accomplished without dewatering the ladder.

Initial installation of the systems will be accomplished during the in-water work period at the projects, which is typically during the winter months. The time required for modifications to the ladders is relatively modest and can be accomplished during this time period. Preliminary testing with water flowing in the ladder should also be accomplished during the in-water work period, so that the ladder can be dewaeered if necessary.

At the end of the in-water work period, any maintenance necessary to the units will need to be accomplished without dewatering the ladder. It may be necessary to change antennas during operation of the ladder.

In the vertical slot monitor, changing the antennas can be accomplished with no disruption to ladder operation. The antenna housing units can be withdrawn from the top of the frames and modified, rebuilt, or replaced as necessary.

Changing antennas in the orifice/weir units is more difficult. It will be necessary to remove the weir panel out of the fishway, replace the antenna housing with a spare, and return the fish ladder to normal operation. The antenna housing can then be taken to a shop where the antenna housings are disassembled and the antennas are rebuilt.

In order to remove the weir panel, it will be necessary to stop the flow over and through the weir. Since the typical ladders have two overflow weirs, all of the flow can be routed to one of them while the other is blocked off. Although this flow routing will have a substantial effect on the local hydraulics of the ladder, it will occur for a relatively short period of time and will not block fish passage.

As indicated on Fig. 25 (Stoplogs - Plan and Section), the stoplogs will consist of two steel-plate sections: one with angle stiffeners, and one with nylon skids.

- ❑ One section is a 0.25-inch-thick steel plate with angle stiffeners which will be installed parallel to the flow in the ladder. This section will be installed first, with water pressure holding the downstream edge against the return wall of a weir. The upstream end of the section is braced off the exterior wall of the ladder with double angle struts.

- ❑ The other section of the stoplogs is a 0.25-inch-thick steel plate with nylon skids. The skids will consist of two sets of MC901 nylon strips. One set of strips, each strip approximately 2 inches wide, will be attached to the face of the stoplog section. The other set of strips will be installed on the face of the existing concrete weir wall. The sets of strips will be placed such that the stop log and wall make contact, nylon to nylon. The skids will decrease frictional resistance to sliding of the section against the upstream face of the weir and orifice wall.

A stoplog will be installed in the affected side of the ladder. This will cause the water level to rise approximately 0.8 feet, which will cause the weir divider wall to overtop slightly. Two options are available to reduce the water level upstream of the stoplog.

The first option is to adjust the existing control section of the ladder to temporarily reduce the flow. This flow reduction is on the order of 32 percent and should occur only for a period of two to four hours.

The second option is to install an operable slide gate in the area between the two weirs. Before installing the stoplogs, the gate would be opened to reduce the differential at the affected weir.

FIGURES

ORGANIZATION

The figures for this report consist of drawings and renderings. They have been divided into three groups.

The first group of figures (Figs. 1-7) are extracts from the construction drawing set for the Bonneville 2ND Powerhouse, U.S. Army Corps of Engineers, Portland District. These seven figures are intended to illustrate the general arrangement and existing conditions at the proposed test ladder.

The second group of figures (Figs. 8-14) are isometric renderings of the antenna housings installed in the Entrance Ladder to the FEL. (Note that vibrant colors are used to highlight the antenna housings and help distinguish them from the existing structure.) This group of seven figures is intended to provide an artist's rendering of the proposed installation and to allow the viewer to see that the fish passages will not be altered by installation of the proposed antenna housings.

The third group of figures (Figs. 15-25) include conceptual design drawings of the antenna housings. This group of 11 figures is intended to provide the detailed dimensions which allow verification that weir and orifice surfaces of the antenna housings match the analogous surfaces on the existing structure. In addition, these figures allow the test equipment's structural integrity to be determined.

TITLE LIST

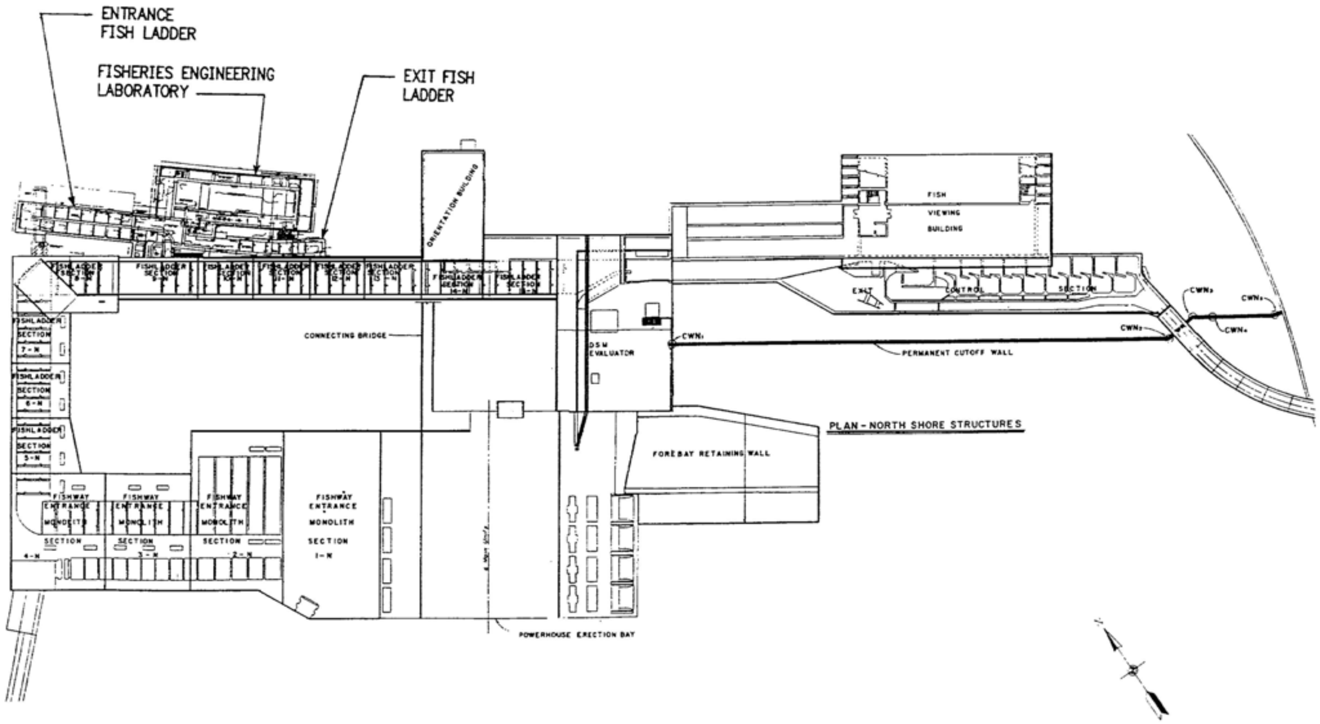


Figure 1. Shore Features - Plan

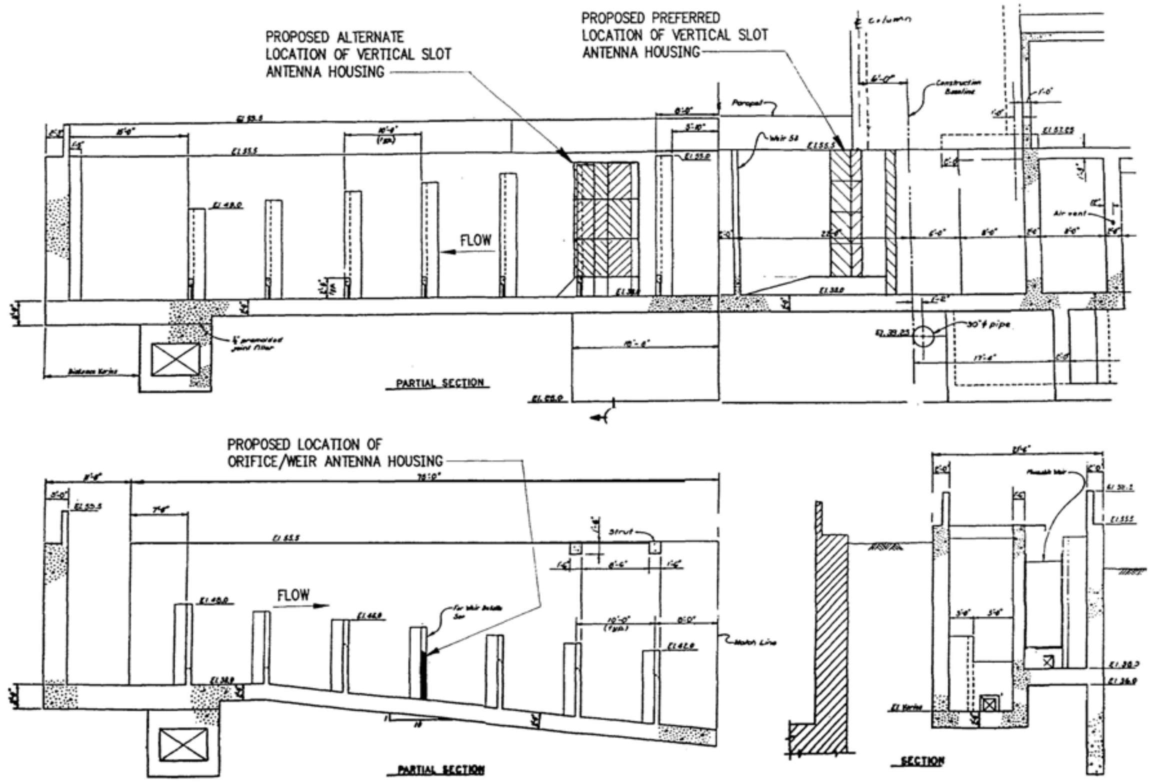


Figure 2. Fisheries Engineering Laboratory - Entrance and Exit Fish Ladders, Plan

