U.S. Army Corps of Engineers
Portland District

Passage Behavior of Radio-Tagged Yearling Chinook Salmon and Steelhead at Bonneville Dam, 2002: *Revised for Corrected Spill*

Annual Report

Prepared by:

Scott D. Evans, Lisa S. Wright, Collin D. Smith, Rachel E. Wardell,
Noah S. Adams, and Dennis W. Rondorf
U.S. Geological Survey
Columbia River Research Laboratory
5501 A Cook-Underwood Road
Cook, Washington 98605

Submitted to:

U.S. Army Corps of Engineers
Portland District
Planning and Engineering Division
Environmental Resources Branch
Robert Duncan Plaza
333 S.W. 1st. Avenue
Portland, Oregon 97204-3495

Contract No. W66QKZ20303685

Submitted:

Original Report: November 12, 2003
Revised: July 20, 2006

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Executive Summary

Flow augmentation, spill, surface collection, and improved turbine guidance systems have been identified as potential management actions to improve passage efficiency and survival of outmigrating juvenile salmonids. The U.S. Army Corps of Engineers (COE), along with regional, state, and federal resource agencies, has designed and implemented studies to determine which management actions would provide significant biological benefits to juvenile salmonids. From 1994 to 2002, the COE contracted the U.S. Geological Survey to evaluate juvenile salmonid behavior in relation to passage improvement tests at Lower Granite, John Day, The Dalles, and Bonneville dams.

In 2002, we used radio telemetry to examine the movements and behavior of yearling Chinook salmon *Oncorhynchus tshawytscha* and steelhead *Oncorhynchus mykiss*, in the forebay of Bonneville Dam. The objectives of this research were to: 1) determine the behavior, distribution, and approach patterns of fish in the forebay areas of Bonneville Dam, 2) determine the timing and route of dam passage of fish, 3) estimate fish passage efficiency for the entire Bonneville Dam complex, fish guidance efficiency for powerhouses I and II, and spillway efficiency and effectiveness, and 4) provide data to estimate survival of radio tagged fish released above Bonneville Dam.

From 30 April to 6 June 2002, we radio tagged and released 2,382 yearling Chinook salmon and 792 steelhead upstream of Bonneville Dam at John Day Dam and The Dalles Dam. At Bonneville Dam, we detected our first radio-tagged fish on 2 May 2002 and we detected our last radio-tagged fish on 9 June 2002. Mean river discharge at Bonneville Dam during the study period was 244.8 kcfs, with 46% of flow discharged at the spillway, 40% at powerhouse II (B2), and 14% at powerhouse I (B1). From 2 May to 9 June 2002, fish were exposed to three different spill treatments. A discharge of 57.1 kcfs during the day (referred to as Day Cap) occurred for a total of 194 h over 14 d. Discharge up to the total dissolved gas cap during daytime hours (referred to as TDG Day) occurred for a total of 430 h over 31 d with an average discharge of 122.4 kcfs. Discharge up to the total dissolved gas cap during nighttime hours (referred to as TDG Night) occurred for a total of 312 h over 39 d, with an average discharge of 125.4 kcfs. Median travel rates of radio-tagged fish from release to Bonneville Dam were 2.1 - 2.5 km/h, depending on species and release site, resulting in median travel times of 30.7 - 53.5 h. Of the fish released, we detected 83% of the yearling Chinook salmon and 77% of the steelhead at Bonneville Dam. Median forebay residence time was shortest at the spillway for both Chinook salmon and steelhead (0.03 and 0.1 h, respectively) compared to 1.3 and 2.0 h at B2 and 2.5 and 2.4 h at the spillway.

Passage routes were determined for 98% of Chinook salmon and 97% of steelhead detected at Bonneville Dam. The spillway passed the most fish (57% of Chinook salmon and 55% of steelhead), followed by B2 (35% of Chinook salmon and 39% of steelhead) and B1 (8% of Chinook salmon and 6% of steelhead). Of the fish that passed at B1, 35% passed into the sluiceway, 30% passed through the turbines (unguided), and 30% were diverted into the turbine bypass system by turbine intake screens (guided). All fish that passed at B2 entered the turbine intakes; 63% were unguided and 37% were guided. At all dam areas, a higher proportion of fish passed

during the day compared to night, the only exception being at B2 where 52% of steelhead passed at night.

Fish passage efficiency (FPE: the proportion of fish that passed the dam via non-turbine routes) at Bonneville Dam in spring 2002 was 76% (SE 1.0%) for Chinook salmon and 84% (SE 1.5%) for steelhead. During hours of Day Cap spill, FPE was 65% (SE 2.2%) for Chinook salmon and 71% (SE 4.7%) for steelhead. Chinook salmon had an FPE of 80% during both TDG Day (SE 1.4%) and TDG Night (SE 1.5%), while steelhead had an FPE of 90% (SE 1.9%) during TDG Day and 82% (SE 2.4%) during TDG Night. At B1, overall FPE was 70% (SE 3.7%) for Chinook salmon and 91% (SE 5.0%) for steelhead. At B2, overall FPE was 37% (SE 1.9) for Chinook salmon and 59% (SE 3.3%) for steelhead. Fish guidance efficiency (FGE: the proportion of powerhouse-entrained fish that are guided by screens into bypass systems) was higher at B1 for both Chinook salmon and steelhead (50% and 75%, respectively) than at B2 (37% and 59%, respectively). Chinook salmon had a spillway efficiency (proportion of fish passing all routes that passed via spill) of 57% (SE 1.1%) overall, 42% (SE 2.3%) during Day Cap, 63% (SE 1.7%) during TDG Day, and 59% (SE 1.9%) during TDG Night. Spillway efficiency for steelhead was 55% (SE 2.0%) overall, 32% (4.7%) during Day Cap, 70% (SE 2.9%) during TDG Day, and 49% (SE 3.1%) during TDG Night. Spillway effectiveness (spillway efficiency divided by the proportion of total discharge through the spillway) for Chinook salmon was 1.2 overall, 1.6 during Day Cap, 1.3 during TDG Day, and 1.2 during TDG Night. Spillway effectiveness for steelhead was 1.2 overall, 1.2 during Day Cap, 1.5 during TDG Day, and 1.0 during TDG Night.

Like in previous years, the proportion of discharge allocated at B1, B2, and the spillway affected which dam area fish entered and passed, as well as the time fish spent in the forebay before passing. Overall, greater than half of both species passed through the spillway and of the three spill treatments, TDG Day spill was the most efficient, passing 63% of Chinook salmon and 70% of steelhead relative to all other passage routes. Spillway efficiency varied significantly among spill treatments for both Chinook salmon ($X^2 = 56.96$, df = 2, $P < 0.001$) and steelhead ($X^2 = 47.21$, df = 2, $P < 0.001$). For Chinook salmon, the TDG Day spill treatment was significantly (Tukey test; q =10.35, df = 3, $P < 0.05$) greater than the Day Cap treatment but not the TDG Night treatment (Tukey test; q = 2.07, df = 3, $P < 0.05$). For steelhead, the TDG Day treatment was significantly greater than both the Day Cap (Tukey test; q = 9.25, df = 3, $P < 0.05$) and the TDG Night (Tukey test; q = 6.77, df = 3, $P < 0.05$) treatments.

Passage metrics for yearling Chinook salmon were higher in 2002 than in 2001. All passage metrics, except FPE_{B1} and FGE_{B2} (and therefore FPE_{B2}), were very similar to passage metrics in 2000. Spillway efficiency and FPE were lower in 2001, largely because of low river flows. Very little water was available for spill in 2001 and that resulted in minimal spill and very low spill efficiency and, therefore, low FPE. Fish passage efficiency at B1 in 2001 was 18-22% greater than in 2002 and 2000, respectively. Fish passage efficiency at B1 was higher in 2001 because a large proportion of smolts entered the sluiceway. We believe the cause of high sluiceway passage in 2001 was due to very low turbine operation at B1, which entrained less fish and made them available to the surface-oriented sluiceway. No steelhead were tagged in 2001 so no comparisons could be made for this species and year. However, comparison of passage metrics for steelhead between 2002 and 2000 shows that, unlike for Chinook salmon, most efficiencies were greater in 2002. In general, this may be attributable to the natural tendency of steelhead to migrate shallower in the water column than Chinook salmon, enabling steelhead to use shallower, non-turbine passage routes to a greater extent than Chinook salmon. Our results indicate that although the current intake screen guidance systems at B1 and B2 have relatively poor guidance efficiency, the project FPE goal of 80% can be attained if sufficient numbers of fish are passed via a combination of non-turbine routes (spill, sluice, and turbine guidance systems).

1.0 Introduction

Years of research have been allocated to ensure the long-term survival of salmon and steelhead stocks in the Columbia River basin. Much of this effort has focused on the effects of dams and reservoirs on juvenile salmonids as they migrate from their natal waters to the ocean. Raymond (1968, 1979) and Park (1969) showed migration times increased after dam construction, and suggested this may be detrimental to juvenile salmonid survival.

Flow augmentation, spill, surface collection, and improved turbine intake guidance systems have been identified as potential management actions to improve juvenile salmonid passage and survival, thereby assisting the recovery of anadromous fish stocks in the Snake and Columbia rivers. One option being evaluated is the improvement of turbine intake guidance systems. The National Marine Fisheries Service (NMFS) and the Northwest Power Planning Council (NPPC) have established goals of 80% fish passage efficiency (FPE) for Columbia and Snake River dams (Whitney et al. 1997). To achieve this goal, migrant salmonids are diverted from turbines via intake screen guidance systems. However, at Bonneville Dam, the present intake screen guidance systems do not divert enough fish to meet the 80% FPE goal.

In 2000, we conducted the first evaluation of species-specific FPE for the entire Bonneville Dam project and estimated that FPE was between 73% and 91%, depending on species (Evans et. al. 2001a and 2001b). The National Marine Fisheries Service Biological Opinion (2000) states, "The dam passage survival rate at Bonneville Dam is currently one of the lowest of any U.S. Army Corps of Engineers Federal Columbia River Power System (FCRPS) project, and is therefore the highest priority relative to the need for improvements," and that the Corps should "continue intake screen guidance improvement investigations and implement as warranted." The COE addressed these concerns in 2001 by field-testing a prototype screen system at turbine unit 15 at Bonneville's second powerhouse (Monk et al. 2002). In 2002, tests were conducted on a new minimum gap runner (MGR) turbine at Bonneville's first powerhouse and on new and old flow deflector bays at the spillway. To determine whether these management actions are effective, it is necessary to estimate passage efficiency metrics such as FPE, fish guidance efficiency (FGE), spillway efficiency (SE), spillway effectiveness (SF), and survival.

During spring 2002, we used radio telemetry to examine the movements and behavior of yearling Chinook salmon, *Oncorhynchus tshawytscha,* and yearling steelhead, *O. mykiss*, in the forebay of Bonneville Dam. Our objectives were to:

- Determine the behavior, distribution, and approach patterns of yearling Chinook salmon and steelhead in the forebay areas of Bonneville Dam.
- Determine the time and route of dam passage of yearling Chinook salmon and steelhead.
- Estimate fish passage efficiency for the entire Bonneville Dam complex, fish guidance efficiency for powerhouses I and II, and spillway efficiency and effectiveness.
- Provide data to estimate route-specific and project survival of radio tagged fish released above Bonneville Dam (reported by Counihan et al. 2003).

2.0 Methods

2.1 Study Area

Bonneville Dam is located on the Columbia River at rkm 233. The dam consists of two powerhouses and a single spillway, each separated by an island. Powerhouse I (B1) consists of 10 turbine units and is located at the south side of the river, spanning from the Oregon shore to Bradford Island. Powerhouse II (B2) consists of eight turbine units and is located at the north side of the river, spanning from Cascades Island to the Washington shore. The spillway lies between Cascades and Bradford islands and has 18 spill gates. A navigation lock is located at the south end of B1 (Figure 1).

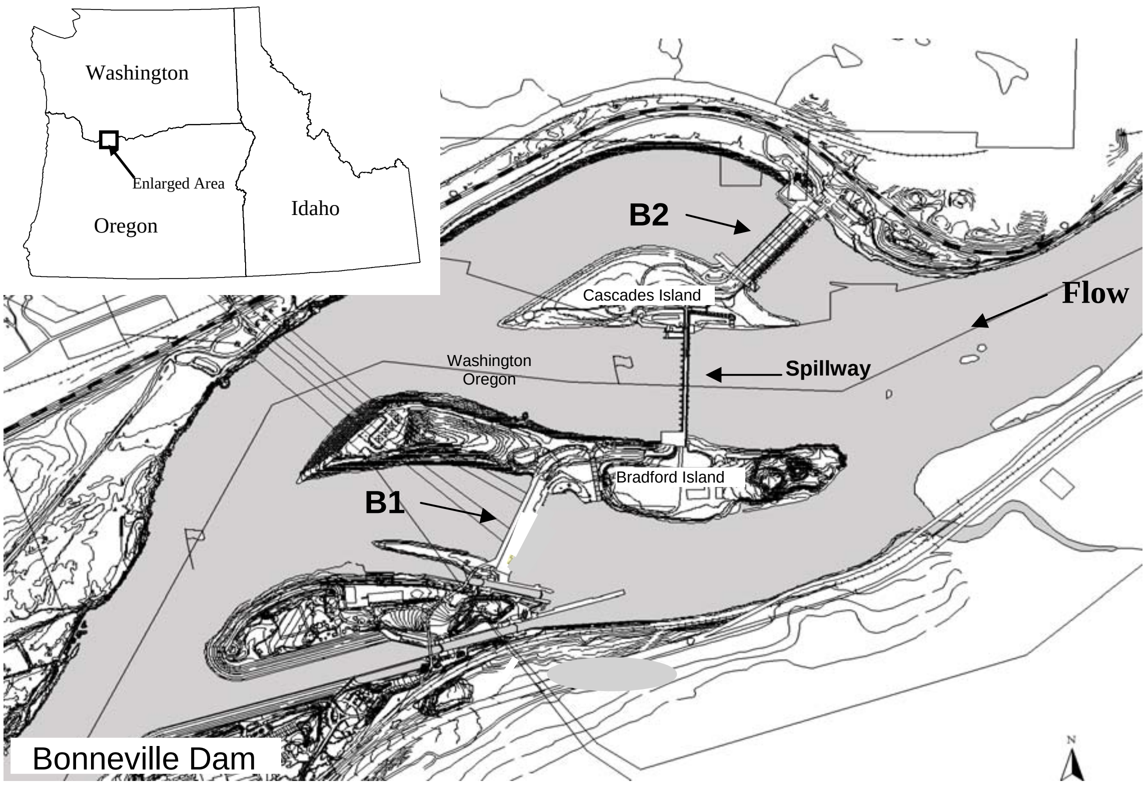

Figure 1. Plan view of Bonneville Dam on the Columbia River, showing the first powerhouse (B1), spillway, and second powerhouse (B2). Image source: U.S. Army Corps of Engineers.

2.2 Fixed Receiving Equipment

Seventy-seven aerial antennas, 62 stripped coax antennas, and 276 underwater dipole antennas were linked to 27 Lotek SRX-400 receivers (SRX; Lotek Engineering, Newmarket, Ontario), three Lotek DSP-500 digital spectrum processors (DSP; Lotek Engineering, Newmarket, Ontario), and three Multiprotocol Integrated Telemetry Acquisition Systems (MITAS; Grant Systems Engineering, Newmarket, Ontario, Canada). Each receiver monitored a maximum of eight aerial antennas. Digital spectrum processor/receiver combinations and MITAS were used to monitor underwater antennas.

The combination of these technologies allowed us to monitor approach behavior and passage through all routes at Bonneville Dam.

Aerial antennas were positioned along the periphery of the forebay to detect fish within about 100 m of the dam face (Figures 2 and 3). Aerial antennas were connected to Lotek SRX-400 data logging receivers, programmed to monitor nine frequencies. Two aerial antenna monitoring configurations were used depending on location: auxiliary/master switching or combined antennas. The auxiliary/master switching configuration was used in the forebay of both powerhouses and at entrance stations where signal acquisition time was longer, and more spatial resolution was required. Combined antenna configurations were used at the spillway and tailrace exit stations where signal acquisition time was limited and less spatial resolution was needed. In addition to combining antennas to reduce scan time, the scan time (a function of the number of frequencies being monitored) was reduced by half by using an extra receiver at each of the tailrace aerial sites. Reducing scan time is beneficial because it increases the probability of detecting transmitters. Underwater dipole and stripped coax antennas had limited ranges (about 6 m) compared to aerial antennas (100 to 300 m depending on transmitter depth, receiver gain, and number of antenna elements). Underwater antennas allowed us to obtain fine scale fish behavior information by limiting the range of signal detection.

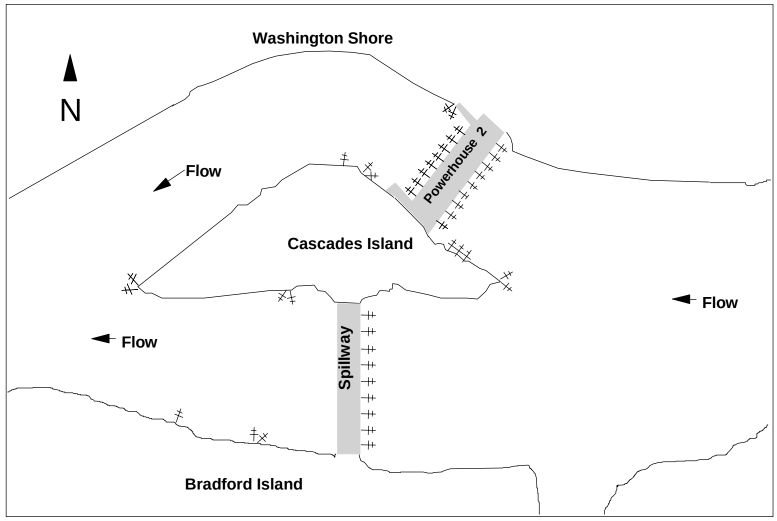

Figure 2. Plan view of aerial antenna coverage at Bonneville's second powerhouse (B2) and spillway during spring 2002.

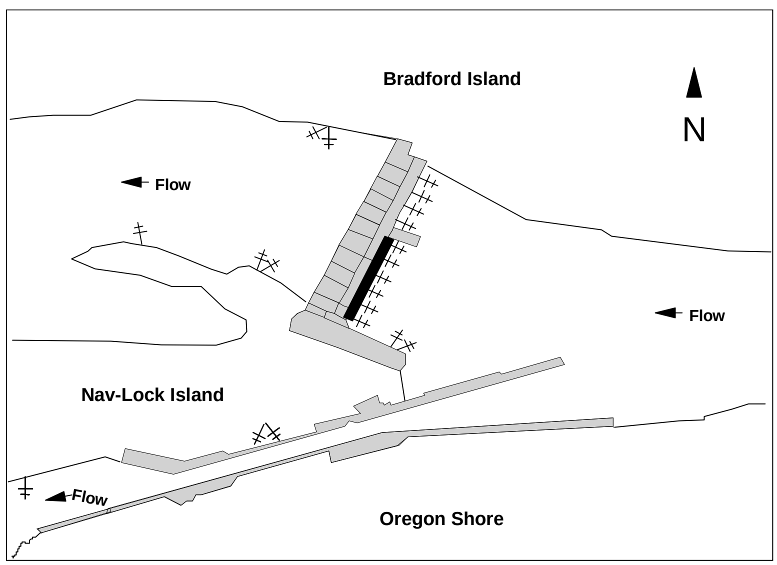

Figure 3. Plan view of aerial antenna coverage at Bonneville's first powerhouse (B1) during spring 2002.

Two receivers in the B2 tailrace and one receiver at the B2 sampling facility were coupled with digital spectrum processors. These receivers had essentially no scan time because a DSP acquires signals over a 1 MHz bandwidth almost instantaneously. Although antennas monitored by DSPs could have been monitored by a MITAS, we chose to use DSPs due to wiring logistics. Using DSPs, rather than a stand-alone SRX, was necessary to document fish passage in turbulent hydraulic environments because signal acquisition time is limited.

Three MITAS systems were incorporated at B1, B2, and the spillway (Figures 4 and 5). Each MITAS was capable of simultaneously monitoring up to 50 inputs with greater multiple transmitter recognition than either the SRX-400 or SRX/DSP combination. Although each MITAS was limited to a maximum of 50 inputs, each input could be a horizontal or vertical combination of multiple underwater dipole or stripped coax antennas. In addition to its enhanced signal recognition, the MITAS' data displays and on-screen diagnostics increased the robustness of the system. These features allowed the user to identify problems in real-time and avoid potential data loss that otherwise would not have been apparent until post-processing.

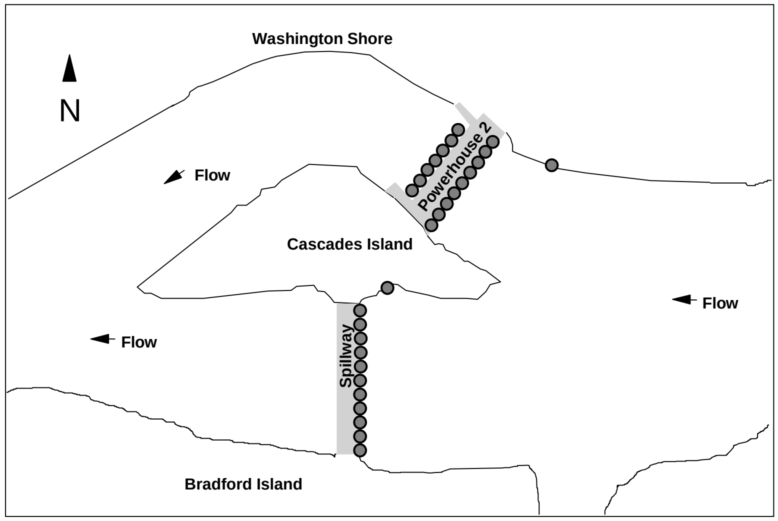

Figure 4. Plan view of underwater antenna coverage at Bonneville's second powerhouse (B2) and spillway during spring 2002.

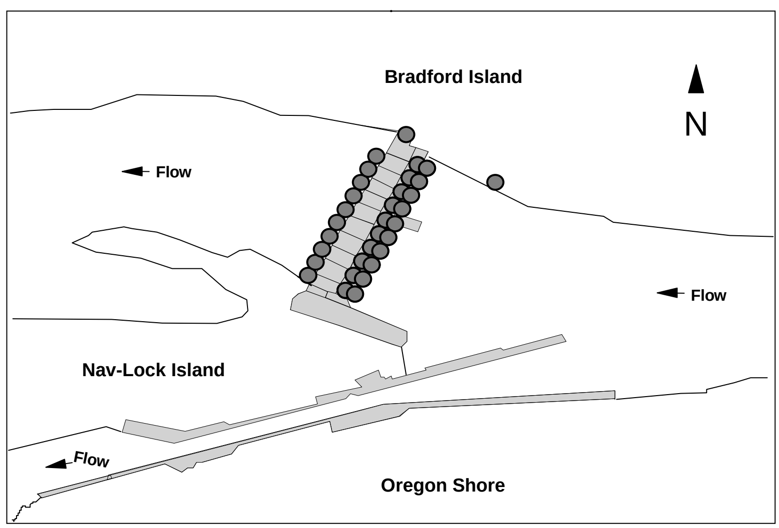

Figure 5. Plan view of underwater antenna coverage at Bonneville's first powerhouse (B1) during spring 2002.

The MITAS at B1 was composed of 144 underwater antennas. Fifty-four dipole underwater antennas monitored turbine passage and were attached to the standard length traveling screens (STS) at units 1-7, and units 9 and 10, as well as the extended submerged bar screens (ESBS) at unit 8. Unit 5 was not in operation through the duration of the study. Two dipole antennas were mounted on the bottom frame of each STS and on the downstream side of the lower portion of the extended screen on each ESBS. Screen antennas were then combined to provide turbine unit-specific passage information. Twenty stripped coax antennas were positioned mid-channel in the sluiceway, two at each unit, to monitor unit-specific sluiceway passage. Twelve stripped coaxial antennas were located inside the Downstream Migrant Channel (DSM); one at each “C-slot” gatewell orifice and two in the DSM down-well to measure guided fish passage (i.e. fish directed by guidance screens) as well as potential delay in the down-well area. Fifty-four underwater dipole antennas were placed in the taillog slots (3 per slot) of units 1-4 and 6-10 (unit 5 was inoperable in 2002) to monitor fish that passed through the turbines and to measure any delay of unguided fish within the taillog slots. The adult fish ladder was monitored with four stripped coax antennas placed mid-channel at a distance of about 30 m from the forebay opening.

The MITAS located at B2 was composed of 113 underwater antennas and two aerial antennas. Forty-eight dipole underwater antennas monitored turbine passage and were attached to the each STS. Eight stripped coax antennas located at each “C-slot” gatewell orifice and one additional stripped coax antenna located at the terminus of the DSM monitored guided fish passage through the DSM. A single aerial and two stripped coax antennas positioned at the entrance to the sluice chute measured fish passage in the chute (however, the sluice chute was not operated in 2002). Forty-eight underwater dipoles were installed in the taillog slots of units 11-18 and the adult fish ladder was monitored by four stripped coax antennas deployed mid-channel about 30 m from the forebay opening. Two stripped coax antennas were used at B2 to monitor radio-tagged fish that were sampled by the National Marine Fisheries Service (NMFS) during their study to assess performance of STS improvements at unit 17. One stripped coax antenna was placed inside NMFS’ sorting trailer and the other antenna was placed in NMFS’ return pipe at unit 18.

