Ice Harbor Lock and Dam

Design Documentation Report
Interim Review

Adult Fish Ladder Weir Gate Hoist Machinery Replacement

Insert Picture

Prepared By:

USACE NWW

February 2026

Contents……i

APPENDICES

PREVIOUS REPORTS AND STUDIES

Ice Harbor Fish Ladder Gate Hoist Phase 1a - Final	

ACRONYMS

Acronym	Definition
HLD	Ice Harbor Lock and Dam
SFE1	South Fishway Entrance One
SFE2	South Fishway Entrance Two
CFE1	Center Fishway Entrance One
CFE2	Center Fishway Entrance Two
NFE1	North Fishway Entrance One
NFE2	North Fishway Entrance Two
SFEW1	South Fishway Entrance Weir One
SFEW2	South Fishway Entrance Weir Two
CFEW1	Central Fishway Entrance Weir One
CFEW2	Central Fishway Entrance Weir Two
NFEW1	North Fishway Entrance Weir One
NFEW2	North Fishway Entrance Weir Two
RMC	Rigid Metal Conduit
PLC	Programable Logic Controller
mA	Milliampere
MCC	Motor Control Center
FPHS	Fish Pump Hydraulic South
FSC	Fishway System Control
FSC	Fishway Control Center
HMI	Human Machine Interface
PDT	Project Delivery Team
NFPA	National Fire Protection Association
NEMA	National Electrical Manufacturers Association
EM	Engineering Manual
K/VA	Kilovolt-ampere
FPP	Fish Passage Plan
BPA	Bonneville Power Administration
FPOM	Fish Passage Operations & Maintenance
NMFS	National Marine Fisheries Service
HP	Horse Power
ATO	Authority to Operate
CCW	Connected Components Workbench
CMAA	Crane Manufacturers of America
DDR	Design Documentation Report
DISA	Defense Information Systems Agency
EIPS	Extra Improved Plow Steel
FRCS	Facility-Related Control System

IWRC	Independent Wire Rope Core
J&A	Justification and Approval
NWW	Walla Walla District
O&M	Operations and Maintenance
POC	Point of Contact
RMF	Risk Management Framework
RPM	Revolutions per Minute
RSW	Removable Spillway Weir
SDR	Scoping Document Report
TBD	To Be Determined
UFC	Unified Facilities Criteria
UHMW	Ultra-High Molecular Weight
USACE	United States Army Corp of Engineers

1 INTRODUCTION

This report has been prepared in accordance with ER 1110-2-1150 to record design decisions, assumptions and methods after the Feasibility Report for this project.

1.1 BACKGROUND

Ice Harbor Lock and Dam is located 7.1 miles upstream from the mouth of the Snake River. It is the first dam on the Snake River that adult salmon approach on their journey upstream to their spawning territory. There are six fishway attraction channel weirs that are raised and lowered by dedicated hoist machinery for regulating the flow, two at each of three fish ladder entrances. Reliable adjustment of the weirs is critical to maintaining the criterion for salmon of at least 8 feet of water depth over the weir and 1 to 2 feet of head differential across the weirs (this equates to roughly an 8 feet per second flow). In recent years, failures of this equipment have become more frequent, requiring unplanned disruption for maintenance and repairs.

The existing fish ladder entrance weir gate hoist equipment at Ice Harbor Dam was installed in the 1960s and is experiencing increased failures despite elevated maintenance. Maintenance data indicates that the gate systems fail and require repair on average almost three times per year (17 failures in six years). This is in addition to major failures in 2011 and 2012 which required divers to repair the failed gates.

The equipment is worn and unreliable, and replacement parts are generally not available. The telescoping weirs get stuck in locations requiring operations to modify operational procedures to free them. There are three weir gate hoist locations: (1) south fish ladder entrance, (2) center entrance at the north end of the powerhouse tailrace deck, and (3) the north entrance at north fish ladder by the navigation lock. Each location has a pair of gate hoists, for a total of six hoists. Each location has two gates, two single-drum hoists, associated motor controllers, programmable logic controller (PLC), as well as ultrasonic water level and resistance water level sensors.

The sheave beam assemblies, chains, and weir gate leaves were all replaced by Contract 99-D-04. The beam sheaves are worn and will be replaced within the scope of this proposal. The chains and weir gate leaves are not included in the scope of this proposal.

This project is to remove and replace the fish ladder entrance weir gate hoist equipment at Ice Harbor Dam so the National Marine Fisheries Service (NMFS) fish migration criteria can be met and maintained. The fish ladder weir gates regulate the attraction flow head and elevations at the downstream entrance to the fish ladder. The recommended upgrade replaces the single drum, single wire rope hoist systems with a single drum, dual wire rope hoist systems. This would include new motors, controls, and water level sensors. Safety and control features will be added to measure and report gate height and slack rope condition. These improvements will increase reliability and enhance the capability to meet NMFS fish migration criteria throughout a larger range of river flow fluctuations.

1.2 PROJECT DELIVERY TEAM (PDT)

Table 1 contains the members of the PDT for this DDR.

Name	Title/Role
Greg Linklater	Project Manager
Mike Mclean	Mechanical (TL)
Tim Ballas	Mechanical Reviewer
Eric Hedine	Electrical Lead
Emily Adshead	Electrical
Steve Summers	Electrical Reviewer
David Orona	Structural
Nikki Lorvick	Structural Reviewer
Beth Milligan	Specifier
Bennett Moore	Ice Harbor POC
Ben Mcarthur	Ice Harbor Fish Biologist

Table 1: Participants and Roles

1.3 TECHNICAL REVIEW DOCUMENTATION

Review Name	Estimated Date	Date Completed
Initial Review	MARCH 2026	
Interim Review	JUNE 2026	
Final Review	SEPT 2026	
BCOES Backcheck	NOV 2026	

Table 2: Reviews

2 MECHANICAL DESIGN

2.1 GENERAL

The Mechanical scope of this project includes the replacement of the Weir Gate lift system from the chain pick points on the gate and up, including the Lift Beam, Wire Rope, Sheaves, Drum, Hoist Drive Train, and Motor.

2.2 REFERENCES

- EM 1110-2-2610 Mechanical and Electrical Design for Lock and Dam Operating Equipment (2025)
- EM 1110-2-3200 Wire Rope for Civil Works Structures
- CMAA Specification No. 70 – 2020 Multiple Girder Cranes

2.3 NEW HOIST, SHEAVE, AND LIFT BEAM DESIGN

The Phase 1a design recommended a dual wire rope drum hoist configuration to replace the existing single wire rope and lift beam configuration. The hoist machinery will be completely redesigned, the lift beam will be removed, the sheave brackets will be redesigned, and the wire rope and gate chain connection points will be redesigned as a part of this effort. The initial (new) configuration included a sheave and reeving configuration as shown in Fig. 1. Project personnel requested a design that did not have the lift beam or any reeving to make the design simpler and more maintenance friendly. The updated (new) design has a configuration as shown in Fig. 2. This design was determined to be feasible after initial review and is chosen as the direction moving forward. This design is determined to perform better and is more maintenance friendly as compared to the existing design because it has a balanced lift configuration by pulling on both sides of the gate with two ropes off of the drum and eliminates the lift beam and reeving.

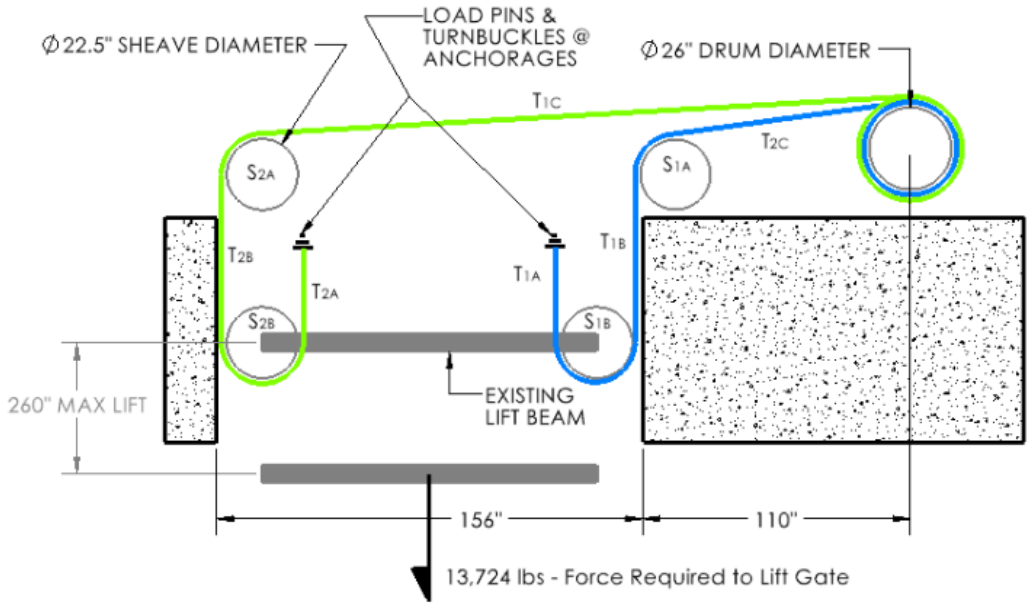

Figure 1 – Initial configuration for the new hoist design

2.4 NEW DRUM AND DRIVE TRAIN DESIGN

The new drum and drive train will be designed as a complete skid mounted unit that can be essentially copied six times for all of the relevant Weir Gates, two at the North Fishway Entrance (NFE), two at the Central Fishway Entrance (CFE), and two at the North Fishway Entrance (NFE). The drum will have opposed helically grooved areas on either end of the drum. The space between the two grooved sections provides the necessary geometry to maintain the fleet angle requirements for the sheaves and the drum as outlined by EM 1110-2-3200 and CMAA 70. The fleet angles for the new design are shown in Fig. 3. Note

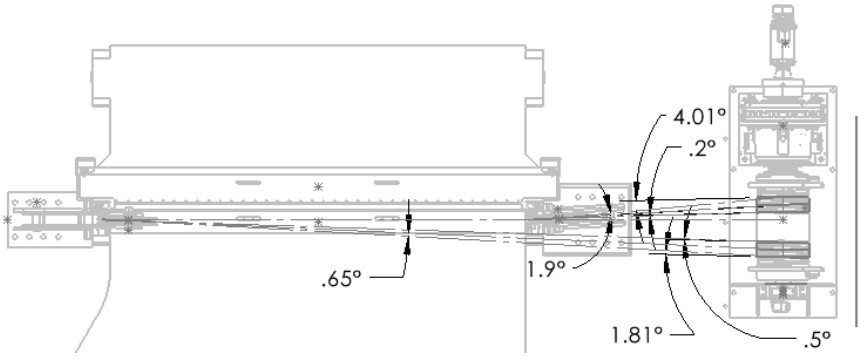

Figure 3 – Fleet angles of the hoist drum and sheaves for the new design.