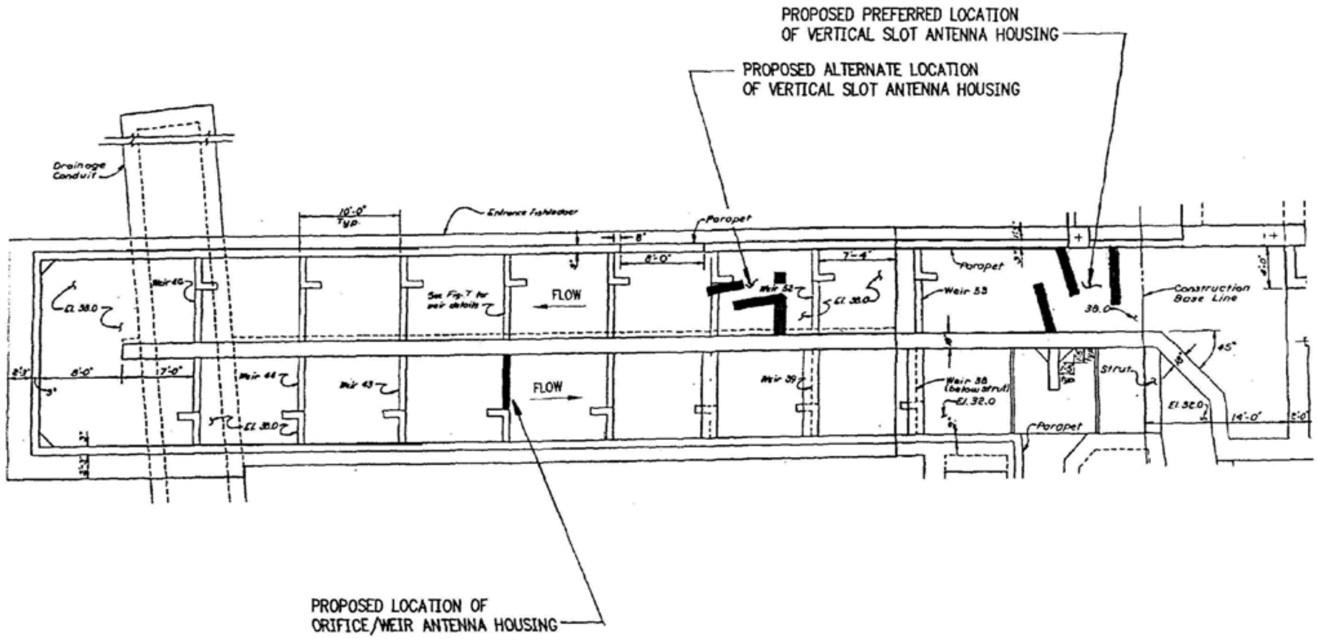


Figure 3. Fisheries Engineering Laboratory - Entrance Fish Ladder, Plan

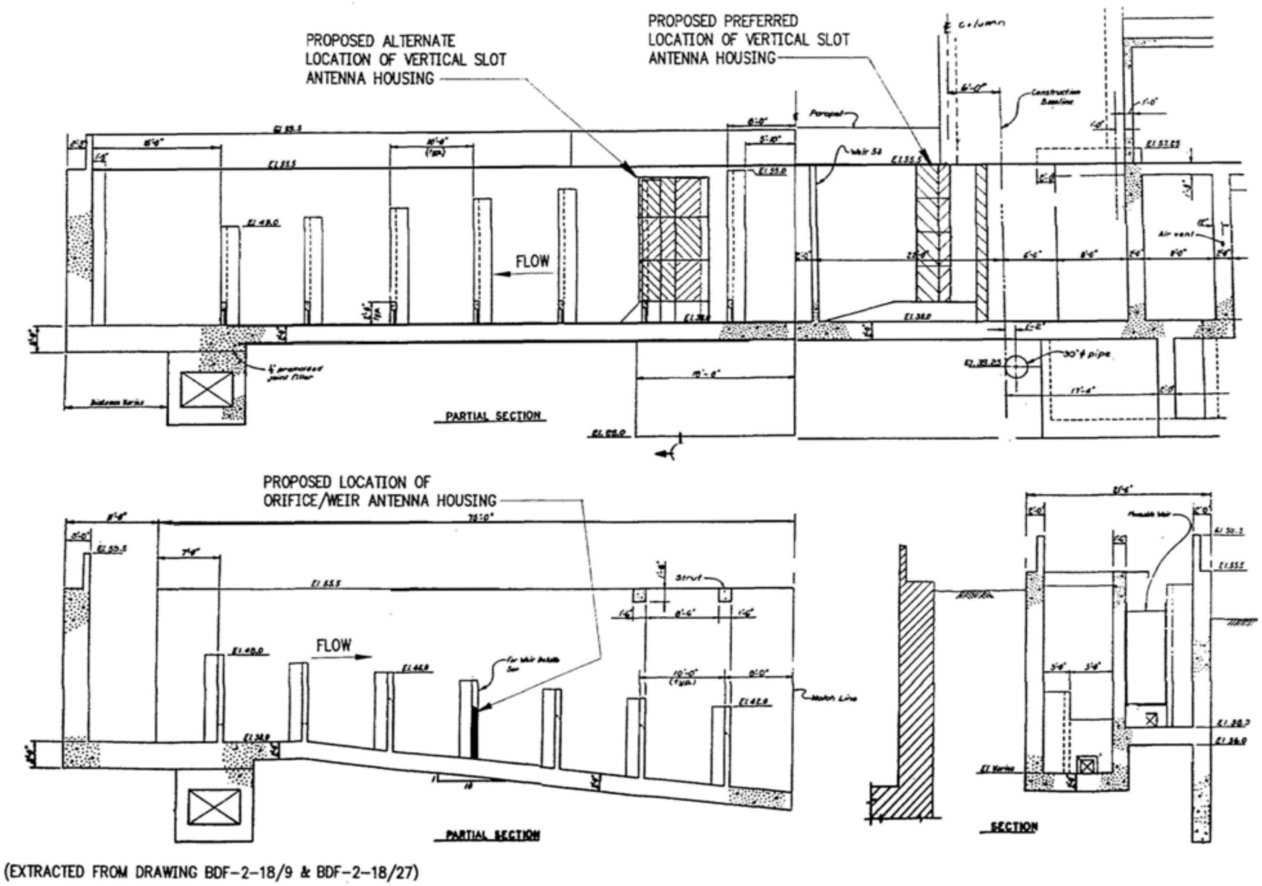


Figure 4. Fisheries Engineering Laboratory - Entrance Fish Ladder, Sections

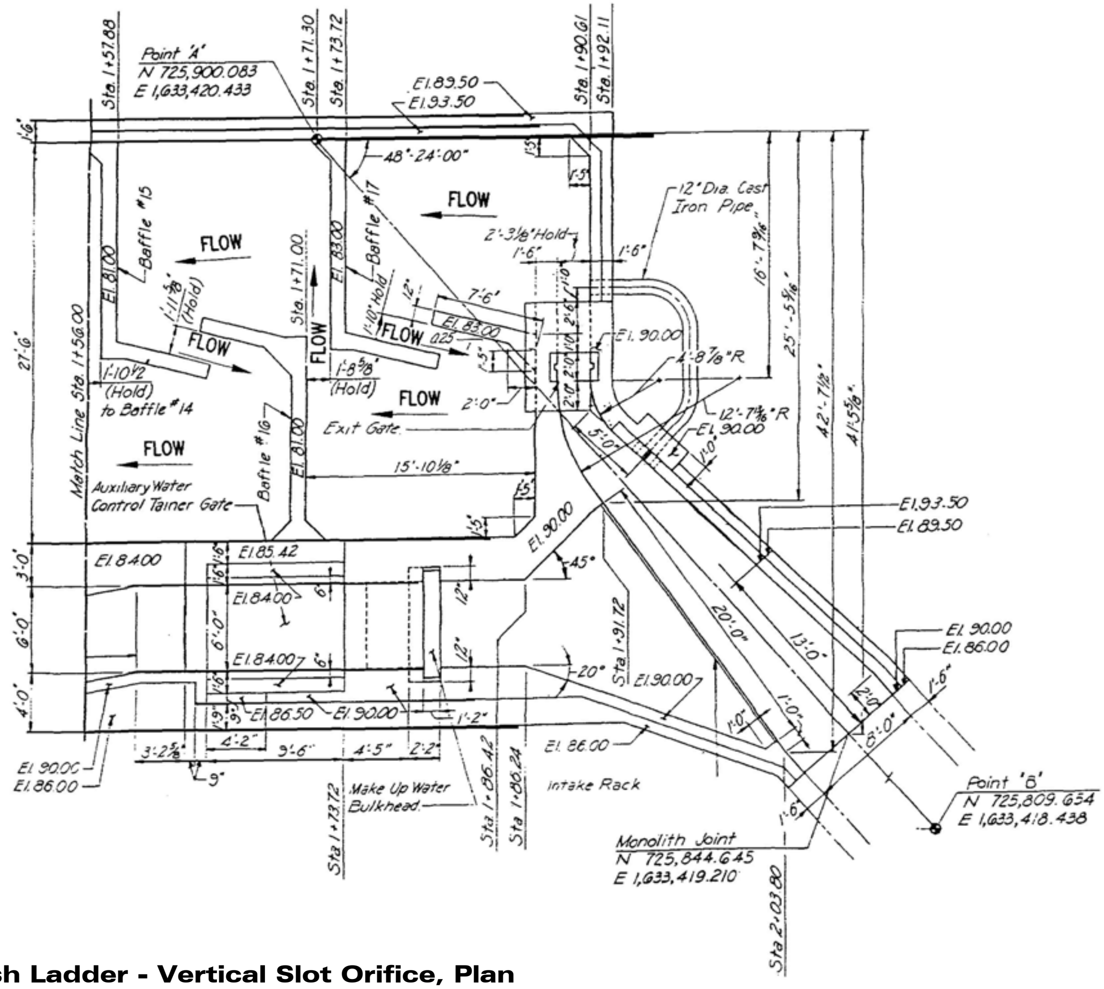


Figure 5. North Shore Fish Ladder - Vertical Slot Orifice, Plan

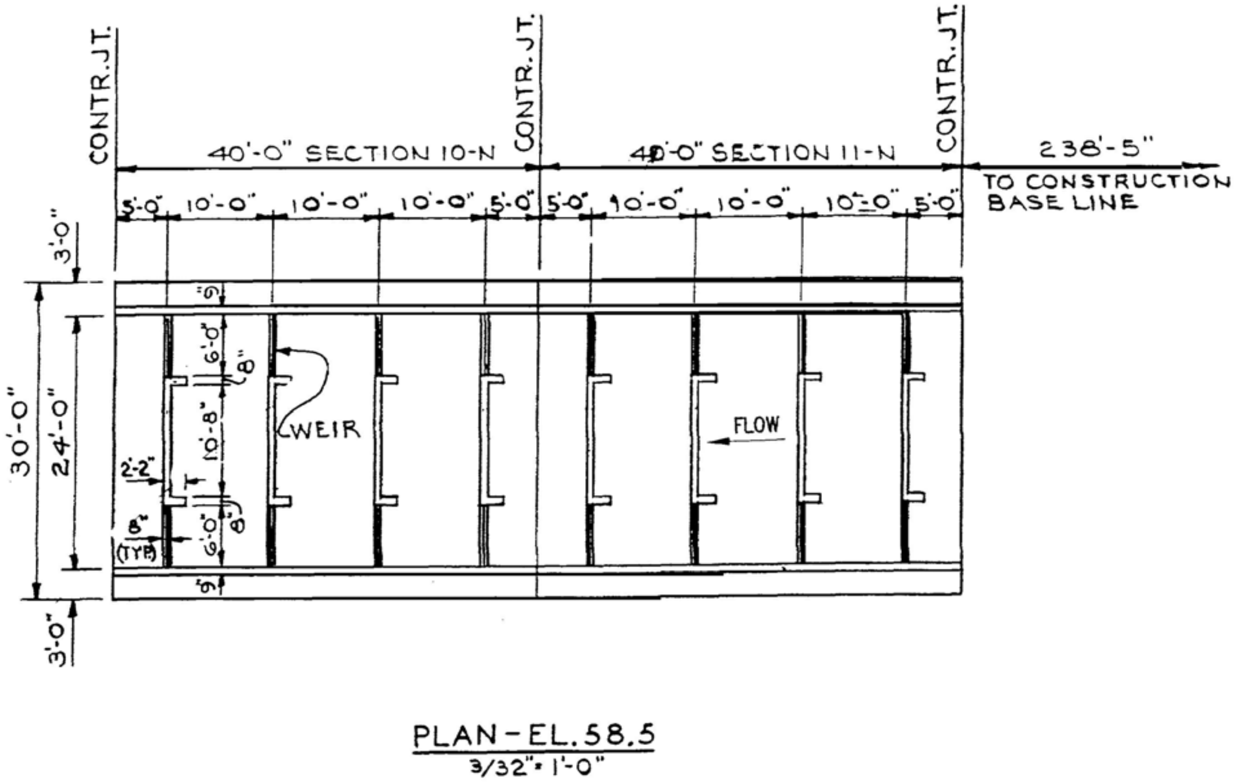


Figure 6. North Shore Fish Ladder - Orifice/ Weir, Plan

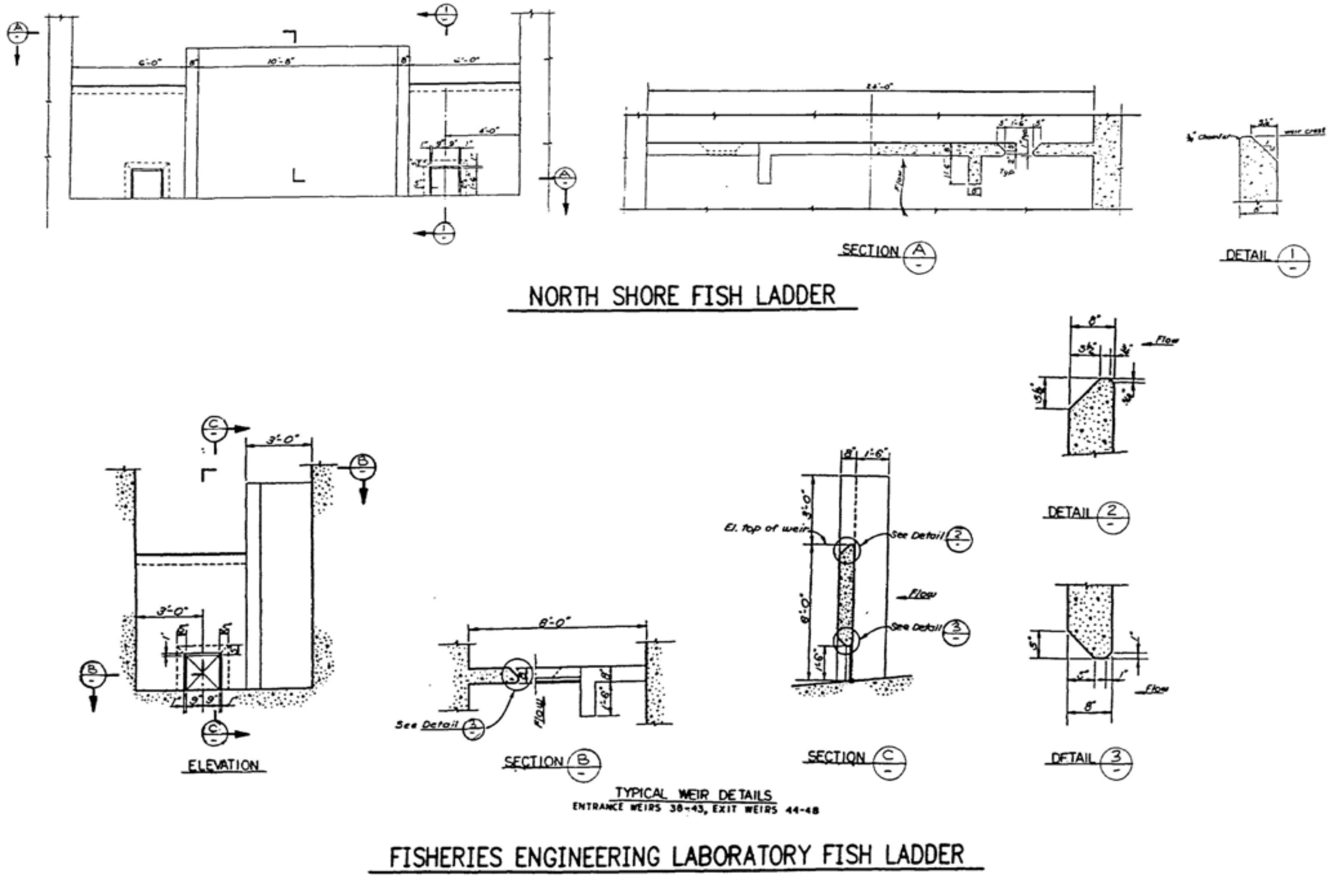


Figure 7. Existing Ladders - Orifice and Weir, Details

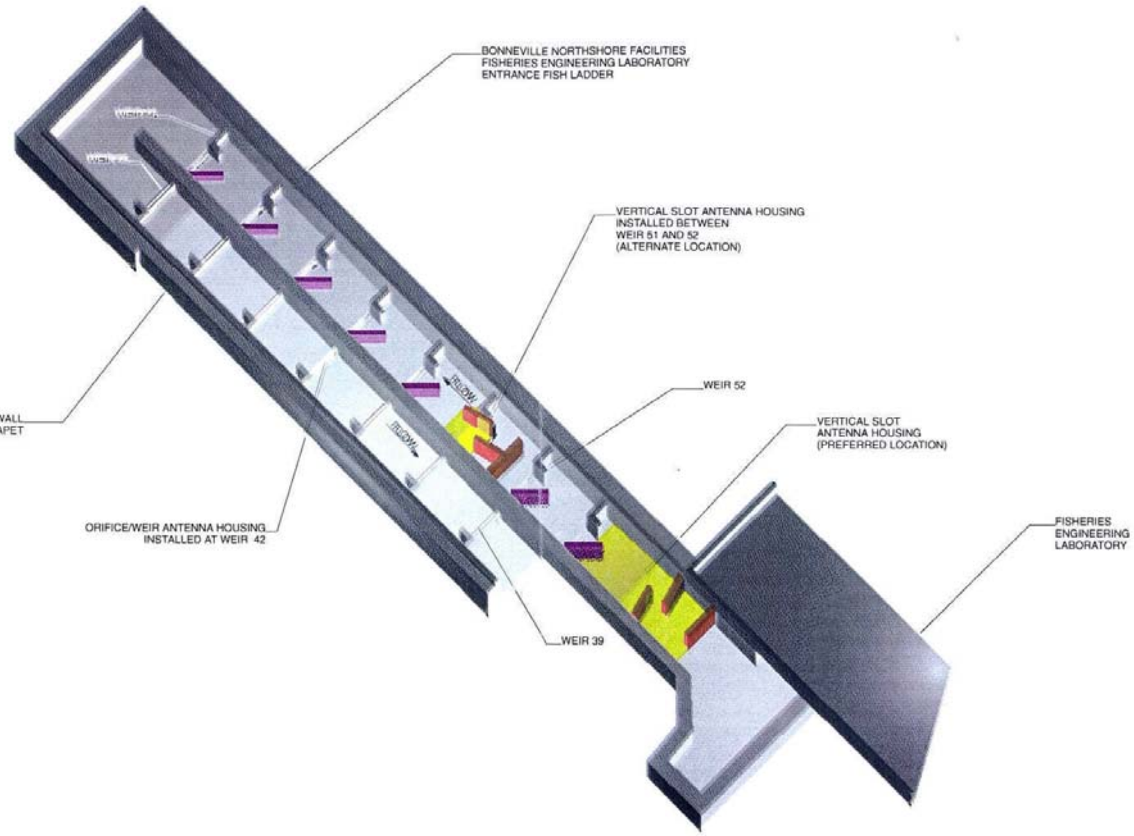


Figure 8. Antenna Housing Installation - Looking North from the Southwest

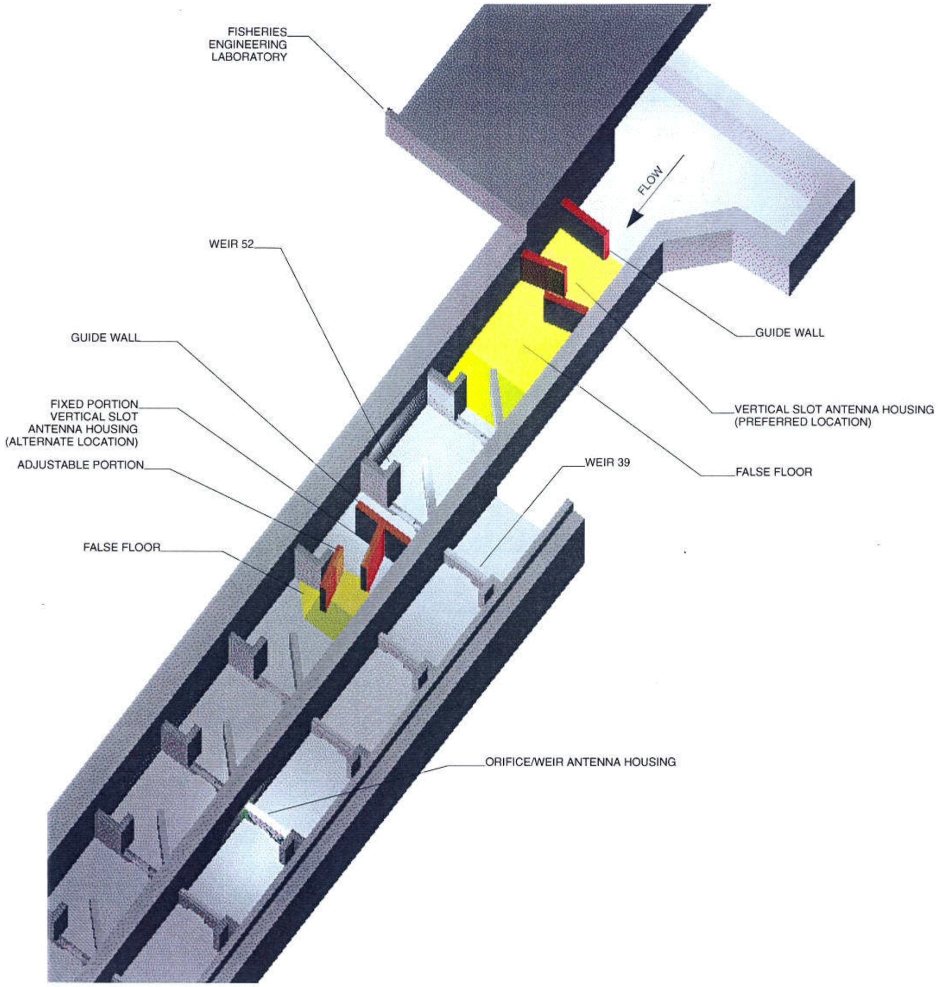


Figure 9. Antenna Housing Installation - Looking Southwest from above Weir 43

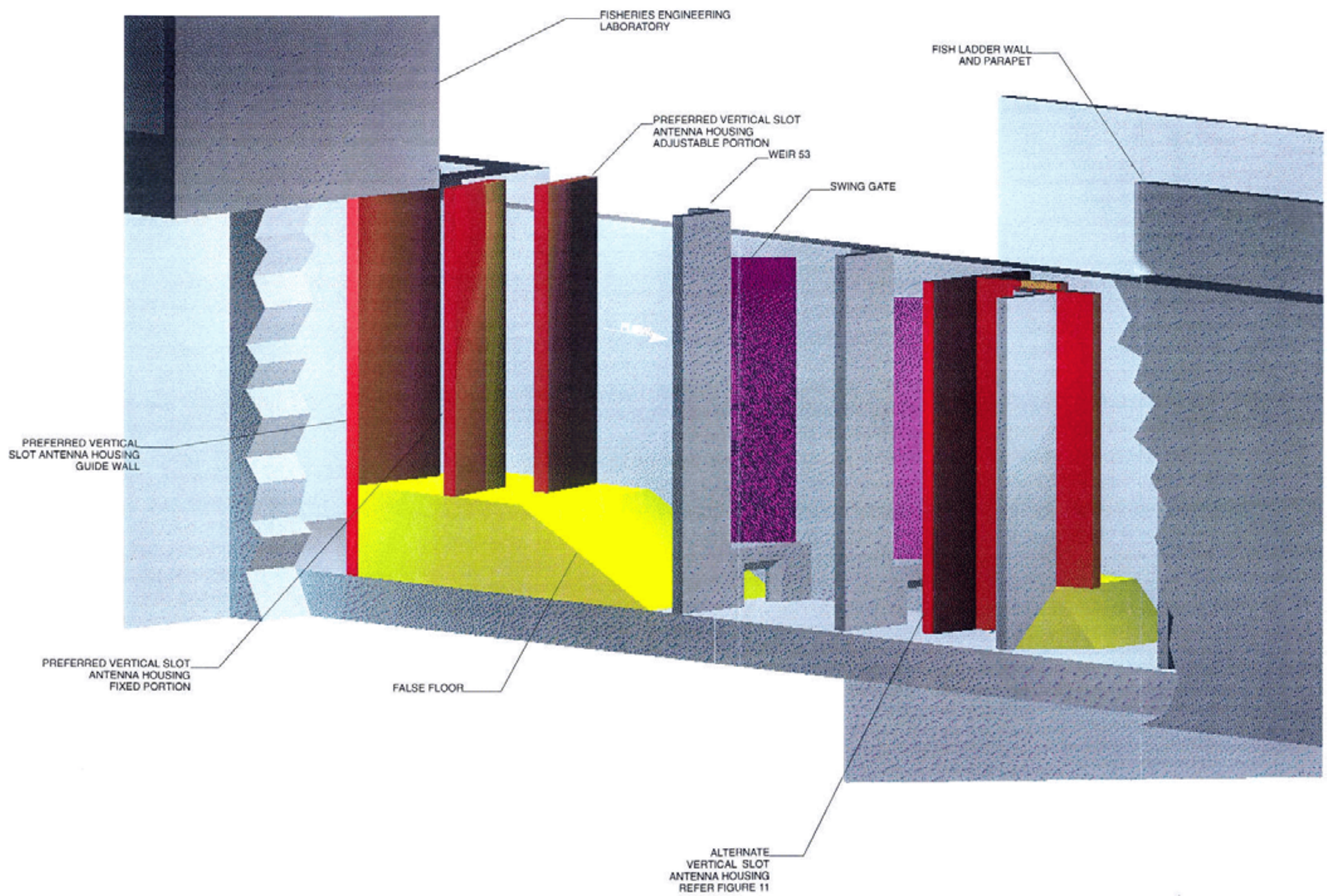


Figure 10. Antenna Housing Installation - Looking through Wall into Poo153 from Southeast

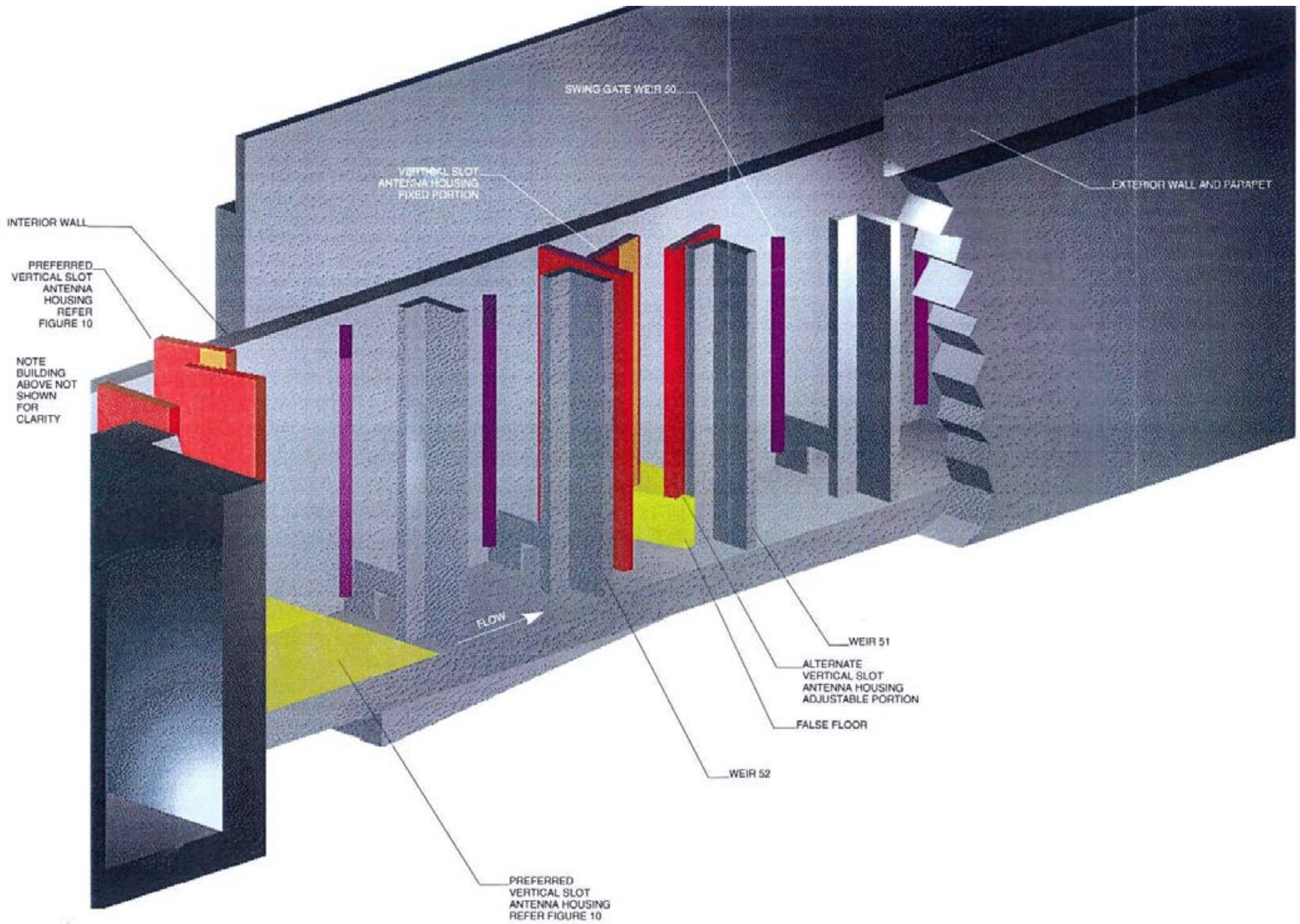


Figure 11. Antenna Housing Installation - Looking through Wall into Pool 51 from Southeast

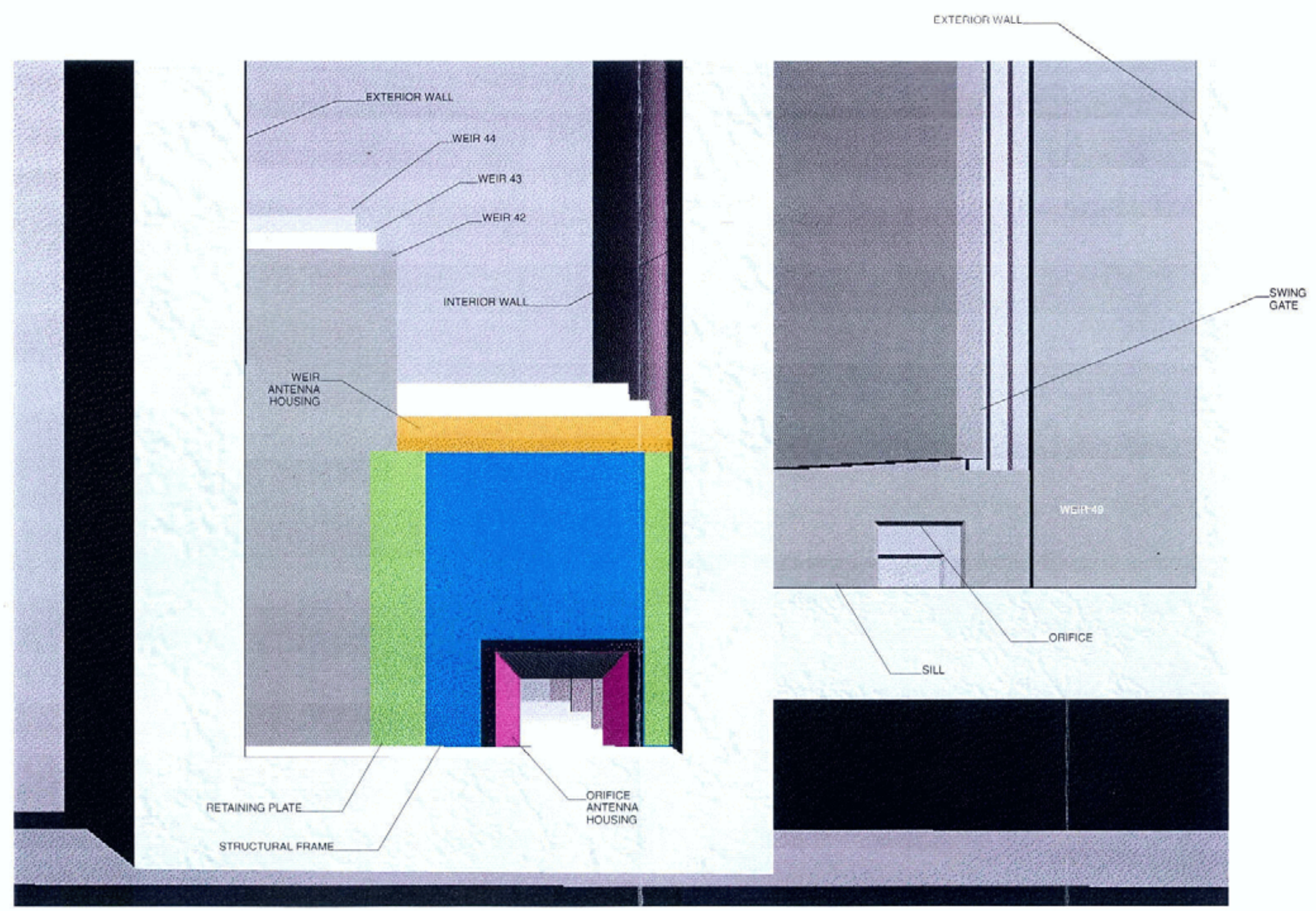


Figure 12. Antenna Housing Installation - Looking North from Just Downstream of Weir 42