The spillway MITAS consisted of 76 underwater antennas. Seventy-two dipole underwater antennas monitored spillway passage and were attached to the forebay pier noses about 4.5 and 10.5 m below mean pool level. In each of the 18 spillbays, four antennas were combined into one to monitor spillbay-specific passage. Four stripped coax antennas monitored the forebay opening of the adult fish ladder.

Regardless of the type of monitoring technology used, a standard input signal of known value was used to determine the signal strength reaching each receiver. All aerial antennas were amplified in close proximity to the receiving antenna and transmission line amplification was used as needed to insure signal quality. Underwater antenna transmission lines were amplified as soon as they reached the deck elevation. Over-amplified signals were attenuated down to a standard level. These efforts insured that all antennas within and among arrays were equally sensitive and resulted in a balanced receiving system.

2.3 Transmitters

Pulse-coded transmitters developed by Lotek Engineering Inc. were implanted in yearling steelhead and Chinook salmon. The transmitters were 7.3 mm (diameter) x 18.9 mm and weighed 1.4 g in air and 0.8g in water. The antenna length was 30 cm and the pulse rate was 2.0 s, resulting in an estimated minimum tag life of 9 d.

2.4 Tagging, Handling, and Release of Fish

Juvenile Chinook salmon and steelhead were collected at John Day Dam's Juvenile Fish Bypass Facility. Employees from the Pacific States Marine Fisheries Commission's (PSMFC) Smolt Monitoring Program and USGS employees sorted and identified study fish. Fish were released into the Columbia River at John Day Dam and The Dalles Dam. Although fish were tagged and released at different locations, the fish handling, tagging, and release methods were standardized as much as practical.

Fish were held in 127 L plastic holding cans for 24 h before tagging. All fish were gastrically implanted with a radio transmitter using procedures similar to those described in Adams et al. (1998). Fish were held at a density no greater than 30 fish/container and were supplied with flow-through river water. Fish were anesthetized using tricaine methanosulfate (MS-222) at 50 mg per one-liter of fresh water. Once a fish began to lose equilibrium, it was weighed, measured, and tagged. Immediately following tagging, fish were placed in a 19 L recovery bucket and supplied with bottled oxygen. After about 10 min, fish were transferred into a 127 L plastic recovery container at a density no greater than 4 fish per container and were supplied with flow-through river water. Fish were held between 18 and 24 h before release.

Before transportation to the release site, each holding container was checked for mortalities, regurgitated tags, and tag functionality. Releases occurred during day and night (1000-1200 and 1800-0100 hours at John Day Dam and 0500-1100 and 2200-0459 hours at The Dalles Dam) to enable tagged fish to mix spatially and temporally with untagged fish in the river before passing the dam. The upstream release locations allowed fish an average of 33 to 56 h, depending on species and release site, to adjust to temperature and hydraulic conditions in the reservoir before reaching the forebay and encountering the dam.

2.5 Data Management and Analysis

Fixed receivers were typically downloaded every day. All data were backed up daily and imported into SAS (version 8.1, SAS Institute Inc., Cary, North Carolina, USA) for subsequent proofing and analysis. Data were manually proofed to eliminate non-valid records including: environmental noise, single records of a particular channel and code, records collected prior to a known release date and time, and records suspected to be fish consumed by avian or aquatic predators. To consider a detection of a radio-tagged fish as valid, we required at least two detections within 1 min of each other.

Entrance into the near-dam area was determined by the location and time an individual fish was first detected by aerial or underwater antennas on the dam face. Similarly, the last detection of a fish by aerial or underwater antennas on the dam face, on the traveling screens, or within either DSM or sluiceway, was considered to be the route and time of passage through the dam. If a fish was not detected in the forebay or within the dam, the tailrace exit stations were used to determine which dam area fish passed (B1, B2, or spillway), but not to determine more specific passage locations (DSM, turbine, or sluiceway). If a fish was detected in the DSM, it was identified as being "guided" (diverted away from the turbine and into the bypass system by the turbine intake screens). If a fish was detected at the screens and subsequently in the tailrace, it was identified as being “unguided” (not diverted by turbine intake screens). If a fish was detected in the sluiceway and subsequently in the tailrace, it was identified as passing through the sluiceway.

Residence time in the near-dam area, defined as the duration of time between the first and last detections in the forebay, was calculated for each radio-tagged fish detected in the near-dam area. Residence times are a minimum estimate of the actual time that radio-tagged fish spend in the near-dam area because of receiver limitations and detection probabilities. For example, fish may enter the forebay before they are first detected and may remain following their last detection. Additionally, fish that approach very deep may have a low probability of detection and thus pass the dam undetected.

The following are definitions of metrics used to measure passage behavior of radio-tagged fish at Bonneville Dam:

- Spillway efficiency $(SE) = \dfrac{SP}{(B1 + SP + B2)}$
- Spillway effectiveness $(SF) = \dfrac{SE}{F_{sp} / F_{tot}}$
- Fish guidance efficiency (FGE) = $\dfrac{G_{tot}}{(G_{tot} + UG_{tot})}$
- Fish passage efficiency (FPE) = $\dfrac{Non-turbine\ \ passage}{TOT_{pass}}$

Where:

SP = Total number of fish passing spillway
B1 = Total number of fish passing B1
B2 = Total number of fish passing B2
G_{tot} = Total number of guided fish
UG_{tot} = Total number of unguided fish
TOT_{pass} = Total number of fish passing the project (B1+SP+B2)
F_{sp} = Average discharge (kcfs) through the spillway during the study period.
F_{tot} = Average discharge (kcfs) through the project (B1+SP+B2) during the study period

We calculated the standard error (SE), as described by Zar (1999), for all fish passage proportions (efficiencies) to provide a measure of precision of our estimate. We tested for equality of proportions among spill treatments using a chi-square test (Zar 1999). We then used a Tukey test to make pairwise comparisons of arcsine-transformed square roots of proportions that were significantly different ($P < 0.05$) to determine which proportions were significantly different from which others (Zar 1999).

3.0 Results

3.1 Tagging

From 30 April to 6 June 2002, we radio tagged and released 2,382 yearling Chinook salmon and 792 steelhead. Of the Chinook salmon, 786 were released from John Day Dam and 1,596 were released from The Dalles Dam. Of the steelhead, all 792 were released from John Day Dam. The release period coincided with the central portion of the “in river” seaward migration of Chinook salmon and steelhead smolts (Figure 6). Of the fish released from John Day Dam, 21% (333 of 1,578) were released during the day and 79% (1,245 of 1,578) were released at night. Of the fish released from The Dalles Dam, 51% (808 of 1,596) were released during the day and 49% (788 of 1,596) were released at night. Mean fork length for Chinook salmon released from all sites was 149.4 mm and the mean weight was 32.8 g. Mean fork length for steelhead released from all sites was 187.7 mm and the mean weight was 60.2 g. The radio tag represented an average of 4.7% of mean Chinook salmon body weight and 3.3% of mean steelhead weight.

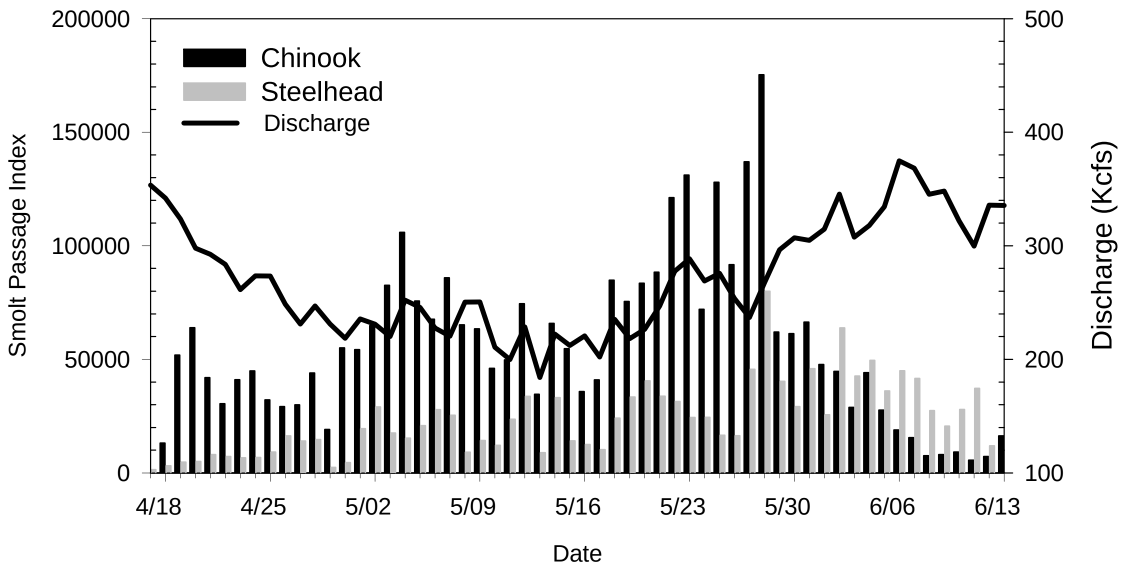

Figure 6. Smolt Passage index for yearling Chinook salmon at Bonneville Dam’s Second Powerhouse (B2) fish collection facility during spring 2002. Smolt index data were acquired from the Fish Passage Center web page at www.fpc.org.

3.2 River Discharge and Project Operations

During spring 2002 (May 2 – June 9), mean river discharge at Bonneville Dam was 244.8 kcfs, and ranged from 175.4 kcfs to 354.4 kcfs. Allocation of mean river discharge among dam areas (i.e., B1, B2, and spillway) during the study period was 14% through B1, 40% through B2, and 46% through spill (Figure 7 and Table 1). Mean daily discharge at B1 (turbines 1–10) was 35.0 kcfs and ranged from 0.7 to 85.2 kcfs. B2 averaged 97.8 kcfs, and ranged from 52.3 to 125.2 kcfs. Spill averaged 112.0 kcfs and ranged from 63.6 to 195.4 kcfs. Over the course of the spring study, discharge at B1 increased as the season progressed, discharge at the spillway peaked on four separate and distinct 10 d periods, and discharge at B2 fluctuated little relative to discharge at B1 and the spillway (Figure 8).

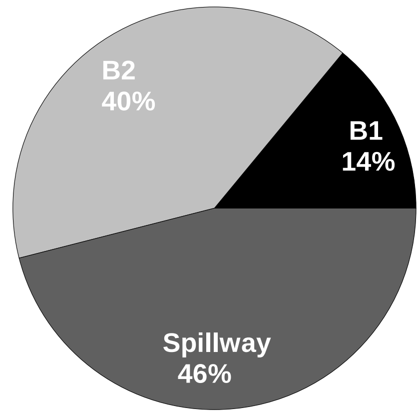

Figure 7. Discharge allocation between dam areas at Bonneville Dam during spring 2002.

Two spill levels were tested in 2002: a discharge of 57 kcfs (original target was 75 kcfs but due to a miscalibration the actual mean spill was 57 kcfs) and a discharge up to the 120% total dissolved gas (TDG) cap. The 57 kcfs spill level occurred only during daytime hours (0500-2000) and flows up to the TDG cap occurred during both day and nighttime hours (2100-0459). Therefore, fish were exposed to three spill treatments (hereafter referred to as Day Cap, TDG Day, and TDG Night) during our 39 d spring study period. Spill during the Day Cap treatment occurred for a total of 194 h in 14 d, averaged 57.1 kcfs, and ranged from 56.1 to 57.9 kcfs. Spill during the TDG Day treatment occurred for a total of 430 h in 31 d, averaged 122.4 kcfs, and ranged from 78.5 to 194.3 kcfs. Spill during the TDG Night treatment occurred for a total of 312 h in 39 d, averaged 125.4 kcfs, and ranged from 75.3 to 209.5 kcfs.

Turbines 1-6 represented 57% and turbines 7-10 represented 43% of mean discharge at B1 (Figure 9). Turbines 11-14 represented 54% and turbines 15-18 represented 46% of mean discharge at B2 (Figure 10). There were considerable differences in discharge between turbine units, although fluctuations in mean daily discharge of turbines 11-14, 15-18, and 11-18 corresponded with mean daily river discharge. Differences in daily turbine discharge were observed for multiple turbines throughout the study (Figures 11, 12, 13, and 14). We found that mean discharge at both B1 and B2 were about 10 kcfs higher during day than night and mean discharge at the spillway was about 20 kcfs higher at night compared to day (Table 2).

Table 1. Descriptive statistics for discharge (kcfs) at Bonneville Dam during spring 2002. Values have been rounded to the nearest tenth and are based on daily totals.

Dam Area	Mean	Median	Min	Max
B1	35.0	33.9	0.7	85.2
B2	97.8	99.2	52.3	125.2
Spillway	112.0	109.2	63.6	195.4
Total	244.8	227.2	175.4	354.4

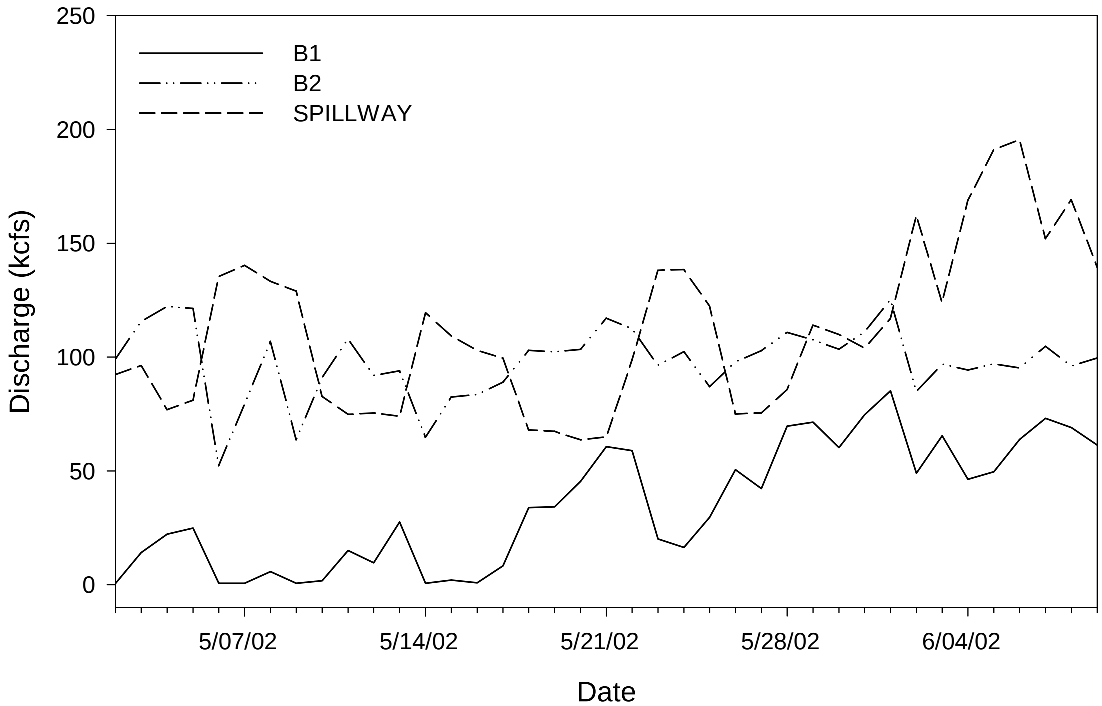

Figure 8. Mean daily discharge at Bonneville Dam by dam area during spring 2002.

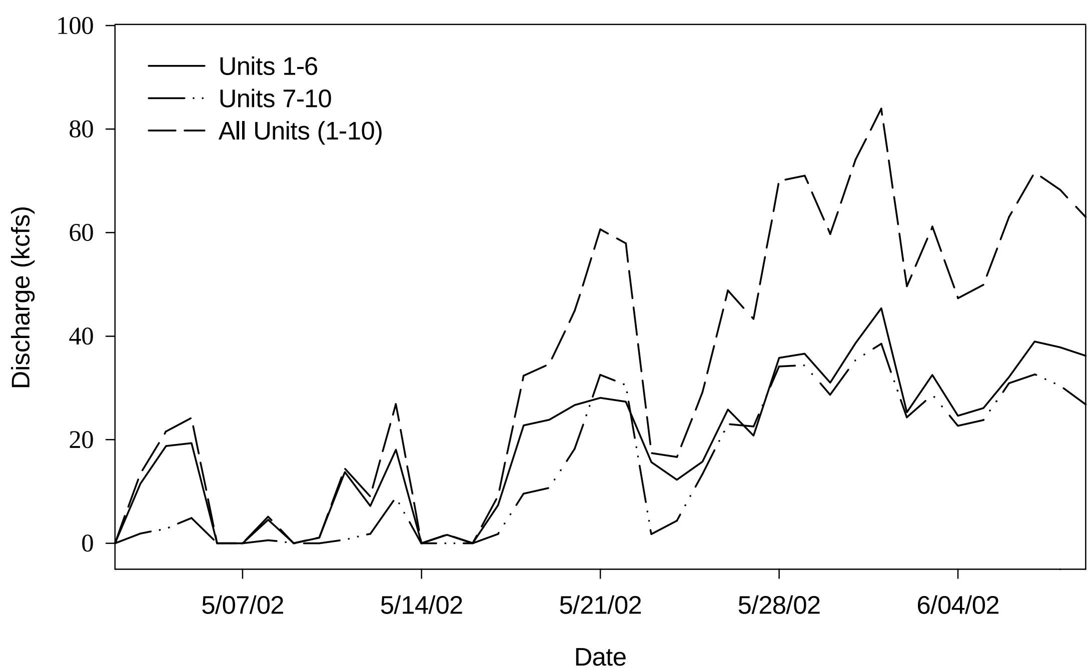

Figure 9. Mean daily discharge through turbines 1-6 and 7-10 during spring 2002.

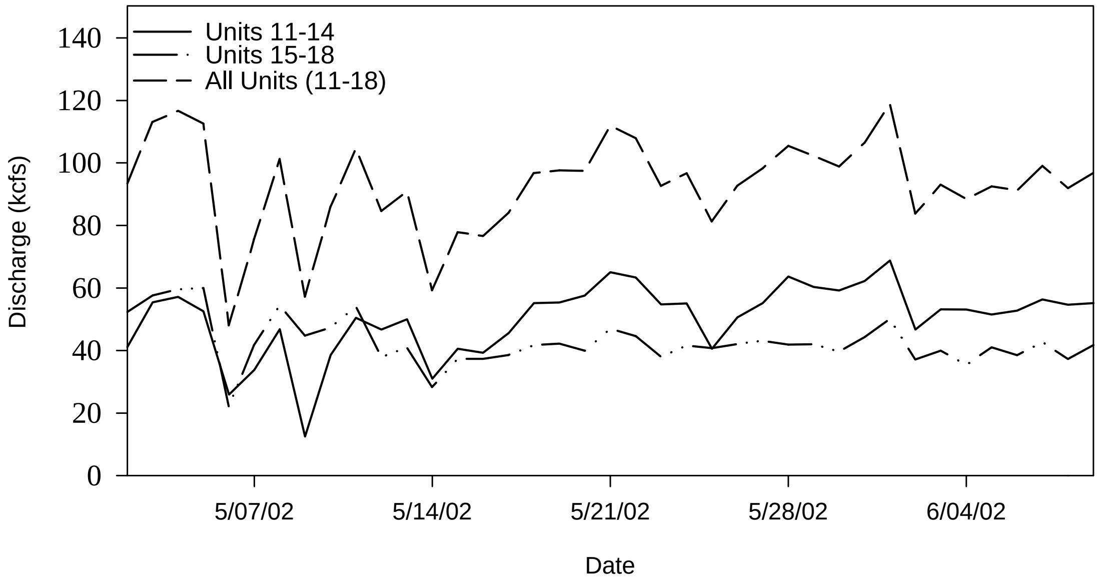

Figure 10. Mean daily discharge through turbines 11-14 and 15-18 during spring 2002.

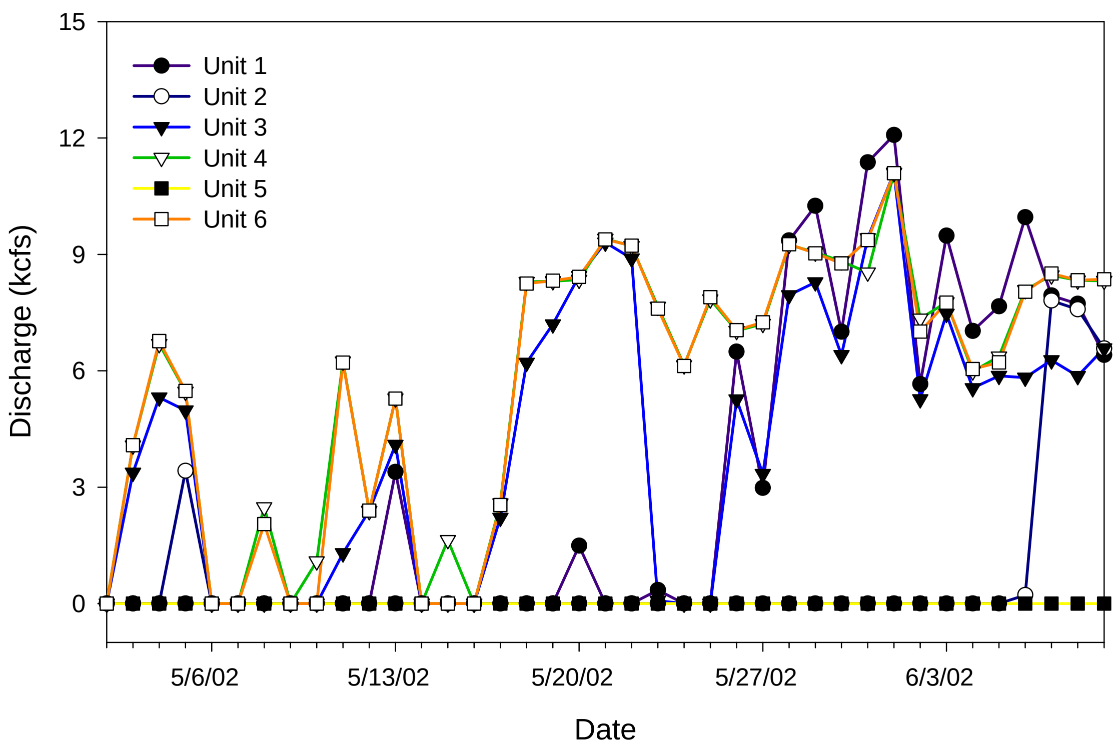

Figure 11. Mean daily discharge by unit for units 1-6 at Bonneville Dam during spring 2002.

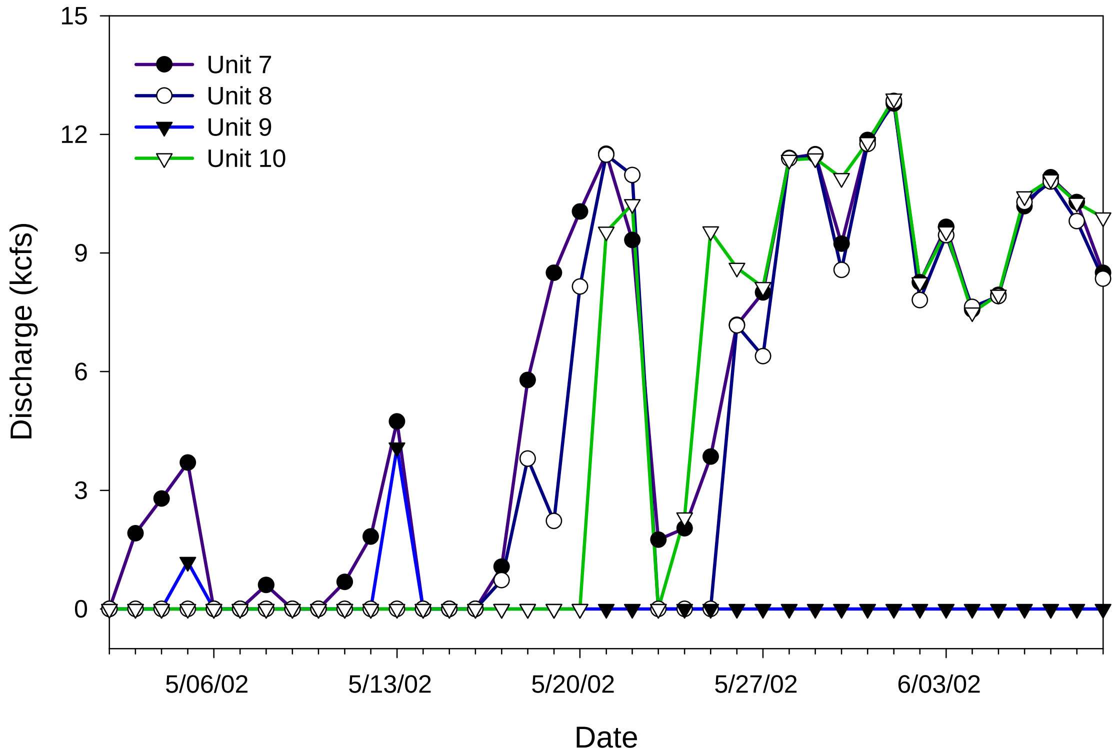

Figure 12. Mean daily discharge by unit for units 7-10 at Bonneville Dam during spring 2002.

