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Evaluation of Quinault National Fish Hatchery Adult Salmonid Electric Barrier

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

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Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Executive Summary

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public. As part of Reclamation's mission, senior Reclamation personnel (now retired) were contacted by the Portland, Oregon U.S. Fish and Wildlife Service office to assist in developing improvements and/or alternatives to an adult salmonid electrical barrier at the Quinault National Fish Hatchery. This effort is intended to help fulfill the mission of the U.S. Fish and Wildlife Service which is to work with others to conserve, protect, and enhance fish, wildlife, and plants and their habitats for the continuing benefit of the American people. As a vital part of the U.S. Fish and Wildlife Service's mission, the agency has been working towards the restoration of depleted anadromous fish species in the Pacific Northwest. Specifically, in western Washington, the U.S. Fish and Wildlife has been working in cooperation with the Quinault Indian Nation, the Washington Department of Fish and Wildlife, National Marine Fisheries Service, Northwest Indian Fisheries Commission, and the Hoh Nation to restore salmon and steelhead stocks along the northern Pacific Coast *http://www.fws.gov/quinaultnfh/species.html*.

To help reach this goal, the U.S. Fish and Wildlife Service established the Quinault National Fish Hatchery in 1968 to restore and enhance the depleted salmon and steelhead fish runs on the Quinault Indian Reservation and adjacent lands because of years of antiquated timber harvest techniques that negatively impacted salmon habitat and water quality to the extent where the fish could no longer sustain reproduction successfully *www.fws.gov/quinaultnfh/Quinault%20National%20Fish%20Hatchery%20history.doc*.

At the Quinault National Fish Hatchery, the Service installed an electrical fish barrier in 1968 that consisted of a sloped wooden deck with hanging electric probes. The electric barrier guides returning adult salmon into the hatchery. The original electric barrier was replaced in 2002 by a concrete slab with embedded electrodes. In recent years however, safety has become an important concern regarding the electrical barrier. We describe the current situation. Then, we provide a number of possible improvements to the electrical barrier to provide better safety at the electrical barrier. Finally, we provide several possible alternatives to the electrical barrier.

Introduction

The Quinault National Fish Hatchery (QNFH) was established by the U.S. Fish and Wildlife Service in 1968 "...to restore and enhance depleted runs of salmon and steelhead on the Quinault Indian Reservation and adjacent Federal lands…". Years of antiquated timber harvest techniques have negatively impacted salmonid habitat and water quality to the extent where the fish could no longer sustain reproduction successfully *www.fws.gov/quinaultnfh/Quinault%20National%20Fish%20Hatchery%20history.doc*.

The fish hatchery is located on Cook Creek 4.5 miles above its confluence with the Quinault River which then flows approximately 16.5 miles before entering the Pacific Ocean. Historically, the hatchery production program released approximately 1.5 million fall chum salmon, 600,000 fall Chinook salmon, 600,000 coho salmon, and 190,000 steelhead trout into Cook Creek along with releasing 50,000 steelhead trout yearlings into the Hoh River. The hatchery also transfers approximately 50,000 sub-yearling steelhead trout to the Chalaat Creek facility operated by the Hoh Tribe while also releasing stealhead and coho fry into the Quinault and Raft Rivers *http://www.fws.gov/quinaultnfh/species.html*. Program changes are being modified in light of recent detections of Infectious Hematopoetic Necrosis Virus (IHNV) in the Quinault River watershed and due to Hatchery Scientific Review Group's recommendations during April 2004. Annual fish production is co-managed between the Quinault Tribe and the state of Washington through an annual Future Brood Document process that coordinates fish production and distributions for hatcheries within the state *http://hatcheryreform.us/hrp/about/hsrg/welcome_show.action*.

The QNFH utilizes native anadromous salmonids from Cook Creek to regenerate fish stocks for both the Quinault Indian Nation and the public. The headwaters for Cook Creek originate from seasonal precipitation deposited onto the Quinault Ridge which is located on the west slope of the Olympic Mountains in the Olympic National Forest. The creek flows through a patchwork of U.S. Forest Service and private lands before leaving the U.S. Forest Service property and entering the Quinault Indian Reservation at about river mile 5.2 *www.haccp-nrm.org/Plans/WA/HACCP-Quin-COS.pdf*. The QNFH was built within the boundaries of the Quinault Indian Reservation and next to Cook Creek as directed by a tribal leader in effort to help fulfill U.S. Treaty obligations *www.fws.gov/quinaultnfh/Quinault%20National%20Fish%20Hatchery%20history.doc*.