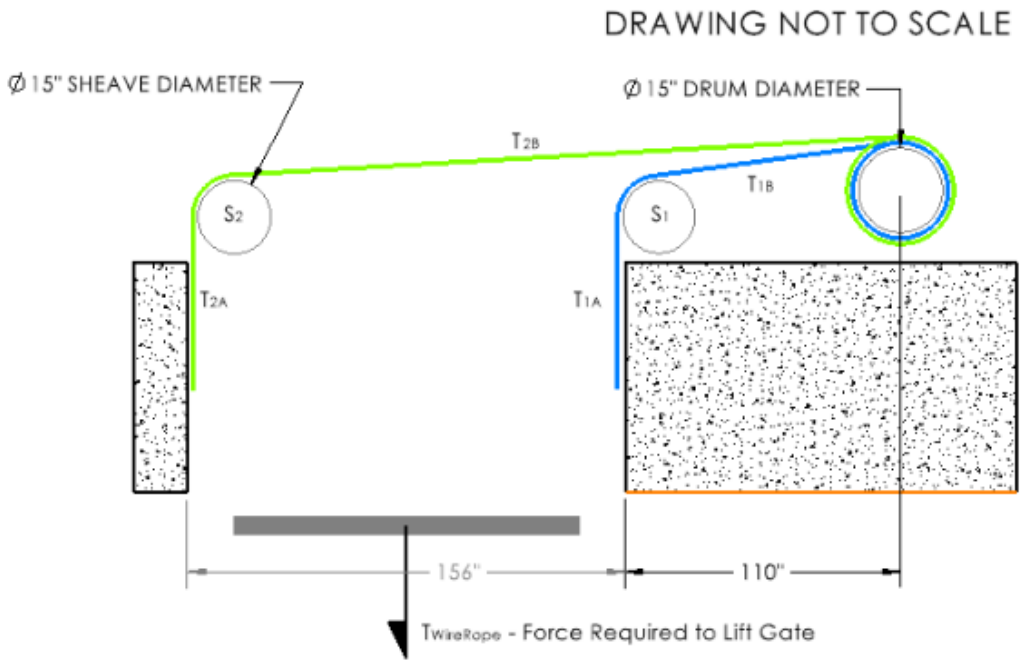

Figure 2 – Updated configuration for the new hoist design with no reeving or lift beam.

that due to space restraints the .2 and 4 degree fleet angles off of the drum for the closer sheave are not within the specified .5 degree minimum and 2 degree maximum fleet angle off of a helically grooved drum. This has been determined to be acceptable because these are the maximum travel limits and are not within the normal working range of the gate. CMAA 70 section 4.4.3.1 also specifies a 4 degree max off of the

helical drum. The Drum will be driven by an off the shelf right gear box and driven by a 2 HP electric motor attached by a NEMA C Face mount and coupling direct to the gear box. This motor will have an integral brake. The Gearbox low speed shaft will be coupled to the drum utilizing a barrel coupling creating a spherical bearing connection that doesn't axially fix the drum to the gear box shaft. On the other end of the drum a stub shaft will extend, and a fixed pillow block spherical bearing will secure the other end to the new base plate as shown in Fig. 4. A radial limit switch will then be driven by the non-driven side of the drum shaft connected by a 1:8 spur gear arrangement. This limit switch will be directly connected to the power input for the motor not allowing the motor to overtravel past its limits.

2.5 SLACK LINK INDICATION

The Phase 1a document recommends the addition of a slack line indication system to ensure the gate is not jammed or skewed in the guide slots and loads up one side unevenly. This will be accomplished by

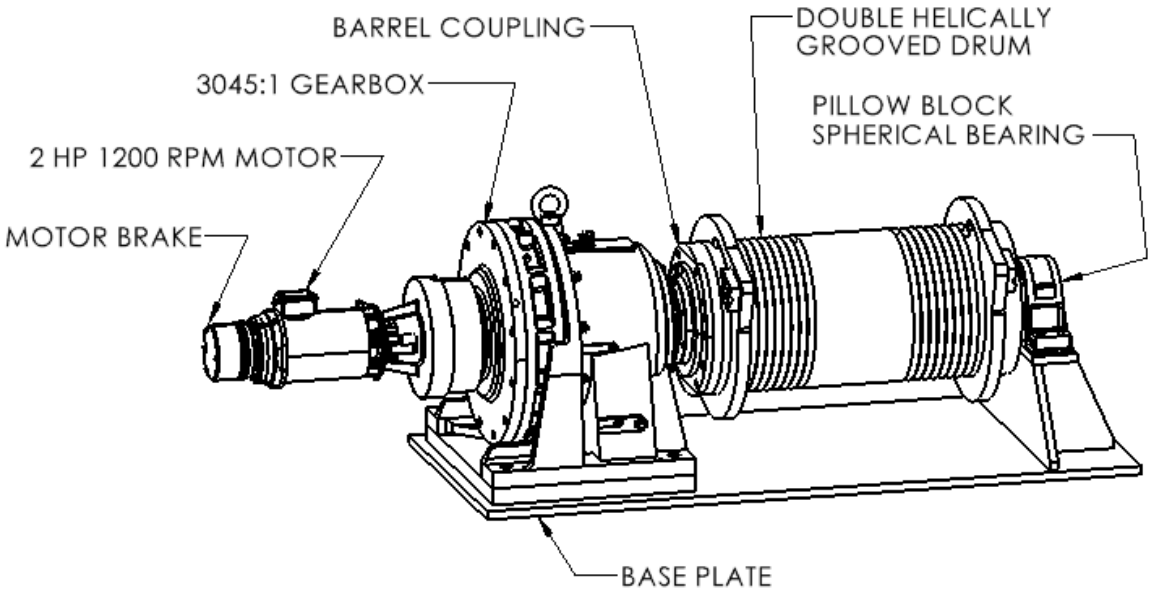

Figure 4 – New hoist machinery configuration.

using a directional load cell that is designed to replace the sheave pins. This will send back a force measurement in a 4-20 mA signal that can be used by the PLC to determine if the difference between the two tensions is large enough to throw an error. The sheave pin replaced by a load cell is shown graphically in Fig. 5

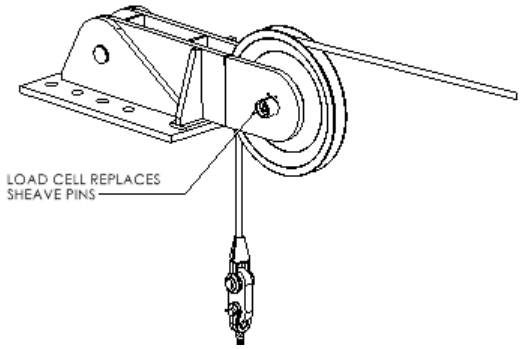

Figure 5 – Load cell replaces the sheave pins to indicate a slack line and indicate an overstress condition.

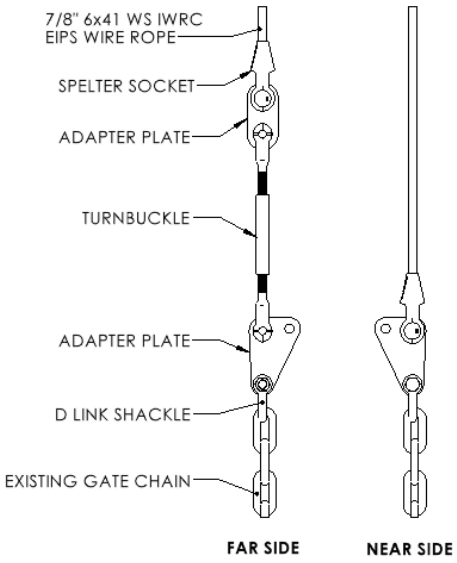

Figure 6 – Wire rope connections to the existing gate chains.

2.6 WIRE ROPE

The wire rope for the new hoists will be a 7/8” 6x41 WS IWRC EIPS. This was chosen because of its high flexibility allowing for a smaller D/d (sheave or drum diameter/wire rope diameter) ratio of 20 as suggested by EM 1110-2-3200. This smaller ratio was required to keep the required drum torque within reasonable amounts because the line pull for the new configuration has essentially doubled from the existing design. The end of the wire ropes will terminate as shown in Fig. 6 and connect directly to the existing gate chains.

2.7 GAUGE WELLS

This project includes replacing the level indicators that are currently installed to monitor the difference in water level. The levels of interest are the level in the Adult Collection Channel, and the level in the Tailrace. There are existing gauge wells that were included with the original construction of the dam. These have since been abandoned, some of them with equipment still in place. These wells will be reused by clearing out the existing equipment and replacing them with modern level indication equipment as outlined in the electrical section of this document. The covers for these wells will also be replaced to properly protect the new level indicators. The level indicators will be connected to the PLC as well as a local readout display close to the entrance weir locations.

2.8 UHMW GATE SLIDES

The Phase 1a document recommended including the addition of UHMW gate slides to the scope of this project. They indicated that one gate already had a system like this installed. Upon investigation we couldn’t find a case onsite of post installed UHMW guides. These will be further researched and developed in later design reviews.

2.9 NEW HOIST MOTOR AND INSTRUMENTATION

The new hoist motor will be a 1200 RPM, 2 HP, AC Induction motor with an electrically actuated motor brake. There will also be a rotary limit switch to with 4 contacts to define the soft and hard limits for the top and bottom of travel for the weir gates.

2.10 SEQUENCE FOR REMOVAL OF GATE WITH THE NEW DESIGN

- Bring Gate to near top position.
- Using a rated off the shelf Lift Beam. Transfer the weight to a crane at the empty holes on the Adapter Plates.
- Lower the hoist slightly to allow the line to go slack
- Unspool the wire ropes from the Sheaves and push out of the way. Pivot the Sheaves back out of the way of the guide slots.
- Lift the Gate with the crane until the bottom of the chain is near the top of the guide slot.
- Secure the Gate to the Piers using the existing Chain Dogs
- Lift the Lower Gate Section out of place with crane
- Lift the Upper Gate Section out of place with crane (ensure Chain Dogs are handled during this lift)

3 ELECTRICAL DESIGN

3.1 GENERAL

The electrical scope of work includes the complete replacement of the PLC control system and the original 1960's MCCs (FCQ1, FCQ2, & FCQ4). All loads fed by the new MCCs will have new conductors installed up to the first point of termination. The only loads being completely replaced are the Fish Entrance Weir Gates. There are three entrances, North Fishway Entrance (NFE), Central Fishway Entrance (CFE), and South Fishway Entrance (SFE). Each entrance contains two weir gates that regulate attraction flow and water levels within the fish ladders. Each of the fishway entrances will receive new local and remote controls. Remote operation will be controlled via an HMI in the control room where the operators can monitor and control.

3.2 REFERENCES

- UFC 4-010-06, CYBERSECURITY OF FACILITY-RELATED CONTROL SYSTEMS (FRCS) 10 OCT 2023
- NFPA 70, National Electrical Code 2023
- EM-1110-2-3006, Mechanical and Electrical Design of Hydroelectric Power Plants 22 APR 2024

3.3 PREVIOUS REPORTS

A scoping document report (SDR) was completed in 2013. The electrical recommendations of this SDR included reprograming existing PLCs and replacing the local weir gate hoist equipment and associated motors, motor control centers, motor controls, and sensors. The motor control centers (MCCs) related to the fishway weirs are FCQ1, FCQ2, and FCQ4. FCQ1 and FCQ2 serve the south and central fishway entrance weir gate hoist motors respectively. MCC FCQ4 serving the north fishway entrance weir gate hoist motors is housed in a metal shed that is exhibiting signs of corrosion. The MCC within the shed is original to the installation and beyond its useful life. All three MCCs should be replaced. Finding existing equipment that will fit in the original enclosures or modifying the enclosures could prove difficult and expensive. The new FCQ4 should be installed in a NEMA 4X rated enclosure that can withstand the conditions on the deck, including water spray and high humidity.