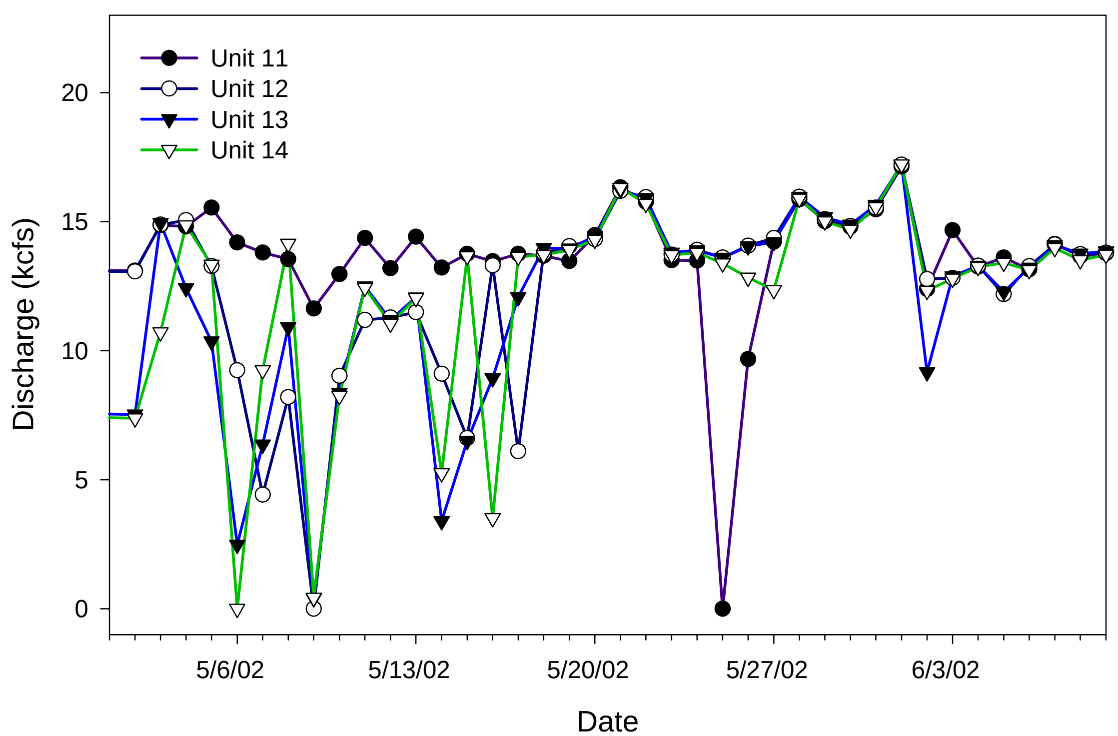

Figure 13. Mean daily discharge by unit for units 11-14 at Bonneville Dam during spring 2002.

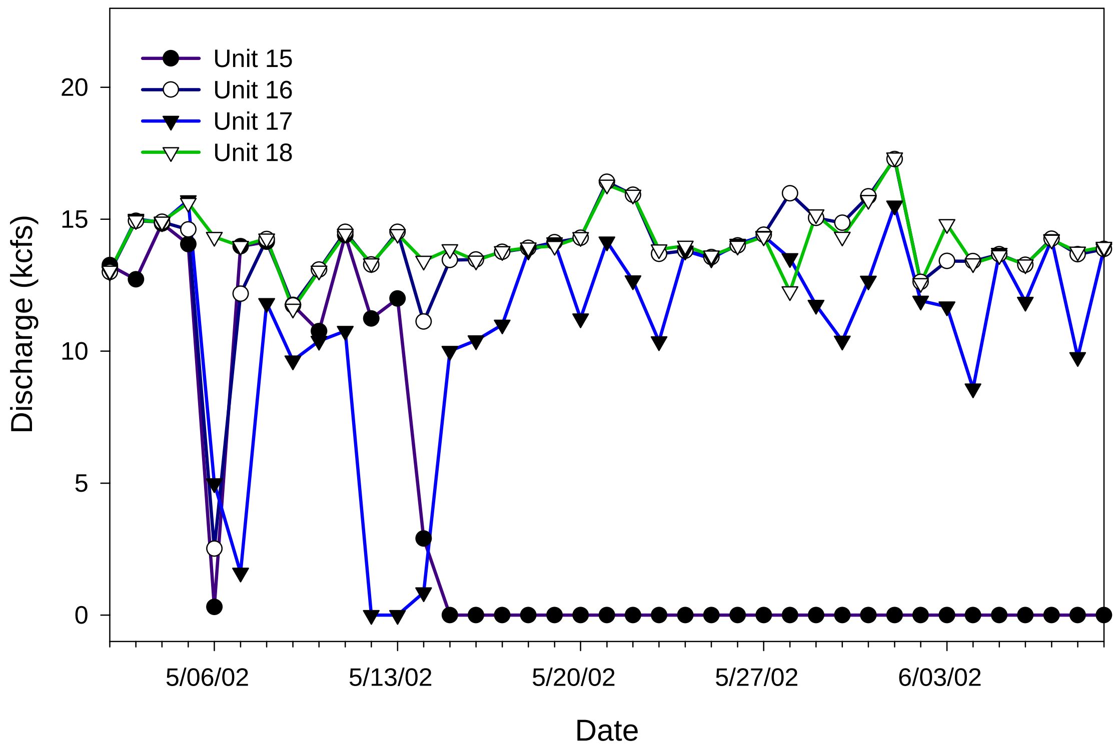

Figure 14. Mean daily discharge for units 15-18 at Bonneville Dam during spring 2002.

Table 2. Mean discharge (kcfs) during day (0500-2059 hours) and night (2100-0459 hours) by dam area during spring 2002. Powerhouse one = B1 and Powerhouse two = B2.

Dam Area	Period	Percent (of mean)	Mean	Median	Min	Max
B1	Day	16%	38.4	36.0	0.6	95.1
B2	Day	41%	101.6	103.6	33.1	142.6
Spillway	Day	43%	105.2	103.5	55.7	223.9
B1	Night	12%	28.4	16.6	0.6	95.3
B2	Night	37%	90.3	93.9	33.3	138.3
Spillway	Night	51%	125.4	114.1	66.2	224.0

3.3 Travel to and Arrival at Bonneville Dam

At Bonneville Dam, we detected 83% (1,976 of 2,382) of the yearling Chinook salmon and 77% (606 of 792) of the steelhead that were released from John Day Dam and The Dalles Dam. The median travel rate for Chinook salmon released from John Day Dam to first detection at Bonneville Dam was 2.1 km/h and the median travel time was 53.5 h. Steelhead released from John Day Dam had a median travel rate of 2.5 km/h and a median travel time of 45.3 h. The median travel rate for Chinook salmon released from The Dalles Dam was 2.4 km/h and the median travel time was 30.7 h. (Table 3).

Table 3. Descriptive statistics for travel time (h) and travel rate (km/h) to Bonneville Dam for radio-tagged yearling Chinook salmon (Ch1) and steelhead (Sth) during spring 2002. Travel rates are represented within parenthesis.

Release Site/Species	Mean	Median	STD	Min	Max
The Dalles Dam - Ch1	33.4 (2.4)	30.7 (2.4)	10.7 (0.7)	6.9 (0.5)	145.9 (10.6)
John Day Dam - Ch1	56.4 (2.2)	53.5 (2.1)	18.2 (0.6)	28.1 (0.6)	202.6 (4.0)
John Day Dam - Sth	48.5 (2.5)	45.3 (2.5)	16.5 (0.6)	23.7 (0.7)	161.4 (4.7)

Fish did not enter dam areas (i.e. B1, B2, and spillway) in equal proportions. Of the Chinook salmon detected at Bonneville Dam, 9% (181 of 1,976) first entered B1 forebay, 34% (679 of 1,976) first entered B2 forebay, and 57% (1,116 of 1,976) first entered the spillway forebay. Steelhead entered the forebays of Bonneville Dam in nearly identical proportions to Chinook salmon. Of the steelhead detected at Bonneville Dam, 7% (41 of 606) first entered B1 forebay, 36% (220 of 606) first entered B2 forebay, and 57% (345 of 606) first entered the spillway forebay. Proportions of fish approaching Bonneville Dam appeared to be strongly related to the allocation of river discharge among dam areas. Discharge at B1, B2, and the spillway represented 14%, 40%, and 46%, respectively, of mean river discharge. To further investigate this relation, we compared the proportion of mean daily discharge through each dam area to the daily proportion of radio-tagged fish that entered each dam area. For both species, the daily arrival of fish fluctuated with daily discharge. At all three dam areas, when discharge increased, fish arrival increased. Likewise, when discharge decreased at a dam area, the number of fish entering that dam area decreased (Figures 15 and 16).

Similarly, we compared the hourly proportion of fish entering each dam area to the hourly proportion of mean discharge through each dam area but found only a slight relation. A pattern of increased fish entrance with increased discharge was most apparent, on an hourly basis, at the spillway (Figures 17 and 18).

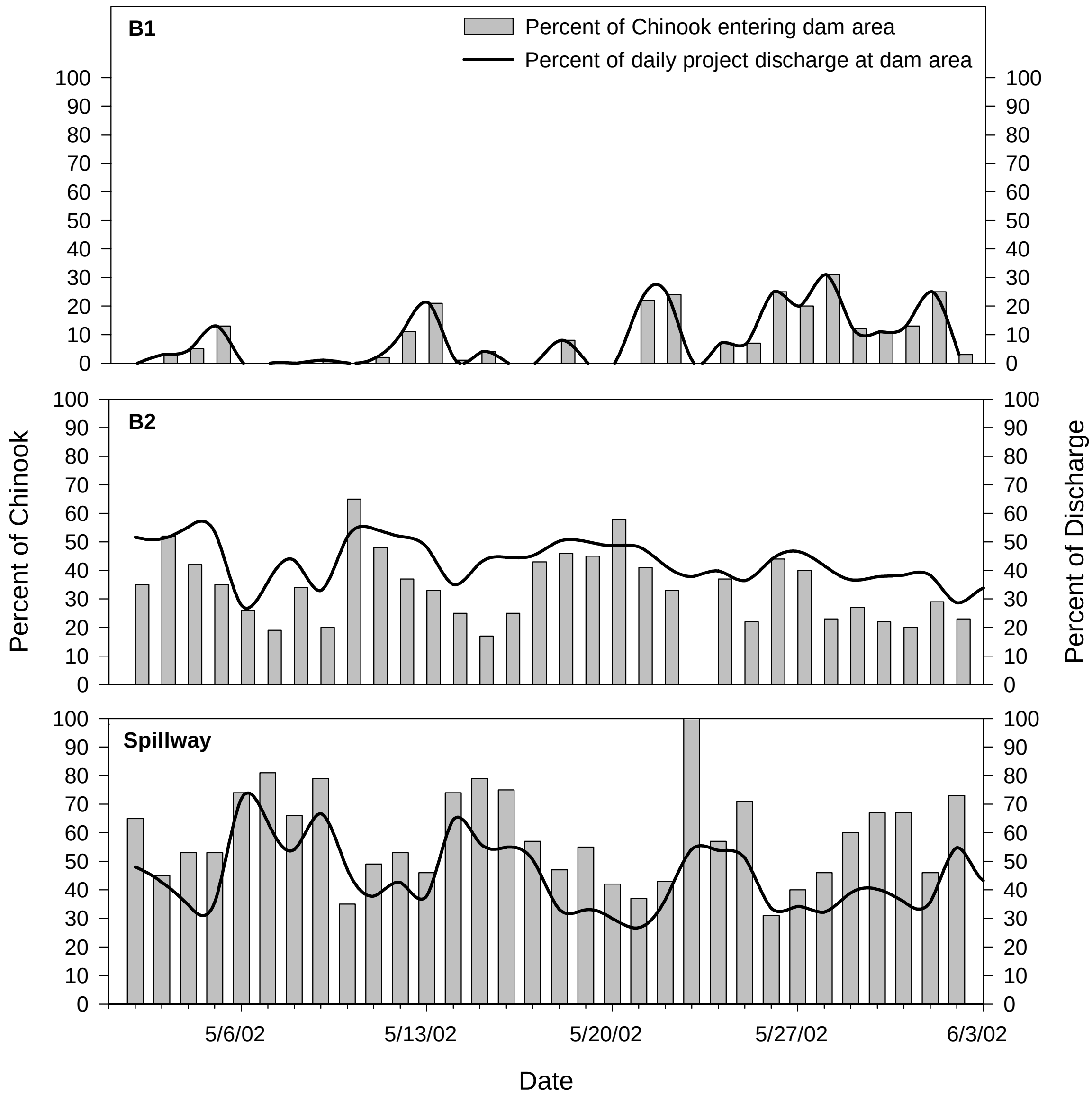

Figure 15. The percentage of yearling Chinook salmon that entered each dam area versus the percentage of mean discharge, by day, at each dam area during spring 2002.

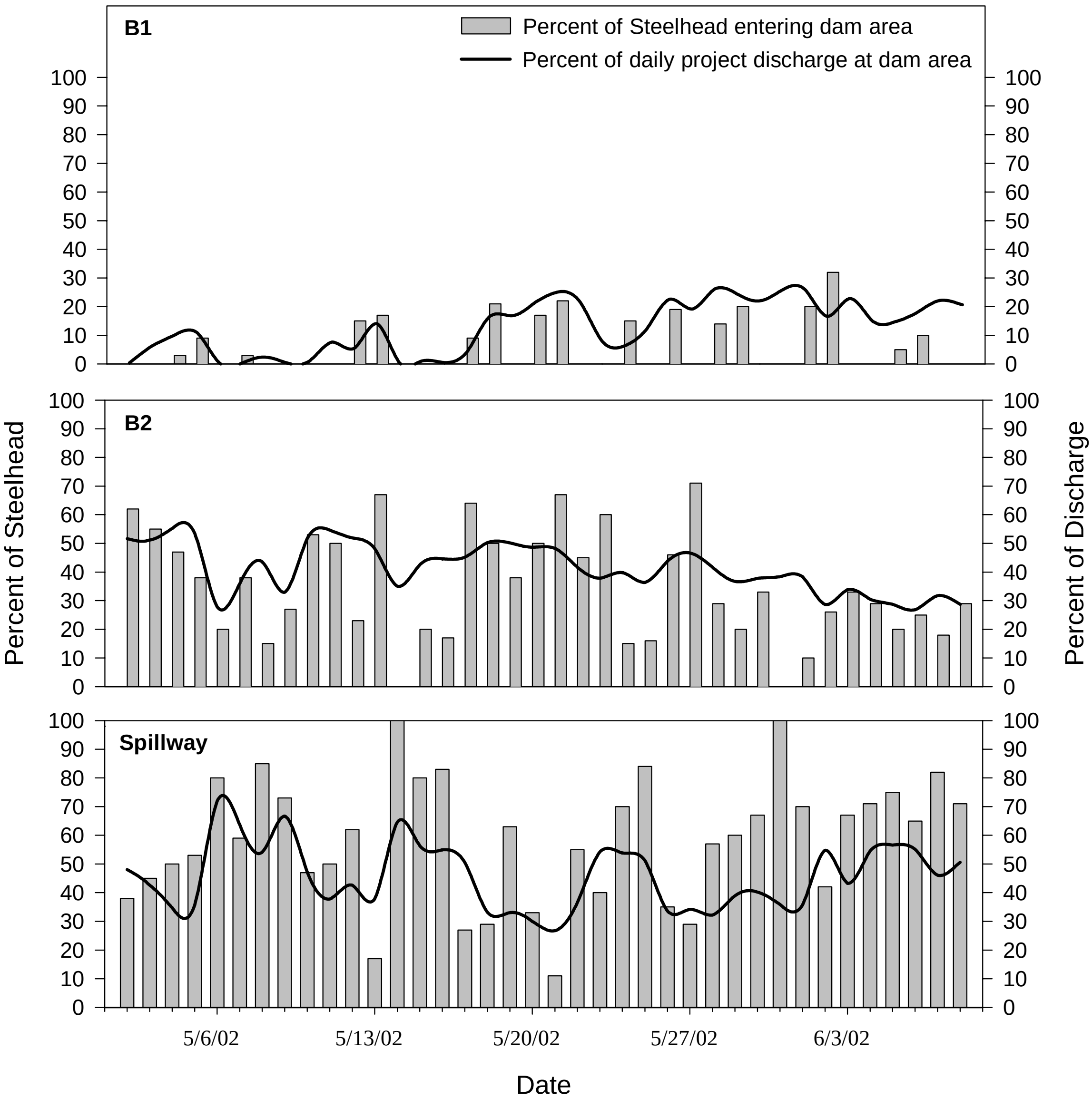

Figure 16. The percentage of yearling steelhead that entered each dam area versus the percentage of mean discharge, by day, at each dam area during spring 2002.

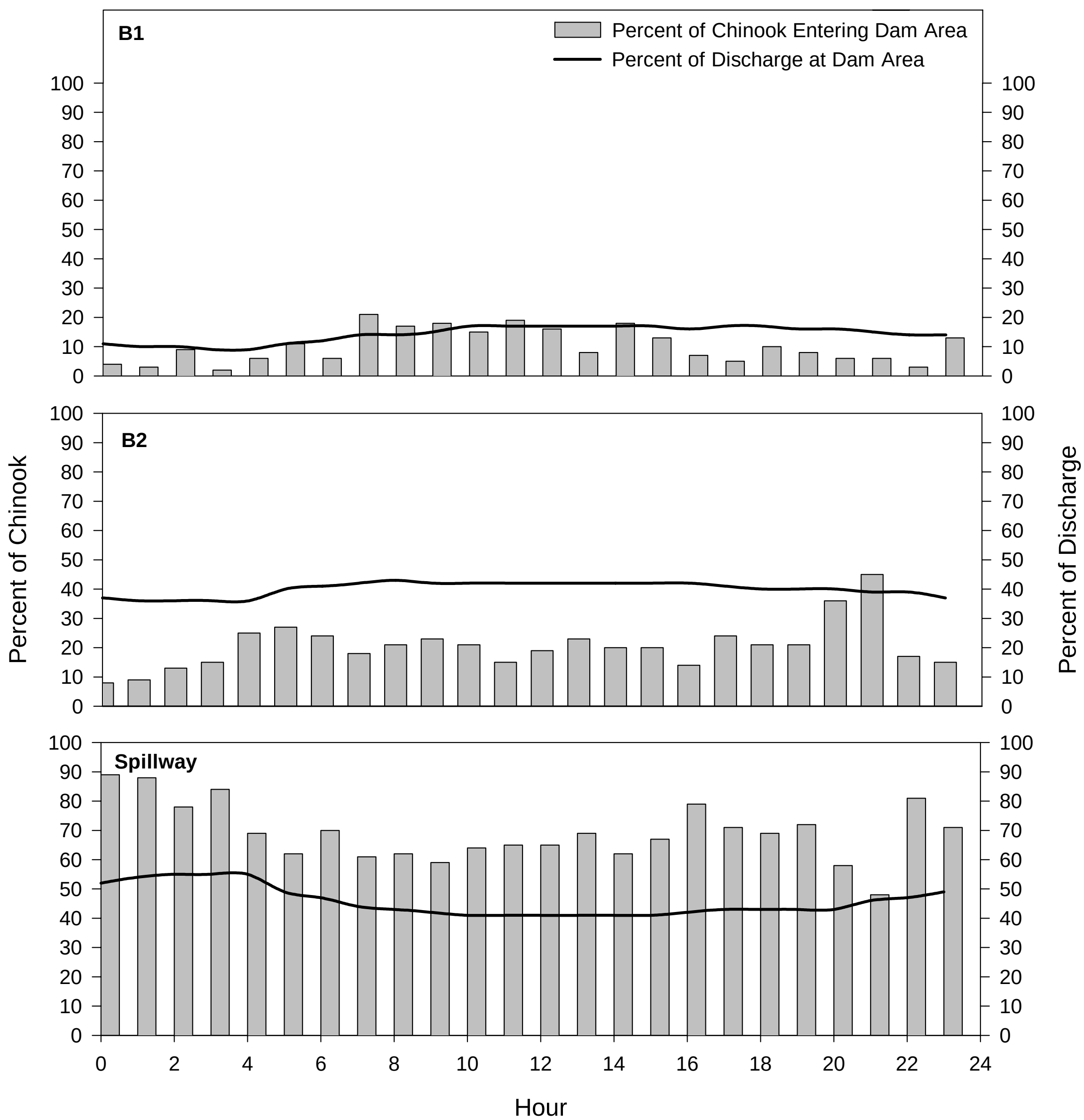

Figure 17. The percentage of yearling Chinook salmon that entered each dam area versus the percentage of mean discharge, by hour, at each dam area during spring 2002.

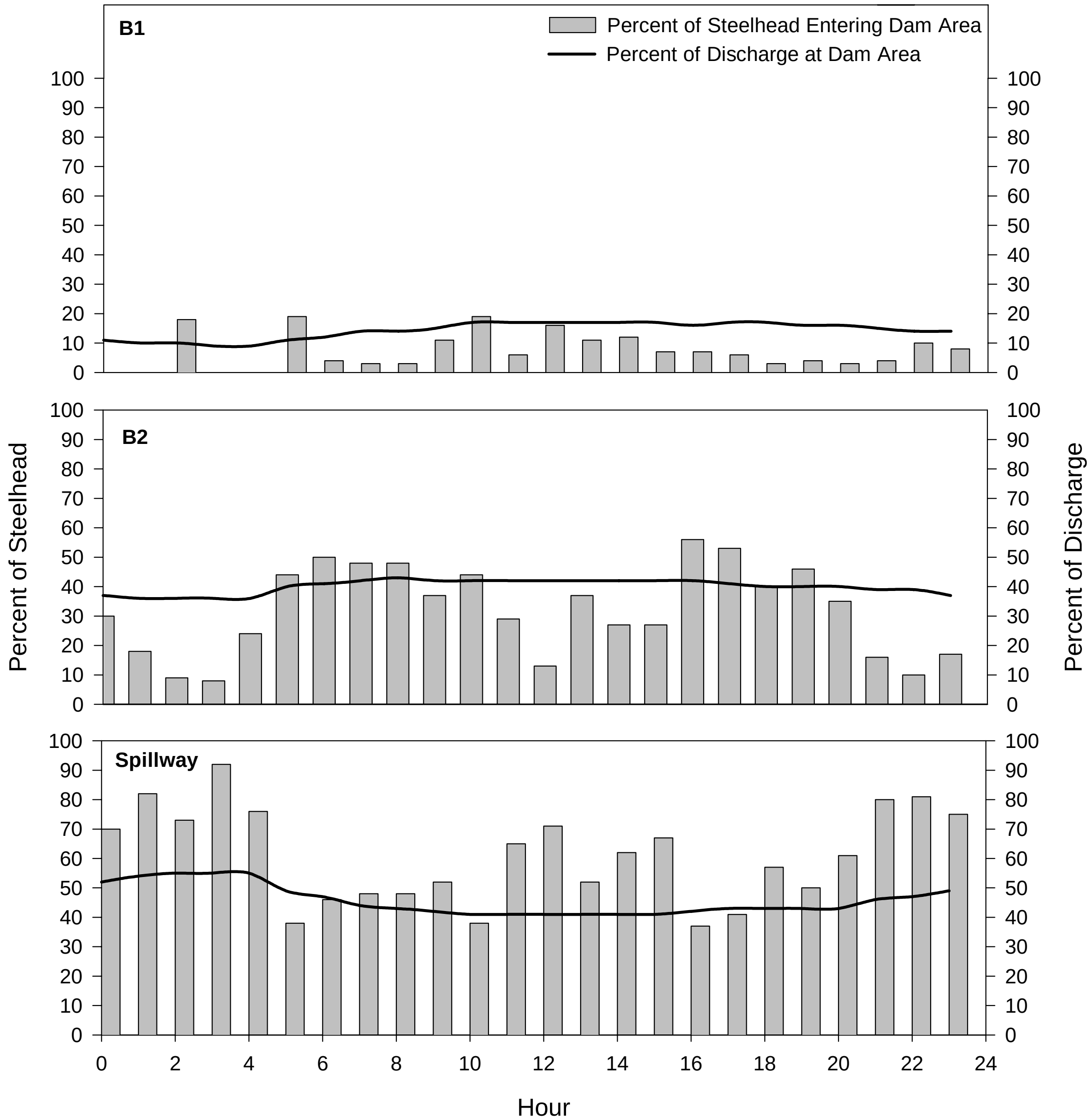

Figure 18. The percentage of yearling steelhead that entered each dam area versus the percentage of mean discharge, by hour, at each dam area during spring 2002.

3.4 Residence Time in the Forebay

Forebay residence time (time from first detection until time of passage) differed between dam areas. Yearling Chinook salmon resided considerably longer in the forebay of B1 (median = 2.5 h) than in the forebays of B2 (median = 1.3 h) or the spillway (median = 1.8 min). Forebay residence times for steelhead were also shortest at the spillway (median = 6.6 min) compared to residence times at B1 and B2 (Table 4). We compared median forebay residence time by day of passage, by hour of passage, and by hour of arrival to mean daily discharge and found no relation (Appendices 1-6).

Table 4. Descriptive statistics of forebay residence time (h) for radio-tagged yearling Chinook salmon and steelhead at Bonneville Dam during spring 2002. Powerhouse one = B1 and Powerhouse two = B2.

Species	Dam Area	*N*	Mean	Median	Min	Max
Chinook	B1	134	9.0	2.5	0.01	76.3
Chinook	B2	203	4.3	1.3	0.01	52.7
Chinook	Spillway	777	0.5	0.03	0.01	43.0
Chinook	All areas	1,114	2.2	0.05	0.01	76.3
Steelhead	B1	34	6.8	2.4	0.01	66.1
Steelhead	B2	151	4.3	2.0	0.01	27.2
Steelhead	Spillway	257	1.5	0.1	0.01	27.6
Steelhead	All areas	442	3.4	0.8	0.01	66.1

3.5 Route and Time of Passage through Bonneville Dam

We determined the route of passage through Bonneville Dam for 98% (1,941 of 1,980) of yearling Chinook salmon and 97% (592 of 610) of steelhead detected at Bonneville Dam. One percent (23 of 1,980) of Chinook salmon and 2% (11 of 610) of steelhead passed the dam but a passage route could not be determined. One percent (16 of 1,980) of Chinook salmon and 1% (9 of 610) of steelhead were not detected below Bonneville Dam. Among the three dam areas, the spillway passed the most fish (55-57%, depending on species), followed by B2 (35-39%) and B1 (6-8%; Figure 19). The distribution of passage among dam areas matched almost identically the distribution of approach (based on first detection of fish) among dam areas: 57% at the spillway, 34-36% at B2, and 7-9% at B1.