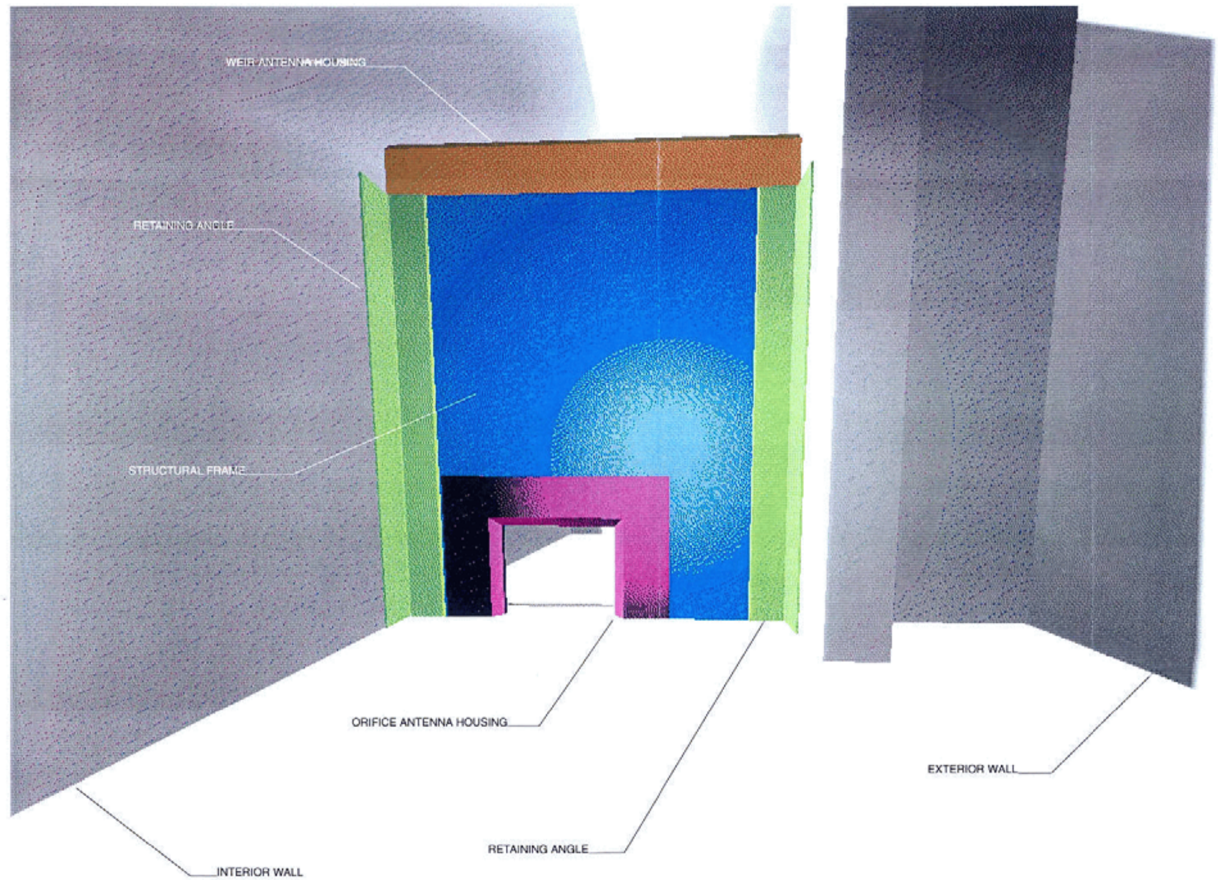


Figure 13. Antenna Housing Installation - Looking Southwest from Just Upstream of Weir 42

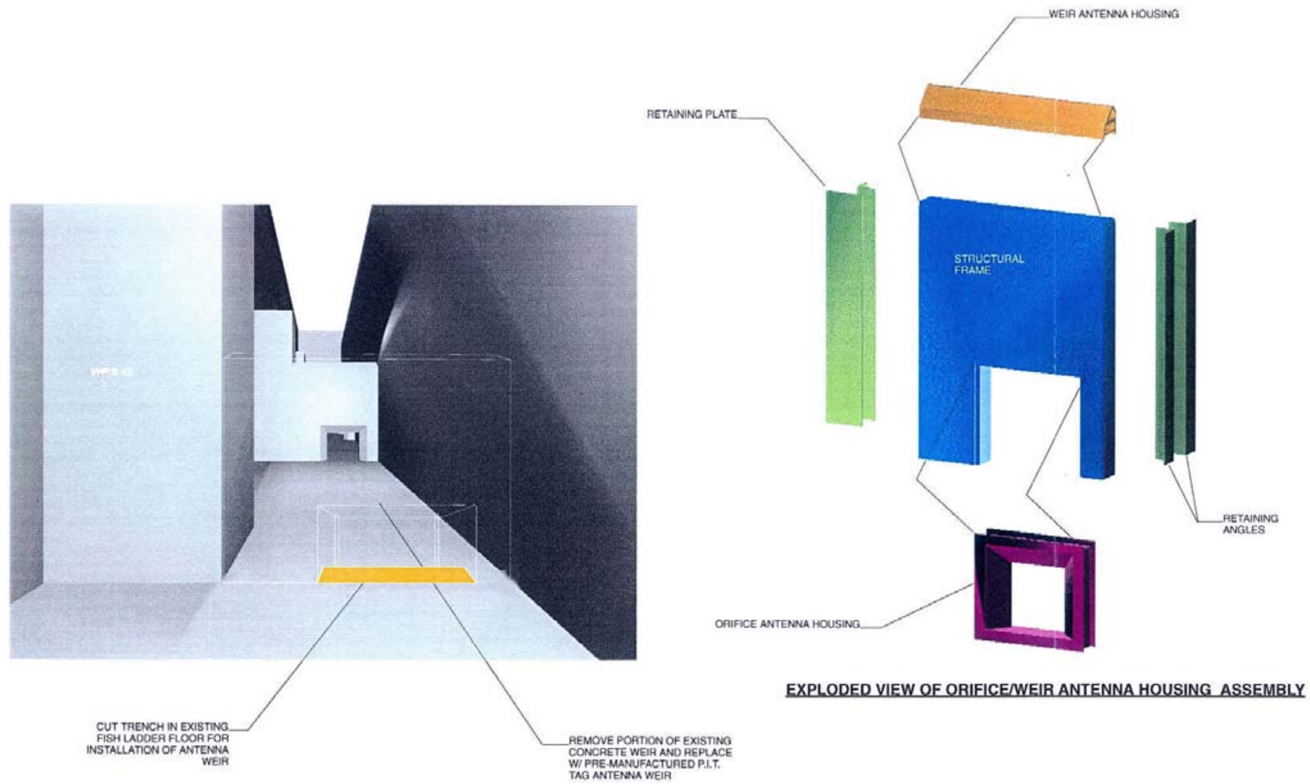


Figure 14. Weir Slot Removal at Weir 42, Exploded View of Orifice/Weir Antenna Housing

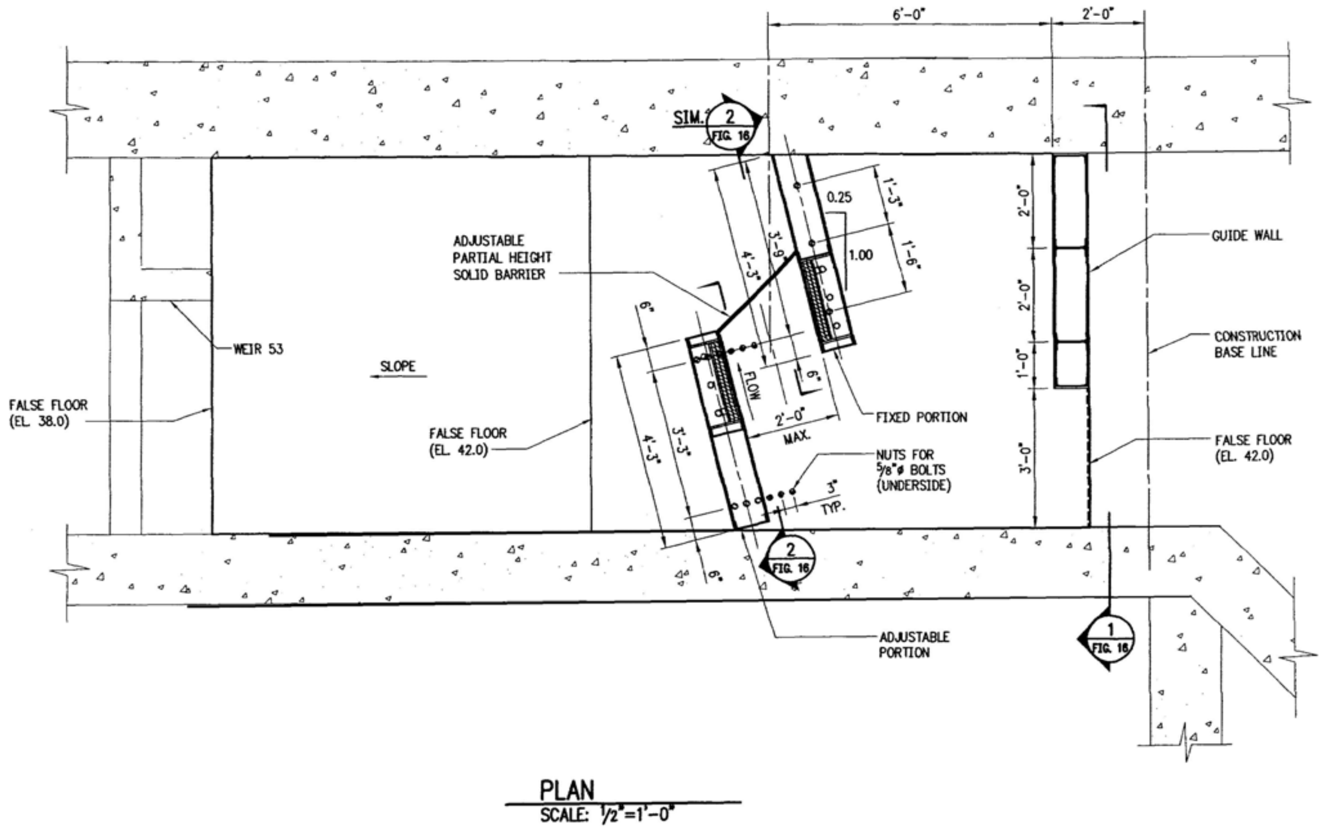
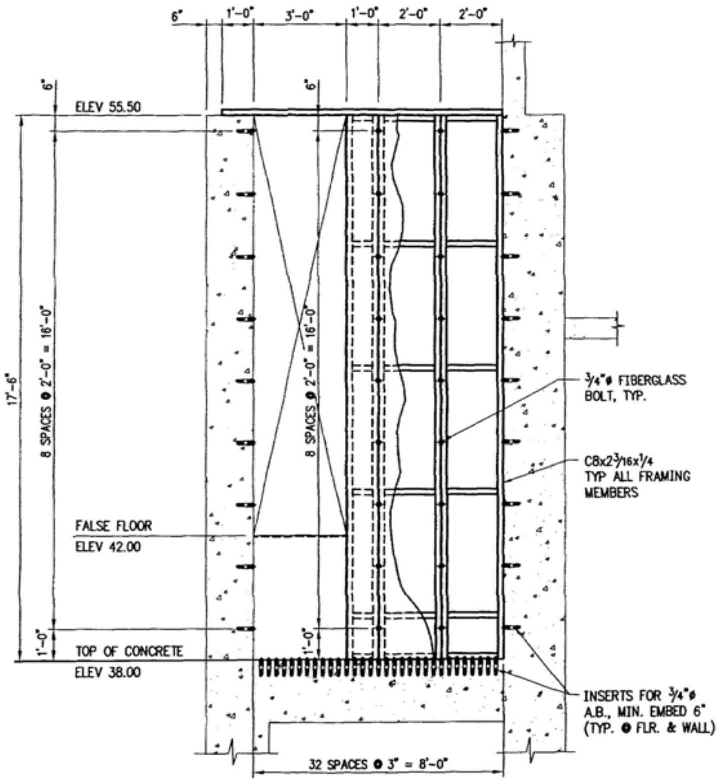
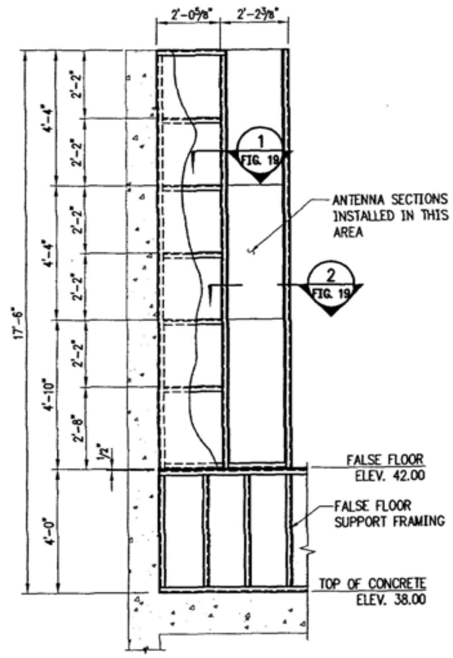


Figure 15. Vertical Slot Antenna Housing - (Preferred Location) - Plan



1 SECTION
SCALE: 3/8"=1'-0"



2 SECTION
SCALE: 3/8"=1'-0"

Figure 16. Vertical Slot Antenna Housing - (Preferred Location) - Sections

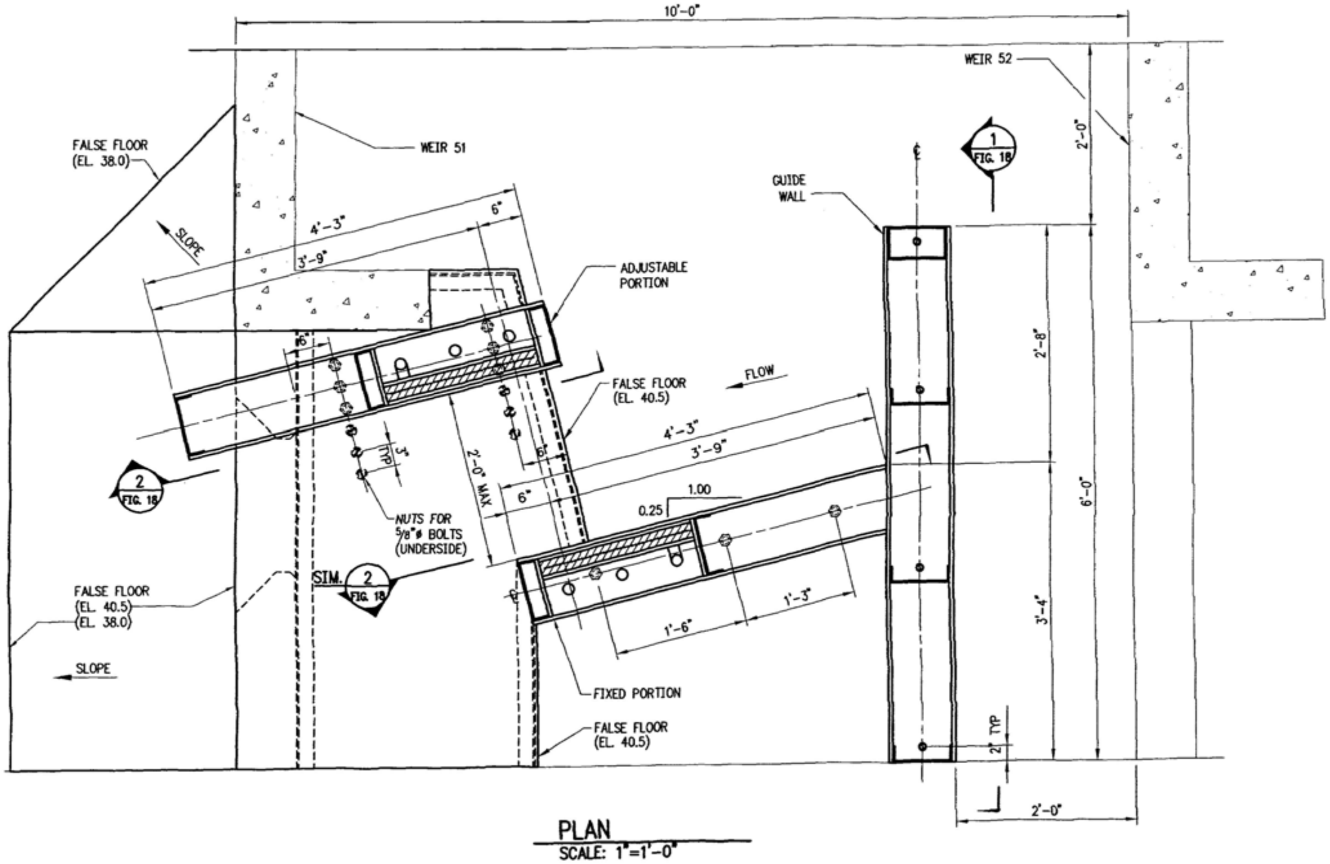


Figure 17. Vertical Slot Antenna Housing - (Alternate Location) - Plan

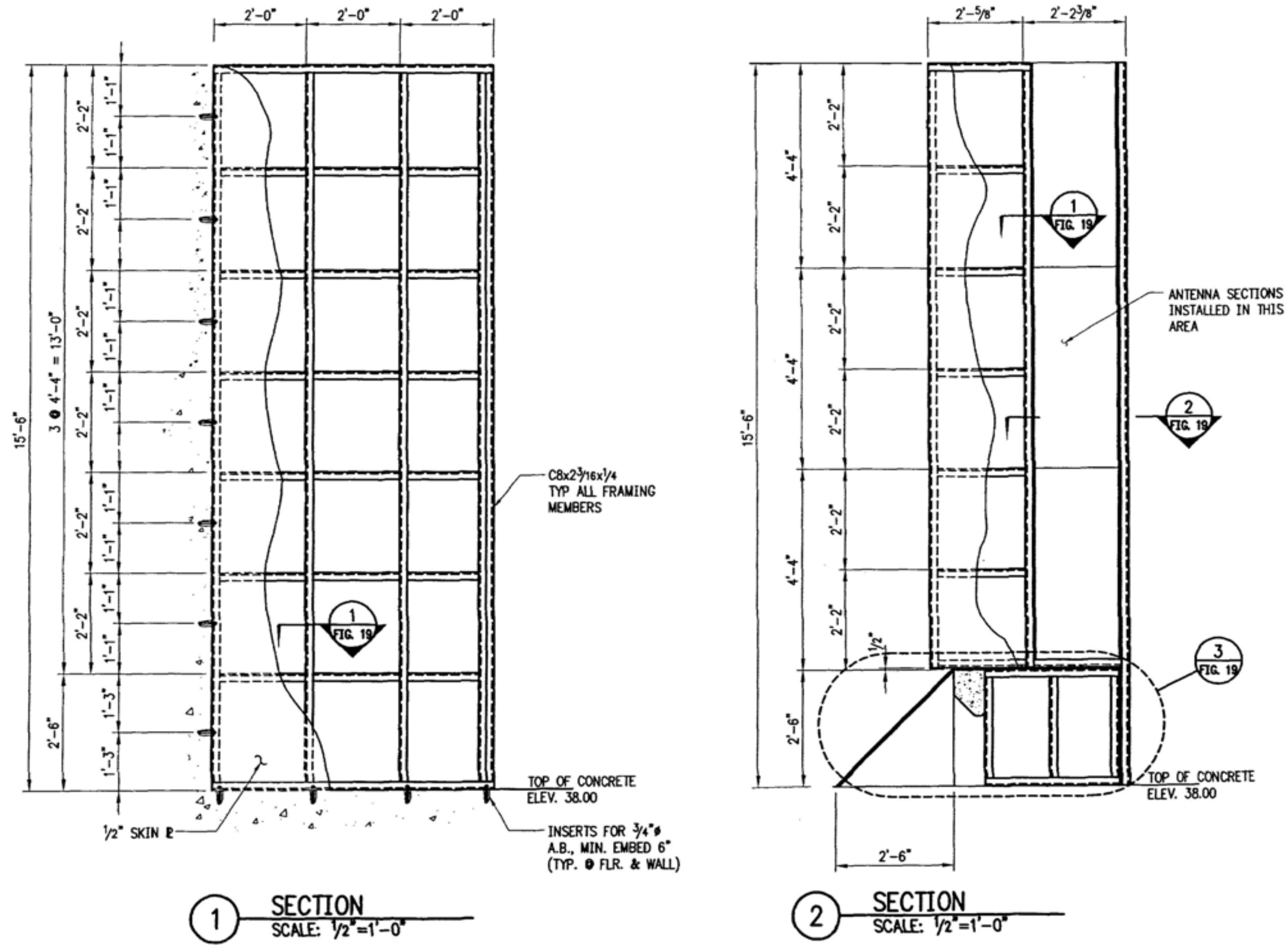


Figure 18. Vertical Slot Antenna Housing - (Alternate Location) - Elevations

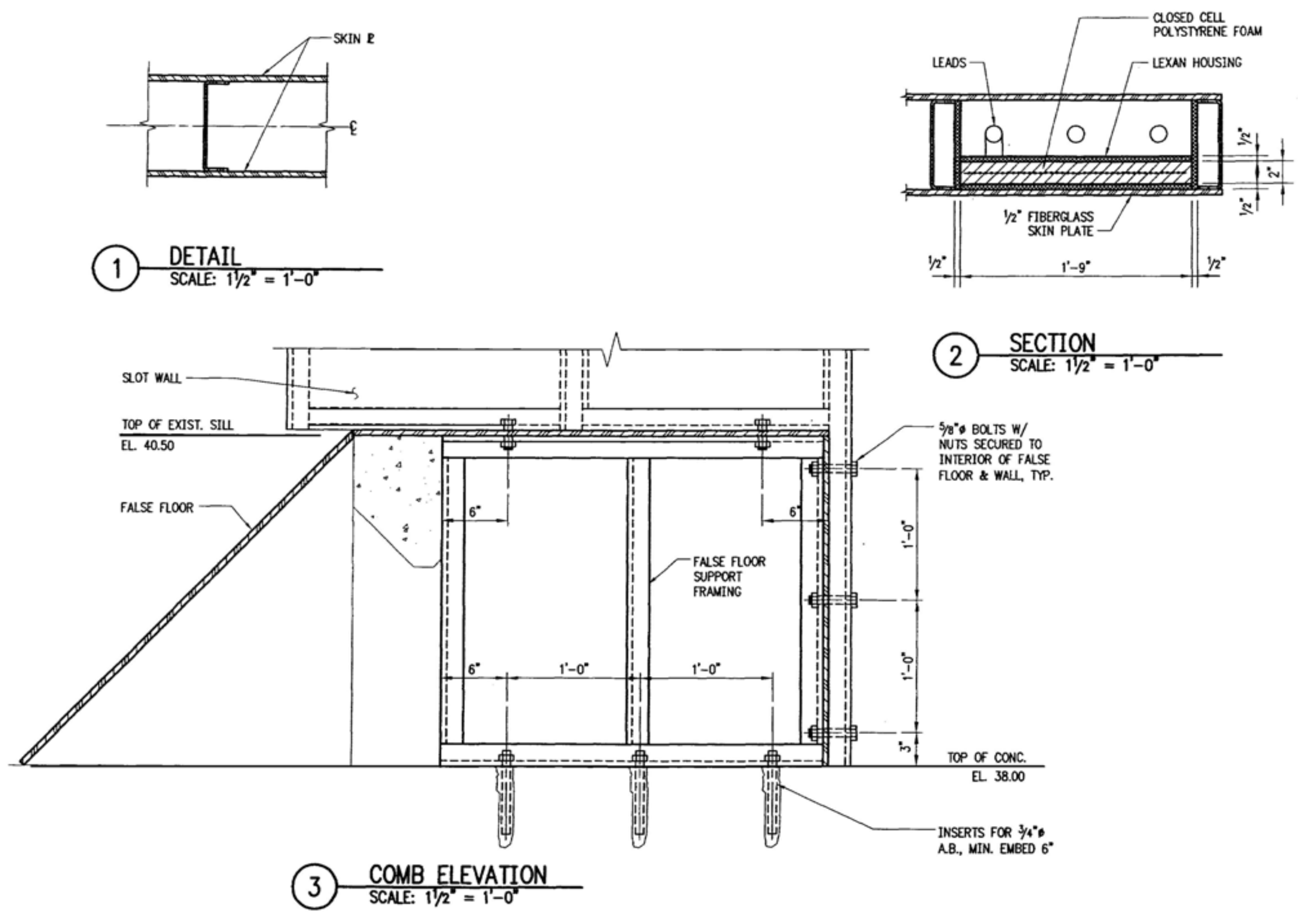


Figure 19. Vertical Slot Antenna Housing - (Alternate Location) - Sections and Details