A Phase 1a report was completed in 2023. This report recommended the same upgrades as mentioned in the SDR. The only difference is the Phase 1a report also recommended a full PLC replacement. This decision was made due to the lack of documentation on the existing PLC system and due to the mixture of different PLCs used. This report also recommended installing central instrument panel for each gate assembly with displays for instrumentation.

3.4 EXISTING ELECTRICAL DISTRIBUTION

The current system is made up of three MCCs; FCQ1 FCQ2, and FCQ4. FCQ1 and FCQ2 are fed from FSQ1 which is located near each other in the Fishway Cable Gallery on elevation 349.5'. FCQ4 is fed from DCQ1 which is in the Service Gallery on elevation 445'.

New equipment standards have changed since the original MCCs were installed. To make new devices fit in old MCC buckets it would require modifying the bucket which could prove difficult and expensive. Most buckets in both FCQs would need to be modified or replaced regardless, making a full replacement timelier and more cost effective.

FSQ1 and DCQ1 would require custom work to make the new FSQ1, FSQ2, and FSQ4 feeder breakers fit. Due to the limited funding and existing layout of equipment these breakers are going to be re-used. An entire replacement of both switchgear is out of scope for this project due to wide range of loads they serve and the cost associated with switchgear replacement.

3.4.1 Fishway South and Central Entrance Power (FCQ1 & FCQ2)

Both motor control centers FCQ1 and FCQ2 are fed by switchgear FSQ1. The main MCC feeder conductors will be demolished back to FSQ1. FCQ1 powers the south entrance weir gates (SFE1 & SFE2). FCQ2 powers the central entrance weir gates (CFE1 & CFE-2). The central fishway entrances were formally called the north entrance. Existing drawings call it this and label them NFE1 & NFE2.

FCQ1, FCQ2 and their associated gate hoisting equipment will be demolished. The remaining loads on FCQ1 and FCQ2 include lighting panels, heating panels, sluice gates will have their conductors demolished from the MCCs to the first point of termination.

The PDT conducted an as-building site visit on 3/24/2026 and verified power routing. Most of the embedded conduits matched the existing drawings with a few exceptions.

Ice Harbor has been asked to provide any information on possible lead paint and asbestos in the electrical wiring and will get back by final design. Division 1 specifications will be updated accordingly.

Embedded conduit FCQ1-r1-CC1
This embedded conduit had a junction box added in the Fishway Gallery, splicing two cables into one. These cables are routed back to FCQ1 where they connect to panel CRA-4 which is mounted within FCQ1. These wires land on a 20A, two pole, breaker that was turned off. A note next to the breaker indicated this load is the tailwater level recorder and to see SG-4 breaker 2, which is most likely the power for the float itself. This circuit is un-related to the MCC and will not be demolished. According to the original drawings FCQ1-r1-CC1 is the heater for the fish collection channel float. Waiting on response from HLD if this is still required.

Figure 1: FCQ1-r1-CC1 Junction Box

Figure 2: CRA4 Panel In FCQ4, Breaker 13

Embedded conduit FSQ1-q2-GSL

This embedded conduit contains a newer power cable and phone line. The project personnel installed the phone cable. These embedded conduits pop up and into a cable channel that runs along the fish ladder.

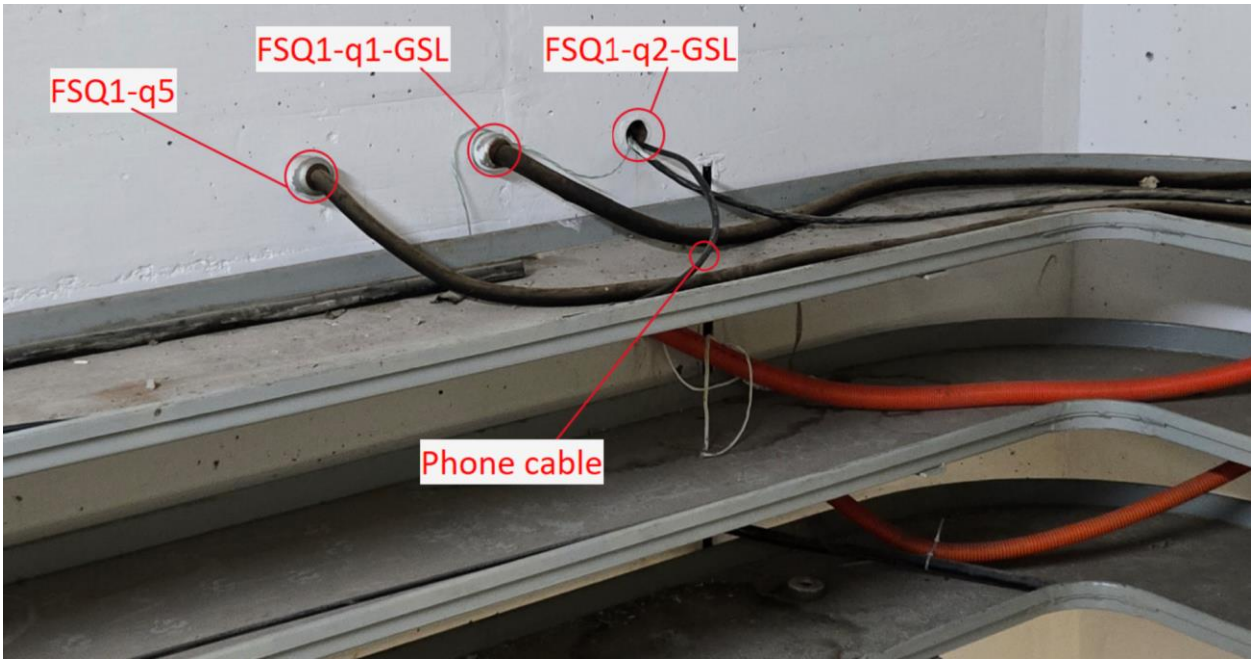

Figure 3: Embedded Conduits South End Fishway Gallery

There were a few embedded conduits not captured on the original drawings. One is capped off, one has cable abandoned in it, and the rest are empty. See Figure 4 for bay 1 top tray and Figure 5 for bay 1 middle tray locations.

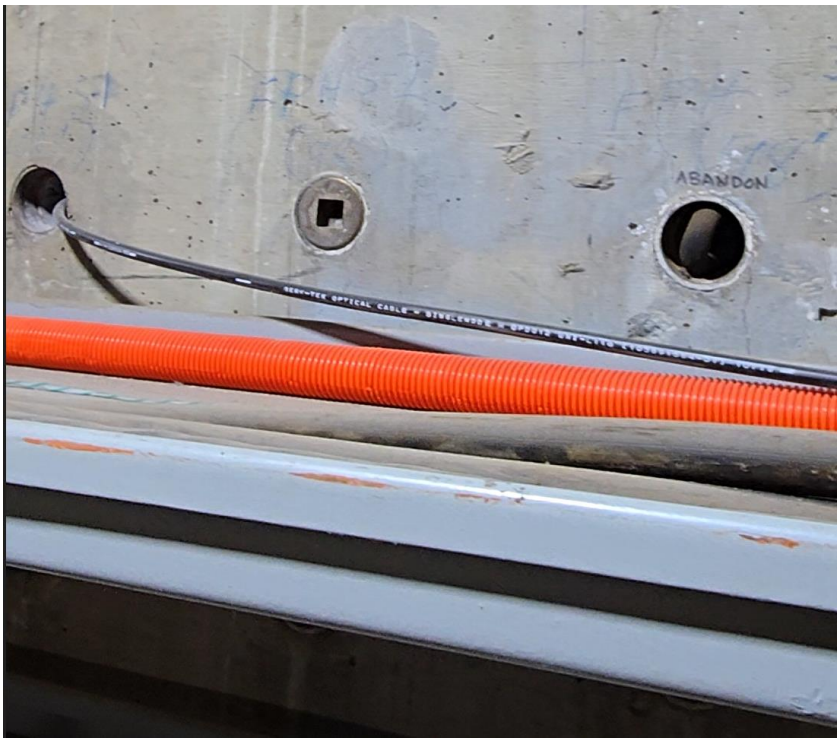

Figure 4: Undocumented Embedded Conduits Bay 1 Top Tray

The faded markings for the top tray embedded conduits seem to indicate these conduits were used for FPHS-1, FPHS-2, and FPHS-3 from left to right. FPHS most likely stands for fish pump hydraulic south. LSQ1 and LSQ2 do not power the fish pumps, so this cable is out of scope.

Figure 5: Undocumented Embedded Conduits Bay 1 Middle Tray

The faded markings for the empty conduits above the middle tray say S1, S2, and S3 from left to right. These loads are probably used for the powerhouse switchboards at some point but have since been removed. Routing of these conduits is unknown, and they will not be used for spares moving forward.

Another undocumented embedded conduit was found at the south end of the Fishway Gallery. During the as-building site visit the PDT determined the conduit contains a cable coming from FSC. The FSC board and all associated cables and equipment is going to be completely removed as the project no longer utilizes this. Therefore, this cable will be removed and not replaced. An exaggerated length will be provided in the cable conduit schedule, and the contractor will determine where this cable is routed.

Figure 6: Undocumented FSC Embedded Conduit

Additionally, the project has built a wooden frame around a portion of the cable tray system. This work bench includes data and power receptacles. The project indicated that they would demolish this so the contractor can access the embedded conduits.

Figure 7: Project Work Bench Blocking Trays

The following loads will be demolished and not replaced as the project indicated they are no longer used.

- FCQ1 Loads:
  - FC-1, COLLECTION CHANNEL WING GATE
  - SFE1 SOUTH FISH ENTRANCE WING GATE
  - FISHWAY SYSTEM CONTROL (FSC) SWITCHBOARD 480 VAC SUPPLY

  - FW2, FW3, TW1, CC1 & SEC - FISHWAY, TAIL WATER, COLLECTION CHANNEL AND FISHWAY ENTRANCE FLOATS.
- FCQ2 Loads:
  - FC-2, COLLECTION CHANNEL WING GATE
  - NET, NEC – FISHWAY ENTRANCE AND TAILWATER FLOATS

- FCQ4 Loads:
  - BRIDGE CRANE

3.4.2 Fishway North Entrance Power (FCQ4)

The motor control center FCQ4 is fed by switchgear DCQ1. FCQ4's main feeder conductors will be demolished. FCQ4 powers the north entrance weir gates (NFE1 & NFE2). FCQ4 and its gate hoisting equipment will be demolished. The remaining loads on FCQ4 includes 480VAC receptacle circuits, diffuser valves, a distribution panel for heater loads and control circuits. Conductors for these loads will be demolished from FCQ4 to the first point of termination.