Passage of Chinook salmon at B1 was distributed relatively equally among the three main routes of passage (35% sluiceway, 30% guided, 30% unguided). The remaining 5% of Chinook salmon that passed at B1 passed via the navigation lock (4%; 6 of 156) and adult ladder (1%; 1 of 156) that flows from the B1 forebay to the B1 and spillway tailraces. An additional 19 Chinook salmon passed B1 through undetermined routes. Passage of Chinook salmon at B2 was not as equally distributed as at B1. Of the Chinook salmon with known passage routes at B2, 63% (423 of 674) passed unguided through the turbines and 37% (251 of 674) were guided into the DSM (Figure 19).

Project passage of steelhead peaked at sunset (2000-2100 hours) and was lowest just after sunrise (0500-0600 hours; Figure 20). No peaks in project passage were observed for Chinook salmon, although more Chinook salmon passed between 0000 and 1200 hours than between 1200 and 0000 hours. Diurnal passage distributions of Chinook salmon and steelhead were similar to overall passage distributions. During the day, more fish passed through the spillway (56-60%) than through B2 (33-34%) and B1 (7-10%). The same was true at night when 50-60% of fish passed through the spillway, 37-46% passed at B2, and 3-4% passed at B1 (Table 5). Upon comparison of the total number of fish that passed each dam area during day and night, we found that a higher number of fish passed during day (Table 5). This was true for both Chinook salmon and steelhead at all dam areas, the only exception being at B2 where 52% (118 of 229) of steelhead passed at night. However, since there was a difference in the number of hours in each diel period (16 for day, 8 for night), we also calculated passage rates (fish/hour) for each dam area and diel period. Passage rates for both species at the spillway and B2 were higher during the night compared to day and passage rates at B1 were higher during the day for Chinook salmon and about the same during day and night for steelhead (Table 6).

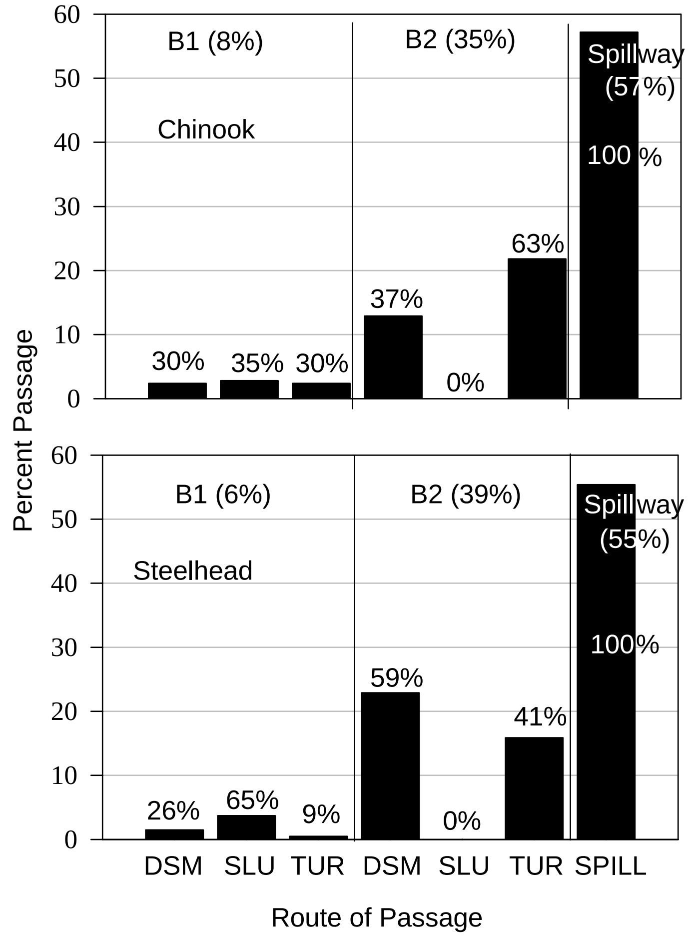

Figure 19. Percent fish passage by dam area and route of passage through Bonneville Dam for radio-tagged yearling Chinook salmon and steelhead during spring 2002. B1 = powerhouse one; B2 = powerhouse two; DSM = Downstream Migrant Channel; SLU = Sluiceway; TUR = Turbine. Note: percentages within parenthesis designate proportions among dam areas, percentages without parenthesis designate proportions within each dam area, and the percent value of each bar represents proportions of all routes at Bonneville Dam. For Chinook salmon at B1, an additional 4% passed via the Navigation Lock and an additional 1% passed from the B1 forebay to the spillway tailrace via the adult ladder.

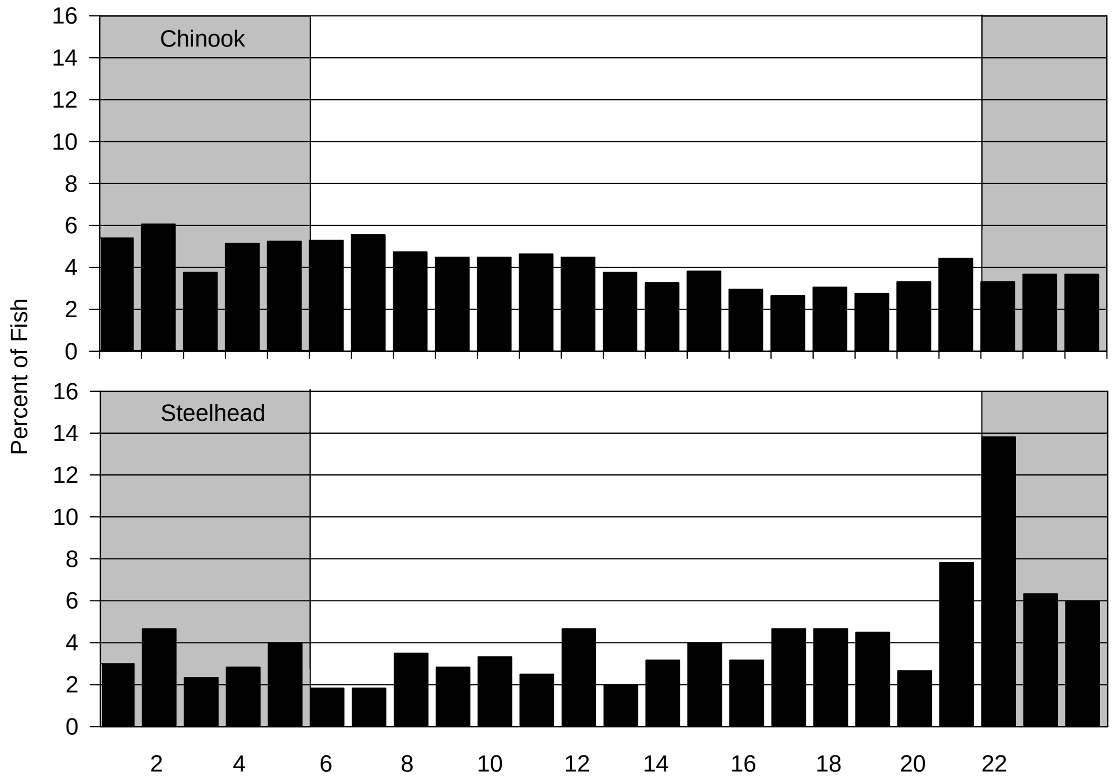

Figure 20. Percent passage by species during day (0500-2059 hours) and night (2100-0459 hours) for radio-tagged yearling Chinook salmon and steelhead at Bonneville Dam during spring 2002.

Table 5. The proportion of radio-tagged yearling Chinook salmon and steelhead that passed each dam area of Bonneville Dam during day (0500-2059 hours) and night (2100-0459 hours) during spring 2002. Percentages are based on total number of fish that passed during each diel period. Powerhouse one = B1 and Powerhouse two = B2.

Period	B1 Passage	B2 Passage	Spill Passage
	Chinook Salmon		
Day	10% (130 of 1248)	34% (421 of 1248)	56% (697 of 1248)
Night	3% (26 of 693)	37% (253 of 693)	60% (414 of 693)
	Steelhead		
Day	7% (24 of 336)	33% (111 of 336)	60% (201 of 336)
Night	4% (10 of 254)	46% (118 of 254)	50% (126 of 254)

Table 6. Passage rates for radio-tagged yearling Chinook salmon and steelhead at each dam area of Bonneville Dam during day (0500-2059 hours) and night (2100-0459 hours) during spring 2002. Powerhouse one = B1 and powerhouse two = B2.

Dam Area	Day	Night
	Chinook Salmon	
B1	$130\,\text{fish} \div (16\,\text{h/d} \times 39\text{d}) = 0.21\,\text{fish/h}$	$26\,\text{fish} \div (8\,\text{h/d} \times 39\text{d}) = 0.08\,\text{fish/h}$
B2	$421\,\text{fish} \div (16\,\text{h/d} \times 39\text{d}) = 0.67\,\text{fish/h}$	$253\,\text{fish} \div (8\,\text{h/d} \times 39\text{d}) = 0.81\,\text{fish/h}$
Spillway	$697\,\text{fish} \div (16\,\text{h/d} \times 39\text{d}) = 1.12\,\text{fish/h}$	$414\,\text{fish} \div (8\,\text{h/d} \times 39\text{d}) = 1.33\,\text{fish/h}$
	Steelhead	
B1	$24\,\text{fish} \div (16\,\text{h/d} \times 39\text{d}) = 0.04\,\text{fish/h}$	$10\,\text{fish} \div (8\,\text{h/d} \times 39\text{d}) = 0.03\,\text{fish/h}$
B2	$111\,\text{fish} \div (16\,\text{h/d} \times 39\text{d}) = 0.18\,\text{fish/h}$	$118\,\text{fish} \div (8\,\text{h/d} \times 39\text{d}) = 0.38\,\text{fish/h}$
Spillway	$201\,\text{fish} \div (16\,\text{h/d} \times 39\text{d}) = 0.32\,\text{fish/h}$	$126\,\text{fish} \div (8\,\text{h/d} \times 39\text{d}) = 0.40\,\text{fish/h}$

3.6 Passage Metrics

3.6.1 Spillway Efficiency

Spillway efficiency is the number of fish that passed through spill divided by the number of fish that passed through all routes at all dam areas (spill, B1, and B2). Overall, greater than half of both species passed through spill and of the three spill treatments, TDG Day spill was the most efficient, passing 63% of Chinook salmon and 70% of steelhead relative to all other passage routes (Table 7). Spillway efficiency varied significantly among spill treatments for both Chinook salmon ($X^2 = 56.96$, df = 2, $P < 0.001$) and steelhead ($X^2 = 47.21$, df = 2, $P < 0.001$). For Chinook salmon, the TDG Day spill treatment was significantly (Tukey test; q =10.35, df = 3, $P < 0.05$) greater than the Day Cap treatment but not the TDG Night treatment (Tukey test; q = 2.07, df = 3, $P < 0.05$). For steelhead, the TDG Day treatment was significantly greater than both the Day Cap (Tukey test; q = 9.25, df = 3, $P < 0.05$) and the TDG Night (Tukey test; q = 6.77, df = 3, $P < 0.05$) treatments.

Table 7. Spillway Efficiency at Bonneville Dam for yearling Chinook salmon and steelhead during spring 2002. Mean discharge spilled during each treatment is shown in parenthesis. SE = standard error of spillway efficiency estimate. Powerhouse one = B1 and Powerhouse two = B2.

Spill Treatment	Efficiency	SE	B1 Passage	B2 Passage	Spill Passage
Chinook Salmon					
Overall	0.57	1.1%	175	675	1111
Day Cap (57 kcfs)	0.42	2.3%	66	211	201
TDG Day (122 kcfs)	0.63	1.7%	79	211	496
TDG Night (125 kcfs)	0.59	1.9%	30	253	414
Steelhead					
Overall	0.55	2.0%	40	231	327
Day Cap (57 kcfs)	0.32	4.7%	17	50	31
TDG Day (122 kcfs)	0.70	2.9%	12	61	170
TDG Night (125 kcfs)	0.49	3.1%	11	120	126

3.6.2 Spillway Effectiveness

Spillway effectiveness is the proportion of fish that passed through spill relative to the proportion of discharge spilled. Chinook salmon had an overall spillway effectiveness of 1.2 and steelhead had an overall spillway effectiveness of 1.2 (Table 8). The most effective spill treatment for Chinook salmon was Day Cap (1.6) and the most effective spill treatment for steelhead was TDG Day (1.5).

Table 8. Spillway Effectiveness at Bonneville Dam for yearling Chinook salmon and steelhead during spring 2002. F_{sp} = mean spillway discharge (kcfs). F_{tot} = mean project discharge (kcfs).

Treatment	Spillway Effectiveness	Spillway Efficiency	F_{sp}	F_{tot}
Chinook Salmon				
Overall	1.2	0.57	112.0	244.8
Day Cap (57 kcfs)	1.6	0.42	57.1	214.2
TDG Day (122 kcfs)	1.3	0.63	122.4	256.7
TDG Night (125 kcfs)	1.2	0.59	125.4	244.1
Steelhead				
Overall	1.2	0.55	112.0	244.8
Day Cap	1.2	0.32	57.1	214.2
TDG Day	1.5	0.70	122.4	256.7
TDG Night	1.0	0.49	125.4	244.1

3.6.3 Fish Guidance Efficiency

Fish guidance efficiency (FGE: proportion of fish entering turbine intakes that were guided by turbine intake screens) was higher at B1 than at B2 for both species overall and during all spill treatments except for TDG Night for Chinook salmon (Table 9). Fish guidance efficiency was highest for steelhead at both powerhouses during the TDG Day treatment. The TDG Day treatment was also most efficient for Chinook salmon at B1, however at B2, FGE was higher during the TDG Night treatment. At B2, turbine unit 11 was the most efficient (44%) at guiding Chinook salmon and units 11, 14, and 17 were the most efficient (61-63%) at guiding steelhead (Table 10). About three-quarters of both species passed at the southern half of B2, at units 11-14 compared to the northern half, at units 15-18, and FGEs were generally higher for southern units (Table 10). At B1, sample sizes were too small for both Chinook salmon (N = 94) and steelhead (N = 12) to calculate FGE by unit.

Table 9. Estimates of Fish Guidance Efficiency (FGE) and corresponding standard error (SE) at Bonneville Dam's powerhouse one (B1) and powerhouse two (B2) for yearling Chinook salmon and steelhead during spring 2002.

Treatment	B1	SE	B2	SE
Chinook salmon				
Overall	50% (47 of 94)	5.2%	37% (251 of 674)	1.9%
Day Cap (57 kcfs)	50% (16 of 32)	9.0%	30% (63 of 210)	3.2%
TDG Day (122 kcfs)	58% (25 of 43)	7.6%	35% (74 of 210)	3.3%
TDG Night (125 kcfs)	32% (6 of 19)	11.0%	45% (114 of 254)	3.1%
Steelhead				
Overall	75% (9 of 12)	13.1%	59% (135 of 229)	3.3%
Day Cap (57 kcfs)	67% (2 of 3)	33.2%	50% (26 of 52)	7.0%
TDG Day (122 kcfs)	100% (3 of 3)	70.7%	63% (41 of 65)	6.0%
TDG Night (125 kcfs)	67% (4 of 6)	21.0%	61% (68 of 112)	4.6%

Table 10. Estimates of Fish Guidance Efficiency (FGE) by turbine unit at Bonneville's second powerhouse (B2) for radio-tagged yearling Chinook salmon and steelhead during spring 2002. These estimates do not include 20 unguided Chinook salmon, 42 guided Chinook salmon, 4 unguided steelhead, and 31 guided steelhead that passed through unknown units at B2.

Chinook Salmon							
11	12	13	14	15	16	17	18
44% (56 of 126)	35% (43 of 122)	34% (35 of 104)	35% (31 of 88)	30% (12 of 40)	27% (18 of 66)	20% (8 of 40)	23% (6 of 26)
Steelhead							
11	12	13	14	15	16	17	18
61% (22 of 36)	50% (17 of 34)	54% (25 of 46)	63% (20 of 32)	47% (7 of 15)	44% (8 of 18)	63% (5 of 8)	0% (0 of 5)

3.6.4 Fish Passage Efficiency

Fish passage efficiency (FPE: the proportion of fish that passed the dam via non-turbine routes) at Bonneville Dam was 76% (SE 1.0%) overall for Chinook salmon and 84% (SE 1.5%) overall for steelhead. FPE was highest during TDG spill levels for both species. FPE was 80% during both TDG Day (SE 1.4%) and TDG Night (SE 1.5%) for Chinook salmon, and FPE was highest for steelhead during TDG Day spill (90%, SE 1.9%; Table 11). Fish passage efficiency varied significantly among spill treatments for both Chinook salmon (X^2 = 37.19, df = 2, P < 0.001) and steelhead (X^2 = 18.34, df = 2, P < 0.001). For Chinook salmon, FPE during the TDG Day spill treatment was significantly (Tukey test; q =5.62, df = 3, P < 0.05) greater than during Day Cap spill but not during TDG Night spill (Tukey test; q = 1.07, df = 3, P < 0.05). Likewise, for steelhead, FPE during the TDG Day spill treatment was significantly greater than during Day Cap spill (Tukey test; q = 3.52, df = 3, P < 0.05) but not during TDG Night spill (Tukey test; q=3.05, df = 3, P < 0.05).

Table 11. Fish passage efficiency (FPE) at Bonneville Dam for radio-tagged yearling Chinook salmon and steelhead during spring 2002. Numbers shown that were used to calculate FPE do not include six Chinook salmon that passed through the navlock and one Chinook salmon that passed through the adult ladder at B1. However, those fish were included in calculations of FPE. Powerhouse one = B1 and Powerhouse two = B2.

Treatment	FPE	B1 Guided	B1 Sluiceway	B2 Guided	Spillway	B1 Unguided	B2 Unguided
Chinook Salmon							
Overall	0.76	47	55	251	1111	47	423
Day Cap	0.65	16	27	63	201	16	147
TDG Day	0.80	25	21	74	496	18	136
TDG Night	0.80	6	7	114	414	13	140
Steelhead							
Overall	0.84	9	22	135	327	3	94
Day Cap	0.71	2	10	26	31	1	26
TDG Day	0.90	3	8	41	170	0	24
TDG Night	0.82	4	4	68	126	2	44

3.7 Comparison of Passage Performance Metrics as Measured by Radio Telemetry and Hydroacoustics

In addition to the radio telemetry evaluation we conducted, Pacific Northwest National Laboratory (PNNL) and MEVATEC Corporation used fixed hydroacoustics to monitor fish passage and estimate passage performance metrics for the run-at-large. Although the spring monitoring period started earlier for hydroacoustics than it did for radio telemetry, passage metrics were calculated for each research tool using data from overlapping time periods (May 2–June 9) to facilitate comparison of the two techniques. Radio telemetry data for yearling Chinook salmon and steelhead were combined to compare with run-of-river hydroacoustic data. Differences in passage performance metrics, as estimated by radio telemetry and hydroacoustics, ranged from 0-16%. Fish passage efficiency was 78% for both methods and estimates of sluiceway$_{project}$ and spillway efficiency were within 5% and 6%, respectively (Table 12). Estimates of FGE by unit at B2 were closest for the southern units and differed considerably at the northern units (Table 13). Although sample sizes for radio-telemetry estimates of FGE by unit were relatively small compared to those for hydroacoustics, standard errors of radio telemetry estimates for FGE by unit ranged from only 3.9-7.2%.

Table 12. Comparison of passage performance metrics for yearling Chinook salmon and steelhead combined, as measured by radio telemetry (RT), and the run-at-large, as measured by hydroacoustics (HA), at Bonneville Dam during spring (overlapping period of May 2-June 9) 2002. Powerhouse one = B1 and Powerhouse two = B2. Hydroacoustic data were provided by Carl Schilt, MEVATEC Corporation (March 18, 2003; revised July 19,2006).

Passage Metric	RT estimate	HA estimate	Difference
Spillway efficiency	56%	53%	3% (RT > HA)
Spillway effectiveness	1.2	1.1	0.1 (RT > HA)
Sluiceway $efficiency_{B1}$	41%	33%	8% (RT > HA)
Sluiceway $effectiveness_{B1}$	21.4	17.2	4.2 (RT > HA)
Sluiceway $efficiency_{Project}$	3%	7	4% (RT < HA)
Sluiceway $effectiveness_{Project}$	11.2	25.9	14.7 (RT < HA)
FGE_{B1}	53%	38%	15% (RT > HA)
FGE_{B2}	43%	53%	10% (RT < HA)
FPE	78%	79%	1% (RT < HA)
FPE_{B1}	74%	58%	16% (RT > HA)
FPE_{B2}[a]	43%	53%	10% (RT < HA)

[a]FPE_{B2} = FGE_{B2} since no fish could pass through closed sluice chute at B2.

Table 13. Estimates of Fish Guidance Efficiency (FGE), by turbine unit, at Bonneville's second powerhouse (B2) for yearling Chinook salmon and steelhead combined, as measured by radio telemetry (RT), and for the run-at-large, as measured by hydroacoustics (HA), during spring (overlapping period of May 2- June 9) 2002. Hydroacoustic data were provided by Carl Schilt, MEVATEC Corporation (March 18, 2003).

Location	RT FGE	HA FGE	Difference
Unit 11	48%	43%	5% (RT > HA)
Unit 12	38%	46%	8% (RT < HA)
Unit 13	40%	59%	19% (RT < HA)
Unit 14	42%	63%	21% (RT < HA)
Unit 15	34%	67%	33% (RT < HA)
Unit 16	31%	56%	25% (RT < HA)
Unit 17	27%	66%	39% (RT < HA)
Unit 18	19%	44%	25% (RT < HA)

3.8 Residence Times at Areas of Potential Delay

Several areas at Bonneville Dam were monitored for the first time in 2002 to determine if they caused delay in the downstream migration of juvenile salmonids. We monitored the down-well area of the B1 DSM, the taillog slots at both B1 and B2, the eddy located just downstream of Cascades Island, and the B2 juvenile bypass system(JBS) conveyance pipe. The B1 down-well is an elevator shaft-like area at the downstream end of the DSM and is the point at which fish must descend (about 25 feet) to reach a pipe that transports them to the B1 tailrace (Figure 21). Of the 47 yearling Chinook salmon and nine steelhead that were guided into the B1 DSM, we detected 46 Chinook salmon and all nine steelhead in the down-well. Chinook salmon resided in the down-well for a median 47.9 s (range, 14.0 s - 7.9 min) and steelhead resided a median 2.2 min in the down-well (range, 42.1 s - 13.1 min). Based on these median residence times, neither yearling Chinook salmon or steelhead were substantially delayed within the B1 DSM down-well.

The taillog slots at both powerhouses are located above and are open to the turbine draft tubes thereby potentially enabling fish to enter and hold within the slots (Figure 22). At B1, of the 47 yearling Chinook salmon and three steelhead that passed through the turbines unguided, we detected 20 (43%) Chinook salmon and one (33%) steelhead at the taillog slot antennas. Of those fish detected at the B1 taillog slots, only six Chinook salmon and no steelhead were detected more than once. Chinook salmon had a median residence time at the B1 taillog slots of 18 s (range, 4 s - 3.1 h) and since no steelhead were detected more than once, a residence time could not be calculated. At B2, of the 423 yearling Chinook salmon and 94 steelhead that passed through the turbines unguided, we detected 49 (12%) Chinook salmon and 24 (26%) steelhead at the taillog slot antennas. Of those fish detected at the B2 taillog slots, only 35 Chinook salmon and 16 steelhead were detected more than once. Chinook salmon had a median residence time at the B2 taillog slots of 18 s (range, 4 s - 4.6 min) and steelhead had a median residence time of 32 s (range, 4 s - 14.6 min). Therefore, neither yearling Chinook salmon or steelhead were delayed within the stoplog slots of B1 or B2.

The Cascades Island eddy lies at the confluence of the B2 and spillway tailraces and is therefore a potential source of delay for fish passing unguided through the B2 turbines or through the spillway (Figure 23). Furthermore, the eddy is very near the area that has been selected for placement of the B2 corner collector outfall, scheduled to become operational in 2004. Of the 1,534 yearling Chinook salmon that passed through the spillway and B2 turbines unguided, 88 (5.7%) were detected at the Cascades Island eddy for a median 30 s. The residence times of Chinook salmon ranged from 4 s to 105.7 h, however, only four fish resided between 2.8 h and 105.7 h with the remainder residing between 4 s and 21.6 min. Of the 421 steelhead that passed through the spillway and B2 turbines unguided, 34 (8.0%) were detected at the Cascades Island eddy for a median 1.4 min. The residence times of steelhead ranged from 4 s to 12.2 h, however, only two fish resided longer than 1 h. Based on the number of fish detected at the eddy, 4.5% of yearling Chinook salmon and 5.9% of steelhead were delayed for longer than 1 h. However, based on the number of fish that passed at the spillway and the B2 turbines unguided and had the potential to enter the eddy area, only 0.3% of Chinook salmon and 0.5% of steelhead were delayed longer than 1 h at the Cascades Island eddy.

The B2 JBS conveyance pipe was shown to transport juvenile salmonids rather quickly in 1999-2001 (Holmberg et al. 2001a, 2001b; Evans et al. 2001a, 2001b). Travel times of juvenile salmonids through the conveyance pipe were monitored again in 2002. According to new survey data gathered early in 2002, the pipe had become out-of-round (exceeded the maximum allowable ovality of 8.5%) in two locations and there was concern that these areas may cause delay in travel times of fish. The median travel time of guided fish through the B2 JBS conveyance pipe in 2002 was slightly less than travel times through the pipe in 1999-2001, indicating that fish were not delayed in the pipe (Table 14).