Since the fish hatchery's inception in 1968, the hatchery has utilized an electrical fish barrier to divert native adult salmon and steelhead into a fish ladder as they try to migrate upstream in Cook Creek. The original electrical fish barrier consisted of a wood deck that sloped towards a low flow bypass section and had metal electrodes suspended above the deck that were energized through an alternating current (AC) electrical power source. With this electric barrier configuration, adult salmon and steelhead were diverted into a fish ladder where they could be trapped and collected by hatchery personnel. Over time, the original electric barrier deteriorated and was replaced in 2002 (MWH Draft Tech Memo, 2008, 1520858.011801).

During 2002 a concrete slab electrical fish barrier, components manufactured by Smith-Root, Inc., replaced the original 1968 electrical fish barrier. The 92-foot (ft)-long concrete slab electrical fish barrier has a relatively flat surface and nearly extends across the width of Cook Creek. Seven steel alloy railway type bars embedded near the surface of the concrete slab and serve as the electrodes. The rails are spaced about 2 ft apart and the barrier is angled 15 degrees towards the low flow channel and fish ladder. The low flow channel is 10 ft wide and about 1 ft lower in elevation than the main channel. The concrete slab electrical barrier operates by using a pulsed direct current (DC) that increases in voltage from downstream to upstream. Returning adult salmonids sense or come in contact with the electrical field and are redirected into the fish ladder (MWH Draft Tech Memo, 2008, 1520858.011801). The concrete slab electrical fish barrier is located south west of the QNFH at latitude 47° 21' 30.06" North and longitude 123° 59' 37.8" West and is at an elevation of 161 ft above mean sea level (figure 1).