FCQ4 is housed in a metal shed that is exhibiting signs of corrosion. The MCC within the shed is original to the installation and beyond its useful life. This MCC and its shed will be demolished and replaced with a NEMA 4X rated enclosure.

3.5 EXISTING CONTROL SYSTEM

There are three fishway entrances South, Central, and North. Each fishway entrances are made up of two weir gates. See Figure 8: Fishway Entrance Locations for general locations. Each fishway entrance utilizes ultrasonic sensors to monitor the tailwater and water head across each weir gate. The objective of the weir gate hoist system is to maintain the fish passage criteria which includes keeping a one foot drop across the weir gates.

The existing control system has had modifications to keep it functional. These modifications were undocumented. The PDT completed an as-building effort to verify how the controls currently function. All three fishway weir gate related PLCs are beyond their normal life expectancy (15 years).

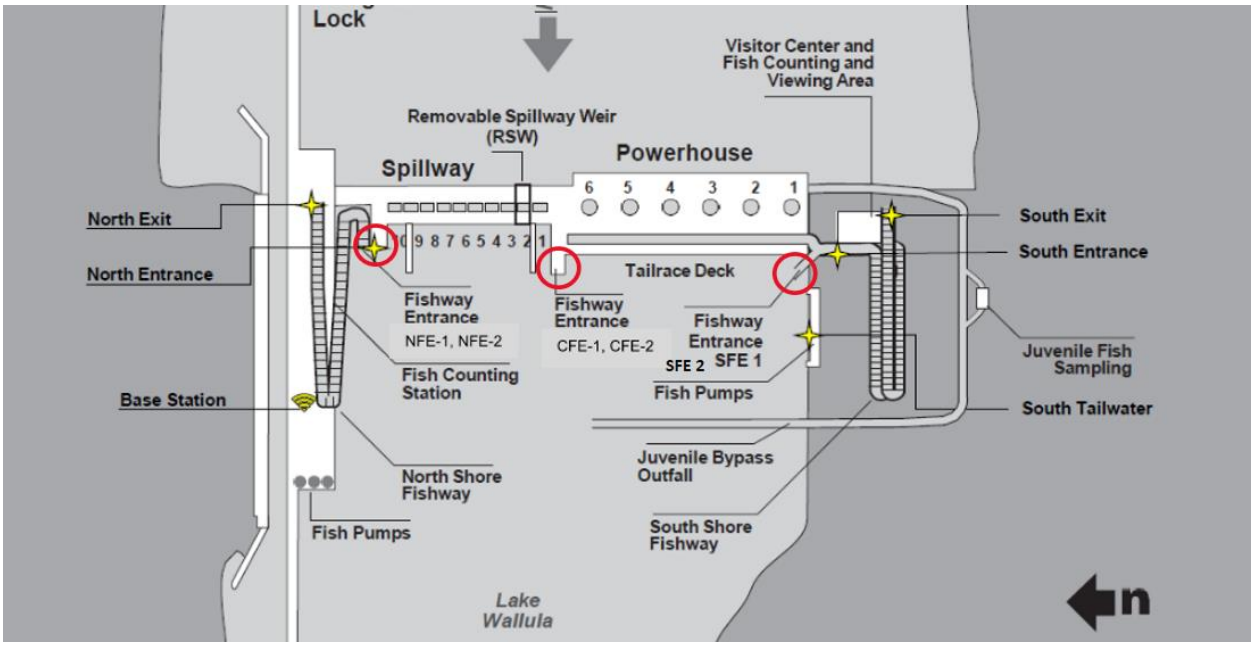

Figure 8: Fishway Entrance Locations

3.5.1 South Fishway Entrance

For the south entrance the downstream ultrasonic sensor mounted near the gate and on the tailrace deck wall were installed by the project to maintain functionality when the original hydro ranger unit failed. See Figure 9: SFE1 & 2 Channel Water Level Sensor and Figure 10: SFE1 & 2 Tailrace Water Level Sensors.

Additionally, the existing hydro ranger enclosure was converted to be a junction box that houses terminal blocks used by the project to test and adjust the ultrasonic water level sensers. Below the hydro ranger enclosure is a junction box that has a conduit connection to a separate radio control enclosure. This radio system is totally unrelated and has a separate control system. The project installed this conduit to route a ground cable to an established ground in that radio control enclosure. From the junction box there are also conduits routing to each ultrasonic sensor, and one conduit connects to the existing stilling well which also houses an abandoned sensor “metritape” that used to be used for water level. The stilling well serves as a junction box for pulling cables into the existing embedded conduits which are used to route the 4-20mA signals back to the Fishway Gallery. See Figure 11: Stilling Well & Airranger Enclosure. All control enclosures, equipment, conduit, and cables/wires will be demolished. Ice Harbor has requested to keep the old level sensors after they are demolished.

The hoisting equipment SFE1 and SFE2 will be demolished as well. This includes power and a 4-20mA signal generated by an encoder for gate position. See Figure 12. All control and power wiring utilizes embedded conduits back to the spillway gallery. In the spillway gallery there is a set of three cable trays that span the entire gallery. These trays are utilized to route control 4-20mA signals to the existing PLC enclosure located in the Fishway Gallery near pier 1 on the downstream wall. See Figure 15: SFE PLC Enclosure and Figure 13: Fishway Gallery Embedded Control Conduits.

Control cables are routed between the SFE PLC enclosure and LSQ1 in the Spillway Gallery. This includes 3 sets of control cables and a 4-20mA signal. See Figure 14: SFE PLC CABLES. For details on fiber optic cables, see section 3.5.5 Control Systems Network.

Figure 9: SFE1 & 2 Channel Water Level Sensor

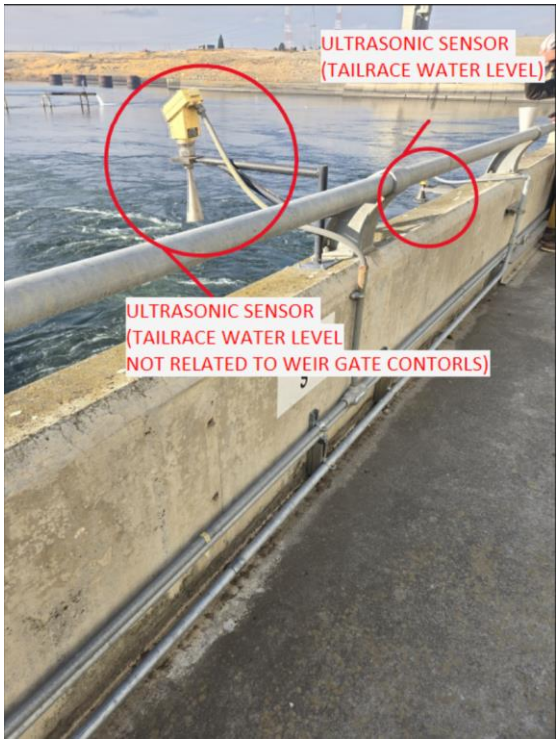

Figure 10: SFE1 & 2 Tailrace Water Level Sensors

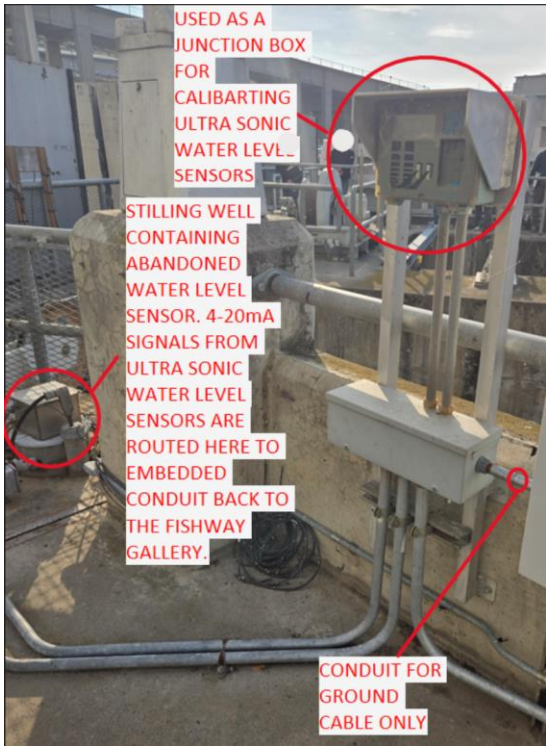

Figure 11: Stilling Well & Airranger Enclosure

Figure 12: SFE1 Hoist Equipment (Typical for all locations)

Figure 13: Fishway Gallery Embedded Control Conduits

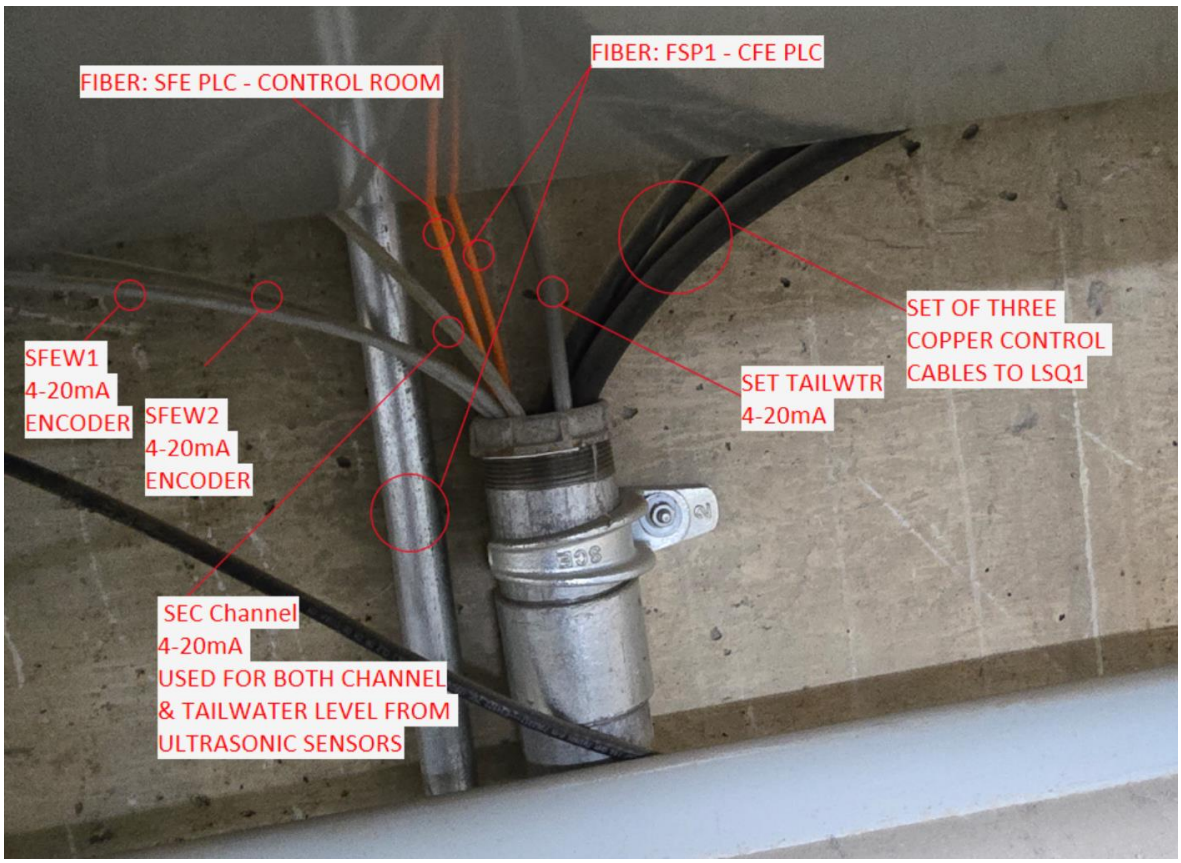

Figure 14: SFE PLC CABLES

Figure 15: SFE PLC Enclosure

3.5.2 Central Fishway Entrance

Two ultrasonic sensors are installed and feed their signals into a device called DPL Airranger. See Figure 16 and Figure 17. One ultrasonic sensor is installed just upstream of the gate and measures the channel water level. The other sensor is installed just downstream of the gate and measures the tailrace water level. Both sensors feed a 4-20mA signal into the Airanger which then uses a CAT5-cable or communication bus to route to the PLC to then be converted back into the 4-20mA signal for the PLC to read. FCQ2-CRA5 feeds the 120VAC power to the Airanger.