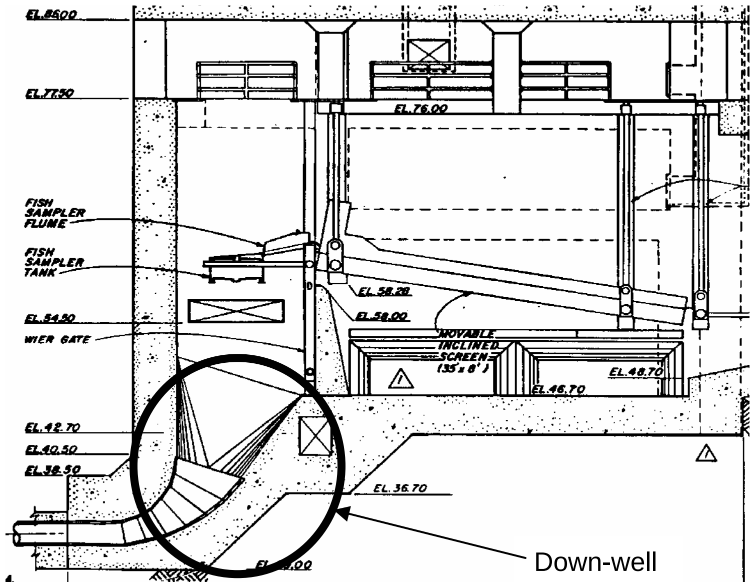

Figure 21. Cross-sectional view of the fish sampler and down-well area (circled) located at the downstream end of the downstream salmonid migrants channel (DSM) at Bonneville Dam's first powerhouse. Image source: U.S. Army Corps of Engineers.

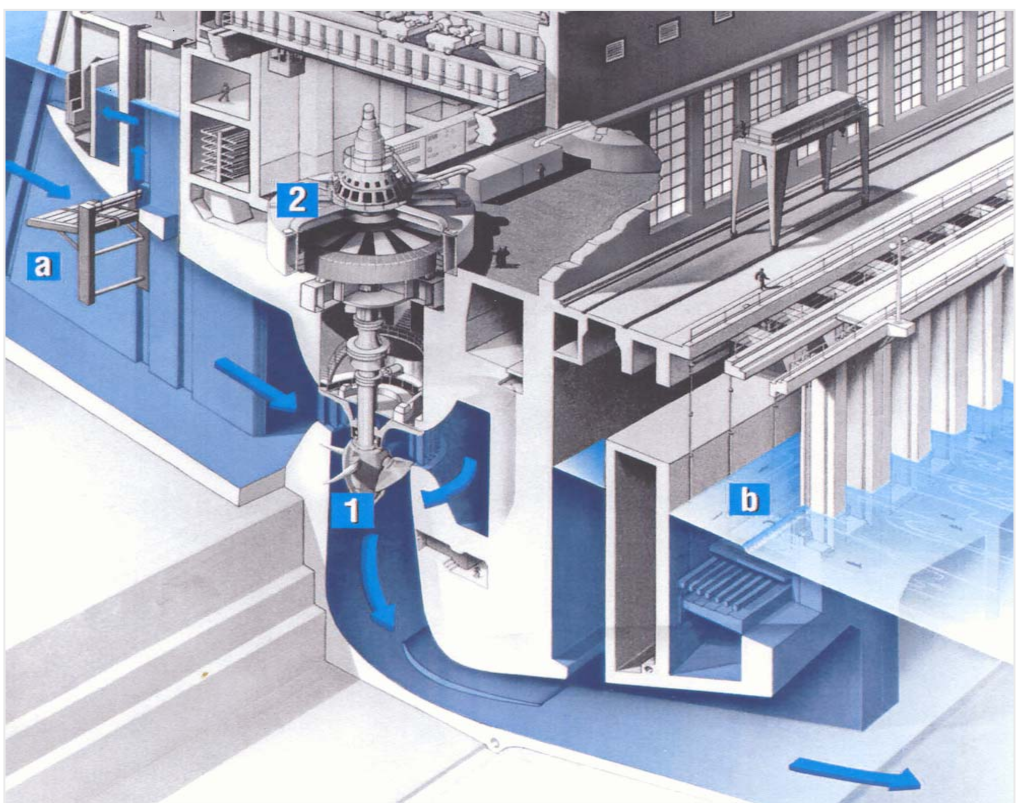

Figure 22. Cross-sectional view of Bonneville Dam's first powerhouse (B1) showing the taillog slots. The taillog slots at the second powerhouse are similar to those at B1. Image source: U.S. Army Corps of Engineers.

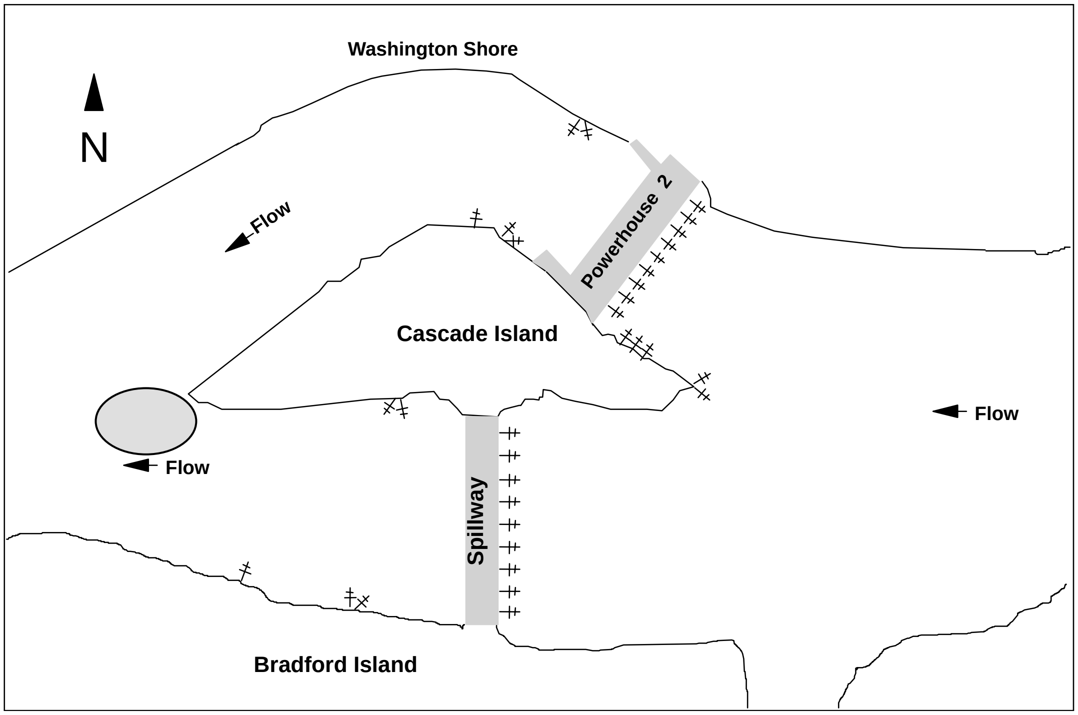

Figure 23. Plan view of Cascades Island Eddy (represented by oval) at Bonneville Dam during spring 2002.

Table 14. Median travel times (minutes) for yearling Chinook salmon and steelhead passing through Bonneville Dam's second powerhouse juvenile bypass system conveyance pipe during spring study periods of 1999-2002.

	1999	2000	2001	2002
Chinook salmon	50.3[a]	41.3	37.9	37.0
Steelhead	56.6[a]	47.7	No data	38.2

[a]Residence times in 1999 were based on travel from the top of the pipe to the outfall. Residence times in 2000-2002 were based on travel from the top of the pipe to the fish sampling facility, which was not yet completed in 1999.

4.0 Discussion

The proportion of discharge at each dam area was likely the determining factor for which forebay fish entered. Based on our analysis of percent discharge per dam area by day related to percent of fish that entered each dam area, fish appeared to follow the bulk flow, entering the dam area with the highest proportion of discharge. Since the spillway discharged the most amount of water during the study (46%), most fish entered the spillway forebay (57% of both Chinook salmon and steelhead). Likewise, since flows were lowest at B1 (14% of project discharge), only 9% of Chinook salmon and 7% of steelhead entered that dam area.

Forebay residence times were similarly affected by discharge. Both Chinook salmon and steelhead spent the least amount of time (1.8 min and 6.6 min, respectively) in the forebay of the spillway, the structure with the highest project discharge. Residence times were longest in the forebay of B1, which had the lowest project discharge. No relation was apparent between daily discharge patterns, hour of arrival, or hour of passage and residence time. Therefore, total discharge per dam area seemed to be the primary factor affecting residence times of yearling Chinook salmon and yearling steelhead. These observations indicate that project operations and the resulting discharge per dam area influence approach paths of migrating yearling Chinook salmon and steelhead and may determine which dam area smolts enter. Likewise, discharge per dam area affected how long fish resided in the forebay of Bonneville Dam before passing.

At B1, the proportions of radio-tagged fish that passed through specific routes indicated that fish were generally shallow in the water column. The greatest percentage of both species (35% of Chinook salmon and 65% of steelhead) passed through the shallow, weir-type entrances of the sluiceway, followed by the deeper guided (30% of Chinook salmon and 26% of steelhead) and unguided (30% of Chinook salmon and 9% of steelhead) routes of passage. At B2, where a shallow, surface-oriented route of passage was unavailable because of the closure of the sluice chute, more Chinook salmon passed directly through the turbines (63%) than were guided into the DSM (37%). However, slightly more steelhead were guided into the DSM (59%) than passed unguided through the turbines (41%).

Diurnal passage distributions did not appear to be influenced by discharge, which were nearly equal during day and night at all dam areas. The higher passage rates of fish at night (based on the number of hours in each diel period) at B2 and the spillway concur with the findings of numerous studies regarding juvenile salmonid behavior at hydroelectric projects. Coutant and Whitney (2000) reported in a review of literature on fish behavior relative to passage of fish through hydropower turbines, that emigrating salmonids descend, mostly at night, to pass the dam through the turbines or turbine intake bypass system. The shallow sluiceway at B1, combined with relatively low turbine discharge, provided an effective surface–oriented route of passage and was likely the determining factor in the higher passage rates for both Chinook salmon and steelhead during the day at this powerhouse. Surface-oriented passage of juvenile salmonids has been shown to increase during the day at Bonneville Dam (Willis and Uremovich 1981; Magne et al.1987; Evans et al. 2001a) as well as at other Columbia River Basin projects (Nichols et al. 1978; Raymond and Sims 1980; Ransom and Ouellette 1991).

Passage metrics for yearling Chinook salmon were higher in 2002 than in 2001. All passage metrics, except FPE_{B1} and FGE_{B2} (and therefore FPE_{B2}), were very similar to passage metrics in 2000 (Table 15). Spillway efficiency and FPE were lower in 2001, largely because of low river flows. Very little water was available for spill in 2001 and that resulted in minimal spill and very low spill efficiency and, therefore, low FPE. Despite low flows, fish passage efficiency at B1 in 2001 was 18 % greater than in 2002 and 22% greater than in 2000. Fish passage efficiency at B1 was higher in 2001 because a large proportion of smolts entered the sluiceway. We believe the cause of high sluiceway passage in 2001 was due to very low turbine operation at B1, which entrained less fish and made them available to the surface-oriented sluiceway. No steelhead were tagged in 2001 so no comparisons could be made for this species and year. However, comparison of passage metrics for steelhead between 2002 and 2000 shows that, unlike for Chinook salmon, most efficiencies were greater in 2002. In general, this may be attributable to the natural tendency of steelhead to migrate shallower in the water column than Chinook salmon, enabling steelhead to use shallower, non-turbine passage routes to a greater extent than Chinook salmon. Our results indicate that although the current intake screen guidance systems at both B1 and B2 have relatively poor guidance efficiency, the project FPE goal of 80% can be attained if sufficient numbers of fish are passed via a combination of non-turbine routes (spill, sluice, and turbine guidance systems).

Table 15. Passage performance metrics for radio-tagged yearling Chinook salmon and steelhead at Bonneville Dam during spring 2000, spring 2001, and spring 2002.

	Chinook Salmon			Steelhead		
Metric	2000	2001	2002	2000	2001	2002
Spillway Efficiency	44%	16%	57%	33%	No Data	55%
Spillway Effectiveness	1.3	0.7	1.2	1.0	No Data	1.2
FGE_{B1}	50%	45%	50%	59%	No Data	75%
FGE_{B2}	39%	46%	37%	55%	No Data	59%
FPE	73%	56%	76%	78%	No Data	84%
FPE_{B1}	65%	87%	69%	77%	No Data	91%
FPE_{B2}	40%	46%	37%	55%	No Data	59%

The comparison of our estimates of passage metrics with those obtained with hydroacoustics demonstrates the importance of having more than one independent estimate of passage performance. Although each research tool has its strengths, each tool also has its weaknesses. Radio telemetry is useful because it enables the investigator to obtain information on a species-specific basis and it has a relatively wide range of spatial resolution in terms of coverage area. However, radio telemetry sample size is often restricted by costs of tags and the number of radio-tagged fish that can be tracked concurrently. Hydroacoustic sampling is an effective means of obtaining information on numerous fish, but deciphering fish species or obtaining information on individual fish is not currently possible. Therefore it can be advantageous to use both technologies to overcome the limitations of each method. We do not have a clear explanation of why differences in passage metric estimates for radio telemetry and hydroacoustics were, in some instances, so great (up to 39%). The smaller sample sizes used by radio telemetry may have contributed to these differences. However, standard errors for radio telemetry estimates were usually under 7%. Equally plausible is that, because hydroacoustics sampled the run-at-large, passage estimates may have been based on a mixture of species with different passage behavior than yearling Chinook salmon or steelhead.

5.0 Acknowledgements

We thank Blaine Ebberts, Rock Peters, Jennifer Sturgill, and other U.S. Army Corps of Engineers personnel for their efforts in managing our contract and assisting in planning and executing this research. Many thanks go to Dean Ballinger, Bruce Mills, John Barton, and Rick Martinson at the Pacific States Marine Fisheries Commission for their assistance in collecting fish for this study. We would also like to thank Gene Ploskey and Carl Schilt for providing hydroacoustic data and information that enabled our comparison of radio telemetry and hydroacoustic results. We thank Steven Atwood, John Crain, Jonathan Entin, Katherine Felton, Cindy French-Lescaleet, Norm Hale, Hal Hansel, Bret Jensen, John Kraut, Tyler Mitchell, Russell Newman, Annette Peterson, and all of our colleagues at the USGS Columbia River Research Laboratory who assisted with field operations, data analysis, and administrative support throughout the study.

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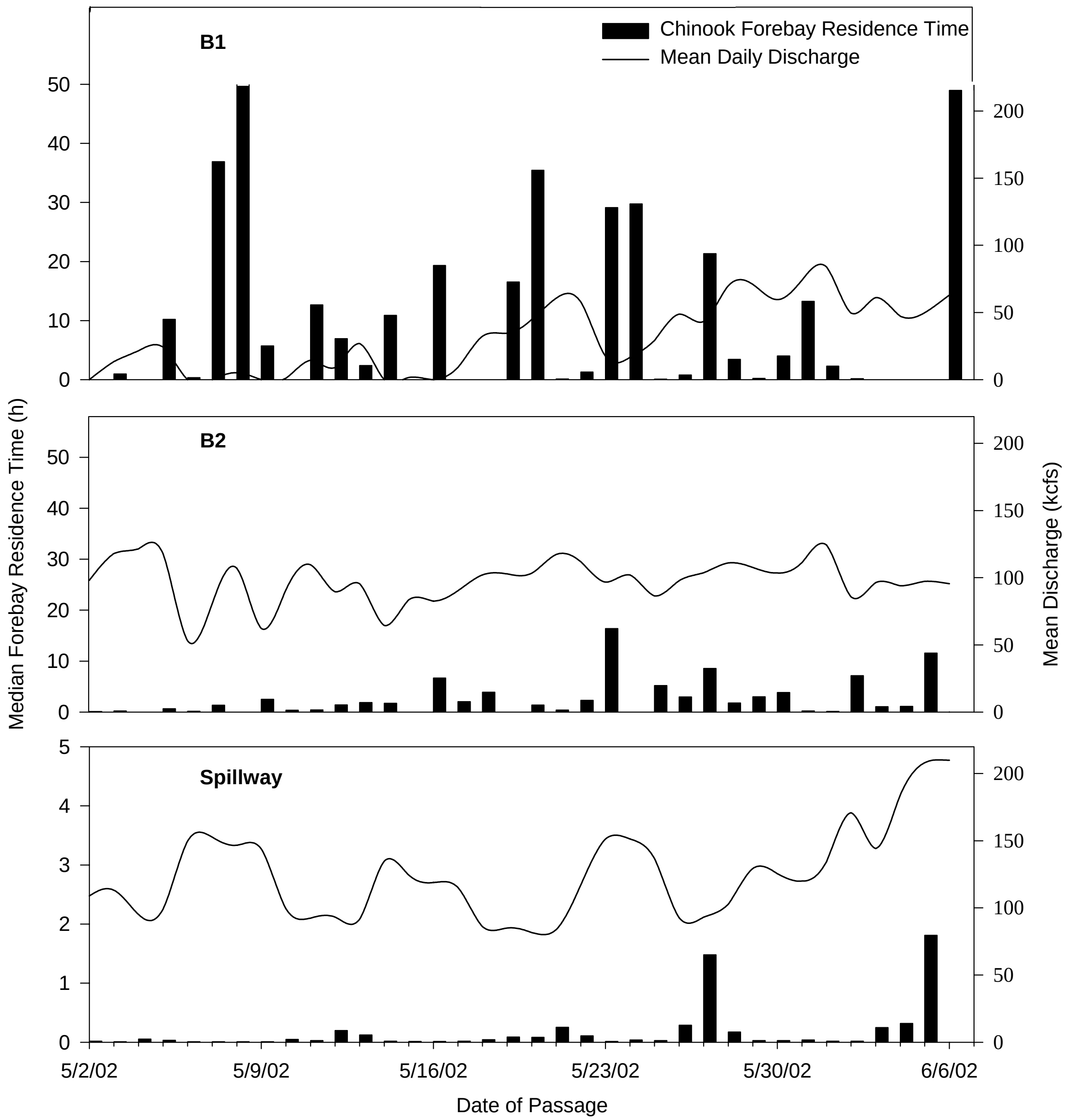
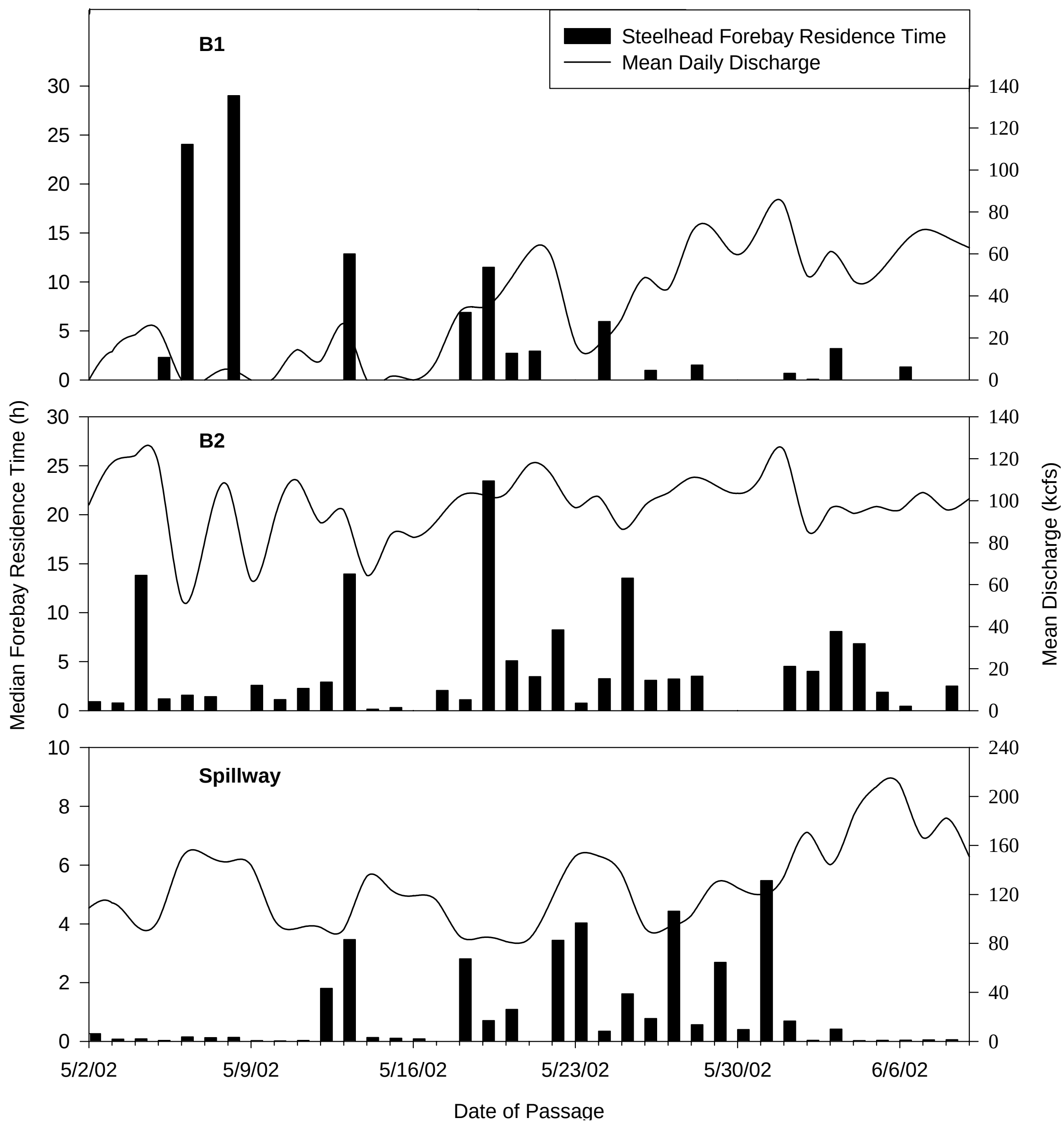
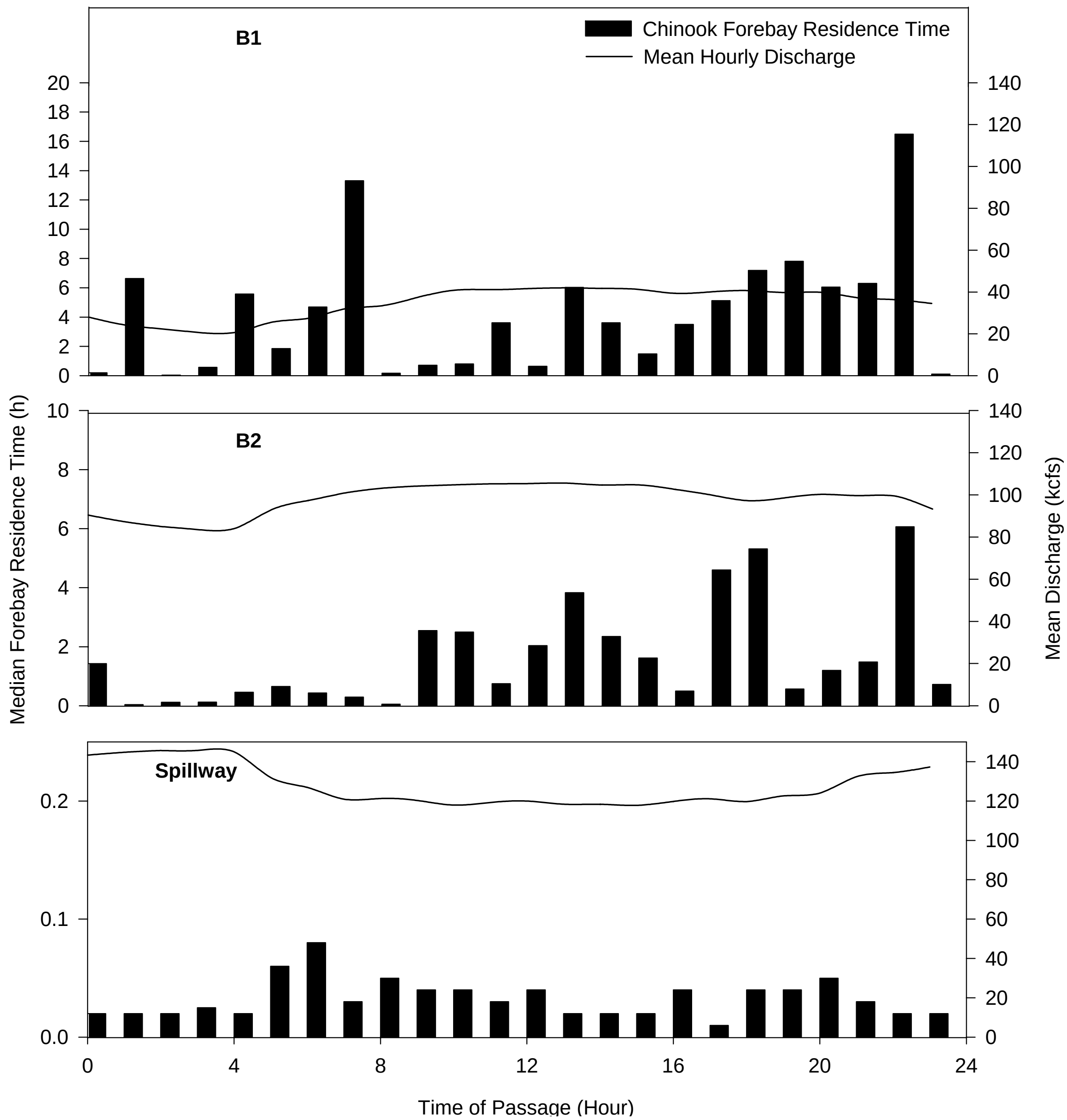
7.0 Appendices