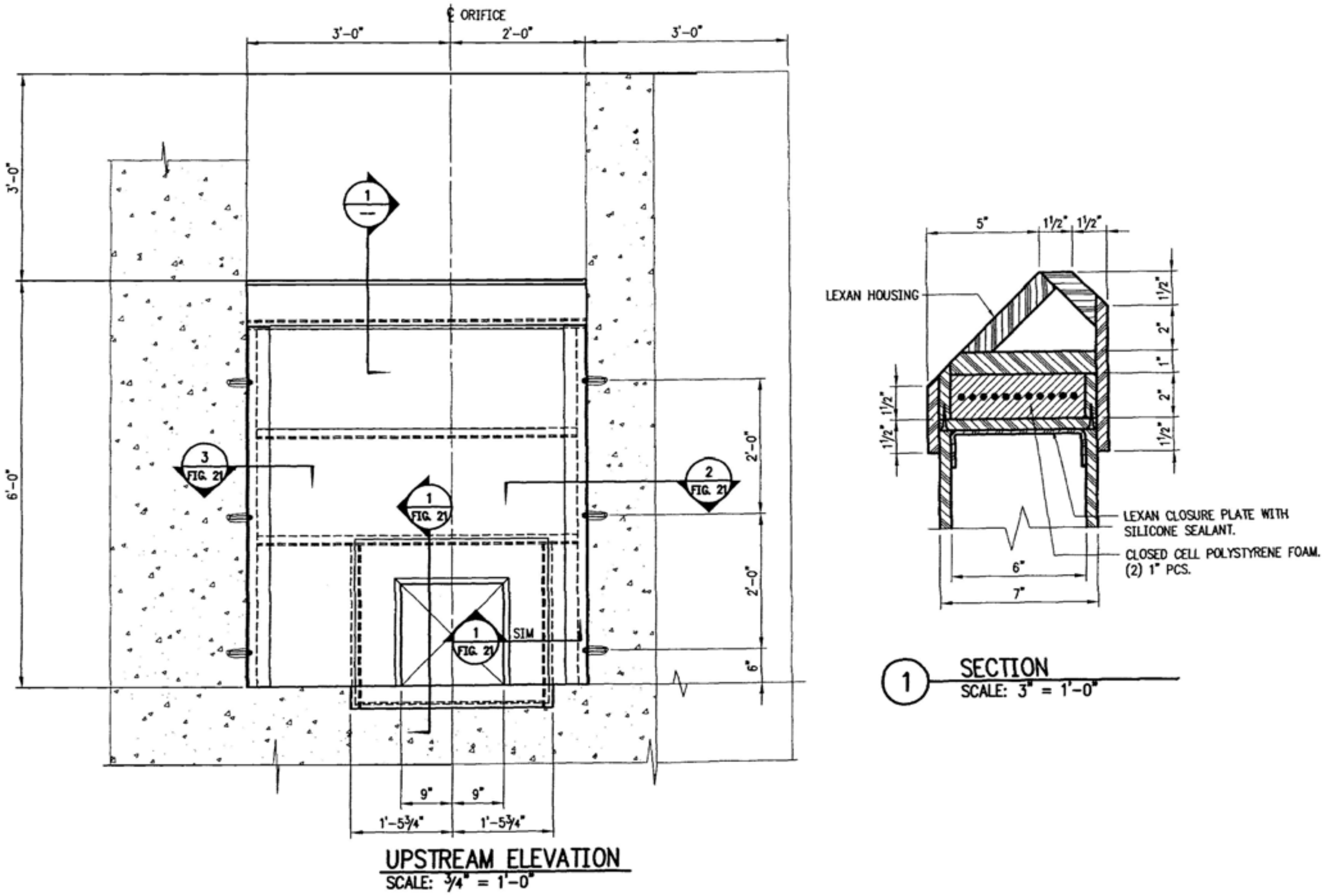


Figure 20. Orifice/ Weir Antenna Housing - Elevation and Section (Structural Fiberglass)

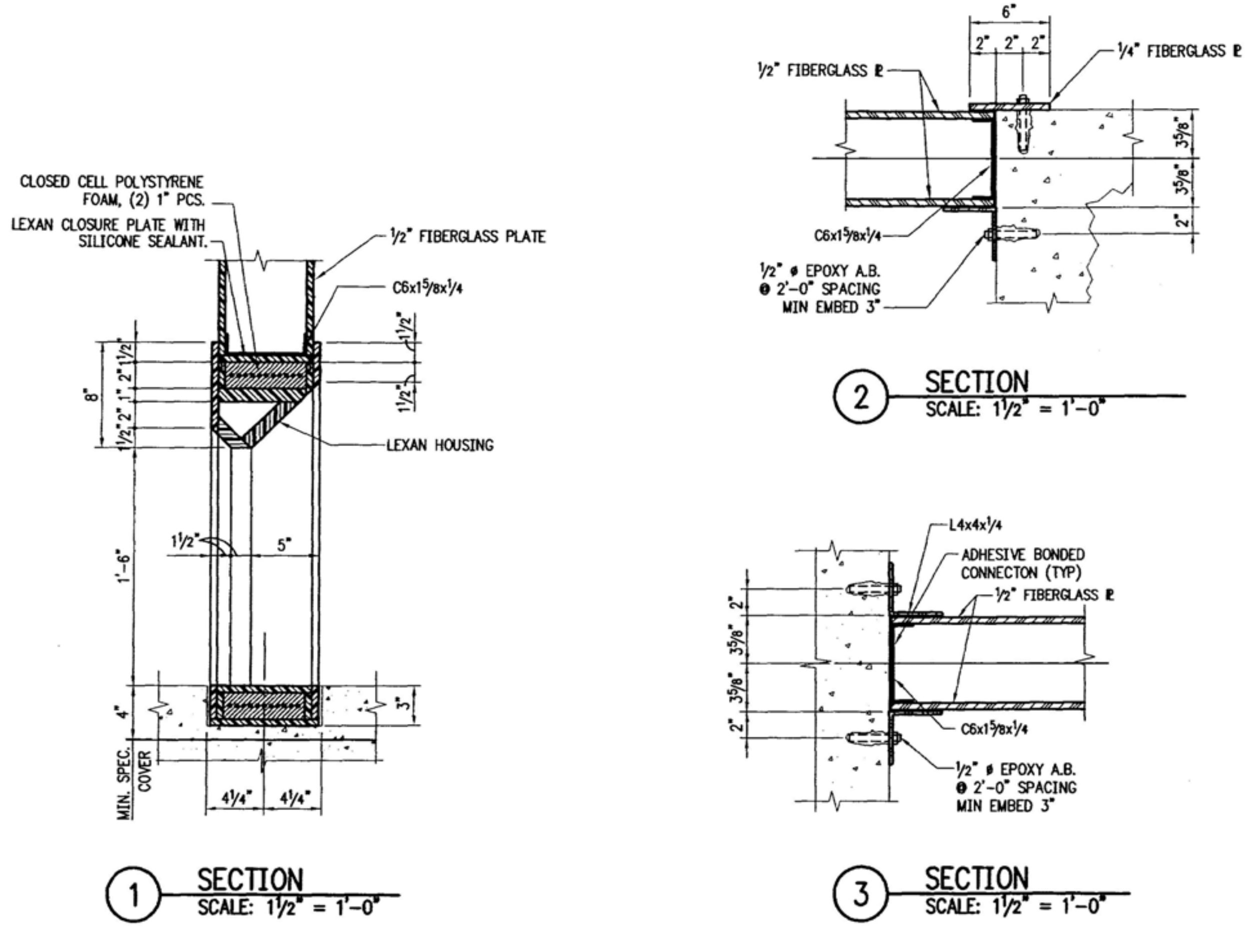


Figure 21. Orifice/Weir Antenna Housing - Sections (Structural Fiberglass)

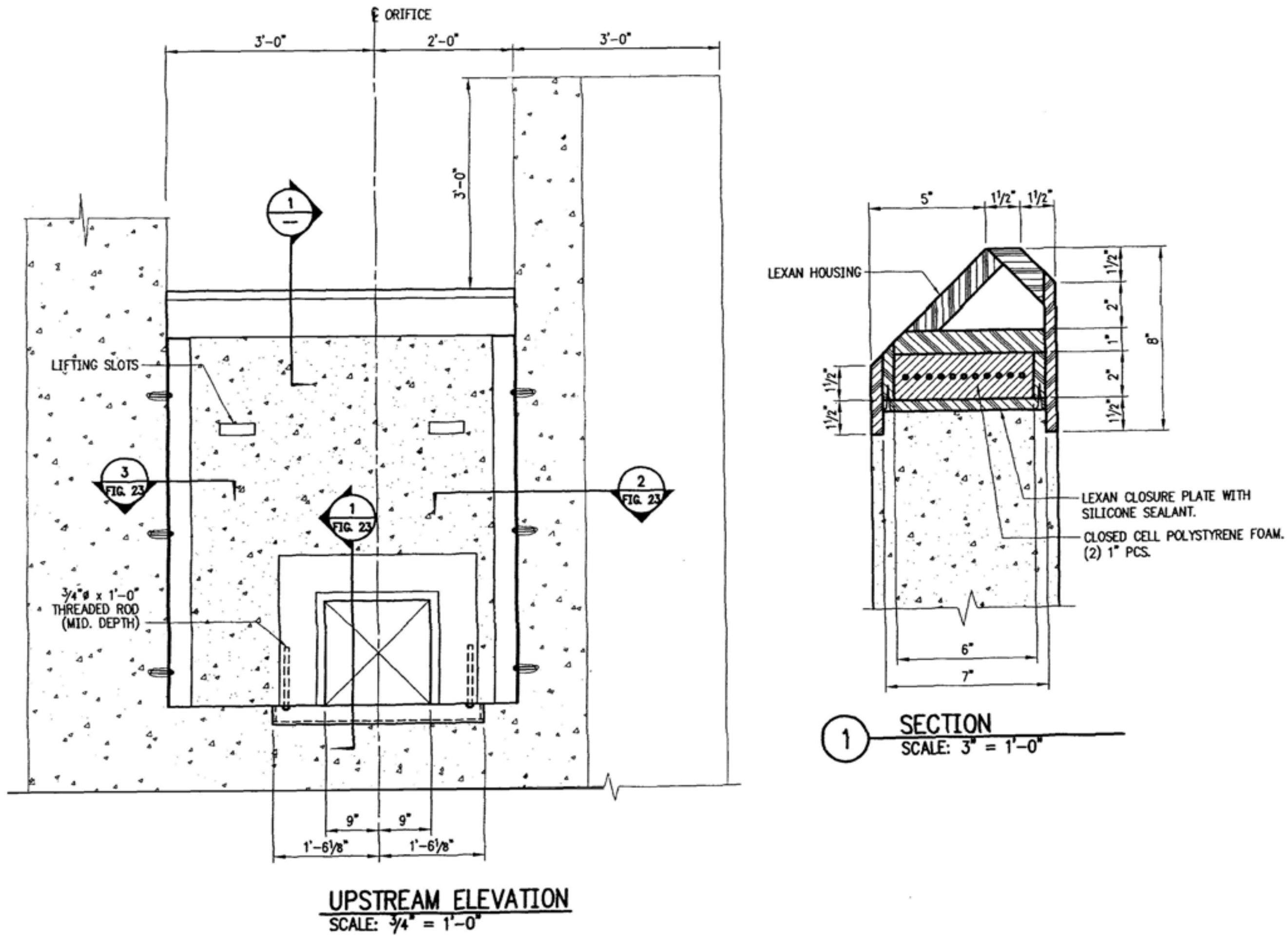


Figure 22. Oifice/Weir Antenna Housing - Elevation and Section (Fiberglass Reinforced Concrete)

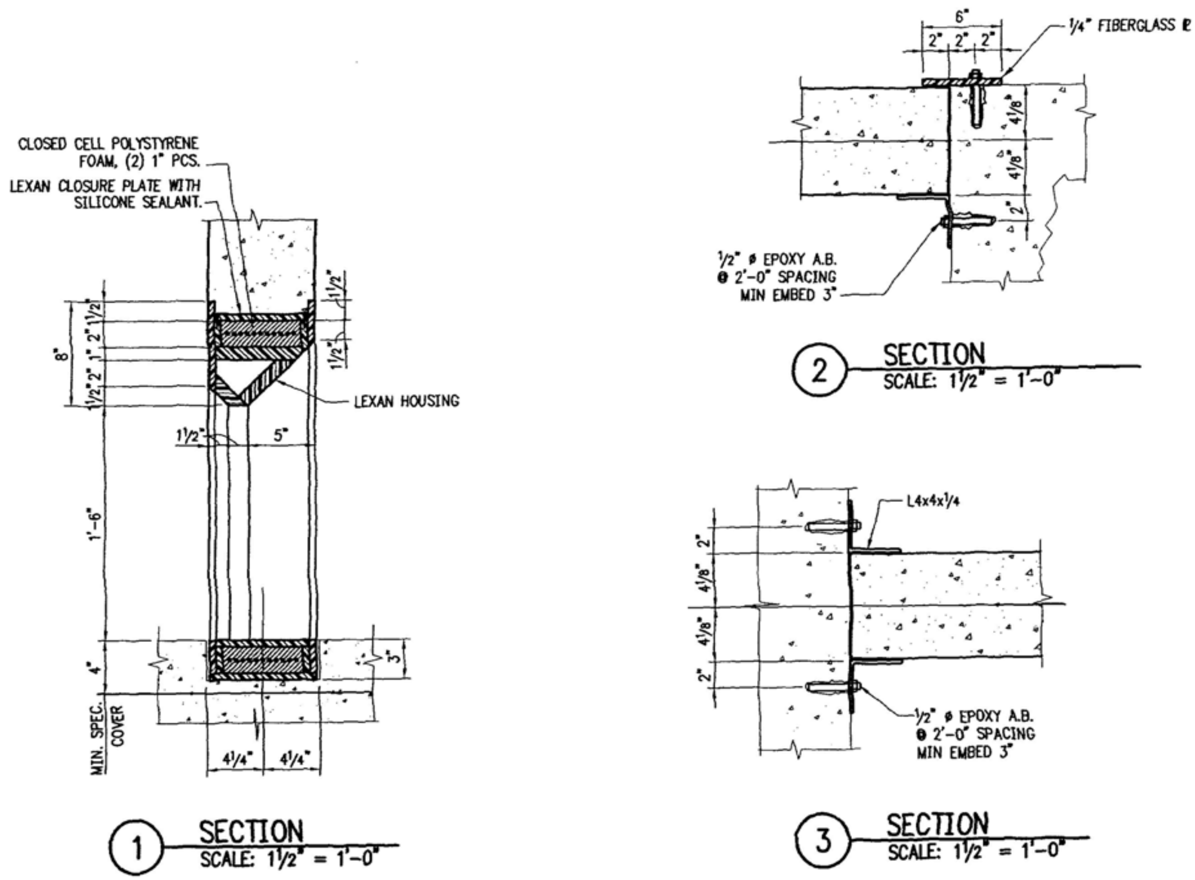


Figure 23. Orifice/ Weir Antenna Housing - Sections (Fiberglass Reinforced Concrete)

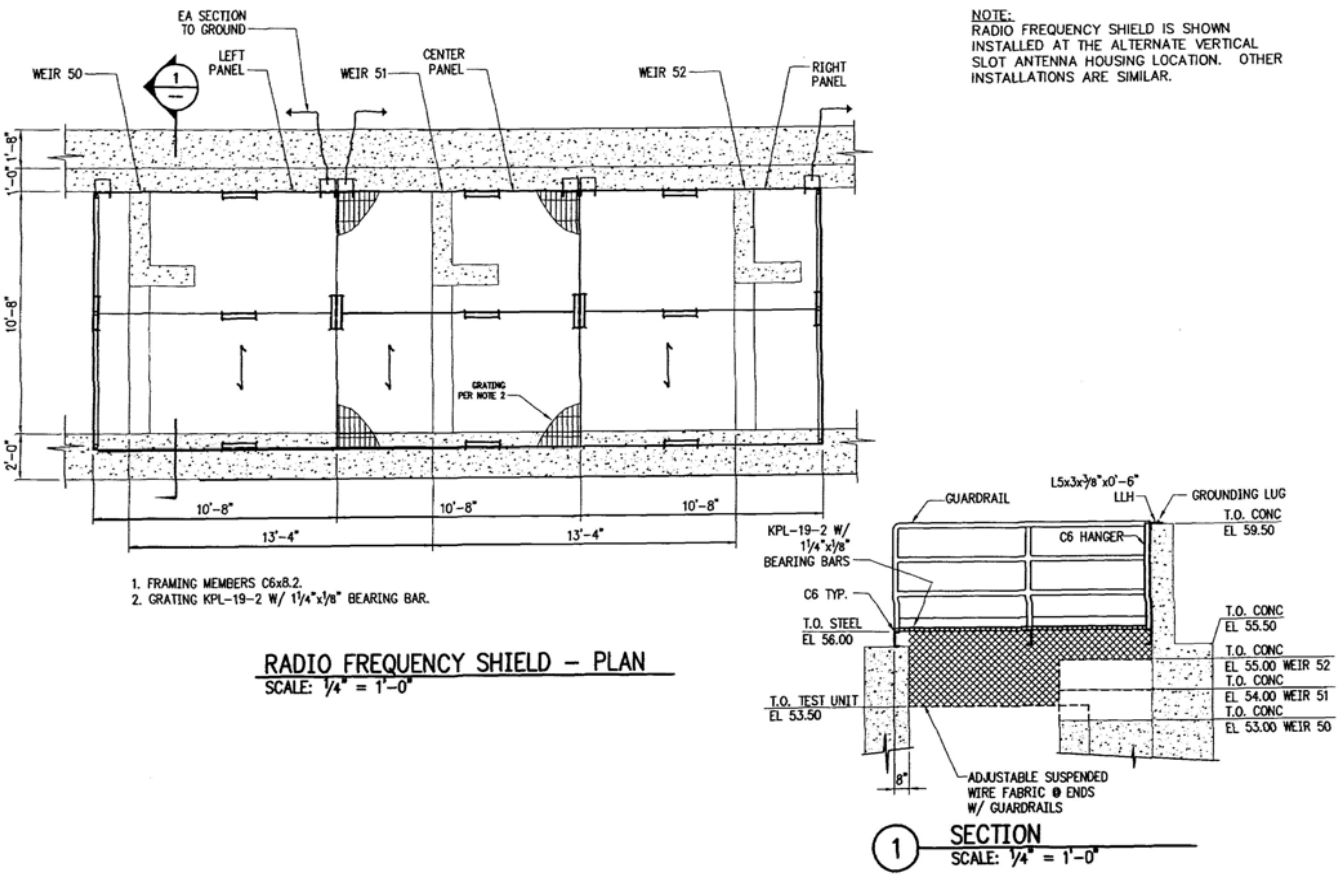


Figure 24. Radio Frequency Shield - Plan and Section

APPENDIX C

Fish behavior at Submerged Orifices. Overflow Weirs, and Vertical Slots in the Fish Ladder at Bonneville Second Powerhouse 1993-1994

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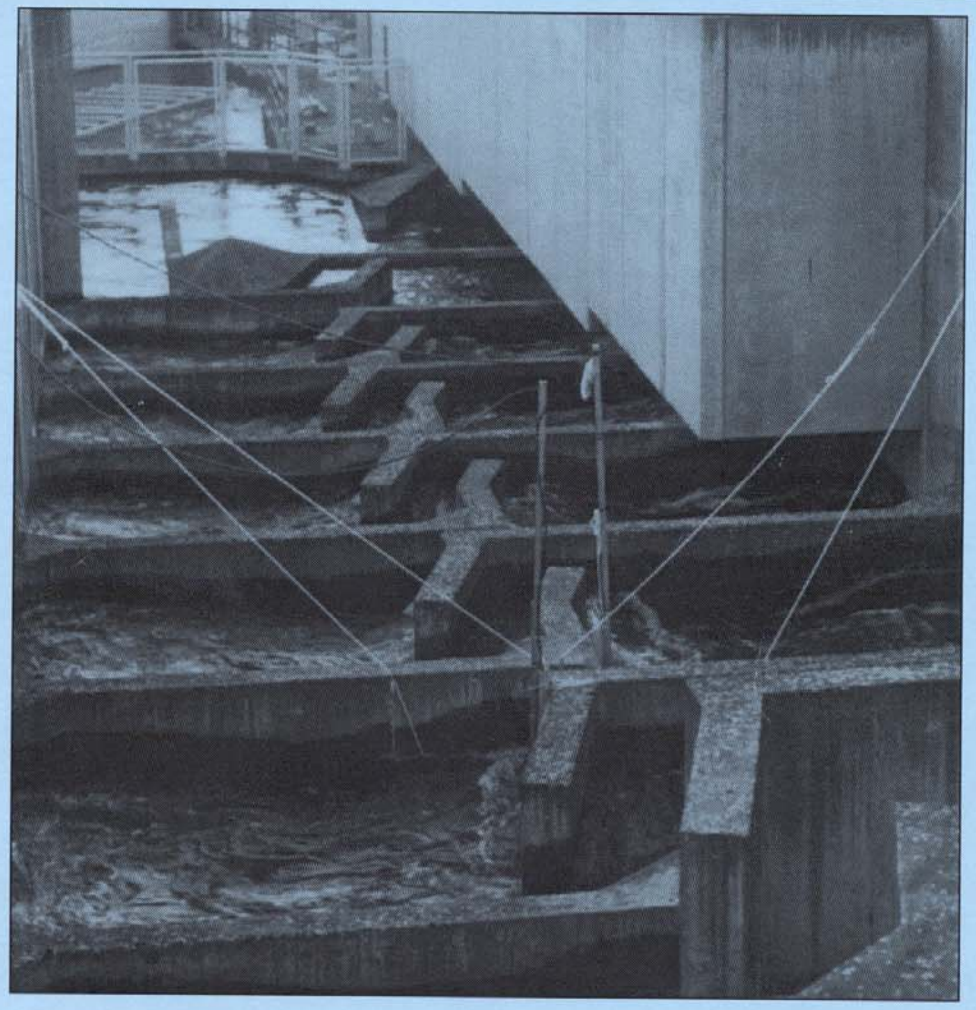

Fish Behavior

at Submerged Orifices, Overflow Weirs, and Vertical Slots in the Fish Ladder at Bonneville Second Powerhouse 1993 - 1994

June 1995

Fish Behavior at Submerged Orifices, Overflow Weirs, and Vertical Slots in the Fish Ladder at Bonneville Second Powerhouse 1993 - 1994

by

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March 14, 2003

Contents

Introduction

The National Marines Fisheries Service is developing passive integrated transponder (PIT) tag methodology to evaluate adult salmonid passage through hydroelectric projects on the Columbia River. PIT tags permit the identification of individual fish without handling after the initial marking, thus reducing stress. The best locations for PIT tag interrogators to monitor adult salmon passage at dams have not been determined. A concern regarding PIT tag interrogation systems is that they emit a strong electromagnetic field. This field may create a health risk for organisms with long exposure times (Earl Prentice personal communications,1993, NMFS, Manchester, Washington). Three potential locations for the PIT tag interrogation system to monitor adult salmon passage were identified: vertical slots, submerged orifices, and the overflow weirs in fish ladders.

Many studies have been conducted on fishways to estimate the rate of fish passage. These studies examined the time fish took to pass through different types of ladders, but not the length of time they stayed at any particular location. Elling and Raymond (1956), Long (1959), Gauley (1960), Bell (1962), Weaver (1962), and Gauley and Thompson (1963) showed median passage times ranging from 20 seconds (s) to 5.8 minutes (min) per pool for a weir and pool type ladder. Monan and Liscom (1974) showed a total passage rate of 15 min through the vertical slot section of Bonneville Dam's Bradford Island ladder. Monk et al. (1989) gave median passage times, ranging from 1.2 to 7.3 min per pool through a vertical slot ladder. Fish ladders were designed to provide resting areas (eddy and low velocity areas) and passage routes (high velocity areas). Passage routes between each pool are submerged orifices, overflow sections of weirs, and vertical slots. Most of the time that a fish spends at each pool is expected to be in the low velocity areas, resting. If the fish is in the low velocity areas most of time, the high velocity areas would be the better locations for the PIT tag interrogation systems because fish would be exposed to the electromagnetic field for the shorter time. To provide baseline data and design criteria, video cameras were used to determine behavior at the overflow sections, submerged orifices, and vertical slots.

Objectives

The objectives were to document the following behaviors of fish in specified regions of a submerged orifice, a vertical slot, and an overflow weir. This information would be used to design PIT tag interrogation systems for adult fish.

1. Establish a baseline of fish behavior prior to installation of PIT tag monitors in the region of interest.
   a. Types of fish movement.
   b. Vertical distribution of fish.

2. Establish the amount of time available to interrogate fish.
   a. Determine the amount of time a fish spends in the region.
   b. Determine the fish's velocity through the region.

Methods

Site Description

Bonneville Dam is the first dam upriver from the Pacific Ocean on the Columbia River, 64.4 km east of Portland, Oregon, at river km 234 (Figure 1). The Washington shore ladder is located on the north side of the second powerhouse (Figure 2).

Fish enter the adult passage facilities through the fish collection system (a system of floating orifices, large entrances, and channels). Fish proceed into a 7.32-m wide pool and overflow weir type ladder. Each weir is named by the elevation, in feet, of the crest of the overflow section. In addition, each weir has two 46-cm square submerged orifices on the floor of the ladder, each located 122 cm from the ladder wall, and two 152-cm wide overflow sections 183 cm from the ladder floor next to each wall (Figure 3). After the ladder, fish enter a junction pool where they join fish from the Cascades Island entrance. Fish are then crowded to facilitate counting. After passing the count station, fish pass into a section of pools (for this study, the numbering for pools at the vertical slots started at 1 at the count station) and vertical slots (Figure 4). After the section of pools and vertical slots, the fish enter a channel which exits into the forebay.

Sampling Locations and Equipment

The submerged orifices of weir 65 and weir 66, were observed with two Simrad Osprey cameras[1], model OE1359, rated at 0.03 lux with a 90° diagonal field of view. The cameras were 0.53 cm in diameter and 1.52 cm in length. One camera was placed facing weir 65 and the other camera facing weir 66 (Figure 5).

A frame, 172-cm wide by 276-cm long by 274-cm tall, was used to secure the cameras in the ladder for observing submerged orifices. This procedure allowed deployment without dewatering or modifying the ladder. A 46-cm wide, white metal plate attached across the bottom at each end of the frame added contrast to the floor of the fishway for the camera. On the plate were lines that were 15.2 cm apart, parallel to the flow. The cameras were placed in three locations designated as stations. The locations were:

Station 1. One camera was located 32 cm upstream from the weir 65 south orifice, 158 cm from the wall, and 20 cm off the fishway floor. The second camera was located 36 cm downstream from the weir 66 south orifice, 158 cm from the wall and 20 cm from the fishway floor.

Station 2. Bubbles hindered the view at station 1, so both cameras were moved 28.5 cm farther away from the orifices. One camera was located 56 cm upstream from the orifice, 158 cm from the wall, and 20 cm from the fishway floor. The second camera was located 58 cm downstream of the orifice, 158 cm from the wall, and 20 cm from the fishway floor (Figures 3 & 5).

1. The use of trade names does not imply endorsement by the government.

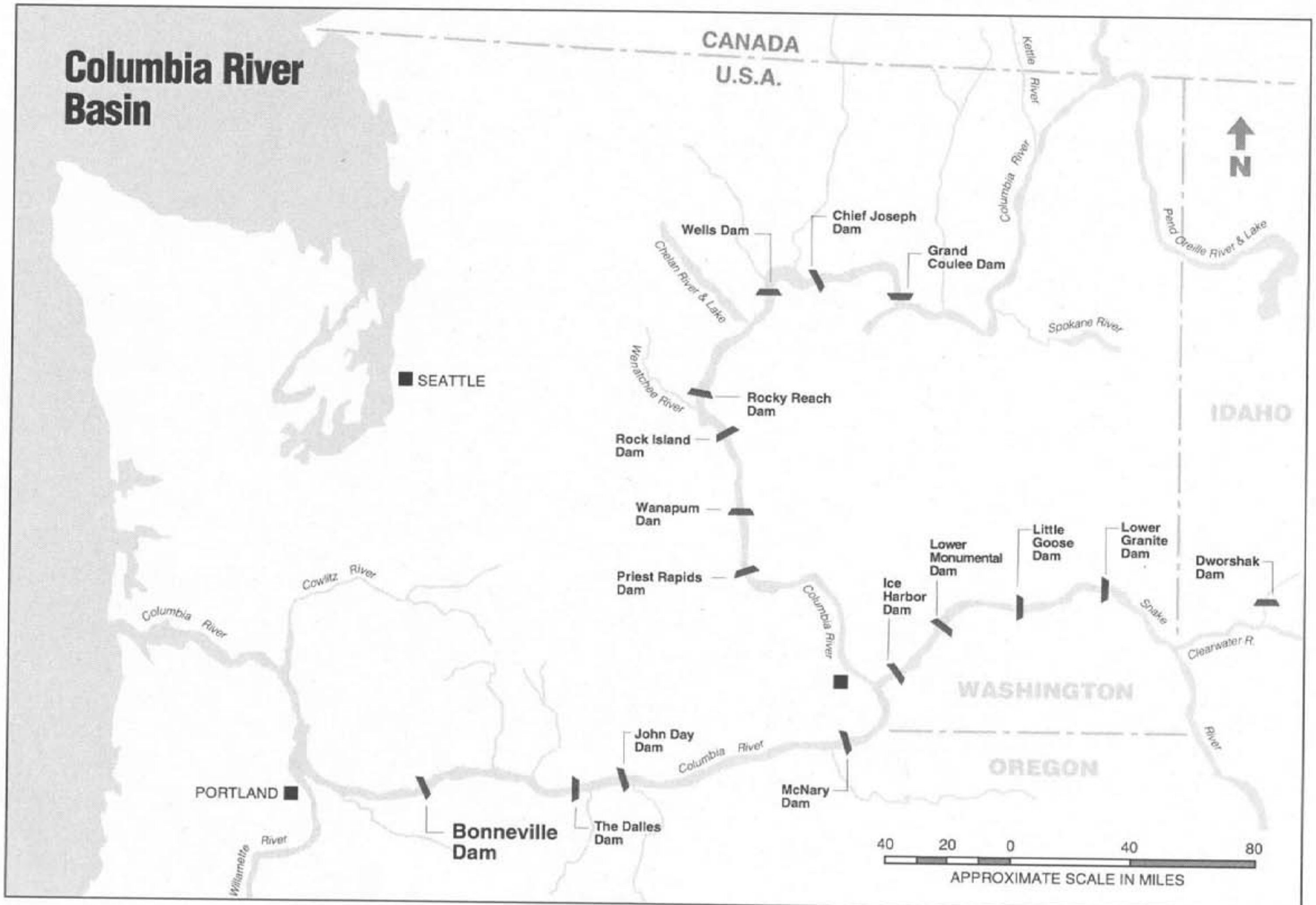

Figure 1. Columbia River Drainage.

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4

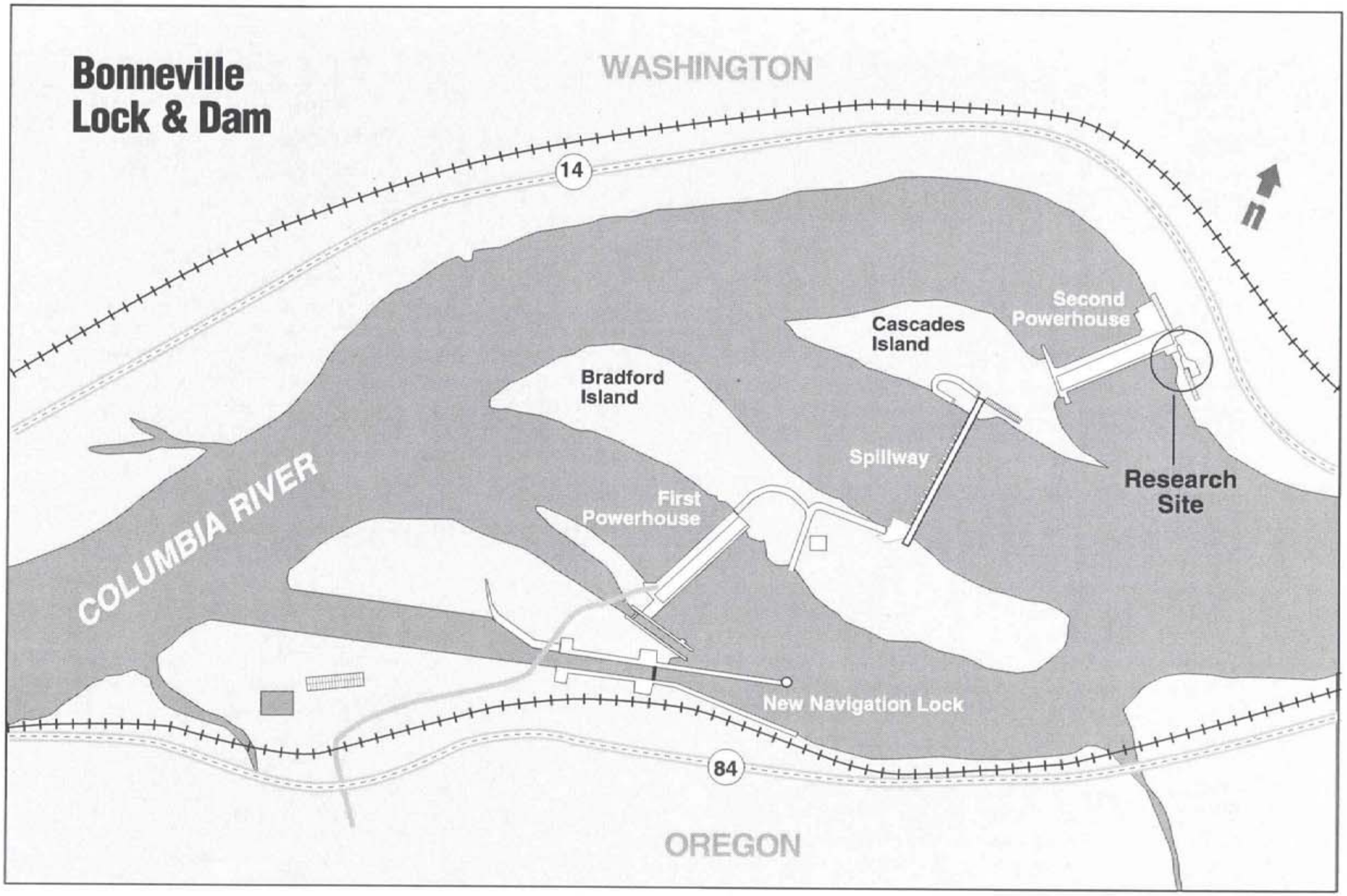


Figure 2. View of Bonneville Dam.

Station 3. Both cameras were moved to observe fish behavior between the orifice and the ladder wall (Figures 3 & 5). One camera was located 91 cm upstream from the orifice, 13 cm from the wall, and 25 cm from the fishway floor. The second camera was located 91 cm downstream of the orifice, 13 cm from the wall, and 25 cm from the fishway floor (Figures 3 & 5).

At weir 67, one Photosea Nighthawk SIT camera, rated at 0.01 lux with a field of view of 110° diagonal, 98° horizonal and 81° vertical, was suspended directly over the overflow on the south side of the weir. The cameras were 0.95 cm in diameter and 2.98 cm in length. The camera was first placed 129.5 cm above the weir and then lowered to 76.2 cm. During the fish ladder's last maintenance period, the top of the weir had been painted white (Figure 5).

At the vertical slot between pool 8 and 9, aluminum guides were installed in the winter of 1993-1994 to allow cameras and white panels with grid marks to be installed during the study. The white panels with grid marks were placed on the wall opposite the camera so that the fish had to swim between the white panel and the camera. This allowed fish location, velocities, and depths to be recorded. One camera was positioned downstream and one camera was positioned upstream of the vertical slot. These cameras were identical to the one used at the overflow weir. The cameras were 76.2 cm from the weir they faced and were 20.3 cm from the weir to which they were attached (Figure 6).

The equipment was washed with unscented soap to remove any human scent and then rinsed before being placed in the fishway. If the equipment was handled after being washed, rubber gloves were worn or the equipment was washed again. Except for installing the overflow weir camera, all adjustments were made after dark.

Information Recorded

The following data were collected from the video tapes: date, time, camera location, camera depth or station, fish species, the number of video frames the fish was in view, grid coordinates of the fish's nose (when possible) entering and exiting the camera's view to the nearest 7.6 cm, and description of what the fish was doing. For the submerged orifice, the grid coordinates of the fish entering and exiting the camera's view were not recorded. For the overflow weir, the time in the view (except for lamprey), the grid coordinates of the fish entering and exiting the camera view, and camera depth were not recorded.

Fish viewed on the tapes were identified into the following categories: teleosts, steelhead (*Oncorhynchus mykiss*), chinook salmon (*O. tshawytscha*), coho salmon (*O. kisutch*), sockeye salmon (*O. nerka*), unidentified salmonids, (*O. sp.*), black bass, (*Micropterus sp.*), Pacific lamprey (*Lampetra tridentatus*), and other fish. Other fish consisted mostly of northern squawfish (*Ptychocheilus oregonensis*), mountain whitefish (*Prosopium williamsoni*), peamouth (*Mylocheilus caurinus*), chiselmouth (*Acrochelilus alutuceus*), suckers (*Catostomus sp*), American shad (*Alosa sapidissima*) and fish that could not be identified.

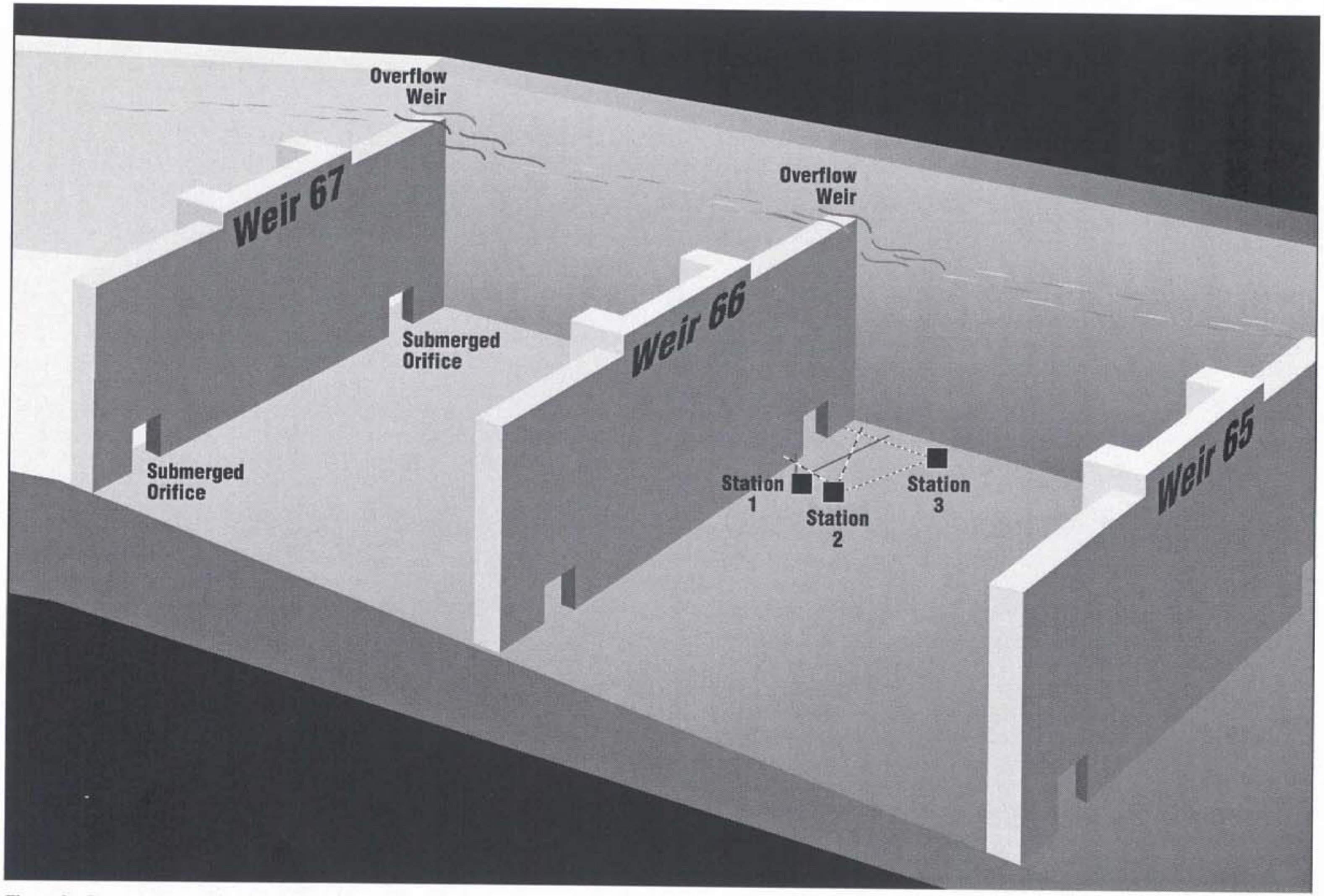


Figure 3. General view of the pool and weir type ladder showing the submerged orifices and overflow weirs in the Washington Shore ladder at the Bonneville Dam second powerhouse.

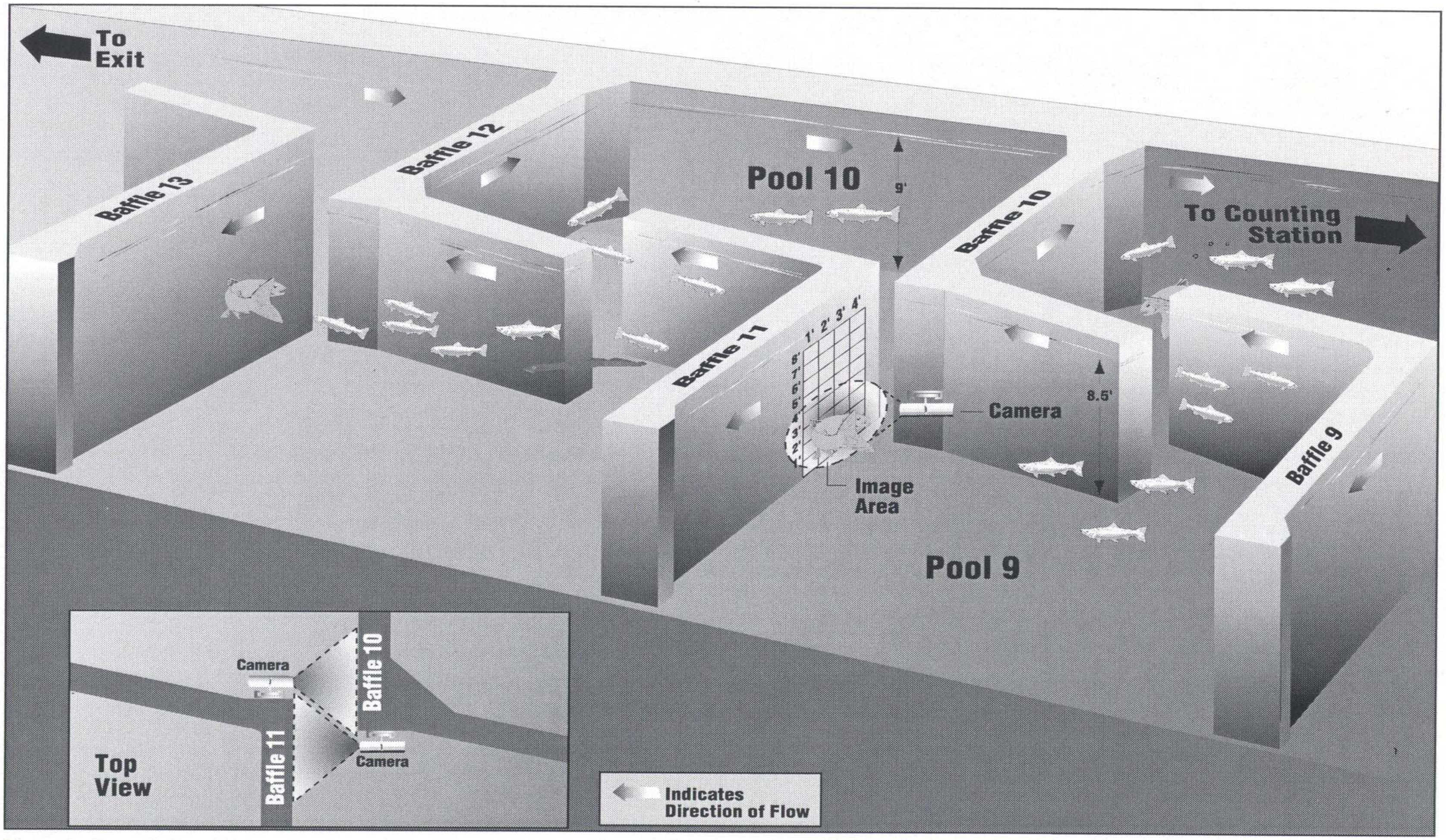


Figure 4. General view of the ladder showing locations of the cameras in the vertical slot at the Washington shore ladder at the Bonneville Dam second powerhouse.

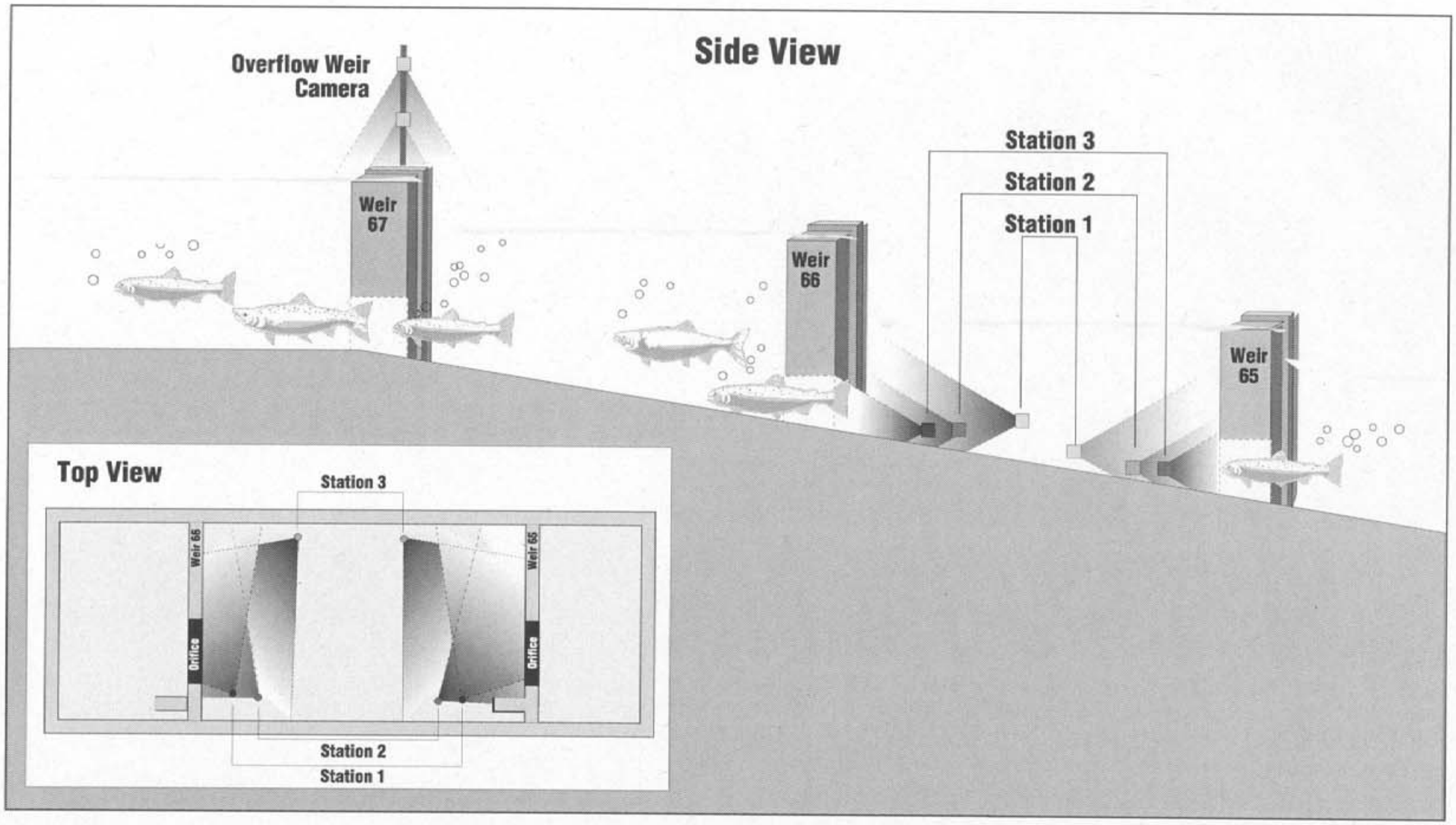


Figure 5. Slide and top view of the cameras that observed the submerged orifice and the overflow weir in the Washington shore ladder at the Bonneville Dam second powerhouse.

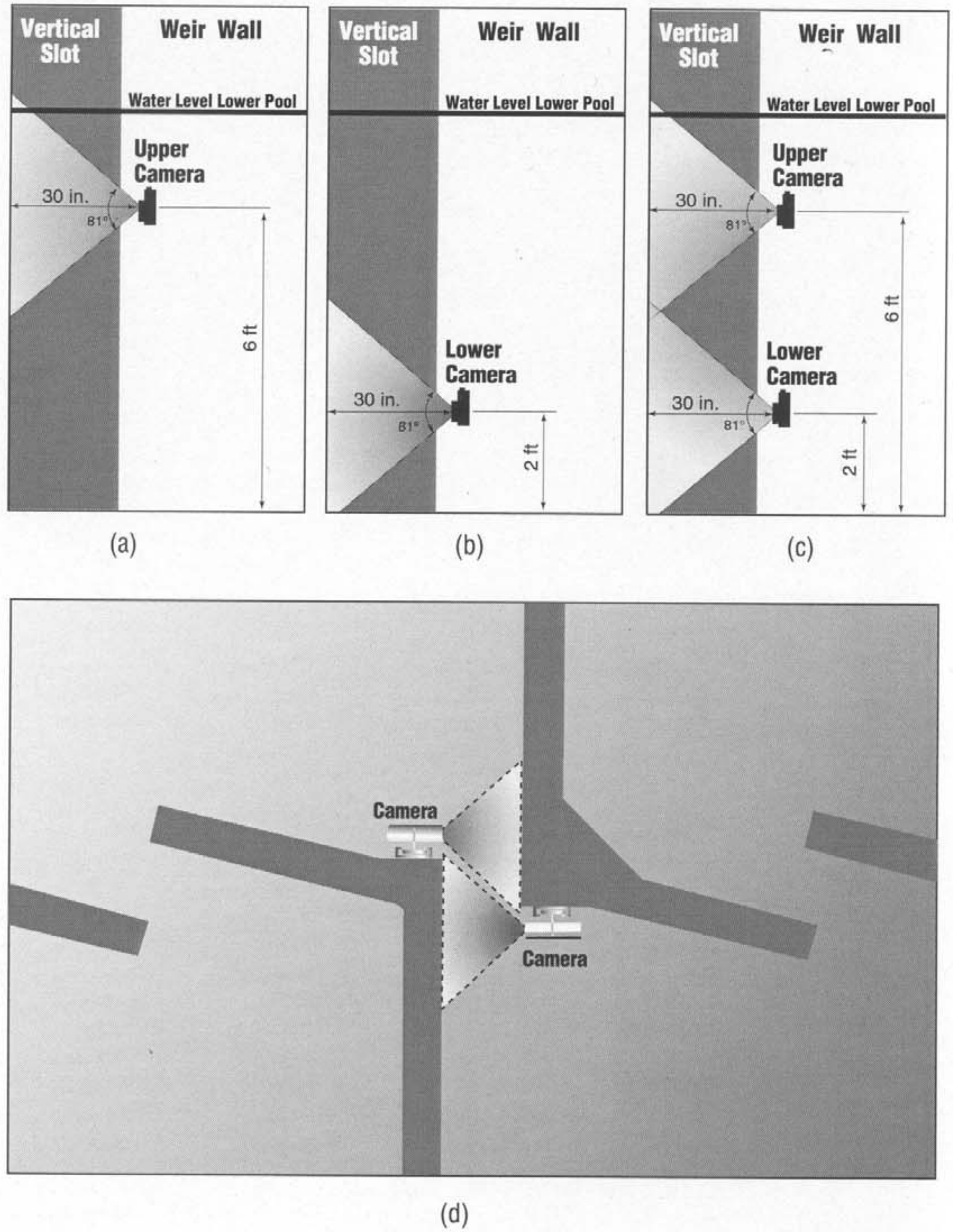


Figure 6. Side and top view of the cameras that observed the vertical slot at the Washington shore ladder at the Bonneville Dam second powerhouse.

9

The fish movements were categorized as follows:

1. up movement - fish passing upstream through the area of interest
2. down movement (tail first) - fish passing downstream through the area of interest with tail downstream
3. down movement (head first) - fish passing downstream through the area of interest with head downstream
4. no passage - fish comes into view of the camera swims around and then goes out of camera view without passing through the area of interest
5. unknown - fish that entered the camera view but could not be placed into any of the above categories

Sampling Times

At the submerged orifices, cameras were placed on 4 October 1993 in the ladder between weir 65 and weir 66 at camera station 1. On 7 October 1993, the cameras were moved to station 2. On 13 October 1993, the cameras were moved to station 3. On 19 October 1993, the cameras were removed. Video recording occurred from 5 to 17 October 1993 between 0400 h and 2000 h. Data were collected from all video recordings. The video recording was set on 24 hour recording mode for the first day and 6 hr recording mode for the remainder of the sampling.

At the overflow weir, the camera was placed on 12 July and lowered on 27 July. Video recording occurred on 12, 13, 15, 20, 27, 28 July, 14 August, and 15 September 1994.
Data were collected from video recordings made on 12 July 1994 between 10:10 h and 16:20 h and on 15 July 1994 between 11:46 h and 17:55 h.

At the vertical slot, the cameras were placed the night before and moved the night after video recording. Video recording occurred on 15, 16, 29, 30 June; 12, 13, 27, 28 July; 24, 25 August; and 14, 15 September 1994 between 0400 h and 2000 h. We recorded for two consecutive days. The first day, cameras were placed 61 cm from the floor (Figure 6b) and the next day they were placed 182.9 cm from the floor (Figure 6a). The position of the camera (182.9 cm or 61 cm off floor) was alternated at the start of each consecutive pair of days. On 24 August 1994, a guide for the backdrop downstream of the slot broke off and was removed the next night. Therefore, the video recording on 14 and 15 September was taken with both cameras in the upstream position, one at 182.9 cm and the other 61 cm above the fishway floor (Figure 6c).

Data were collected from the first 8 hours of the 15 June video recordings for the areas both upstream and downstream of the vertical slot. After the 1120 h on the 15 June recordings, the only information recorded for shad was the number going upstream. On the 16 June tape, data were collected until 0830 h upstream and downstream of the slot. Between 0830 and 1120 h on 16 June, no data were collected. Between the 1120 h and the 1800 h on the 16 June tape, the only information recorded for shad was the number going upstream. On the 24 August and 14, 15 September tapes, data were collected from four to five randomly selected 15 min periods per day for each camera.

Data Analysis

Fish velocity (cm/sec) through the vertical slot was determined by the time (number of video frames converted to seconds) that a fish took to travel between grid coordinates on the backdrop. The field of view near the camera is narrow, but farther away from the camera, the field of view becomes large. This caused fish to appear on the grid coordinates differently than if viewed on axis of the camera, a condition know as parallax. Parallax causes a fish swimming near the camera to appear to have traveled a distance up to three time greater then it actually did. Therefore, the actual fish velocity may be up to three times slower then reported.

The velocity through the submerged orifice was estimated at station 1 as the time from first appearance in the camera field until the fish passed the plane of the orifice (35.6 cm), and at stations 2 and 3 as the time from first appearance crossing the metal plate until it crossed the plane of the orifice (45.7 cm). At station 1, the edge of camera field of view was not parallel to the weir, so the farther away from the camera the fish entered the camera's viewing field, the greater the distance the fish was from the orifice.

To analyze their velocity and time spent in view at each location, the fish were separated into two categories, lamprey and teleosts.

The vertical distribution of fish entering the camera view for each side of the vertical slot was determined from 15 and 16 June 1994 tapes. Vertical distribution data were adjusted to equalize the sampling area of the camera and to equalize sample size. The adjustment was made because the cameras sampled at one depth one day and the another depth the next day. Data were adjusted to account for the differences in the number of fish present at the count station on these days (the number of fish at the count station was used to determine the number of fish present at the vertical slot). In addition, the camera's view is pyramidal in shape, small near the camera and large at the backdrop. To correct for the camera's view, the percentage of the slot viewed for each 7.6 cm depth was determined and then divided into the number of observed fish at that depth.

Water velocity in the vertical slot was measured with a Marsh McBirney model 201D portable water current meter on 27 September 1994. Velocity was measured 55 cm and 220 cm from the floor at 61 cm intervals horizontally through the area viewed by cameras.

Results

Submerged Orifice

A total of 728 fish were observed in the two camera positions at the submerged orifices: 388 downstream of the orifice at weir 66 during 84 h and 6 min of video and 340 upstream of the orifice at weir 65 during 85 h and 4 min of video. Downstream of the orifice at weir 66, there were 8 Pacific lamprey, 44 unidentified salmonids, 107 steelhead, 6 coho salmon, 43 chinook salmon, 42 bass and 138 other fish. Upstream of the orifice at weir 65, there were 3 Pacific lamprey, 38 unidentified salmonids, 66 steelhead, 25 coho salmon, 70 chinook salmon, 36 bass and 102 other fish.

Eight Pacific lamprey were observed downstream of the submerged orifice at weir 66 for a net passage up through the orifice of 1. Of these lamprey, 4 were moving upstream, 3 were moving downstream head first, and 1 did not pass. The mean time in view was 50 s and the median time was 11.5 s. Three Pacific lamprey were seen upstream of the submerged orifice at weir 65 and none passed. The mean time in view was 267 s and the median time was 364 s (Table 1).

The 309 teleosts observed downstream of the submerged orifice at weir 66 stayed in view an average 1.1 s with a maximum time of 5.8 s. Of these teleosts, 52% passed upstream, 4% passed downstream head first, 3% passed downstream tail first, and 42% did not pass. Of the 134 teleosts for which velocities were calculated, the mean velocity was 86 cm/s with a maximum of 392 cm/s. The 337 teleosts observed upstream of the submerged orifice at weir 65 stayed a mean of 1 s in view. Of these teleost, 81% passed upstream, 2% passed downstream head first, 2% passed downstream tail first, and 15% did not pass. Of the 255 teleosts for which velocities were calculated, the mean velocity was 158 cm/s, with a maximum of 343 cm/s (Table 2).

Overflow Weir

Seventy fish were observed at the overflow weir 67 during 12 hours and 18 min, but only Pacific lamprey could be identified as to species. Of the 67 teleosts, 48% went upstream over the weir, 43% did not pass, and 9% went downstream. Three Pacific lamprey were seen, one went upstream, one went downstream and one did not pass. Time in view was not taken.

Vertical Slot

A total of 2,961 fish were observed at the vertical slot in two camera positions: 1,116 downstream of the slot during 26 h and 59 min of viewing and 1,845 upstream of the slot during 30 h and 57 min of viewing. Downstream of the slot, there were 758 American shad, 156 Pacific lamprey, 23 unidentified salmonids, 7 sockeye salmon, 34 steelhead, 2 coho salmon, 42 chinook salmon, and 94 other fish. Upstream of the slot, there were 517 American shad, 171 Pacific lamprey, 264 unidentified salmonids, 30 sockeye salmon, 144 steelhead, 39 coho salmon, 189 chinook salmon, and 491 other fish.

One-hundred-fifty-six Pacific lamprey were observed downstream of the vertical slot, but these had a net passage upstream of 20. Of the 156 lamprey 43% passed upstream, 13% passed downstream head first, 17% passed downstream tail first, 8% passed with an unknown type of passage, and 19% did not pass. The mean time in view was 87.5 s and the median was 1.4 s. Of the 72 Pacific lamprey for which velocities were calculated, the mean was 187 cm/s with a maximum of 1,045 cm/s. Of these velocities, 80% had velocities below 274 cm/s and 90% below 396 cm/s. Of the lampreys going upstream, all had velocities less than 244 cm/c (Figure 7). As mentioned in the method section, actual velocities may have been three times slower then the calculated ones. One-hundred-seventy-one Pacific lamprey were observed upstream of the vertical slot for a net passage downstream of 35. Of the 171 lamprey, 27% passed upstream, 22% passed downstream head first, 26% passed downstream tail first, 5% passed with an unknown type of passage, and 20% did not pass. The mean time in view was 10.3 s and the median was 1.2 s. Of the 85 Pacific lamprey for which velocities were calculated, the mean was 159 cm/s with a maximum of 430 cm/s (Table 3, Figure 7). Of these velocities, 80% had velocities below 213 cm/s and 90% below 305 cm/s.

The 960 teleosts observed downstream of the vertical slot stayed a mean 1.4 s in view with a maximum of 8 s. Of these teleosts, 80% passed upstream, 1% passed downstream head first, 1% passed downstream tail first, 11% passed with an unknown type of passage, and 8% did not pass. Of the 737 teleosts for which velocities were calculated, the mean was 117 cm/s with a maximum of 914 cm/s. Of these velocities, 80% had velocities below 152 cm/s and 90% below 183 cm/s (Figure 8). The 1,674 teleosts observed upstream of the vertical slot orifice stayed a mean of 1.1 s in view. Of these teleosts, 73% passed upstream, 2% passed downstream tail first, 5% passed with an unknown type of passage, and 19% did not pass. Of 1,014 teleosts for which velocities were calculated, the mean was 230 cm/s with a maximum of 813 cm/s. Of these velocities, 80% had velocities below 305 cm/s and 90% below 335 cm/s (Table 4, Figure 8). The information by species is displayed in the Addendum Tables A1 - A7.

Of the teleosts on the downstream side of the vertical slot, 83% stayed in view less than 2 s, 95% less then 3 s, and 98.8% less then 4 s. Of these, 100% of salmonids stayed in view less then 2 s (Table 5). Of the teleosts on the upstream side of the vertical slot, 93% stayed in view less then 2 s and 98% stayed less the 3 s. Of these, 87% of salmonids stayed in view less then 2 s (Table 6).

Of the Pacific lamprey downstream of the vertical slot, 66% stayed in view less than 2 s, 86% stayed less than 4 s, 87% stayed less than 10 s, 91% stayed less than 70 s, and 96% stayed less than 200 s (Table 5). Of the Pacific lamprey upstream of the vertical slot, 70% stayed in view less than 2 s, 83% stayed less than 4 s, 90% stayed less than 10 s, 95% stayed less than 70 s, and 99% stayed less than 200 s (Table 6).

Fifty-four percent of teleosts, 51% of Pacific lamprey, 66% of American shad, and 4% of salmonids entered the camera's view downstream of the vertical slot at a depth less than 122 cm (Table 7, Figure 9, 10, 11, and 12). Forty-six percent of teleosts, 46% of Pacific lamprey, 75% of American shad, and 6% of the salmonids upstream of the vertical slot entered the camera's view at a depth less than 122 cm (Table 8, Figure 9, 10, 11, and 12).

Current velocity was measured on 27 September 1994 between 2000 h and 2200 h. The forebay elevations ranged between 22.98 m and 23.07 m msl. Velocity reading upstream of the slot ranged from 140 to 152 cm/s. Velocity reading downstream of the slot ranged from 168 to 189 cm/s.

Table 1. Passage behavior of Pacific lamprey at the submerged orifices between weir 66 and weir 67 in Bonneville's Washington shore ladder. Behavior was classified as upstream (up), no passage, downstream head first (Dn-hf), and downstream tail first (Dn-tf) movements.

	Up	No passage	Dn-hf	Dn-tf	All fish
Time in view downstream of orifice (s)					
N	4	1	0	3	8
Mean	94.1	0.2		8.8	50.4
SD	63.0			4.9	62.5
Min	0.4			3.5	0.2
Max	137			13	137
Median	119.5	0.2		10	11.5
Time in view upstream of orifice (s)					
N	0	3	0	0	3
Mean		266.7			266.7
SD		219.8			219.8
Min		15			15
Max		421			421
Median		364			364

Table 2. Passage behavior of teleosts at the submerged orifices between weir 66 and weir 67 in Bonneville's Washington shore ladder. Behavior was classified as upstream (up), no passage, downstream head first (Dn-hf), and downstream tail first (Dn-tf).

	Up	No passage	Dn-hf	Dn-tf	All fish
Time in view downstream of orifice (s)					
N	160	129	12	8	309
Mean	1.2	1.0	0.6	1.4	1.1
SD	0.51	0.8	0.3	0.9	0.7
95% confidence interval	0.1	0.1			0.1
Min	0.4	0.2	0.1	0.4	0.1
Max	3.4	5.8	1.2	2.8	5.8
Fish velocity downstream of orifice (cm/s)					
N	116	4	7	7	134
Mean	78	71	208	106	86
SD	39	28	120	63	56
95% confidence interval	7				9
Min	6	30	30	8	6
Max	274	89	392	213	392
Time in view upstream of the orifice (s)					
N	273	51	7	6	337
Mean	0.9	1.4	0.5	1.1	1.0
SD	0.4	1	0.2	0.8	0.5
95% confidence interval	0.0	0.3			0.1
Min	0.3	0.3	0.2	0.4	0.2
Max	2.5	4.4	0.8	2.6	4.4
Fish velocity upstream of orifice (cm/s)					
N	243	3	6	3	255
Mean	160	130	115	66	158
SD	51	79	22	43	52
95% confidence interval	6				6
Min	32	43	80	27	27
Max	343	196	137	113	343

Table 3. Passage behavior of Pacific lamprey at the vertical slots above the fish count station in Bonneville's Washington shore ladder. Behavior was classified as upstream (up), no passage, downstream head first (Dn-hf), downstream tail first (Dn-tf), and unknown.

	Up	No passage	Dn-hf	Dn-tf	Unknown	Total
Time in view downstream of vertical slots (s)						
N	67	30	21	26	12	156
Mean	22.5	393.3	0.5	2.6	122.6	87.5
SD	59.7	1958.8	0.2	9.5	70.1	861.5
95% confidence interval	14.3					135.2
Min	0.7	0.4	0.3	0.3	0.5	0.3
Max	305	10757	1.0	49.0	245	10757
Median	2.1	1.5	0.5	0.6	1.41	1.38
Fish velocity downstream of vertical slot (cm/s)						
N	48	1	12	11	0	72
Mean	86	281	389	400		187
SD	35		207	325		208
95% confidence interval	10					48
Min	36	281	111	104		36
Max	239	281	914	1045		1045
Median	76	281	354	261		105
Time in view upstream of vertical slot (s)						
N	46	35	38	43	8	171
Mean	1.7	40.7	0.9	4.7	3.0	10.3
SD	1.4	69.2	0.7	16.3	3.2	35.6
95% confidence interval	0.4	22.9	0.2	4.9		5.3
Min	0.4	0.4	0.4	0.4	0.4	0.4
Max	6.8	315	5.0	107	9.0	315.0
Median	1.2	3.4	0.7	1.4	1.7	1.2
Fish velocity upstream of vertical slot (cm/s)						
N	32	0	26	27	0	85
Mean	155		215	109		159
SD	102		76	53		91
95% confidence interval	36					19
Min	20		112	44		20
Max	430		385	305		430
Median	130		198	103		141

Table 4. Passage behavior of teleosts at the vertical slots above the fish count station in Bonneville's Washington shore ladder. Behavior was classified as upstream (up), no passage, downstream head first (Dn-hf), downstream tail first (Dn-tf), and unknown.

	Up	No passage	Dn-hf	Dn-tf	Unknown	Total
Time in view downstream of vertical slot (s)						
N	766	72	6	12	104	960
Mean	1.5	1.4	0.8	1.1	1.0	1.4
SD	0.8	1.1	1.0	0.4	0.6	0.8
95% confidence interval	0.1	0.3			0.1	0.1
Min	0.2	0.3	0.3	0.5	0.3	0.2
Max	5.7	8.0	2.8	1.7	3.7	8.0
Fish velocity downstream of vertical slot (cm/s)						
N	673	16	3	9	36	737
Mean	115	104	518	169	114	117
SD	57	36	369	48	53	65
95% confidence interval	4				17	5
Min	5	36	183	100	34	5
Max	457	177	914	249	261	914
Time in view upstream of vertical slot (s)						
N	1226	319	6	41	82	1674
Mean	1.0	1.3	0.7	2.0	0.9	1.1
SD	0.5	1.0	0.4	1.2	0.6	0.7
95% confidence interval	0.0	0.1		0.4	0.1	0.0
Min	0.1	0.1	0.5	0.2	0.1	0.1
Max	7.48	6.5	1.6	7.5	2.8	7.5
Fish velocity upstream of vertical slot (cm/s)						
N	965	13	4	25	8	1014
Mean	234	186	268	127	198	230
SD	92	87	195	53	40	93
95% confidence interval	6					6
Min	31	75	126	56	114	31
Max	813	366	549	322	239	813

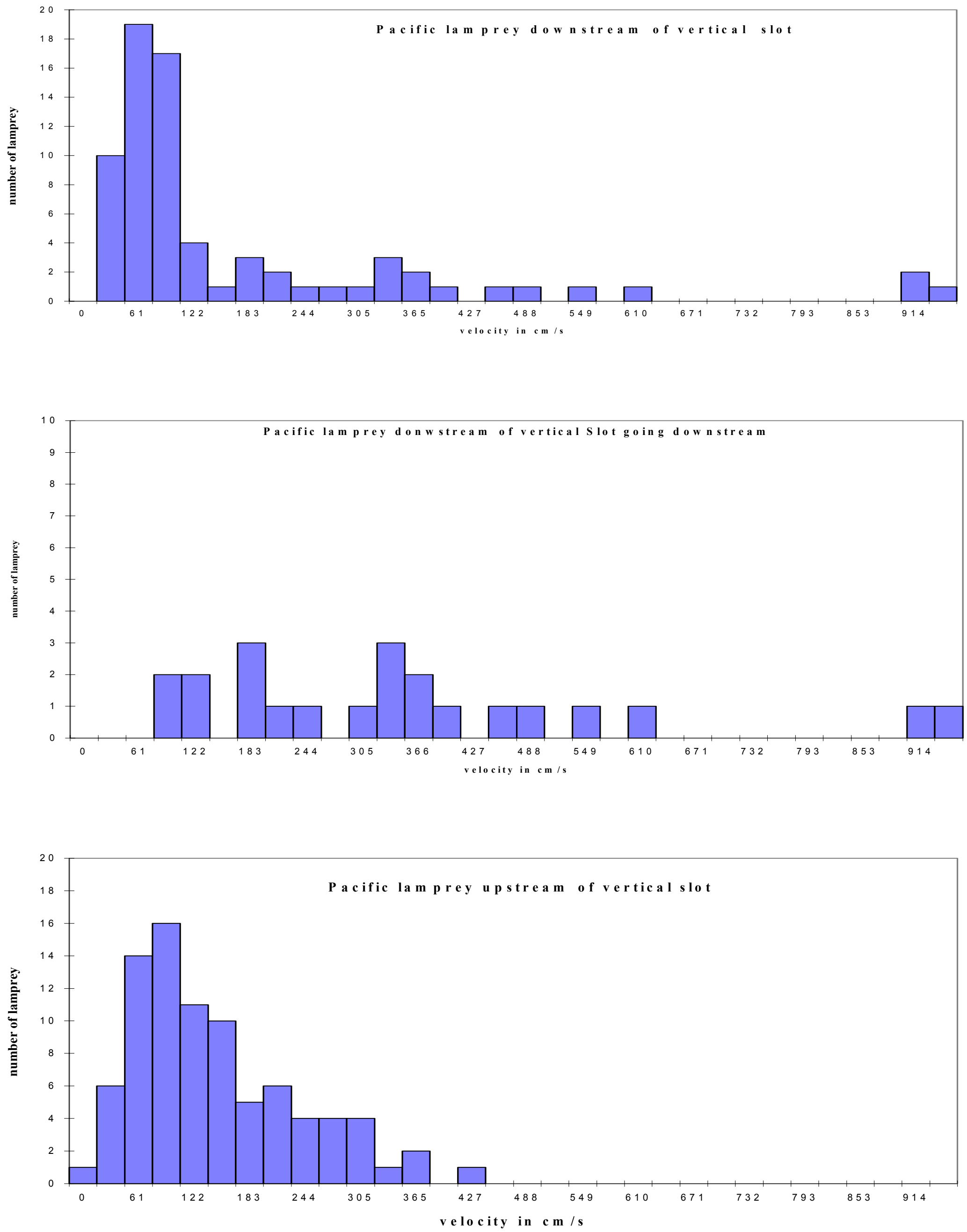
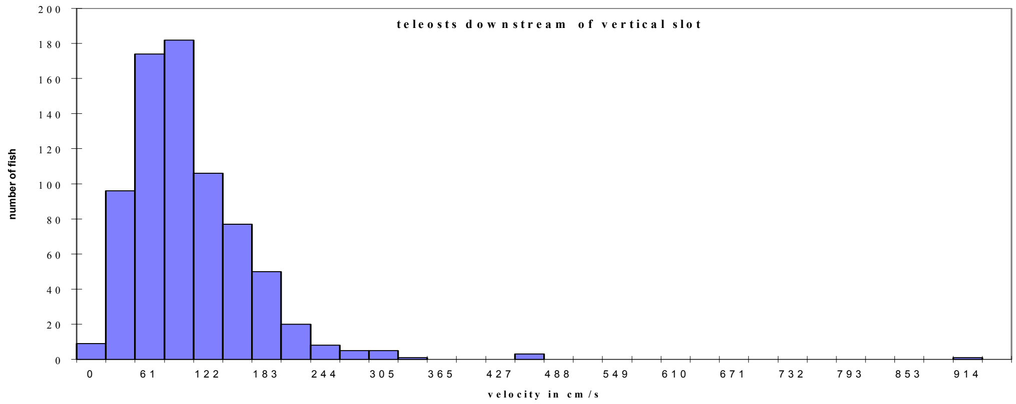


Figure 7. Frequency of velocity of Pacific lamprey downstream and upstream of vertical slot between pool 9 and 10 at Bonneville Dam second powerhouse Washington shore ladder in 1994.



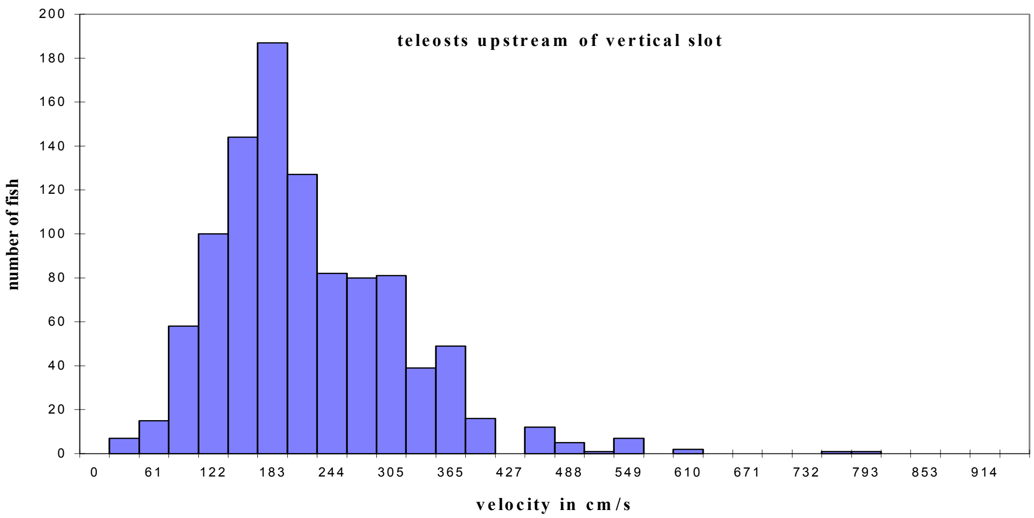
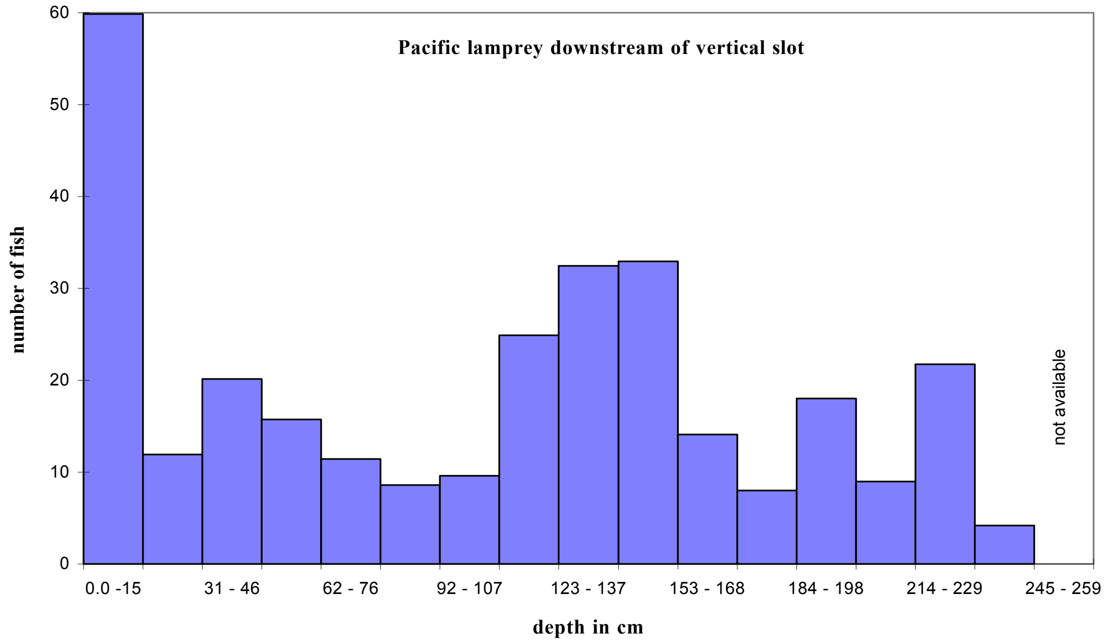


Figure 8. Frequency of teleosts velocities downstream and upstream of vertical slot between pool 9 and 10 at Bonneville Dam second powerhouse Washington shore ladder in 1994.

Table 5. Frequency of the time fish spent in the camera field downstream of the vertical slot in the Washington Shore ladder at Bonneville Dam second powerhouse.									
Time in s	Pacific Lamprey	All Fish	American Shad	Unidentified Salmonid	Sockeye Salmon	Chinook Salmon	Steelhead	Coho Salmon	Other Fish
0.0-0.99	53	298	178	21	5	16	17		61
1.0-1.99	50	502	424	2	2	26	17	2	29
2.0-2.99	24	115	112						3
3.0-3.99	7	34	33						1
4.0-4.99		8	8						
5.0-5.99		2	2						
6.0-6.99	1								
7.0-7.99	1								
8.0-8.99		1	1						
9.0-9.99									
10.0-19.99	1								
20-29.99	1								
30-39.99	1								
40-49.99	1								
50-59.99	1								
60-69.99	1								
70-79.99									
80-89.99									
90-99.99									
100-199.9	9								
200-299.9	3								
300-399.9	1								
400-499.9									
500-599.9									
600-699.9									
700-799.9									
800-899.9									
900-999.9									
>1000	1								
Total	156	960	758	23	7	42	34	2	94

Table 6. Frequency of the time fish spent in the camera field upstream of the vertical slot in the Washington Shore ladder at Bonneville Dam second powerhouse.									
Time in s	Pacific Lamprey	All Fish	American Shad	Unidentified Salmonid	Sockeye Salmon	Chinook Salmon	Steelhead	Coho Salmon	Other Fish
0.0-0.99	73	847	272	108	14	41	31	5	375
1.0-1.99	46	711	238	123	13	126	94	19	96
2.0-2.99	14	87	6	22	2	20	13	9	15
3.0-3.99	9	17		7			3	3	4
4.0-4.99	4	7		1	1		2	3	
5.0-5.99	3	2				1	1		
6.0-6.99	4	1				1			
7.0-7.99		2	1						1
8.0-8.99									
9.0-9.99	1								
10-19.99	4								
20-29.99	2								
30-39.99									
40-49.99	1								
50-59.99									
60-69.99	1								
70-79.99	1								
80-80.99									
90-99.99	1								
100-199.9	6								
200-299.9									
300-399.9	1								
400-499.9									
500-599.9									
600-699.9									
700-799.9									
800-899.9									
900-999.9									
>1000									
Total	171	1674	517	261	30	189	144	39	491



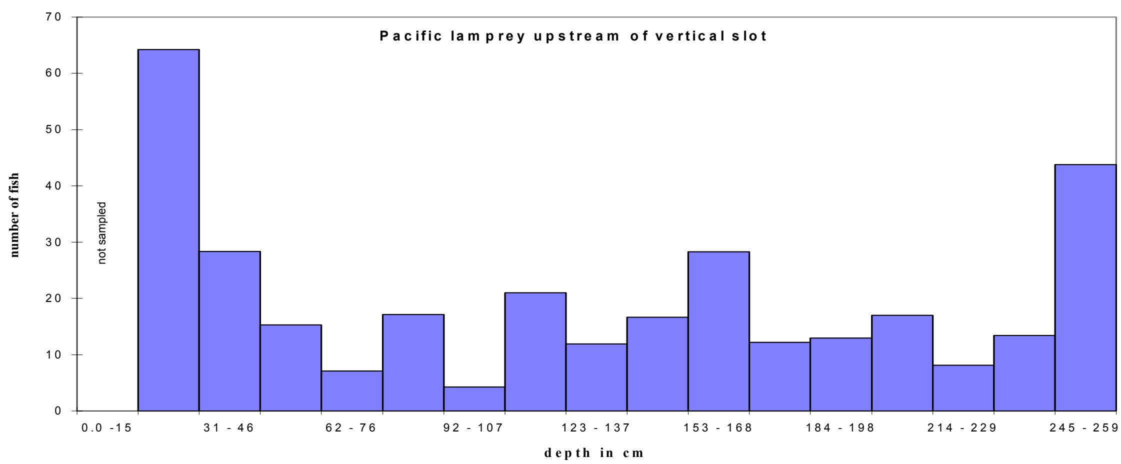
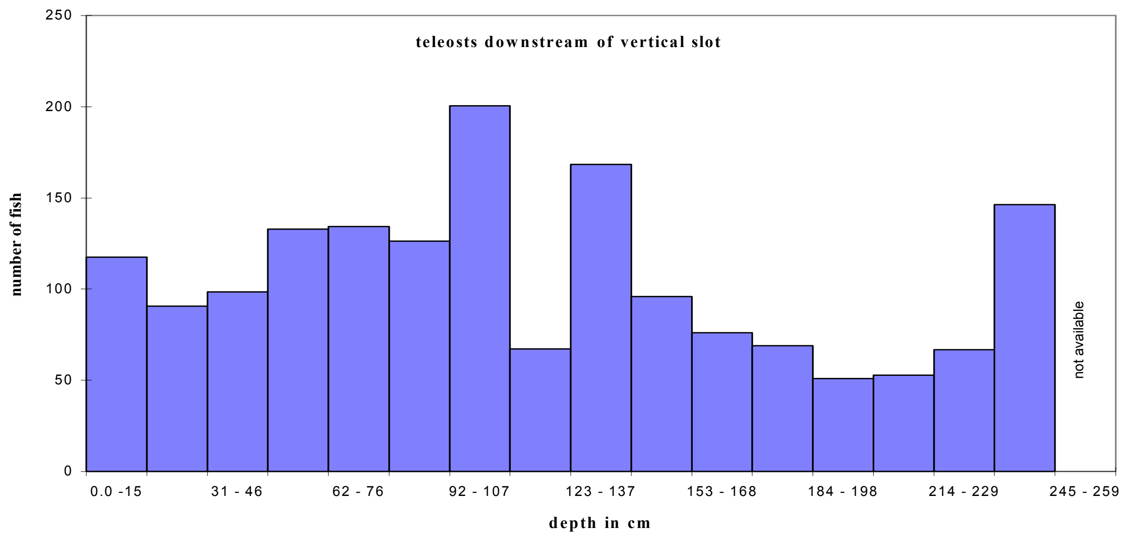


Figure 9. Frequency of depth of Pacific lamprey downstream and upstream of vertical slot between pool 9 and 10 at Bonneville Dam second powerhouse from 15 - 16 June 1994.



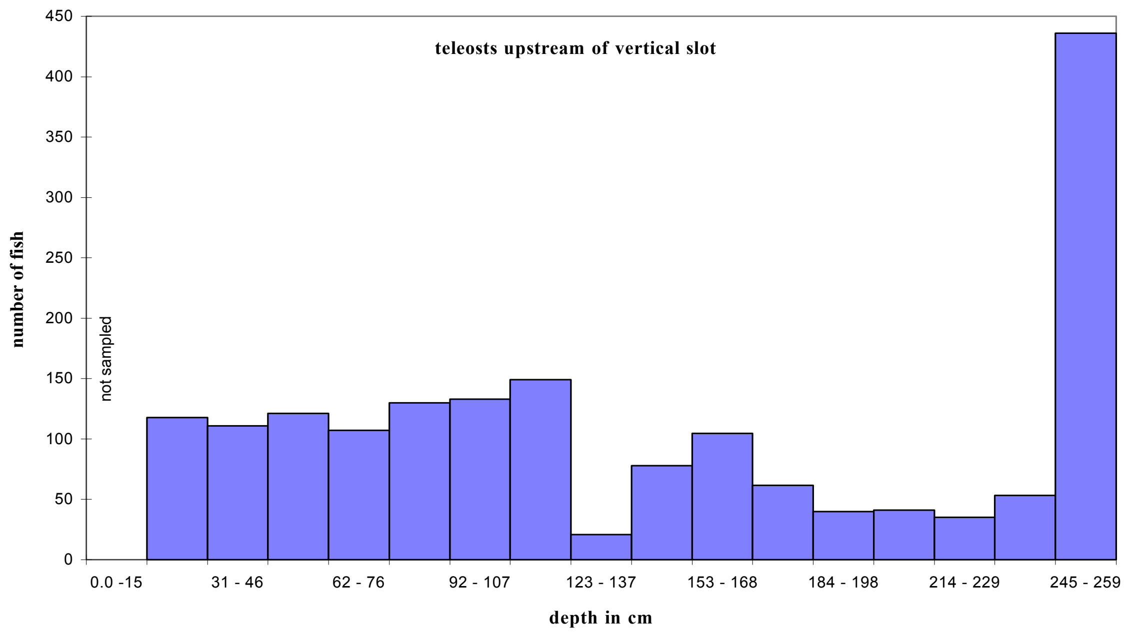
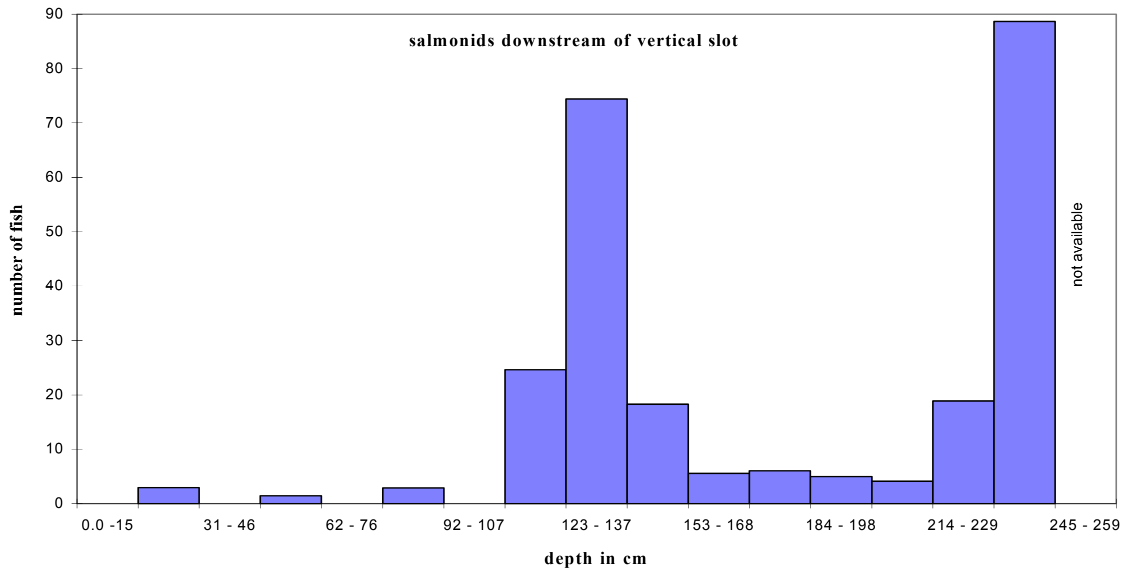


Figure 10. Frequency of depth of teleosts downstream and upstream of vertical slot between pool 9 and 10 at Bonneville Dam second powerhouse shore ladder from 15 - 16 June 1994.



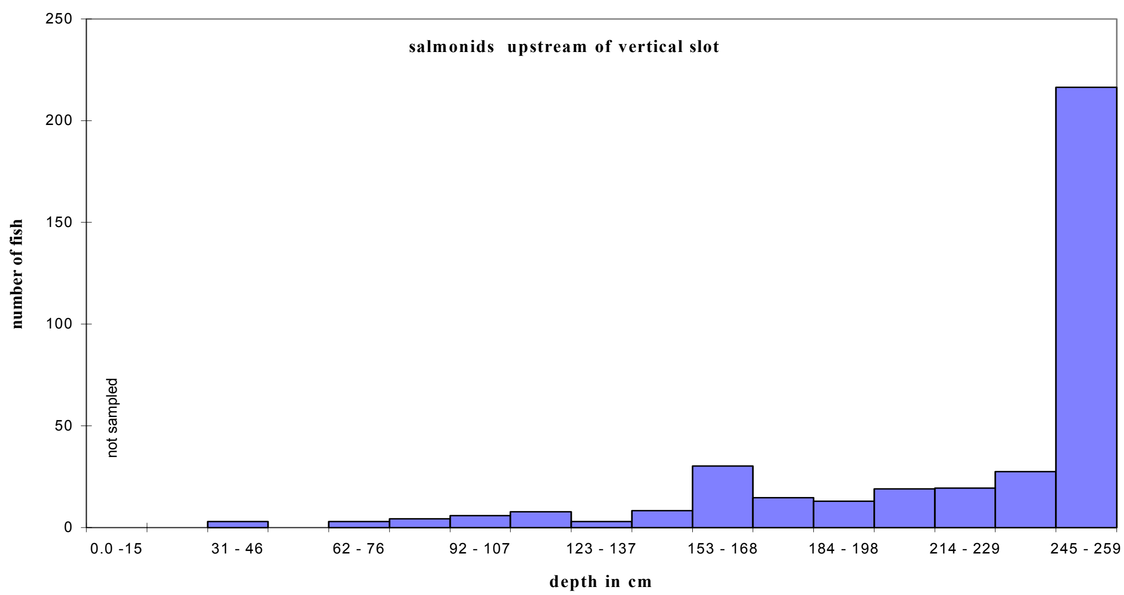


Figure 11. Frequency of depth of salmonids downstream and upstream of vertical slot between pool 9 and 10 at Bonneville Dam second powerhouse Washington shore ladder from 15 - 16 June 1994.