In the stilling well there is a metritape water level sensor that has been abandoned in place. See Figure 18: Stilling Well – Water level Sensor Metritape. All controls and abandoned devices will be demolished. Ice Harbor has requested to keep the old level sensors after they are demolished. The stilling well serves as a junction box for pulling cables into the existing embedded conduits which are used to route the 4-20mA signals back to the Fishway Gallery and then onto cable trays and to the PLC.

The hoisting equipment NFE1 and NFE2 will be demolished as well and relabeled as CFE1 and CFE2. This includes power and controls and a 4-20mA signal generated by an encoder for gate position. All control and power wiring utilizes embedded conduits back to the spillway gallery onto trays that go to FCQ2 and the central PLC. See Figure 19. These trays are utilized to route control 4-20mA signals to the existing PLC enclosure located in the Fishway Gallery in between piers 6 and 5 on the downstream wall. See Figure 20.

There is a cable that is utilizing the Central PLC enclosure as a pull box that is related to the security of some north and south entrance doors, but it was abandoned and spooled at the end of the line. See Figure 21. It will be pulled from the enclosure and terminated at the existing pulling elbow.

Figure 16: Central Weir Gate Sensor & Devices

Figure 17: Central Weir Gate Ultrasonic Sensors

Figure 18: Stilling Well – Water level Sensor Metritape

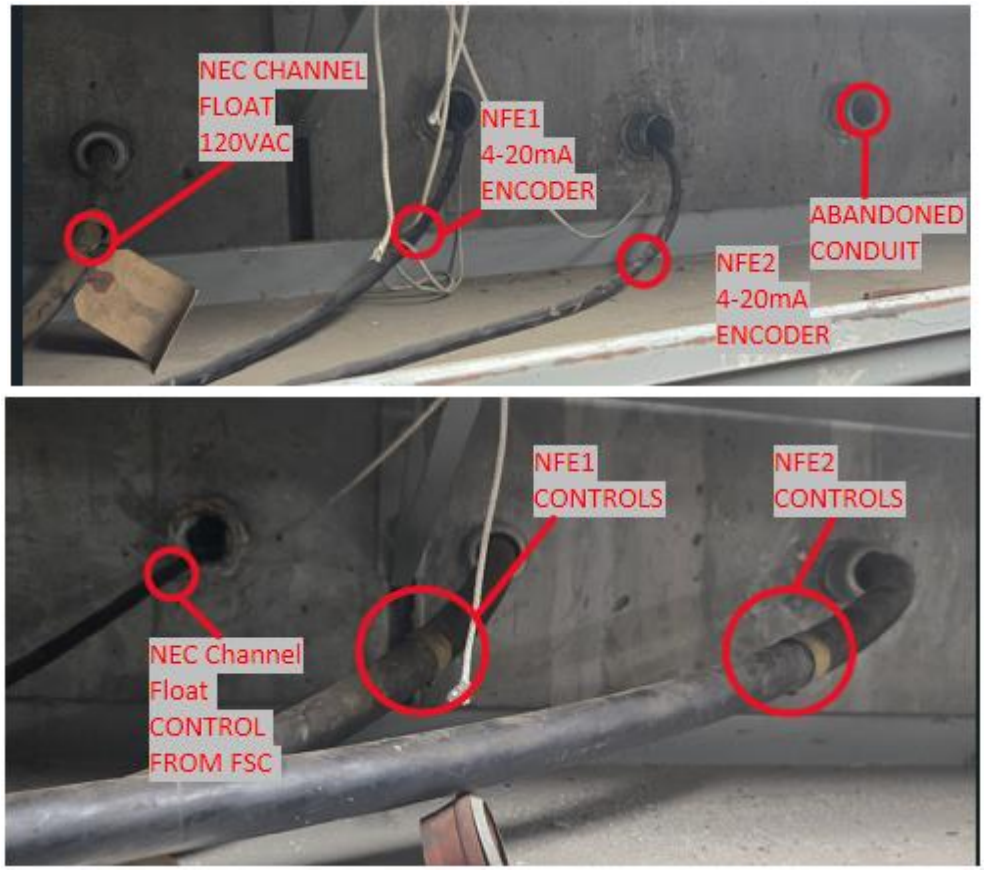

Figure 19: Embedded Conduits Bay 6

Figure 20: Central PLC Control Cables

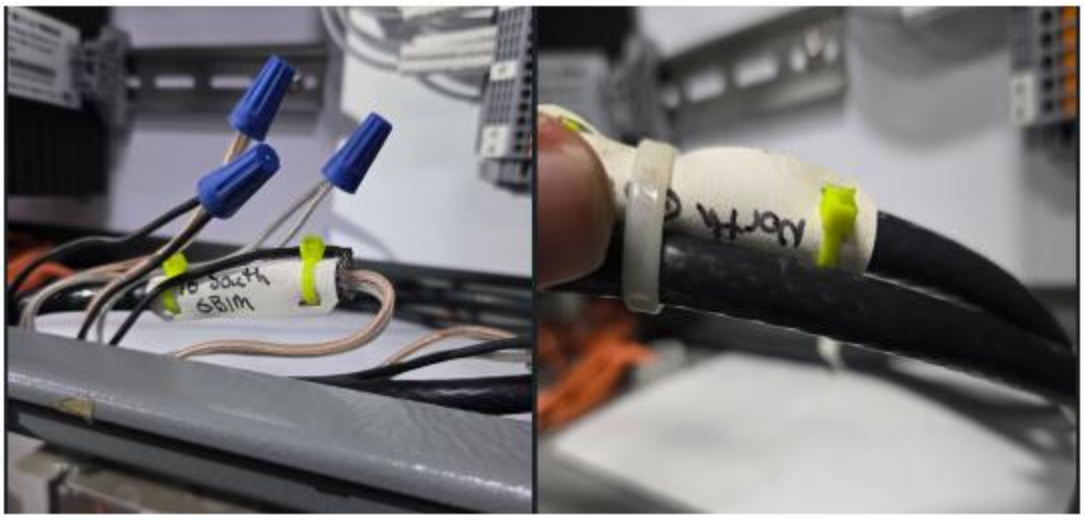

Figure 21: Security Cable

3.5.3 North Fishway Entrance

Similar to the SFE, the NFE had its controls repaired due to issues with the hydro ranger unit and damage from the water being sprayed on the equipment every time spillway bay 6 is open. Some of these changes were undocumented but during as-building we confirmed the original airranger was gutted and its enclosure is now used to house terminal blocks used to help test and adjust the new 4-20mA signals coming from the ultra-sonic sensors seen in Figure 22 and Figure 24. The original arranger ultrasonic sensor seen in Figure 23 is abandoned. In the stilling well there is a metritape water level sensor that has been abandoned. All controls and abandoned devices will be demolished. Ice Harbor has requested to keep the old level sensors after they are demolished.

In 2021, new conduits and control boxes were installed. Four conduits were coming from FCQ4 to the weir gates, but only one was being used, the other three are empty, see Figure 29. NFEW2 new controls are connected and active. See Figure 27: NFEW2 Control Enclosure. NFEW1 new control panel was installed but not connected as the existing controls are still functioning, see Figure 28: NFE1 Control Enclosure.

An HMI was installed in FCQ4 shack as shown in Figure 26. This HMI displays the same data as the HMI in the control room. The major items are:

- NFEW1 position
- NFEW2 position
- Channel water level
- Tailwater level
- Difference between tailwater and channel water levels
- Water depth over each weir gate
- Control mode status (manual/automatic and on/off)
- Status of ultrasonic devices
- Whether the gates are in or out of “range” meaning within the fish passage requirements

The hoisting equipment NFE1 and NFE2 will be demolished as well. This includes power and a 4-20mA signal generated by an encoder for gate position. Encoder 4-20mA signals are routed back to FCQ4 in RMC.

There is an existing fiber optic cable routing up through FCQ4 on the monolith wall and up to the gallery containing DCQ1. This fiber has plenty of slack and will be re-used. Fiber optic cable will be pulled back into the cable tray next to DCQ1 and stored there during the demolition phase.

Figure 22: North Fishway Tailrace Ultrasonic Sensor

Figure 23: ULTRASONIC SENSOR NFE2

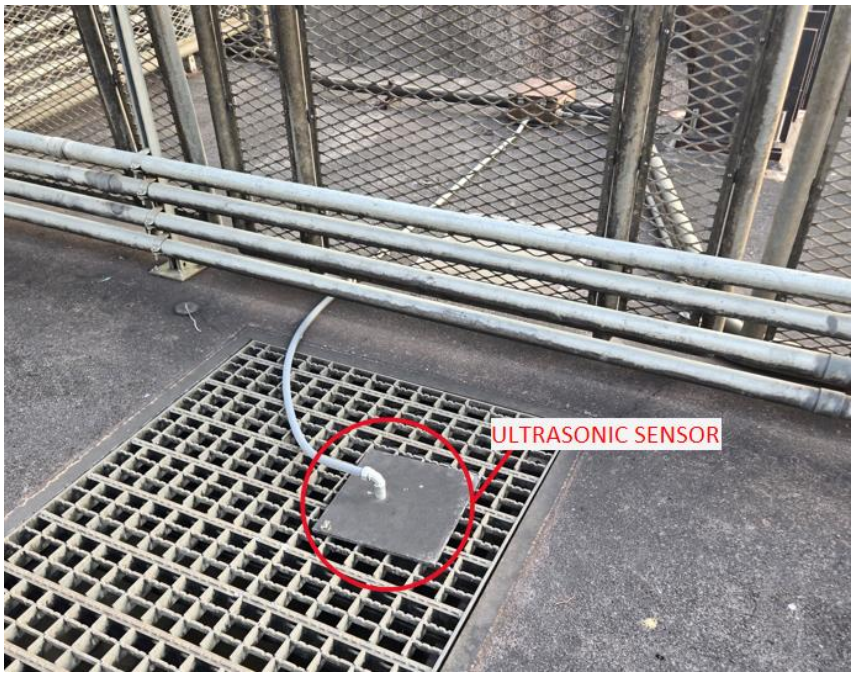

Figure 24: North Fishway Ultrasonic Sensor

Figure 25: Stilling Well – Water level Sensor Metritape

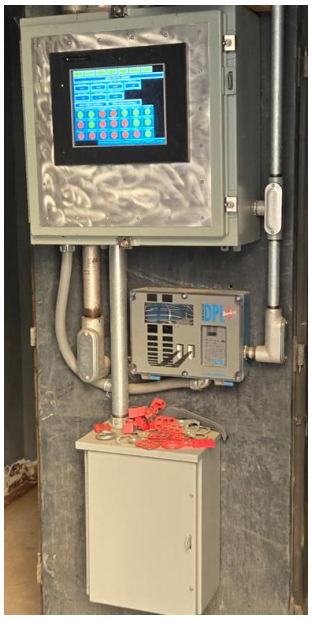

Figure 26: North Fishway HMI/PLC Cabinet In FCQ4 Shack

Figure 27: NFEW2 Control Enclosure

Figure 28: NFE1 Control Enclosure

Figure 29: Spare Conduits

3.5.4 FSC

The Fishway Control Center (FSC) is in the Fishway Gallery between FSQ1 and FCQ1, see Figure 30. It was the original method for remote control and position feedback for the south and central fishway entrance gates. This equipment is not used and the project personnel indicated they would like it removed and not replaced.