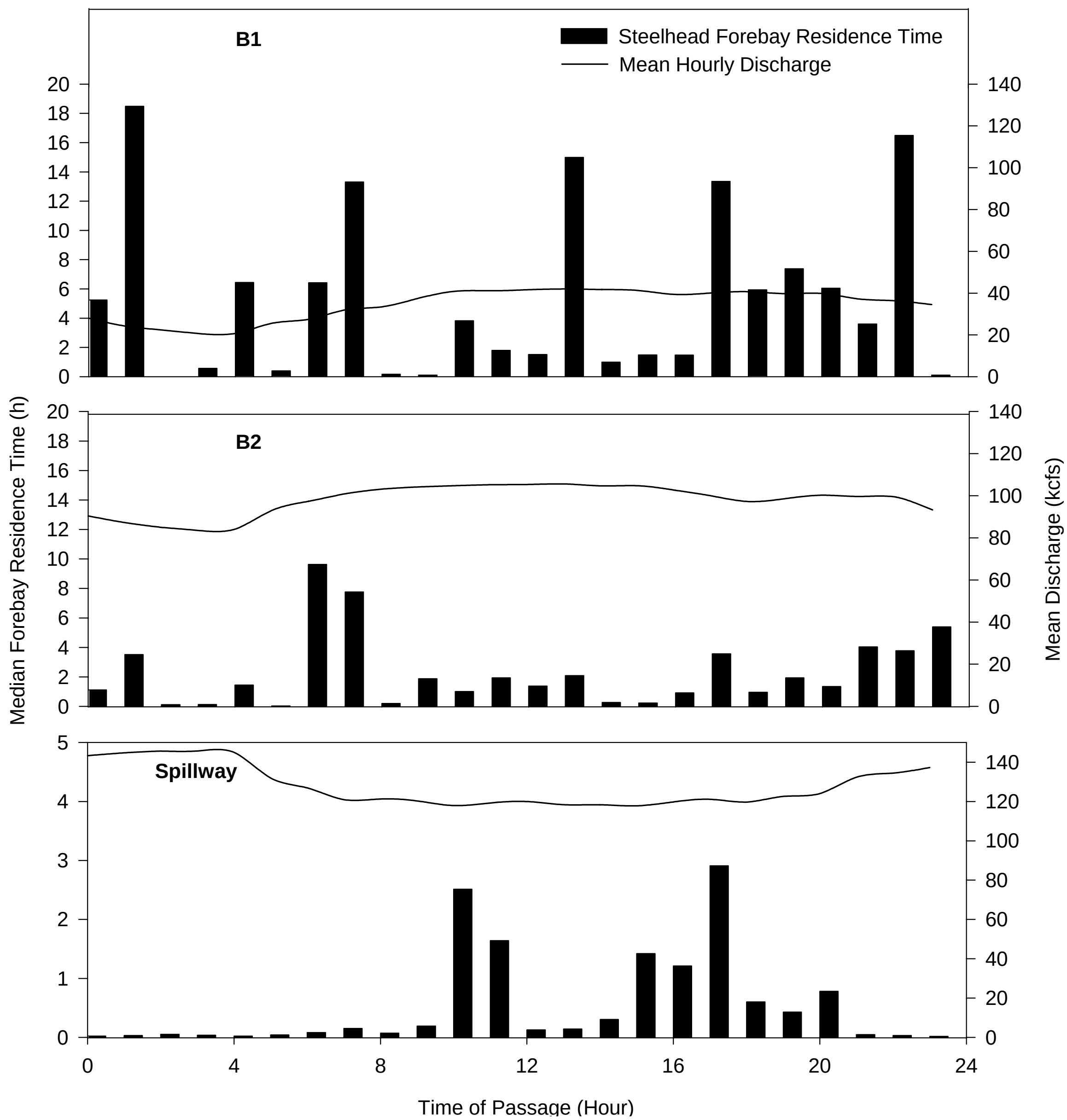
Appendix 1. Median forebay residence time by day of passage versus mean discharge by dam area for radio-tagged yearling Chinook salmon at Bonneville Dam, spring 2002. Scale of y-axis for spillway graph differs from graphs for B1 and B2 for visual clarity of residence time data.



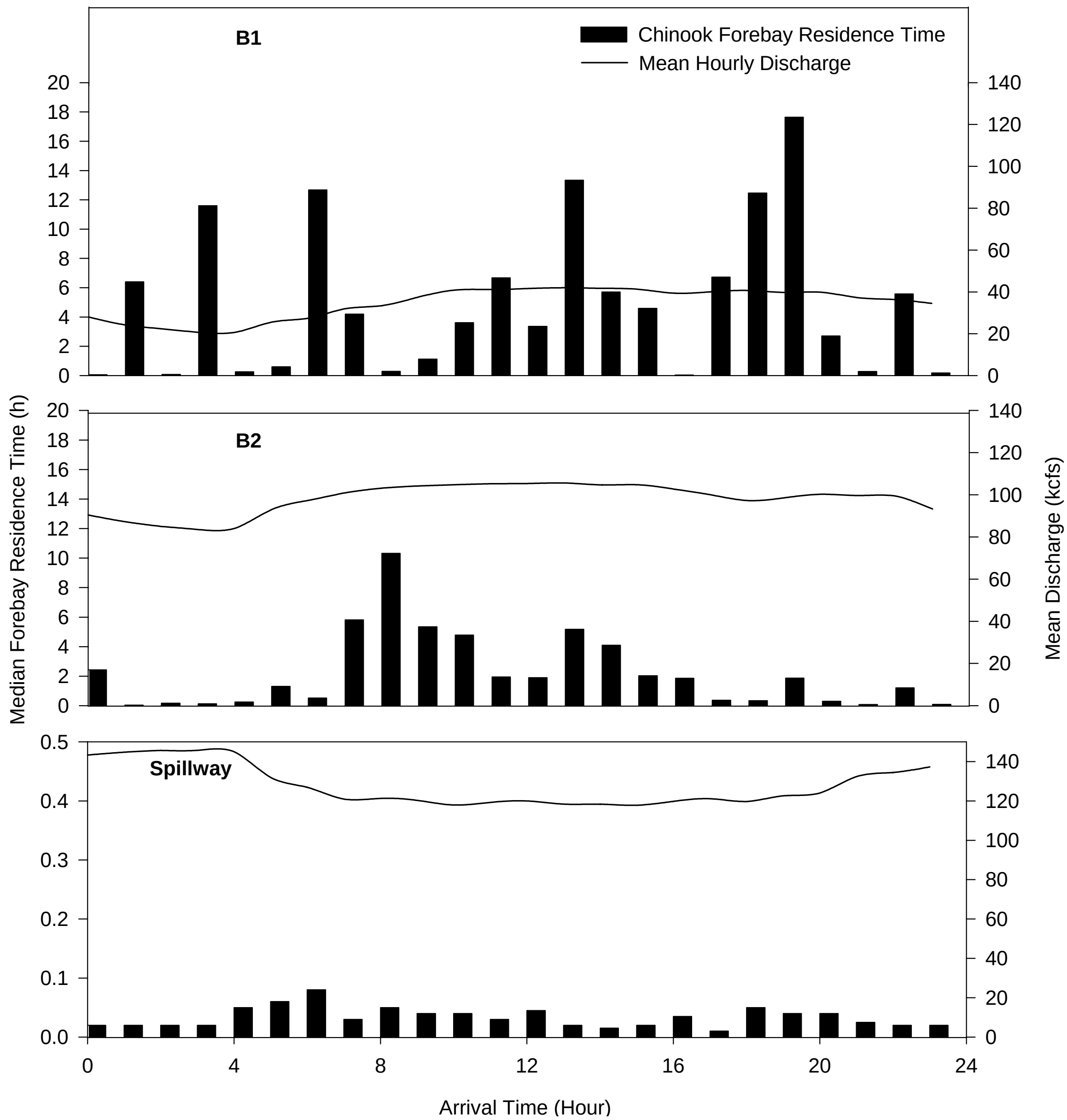
Appendix 2. Median forebay residence time by day of passage versus mean discharge by dam area for radio-tagged yearling steelhead at Bonneville Dam, spring 2002. Scale of y-axis for spillway graph differs from graphs for B1 and B2 for visual clarity of residence time data.



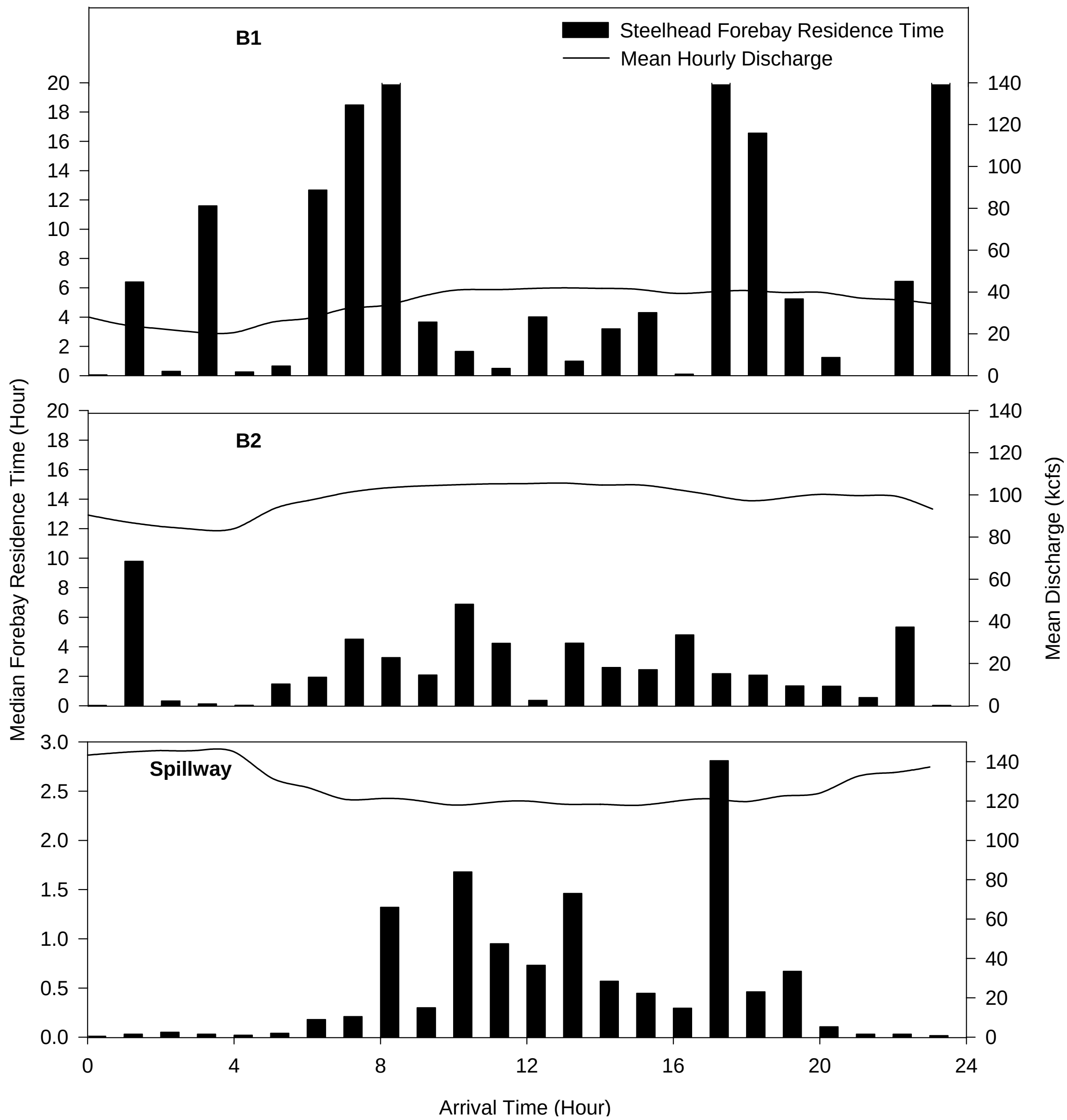
Appendix 3. Median forebay residence time by hour of passage versus mean discharge by dam area for radio-tagged yearling Chinook salmon at Bonneville Dam during spring 2002. Y-axis scale for all graphs differ for visual clarity of residence time data.



Appendix 4. Median forebay residence time by hour of passage versus mean discharge by dam area for radio-tagged yearling steelhead at Bonneville Dam during spring 2002. Scale of y-axis for spillway graph differs from graphs for B1 and B2 for visual clarity of residence time data.



Appendix 5. Median forebay residence time by hour of arrival versus mean discharge by dam area for radio-tagged yearling Chinook salmon at Bonneville Dam during spring 2002. Scale of y-axis for spillway graph differs from graphs for B1 and B2 for visual clarity of residence time data.



Appendix 6. Median forebay residence time by hour of arrival versus mean discharge by dam area for radio-tagged yearling steelhead at Bonneville Dam during spring 2002. Scale of y-axis for spillway graph differs from graphs for B1 and B2 for visual clarity of residence time data.

U.S. Army Corps of Engineers
Portland District

ADDENDUM 1

To

Passage Behavior of Radio-Tagged Yearling
Chinook Salmon and Steelhead at Bonneville Dam, 2002
Revised for Corrected Spill

Prepared by:

Scott D. Evans, Lisa S. Wright, Collin D. Smith, Rachel E. Wardell,
Noah S. Adams, and Dennis W. Rondorf
U.S. Geological Survey
Columbia River Research Laboratory
5501 A Cook-Underwood Road
Cook, Washington 98605

Submitted to:

U.S. Army Corps of Engineers
Portland District
Planning and Engineering Division
Environmental Resources Branch
Robert Duncan Plaza
333 S.W. 1st. Avenue
Portland, Oregon 97204-3495

Contract No. W66QKZ20303685

Submitted:

Final Report: November 12, 2003
Revised: July 20, 2006
Addendum1: October 4, 2005
Revised: July 20, 2006

This addendum is issued in response to a request for additional information regarding radio-telemetry data collected and reported on juvenile salmonids at Bonneville Dam during spring 2002. The annual report titled “Passage Behavior of Radio-Tagged Yearling Chinook Salmon and Steelhead at Bonneville Dam, 2002” submitted 12 November 2003, presented fish passage efficiencies with respect to three spill treatments: 1) Day Cap, 2) TDG Day, and 3) TDG Night. As defined on page 9 of the report, the Day Cap treatment consisted of 57 kcfs spill during the day, the TDG Day treatment consisted of spill to the 120% total dissolved gas (TDG) cap during the day, and the TDG Night treatment consisted of spill to the 120% TDG cap at night. However, the U.S. Army Corps of Engineers defined two spill treatments for 2002: 1) 57 kcfs and 2) TDG Cap. The 57 kcfs treatment block consisted of 57 kcfs spill during the day and spill to the 120% TDG cap at night. The TDG Cap treatment block consisted of spill to the 120% TDG cap during day and night. We used three spill treatments for analysis in the report because under the two-treatment plan of 57 kcfs and TDG Cap, spill to the TDG cap during the night was confounded between the two treatments. Since other variables may have affected passage efficiencies in the context of the two-treatment spill plan, we have calculated passage metrics for the two treatments: 57 kcfs and TDG Cap (Tables 1-4). We found that spillway efficiency was significantly higher for both yearling Chinook salmon (X^2 = 65.5, df = 1, P < 0.0001) and steelhead (X^2 = 42.5, df = 1, P < 0.0001) during the TDG Cap spill treatment compared to the 57 kcfs spill treatment (Table 1). Similarly, fish passage efficiency (FPE) relative to the project was significantly higher for both species (yearling Chinook salmon: X^2 = 27.2, df = 1, P < 0.0001; steelhead: X^2 = 16.5, df = 1, P < 0.0001) during the TDG Cap spill treatment (Table 3). We found no significant difference between spill treatments for either species for fish guidance efficiency (FGE) at either powerhouse (Table 4).

Diel passage data was reported on page 21 (Figure 20) of the final report for each species passing the project but not for specific routes of passage or for spill treatments. Graphics depicting hourly passage percentages by passage route and by spill treatment are provided in Figures 1-24 of this addendum. Specific numbers of fish that passed each hour are included on the figures.

Another diel presentation was reported on page 21 (Table 5) of the final report that described day and night passage proportions of fish among the three dam areas at the Bonneville project. Those proportions were based on the total number of fish that passed during each diel period. We were asked to provide a similar table, for each spill treatment, that compares day and night passage proportions but that is based on the total number of fish that passed each dam area. Those results are presented in Tables 5-7 of this addendum.

Table 1. Spillway Efficiency at Bonneville Dam for yearling Chinook salmon and steelhead during spring 2002. Mean discharge spilled during each treatment is shown in parenthesis. SE = standard error of spillway efficiency estimate. Powerhouse one = B1 and Powerhouse two = B2.

Spill Treatment	Efficiency	SE	B1 Passage	B2 Passage	Spill Passage
Chinook Salmon					
Overall	0.57	1.1%	175	675	1111
57 kcfs (80 kcfs)	0.46	1.7%	91	352	377
TDG Cap (128 kcfs)	0.64	1.4%	84	323	734
Steelhead					
Overall	0.55	2.0%	40	231	327
57 kcfs (80 kcfs)	0.37	3.3%	22	114	80
TDG Cap (128 kcfs)	0.65	2.4%	18	117	247

Table 2. Spillway Effectiveness at Bonneville Dam for yearling Chinook salmon and steelhead during spring 2002. F_{sp} = mean spillway discharge (kcfs). F_{tot} = mean project discharge (kcfs).

Treatment	Spillway Effectiveness	Spillway Efficiency	F_{sp}	F_{tot}
Chinook Salmon				
Overall	1.2	0.57	127.9	260.9
57 kcfs	1.2	0.46	97.8	232.0
TDG Cap	1.3	0.64	143.4	270.8
Steelhead				
Overall	1.1	0.55	127.9	260.9
57 kcfs	1.0	0.37	97.8	232.0
TDG Cap	1.3	0.65	143.4	270.8

Table 3. Fish passage efficiency (FPE) at Bonneville Dam for radio-tagged yearling Chinook salmon and steelhead during spring 2002. Numbers shown that were used to calculate FPE do not include six Chinook salmon that passed through the navigation lock and one Chinook salmon that passed through the adult ladder at B1. However, those fish were included in calculations of FPE. Powerhouse one = B1 and Powerhouse two = B2.

Treatment	FPE	B1 Guided	B1 Sluiceway	B2 Guided	Spillway	B1 Unguided	B2 Unguided
Chinook Salmon							
Overall	0.76	47	55	251	1111	47	423
57 kcfs	0.70	20	34	129	377	22	222
TDG Cap	0.80	27	21	122	734	25	201
Steelhead							
Overall	0.84	9	22	135	327	3	94
57 kcfs	0.76	3	13	63	80	1	50
TDG Cap	0.88	6	9	72	247	2	44

Table 4. Fish Guidance Efficiency (FGE) and corresponding standard error (SE) at Bonneville Dam's powerhouse one (B1) and powerhouse two (B2) for yearling Chinook salmon and steelhead during spring 2002.

Treatment	B1	SE	B2	SE
Chinook salmon				
Overall	50% (47 of 94)	5.2%	37% (251 of 674)	1.9%
57 kcfs	48% (20 of 42)	7.8%	37% (129 of 351)	2.6%
TDG Cap	52% (27 of 52)	7.0%	38% (122 of 323)	2.7%
Steelhead				
Overall	75% (9 of 12)	13.1%	59% (135 of 229)	3.3%
57 kcfs	75% (3 of 4)	25.0%	56% (63 of 113)	4.7%
TDG Cap	75% (6 of 8)	16.4%	62% (72 of 116)	4.5%

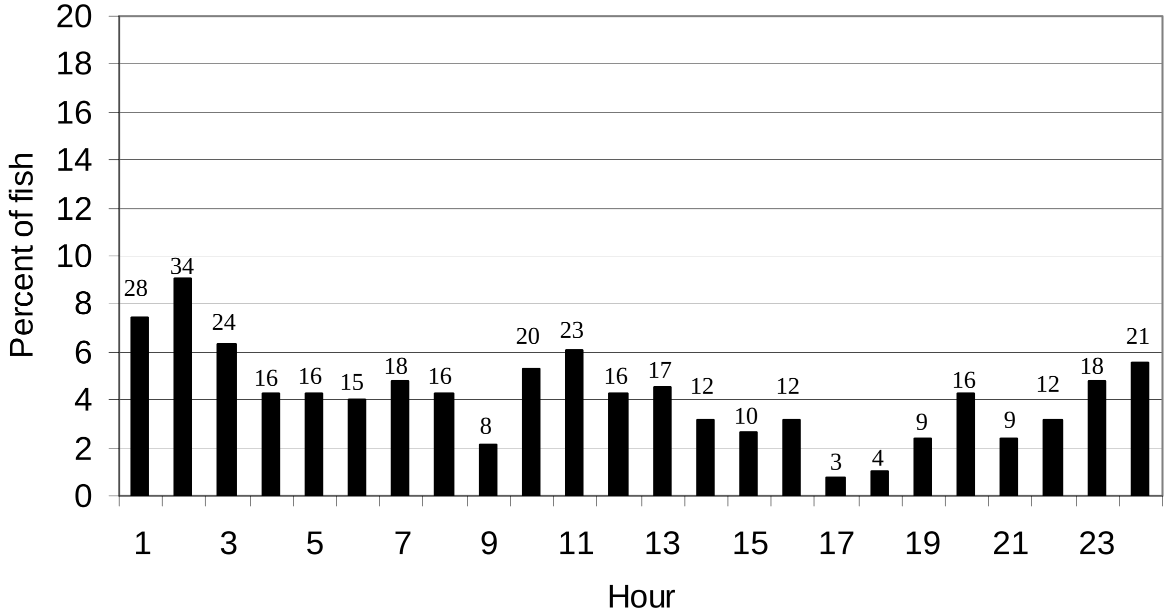


Figure 1. Hourly spillway passage of yearling Chinook salmon during 57 kcfs spill treatment blocks at Bonneville Dam during spring 2002. Numbers above the bars represent number of fish that passed during that hour.

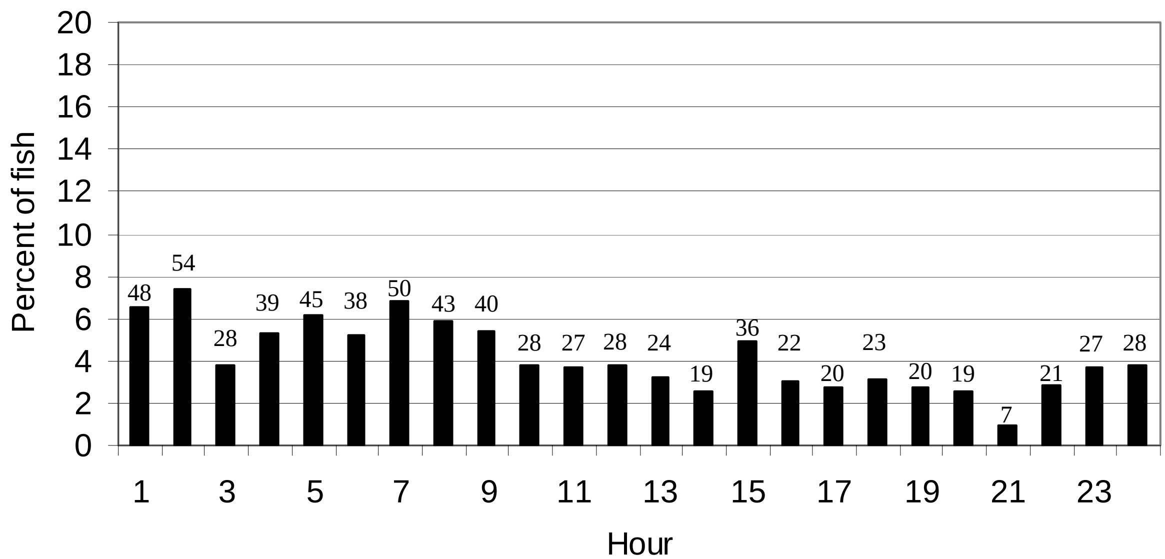


Figure 2. Hourly spillway passage of yearling Chinook salmon during TDG Cap spill treatment blocks at Bonneville Dam during spring 2002. Numbers above the bars represent number of fish that passed during that hour.

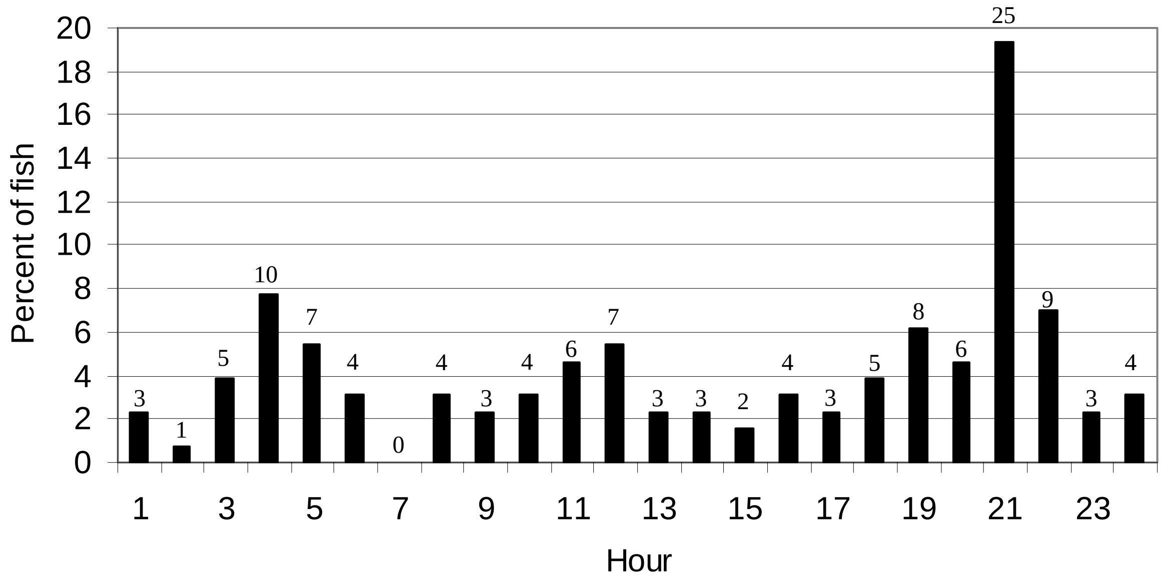


Figure 3. Hourly guided passage of yearling Chinook salmon at Bonneville Dam's second powerhouse during 57 kcfs spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

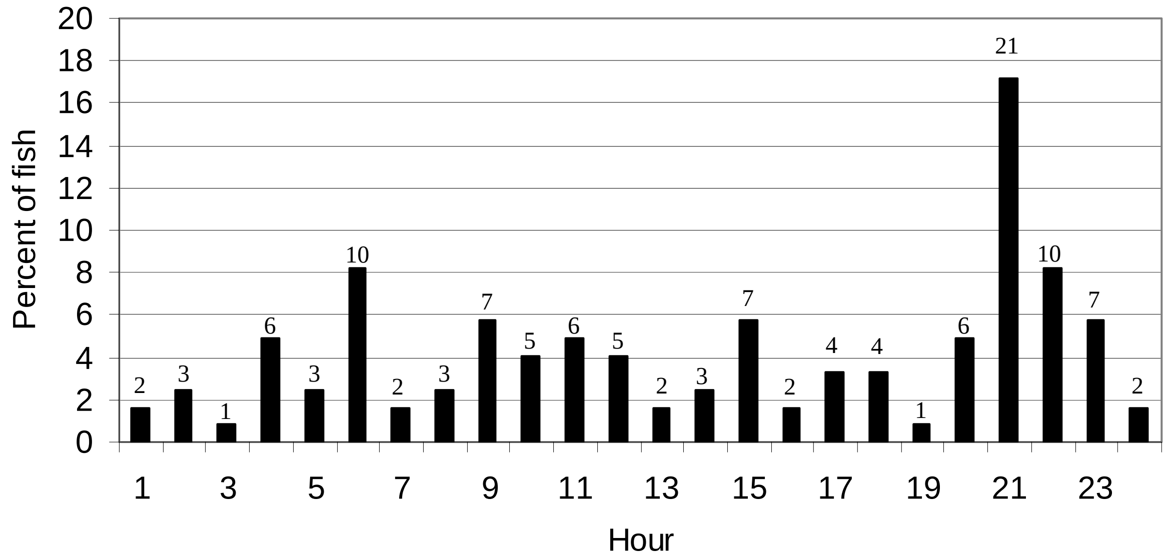


Figure 4. Hourly guided passage of yearling Chinook salmon at Bonneville Dam's second powerhouse during TDG Cap spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

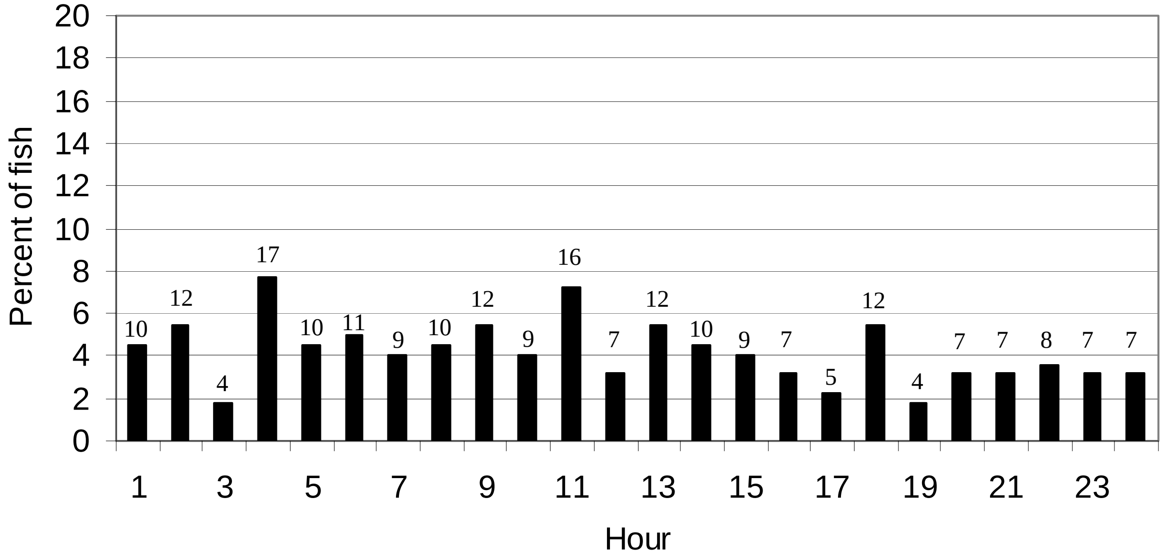


Figure 5. Hourly unguided passage of yearling Chinook salmon at Bonneville Dam's second powerhouse during 57 kcfs spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

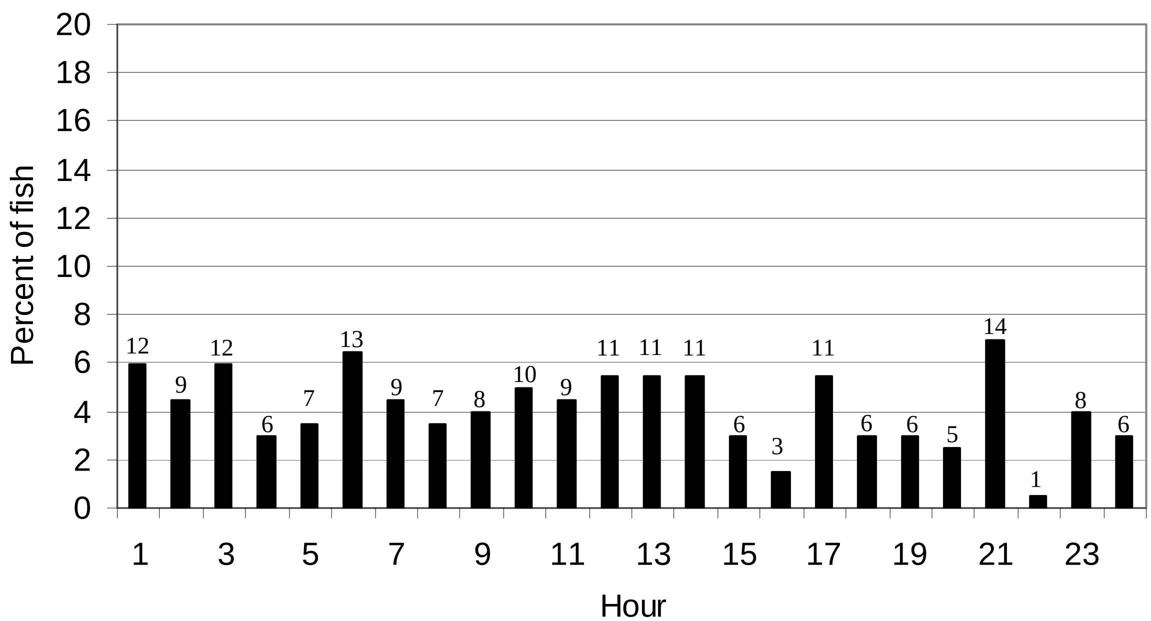


Figure 6. Hourly unguided passage of yearling Chinook salmon at Bonneville Dam's second powerhouse during TDG Cap spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

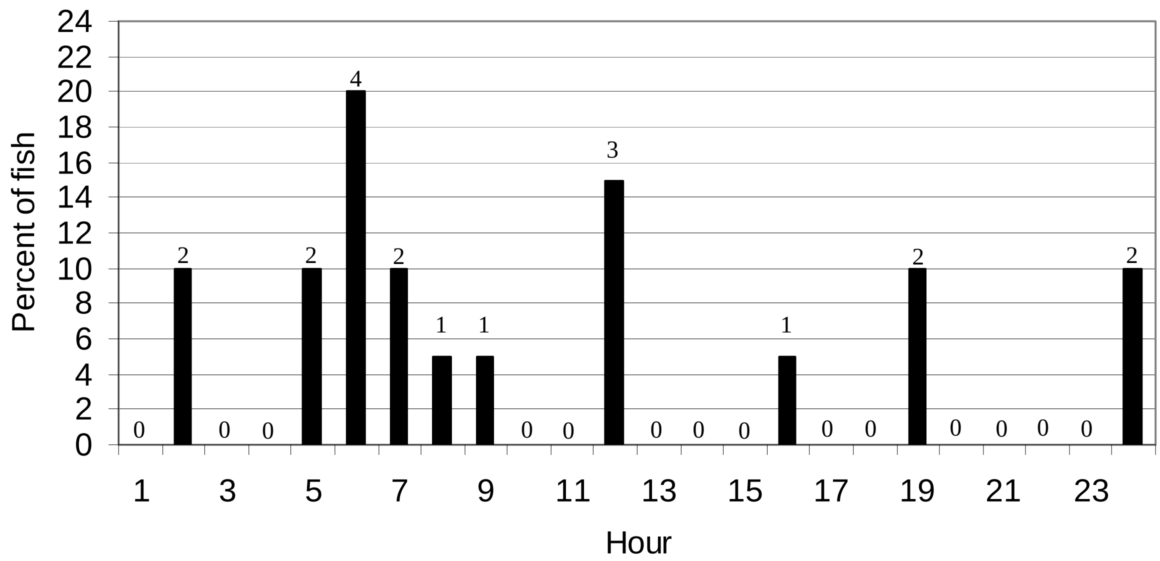


Figure 7. Hourly guided passage of yearling Chinook salmon at Bonneville Dam's first powerhouse during 57 kcfs spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

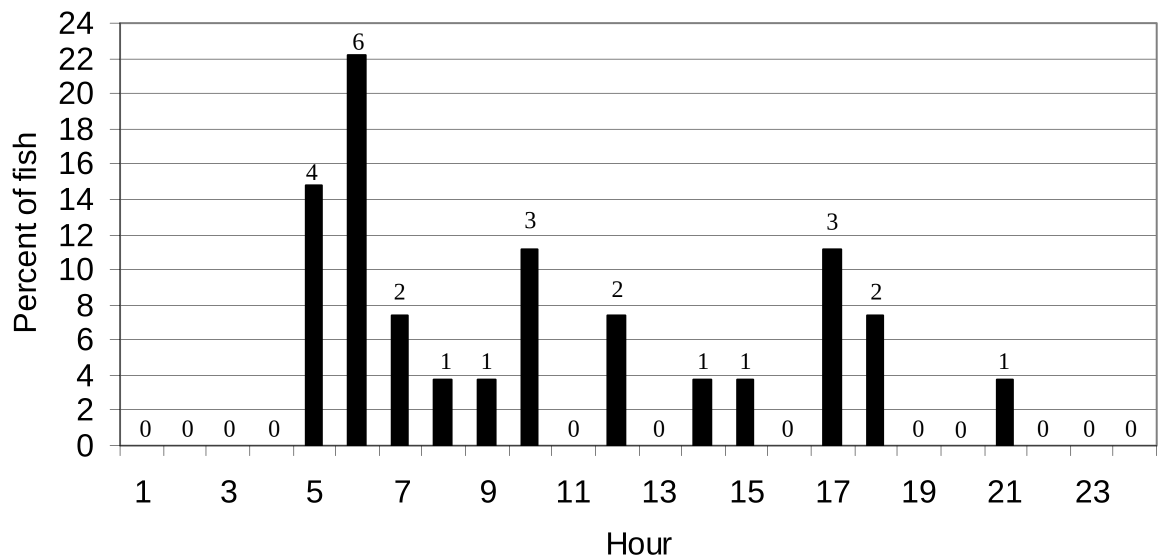


Figure 8. Hourly guided passage of yearling Chinook salmon at Bonneville Dam's first powerhouse during TDG Cap spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

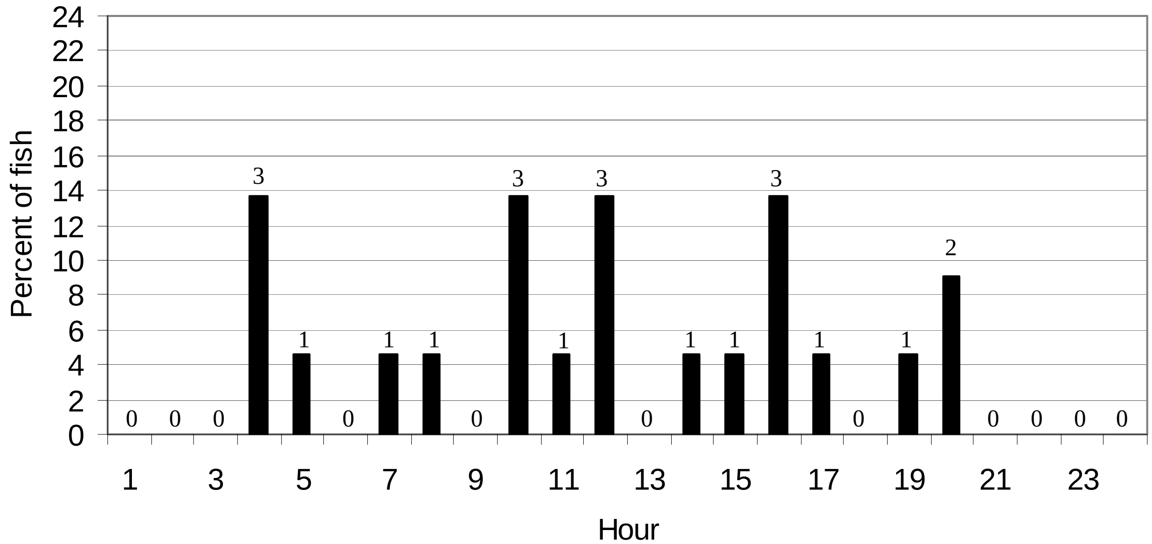


Figure 9. Hourly unguided passage of yearling Chinook salmon at Bonneville Dam's first powerhouse during 57 kcfs spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

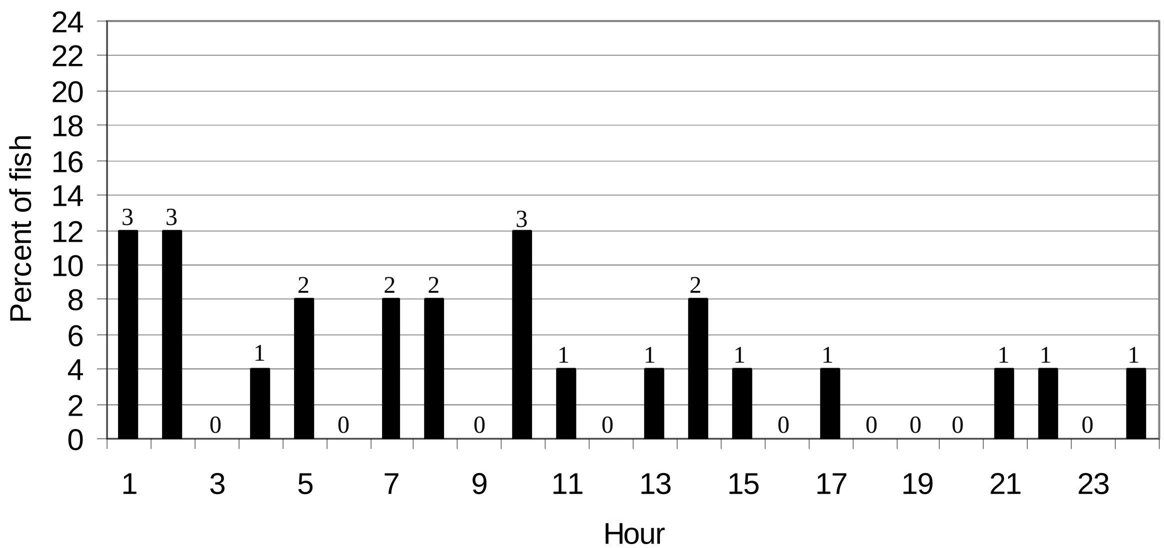


Figure 10. Hourly unguided passage of yearling Chinook salmon at Bonneville Dam's first powerhouse during TDG Cap spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

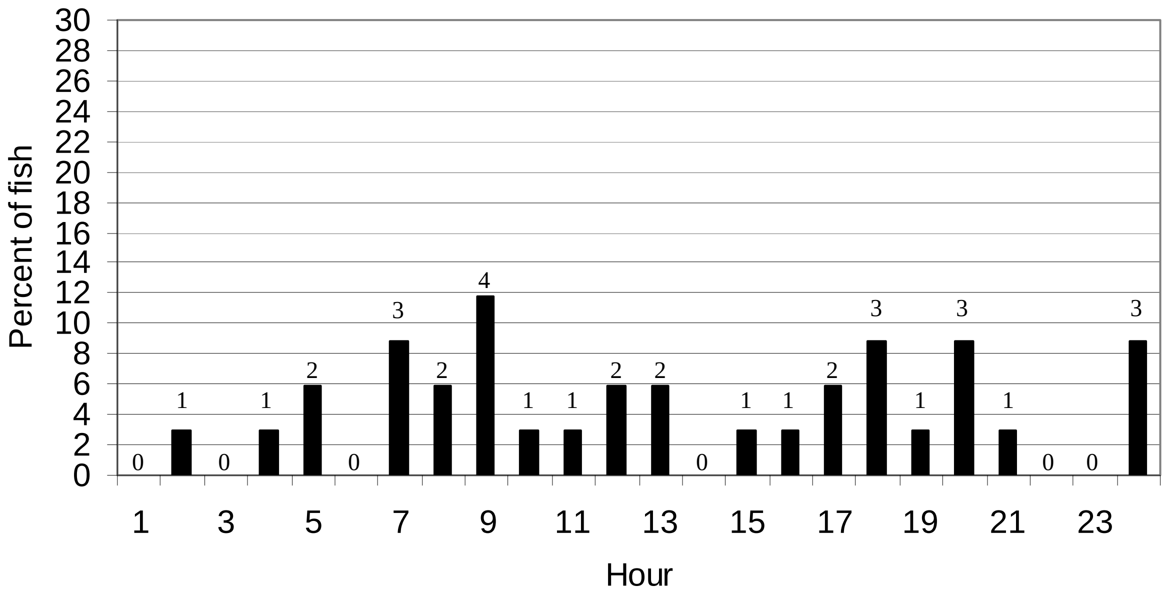


Figure 11. Hourly sluiceway passage of yearling Chinook salmon at Bonneville Dam's first powerhouse during 57 kcfs spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

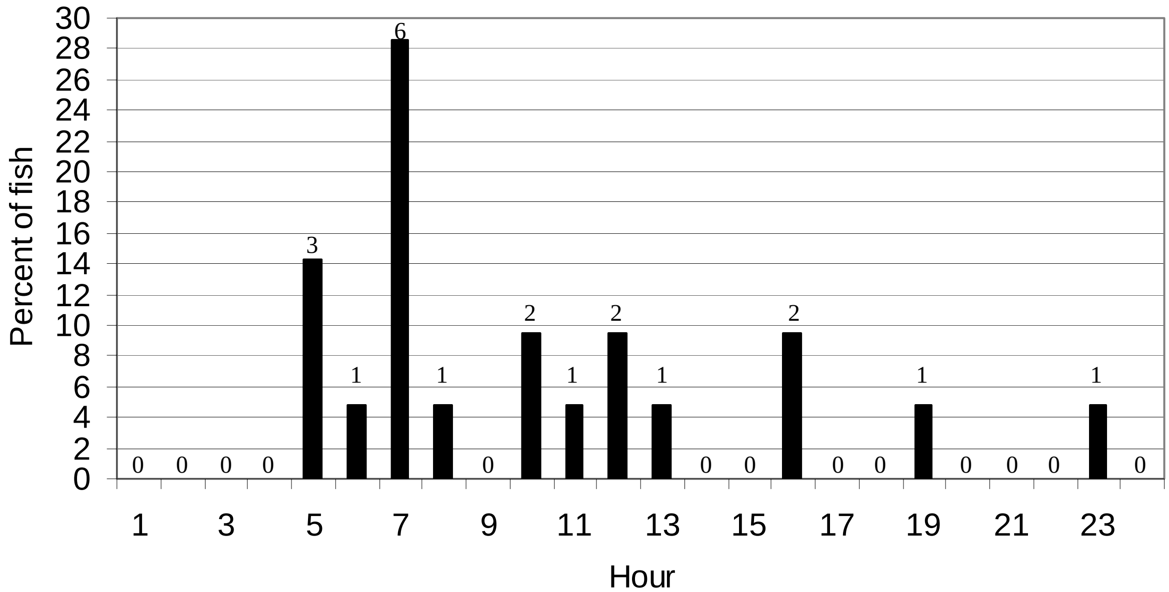


Figure 12. Hourly sluiceway passage of yearling Chinook salmon at Bonneville Dam's first powerhouse during TDG Cap spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

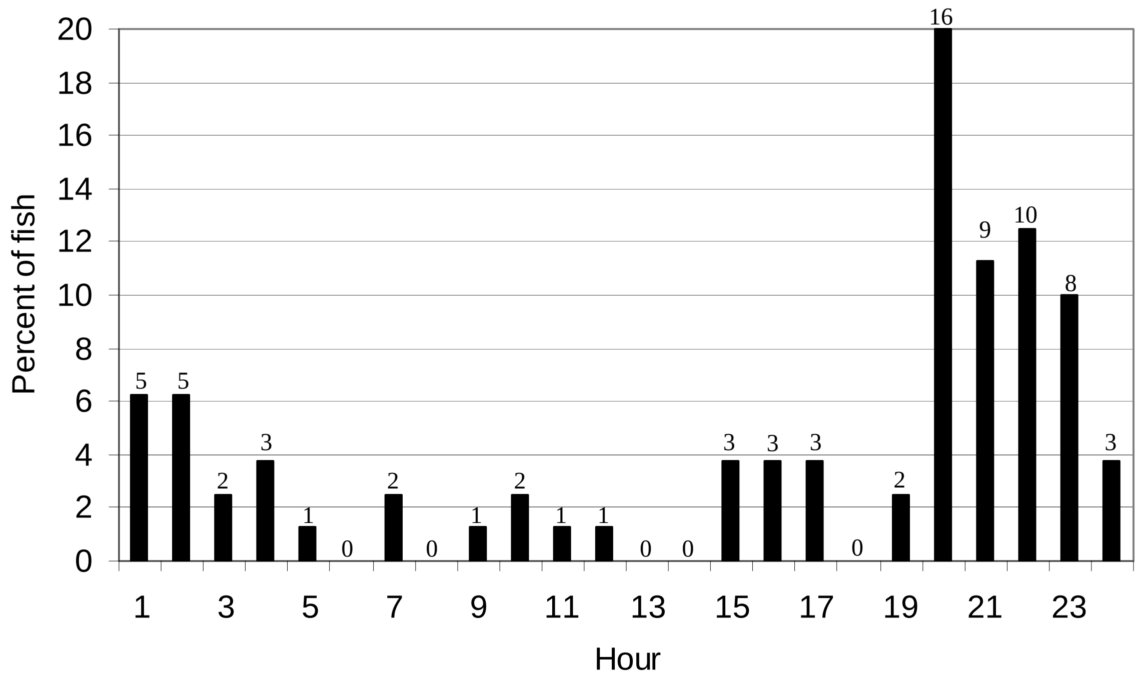


Figure 13. Hourly spillway passage of yearling steelhead during 57 kcfs spill treatment blocks at Bonneville Dam during spring 2002. Numbers above the bars represent number of fish that passed during that hour.

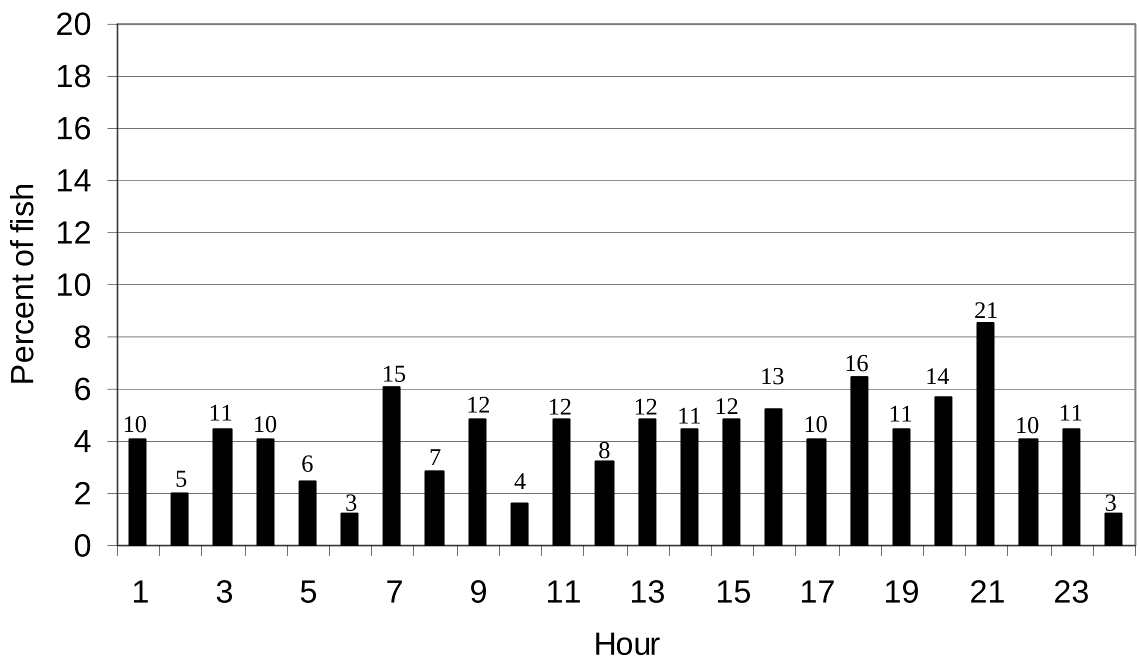


Figure 14. Hourly spillway passage of yearling steelhead during TDG Cap spill treatment blocks at Bonneville Dam during spring 2002. Numbers above the bars represent number of fish that passed during that hour.

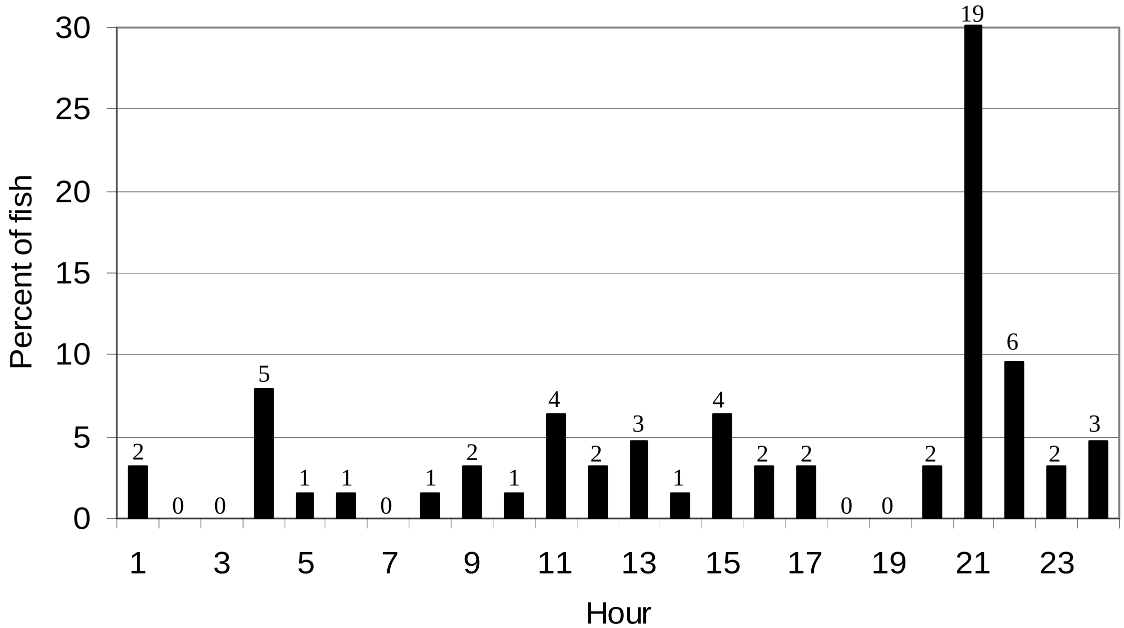


Figure 15. Hourly guided passage of yearling steelhead at Bonneville Dam's second powerhouse during 57 kcfs spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

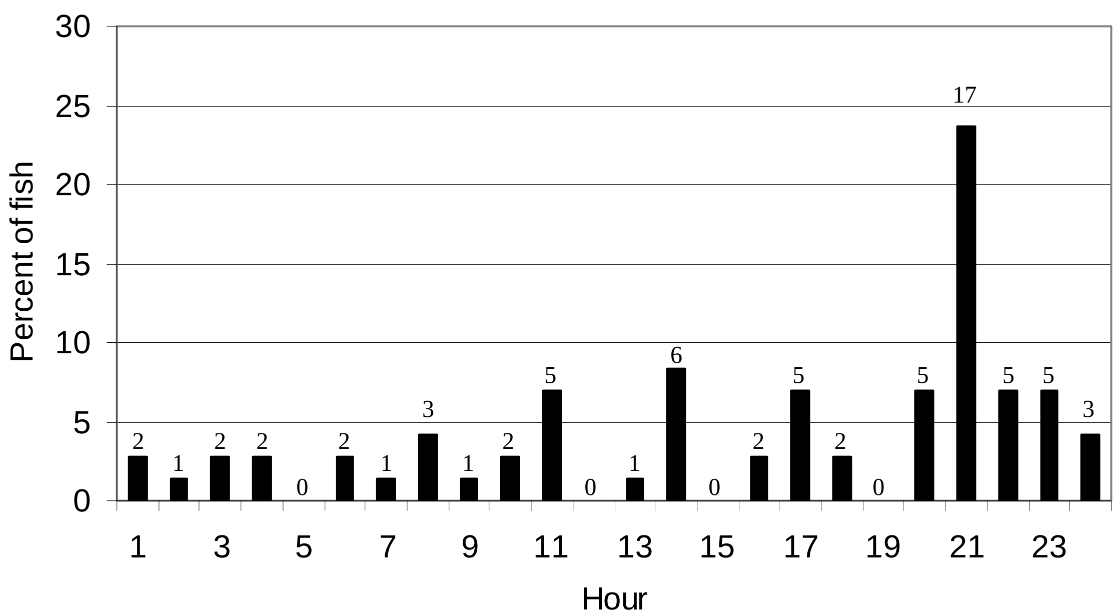


Figure 16. Hourly guided passage of yearling steelhead at Bonneville Dam's second powerhouse during TDG Cap spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

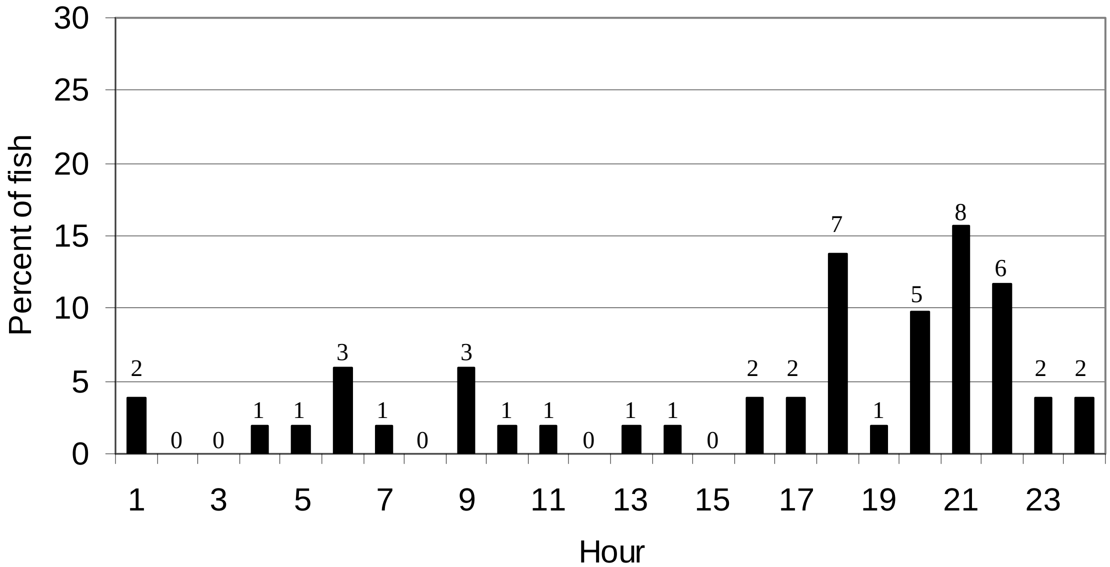


Figure 17. Hourly unguided passage of yearling steelhead at Bonneville Dam's second powerhouse during 57 kcfs spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

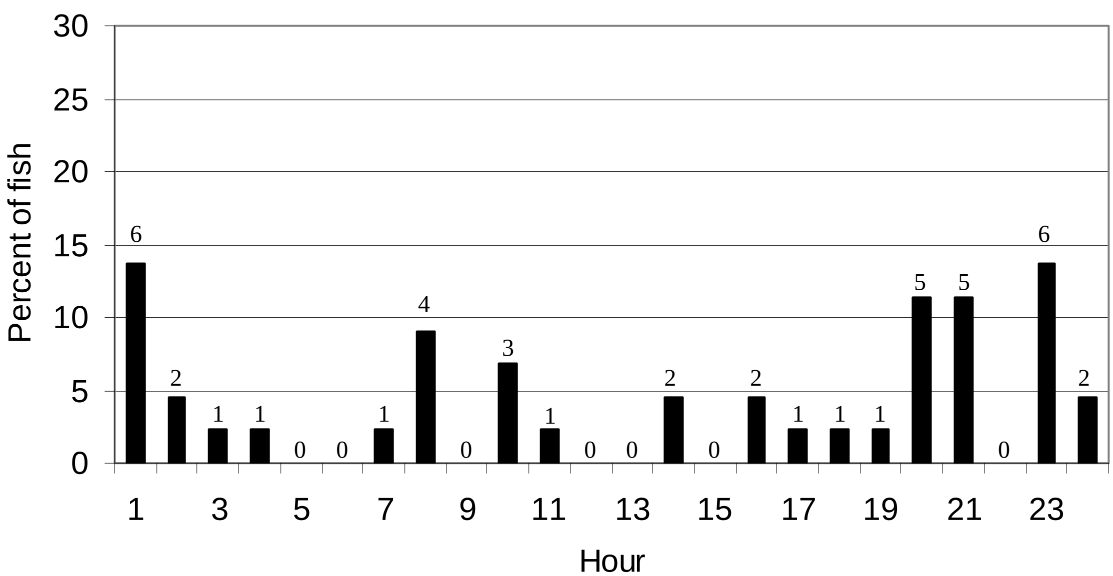


Figure 18. Hourly unguided passage of yearling steelhead at Bonneville Dam's second powerhouse during TDG Cap spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

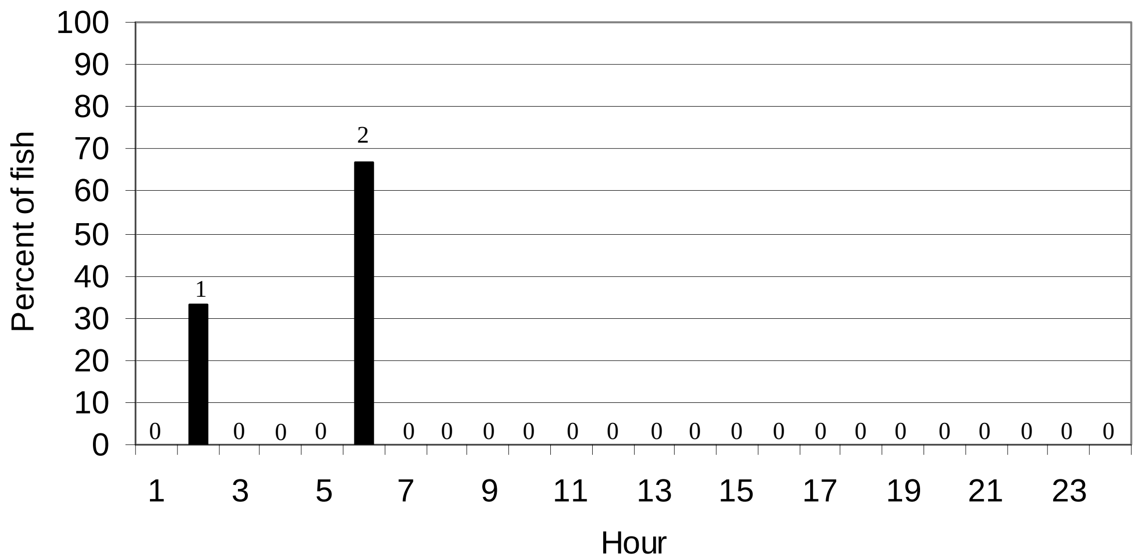


Figure 19. Hourly guided passage of yearling steelhead at Bonneville Dam's first powerhouse during 57 kcfs spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

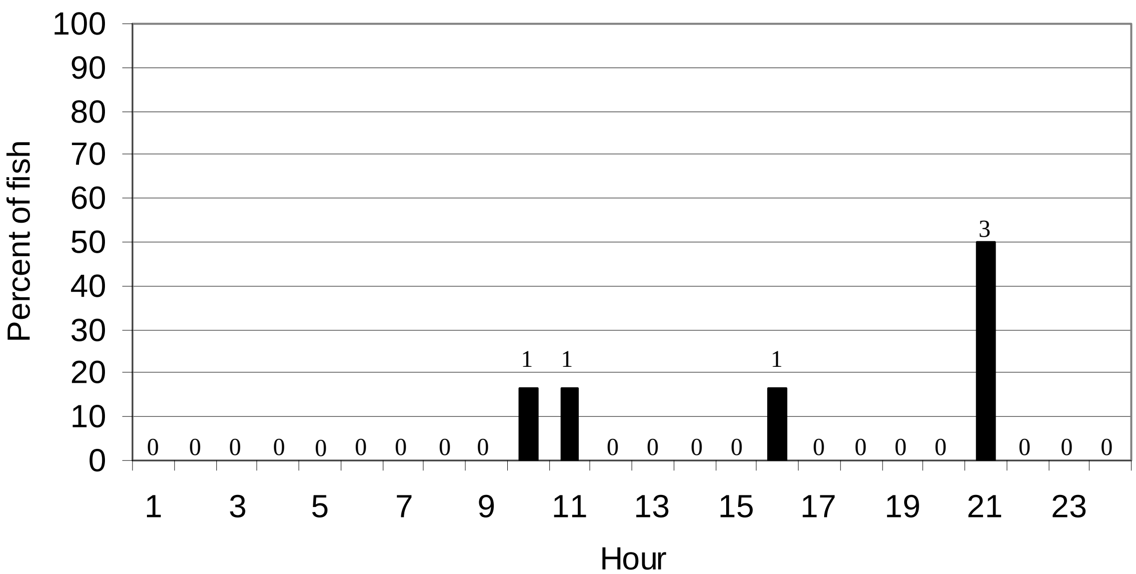


Figure 20. Hourly guided passage of yearling steelhead at Bonneville Dam's first powerhouse during TDG Cap spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

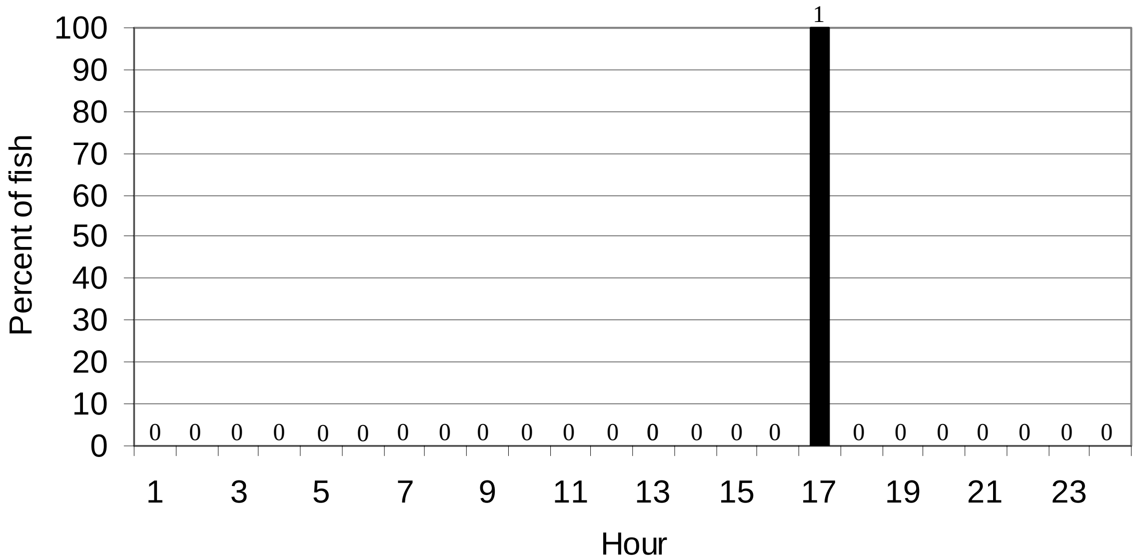


Figure 21. Hourly unguided passage of yearling steelhead at Bonneville Dam’s first powerhouse during 57 kcfs spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

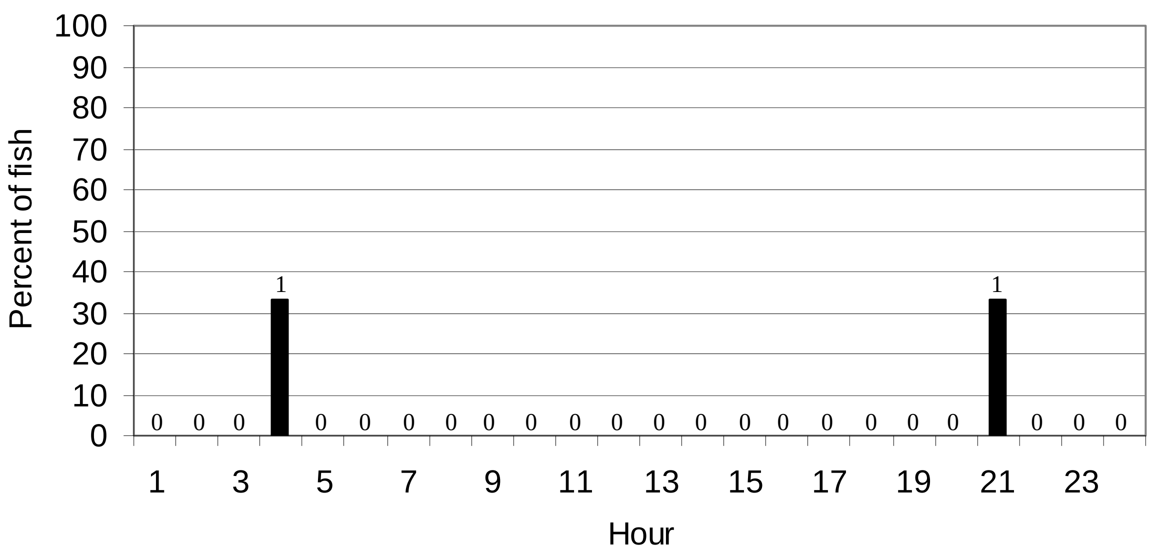


Figure 22. Hourly unguided passage of yearling steelhead at Bonneville Dam’s first powerhouse during TDG Cap spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

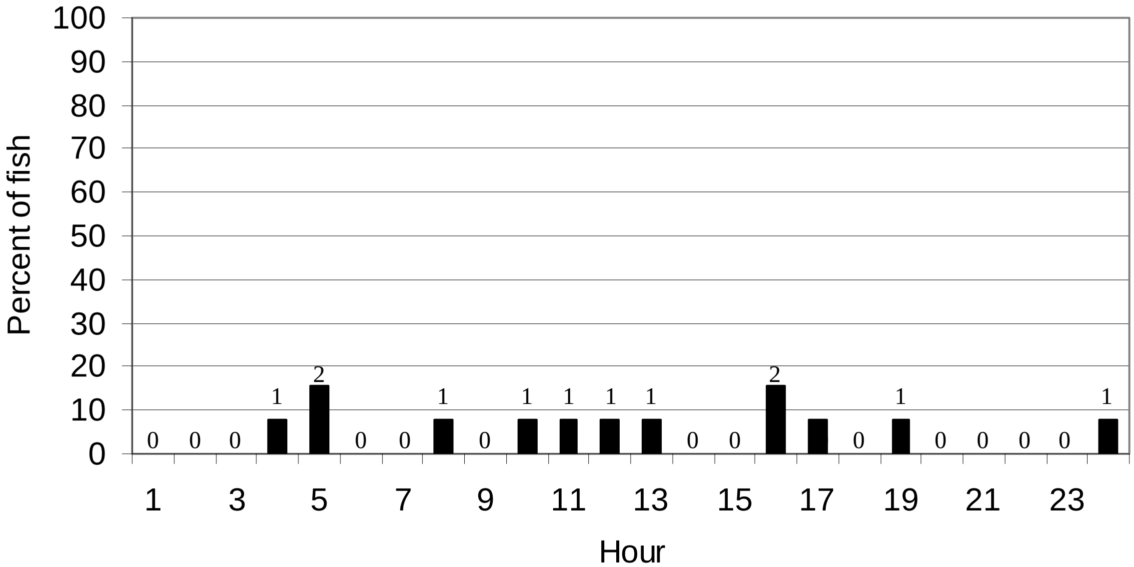


Figure 23. Hourly sluiceway passage of yearling steelhead at Bonneville Dam's first powerhouse during 57 kcfs spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

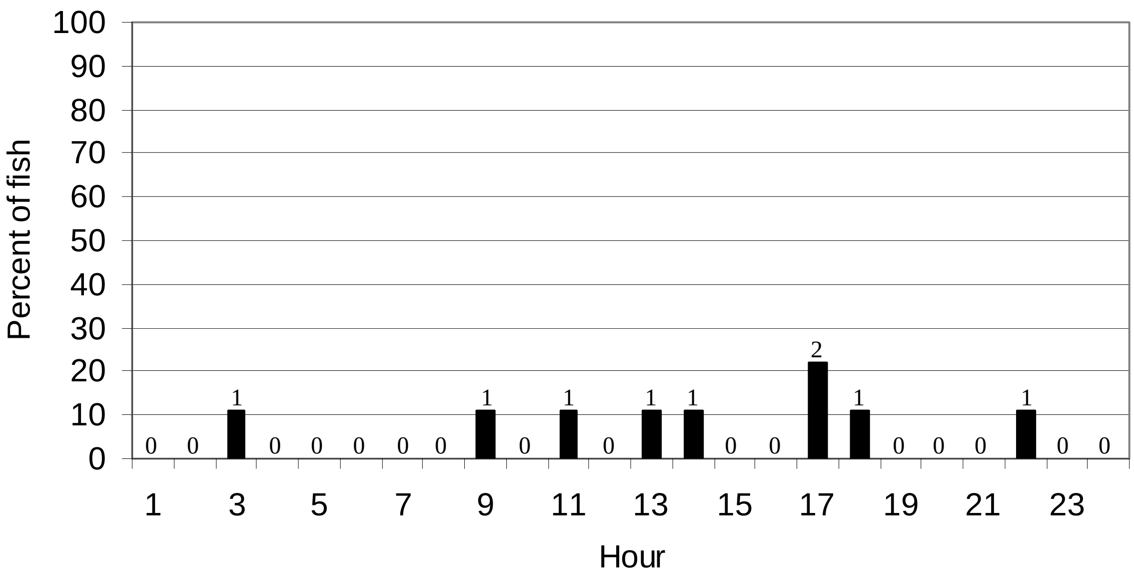


Figure 24. Hourly sluiceway passage of yearling steelhead at Bonneville Dam's first powerhouse during TDG Cap spill treatment blocks, spring 2002. Numbers above the bars represent number of fish that passed during that hour.

Table 5. The proportion of radio-tagged yearling Chinook salmon and steelhead that passed each dam area of Bonneville Dam during day (0500-2059 hours) and night (2100-0459 hours) during spring 2002. Percentages are based on total number of fish that passed each dam area (e.g. B1, B2, or Spillway). Powerhouse one = B1 and Powerhouse two = B2.

Period	B1 Passage	B2 Passage	Spill Passage
Chinook Salmon			
Day	83% (130 of 156)	62% (421 of 674)	63% (697 of 1111)
Night	17% (26 of 156)	38% (253 of 674)	37% (414 of 1111)
Steelhead			
Day	71% (24 of 34)	48% (111 of 229)	61% (201 of 327)
Night	29% (10 of 34)	52% (118 of 229)	39% (126 of 327)

Table 6. The proportion of radio-tagged yearling Chinook salmon and steelhead that passed each dam area of Bonneville Dam during day (0500-2059 hours) and night (2100-0459 hours) during the 57 kcfs spill treatment, spring 2002. Percentages are based on total number of fish that passed each dam area (e.g. B1, B2, or Spillway). Powerhouse one = B1 and Powerhouse two = B2.

Period	B1 Passage	B2 Passage	Spill Passage
Chinook Salmon			
Day	82% (65 of 79)	62% (218 of 351)	57% (215 of 377)
Night	18% (14 of 79)	38% (133 of 351)	43% (162 of 377)
Steelhead			
Day	82% (14 of 17)	49% (55 of 113)	44% (35 of 80)
Night	18% (3 of 17)	51% (58 of 113)	56% (45 of 80)

Table 7. The proportion of radio-tagged yearling Chinook salmon and steelhead that passed each dam area of Bonneville Dam during day (0500-2059 hours) and night (2100-0459 hours) during the TDG Cap spill treatment, spring 2002. Percentages are based on total number of fish that passed each dam area (e.g. B1, B2, or Spillway). Powerhouse one = B1 and Powerhouse two = B2.

Period	B1 Passage	B2 Passage	Spill Passage
Chinook Salmon			
Day	84% (65 of 77)	63% (203 of 323)	66% (482 of 734)
Night	16% (12 of 77)	37% (120 of 323)	34% (252 of 734)
Steelhead			
Day	59% (10 of 17)	48% (56 of 116)	67% (166 of 247)
Night	41% (7 of 17)	52% (60 of 116)	33% (81 of 247)