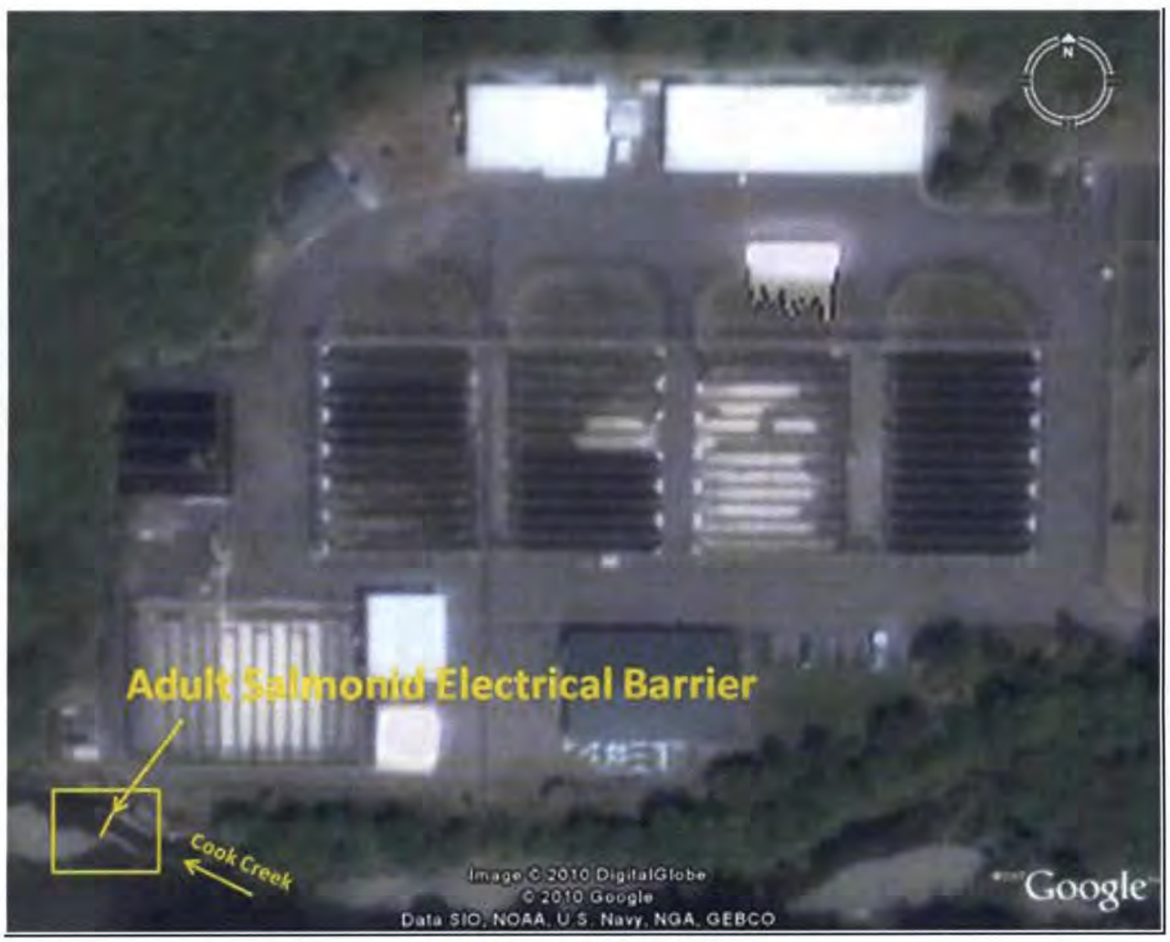

Figure 1. Site of adult salmonid electric barrier along Cook Creek, WA. and Quinault National Fish Hatchery (image from Google Earth, 2010).

Figure 2. Main deck of concrete slab electric barrier with gravel-cobble deposition on downstream end of the southern side of Cook Creek.

Electric Field

The concrete slab electrical barrier functions by sending a pulsed DC electrical current between the embedded steel alloy rails powerful enough to prevent adult salmonid fish passage beyond the barrier. Ideally, adult salmonids would sense the electric barrier prior to coming into contact with it and instead, utilize the fish ladder as the only alternative to migrate upstream. However, the spawning and migratory behavior of adult salmonids creates a strong and vigorous desire to access natal tributary waters. This instinctual behavioral trait in adult salmonids often will cause the fish to make repeated attempts to pass barriers (Groot and Margolis, 1991). The concrete slab electrical barrier was designed to have a progressively stronger electrical field between the downstream and upstream electrodes that produces an increasing electric field to prevent the fish from passing the barrier.

The electrical field is created when two metal electrodes (anode and cathode) are submersed in water and an electrical current is generated between them. When fish are within the electrical field, they become part of the electrical circuit and subsequently receive an electrical shock by having some of the current flow through their body. The most effective electric field pattern to inhibit fish passage or to guide fish is to produce a field with electric lines going from head-to-tail along the fish thus, receiving maximum current. Fish typically swim with their heads into the flow therefore; the electrical field is most effective with the field lines running parallel to water flow (figure 3, www.smith-root.com/barriers/). Figure 4 shows a cross section of the electric field generated along a serially connected bottom-mounted array. The flush embedded electrodes do not alter water flow or catch debris.

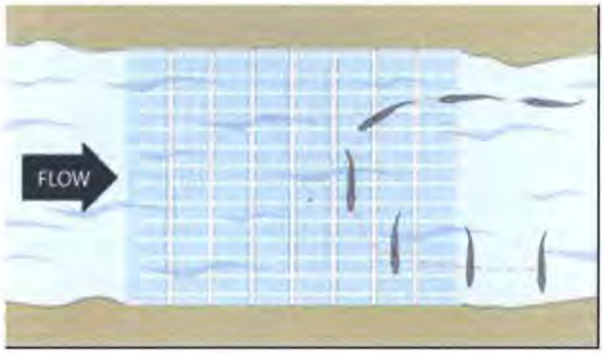

Figure 3. Common approach of a fish to an electrical barrier (diagram from, www.smith-root.com/barriers/).

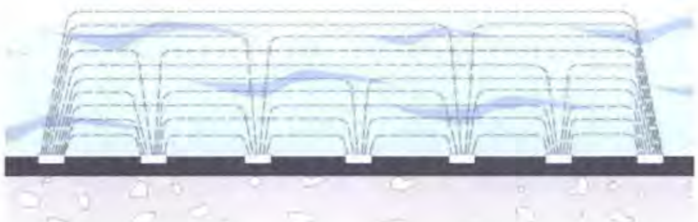

Figure 4. Cross section diagram of the electric field generated by the embedded steel rails in the concrete slab electric barrier (diagram from, www.smith-root.com/barriers/).

The Smith-Root concrete slab electric barrier design features a graduated electric field in effort to deter fish without causing mortality or irreparable damage to the fish. The pulsator units that control the electrical field can be adjusted individually to provide a desired increasing voltage gradient between successive electrodes. The voltage level should be low enough on the downstream end to cause large fish to avoid the electric barrier and high enough on the upstream end to cause narcosis, which is when the fish is in a full but temporary paralysis. Adequate water flow across the barrier will push the stunned fish off of the electric barrier where it can recover full movement. At the QNFH, the various adult salmonids approach the barrier differently throughout the span of their return. This produces a variety of exposure cases which makes the barrier difficult to be effective for all species under changing water depths and at different times of the year.

Upstream Voltage Gradient Measurements

During the site visit to the QNFH, Reclamation personnel were allowed to access the barrier and were given an overview of operations of the electric barrier. During that period (August 2010), the main deck of the barrier was not submerged and therefore, was not in operation. However, the low flow bypass was functioning and we were given the opportunity to measure the voltage gradient level near and within the bypass.

Voltage gradient measurements were taken 3 inches above the substrate on both sides of a gravel bar immediately upstream of the low flow bypass entrance. The voltage gradient meter did not register a reading between 4 and 5 meters upstream of the low flow channel on the north side of the gravel bar (voltage measurement locations not shown in figure 5). The voltage gradient meter registered very low values of 0.01 volts per centimeter (V/cm) at 3, 4 and 5 meters south of the gravel bar. Directly upstream from the low flow channel next to the gravel bar, voltage measured 0.03 V/cm at 2 and 3 meters, while only measuring 0.01 V/cm on each end of the low flow channel. One meter from the nearest anode and at the upstream edge of the low flow channel, voltage read 0.16, 0.12 and 0.03 V/cm, going north to south. Voltage measurements registered 5.31, 5.09, and 5.07 V/cm 3 inches directly over the furthest most upstream anode (figure 5).

Figure 5. Voltage gradient measurements upstream of low flow channel and over the furthest most upstream anode located next to the main deck of the concrete slab electrical barrier.

Downstream Voltage Gradient Measurements

Similarly, voltage gradient measurements were taken downstream of the low flow bypass exit. Again, the voltage gradient meter did not register a reading at 5 meters downstream of the low flow channel. At 3 and 4 meters, the voltage gradient meter registered 0.01 V/cm. The voltage meter did not register any readings at 2 and 3 meters distance while next to the sacrificial cathode and remained very low (0.01 and 0.02 V/cm) south of the low flow channel (at 3 and 2 meters distance). At 1 meter downstream from the low flow channel, voltage levels were 0.02 and 0.05 V/cm, less than they were at the same upstream distance. Due to access constraints, only one voltage measurement was taken 3 inches over the furthest most downstream anode registering 5.02 V/cm (figure 6).

Figure 6. Voltage gradient measurements downstream of the low flow channel, between the main deck of the electrical barrier and the fish ladder.

Before the voltage gradient measurements were taken in the low flow bypass channel on August 4, 2010, Reclamation personnel toured the building where the electronic equipment is housed and noted that the voltage setting was between 3.81 and 3.89 V/cm for the low flow bypass electric barrier. The voltage gradient meter used for the readings was left at the QNFH by Smith-Root, Inc. and seemed to be in excellent condition but the readings could not be verified with a more recently calibrated voltage gradient meter. Nevertheless, readings from the voltage meter were repeatable both directly above the electrified anodes as well as away from the electric field.

Improvements for the Existing Adult Salmonid Fish Barrier

Safety

Foremost, human safety must be recognized as the most important factor for the operation of the concrete slab electrical barrier. While the electrical current is almost nonexistent a meter away from the barrier, it is possible that the current directly over the barrier could be lethal at high settings depending on a range of other factors. Ohm's law for electrical current is voltage divided by resistance, meaning that the amount of current through a body is equal to the amount of voltage applied between two points on that body, divided by the electrical resistance of the body between those two points. Thus, greater available voltage increases the flow of electrons through a body and the easier they will travel in a given amount of resistance. Body resistance to an electrical current is not the same between two different species much less between two different bodies of the same species. Body size, chemistry, body fat, hydration level, and health affect the transfer of electrical current through the body, some being more or less sensitive. Body resistance also depends greatly on how the electrical current comes into contact with the body as discussed earlier where maximum current is transferred lengthwise from head to tail for a fish.

For some humans, involuntary muscle contractions can occur from just static electricity alone while it may take about 3 – 5 milliamp (mA) of DC to know that you are in contact with electricity. Pain caused by electricity begins around 40 – 60 mA and severe pain starts in the 60 – 90 mA range, whereas, 500 mA can cause heart fibrillations within 3 seconds (for humans) http://www.allaboutcircuits.com/vol_1/chpt_3/4.html. For fish, ranges of electrical current to create a given response are documented for some fish species and sizes. Larger fish are more affected by electrical current than their smaller counterparts, while it may also be possible that different species are affected differently despite being similar in size.

Fencing

One method to improve the safety of the electrical barrier is to further inhibit access to the concrete slab. If humans as well as other mammals cannot access the electrical barrier, they will be safe from the danger it can cause and its potential lethal effect. The existing 8-ft high chain link fence can be more effective to people by extending the length of the fence farther upstream and downstream into Cook Creek. Two sections of additional fencing can be extended slightly into Cook Creek and possibly angled downstream to deflect floating debris, mainly small and medium-sized woody debris (see figure 7 for fencing option). If bottom fence passage is possible, the fence can be reinforced using steel straps or can be anchored into the ground. A concrete retaining wall can also be extended farther downstream of the barrier on the south bank with fencing placed on top of the wall. A vertical retaining wall restricts access to the river by eliminating the possibility of walking around the fence on the creek bank. In the event that people access this area using waders or small water craft, an orange fluorescent buoy line or a floating fence can be strung across the creek to warn against access. Additional access restriction can be achieved by adding several strands of barbed-wire with fluorescent markers and stretched across the creek but mounted separately from the chain link fence. However, any fencing placed into the creek may require periodic replacement due to downstream movement of large woody debris.

Figure 7. Safety fencing at Granite Reef Dam on the Salt River (image from, www.smith-root.com).

Security Guard/Fines

A more visible method to inhibit access to the electrical barrier would be to hire a security guard. A security guard could be hired on a temporary basis to patrol the public access areas near the QNFH while focusing mainly on excluding access to the electric barrier. The security guard would only be necessary during the fishing season when the public is attempting to access fish immediately downstream of the electric barrier. The presence of a security guard alone should be enough to ward off anglers from accessing the barrier.

Construct Fishing Access

Coupled with a more visible form of limiting access to the electric barrier, such as improved fencing and the presence of a security guard, fishing access areas can be constructed to reduce the enticement of accessing fish from the concrete slab electric barrier. A long curvilinear concrete deck can be constructed along the southern edge of Cook Creek across from the downstream area of the electric barrier where anglers can cast their line towards fish that are stacking up downstream of the barrier. A known fishing access area may off-set the desire to get onto the concrete slab providing that access to fish downstream of the electric barrier is adequate and the safety of the access area is realized by anglers. The fishing access deck can also serve to stabilize the southern bank and to help flush substrate downstream.

Modify Electric Barrier DC System

Ground Fault Indicator Protection and Laser-Motion Detectors

To reduce the electrical shock risk to humans and large mammals the existing DC electrical system may be able to be modified to turn off when large bodies are within 1 meter of the immediate vicinity of the embedded electrodes. A Ground Fault Indicator protection (GFI) system could be developed and installed to detect significant changes in the electric current field and to automatically turn off when resistance increases. Adding the GFI feature to the electric barrier may require an additional operations contract with Smith-Root, Inc., (contact Kerry Smith; ksmith@smith-root.com) if this type of shut-off protection can be developed. If the GFI system cannot be developed or is cost prohibitive, a more cost effective alternative may be a laser-motion detection system that would also turn off the electric barrier when a large physical body is present near the electrodes. Either type of electrical barrier turn off systems can also be augmented by an alarm or siren that would sound off when the electric barrier is tripped off. Manually turning the electric barrier back on may be advantageous in the event that there is a large body present in the electric field, thus requiring personnel to visually inspect the barrier.

Voltage Gradient Adjustment

One of the primary features of the Smith-Root concrete slab electric fish barrier is the graduated electrical field designed to deter fish away from the barrier. The electric barrier uses pulse type generators to create an ascending level of electrical field intensity and can be adjusted individually to provide an increasing voltage gradient between electrodes. The electric gradient lines become oriented with stream flow where the voltage level should be low enough on the downstream end to cause large fish to avoid the barrier and be strong enough on the upstream end to stun the same fish causing them to fall back.

Field voltage gradient measurements collected during the site visit did not show that there was an electric voltage gradient between the downstream and upstream electrodes in the low flow channel. The voltage magnitude was also different between the field measurements and the control house display screen. However, the depth of our measurements as well as the water depth in the channel may have been different than what the control house was set for. Also, the voltage gradient field created from the main deck may be different than the low flow channel.

To improve the effectiveness of the electrical barrier, both the main deck and low flow channel can be periodically checked by taking voltage gradient level measurements near the anodes and between them. This data can then be used to calibrate the electronic settings in the control house to what is found in Cook Creek and voltage gradient adjustments to the electric barrier can be identified. Ideally, three-dimensional maps can be constructed showing the electrical current field over the barrier at key stream elevations when adult salmonids are arriving at the barrier. The specific conductance of Cook Creek may also influence the electrical current field if there are seasonal variations.

Modify Cook Creek Channel

Flush Substrate Downstream

Another potential improvement for the existing electrical barrier would be to modify Cook Creek immediately downstream of the concrete slab. The hydraulic energy of the creek slows downstream of the south side of the main deck and deposits large amounts of substrate, which potentially adds access to the main deck area. To deflect flow away from the south bank and produce scour, a wing wall could be added near the downstream end of the south bank of the barrier (figure 8). A wing wall should produce scour along the wall, particularly at the end of the wall, and may assist in moving gravel-cobble substrate toward the center of the channel. If too much scour occurs and exposes the footings of the main deck, additional footings may be necessary. Also, the south bank area of Cook Creek could be sloped inward to serve the same purpose but would probably require additional bank stabilization measures. Physical modeling is recommended before a wing wall or bank modification is constructed at the site.

Figure 8. Wing wall to off set downstream barrier substrate deposition.

Remove Downstream Debris and Gravel

To further facilitate the downstream movement of the gravel-cobble substrate, large woody debris downstream of the electric barrier should also be removed. The most critical single item of debris that needs to be removed is a large spruce tree that fell across Cook Creek immediately downstream of the barrier site a few years ago. The spruce tree causes flow restriction for Cook Creek during high flow events. During high flows, backwater can be produced at the barrier site which will farther decrease velocities downstream of the structure. High flow events can wash smaller woody debris downstream that will accumulate onto the large spruce tree producing even greater flow restriction. Large woody debris and gravel removal downstream of the barrier should continue as part of the annual maintenance for the barrier.

Narrow Channel Width at Barrier

Cook Creek appears that it was widened for barrier construction and installation. Historical topography records or drawings should be referenced to determine creek topography before barrier construction. Because the channel is wider in this section than upstream or downstream of the barrier, the velocity drops and large amounts of substrate deposit. Reducing the length of the barrier deck and returning the channel to its natural width should keep sediment mobilized. This will reduce sediment removal costs, limit access to the electric barrier, and increase flow depth on the concrete deck for proper operation of the electric barrier. However, hydraulic energy of the channel will increase downstream of the barrier. A physical or numerical model analysis should be conducted to determine the effects of a reduced channel width on river hydraulics and stability.

Alternatives to the Existing Adult Salmonid Fish Barrier

The concrete slab electric barrier was designed as an exclusion barrier for adult salmonids to guide fish into a trap facility for broodstock collection. This method of using electricity to guide fish can also be accomplished by different types of exclusion barriers, physical and non-physical, that may not require electricity. There are three primary types of physical exclusion barriers which are broadly categorized as picket barriers, velocity barriers, or vertical drop structures. Vertical drop structures exceed the height of the vertical leaping ability of the fish that it is attempting to control. Vertical drop structures will not be considered here because of the large volume of water impounded behind the structure that would require substantial river alterations. Non-physical barriers include electric and acoustic fields that are known to have inconsistent results that are typically attributed to varying water quality (NMFS, 2008). Alternate non-physical barriers were not explored in this review.

Fixed bottom-hinged bar rack and velocity barrier alternatives were explored by MWH in 2008 (MWH Draft Tech Memo, 2008, 1520858.011801). Velocity barrier alternatives were considered at 3 locations near to the hatchery due to the impact of the low head dam on flood elevations. Only the current electrical barrier site was considered for the bar rack since only minor changes to the upstream water surface elevation are predicted. These options were discussed by the team along with additional hybrid alternatives and design alternatives that require regulatory waivers.

Hybrid Velocity/Picket Barrier with Radial Gate

Both velocity barriers and picket barriers have associated advantages and disadvantages. By combining elements of the two types of barriers, the benefits of each barrier may be realized while minimizing detrimental effects. The required National Marine Fisheries Service (NMFS) minimum weir height is 3.5 ft for a velocity barrier while the slope of the apron must be 16 ft long for every 1 ft drop in slope. This height may produce substantial backwater upstream of the weir, requiring levee construction up to 1500 ft upstream of the barrier during the 5% exceedence flow (MWH Draft Tech Memo, 2008, 1520858.011801). A shorter weir height is not compliant with regulatory requirements; however in combination with another design feature, a 3-ft-high weir may be effective at blocking fish passage while reducing upstream flooding. HEC-RAS modeling (such as the modeling completed previously by MWH) can be analyzed to determine the extent to which a 0.5 ft reduction in weir height affects flood scenarios. A radial gate would be placed in the existing low flow channel to move up or down and allow flow to pass under or over it and used primarily for flood control and to shed debris. Other NMFS criteria require velocity barriers to have a maximum of 2 ft of head over the weir crest while maintaining a downstream elevation at the end of the apron to be greater than the tailrace water surface elevation corresponding to the high design flow. Also the entire length of the weir must be continuously vented to allow an aerated flow nappe to develop between the weir crest and apron. This greatly hinders the jumping ability of the fish to pass the weir (NMFS 2008).

Constructing a picket barrier to achieve NMFS criteria at this site would be difficult. However, in conjunction with a velocity barrier, picket barrier panels could be attached to the top of the velocity barrier to prevent jumping fish from passing the shorter weir. The picket barrier provides additional weir height without significantly increasing backwater. The picket panels would need to be lowered to shed debris when differentials exceed design values to meet NMFS criteria. When the picket panels are lowered, it may be possible for adult salmonids to ascend that section of the barrier during that brief period of time.

The radial gate would be placed in the existing low flow channel to sluice sediment and debris, meet NMFS weir crest criteria, and to reduce flooding during high flows. But it is possible that migrating adult salmonids could pass through the gate, even when operated as orifice flow. If the radial gate is designed to pass water over it instead of under it, the radial gate will require a downstream 5-ft pool of water for the fish to land in. All design features that do not follow specified design criteria for fish barriers will require a written waiver from NMFS. This hybrid/picket barrier with a radial gate could work well during a range of river discharges while limiting upstream flooding; however the hybrid barrier may not be effective at preventing fish passage when operation of the radial gate is required.

The velocity barrier would require a radial gate to achieve NMFS target water elevations above and below the weir. The width and height of the radial gate will have to be balanced to best meet NMFS target water elevations. However, operating the radial gate may allow fish passage thus requiring a NMFS waiver. Conversely, the radial gate can allow limited passage of desired species upstream and also serve to flush large amounts of water downstream to reduce sediment deposition. Further physical modeling may be needed to ensure that this concept is viable at the QNFH facility.

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