Figure 30: FSC

3.5.5 Control System Network & Control Room

The control system network currently includes more items than just the adult fishway weirs. This network also includes the pumping house. After the as-building site visit in 3/23/2026 the project and PDT agreed the best path forward is to separate out the adult fishway from the existing network and place it on its own dedicated network. The existing annunciation network switch in the control room has had issues in the past and can take almost a minute to pass data at times which is too slow for systems such as gate position feedback. The current system uses unmanaged network switches and is out of compliance with new cybersecurity standards. However, updating the entire system is out of scope for this project.

This project is demolishing the SFE and CFE PLC panels. This will disrupt the signals from LSP1 because the fiber is routed from LSP1 to the SFE PLC fiber patch panel and network switch. A new fiber cable will be required to be installed from LSP1 to the control room. The PLC and switches in the control room SO switchboard, cabinet SOR5 will remain. The project agreed they would adjust the control room PLC code to remove the adult fishway related alarms and controls.

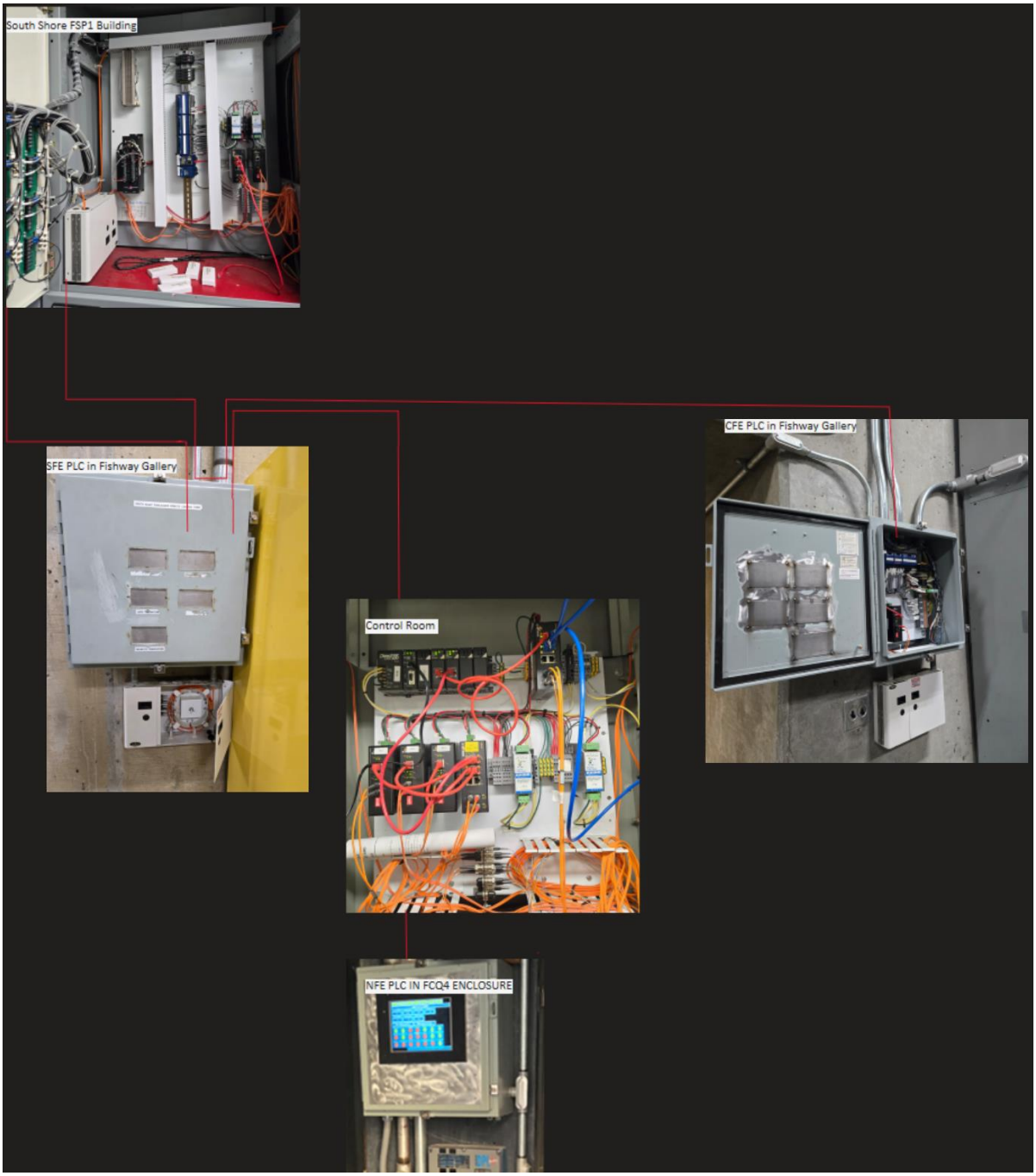

Figure 31: Fiberoptic Cable Terminations

Operators have the capability to control the adult fish ladder weir gates via an HMI mounted in the operator's desk. This HMI will be demolished.

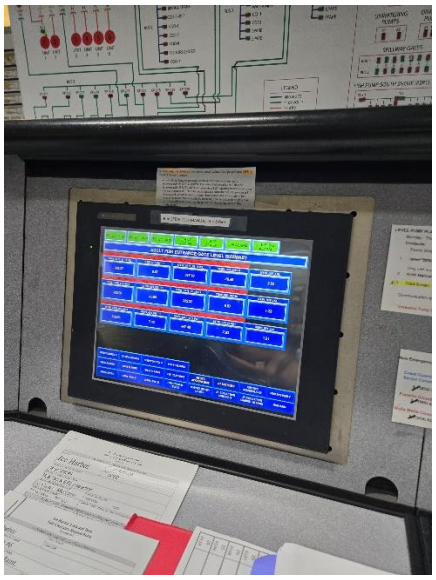

Figure 32: Control Room Fishway HMI

3.6 NEW ELECTRICAL DISTRIBUTION

EM 1110-2-3006 recommends the feeders should be sized based on maximum expected load, with proper allowance made for voltage drop, motor starting inrush, and to withstand short-circuit currents.

3.6.1 Motor Control Centers

MCCs provide a convenient grouping of motor starters and controls within the power distribution equipment, which allows less clutter and hazards at the utilization equipment where space is often at a premium. According to EM 1110-2-3006 NEMA 1 enclosure are suitable for clean and controlled environments. NEMA 12 is recommended for dirty and/or oily environments or where temperature is not well controlled. Such environments should require enclosure strip heaters to help reduce condensation. According to NEMA Standards Publication 250-2003, NEMA 4X are constructed for either indoor or outdoor use to provide a degree of protection against windblown dust, the ingress of water, corrosion, and by the external formation of ice on the enclosure. This project will utilize NEMA 12 enclosures for FCQ1 and FCQ2. FCQ4 will be installed in its own prefabricated container and will have a NEMA 4X rating due to its proximity to the spillway.

3.6.1.1 MCC House Keeping Pads

The MCCs will be elevated up to 3 inches on housekeeping concrete pads. This will prevent any liquids from entering the bottom of the MCC or its embedded conduits. The existing embedded conduits will need to be extended to account for the new pad.

3.6.1.2 Weir Gate Motor Starters

The traditional across-the-line starting of the motors will be utilized. The weir gate motors are only two horsepower. The inrush would be around 3.4 Amps.

3.7 ELECTRICAL STUDIES

3.7.1 Load Flow Study

The load study confirms whether the designed power system can supply the various loads. It confirms whether services, feeders, and equipment are sized properly, or they are overloaded. See Appendix F for detailed load calculations and screen shots of the load flow study.

The loads are not being increased for this project but it's still important to verify instead of blindly copying original documentation. Wing gates and the FSC panel were not included in the load flow as they will be demolished and not re-installed.

In summary, the load flow study completed in ETAP resulted in load current values similar to what was calculated. The only outliers were control panels which drew less current than what was calculated. This difference is due to the calculation being based off of the transformer VA rating while ETAP uses the entered KVA for the load to determine what the load current is. For this design, transformer secondary protection and feeder size will be based off NFPA standards which uses the transformer VA.

3.7.2 Short Circuit Study

Short-circuit calculations are necessary to specify equipment withstand ratings and for use in conjunction with the protective device coordination study. Switchgear, MCCs, safety switches, panelboards, motor starters, and busbar must be capable of withstanding available fault currents. After the available fault current has been calculated at each bus in the electrical network, the available fault current withstand ratings are specified. See Appendix F for more information, short circuit currents for each load, and screenshots from ETAP.

Bus	3-Phase Short Circuit Current (kA)
FCQ1	8.057
FCQ2	3.703
FCQ4	14.532

Table 3: Short Circuit Current Summary

The MCC design is based off Eaton equipment. According to Eaton's low voltage MCC design guide, the typical short circuit bus ratings are: 42kA, 65kA, and 100kA.

3.7.3 Voltage Drop Study

Conductors have an electrical resistance that increase with length. This resistance over long runs will result in a drop in voltage. Conductors must be upsized to account for voltage drop, alternatively voltage can be increased. The maximum voltage drop for feeder circuits is 2% and the maximum voltage drop for branch circuits is 3%. See Appendix F for voltage drop study results. The cable sizes displayed in the cable and conduit schedule have been adjusted accordingly to account for voltage drop.

