EVALUATION OF STEELHEAD KELT PASSAGE ROUTES AT BONNEVILLE DAM, 2000

Report of Monitoring

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EXECUTIVE SUMMARY

In 2000, the U.S. Army Corps of Engineers (COE) Fisheries Field Unit (FFU) initiated a program to evaluate the downstream passage behavior of post-spawn steelhead (*Oncorhynchus mykiss*) kelts at Bonneville Dam. The primary goal of this study was to develop a better understanding of the efficacy of prototype and existing juvenile bypass structures in passing steelhead kelts migrating back to the Pacific Ocean. This information can then be used to determine whether operational or structural improvements could be made to enhance steelhead survival and reproductive productivity.

Radio-telemetry was used to monitor the downstream passage behavior of steelhead kelts released above BON. The objectives of this research were to determine: 1) the behavior (e.g., holding, milling) and residence times of kelts once in the near dam forebay area (i.e. ~ 100 m); and 2) passage of kelts through existing and prototype bypass structures (i.e., Prototype Surface Collector (PSC), Submerged Traveling Screens (STS), Extended Submersible Bar Screens (ESBS), Ice & Trash Sluiceway (ITS)), and other passage routes (e.g., spillway, navigation lock, and turbine units). The results of the 2000 evaluation are summarized as follows.

General: Radio-tags were attached to 148 Snake River (SnR) steelhead kelts with tagged kelts transported to and released at the Cascade Locks (CCL) or Stevenson boat ramp (SBR). In addition, 11 air-spawned Hood River (HR) female[1] steelhead were radio-tagged and released at the same locations to evaluate the downstream passage behavior of these Bonneville Pool steelhead. Of the 159 tagged and released kelts, 91% were contacted before passing, and 93% after passing through Bonneville Dam. Similarly, of the kelts for which there are full passage histories[2], 89% were contacted at the exit station, approximately 3.5 km below Bonneville Dam. There are no contact records for three of the released kelts (2 SnR, 1 HR). Two air-spawned steelhead from the HR were released at CCL and only contacted at sites above Bonneville Dam.

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[1] For the purpose of this evaluation, air-spawned steelhead will be referred to as kelts (N=11).
[2] Full passage histories are defined as kelts that were contacted in their passage forebay, and subsequently contacted in juvenile bypass systems, tailrace areas, at exit stations, or in combinations of these sites.

Project Operations: Total discharge at Bonneville Dam between 15 March and 15 June was moderate and ranged from 164.4 kcfs to 387.1 kcfs. The spill discharge ranged from zero kcfs during the two days prior to our first release of tagged kelts at Cascade Locks, to 143.8 kcfs through the spring study period. The percentage of the total discharge that passed through the spillway increased in April and remained relatively steady through May. During April through June discharge from PH II decreased, with PH I discharge remaining constant, averaging 98.8 kcfs for the study period.

Passage Summary: Overall, 39.5% of tagged kelts passed through the spillway, 39.5% through PH I, and 21% through PH II. At PH I, 83% (43/52) of tagged kelts passed through turbine units, 8% (4/52) routed through the PSC into the ITS, and 10% (5/52) were guided by STS into gatewells, and subsequently passed through gatewell orifices into the JBS. At PH II, 79% (23/29) of tagged kelts passed turbine units and 21% of kelts were guided by STS into gatewells, thereafter, passing through gatewell orifices into the JBS.

Residence times and behaviors of kelts in the near dam forebay area: Median final forebay residence (hh:mm) times were longest at Powerhouse I (PH I; 8:39), followed by Powerhouse II (PH II; 4:34), with significantly shorter times than either PH I (Wilcoxon, $P < 0.0001$) or PH II (Wilcoxon, $P = 0.0001$) at the spillway (0:15). Of the kelts for which there are full passage histories, 78% (109/139) passed the dam through the initial site (i.e., forebay) they contacted. In contrast, 17% of kelts switched sites once, 4% switched sites twice, and one kelt switched sites three times before passage.

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INTRODUCTION

The decline of steelhead (*Oncorhynchus mykiss)* populations from historical levels in the Columbia Basin has led to the listings under the Endangered Species Act (ESA) of 'threatened' for the Snake, lower & mid Columbia rivers' stocks, and 'endangered' for the upper Columbia River stocks (NMFS 1998). Cited explanations for these declines are largely derived from human impacts such as exploitation rates, resource extraction, roads, and the system wide changes that are resultant from impoundment (NWPPC 1986, ISG 1996). Agencies within the Columbia basin are beginning to evaluate the steelhead's iteroparous life history with the goal of developing strategies to aid listed steelhead populations. When developed, these strategies will probably relate combinations of kelt reconditioning, transport, and improved in-river passage to the specific life history attributes and obstacles faced by the differing evolutionarily significant units (NMFS 2000).

To assess current passage conditions in the lower Columbia River, the U.S. Army Corps of Engineers (COE) Fisheries Field Unit (FFU) initiated a program in 1999 to develop knowledge of the downstream passage behavior of post-spawn steelhead at Bonneville Dam. Bonneville Dam was selected for evaluation due to its location, as the first hydroelectric facility on the mainstem Columbia River, thereby, affecting potentially thousands of repeat spawners. Additionally, Bonneville Dam passes steelhead populations with diverse life histories including both ocean (i.e., winter steelhead) and stream maturing (summer) varieties (Withler 1966).

In this report, data are presented on the passage routes, passage proportions, forebay residence times, and passage times of radio-tagged kelts migrating through Bonneville Dam. To acquire the sample of fish for this study, efforts were focused on obtaining actively migrating kelts, from the Snake River, where thousands of post-spawn steelhead were outmigrating through Lower Granite and Little Goose dams. The endangered status of upper Columbia River steelhead stocks precluded our sampling of kelts from McNary and John Day dams in 2000.

METHODS

Study Site

Bonneville Dam is the first mainstem Columbia River hydroelectric project and is located at river km 235.1. Bonneville Dam was constructed in 1938 and is unique among hydroelectric projects in the Columbia Basin as it consists of two separate powerhouses and a spillway separated by two large islands. Powerhouse I borders Oregon on the south shore and Bradford Island on the north, and contains ten turbine units. The spillway has 18 spill gates, which are raised vertically to release water from the channel bottom, and lies between Bradford and Cascades islands. Powerhouse II contains eight turbine units, and is separated from the spillway on the south side by Cascades Island and borders the Washington shore on the north. The dam structures and the islands combine to give Bonneville Dam three separate forebay and tailrace areas (Figure 1).

Fixed Receiving System Telemetry-Equipment and Transmitters

Transmissions from radio-tagged kelts were monitored by antenna/receiver 'fixed station' arrays located in and around Bonneville Dam. Radio-tags for this study transmitted at radio frequency 150.600 MHz, one of a dozen or more frequencies each receiver was set to monitor. Fixed stations were installed and maintained by University of Idaho (UI) and U.S. Geological Survey (USGS) researchers (USGS fixed arrays stations described by Evans (et al. 2000)). Both aerial and underwater receiving arrays at the fixed stations were made available to us (Appendix A). However, prior to 28 April, only aerial antenna arrays were available. Operation of the PSC at PH I corresponded with periods of underwater telemetry coverage. Underwater dipole and stripped co-ax antennas had a limited range (about 6 m) compared to aerial antennas (100 to 300 m depending on transmitter depth, receiver gain, and number of elements). When positioned directly below aerial antenna arrays, tagged kelts were detectable to 8 m in water depth (Kelly and Adams 1996). Underwater antennas were specifically used to detect tagged fish in and around the prototype surface collector (PSC), submerged traveling screens (STS), extended submersible bar screens (ESBS), ice and trash sluiceways (ITS), and juvenile bypass systems (JBS).

The underwater antennas were monitored with Digital Spectrum Processors (DSP) or the Multi-Integrated-Telemetry-Array-System (MITAS). These systems automatically identified the specific antenna and location where a radio-transmission was received. Aerial fixed receiving arrays consisted of up to eight antennas connected to a Lotek[3] SRX 400 receiver. In contrast to the DSP or MITAS arrays, SRX 400 receivers combined signals from all attached antennas and recorded transmissions as a 'master' antenna contact. The receiver cycled through each antenna separately to determine the specific antenna where a radio-tag's transmission was located. If several radio-tagged fish were present, it took approximately two minutes for the receivers to listen to the antennas combined, listen to each antenna separately, and log transmissions for each frequency. This procedure was then repeated through all frequencies before completing a scan cycle (Evans et al. 2000). For this reason, criteria were developed to determine what constituted a valid kelt contact at a fixed station. In general, a contact was considered valid when two or more transmissions from a unique radio-tag were recorded at a fixed station in less than three minutes. The three-minute rule was adopted for two reasons. First, receivers occasionally picked up weak transmissions from tagged kelts outside the immediate area of the receiver's antennas. Second, when several radio-tagged kelts were transmitting near a receiver bank, receivers could potentially mix the radio transmissions of two or more tags and incorrectly record this signal as a different radio-tag.

The presence of a tagged kelt in the area of a fixed station was established using the three-minute rule. If the three-minute rule failed to filter out the false presence of a radio-tagged kelt in an area due to weak or mixed radio signals, contacts were negated through proofing verification. In addition, because fixed sites outside of the area where kelts were transmitting occasionally detected tags for brief periods, these contacts were also negated. Single contacts (more than three minutes apart) were included only if the record of a kelts plausible passage history was supported by valid hits before and after the single contact.

Data Management and Analysis

Downloaded data from fixed receiver arrays maintained by the USGS were transferred from the USGS directly to us. The protocol for obtaining the telemetry data from fixed-arrays

[3] Use of trade name does not imply endorsement by USACE.

maintained by the UI was as follows: Following each of the kelt releases, data containing release location, date, time, frequency, and unique codes of kelts were sent to the National Marine Fisheries Service North West Fisheries Science Center (NWFSC). After downloading, UI fixed telemetry array data were forwarded by UI personnel to the NWFSC for formatting and coding. Contact locations with our specific frequencies and codes were then sent to us from the NWFSC.

To describe the time it took for kelts to pass Bonneville Dam, passage times were calculated. Passage times are defined as the time it took from initial contact in forebay areas to the time at which kelts were contacted at the exit station. Full and final forebay residence times were calculated for each radio-tagged kelt contacted in the near-dam area. Full forebay residence times are between the first and last contacts in forebay areas. Final forebay residence times are the amount of time between the first and last contacts in a kelts passage forebay. Forebay residence times were a conservative estimate of the actual time that tagged-kelts spent in the near-dam area. These estimates are conservative due to receiver limitations. For instance, kelts may have been in the near-dam area prior to their first radio-contact, and following their last contact. Ancillary to forebay residence and overall passage times, tailrace residence times were calculated, identifying the time it took kelts to pass from first tailrace contact to the exit station.

To assess the efficacy of bypass structures in passing kelts, standard fish guidance efficiency (FGE) metrics were calculated (guided /[guided + unguided]). Similarly, separate metrics associated with PSC efficiency were calculated. First, ‘entrance efficiency’ is defined as the number of kelts entering the PSC divided by the total number of fish that encountered the face of the PSC. Second, ‘passage efficiency’ is defined as the number of kelts passing the dam through the PSC, divided by the number of kelts entering the PSC. The PSC configuration extends across turbine units 1-6 and 20 feet upstream into the forebay. Kelts entering the PSC can pass above trash racks into the ITS when open, or through the turbine intakes. Kelts entering into the turbine intakes can be screened into gatewells or travel turbine units. Due to potential violations in assumptions of data normality, nonparametric tests were used to compare median residence and passage times (Zar 1996). Once data were completely proofed, all subsequent analyses were conducted in Statistical Analysis Systems (SAS, version 8.0, SAS Institute Inc., Car N.C., USA) [4].

Kelt Collection, Tagging, Transport, and Release

Migrating steelhead were obtained from the COE juvenile bypass separators at Lower Granite and Little Goose dams. Steelhead were removed from the bypass separator and transferred via sanctuary dip-net to a nearby 190-liter sampling tank containing river water and a buffered solution of tricaine methanesulfonate (MS-222) at 60 parts-per-million. To differentiate between kelts and pre-spawn migrants, specimens were scanned with an Aloka®[4] ultrasound machine to assess gonad maturation and sex (Martin et al. 1983, Reimers et al. 1987, Shields et al. 1993, Blythe et al. 1994, Arkush and Petervary 1998). Sexually mature steelhead were immediately released back to the bypass system, while kelts were retained for tagging.

Fish condition factors were evaluated concurrent with the ultrasound spawning status identification (Evans and Beatty 2000). Data on fish length (cm fork length), condition (good, fair, poor, dead), coloration (bright, intermediate, dark), fin wear and fungus (ranked by degree of severity), hatchery or wild lineage (based on adipose fin clips), and physical anomalies (e.g., head burn) were recorded. The abdominal appearance (fat, intermediate, imploded/thin) was also recorded. Examination time averaged approximately five minutes per fish.

Radio-tags operating on a frequency of 150.600 MHZ were attached to steelhead kelts. Sixty-nine day (d) tags were 10.3 mm (diameter) x 29 mm and weighed 3.7 g in air, while 40-d tags were 9.2 mm x 20 mm and weighed 1.3 g, and 17-d tags were 8.2 mm x 19 mm and weighed 1.0 g. Sixty-nine and 40-d tags transmitted once every five seconds, while the 17-d tags transmitted every two seconds. Conservative radio-tag to body weight standards for biotelemetry applications (Brown et al. 1999) were met. All attached radio-tags were below 2% of the body weight of tagged kelts.

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[4] Use of trade name does not imply endorsement by the USACE.

Radio-tags had a wrap of polyolefin with a 0.05 cm. hollow tube underneath, thus, allowing a suture to pass through the tube for affixing transmitters to kelts. A 16 cm piece of size 1 chromic-gut resorbing suture was inserted through the tube of the transmitter; a surgical needle was then tied to each end of the suture. Suture ends were passed through the cartilage at the base of the kelts' dorsal fin; three dorsal spines separated insertion points. Needles were then removed from the suture and a surgical knot was tied on the far side of the dorsal fin affixing the transmitter to the kelt (Figure 2).

Figure 2. Radio-tagged steelhead kelt.

Radio tags were attached to kelts represented by all of the condition categories (i.e., good, fair, poor). However, due to concerns of exceeding ESA take authorization few fish from the poor condition category were tagged. Of the 159 radio-tagged and released kelts, four were in poor condition, 33 were in fair condition, and 122 of the kelts were in good condition. After radio-tag attachment, kelts were placed head down in a cylindrical tube (10 cm in diameter) containing enough river water to cover the operculum. Kelts were then carried via the capped tube and placed into circulated oxygenated river water in a 300-gallon transport trailer. Transportation from the Snake River dams to the release site averaged between 6-7 hours, with most releases occurring between 2000 and 2200 hours. Air-spawned Hood River female steelhead were radio tagged and transported from the Parkdale Fish Monitoring and Production Facility to evaluate the downstream passage behavior of these Bonneville Pool steelhead. One hundred fifty-nine steelhead were released, 148 kelts from the Snake River, and 11 air-spawned steelhead from the Hood River (Table 1).

RESULTS

Project Operations

Total discharge at Bonneville Dam between 15 March and 15 June was moderate and ranged from 164.4 kcfs to 387.1 kcfs. The spill discharge ranged from zero kcfs during the two days prior to our first release of tagged kelts at Cascade Locks, to 143.8 kcfs through the spring study period. The percentage of the total discharge that passed through the spillway increased in April and remained relatively steady through May. During April through June discharge from PH II decreased, with PH I discharge remaining constant, averaging 98.8 kcfs for the study period (Figure 3, FPC 2000).

Number of Kelts Contacted

Overall, 91% (145/159) of the kelts that were radio-tagged and released were contacted above Bonneville Dam. Below Bonneville Dam, 93% (148/159) of the tagged kelts were contacted in juvenile bypass systems, tailrace areas, at exit stations, or in combinations of these areas. Similarly, 89% (124/139) of the kelts for which there are full passage histories were contacted at the exit station (Table 2). Separated from the 139 kelts with full passage histories are 15 kelts with partial passage histories. Partial passage histories include; six kelts whose last known locations were in forebay areas, and nine kelts whose history of receiver contacts begins at the at the exit station below Bonneville Dam. In addition to partial histories, there are no contact records for three of the released kelts (2 SnR, 1 HR), and two air-spawned steelhead from the HR were only contacted at sites upriver from Bonneville Dam. Kelt detection rates and residence times (Table 3) could have been influenced by a variety of factors including; radio interference, transmitter loss, transmitter depth, and kelt mortality.

Passage Efficiencies

PH I

Passage through PH I was predominately through turbine units. Of the released kelts with full passage records, 39.5% (55/139) were contacted passing via PH I. Due to a lack of receiver contacts prior to, during, and directly after passage we were unable to assign a specific passage route (i.e. turbine, bypass) to three kelts at PH I with full passage histories. These three kelts are excluded from PH I FGE calculations. At PH I, 83% (43/52) of the kelts passing this powerhouse were detected passing through turbine units. Of kelts passing PH I turbine units, 77% (33/43) were detected in the PH I tailrace, and 88% (38/43) contacted while passing the exit station. Characterizing guidance as kelts migrating through the PSC and JBS generates an overall PH I FGE of 44% ($4^{ITS}+5^{JBS}+14^{PSC\text{-}TU}$/[23+29]). Determining FGE in terms of kelts solely traveling through bypass systems (i.e., ITS and JBS) produces the standard PH I FGE metric of 17% ($4^{ITS}+5^{JBS}$/[9+43]). Two kelts at PH I were contacted at the ESBS and both passed underneath the screens and subsequently passed through turbine unit eight.

PH I Prototype Surface Collector (PSC)

Sixty-eight percent (38/56) of the kelts that entered the PH I forebay were contacted at the face of the PSC. At the PSC, initial entrance efficiency equaled 79% (30/38). Of the 30 kelts that entered the PSC, 67% (20/30) passed through; of those, 20% (4/20) traveled through the ITS, 70% (14/20) passed turbine units, and 10% (2/20) were guided by STS into gatewells, and subsequently passed through gatewell orifices to the DSM channel. Twelve of the 30 kelts that initially entered the collector (40%), passed through on their initial PSC entrance. The remaining 60% (18/30) exited the collector and re-entered, with 30% (9/30) re-entering up to a maximum of four times before passing through the ITS, or into the intakes. This pattern of behavior is also reflected by the 33% (10/30) of kelts that entered the collector, exited and re-entered, up to seven times before exiting the collector and passing through a differing route. Kelt exit and re-entrance behavior resulted in a passage efficiency of 29% (20/68) for the PSC. Of the eight kelts that contacted and did not enter the PSC, 88% (7/8) subsequently passed through intakes and into turbine units 1-6. Overall, of the 38 kelts that contacted the PSC, 53% (20/38) passed through the dam via the PSC (Table 4).

PH II

Of the released kelts with full passage records, 21% (29/139) were contacted passing PH II. Similar to the data from PH I, passage through PH II was mainly through turbine units. At PH II, 79% (23/29) of kelts were detected passing through turbine units, thereby, generating a screened FGE of 21% (6/[6+23]) for the kelts that passed there. In the PH II tailrace, 100% of the kelts that exited turbines were detected, while 91% (21/23) of the kelts that passed turbines were contacted at the exit station (Table 2).

Spillway

Overall, 39.5% (55/139) of the released kelts with full passage records were contacted passing via the spillway.

Behavior

The cumulative number of antennas contacted was a measure of the amount of lateral movement exhibited by kelts across the face of the dam (Figure 4). Kelts passing via the spillway displayed significantly fewer lateral movements than kelts at the powerhouses (Wilcoxon; PH I $P < 0.0001$; PH II $P = 0.0018$). Fewer lateral movements by kelts at the spillway resulted in significantly shorter forebay residence and passage times than kelts passing via turbine units (Wilcoxon; full forebay, $P < 0.0001$; final forebay, $P < 0.0001$; passage times, $P < 0.0001$) or juvenile bypass systems (Wilcoxon; full forebay, $P = 0.0026$; final forebay, $P < 0.0001$; passage times, $P = 0.0036$). Radio-tagged kelts at the powerhouses were similar in terms of lateral movements and residence times (Table 3).

Overall, kelts passing via the spillway displayed significantly shorter passage times (1:53) than through either PH I (10:58; Wilcoxon, $P < 0.0001$), or PH II (15:21; Wilcoxon, $P = 0.0003$) (Table 3). Median final forebay residence times were longest at PH I (8:39), followed by PH II (4:34), with significantly shorter times than either, PH I (Wilcoxon, $P < 0.0001$) or PH II (Wilcoxon, $P = 0.0001$) at the spillway (0:15). Tailrace residence times were representative of the tailrace distance to the exit gates (i.e. shortest distance from PH I, the spillway, followed by PH II), with the PH I tailrace having the shortest median times (0:17), followed by the spillway (0:27), and PH II (0:47). Forebay residence and overall passage times decreased through all passage areas as the kelt passage season progressed through May.

Kelts collected from the Hood River, Little Goose, and Lower Granite dams showed no difference in passage route while emigrating through Bonneville Dam (Fisher's, $P = 0.3272$). The forebay residence and passage times of the 13 CCL release groups were not different between releases (Kruskal-Wallis; full forebay, $P = 0.2363$; final forebay, $P = 0.2526$; passage times, $P = 0.2622$). Similar to CCL releases, the forebay residence and passage times of the four groups of kelts released at SBR were not different between releases (Kruskal-Wallis; full times, P = 0.4155; final times, P = 0.5815; passage times, P = 0.2065). Kelts released from either the Washington (SBR) or Oregon (CCL) shores showed no differences in passage route selection through Bonneville Dam (Fisher's, P=0.3731). As well, no differences in the forebay residence or passage times were found between the two release sites (Wilcoxon; full forebay, P = 0.3776; final forebay, P = 0.5733; passage times, P = 0.3252).

The passage routes that kelts took at Bonneville Dam seemed to change as the season progressed (Fisher's, P = 0.0109; 99% lower confidence limit, P = 0.0082; 99% upper confidence limit, P = 0.0136). A higher proportion of kelts passing via the spillway from the first four releases influenced the analysis of passage routes, by release group, to the degree that these two variables (i.e. passage route, release group) were not constant through the entire season at Bonneville Dam (Mantel-Haenszel Chi-Square, P = 0.0031). That is, kelts within the first four releases passed through the spillway in significantly greater proportions than kelts subsequently released.

PROJECT SUMMARY AND DISCUSSION

Results from our study showed that kelt passage routes at Bonneville Dam in 2000 were primarily through turbine units and the spillway. Roughly, 47% (66/139) of kelts for which there are full passage records traveled through turbine units, and 40% (55/139) through the spillway (Table 2).

The evaluation of the prototype surface collector at PH I showed good potential for surface flow bypass in routing kelts away from turbine units. Of the kelts within the PH I forebay, 68% were contacted at the face of the PSC. The majority of these kelts (80%) initially entered the PSC. Once within the PSC test configuration, over two thirds (i.e., 67%) of kelts (20/30) passed through the dam. However, many of these kelts (70%) passed through turbine units. Kelt exit and reentrance behaviors resulted in low passage efficiency (i.e., 29% (20/68)) for the PSC. As a true surface bypass or collector would likely entrain fishes through water velocities, or other means (e.g., guidance structures) passage efficiencies observed in 2000 at the PSC are probably indicative of the prototype nature of the tested collector.

In contrast to surface flow bypass, intake screen systems displayed poor efficacy in guiding kelts away from turbine units. That is, 79% of the kelts for which we have a specific passage route at the powerhouses migrated through the dam via turbine units. Whether kelts actively sought out areas of high flow in searching for a passage route, or were entrained by water currents is unknown. Small sample size seen at the ESBS of PH I (N=2) give little information on the kelt guidance efficiencies of these structures.

The majority (~80%) of kelts passed through the dam from the forebay area they initially entered. Kelt 'searching' or 'milling' behaviors, as determined through lateral movements, prolonged forebay residence times at the powerhouses. The PSC at PH I caused uncertainty in kelts, which was exhibited through entrance and exit behaviors. These behaviors lengthened the passage times documented at the PSC, and resulted in PH I having the longest forebay residence times. Despite the forebay residence times seen at PH I, the longest passage times were documented at PH II. However, small sample sizes passing PH II, tends to bias these data. Specifically, holding behaviors by some kelts below the PH II 3.5 km JBS tube, in areas both above and below the secondary dewatering structure (i.e. separator bars), protracted PH II passage times (Table 2.).

Passage route selection was not influenced by kelt origin or release location. Data, from early in the passage season, suggests that low or moderate levels of spill may be effective for passing kelts. Passage times through the spillway were significantly shorter than seen through any other route. Further evaluation is needed to assess effects of spill timing and volume on kelt passage and success (i.e. survival). Kelt passage proportions at the powerhouses and spillway (e.g., 39.5% PH I, 39.5% spillway, 21% PH II) reflect the hydro acoustic passage estimates of juvenile fish in 2000 at Bonneville Dam (i.e., 34% PH I, 45% spillway, 21% PH II) (Ploskey et al. 2000). Overall, passage proportions of kelts through forebay areas were also similar to passage proportions of telemetered steelhead smolts (i.e., 46% PH I, 35% spillway, 19% PH II).

However, telemetry data indicates that steelhead smolt passage distributions were oriented more toward bypass system than kelts (i.e. 26% JBS, 20% ITS, 35% spillway, and 19% turbine units) (Evans et al. 2000). These data compare to kelt passage distributions of 3% ITS, 8% JBS', 40% spillway, and 49% turbine units. Loss of detection capability of kelts traveling at underwater distances from telemetry arrays (i.e. > 8 m) may indicate a good portion of kelts with partial passage histories also traveled through turbine units or the spillway.

While this study evaluated passage routes of kelts through radio-telemetry contacts, no conclusions on the passage success (i.e. survival) of kelts passing through the various routes are offered. Further evaluation is needed to understand the effects of turbine and spillway passage on kelt in-river survival, and subsequent reproductive productivity. Toward this end, more rigorous evaluations of kelt passage and conversion through the lower Columbia River are being developed.

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Table 1. Summary of the date, collection location, sample size (N), mean, standard deviation (SD) and range of the fork length (cm), sex, lineage, release location and time of release of the radio-tagged steelhead kelts in 2000. Of these transported and released kelts, the number contacted at Bonneville (PH II, spillway, PH I), the number of full path kelts (forebay, juvenile bypass system, tailrace, and/or exit), and the passage distribution.

Collection		**Fork Length (cm)**			**Sex**			**Lineage**		**Release**	**Contact**	**Full**	**Distribution**		
Site/Date	**N**	**Mean**	**SD**	**Range**	**M**	**F**	**Un**	**Wild/**	**Hatch**	**Site/Time**	**At Bon**	**Path**	**PH II**	**spill**	**PH I**
HR 30-Mar	2	77.0	1.4	76.0 - 78.0		2		2		NBR 11:30	1	1		1	
LGR 04-Apr	6	71.5	8.6	66.5 - 72.0		5	1	6		CCL 20:00	6	3		3	
HR 06-Apr	3	69.0	2.8	63.5 - 86.4		3		3		CCL 12:30	2	1	1		
LGR 07-Apr	13	65.5	10.5	55.9 - 86.4	1	5	7	6	7	CCL 20:10	13	9		8	1
LGO 12-Apr	3	67.3	9.9	60.9 - 78.7		2	1	3		CCL 19:30	3	3	1	2	
HR 13-Apr	3	73.0	10.2	62.0 - 82.0		3		1	2	CCL 12:00	1	1		1	
LGR 18-Apr	16	64.5	8.8	55.9 - 86.4		10	6	7	9	SBR 20:30	16	16	6	2	8
HR 20-Apr	2	69.0	8.5	63.0 - 75.0		2		2		SBR 12:00	2	2		2	
LGO 25-Apr	3	56.3	3.9	53.3 - 61.0	1	2		2	1	SBR 21:45	13	13	4	6	3
LGR 25-Apr	10	63.5	7.1	58.4 - 81.3		4	6	4	6	SBR 21:45					
LGO 27-Apr	4	62.2	6.7	53.3 - 68.6		3	1	4		SBR 20:45	10	9		2	7
LGR 27-Apr	6	56.7	4.2	53.3 - 63.5		3	3	2	4	SBR 20:45					
LGO 3-May	11	61.0	7.2	55.9 - 78.7		7	4	3	8	CCL 20:45	11	11	3	2	6
HR 4-May	1	68.5	---	---		1		1		CCL 11:30	1	1			1
LGR 6-May	15	62.6	4.8	53.3 - 71.1	6	3	6	12	3	CCL 21:00	14	13	2	6	5
LGO 10-May	5	60.5	1.5	58.4 - 62.2	1	2	2	4	1	CCL 2:30	5	4		3	1
LGO 11-May	3	61.4	3.9	57.2 - 64.8		1	2	2	1	CCL 22:10	14	14	3	4	7
LGR 11-May	11	59.3	3.6	55.9 - 66.0	3	5	3	6	5	CCL 22:10					
LGO 16-May	2	69.9	12.5	61.0 - 79.0	1		1	1	1	CCL 20:15	11	10	3	2	5
LGR 16-May	9	59.1	2.5	55.9 - 62.2	5	4		6	3	CCL 20:15					
LGR 19-May	17	64.1	7.8	53.3 - 82.6	5	3	9	12	5	CCL 19:40	17	15	1	6	8
LGR 23-May	14	59.7	3.7	55.9 - 69.9	8	6		6	8	CCL 19:15	14	13	5	5	3
Overall:	**159**	**63.2**	**7.6**	**53.3 - 86.4**	**31**	**76**	**52**	**95**	**64**	**---**	**154**	**139**	**29**	**55**	**55**
										Of number released	***97%***	***87%***			
										Of full contact at Bonneville			***21%***	***39.5%***	***39.5%***

Table 2. Summary of the transport and releases of radio-tagged kelts, that occurred between 30 March and 23 May. The number contacted at Bonneville (PH II, spillway, PH I), the number of full path kelts (forebay, tailrace, and/or exit station), and the passage distribution. `

Summary	N	Passage	Contacted in Bonneville Forebays	Contacted in Bypasses	Contacted in Tailraces	Contacted at Exits	At Bypasses, Tailraces, and/or Exits
Transported & Released:	159	All Routes	91% (145/159)	9% (15/159)	69% (110/159)	82% (131/159)	93% (148/159)
No Contact:	2	seen upriver only	0%	0%	0%	0%	0%
	3	No data	0%	0%	0%	0%	0%
Contacted At Bonneville	154	97% (154/159)	94% (145/154)	10% (15/154)	71% (110/154)	85% (131/154)	96% (148/154)
Partial Path:	6	Last contact forebay	100%	0%	0%	0%	0%
	9	First contact below Bonneville Dam	0%	0%	22% (2/9)	78% (7/9)	100%
Full Path:	139	Summary	100%	11% (15/139)	78% (108/139)	89% (124/139)	100%
	6	PH II JBS	100%	100%	N/A	83% (5/6)	100%
	23	PH II turbines	100%	0%	100%	91% (21/23)	100%
	55	Spillway	100%	0%	76% (42/55)	95% (52/55)	100%
	4	PH I ITS	100%	100%	75% (3/4)	75% (3/4)	100%
	5	PH I JBS	100%	100%	80% (4/5)	40% (2/5)	100%
	43	PH I turbines	100%	0%	77% (33/43)	88% (38/43)	100%
	3	PH I route unk.	100%	0%	100%	100%	100%

Table 3. Fate and residence times of the 38 tagged kelts that interacted with the Prototype Surface Collector (PSC). Fish had to be within 6 m of the PSC to be detected by the radio receiver antennas mounted on the PSC. Note: Q1 = 25th, median forebay, and Q3 =75th percentile. Note: one kelt contacted the face of the PSC, and subsequently passed at *PH II.

Fate	N	Pass – Location	Route	Bypass System	Q1	Full Forebay	Q3	Q1	Final Forebay	Q3
Did not contact the PSC.	8	PH I south	turbine	None	3:49	12:20	19:42	1:45	7:49	13:44
	9	PH I north	turbine	None	0:47	4:14	6:13	0:47	4:14	6:13
	1	PH I north	bypass	JBS via STS		0:14			0:14	
Contacted the face of the PSC but did not enter the PSC.	7	PH I south	turbine	None	5:04	7:17	20:53	5:04	7:17	20:53
	1	*PH II	other	None		46:01			3:37	
Entered and exited the PSC but did not pass from within the PSC.	7	PH I south	turbine	None	7:50	11:12	38:37	4:09	11:12	38:37
	1	PH I north	turbine	None		8:59			8:59	
	1	PH I south	bypass	JBS via STS		7:11			7:11	
	1	PH I north	bypass	JBS via STS		15:41			15:41	
Entered and exited the PSC and passed from within the PSC.	14	PH I south	turbine	None	9:59	17:42	33:28	3:03	16:12	31:51
	4	PH I south	bypass	ITS	14:14	21:01	53:53	14:14	21:01	53:53
	2	PH I south	bypass	JBS via STS	2:36	4:37	6:39	2:36	4:37	6:39

Table 4. Overall Bonneville passage times, full forebay (first and last contact in a Bonneville forebay) and final forebay (first and last contact of passage forebay) and tailrace times, by passage routes, in quartiles (hh:mm). Note: Three kelts at PH I, without routes specific passage information not depicted. Q1 = 25th percentile, median times, and Q3 =75th percentile.

	Overall Passage				Full Forebay			Final Forebay			Tailrace		
	N	Q1	Median	Q3	Q1	Median	Q3	Q1	Median	Q3	Q1	Median	Q3
Powerhouse I													
ITS	4	8:27	20:41	21:57	14:14	21:01	53:53	14:14	21:01	53:53	0:12	0:16	0:17
JBS	5	3:53	6:09	8:26	2:36	6:39	7:11	2:36	6:39	7:11	0:25	0:25	0:25
Turbine	43	5:38	11:38	21:35	4:14	10:34	23:04	1:51	8:49	20:53	0:14	0:17	0:21
All	55	5:38	10:58	21:35	4:14	9:59	21:40	2:36	8:39	20:53	0:15	0:17	0:22
Powerhouse II													
JBS	6	13:59	23:50	40:49	6:45	10:05	11:49	6:45	10:05	11:49	N/A	N/A	N/A
Turbine	23	3:47	12:19	23:31	1:42	3:48	13:33	1:42	3:37	10:55	0:37	0:47	1:08
All	29	4:43	15:21	31:22	1:57	6:09	11:49	1:57	4:34	10:55	0:37	0:47	1:08
Spillway													
All	55	0:43	1:53	10:25	0:09	0:36	7:34	0:08	0:15	2:12	0:22	0:27	0:46

Figure 1. Map of Bonneville Dam indicating all forebay and tailrace areas for the various routes of Steelhead kelt passage.

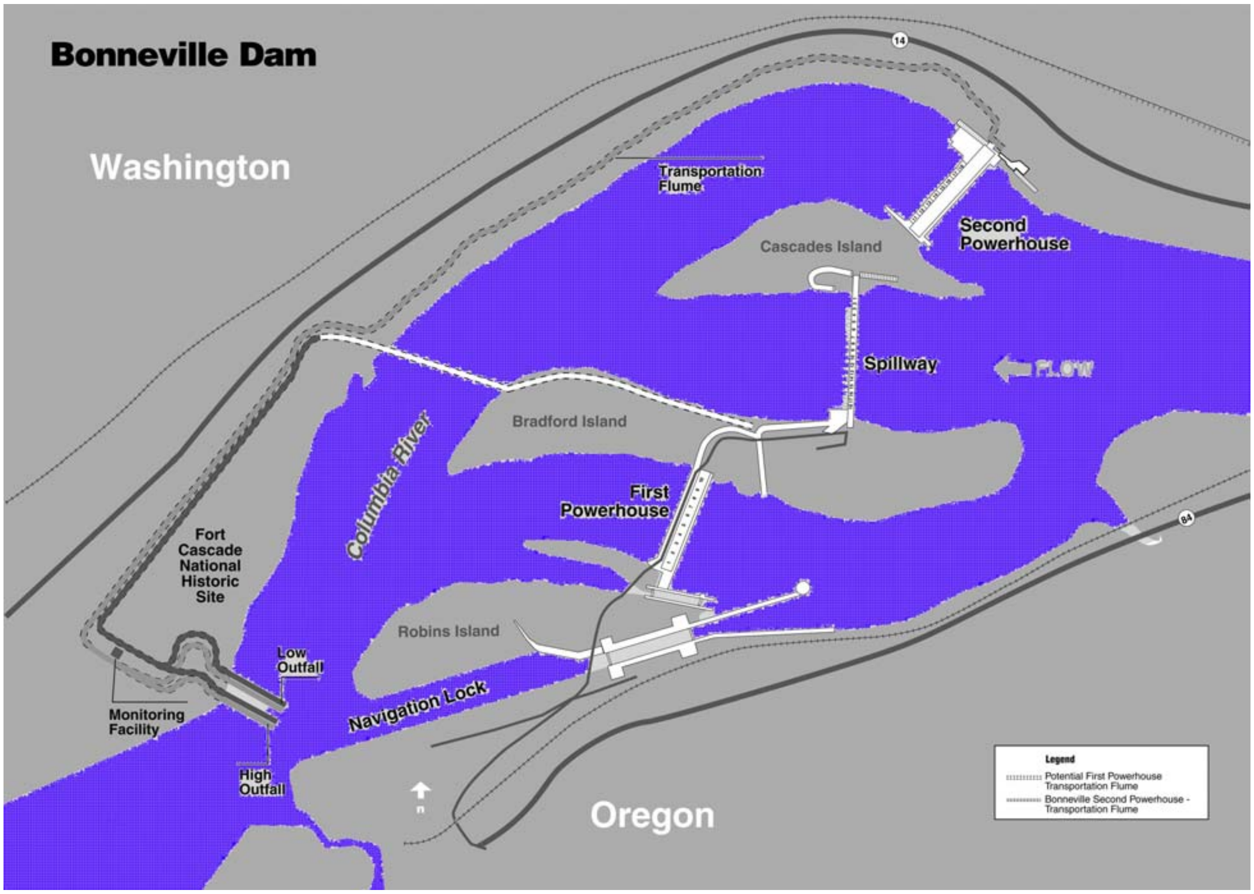


Figure 3. Percentage of weekly flow at Bonneville Dam through PHI, PHII and the spillway from April through May 2000.

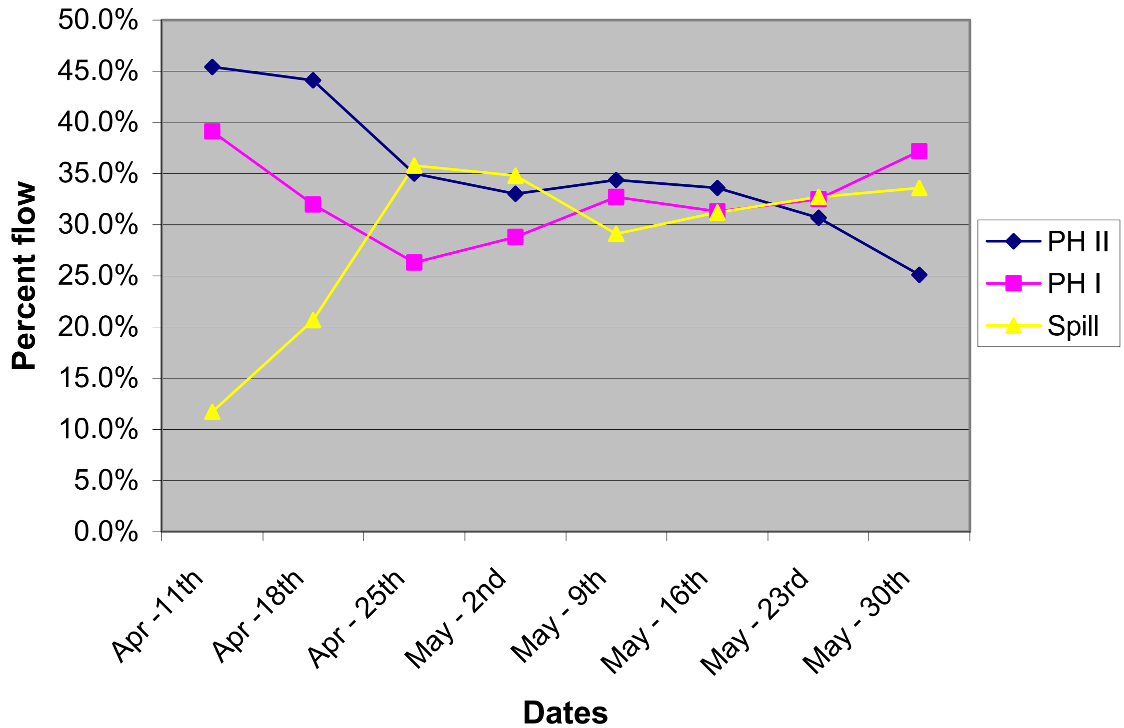
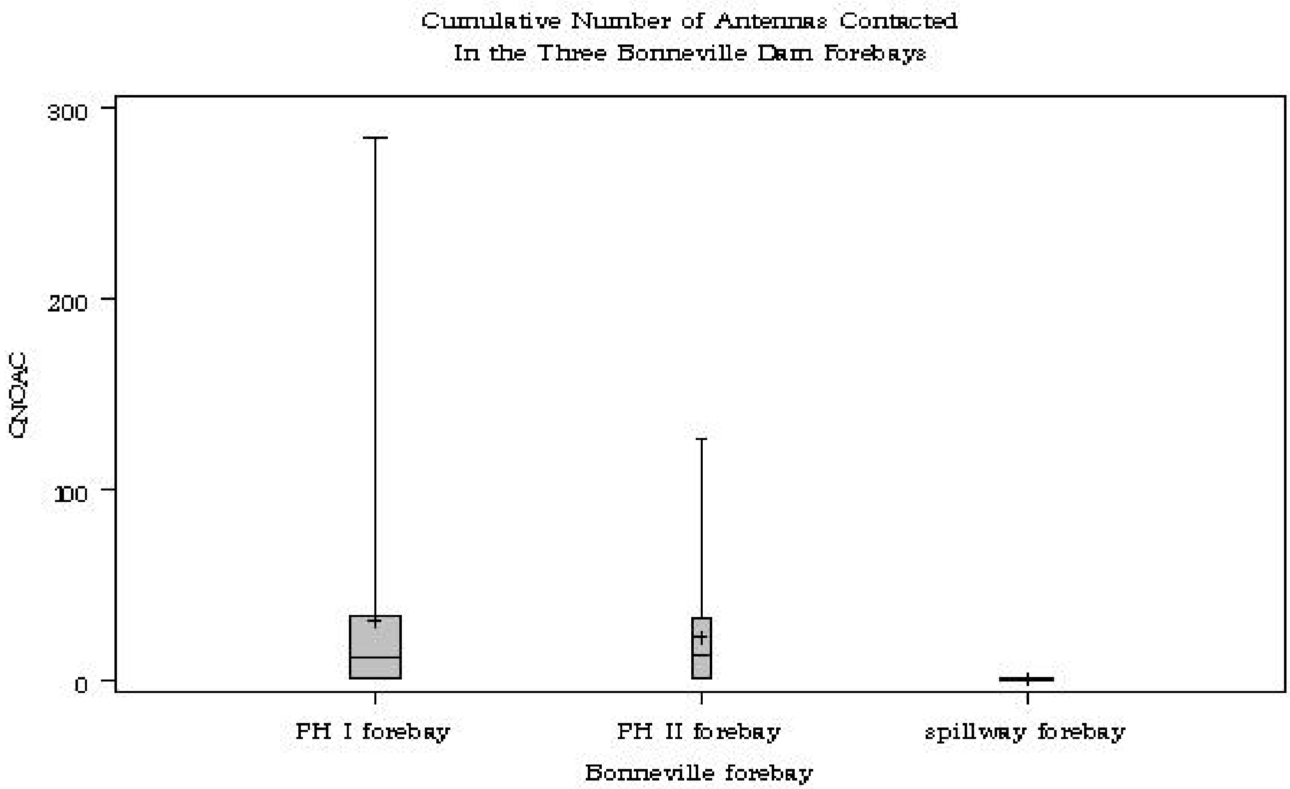


Figure 4. Cumulative number of radio receiver antennas contacted (CNOAC) by Steelhead Kelts in the three forebays at Bonneville Dam, spring 2000.



Appendix A

Fixed receiver/antenna stations installed and maintained by University of Idaho and U.S. Geological Survey researchers and made available to Fisheries Field Unit.

University of Idaho fixed stations.

Site	Antennas	RKM	Receiver	Description
1BO	1	232.3	SRX	Washington shore at the Hamilton Island boat ramp
2BO	1	232.3	SRX	Oregon shore across from the Hamilton Island boat ramp
SBO	1	235.3	SRX	Forebay above spillway, north shore facing south
BF2	1-5	235.2	SRX	Bonneville Spillway Forebay
BF3	1-4	235.2	SRX	Bonneville Spillway Forebay
FTR	1	235.3	DSP	Washington shore, Ft Rains
BOG	1	238.6	DSP	Bridge of the Gods, at Cascade Locks
WIN	1	249.2	DSP	Wind River, Wind River boat launch
UPA	1	246.6	DSP	Oregon shore, across from Depot Road
DPR	1	246.6	DSP	Washington shore, Depot Road, downstream from Wind River
LWD	1	260.1	DSP	Washington shore, downstream from Little White Salmon River
LWS	1	261	DSP	Little White Salmon, inside at mouth of Drano Lake
LWU	1	261.3	DSP	Washington shore upstream from Little White Salmon River
WHD	1	270.3	DSP	Washington shore, downstream from White Salmon River
WHR	1	270.9	DSP	White Salmon River, landing at mouth
WSU	1	272.5	DSP	White Salmon River, upstream from WHR
HDR	1	272.6	DSP	Hood River
BMA	1	276.4	DSP	Washington shore, Bingen Marina

U.S. Geological Survey fixed stations.

Area	Receiver	Antenna	Type	Antenna Coverage
Forebay Aerial Antennas				
Entrance Stations	**L01**	1	AERIAL	Tip of Cascade Island Pointing Upstream
		2	AERIAL	Tip of Cascade Island Pointing Across to Spillway / PH1 Entrance Channels
	L03	1 (3 COMB)	AERIAL	Powerhouse 1 Channel
Powerhouse II	**M01**	1	AERIAL	Fish Unit / North Eddy
		2	AERIAL	Turbine 18
		3	AERIAL	Turbine 17
		4	AERIAL	Turbine 16
		5	AERIAL	Turbine 15
		6	AERIAL	Turbine 14
	M03	1	AERIAL	Turbine 13
		2	AERIAL	Turbine 12

Area	Receiver	Antenna	Type	Antenna Coverage
		3	AERIAL	Turbine 11
		4	AERIAL	Sluiceway Opening / South Eddy
		5	AERIAL	South Eddy
		6	AERIAL	South Eddy
Spillway	**M05**	1 (5 COMB)	AERIAL	Spillbays 1-10 (North End of Spillway Forebay)
	M07	1 (4 COMB)	AERIAL	Spillbays 11-18 (South End of Spillway Forebay)
Powerhouse I	**M09**	4	AERIAL	Turbine 10
		3	AERIAL	Turbine 9
		2	AERIAL	Turbine 8
		1	AERIAL	Turbine 7
	M11	6	AERIAL	Turbine 6 / Prototype Surface Collector
		5	AERIAL	Turbine 5 / Prototype Surface Collector
		4	AERIAL	Turbine 4 / Prototype Surface Collector
		3	AERIAL	Turbine 3 / Prototype Surface Collector
		2	AERIAL	Turbine 2 / Prototype Surface Collector
		1	AERIAL	Turbine 1 / Prototype Surface Collector
	M13	1	AERIAL	Old Navlock Peninsula - (upstream antenna)
		2	AERIAL	Old Navlock Peninsula (downstream antenna)
Forebay Underwater Antennas (MITAS)				
Powerhouse I	**N01**	1 (6 COMB)	UNDERW	Unit 1 Submerged Traveling Screens
		2 (6 COMB)	UNDERW	Unit 2 Submerged Traveling Screens
		3 (6 COMB)	UNDERW	Unit 3 Submerged Traveling Screens
		4 (6 COMB)	UNDERW	Unit 4 Submerged Traveling Screens
		5 (6 COMB)	UNDERW	Unit 5 Submerged Traveling Screens
		6 (6 COMB)	UNDERW	Unit 6 Submerged Traveling Screens
		7 (6 COMB)	UNDERW	Unit 7 Submerged Traveling Screens
		8 (6 COMB)	UNDERW	Unit 8 Extended Length Bar Screens
		9 (6 COMB)	UNDERW	Unit 9 Submerged Traveling Screens
		10 (6 COMB)	UNDERW	Unit 10 Submerged Traveling Screens
		11	UNDERW	Unit 1 Downstream Migrants Channel
		12	UNDERW	Unit 2 Downstream Migrants Channel
		13	UNDERW	Unit 3 Downstream Migrants Channel
		14	UNDERW	Unit 4 Downstream Migrants Channel
		15	UNDERW	Unit 5 Downstream Migrants Channel
		16	UNDERW	Unit 6 Downstream Migrants Channel
		17	UNDERW	Unit 7 Downstream Migrants Channel
		18	UNDERW	Unit 8 Downstream Migrants Channel
		19	UNDERW	Unit 9 Downstream Migrants Channel
		20	UNDERW	Unit 10 Downstream Migrants Channel
Surface	**N02**	1	UNDERW	Shallow South End of Collector

Area	Receiver	Antenna	Type	Antenna Coverage
		2	UNDERW	Middle South End of Collector
		3	UNDERW	Deep South End of Collector
		4 (2 COMB)	UNDERW	Shallow Opening of Unit 1
		5 (2 COMB)	UNDERW	Middle Opening of Unit 1
		6 (2 COMB)	UNDERW	Deep Opening of Unit 1
		7 (10 COMB)	UNDERW	Internal of Unit 1
		8	UNDERW	Shallow between Units 1 & 2
		9	UNDERW	Middle between Units 1 & 2
		10	UNDERW	Deep between Units 1 & 2
		11 (2 COMB)	UNDERW	Shallow Opening of Unit 2
		12 (2 COMB)	UNDERW	Middle Opening of Unit 2
		13 (2 COMB)	UNDERW	Deep Opening of Unit 2
		14 (10 COMB)	UNDERW	Internal of Unit 2
		15	UNDERW	Shallow between Units 2 & 3
		16	UNDERW	Middle between Units 2 & 3
		17	UNDERW	Deep between Units 2 & 3
		18 (2 COMB)	UNDERW	Shallow Opening of Unit 3
		19 (2 COMB)	UNDERW	Middle Opening of Unit 3
		20 (2 COMB)	UNDERW	Deep Opening of Unit 3
		21 (10 COMB)	UNDERW	Internal of Unit 3
		22	UNDERW	Shallow between Units 3 & 4
		23	UNDERW	Middle between Units 3 & 4
		24	UNDERW	Deep between Units 3 & 4
		25 (2 COMB)	UNDERW	Shallow Opening of Unit 4
		26 (2 COMB)	UNDERW	Middle Opening of Unit 4
		27 (2 COMB)	UNDERW	Deep Opening of Unit 4
		28 (10 COMB)	UNDERW	Internal of Unit 4
		29	UNDERW	Shallow between Units 4 & 5
		30	UNDERW	Middle between Units 4 & 5
		31	UNDERW	Deep between Units 4 & 5
		32 (2 COMB)	UNDERW	Shallow Opening of Unit 5
		33 (2 COMB)	UNDERW	Middle Opening of Unit 5
		34 (2 COMB)	UNDERW	Deep Opening of Unit 5
		35 (10 COMB)	UNDERW	Internal of Unit 5
		36	UNDERW	Shallow between Units 5 & 6
		37	UNDERW	Middle between Units 5 & 6
		38	UNDERW	Deep between Units 5 & 6
		39 (2 COMB)	UNDERW	Shallow Opening of Unit 6
		40 (2 COMB)	UNDERW	Middle Opening of Unit 6
		41 (2 COMB)	UNDERW	Deep Opening of Unit 6

Area	Receiver	Antenna	Type	Antenna Coverage
		42 (10 COMB)	UNDERW	Internal of Unit 6
		43	UNDERW	Shallow North End of Collector
		44	UNDERW	Middle North End of Collector
		45	UNDERW	Deep North End of Collector
Forebay Underwater Antennas (LOTEK DSPs)				
PH I Sluiceway	**N03**	1	UNDERW	Sluiceway, mid-channel, @unit 1, B slot
		2	UNDERW	Sluiceway, mid-channel, @unit 1, C slot
		3	UNDERW	Sluiceway, mid-channel, @unit 2, A slot
		4	UNDERW	Sluiceway, mid-channel, @unit 2, B slot
Powerhouse II	**O01**	1 (6 COMB)	UNDERW	Unit 11 Submerged Traveling Screens
		2 (6 COMB)	UNDERW	Unit 12 Submerged Traveling Screens
		3 (6 COMB)	UNDERW	Unit 13 Submerged Traveling Screens
		4 (6 COMB)	UNDERW	Unit 14 Submerged Traveling Screens
	O02	1 (6 COMB)	UNDERW	Unit 15 Submerged Traveling Screens
		2 (6 COMB)	UNDERW	Unit 16 Submerged Traveling Screens
		3 (6 COMB)	UNDERW	Unit 17 Submerged Traveling Screens
		4 (6 COMB)	UNDERW	Unit 18 Submerged Traveling Screens
	O03	1	UNDERW	Unit 11 Downstream Migrants Channel
		2	UNDERW	Unit 12 Downstream Migrants Channel
		3	UNDERW	Unit 13 Downstream Migrants Channel
		4	UNDERW	Unit 14 Downstream Migrants Channel
	O04	1	UNDERW	Unit 15 Downstream Migrants Channel
		2	UNDERW	Unit 16 Downstream Migrants Channel
		3	UNDERW	Unit 17 Downstream Migrants Channel
		4	UNDERW	Unit 18 Downstream Migrants Channel
	O05	1	UNDERW	Sluiceway Entrance
		2	AERIAL	Sluiceway Channel
JBS Bypass Pipe	**O06**	1	UNDERW	First antenna at entrance to pipe
		2	UNDERW	Second antenna at entrance to pipe
		3	UNDERW	Third antenna at entrance to pipe
Sampling Facility	**O07**	1	UNDERW	MAIN FLUME ABOVE SAMPLING FLUME
		2	UNDERW	SALMONID (FINGLING) FLUME
		3	UNDERW	SALMONID (FINGLING) FLUME
		4	UNDERW	SALMONID (FINGLING) FLUME
		5	UNDERW	SAMPLING FACILITY (In Building)
		6	UNDERW	MAIN FLUME BELOW SAMPLING FLUME
		7	UNDERW	MAIN FLUME BELOW SAMPLING FLUME
Tailrace Aerial Antennas				
Exit Stations	**P01 / P02**	1 (2 COMB)	AERIAL	North Powerhouse 2

Area	Receiver	Antenna	Type	Antenna Coverage
	P03 / P04	1 (3 COMB)	AERIAL	South Powerhouse 2
	P05 / P06	1 (3 COMB)	AERIAL	North Spillway
	P07 / P08	1 (3 COMB)	AERIAL	South Spillway
	P09 / P10	1 (2 COMB)	AERIAL	North Powerhouse 1
	P11 / P12	1 (3 COMB)	AERIAL	South Powerhouse 1
JBS project site	**Q01 / Q02**	1 (4 COMB)	AERIAL	Washington Shore (just downstream of the outfall)
Survival Gates				
	Q19 / Q20	1 (2 COMB)	AERIAL	Pole site near OR shore/ Cape Horn – GATE 3