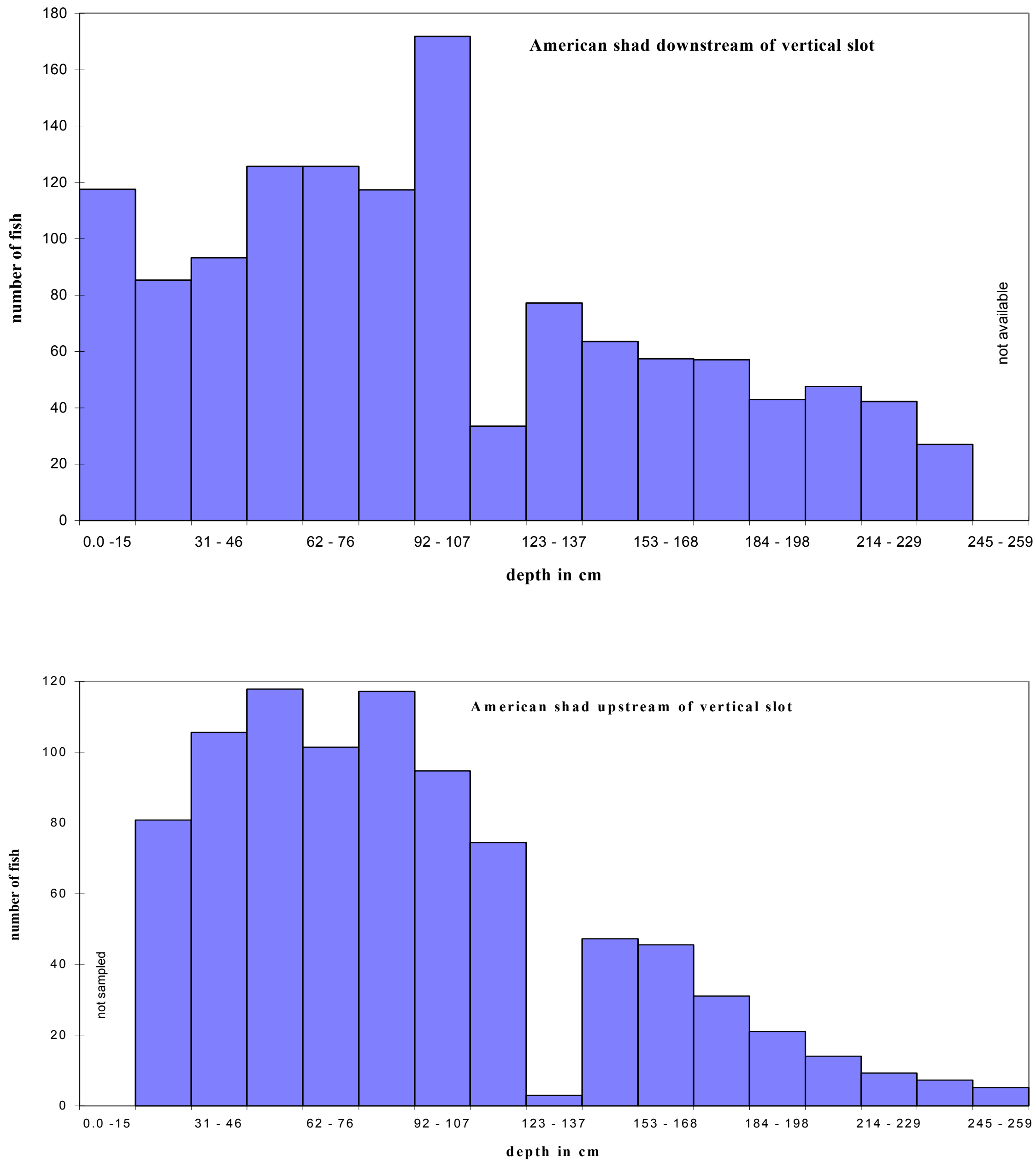


Figure 12. Frequency of depth of American shad downstream and upstream of the vertical slot between pool 9 and 10 at Bonneville Dam second powerhouse Washington shore ladder from 15 - 16 June 1994.

Table 7. Frequency of the depth of the fish entering the camera field downstream of the vertical slot in the Washington shore Bonneville Dam second powerhouse.

Depth in cm	Pacific Lamprey	All Fish	American Shad	Unidentified Salmonid	Sockeye Salmon	Chinook Salmon	Steelhead	Coho Salmon	Other Fish
0.0 - 15	56	87	87	0	0	0	0		0
16 - 30	16	87	84	3	0	0	0		0
31 - 46	20	102	96	0	0	0	0		6
47 - 61	14	115	109	1	0	0	0		4
62 - 76	9	139	134	0	0	0	0		6
77 - 91	13	123	110	0	0	1	1		14
92 - 107	7	158	132	0	0	0	0		25
108 - 122	14	115	96	0	0	0	3		22
123 - 137	32	168	77	14	11	24	25		17
138 - 152	28	117	58	8	2	11	13		25
153 - 168	22	78	66	0	1	2	0		9
169 - 183	6	78	62	0	0	3	5		8
184 - 198	16	57	46	0	2	1	4		4
199 - 213	13	58	53	0	0	0	2		3
214 - 229	15	63	44	1	0	10	5		3
230 - 244	11	77	33	7	0	18	6		12
245 - 259	0	84	0	39	0	11	6		22
Total	292	1706	1287	73	16	81	70	6	180

Table 8. Frequency of the depth of the fish entering the camera field upstream of the vertical slot in the Washington shore ladder ville Dam second powerhouse

Depth in cm	Pacific Lamprey	All Fish	American Shad	Unidentified Salmonid	Sockeye Salmon	Chinook Salmon	Steelhead	Coho Salmon	Other Fish
0.0 - 15									
16 - 30	56	40	16	0	0	0	0		24
31 - 46	32	143	127	0	3	0	0		13
47 - 61	14	111	107	0	0	0	0		4
62 - 76	10	115	112	1	0	0	0		2
77 - 91	14	124	113	3	0	1	0		7
92 - 107	10	143	116	0	3	0	3		21
108 - 122	16	149	76	3	2	2	0		65
123 - 137	16	64	28	0	3	2	0		31
138 - 152	17	78	47	3	6	0	0		22
153 - 168	25	100	46	8	11	2	5		27
169 - 183	18	68	27	3	9	5	4		19
184 - 198	12	449	29	3	3	3	2		8
199 - 213	15	42	18	0	3	9	3		9
214 - 229	12	36	11	1	1	11	9		3
230 - 244	12	45	7	4	0	11	9		13
245 - 259	16	107	7	8	0	39	19		35
260 - 274	31	353	3	62	6	50	42		189
Total	326	1767	890	99	50	135	96	0	492

Discussion

General

Past studies indicate fish take from 20 s to six min to pass through a pool in the ladder (Elling and Raymond 1956, Long 1959, Gauley 1960, Bell 1962, Weaver 1962, Thompson and Gauley 1963, and Monk et al. 1989). This study indicates fish were not spending much time in our sampling areas. Our sampling areas had high velocity flows which discouraged fish, except Pacific lamprey, from staying in the area. The mean times for the teleosts in view did not exceed 1.4 s at any location (Table 2 and 4). However, mean time in view for Pacific lamprey was as high as 267 s because some Pacific lamprey attached to the wall or floor for long periods of time.

Fish could have spent more cumulative time within the camera field than these results indicate. A fish was considered a different fish if it passed through the camera field and then reappeared. Observers believed that the same fish was occasionally observed several times.

It appears that, except for Pacific lamprey, submerged orifices and vertical slots would be good sites for PIT interrogator systems based on the time that a fish would spend in the electromagnetic field. Pacific lampreys could be discouraged from attaching near or in the PIT tag detectors. However, if the Pacific lamprey were not allowed to attach, their passage may be blocked. In addition, we could not determine from our data if the overflow weir was a good site because we had problems with the data.

The time in view is important because it provides an estimate of how long a fish may be exposed to the high electromagnetic field. The time in view is a maximum for a one time exposure because the PIT Tag systems should not extend 3 feet above or below the vertical slot as the camera field of view does.

The time in the PIT tag system may be calculated by knowing the fish's velocity and dimension of the PIT tag system. This time answers the question "do fish swimming through this area allow enough time to correctly interrogate a PIT tag?". The literature shows a maximum burst speed of 1,050 cm/s for the species we observed (Beamish, 1978) and we calculated a maximum velocity of 1,045 cm/s for lamprey going downstream. As we stated in the methods section, a fish's calculated velocity may be up to 3 times faster than its actual velocity because of parallax. Theoretically, the reported fish's velocity could be 3 times their actual velocity plus the water's velocity.

Because we were unable to correct for the error caused by parallax, we wondered if the velocities were reasonable and realistic. So, we compared velocities at the submerged orifice with those at the vertical slot which had similar current velocities. Mean velocities above and below the vertical slot were 230 and 117 cm/s. Mean velocities above and below the submerged orifice were 158 and 86 cm/s. We feel these velocities are comparable but the velocity at the vertical slot may be exaggerated. Secondly, the distribution of velocities shows 95% are below 365 cm/s upstream of vertical slot and 95% were below 213 cm/s downstream of the slot. These velocities are within the upper limit of sustainable speeds of the fish stated in the literature which is an indication that they are reasonable. Many of the velocities calculated for the lamprey exceeded burst speeds for salmonids as cited in the literature. When velocities from lamprey going downstream are excluded, then the velocities do not exceed 244 cm/s (figure 9). These velocities still seem high but are more reasonable.

Submerged Orifice

The mean times in view at the submerged orifices for teleosts did not exceed 1.1 s, and teleosts had mean velocities of 85 to 158 cm/s (Table 2). Thompson and Gauley (1965) show water velocities through the submerged orifice to be as high as 232 cm/s. Therefore, teleosts are not spending much time near the submerged orifice, and when they pass through the orifice, they do it quickly. Mean times in view for Pacific lamprey ranged from 56.4 to 267 s (Table 1); however only nine Pacific lamprey were observed. At station 2, more fish were seen traveling past the camera and turning into the middle of the ladder then at station 1. This would indicate that fish make a decision to pass through the orifice before they get within 30 cm of orifice.

Vertical Slot

Teleosts did not stay long in view at the vertical slot. The mean time in view did not exceed 1.4 s (Table 4) and mean velocities ranged from 116 to 232 cm/s. The maximum in either the upstream or downstream areas was 8.0 s. Water current measurements showed velocities as high as 189 cm/s. Therefore, teleosts pass through the vertical slot quickly. For information by species see the Addendum.

Most Pacific lamprey passed through the slot quickly, but a small percent stayed for extended times (Tables 5 and 6). Mean times for Pacific lamprey in view were as high as 87.5 s; median times were less then 1.4 s (Table 3). Although maximum time in view was as long as 3 hours, in both areas, 96% of the Pacific lamprey were in view less then 100 s, 90% were less then 60 s, and 83% were less then 3 s.

Many of the fish in the "unknown" movement category were observed by the lower downstream camera moving above the field of view. The upper downstream camera showed most fish passing upstream. This suggests that many fish in the unknown category were actually passing upstream. Upstream of the slot, fish were seen swimming towards the camera as they proceeded upstream. We assume these fish were going to the slow flow area on the inside of the pool.

The vertical distribution of the fish was affected by parallax, so only general observations may be made from the vertical distribution. The vertical distribution for the two day sampling period of Pacific lamprey and teleosts were generally uniform. Of the teleosts, most salmonids were seen at a greater depth than American shad which were shallower (Tables 7 and 8, Figure 9, 10, 11, and 12).

Overflow Weir

Fish at overflow weirs could not be identified to species because of the poor camera image. It was difficult at times to determine if what was being observed was a fish. The camera image may be improved by using polarizing filter, different cameras, different camera positions, and different viewing angles. The camera was placed over the last weir of the ladder because few air bubbles were present as water cascaded over the weir. Fish behavior upstream of this weir may be different than at most weirs, because fish are crowded to facilitate counting. Time in view was not taken because the fish would first appear near the downstream side of the weir. We feel that these fish could have been near the weir but not seen. If we had reported the time in view it may have been much shorter than what it actually is.

Miscellaneous

We found that the 6-hour recording mode was better for viewing fish than the 24-hour mode because it recorded rapidly swimming fish that the 24 hour mode missed. Recording during darkness failed to provide any useful information because of insufficient illumination.

We found that identification of fish could be difficult. Factors limiting identification are: seeing only parts of the fish, differing lighting conditions, and the changing profile of fish as they react to environmental conditions. A Washington Department of Fish and Wildlife fish counter, who was asked to identify fish we failed to identify, was able to identify more, but still was not able to identify all the fish. Further, we did not always agree on the species when the view was poor.

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Addendum A.

Passage Behavior for Different Species of Fish

Table A1. Passage behavior of unidentified salmonids at the vertical slots above the fish count station in Bonneville's Washington shore ladder. Behavior was classified as upstream (up), no passage, downstream head first (Dn-hf), downstream tail first (Dn-tf), and unknown.						
	Up	No passage	Dn-hf	Dn-tf	Unknown	Total
Time in view downstream of vertical slot (s)						
N	19	2	0	2	0	23
Mean	0.7	0.5		1.2		0.7
SD	0.2	0.1		0.8		0.3
95% confidence interval						
Min	0.3	0.4		0.7		0.3
Max	1.0	0.6		1.7		1.7
Velocity of fish downstream of vertical slot (cm/s)						
N	4	0	0	2	0	6
X	191			123		168
SD	29			33		44
95% confidence interval						
Min	157			100		100
Max	229			146		229
Time in view upstream of vertical slot (s)						
N	146	96	1	10	11	264
Mean	1.1	1.3	0.7	1.9	1.1	1.2
SD	0.5	0.8		1.2	0.6	0.7
95% confidence interval	0.1	0.2				0.1
Min	0.3	0.2		0.2	0.2	0.2
Max	3.6	4.3		3.7	2.5	4.3
Velocity of fish upstream of vertical slot (cm/s)						
N	103	0	0	5	1	109
Mean	264			129	189	258
SD	98			44		100
95% confidence interval	19					19
Min	80			70		70
Max	549			166		549

Table A2. Passage behavior of chinook salmon at the vertical slots above the fish count station in Bonneville's Washington shore ladder. Behavior was classified as upstream (up), no passage, downstream head first (Dn-hf), downstream tail first (Dn-tf), and unknown.

	Up	No passage	Dn-hf	Dn-tf	Unknown	Total
Time in view downstream of vertical slot (s)						
N	36	0	0	5	1	42
Mean	1.1			1.1	0.8	1.1
SD	0.3			0.4		0.3
95% confidence interval	0.1					0.1
Min	0.7			0.5		0.5
Max	1.6			1.5		1.6
Fish velocity downstream of vertical slot (cm/s)						
N	27	0	0	5	0	32
Mean	217			180		211
SD	83			54		79
95% confidence interval						27
Min	76			114		76
Max	457			249		457
Time in view upstream of vertical slot (s)						
N	166	14	0	8	1	189
Mean	1.3	2.3		2.2	1.5	1.4
SD	0.4	1.7		0.6		0.7
95% confidence interval	0.1					0.1
Min	0.4	0.5		1.2		0.4
Max	2.6	6.5		2.9		6.5
Fish velocity upstream of vertical slot (cm/s)						
N	157	1	0	7	1	166
Mean	253	366		145	239	249
SD	74			84		77
95% confidence interval	12					12
Min	99			77		77
Max	499			323		499

Table A3. Passage behavior of steelhead at the vertical slots above the fish count station in Bonneville's Washington shore ladder. Behavior was classified as upstream (up), no passage, downstream head first (Dn-hf), downstream tail first (Dn-tf), and unknown.

	Up	No passage	Dn-hf	Dn-tf	Unknown	Total
Time in view downstream of vertical slot (s)						
N	30	1	0	2	1	34
Mean	1.1	0.8		1.1	0.9	1.0
SD	0.3			0.3		0.3
95% confidence interval	0.1					0.1
Min	0.6			0.9		0.6
Max	1.9			1.3		1.9
Fish velocity downstream of vertical slot (cm/s)						
N	20	0	0	2	0	22
Mean	168			186		169
SD	36			5		35
95% confidence interval						
Min	102			183		102
Max	229			189		229
Time in view upstream of vertical slot (s)						
N	86	40	1	8	9	144
Mean	1.3	1.6	1.6	2.2	1.5	1.5
SD	0.5	1.1		0.6	0.8	0.8
95% confidence interval	0.1	0.3				0.1
Min	0.6	0.2		1.2	0.6	0.2
Max	3.9	5.3		3.2	2.6	5.3
Fish velocity upstream of vertical slot (cm/s)						
N	74	4	1	5	0	84
Mean	232	155	126	108		220
SD	98	93		26		100
95% confidence interval	22					21
Min	91	75		70		70
Max	813	289		144		813

Table A4. Passage behavior of sockeye salmon at the vertical slots above the fish count station in Bonneville's Washington shore ladder. Behavior was classified as upstream (up), no passage, downstream head first (Dn-hf), downstream tail first (Dn-tf), and unknown.

	Up	No passage	Dn-hf	Dn-tf	Unknown	Total
Time in view downstream of vertical slot (s)						
N	6				1	7
Mean	0.8				0.5	0.8
SD	0.2					0.2
95% confidence interval						
Min	0.7				0.5	0.5
Max	1.0				0.5	1.0
Fish velocity downstream of vertical slot (cm/s)						
N	5				1	6
Mean	263				261	263
SD	110					99
95% confidence interval						
Min	189				261	189
Max	457				261	457
Time in view upstream of vertical slot (s)						
N	25	3	0	0	2	30
Mean	1.0	2.7			0.9	1.2
SD	0.5	1.2			0.4	0.8
95% confidence interval						0.3
Min	0.4	1.8			0.7	0.4
Max	2.4	4			1.2	4.0
Fish velocity upstream of vertical slot (cm/s)						
N	24	0	0	0	0	24
Mean	288					288
SD	103					103
95% confidence interval						
Min	124					124
Max	499					499

Table A5. Passage behavior of coho salmon at the vertical slots above the fish count station in Bonneville's Washington shore ladder. Behavior was classified as upstream (up), no passage, downstream head first (Dn-hf), downstream tail first (Dn-tf), and unknown.

	Up	No passage	Dn-hf	Dn-tf	Unknown	Total
Time in view downstream of vertical slot (s)						
N	2	0	0	0	0	2
Mean	1.1					1.1
SD	0.1					0.1
95% confidence interval						
Min	1.0					1.0
Max	1.2					1.2
Velocity of fish downstream of vertical slot (cm/s)						
N	1					1
Mean	157					157
SD						
95% confidence interval						
Min						
Max						
Time in view upstream of vertical slot (s)						
N	25	11	0	2	1	39
Mean	1.4	2.9		3.2	2.8	2.0
SD	0.8	1.0		0.3		1.1
95% confidence interval						0.35
Min	0.5	1.3		3.0		0.5
Max	4.8	4.4		3.4		4.8
Velocity of fish upstream of vertical slot (cm/s)						
N	24	1	0	1	0	26
Mean	257	203		56		248
SD	102					106
95% confidence interval						
Min	110					56
Max	610					610

Table A6. Passage behavior of American shad at the vertical slots above the fish count station in Bonneville's Washington shore ladder. Behavior was classified as upstream (up), no passage, downstream head first (Dn-hf), downstream tail first (Dn-tf), and unknown.

	Up	No passage	Dn-hf	Dn-tf	Unknown	Total
Time in view downstream of vertical slot (s)						
N	612	61	3	3	79	758
Mean	1.6	1.5	1.1	1.0	1.0	1.5
SD	0.8	1.2	1.4	0.4	0.6	0.8
95% confidence interval	0.1	0.3			0.1	0.1
Min	0.3	0.3	0.3	0.6	0.3	0.3
Max	5.7	8.0	2.8	1.3	3.7	8.0
Fish velocity downstream of vertical slot (cm/s)						
N	573	15	2	0	30	620
Mean	104	105	686		102	106
SD	46	37	323		44	58
95% confidence interval	4				16	5
Min	5	36	457		34	5
Max	348	177	914		203	914
Time in view upstream of vertical slot (s)						
N	498	5	0	2	12	517
Mean	1.0	1.1		1.8	0.9	1.0
SD	0.5	0.5		0.3	0.7	0.5
95% confidence interval	0.0					0.0
Min	0.1	0.5		1.6	0.1	0.1
Max	7.5	1.8		2.1	2.5	7.5
Fish velocity upstream of vertical slot (cm/s)						
N	469	1	0	1	3	474
Mean	214	134		99	182	213
SD	80				58	80
95% confidence interval	7					7
Min	31				114	31
Max	549				215	549

Table A7. Passage behavior of other fish at the vertical slots above the fish count station in Bonneville's Washington shore ladder. Behavior was classified as upstream (up), no passage, downstream head first (Dn-hf), downstream tail first (Dn-tf), and unknown.

	Up	No passage	Dn-hf	Dn-tf	Unknown	Total
Time in view downstream of vertical slot (s)						
N	61	8	3	0	22	94
Mean	1.0	1.0	0.5		0.8	0.9
SD	0.5	0.6	0.2		0.4	0.5
95% confidence interval	0.1					0.1
Min	0.2	0.5	0.4		0.3	0.2
Max	3.2	2.2	0.7		2.1	3.2
Fish velocity downstream of vertical slot (cm/s)						
N	43	1	1	0	5	50
Mean	148	87	183		152	148
SD	60				44	58
95% confidence interval	18					16
Min	39	87	183		102	39
Max	274	87	183		215	274
Time in view upstream of vertical slot (s)						
N	280	150	4	11	46	491
Mean	0.7	0.9	0.5	1.7	0.7	0.8
SD	0.4	0.7	0.0	2.0	0.5	0.6
95% confidence interval	0.1				0.4	
Min	0.1	0.1	0.5	0.4	0.2	0.1
Max	3.7	3.8	0.5	7.5	2.5	7.5
Fish velocity upstream of vertical slot (cm/s)						
N	114	6	3	6	3	131
Mean	247	182	315	137	203	240
SD	125	72	209	31	32	124
95% confidence interval	23	63				21
Min	54	76	146	87	177	54
Max	784	274	549	177	239	784