3.8 NEW CONTROL SYSTEM

The fishway weir gates will receive a new control system that will allow the project to stay in compliance with the fish passage plan which includes all applicable criteria. This system will have an automatic mode and a manual mode. Additionally, local hardwired controls will be implemented for maintenance, and to serve as an emergency backup if the fishway entrance gate control network goes down.
Simple raise, lower, and stop commands will be utilized for each gate. Automatic mode will utilize gate position (tracked via an encoder) and compare that against water levels (tracked with radar sensors) just upstream and downstream of the gate. The encoder which will be attached to the hoist converts mechanical movements into analog output signals of 4-20mA to track its exact location and sends those output signals to the PLC. This will allow the gates to stay in compliance with regulations automatically. Alarms and remote controls will be visible in the control room where the operator can adjust the weir gates from a new HMI. The new control system will utilize fiber only.

3.8.1 Fishway Passage Plan Requirements

The annual Fish Passage Plan (FPP) is developed by the U.S. Army Corps of Engineers in coordination with the Bonneville Power Administration (BPA), regional Federal, State, and Tribal fish agencies, and other partners through the Fish Passage Operations & Maintenance (FPOM) coordination team. The FPP describes year-round operations and maintenance (O&M) actions scheduled to occur each year from March 1 through the end of February to provide fish passage and protection at the eight Corps hydropower projects on the lower Columbia and lower Snake rivers The fish passage plans are posted at this location: https://public.crohms.org/tmt/documents/fpp/2026/final/FPP26_06_IHR_03-25-2026.pdf

FPP requires fishways to maintain water velocities in the range of 1.5 - 4.0 feet per second (fps). Ice Harbor monitors water velocity at the junction pool in the lower south fish ladder. This is controlled via fish ladder water pumps

Head is measured at the north, central, and south fishway entrances. The water depth over fishway ladder weirs must be kept between 1.0 foot and 1.3 feet. The water head on all fishway entrances must be kept between 1 foot and 2 feet. This is controlled by adjusting the weir gate height or manually adjusting the fish ladder water pumps.

3.8.1.1 South Fishway Entrance

Fish Passage plan requirements:

1. The control system should operate the entrance closest to powerhouse (SFE1). SFE2 will only be operated for adult salmonid passage.
2. Elevation of top of SFE1 gate on sill = 332.25 feet. Elevation of top of SFE2 gate on sill = 333.25 feet with the installation of the lamprey passage structure.
3. At tailwater lower than elevation 340.25 feet for SFE1 and 341.25 feet for SFE2, weirs should be on sill.
4. From July 1 to October 1, operate entrance furthest from powerhouse (SFE2) for adult lamprey passage with it being just lifted slightly off sill to allow lamprey to travel underneath. The other weir is operated as the on-service weir as normal during that time.

3.8.1.2 Central Fishway Entrance

Fish Passage plan requirements:

1. Operate one downstream gate.
2. Elevation at top of gate on sill = 332.25 feet.
3. Weir depth ≥ 8 feet below tailwater. At tailwater lower than elevation 340.25 feet, weirs should be on sill. [Note: At low tailwater, weirs will bottom out and will be less than 8 feet below tailwater.]

3.8.1.3 North Fishway Entrance

Fish Passage plan requirements:

1. Operate downstream gate closest to shore (NFE1).
2. NFE2 will only be operated for adult salmonid passage if NFE1 gate is not functioning properly to maintain criteria.
3. Elevation at top of gate on sill = 332.25 feet.
4. Weir depth 8 feet or greater below tailwater. At tailwaters less than 340.25 feet, weirs should be on sill. Note that at low flow and tailwater, some of the diffusers are above tailwater and the project may only be able to maintain a 6 feet weir depth.

3.8.2 PLCs

Ice Harbor personnel indicated the preferred PLC for this application is the Allen Bradley Micro800 controllers. Due to the limited inputs at each weir gate and its ability to connect to an HMI the Micro820 will be utilized. Design currently has an existing five-year Justification and Approval (J&A) awarded in 2023 and set to expire in 2028 for the use of all Allen Bradley products. The 800 series utilize connected components workbench (CCW) for its programming language.

Each fishway entrance will have its own PLC. Specifically the micro 820 which includes inputs and outputs on the main unit and includes two expansion slots. The expansion slots will each be filled with a 4 channel analog input card.

The main inputs and outputs are:
Inputs:

- Motor overloads
- Radar sensors for water level
- Encoders used for gate position
- Load cell amplifiers checking for gate tensions

Outputs:

- Gates raise and lower control
- Load cell indication (cuts power to motor if gate gets stuck or skewed)

3.8.2.1 Encoders

Two 4-20mA encoders will be connected to the 4 channel analog input cards. They will be used in conjunction with the water level sensors when in automatic mode to adjust to the correct gate height needed for fish passage. They are easy to program, are more accurate than other types of devices due to control dead band and adjustment frequency, and can easily be tested using just a multimeter.

3.8.2.2 Radar Water Level Sensors

All fishway entrances have stilling wells that will be used to house new radar water level sensors. Radar water level sensors will also be mounted just beyond the gates to capture the tailrace water level. Sensor placement was not only based on the single most representative position, but also the placement for ease of installation and maintenance.

Two radar sensors will be installed to monitor the inlet water level. Standard ultrasonic sensors struggle with buildup from condensation, spider webs or other contamination sources. This influences the reliability

of the measurement signal and increases the dead zone. Thanks to optimized signal processing, radar sensors can suppress interference caused by buildup on the antenna system.

Due to their physical measuring principle, ultrasonic sensors are exposed to considerable influences because the sound running time changes with temperature, e.g. due to solar radiation and gas composition. Even in heavy fog, wind or rain, the sound waves are additionally attenuated, and the measuring range further restricted. Radar sensors are unaffected by temperature, pressure or vacuum and provide correct readings under all environmental conditions.

Radar sensors can also be used in confined spaces and installations such as the stilling wells. Due to the high focus of the 80 GHz technology, the radar beam can be aligned almost precisely to the medium to be measured. This means that there are no interference signals even with installations such as pipes or pumps, in narrow shafts or with deposits on walls. Compared to ultrasonic sensors, no interference signal suppression is necessary. Radar sensors also avoid the maintenance associated with silt which can build up in underwater pressure sensors. Radar sensors utilize a two wire 4-20mA signal.

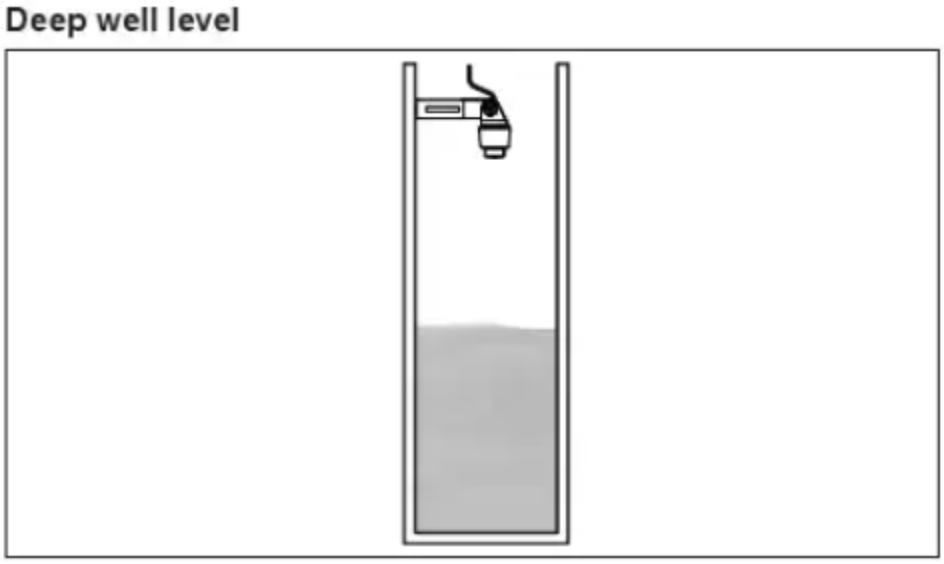

Figure 33: RADAR SENSOR STILLING WELL APPLICATION

3.8.2.3 PLC Control Network

The micro 820 includes an ethernet port which will be utilized to connect to a cisco network switch. The selected switch is the Cisco C9200CX-12T-2X2G. It was chosen for its compact size, reliability, and small number of ports as this network is not complicated. This switch is on the Defense Information Systems Agency (DISA) approved list meaning it meets cybersecurity requirements.

Each weir gate PLC will connect to its own network switch. The network switches will utilize fiber-optic cable and route back to the control room where they land on a new network switch and PLC mounted in the SO board. Specifically, the internal side of SOR5. The new control room PLC will receive the gate data and display it on an HMI located in the Operator’s desk.

3.8.2.4 PLC Ladder Logic Considerations

Ladder logic is developed at the early stages of construction. NWW Electrical design will be programming this system with operations review. PDT will have one week during the outage to commission the PLC control system. At interim review, the exact expectations are either full PLC replacement at once vs replacing one at a time and updating the existing plc/network switches to accommodate connection to new PLCs.

3.8.3 Control Modes

3.8.3.1 Hand-Mode (Local only)

Each weir gate will be capable of switching to hand mode which implements simple relay logic controls to either open, close or stop the gate manually. Limit switches will prevent the gate from moving beyond its allowable range. A local HMI will be utilized to display gate position, water levels above and below the gate, and the differential between the water levels. Additionally, gate related alarms such as overtravel, wire spooling, and motor overload status will be displayed on the HMI.

3.8.3.2 Auto-Mode

Each fishway weir gate will be capable of automatically adjusting to maintain fish passage criteria. Automatic mode relies on local PLCs which take in water levels just above and below the gate. The gate position itself is tracked via an encoder.

3.8.3.3 Remote-Mode

Operators will be able to remote control any of the fishway weir gates from the new HMI in the control room. The project indicated they wanted the new fishway entrance HMI to have a display similar to what is used at MNA. See Figure 34 below for a screen shot from MNA's fishway entrance HMI.

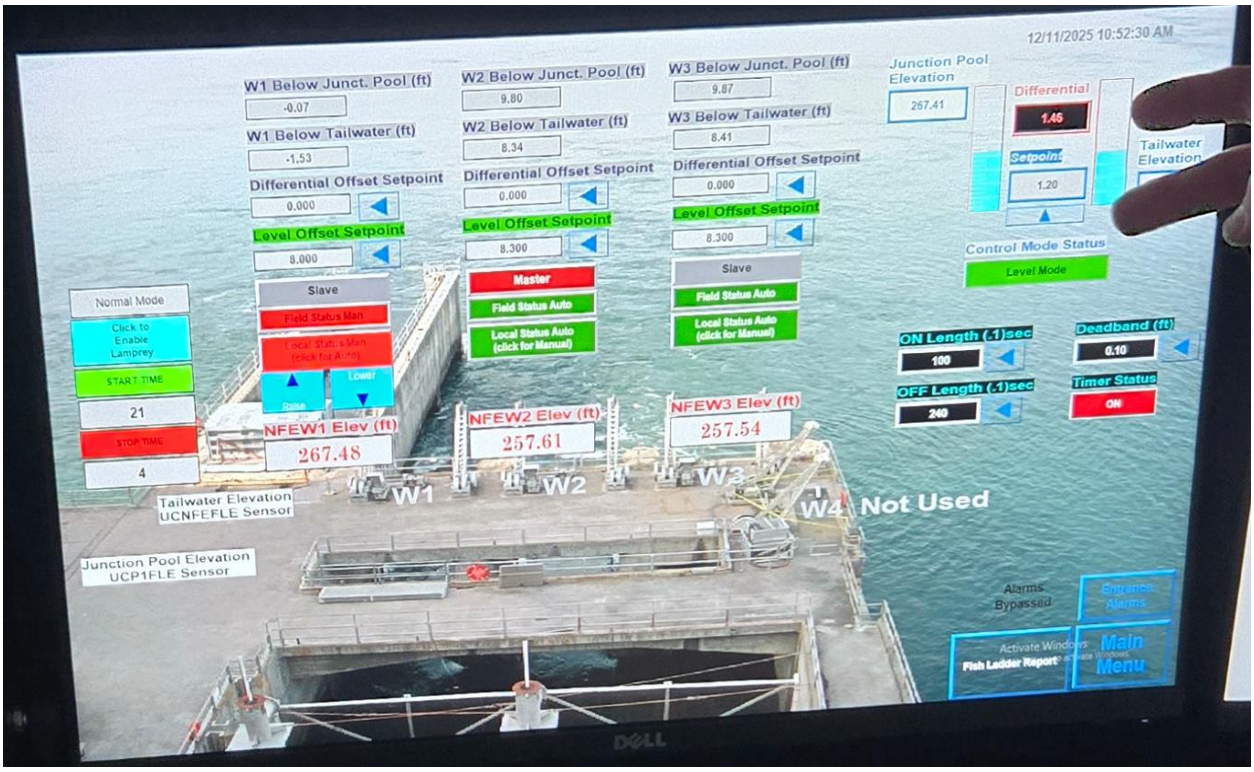

Figure 34: MNA HMI Weir Gate Control Example

3.9 CYBERSECURITY

UFC 4-010-06 applies to all design and construction of new and existing facilities which include a control system with a network regardless of funding source and regardless of network type. This UFC defines a process for identification of cybersecurity requirements based on the Risk Management Framework (RMF) suitable for control systems of any impact rating and provides specific guidance suitable for control systems assigned LOW or MODERATE impact level.

Before the new control system can be turned over to the project it must receive an Authority to Operate (ATO). To receive an ATO the Authorizing Official (AO) evaluates the risk and either accepts the risk or denies it. This PDT is working closely with NWW's assigned Information System Security officer (ISSO), Lidia Thomas and USACE Critical Infrastructure Cybersecurity (UCIC) Regional Information System Security Managers.

Network components have been selected from the DISA approved product list. The chosen network switch for this project is the Cisco C9200CX-12T-2X2G.

3.10 ANTICIPATED DRAWINGS

E-001	Legend
ED101	Overall site plan demo
ED102	Overall south & central site plan demo

ED103 - ED111	Fishway gallery plan views demo
ED112	Erection bay plan view demo
ED113	Control room plan view demo
ED114	Central weir gate plan view demo
ED115 – ED118	Tailrace decks plan view demo
ED119	South weir gate plan view demo
ED120	Fish pump house plan view demo
ED121	South tailrace deck plan view demo
ED122	South fish ladder plan view demo
ED123 – ED126	North fishway entrance plan view demo
ED201	FCQ1, FCQ2 elevation view demo
ED202	FCQ4 elevation view demo
ED203	SO board elevation views demo
ED301 – ED304	FCQ2, FCQ1, FSC, FSQ1 section view demo
ED901 – ED903	Demo pictures
ED601 – ED605	Demo one lines
ED610 – ED611	North, south, central schematics demo
ED612	Demo network drawing
E-101	Overall site plan install
E-102	Overall south & central site plan install
E-103 – E-112	Fishway gallery plan views install
E-113	Erection bay plan view install
E-114	Control room plan view install
E-115	Fish pump house plan view install
E-116 – E-117	Central weir gate plan view install
E-118 – E-119	Tailrace decks plan view install
E-120	South weir gate plan view install
E-121	South tailrace deck plan view install
E-122	South fish ladder plan view install
E-123 – E-127	North fishway entrance plan view install
E-201 (for final)	FCQ1, FCQ2 elevation view install
E-202 (for final)	FCQ4 elevation view install
E-301 – E-302 (for final)	MCCs section views install
E-601 – E-605	Install one lines
E-610 – E-611	North, south, central schematics install
E-612	Install network diagram
ED606 (for final)	Demo cable and conduit schedule
ED607 (for final)	Demo cable and conduit schedule
E-606 (for final)	Install cable and conduit schedule
E-607 (for final)	Install cable and conduit schedule

3.11 RESOURCE DRAWINGS

File Number/Drawing number	Description
IHF-1-6-5/8	Entrance Weirs power and control (FCQ4)
IHF-1-6-5/9	FCQ4 to 120/240VAC panel FR5, three line diagram
IHF-1-6-5/10	FCQ4 to entrance weirs 1 and 2, connection diagram
IHF-1-6-5/11	FCQ4 conduit stub up detail/North Shore Fishway Entrance Plan view
IHF-1-6-5/14.1	FCQ4 Switchgear Wiring Diagram
IHF-1-6-5/16	FCQ4 - weirs 1&2 hardwired control & Weir gates alarm circuit
IHF-1-6-5/18	North Shore Fish Ladder - Entrance weirs 1,2,3 connection diagram
IHF-1-6-5/19	FCQ4 plan view
IHF-1-6-5/20	FCQ4 arrangement and details
1HP-1.1-3-2/10	Fish Collection System Weir Gate Operating Machinery
144A2565 SH 1	Fishway Power Distribution and control
144A2565 SH 5A	Adult Fish entrance weir gate hoist control (South)
144A2565 SH 5B	Adult Fish entrance weir gate hoist control (Central)
144A2565 SH 6	South Fishway Annunciator
144A2565 SH 9	Fishway Material List
144A2565 SH 10	(FCQ4) North Fishway One line- weir gates 1,2,3
144A2565 SH 13	Fishway entrance weir #1 and 2 control schematic (North)
144A2565 SH 15	Sylsyns removed in 2000
144A2565 SH 26	Lighting Panel - "logic power" for entrance weir gate control
144A2565 SH 80	FCQ4 control center views
144A2565 SH 81	FSC board
144A2565 SH 81	FSC board
6010-E-1 SH 1	Ultrasonic Level Sensing Controller (Airanger) Central Entrance
6010-E-1 SH 2	Ultrasonic Level Sensing Controller (Airanger) South Entrance
6010-E-1 SH 3	Tail water and channel level metritape

6010-E-1 SH 4	Ultrasonic Level Sensing Controller (Airanger) North Entrance
IHP-1-6-IC2/2	FCQ1 and FCQ2 MCC front views
IHP-1.1-6-IC21/1	FSP1-FSQ1-FCQ1 and FCQ2 one-line
IHP-1.1-6-IC21/2	FCQ1 one line
IHP-1.1-6-IC21/3	FCQ2 one line
IHP-1.1-6-9C9/1	South Shore Fish facilities Cable tray diagram
IHP-1.1-6-9C9/2	South Shore Fish facilities Cable tray diagram
IHP-1.1-6-9C9/3	South Shore Fish facilities Cable tray diagram
IHP-1.1-6-9C24/1	South Shore Fish facilities Auto control diagram (1960s)
IHP-1.1-6-9C24/1	South Shore Fish facilities Motor control (1960s)
IHP-1.1-6-9C51/1	South Shore Fish Facilities Gate Machinery Wiring diagram (UPDATED 2008)
IHP-1.1-6-9C51/3	South shore FCQ1 FCQ2 terminal block arrangement
IHP-1.1-6-9C52/1	FSC SWBD External wiring (Goes to FCQ1, FCQ2
IHP1.1-6-9C0/1	FSC location and mounting
IHP-1-6-9C40/1	Central and south large site plan view
IHP-1.1-6-7A0/1	Grounding System (Shows connections to FCQ1, FCQ2)
IHP-1.2-6-7A21/1	Grounding System Riser
IHP-9-6-9A40/1	Control Room Switchgear Location
IHN-1-6-14/4	DCQ1-FCQ4
IHD-1-6-13/9	Central Fishway Entrance (CFE1, CFE2) plan views embedded conduits
IHD-1-6-13/41.1	DCQ1 Wiring Diagram
IHD-1-6-13/45	DCQ1 Cable & Conduit Schedule (DCQ1-q1-FCQ4)
IHD-1-6-13/45	DCQ1 one-line and panel arrangement
IHP-1-6-1F/5	Fishway Gallery Plan - Conduit (bays 4,5 & 6)
IHP-1-6-1E/5	Fishway Gallery Plan - Conduit (bays 1,2 & 3)
IHP-1-6-1D/2	Tailrace Deck and service bay (FCQ1 conduits)
IHP-1-6-1D/3	Tailrace Deck and Erection Bay (FCQ1 conduits)
IHP-1-6-1D/4	Fishway Gallery and Erection Bay (FCQ1 and FSC conduits)
IHP-9-6-13-87	FCQ1 CCS part 1

IHP-9-6-13-88	FCQ1 CCS part 2
IHP-9-6-13-89	FCQ1 CCS part 3
IHP-9-6-13-90	FCQ1 CCS part 4
IHP-9-6-13-91	FCQ2 & FSC CCS
IHP-9-6-13-92	FCQ2 CCS part 1
IHP-9-6-13-93	FCQ2 CCS part 2
IHP-9-6-13-94	FCQ2 CCS part 3
IHP-9-6-13-95	FCQ2 CCS part 4
IHP-9-6-13-20	FCQ1 & FSC CCS
IHP-9-6-13-85	FSQ1 CCS

3.12 Anticipated Electrical Specifications

- 25 05 11.00 Cybersecurity
- 26 05 19.00 10 Insulated Wire and Cable
- 26 28 00.00 10, Motor Control Centers
- 40 60 00, Process Control

3.13 Construction Considerations

According to the FPP, Winter maintenance is from January 1st till the end of February. The FPP also states that construction will not be conducted within 100’ of any fishway entrance or exit, within 50’ of any other part of the adult fishway, or directly in, above, or adjacent to any fishway, unless coordinated with FPOM or FFDRWG by the Project, District Operations and/or Planning or Construction office. The restriction is only for noisy construction and only applied during the fish passage season, all work is allowed during the winter period. These distances are approximate and will be updated after data are collected and analyzed to determine the threshold for adverse impacts to adult fish behavior. Alternate actions will be considered by District and Project biologists in conjunction with the regional fish agencies on a case-by-case basis.

3.14 Project Feedback

J-grades have indicated they want to use HART protocol for the 4-20mA signals. Basis of design is based on HART capable components. The specifications are not edited as of the interim review, but this will need to be added to the radar level sensor spec for final review.

4 ENVIRONMENTAL AND CULTURAL RESOURCES

4.1 GENERAL

Insert Text.

APPENDIX A – STRUCTURAL

Prepared by:

APPENDIX B – MECHANICAL

Prepared by: Mike Mclean

APPENDIX C – ELECTRICAL

Prepared by:

APPENDIX D – COST

Prepared by: