U.S. Army Corps of Engineers
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Passage Behavior of Radio-Tagged Subyearling Chinook Salmon at Bonneville Dam, 2002: *Revised for Corrected Spill*

Annual Report

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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 subyearling Chinook salmon, *Oncorhynchus tshawytscha*, 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. This report covers the study of subyearling Chinook salmon during the summer of 2002. Study activities on yearling Chinook salmon and steelhead conducted in spring 2002 were reported by Evans et al. (2002).

From 21 June to 25 July 2002, we radio-tagged and released 3,357 subyearling Chinook salmon upstream of Bonneville Dam at The Dalles Dam, John Day Dam and Rock Creek, Washington. We detected our last radio-tagged fish on July 30, 2002. Mean river discharge at Bonneville Dam during the study period was 228 kcfs, with 43% of flow discharged at the spillway, 40% at powerhouse II (B2), and 17% at powerhouse I (B1). The median travel rates of radio-tagged fish from release to Bonneville Dam was 2.1 km/h for fish released from Rock Creek and 2.5 km/h for fish released from both John Day Dam and The Dalles Dam. Resulting median travel times from the release site to Bonneville Dam were 64.4 h for Rock Creek fish, 45.6 h for John Day fish, and 29.1 h for The Dalles fish. Of the fish released, we detected 78% at Bonneville Dam. Median forebay residence time was shortest at the spillway (3 min), compared to 1.8 h at B1 and 1.3 h at B2.

Passage routes were determined for 97% of fish detected at Bonneville Dam. The spillway passed the most fish (59%), followed by B2 (27%) and B1 (14%). Of the fish that passed at B1, 48% passed into the sluiceway, 28% passed through the turbines (unguided), 21% were diverted into the turbine bypass system by turbine intake screens (guided), and 2% passed through the navigation lock. All but one fish that passed at B2 entered the turbine intakes; 53% were unguided and 47% were guided (one fish passed via the adult fish ladder). Overall, a higher proportion of fish passed during day (60%) compared to night (40%). Likewise, at the spillway and B1, more fish (66%) passed during day than night. However, at B2, the majority (57%) of fish passed at night and based on the number of hours in each diel period (8 for day and 16 for night), passage rates were highest at night at all dam areas.

Fish passage efficiency (FPE: the proportion of total fish that passed through non-turbine routes) at Bonneville Dam in summer 2002 was 82% (SE 0.8%) overall, 72% (SE

2.4%) at B1 and 46.5% (SE 1.9%) at B2. Fish guidance efficiency (FGE: the proportion of powerhouse-entrained fish that were guided by screens into the bypass system) was higher at B2 (47%, SE 1.9%) than at B1 (43%, SE 3.7%). Spillway efficiency, which is the proportion of total fish passing the project that passed through the spillway, was 58% (SE 1.0%). Spillway effectiveness (spillway efficiency divided by the proportion of total discharge spilled) was 1.3. Sluiceway efficiency at B1 (the proportion of total fish passing B1 that passed through the sluiceway) was 48% (SE 2.6%) and sluiceway effectiveness at B1 (sluiceway efficiency divided by the proportion of total discharge through the sluiceway) was 27.9.

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 spent in the forebay before passing. Overall, greater than half of subyearling Chinook salmon passed through the spillway and of the three spill treatments, TDG Day was the most efficient, passing 71% of fish relative to all other passage routes. Spillway efficiency varied significantly among spill treatments ($X^2 = 126.82$, df = 2, $P < 0.001$) and the TDG Day spill treatment was significantly greater than both the Day Cap (Tukey test; q =15.00, df = 3, $P < 0.05$) and the TDG Night (Tukey test; q = 11.70, df = 3, $P < 0.05$) treatments.

All passage metrics except B1 FGE and B1 FPE were higher in 2002 than 2001, largely due to higher river flows in 2002. Lower passage metrics at B1 in 2002 might be explained by increased discharge at B1, which entrained a higher percentage of fish in turbine flow and thereby decreased the number of fish available to the surface-oriented sluiceway. Results from our 2002 study indicate that although the current intake screen guidance systems at B1 and B2 only diverted 43% and 47% of subyearling Chinook salmon, respectively, the project FPE goal of 80% can be attained if sufficient 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 and the Northwest Power Planning Council 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 summer 2002, we used radio telemetry to examine the movements and behavior of subyearling Chinook salmon, *Oncorhynchus tshawytscha,* in the forebay of Bonneville Dam. Our objectives were to:

- Determine the behavior, distribution, and approach patterns of subyearling Chinook salmon in the forebay areas of Bonneville Dam.
- Determine the time and route of dam passage of subyearling Chinook salmon.
- 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 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 one (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 two (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).

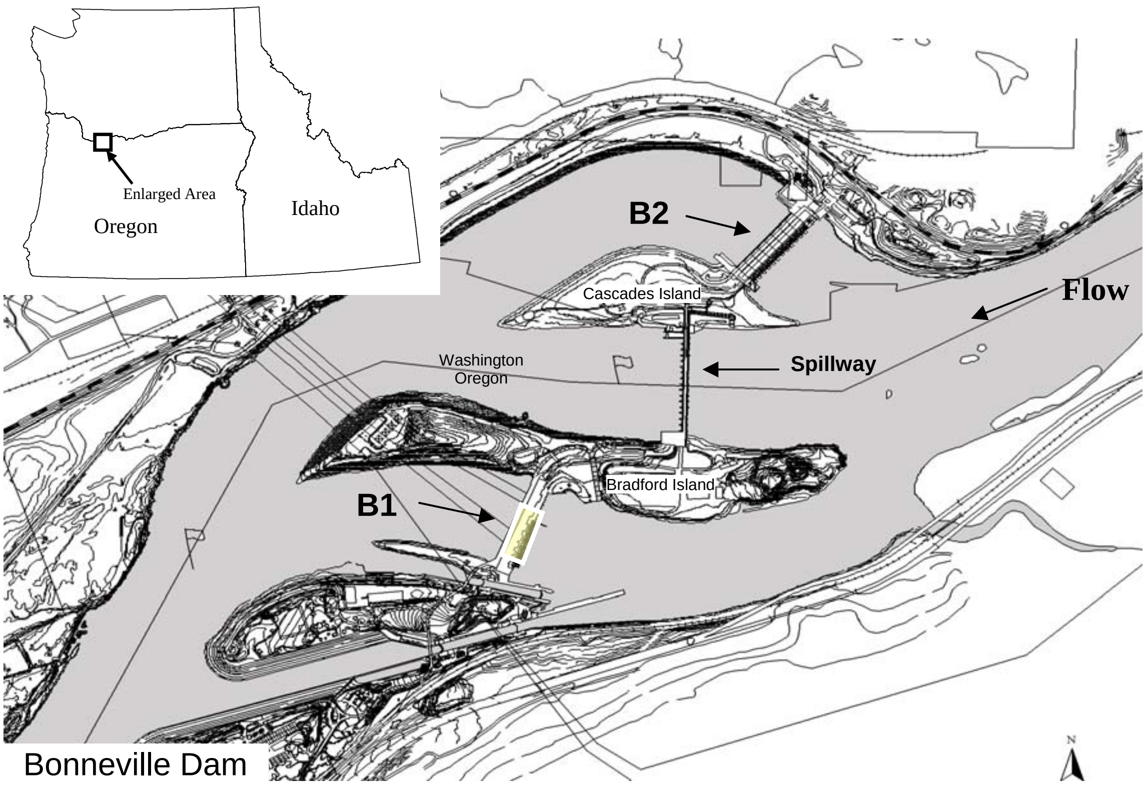

Figure 1. Plan view of Bonneville Dam on the Columbia River, showing the first powerhouse (B1), spillway, and second powerhouse (B2). Image source: U.S. Army Corps of Engineers.

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, Canada), three Lotek DSP-500 digital spectrum processors (DSP, Lotek Engineering, Newmarket, Ontario, Canada), 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 10 frequencies split between two receivers. 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 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.

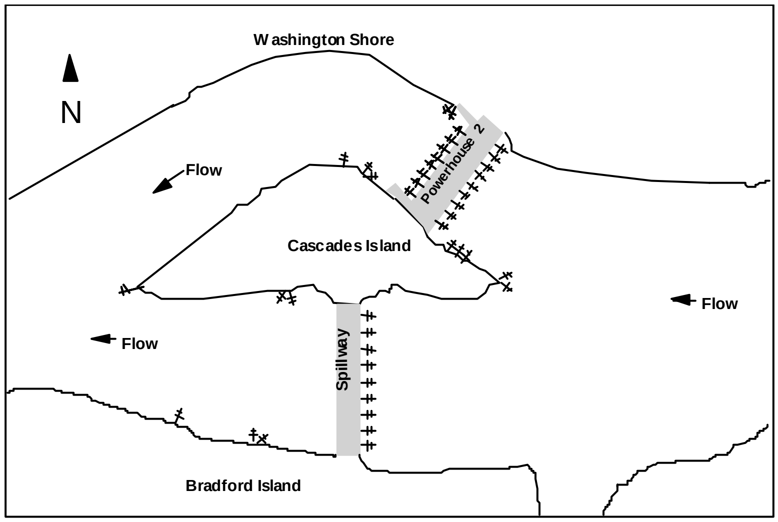

Figure 2. Plan view of aerial antenna coverage at Bonneville's second powerhouse (B2) and spillway during summer 2002.

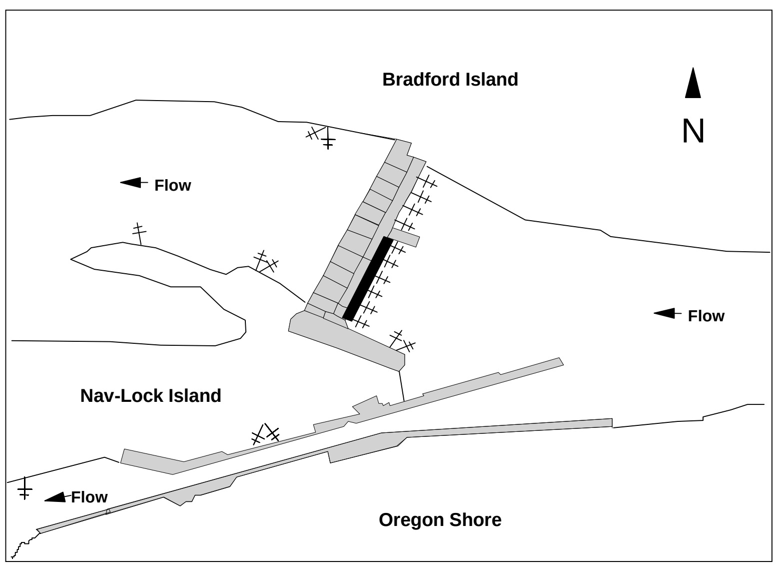

Figure 3. Plan view of aerial antenna coverage at Bonneville's first powerhouse (B1) during summer 2002.

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.

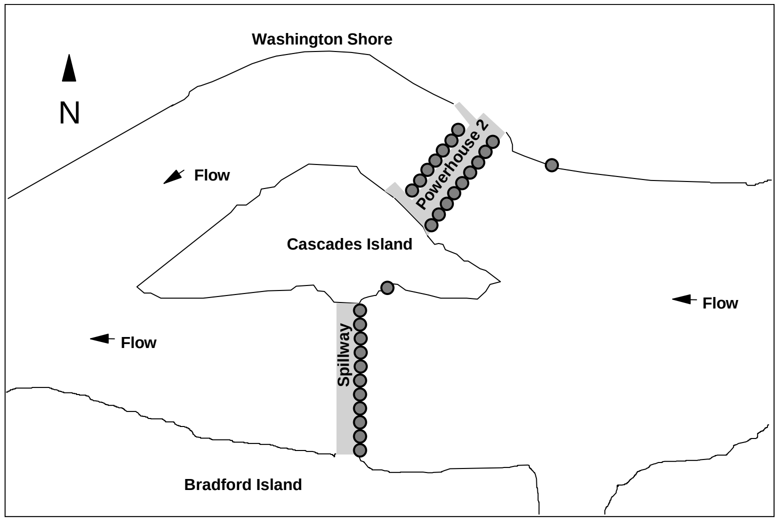

Figure 4. Plan view of underwater antenna coverage at Bonneville's second powerhouse (B2) and spillway during summer 2002.

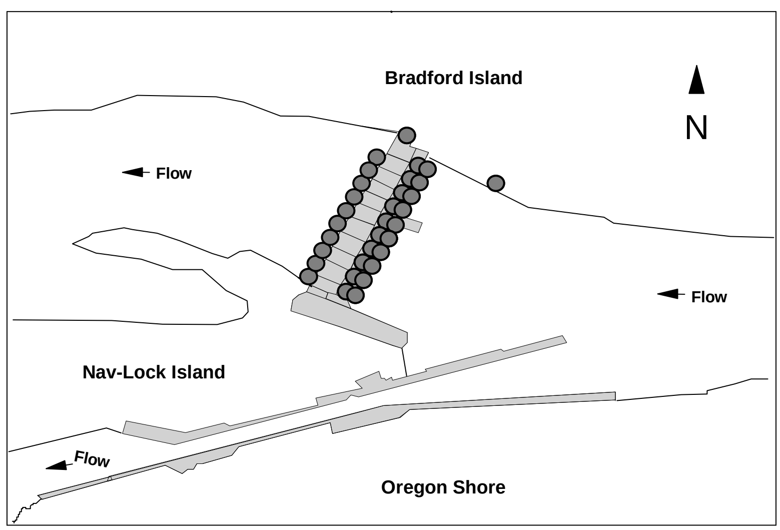

Figure 5. Plan view of underwater antenna coverage at Bonneville's first powerhouse (B1) during summer 2002.

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 coax antennas were located inside the 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 approximately 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 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. Although aerial antennas are not typically used with a MITAS due to noise sensitivity, the quiet environment of the sluice chute enabled the successful use of an aerial antenna with the MITAS at B2. 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 approximately 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 ensure 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. (Lotek) were implanted in subyearling Chinook salmon. The transmitters were 6.8 mm (diameter) x 15 mm and weighed 0.85 g in air and 0.5g in water. The antenna length was 30 cm and the pulse rate was 2.0 s, resulting in an estimated minimum tag life of 8 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/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 (0900 and 2100 at Rock Creek, 1000-1200 and 2200-0100 hours at John Day Dam and 0400-0500 and 2200-0100 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 31 to 69 h, depending on 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 that had been predated 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 the 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 $= \dfrac{SP}{(B1 + SP + B2)}$
- Spillway effectiveness $= \dfrac{SE}{F_{sp} / F_{tot}}$
- 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 21 June to 25 July 2002, we radio-tagged and released 3,357 subyearling Chinook salmon. Of the fish tagged, 790 were released from Rock Creek, 1,137 were released from John Day Dam and 1,430 were released from The Dalles Dam. The release period coincided with the central portion of the “in river” seaward migration of subyearling Chinook salmon (Figure 6). Of the fish released from Rock Creek, 81% (640 of 790) were released during the day and 19% (150 of 790) were released at night. Of the fish released from John Day Dam, 26% (291 of 1,137) were released during the day and 74% (846 of 1,137) were released at night. Of the fish released from The Dalles Dam, 43% (610 of 1,430) were released during the day and 57% (820 of 1,430) were released at night. Mean fork length for Chinook salmon released from all sites was 117.1 mm and the mean weight was 17.4 g. The radio tag represented an average of 4.7% of mean Chinook salmon body weight.

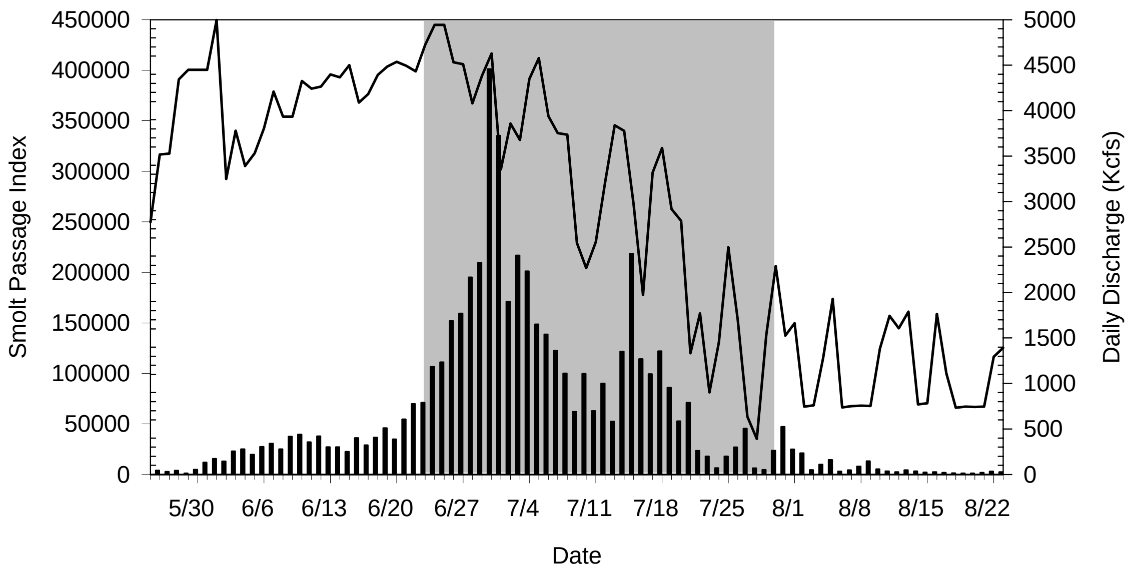

Figure 6. Smolt Passage Index for subyearling Chinook salmon at Bonneville Dam’s Second Powerhouse (B2) fish collection facility during summer 2002. Shaded area represents study period. Smolt index data were acquired from the Fish Passage Center web page at www.fpc.org.

3.2 River Discharge and Project Operations

During summer 2002 (23 June – 30 July), mean river discharge at Bonneville Dam was 228.5 kcfs, and ranged from 139.1 kcfs to 338.6 kcfs. Allocation of mean river discharge among dam areas (i.e., B1, B2, and spillway) during the study period was 17% through B1, 40% through B2, and 43% through spill (Figure 7 and Table 1). Mean daily discharge at B1 (turbines 1–10) was 38.0 kcfs and ranged from 0.6 to 81.2 kcfs. B2 displayed the greatest fluctuation in mean daily discharge with a mean of 91.8 kcfs, minimum of 15.3 kcfs and a maximum of 129.3 kcfs. Mean daily spill was 98.7 kcfs and ranged from 66.7 to 156.5 kcfs (Table 1). Spill occurred from 0500-2059 hours during the day and from 2100-0459 hours during the night.

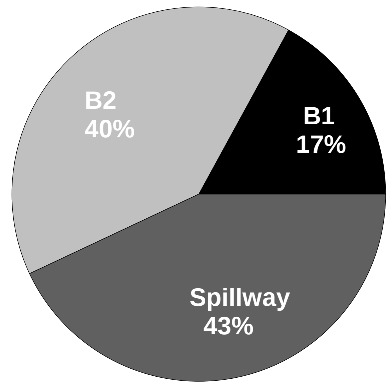

Figure 7. Discharge allocation between dam areas at Bonneville Dam during summer 2002.

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 (0500-2059) and flows up to the TDG cap occurred during both daytime 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 38 d summer study period. Spill during the Day Cap treatment occurred for a total of 288 h over 18 d, averaged 56.8 kcfs, and ranged from 54.4 to 57.7 kcfs. Spill during the TDG Day treatment occurred for a total of 343 h over 30 d, averaged 109.8 kcfs, and ranged from 62.5 to 163.2 kcfs. Spill during the TDG Night treatment occurred for a total of 280 h over 38 d, averaged 119.8 kcfs, and ranged from 93.5 to 171.3 kcfs. Turbines 1-6 represented 44% and turbines 7-10 represented 56% of mean discharge at B1 (Figure 8). Turbines 11-14 represented 46% and turbines 15-18 represented 54% of mean discharge at B2 (Figure 9). 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 10, 11, 12, and 13). We found that mean discharge at both B1 and B2 were higher during day than night (B1 discharged about 4 kcfs more during the day and B2 discharged about 10 kcfs more during day) while mean discharge at the spillway was 25 kcfs higher at night compared to day (Table 2).

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

Dam Area	Mean	Median	Min	Max
First Powerhouse	38.0	41.8	0.6	81.2
Sluiceway	0.7	0.7	0.6	0.7
Second Powerhouse	91.8	98.1	15.3	129.3
Spillway	98.7	95.1	66.7	156.5
Total	228.5	225.9	139.1	338.6

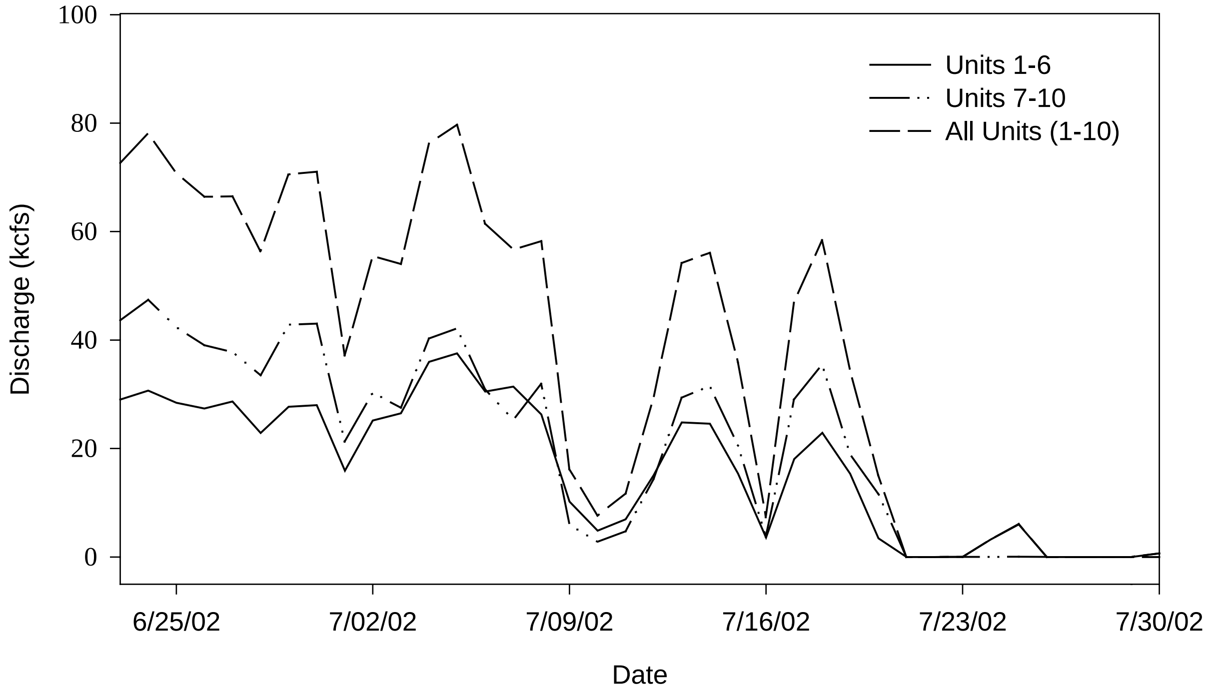

Figure 8. Mean daily discharge through turbines 1-6 and turbines 7-10 during summer 2002.

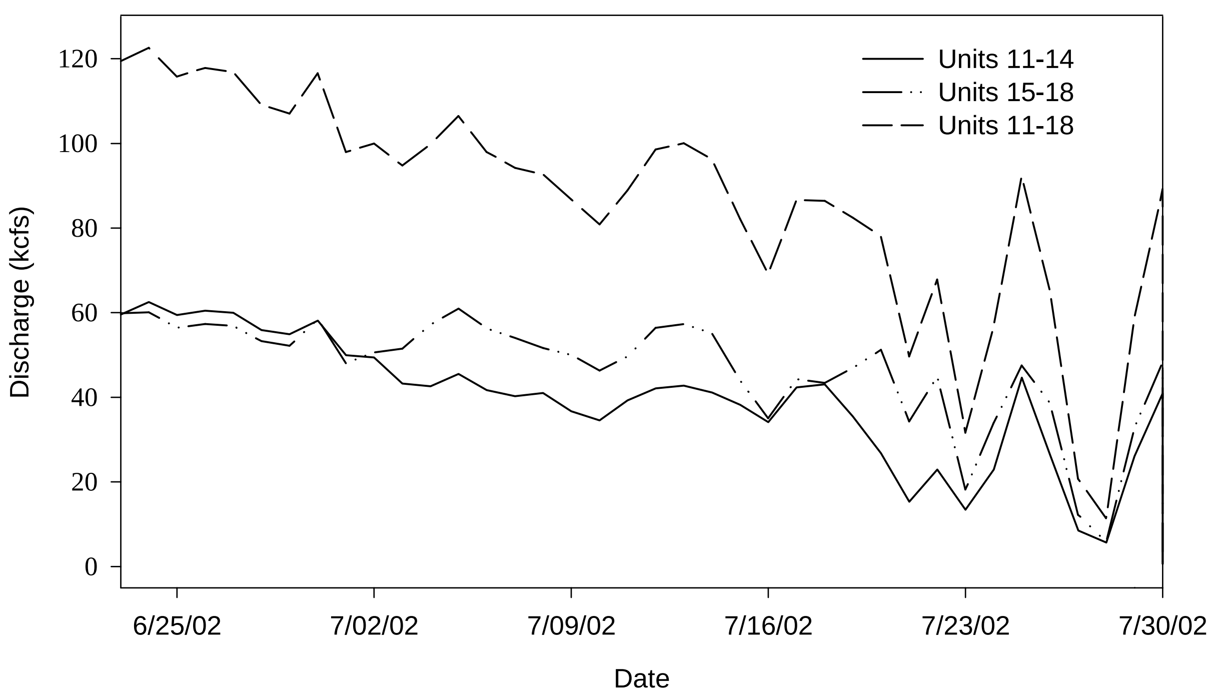

Figure 9. Mean daily discharge through turbines 11-14 and turbines 15-18 during summer 2002.

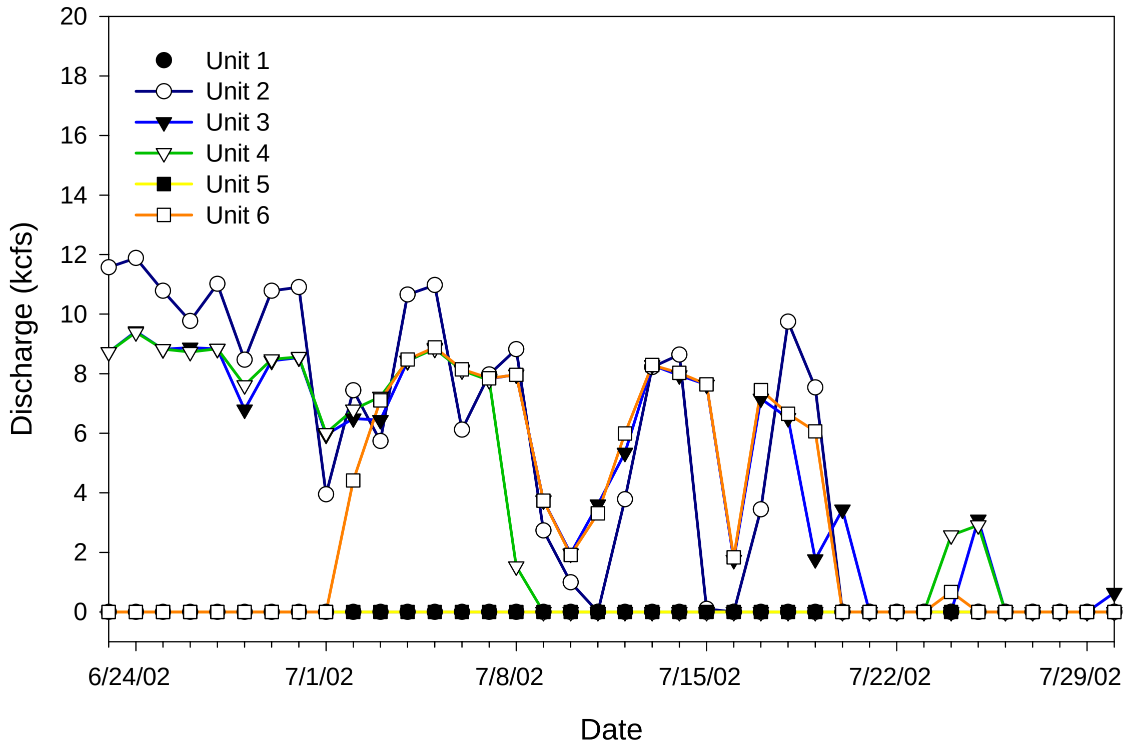

Figure 10. Mean daily discharge by unit for units 1-6 at Bonneville Dam during summer 2002.

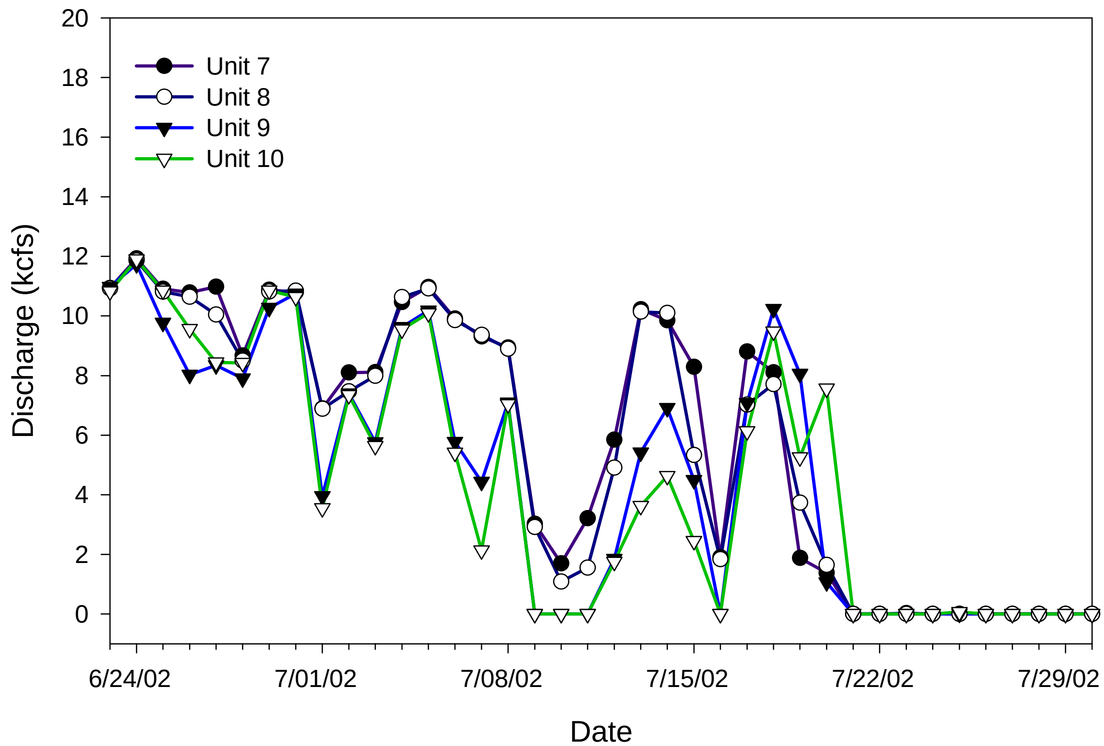

Figure 11. Mean daily discharge by unit for units 7-10 at Bonneville Dam during summer 2002.

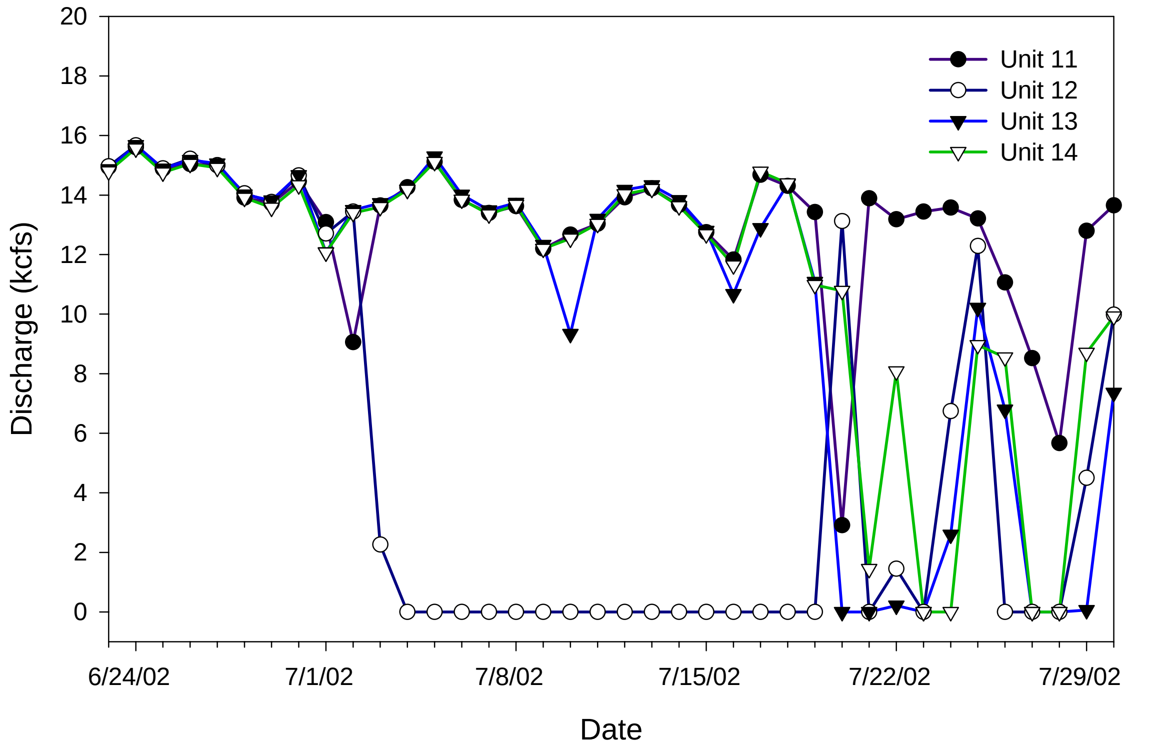

Figure 12. Mean daily discharge by unit for units 11-14 at Bonneville Dam during summer 2002.

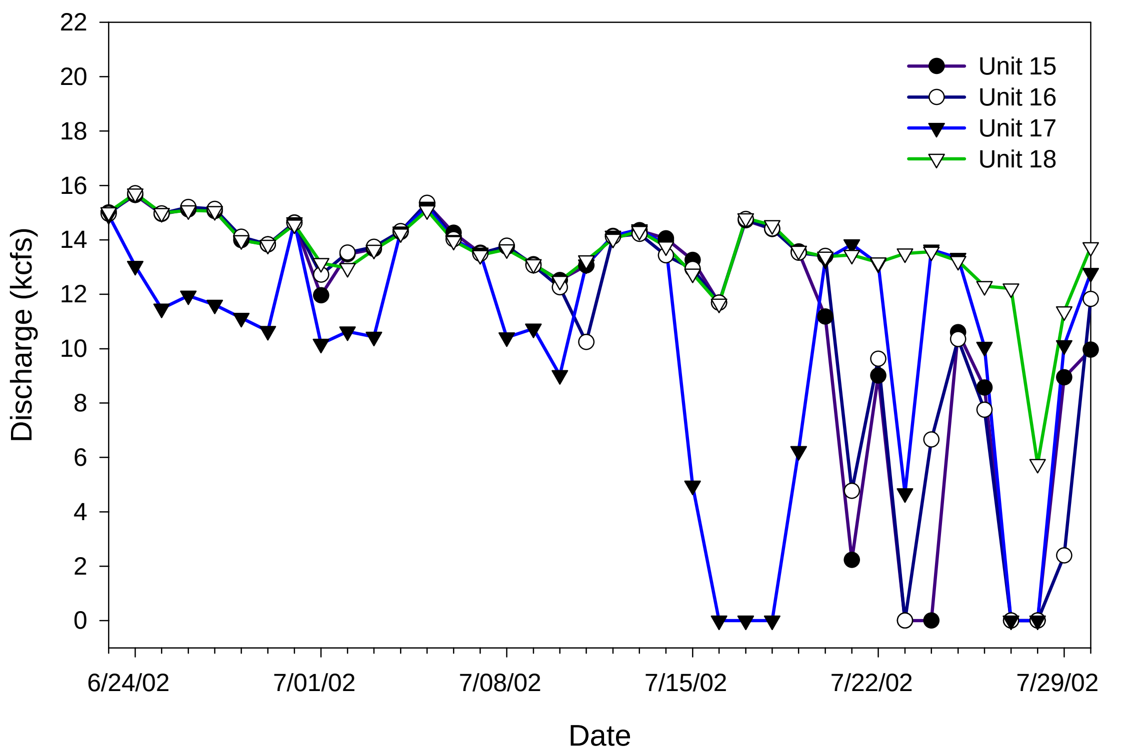

Figure 13. Mean daily discharge by unit for units 15-18 at Bonneville Dam during summer 2002.

Table 2. Mean discharge (kcfs) during day (0500-2059 hours) and night (2100-0459 hours) by dam area during summer 2002.

Dam Area	Period	Percent (of mean)	Mean	Median	Min	Max
B1	Day	17.5	39.2	42.1	0.0	90.9
B2	Day	42.3	94.8	100.2	0.0	138.7
Spillway	Day	40.3	90.4	92.4	0.0	193.3
B1	Night	15.0	35.4	33.5	0.6	89.3
B2	Night	36.3	85.7	92.7	0.0	134.8
Spillway	Night	48.8	115.3	113.9	56.1	193.4

3.3 Travel to and Arrival at Bonneville Dam

At Bonneville Dam, we detected 78% (2,614 of 3,357) of the subyearling Chinook salmon that were released from all of the upstream sites. The median travel rates from release site to first detection at Bonneville Dam were 2.1 km/h for fish released from Rock Creek and 2.5 km/h for fish released from both John Day Dam and The Dalles Dam. The corresponding median travel times from release to first detection at Bonneville Dam were 64.4 h from Rock Creek, 45.6 h from John Day Dam, and 29.1 h from The Dalles Dam (Table 3).

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

Release Site	Mean	Median	Min	Max
Rock Creek	69.5 (2.1)	64.4 (2.1)	32.9 (0.8)	177.7 (4.1)
John Day Dam	48.5 (2.4)	45.6 (2.5)	29.1 (0.6)	189.0 (3.9)
The Dalles Dam	31.5 (2.5)	29.1 (2.5)	16.7 (1.0)	76.0 (4.4)

Fish did not enter dam areas (i.e., B1, B2, and spillway) in equal proportions. Of the fish detected at Bonneville Dam, 15% (394 of 2,614) first entered B1 forebay, 28% (730 of 2,614) first entered B2 forebay, and 57% (1,490 of 2,614) first entered the spillway forebay. Differences in the number of fish entering the forebay of each dam area appeared to be related to allocation of river discharge among dam areas. Discharge at B1, B2, and the spillway represented 17%, 40%, and 43%, 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. At B1 and B2, daily proportions of fish fluctuated somewhat with the proportion of daily discharge (Figure 14). The higher proportion of discharge at the spillway compared to the powerhouses was likely the largest contributing factor to the higher number of fish that entered the spillway forebay. Similarly, we compared the hourly proportion of fish entering each dam area to the hourly proportion of mean discharge through each dam area. Although we found no relation between hourly discharge and fish entrance, we did see a relation between fish entrance and time of day. Hourly discharge was fairly constant at each dam area; however, most fish entered B2 at night and the spillway during morning hours (Figure 15).

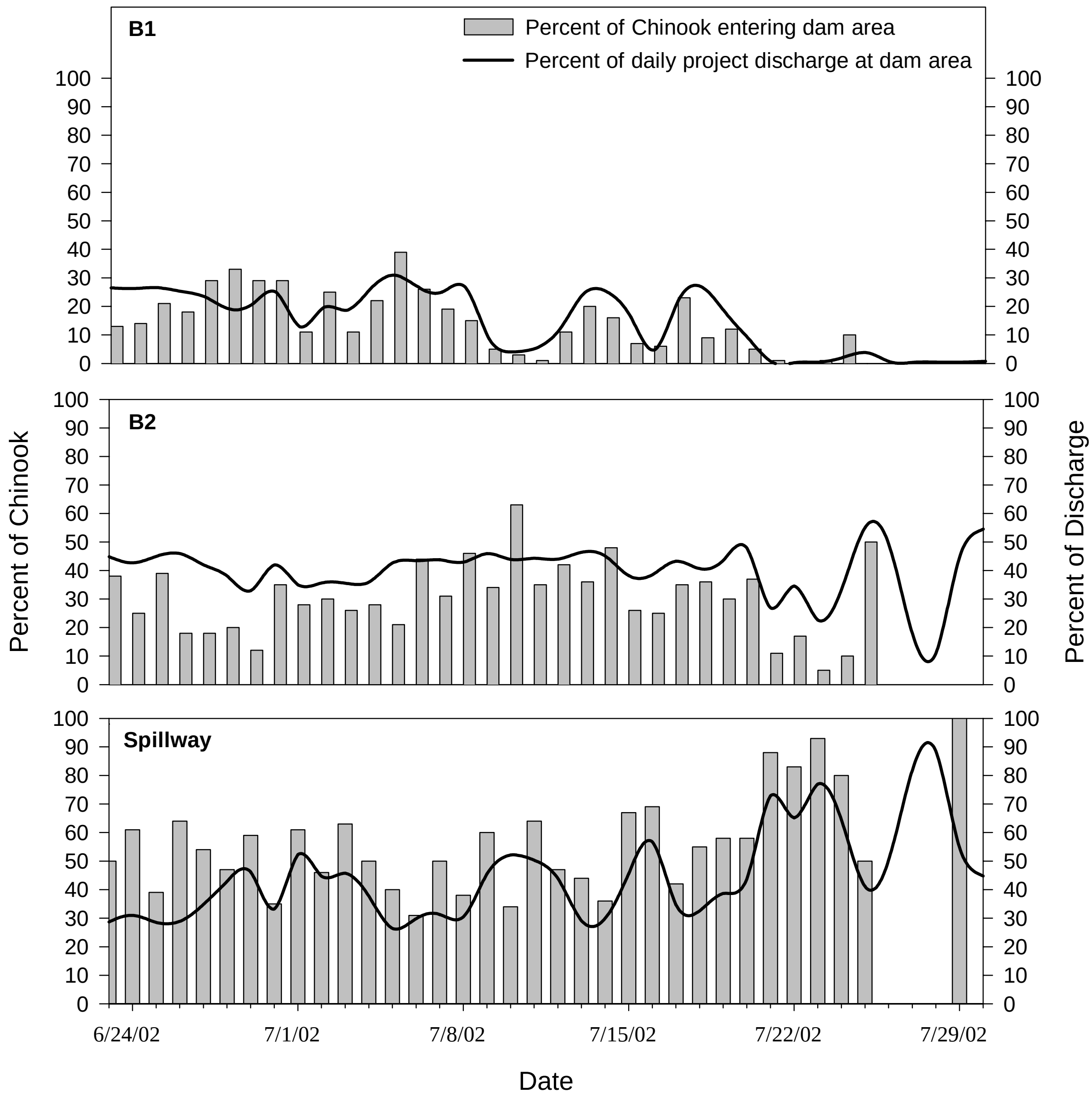

Figure 14. The percentage of subyearling Chinook salmon that entered each dam area versus the percentage of mean discharge at each dam area by day during summer 2002.

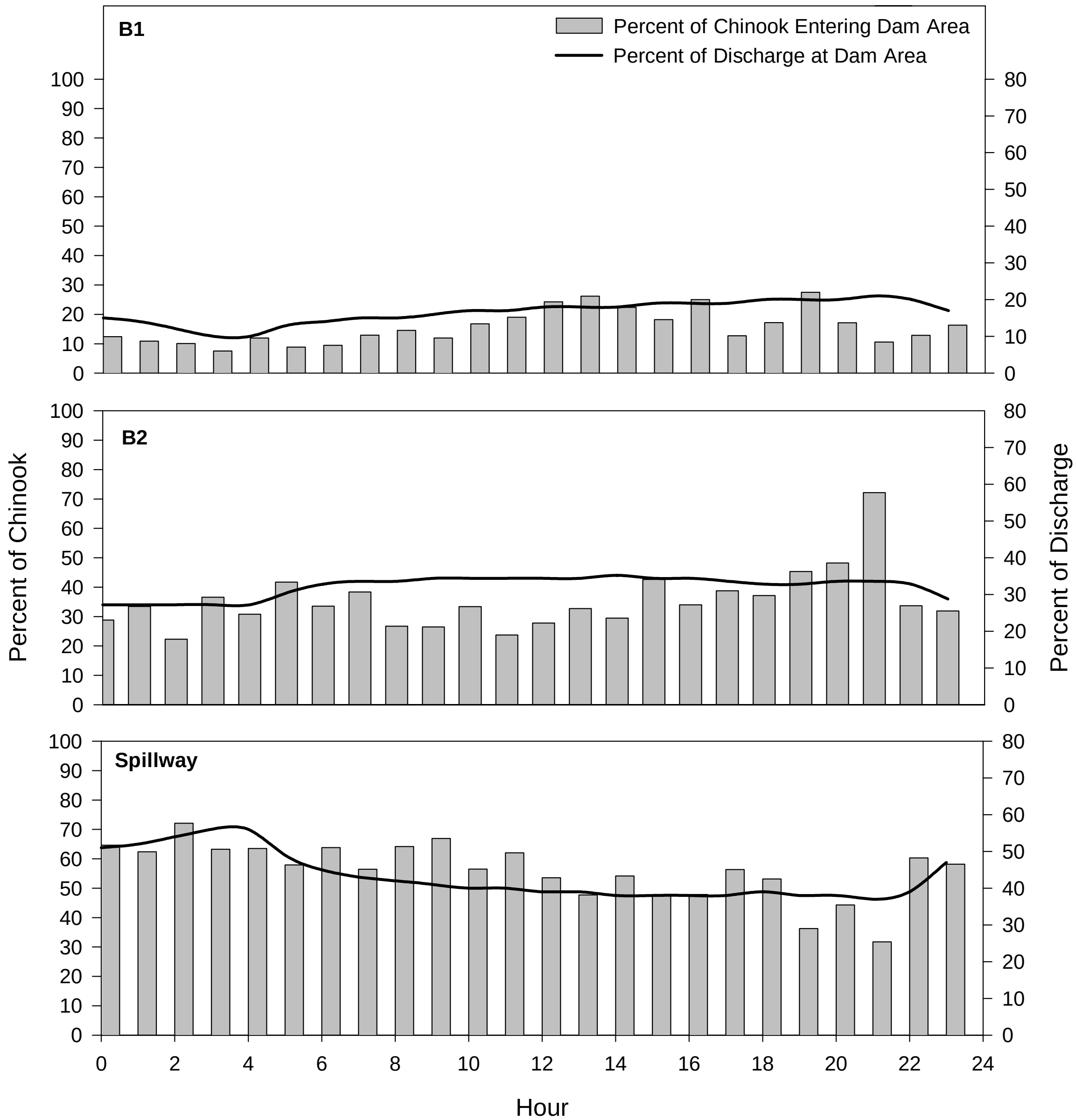

Figure 15. The percentage of subyearling Chinook salmon that entered each dam area versus the percentage of mean discharge at each dam area by hour of day during summer 2002.

3.4 Residence Time in the Forebay

Forebay residence time (time from first detection until time of passage) differed between dam areas. Subyearling Chinook salmon resided considerably longer in the powerhouse forebays (B1 median = 1.8 h and B2 median = 1.1 h) than in the forebay of the spillway (3 min; 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 and 2).

Table 4. Descriptive statistics of forebay residence time (h) for radio-tagged subyearling Chinook salmon at Bonneville Dam during summer 2002. Note: 36 fish that passed at a dam area different than the one they first entered and 792 fish with one or no detections in the forebay were excluded from calculations of forebay residence time.

Dam Area	*N*	Mean	Median	Min	Max
B1	281	4.2	1.8	0.01	41.7
B2	328	3.5	1.1	0.01	54.22
Spillway	1,107	0.5	0.05	0.01	27.5
All areas	1,716	1.7	0.11	0.01	54.22

3.5 Route and Time of Passage Through Bonneville Dam

We determined the route of passage through Bonneville Dam for 97% (2,544 of 2,626) of subyearling Chinook salmon detected at the dam. A passage route could not be determined for 1.6% (41 of 2,626) of fish detected at the dam and an additional 1.6% (41 of 2,626) were not detected below the dam. Among the three dam areas, the spillway passed the most fish (59%, 1,498 of 2,543), while 27% passed at B2 (682 of 2,543) and 14% passed at B1 (364 of 2,543) (Figure 16). These percentages are similar to the percentages of fish that first entered each dam area: 57% at the spillway, 28% at B2, and 15% at B1. Therefore, 1% of the fish that first entered B1 and 1% of the fish that first entered B2 eventually passed at the spillway.

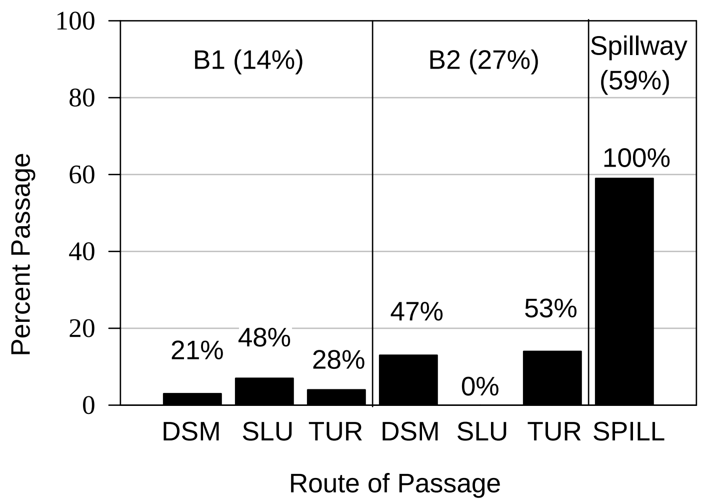

Figure 16. Percent fish passage by dam area and route of passage through Bonneville Dam for radio-tagged subyearling Chinook salmon during summer 2002. B1 = powerhouse one; B2 = powerhouse two; DSM = Downstream Migrant Channel; SLU = sluiceway; TUR = turbine. Percentages in parenthesis designate proportions between dam areas, percentages without parenthesis designate proportions within dam area, and the percent value of the bars represent proportions of all routes.

At B1, of the fish with known passage routes, 48% (175 of 364) passed via the sluiceway, 28% (103 of 364) passed unguided through the turbines, 21% (78 of 364) were guided into the DSM, and 2% (8 of 364) passed through the navigation lock. An additional 19 fish passed B1 through undetermined routes. At B2, of the fish with known passage routes, 53% (364 of 682) passed unguided through the turbines and 47% (317 of 682) were guided into the DSM (Figure 16). The spillway passed 1,498 fish and 41 fish passed through an unknown dam area.

Passage of subyearling Chinook salmon peaked at 2200 hours and was lowest at 2000 hours (Figure 17). For the entire dam, a higher number of fish passed during the day (1,534) compared to night (1,025; Table 5). However, at B2, more fish passed at night (57%; 388 of 681) compared to day. Based on the number of hours in each diel period (16 for day, 8 for night), passage rates were higher at night at all three dam areas (Table 6).

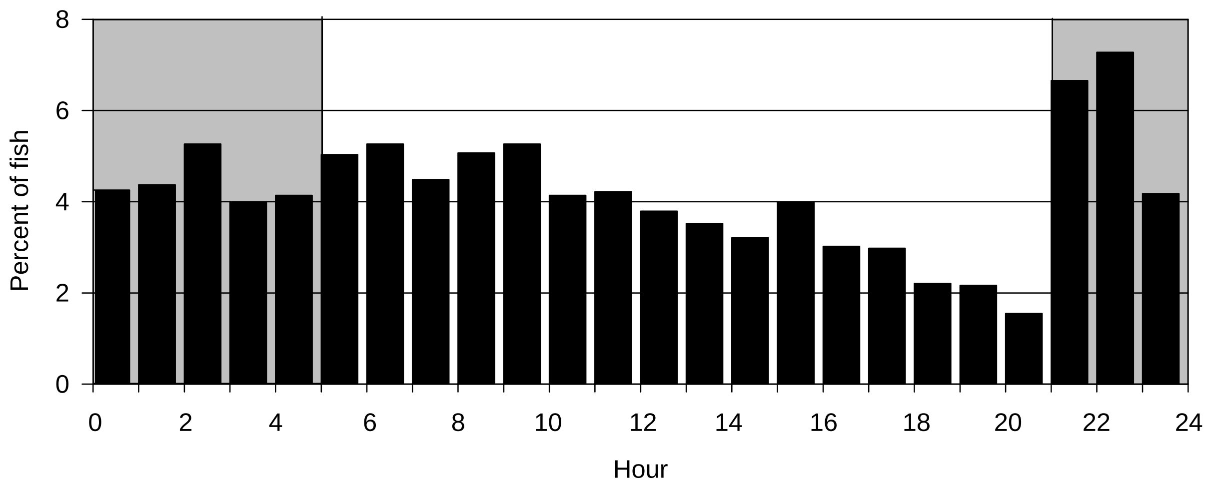

Figure 17. Percent passage during day (0550-2059 hours) and night (2100-0459 hours) for radio-tagged subyearling Chinook salmon at Bonneville Dam during summer 2002.

Route-specific passage in regard to the diel cycle also indicated the majority of fish passed during day. Regardless of route, more fish passed during day than night at B1 and the spillway (Figure 18). At the spillway, 66% (991 of 1,498) of fish passed during the day. At B1, 83% of fish that passed through the sluiceway, 75% of fish that passed through the navigation lock, 49% of unguided fish, and 40% of guided fish passed Bonneville Dam during the day. At B2, most fish passed during the night (52% of unguided fish and 65% of guided fish).

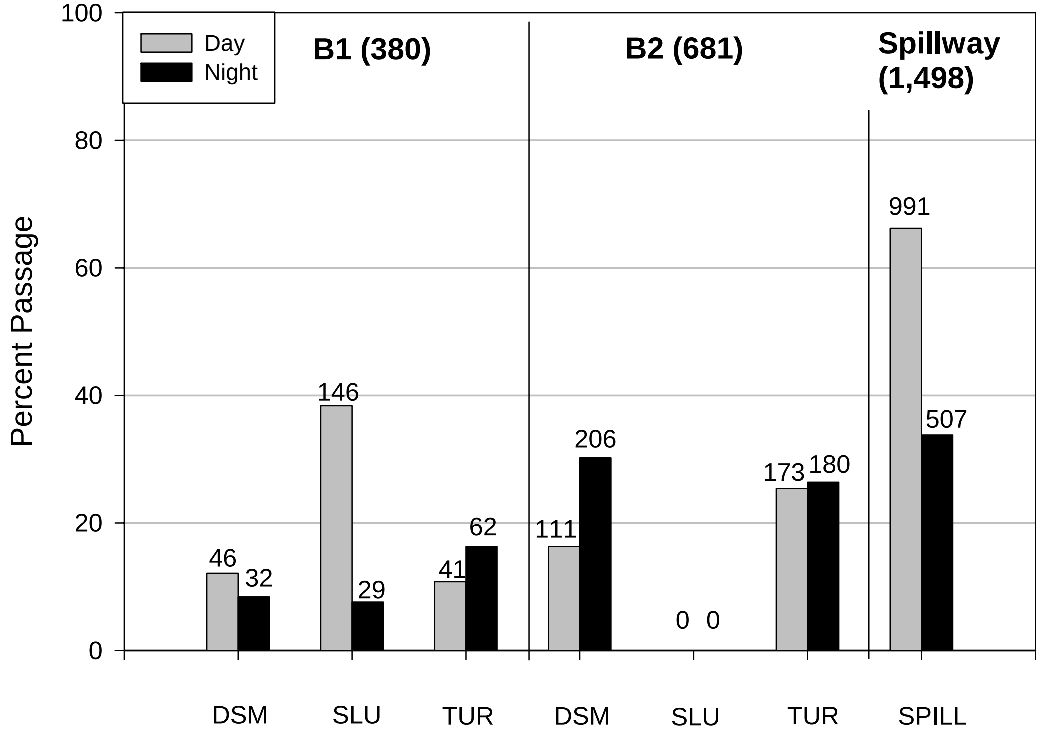

Figure 18. Percent passage by route of passage during day (0500-2059 hours) and night (2100-0459 hours) for radio-tagged subyearling Chinook salmon at Bonneville Dam during summer 2002. B1 = powerhouse one; B2 = powerhouse two; DSM = Downstream Migrant Channel; SLU = sluiceway; TUR = turbine.

Table 5. The proportion of radio-tagged subyearling Chinook salmon that passed each dam area of Bonneville Dam by day (0500-2059 hours) and by night (2100-0459 hours) during summer 2002.

Period	B1 Passage	B2 Passage	Spill Passage
Day	16.3% (250 of 1534)	19.1% (293 of 1534)	64.6% (991 of 1534)
Night	12.7% (130 of 1025)	37.9% (388 of 1025)	49.4% (507 of 1025)

Table 6. Passage rates for radio-tagged subyearling Chinook salmon at each dam area of Bonneville Dam during day (0500-2059 hours) and night (2100-0459 hours) during a 35 d test period in summer 2002. Powerhouse one = B1 and powerhouse two = B2.

Dam Area	Day	Night
B1	$250\text{ fish} \div \left(16\text{ h/d} \times 35\text{d}\right) = 0.45\text{ fish/h}$	$130\text{ fish} \div \left(8\text{ h/d} \times 35\text{d}\right) = 0.46\text{ fish/h}$
B2	$293\text{ fish} \div \left(16\text{ h/d} \times 35\text{d}\right) = 0.52\text{ fish/h}$	$388\text{ fish} \div \left(8\text{ h/d} \times 35\text{d}\right) = 1.39\text{ fish/h}$
Spillway	$991\text{ fish} \div \left(16\text{ h/d} \times 35\text{d}\right) = 1.77\text{ fish/h}$	$507\text{ fish} \div \left(8\text{ h/d} \times 35\text{d}\right) = 1.81\text{ fish/h}$

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 subyearling Chinook salmon passed through the spillway and of the three spill treatments, TDG Day was the most efficient, passing 71% of fish relative to all other passage routes. Spillway efficiency varied significantly among spill treatments ($X^2 = 126.82$, df = 2, $P < 0.001$) and the TDG Day spill treatment was significantly greater than both the Day Cap (Tukey test; q =15,00, df = 3, $P < 0.05$) and the TDG Night (Tukey test; q = 11.70, df = 3, $P < 0.05$) treatments.

Table 7. Spillway Efficiency at Bonneville Dam for subyearling Chinook salmon during summer 2002. Mean discharge spilled during each treatment is shown in parenthesis. SE = standard error of spillway efficiency estimate; B1 = powerhouse one; B2 = powerhouse two.

Spill Treatment	Efficiency	SE	B1 Passage	B2 Passage	Spill Passage
Overall	0.58	0.97%	383	692	1,498
Day Cap (57 kcfs)	0.45	2.0%	126	214	274
TDG Day (110 kcfs)	0.71	1.4%	139	163	738
TDG Night (120 kcfs)	0.53	1.6%	118	315	486

3.6.2 Spillway Effectiveness

Spillway effectiveness is the proportion of fish that passed through spill relative to the proportion of discharge spilled. Subyearling Chinook salmon had an overall spillway effectiveness of 1.3 and the Day Cap treatment had the highest effectiveness (1.7; Table 8).

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

Spill Treatment	Effectiveness	Efficiency	F_{sp}	F_{tot}
Overall	1.3	0.58	98.7	228.5
Day Cap (57 kcfs)	1.7	0.45	56.8	213.5
TDG Day (110 kcfs)	1.5	0.71	109.8	229.1
TDG Night (120 kcfs)	1.0	0.53	119.8	237.0

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 B2 than at B1 overall and during all spill treatments except for TDG Day (Table 9). Fish guidance efficiency was highest at B1 during TDG Day treatment and at B2 during Day Cap Treatment.

The most efficient units at guiding juvenile Chinook salmon were units 10 (B1) and 14 (B2), which guided 81% and 60%, respectively (Tables 10 and 11). The majority of fish (73%) passed B1 at the northern end through units 6-10, while the majority at B2 (59%) passed at the southern end through units 11-14. Guidance efficiencies at B1 were highest for the outside units (2 and 10) and at B2, FGEs were highest at the center of the powerhouse (units 13-15).

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 subyearling Chinook salmon during summer 2002. Mean discharge spilled during each treatment is shown in parenthesis.

Treatment	B1	SE	B2	SE
Overall	43% (78 of 181)	3.7%	47% (317 of 681)	1.9%
Day Cap (57 kcfs)	44% (14 of 32)	8.9%	59% (124 of 210)	3.4%
TDG Day (110 kcfs)	57% (36 of 63)	6.3%	36% (57 of 158)	3.8%
TDG Night (120 kcfs)	38% (28 of 86)	5.1%	43% (136 of 313)	2.8%

Table 10. Estimates of Fish Guidance Efficiency (FGE) by turbine unit at Bonneville Dam's first powerhouse (B1) for radio-tagged subyearling Chinook salmon during summer 2002. These estimates do not include 19 guided Chinook salmon that passed through unknown units at B1. Units 1 and 5 (not shown) did not operate.

2	3	4	6	7	8	9	10
44% (7 of 16)	27% (3 of 11)	25% (4 of 16)	13% (2 of 15)	21% (6 of 28)	29% (6 of 21)	22% (5 of 23)	81% (26 of 32)

Table 11. Estimates of Fish Guidance Efficiency (FGE) by turbine unit at Bonneville Dam's second powerhouse (B2) for radio-tagged subyearling Chinook salmon during summer 2002. These estimates do not include 22 unguided and 27guided Chinook salmon that passed through unknown units at B2.

11	12	13	14	15	16	17	18
23% (17 of 73)	43% (18 of 42)	51% (54 of 106)	60% (91 of 151)	54% (75 of 138)	37% (27 of 73)	22% (6 of 27)	9% (2 of 22)

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 82% (SE 0.8%) overall for subyearling Chinook salmon. FPE was highest (88%; SE 1.0%) during the TDG Day spill level and lowest (74%; SE 1.5%) during the TDG Night spill level (Table 12). Fish passage efficiency varied significantly among spill treatments ($X^2 = 57.72$, df = 2, $P < 0.001$). FPE during TDG Day spill was significantly (Tukey test; $q = 8.31$, df = 3, $P < 0.05$) greater than during TDG Night spill. Likewise FPE during Day Cap spill was significantly (Tukey test; $q = 3.92$, df = 3, $P < 0.05$) greater than during TDG Night spill. However, FPE during TDG Day was not significantly different (Tukey test; $q = 2.68$, df = 3, $P < 0.05$) than FPE during Day Cap spill.

Table 12. Fish passage efficiency (FPE) at Bonneville Dam for radio-tagged subyearling Chinook salmon during summer 2002. Numbers do not include eight Chinook salmon that passed through the navigation lock and one Chinook salmon that passed through the adult ladder at B2. Those fish are, however, included in calculations of FPE. B1 = powerhouse one; B2 = powerhouse two.

Treatment	FPE	B1 Guided	B1 Sluiceway	B2 Guided	Spillway	B1 Unguided	B2 Unguided
Overall	0.82	78	175	317	1,498	103	364
Day Cap	0.83	14	87	124	274	18	86
TDG Day	0.88	36	64	57	738	27	101
TDG Night	0.74	28	24	136	486	58	177

3.7 Comparison of Passage Performance Metrics as Measured by RadioTelemetry 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. Because the summer monitoring period for radio telemetry ended later than hydroacoustics monitoring, passage metrics were calculated for each research tool using data from overlapping time periods (June 23 – July 15) to facilitate comparison of the two techniques. With the exception of spillway efficiency and sluiceway efficiency$_{B1}$, passage performance estimates were very similar between the two methods, and were usually well within 10% of each other (Table 13). Estimates of spillway efficiency differed by 14% and estimates of sluiceway efficiency$_{B1}$ differed by 16%.

Estimates of FGE by unit at B2 between radio telemetry and hydroacoustics were within 5% at units 12-14, but differed by as much as 44% at unit 17 (Table 14). 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 4.0-8.1%. The hydroacoustics study did not provide unit-specific FGE estimates for B1 so no comparisons were made between the two methods.

Table 13. Comparison of passage performance metrics for subyearling Chinook salmon, as measured by radio telemetry (RT), and the run-at-large, as measured by hydroacoustics (HA), at Bonneville Dam during summer (overlapping period of June 23-July 15) 2002. Hydroacoustic data were provided by Carl Schilt, MEVATEC Corporation, (March 18, 2002; revised July 19, 2006).

Metric	RT estimate	HA estimate	Difference
Spillway efficiency	54%	41%	13% (RT > HA)
Spillway effectiveness	1.4	1.1	0.3 (RT > HA)
Sluiceway efficiency$_{B1}$	45%	29%	16%(RT > HA)
Sluiceway effectiveness$_{B1}$	37	25	12 (RT > HA)
Sluiceway efficiency$_{Project}$	7%	11%	4% (RT < HA)
Sluiceway effectiveness$_{Project}$	29	43.8	14.8 (RT < HA)
FGE$_{B1}$	44%	48%	4% (RT < HA)
FGE$_{B2}$	44%	50%	6% (RT < HA)
FPE	79%	76%	3% (RT > HA)
FPE$_{B1}$	70%	63%	7% (RT > HA)
FPE$_{B2}$[a]	44%	50%	6% (RT < HA)

[a]FPE$_{B2}$= FGE$_{B2}$ since no fish could pass through closed sluice chute at B2.

Table 14. Estimates of Fish Guidance Efficiency (FGE), by turbine unit, at Bonneville Dam's second powerhouse (B2) for subyearling Chinook salmon, as measured by radio telemetry (RT), and for the run-at-large, as measured by hydroacoustics (HA), during summer (overlapping period of June 23- July 15) 2002. Hydroacoustic data were provided by Carl Schilt, MEVATEC Corporation (March 18, 2002).

Location	RT FGE	HA FGE	Difference
Unit 11	23%	38%	15% (RT < HA)
Unit 12	43%	48%	5% (RT < HA)
Unit 13	51%	53%	2% (RT < HA)
Unit 14	60%	57%	3% (RT > HA)
Unit 15	54%	65%	11% (RT < HA)
Unit 16	37%	25%	12% (RT > HA)
Unit 17	22%	66%	44% (RT < HA)
Unit 18	9%	35%	26% (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 19). Of the 78 subyearling Chinook salmon that were guided into the B1 DSM, we detected 63 at the down-well. Subyearling Chinook salmon resided in the down-well for a median 38.2 s (range, 4.0 s - 2.3 min) and therefore were not considered to be 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 hold within the slots (Figure 20). At B1, of the 103 subyearling Chinook salmon that passed through the turbines unguided, we detected 38 (37%) at the taillog slot antennas. Of those fish detected at the B1 taillog slots, only eight were detected more than once and had a median residence time of 18 s (range, 4 s - 3.1 h). At B2, of the 364 subyearling Chinook salmon that passed through the turbines unguided, we detected 125 (34%) at the taillog slot antennas. Of those fish detected at the B2 taillog slots, only 48 were detected more than once and had a median residence time of 18 s (range, 4 s - 4.6 min). Based on median residence times, subyearling Chinook salmon were not delayed within the taillog 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 21). 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 1,862 subyearling Chinook salmon that passed through the spillway and B2 turbines unguided, 76 (4.1%) were detected at the Cascades Island eddy for a median 37.1 s. The residence times ranged from 4 s to 74.1 h, however, only 12 fish resided greater than 2.5 h with the remainder residing between 4 s and 45.6 min. Based on the number of fish that were detected at the eddy, 16% of subyearling Chinook salmon 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

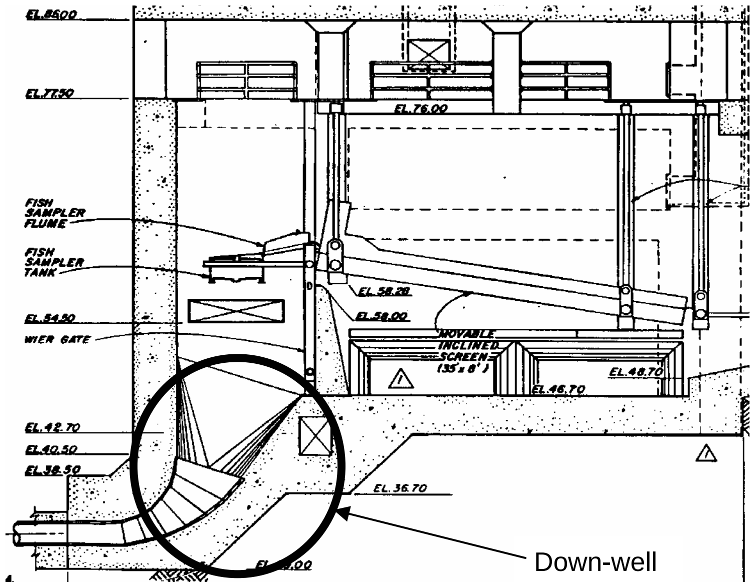

Figure 19. Cross-sectional view of the fish sampler and down-well area (circled) located at the downstream end of the downstream salmonid migrants channel (DSM) at Bonneville Dam's first powerhouse. Image source: U.S. Army Corps of Engineers.

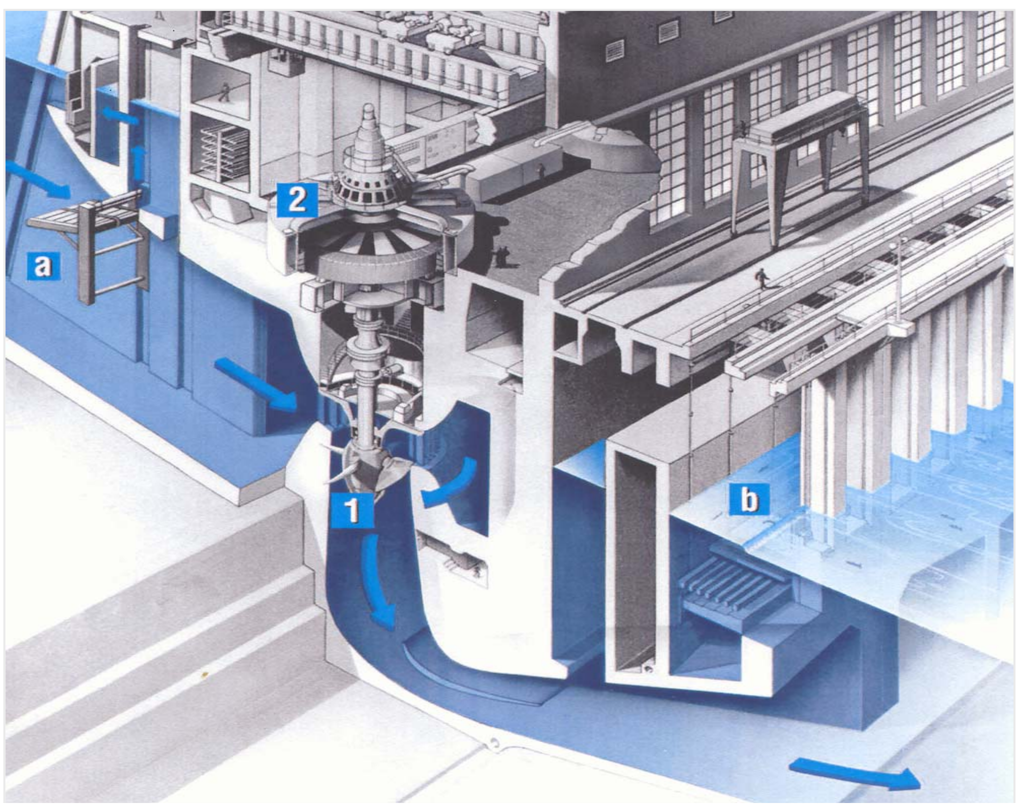

Figure 20. Cross-sectional view of Bonneville Dam's first powerhouse (B1) showing the taillog slots. The taillog slots at the second powerhouse (B2) are similar to those at B1.

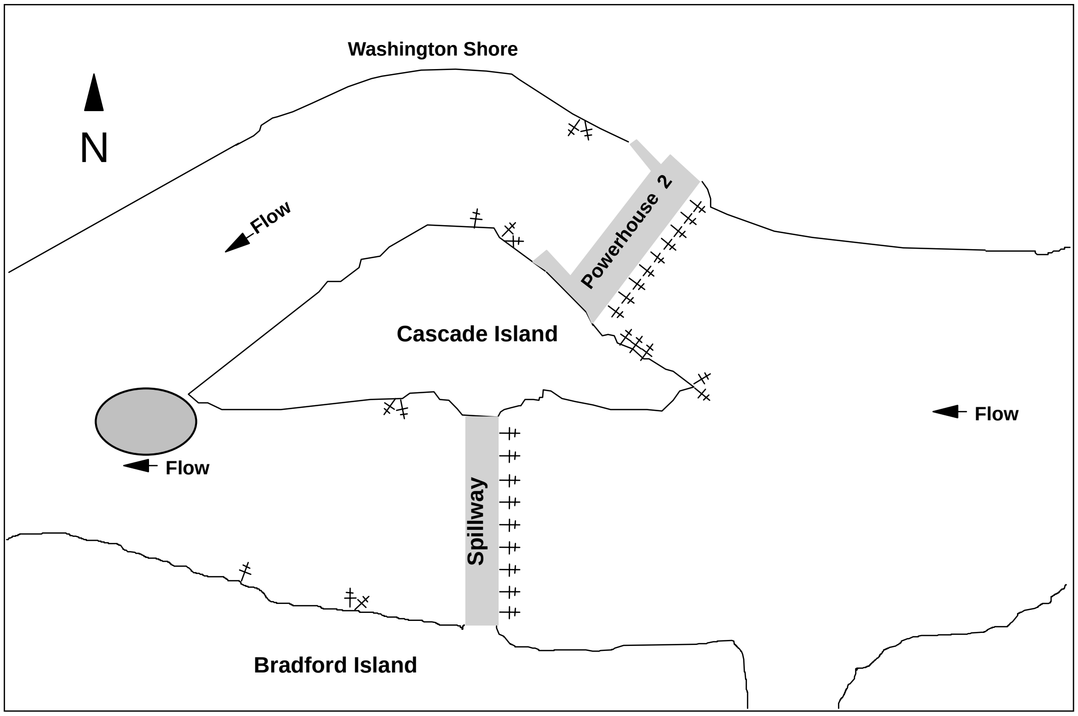

Figure 21. Plan view of Cascades Island Eddy (represented by oval) at Bonneville Dam during summer 2002.

eddy area, only 0.6% of subyearling Chinook salmon 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 15).

Table 15. Median travel times (min) for subyearling Chinook salmon passing through Bonneville Dam's second powerhouse juvenile bypass system conveyance pipe during summer study periods of 1999-2002.

	1999	2000	2001	2002
Subyearling Chinook salmon	41.3[a]	36.5	38.1	35.9

[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. Fish appeared to follow the bulk flow during approach to Bonneville Dam, entering the dam area with the highest proportion of discharge. Since the spillway discharged the greatest amount of water during the study (43%) most fish entered the spillway forebay (57%). Likewise, since the least discharge occurred at B1 (17% of project discharge), only 15% of subyearling Chinook salmon entered that dam area.

Our results also showed that forebay residence times of subyearling Chinook salmon were also largely defined by discharge. The spillway provided the quickest route of passage as residence times there were substantially less than at both powerhouses. Subyearling Chinook took a median 3 min to pass the spillway but spent nearly 2 h in the forebay of B1 and just over 1 h in the forebay of B2. 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 subyearling Chinook salmon. These observations indicate that project operations and the resulting discharge per dam area influence approach paths of migrating subyearling Chinook salmon 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.

Although some movement occurred between the three dam areas (B1, B2, and the spillway), most fish passed through the dam area they first entered. Only 1% of the fish that first entered B1 and B2 eventually passed at the spillway. Therefore, project discharge was the primary factor in affecting not only approach behavior but also which dam area fish ultimately passed.

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 fish passed through the shallow, weir-type entrance of the sluiceway (48%), followed by the deeper unguided (28%) and guided (21%) routes of passage. At B2, where a shallow, surface-oriented route of passage was unavailable because of the closure of the sluice chute, more fish passed directly through the turbines (53%) than were guided into the DSM (47%).

Diurnal passage distributions did not appear to be influenced by discharge, which was nearly equal during day and night at all dam areas. The higher proportion of fish that passed B1, B2 and the spillway at night (based on the number of hours in each diel period) concurs 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 nearly equal passage rates for day and night 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 subyearling Chinook salmon in 2002 were similar to those in 2000 and higher than in 2001, with the exception of FGE_{B1} and FPE_{B1} (Table 16). Passage metrics increased in 2002 primarily due to higher river flows compared to 2001. Greater river flows enabled more spill and resulted in much higher spillway efficiency compared to 2001. Lower passage metrics at B1 in 2002 might be explained by increased discharge at B1 which entrained a higher percentage of fish in turbine flow and thereby decreased the number of fish available to the surface-oriented sluiceway. Results from our 2002 study indicate that although the current intake screen guidance systems at B1 and B2 only diverted 43% and 47% of subyearling Chinook salmon, respectively, the project FPE goal of 80% can be attained if sufficient fish are passed via a combination of non-turbine routes (spill, sluice, and turbine guidance systems).

Table 16. Passage performance metrics for radio-tagged subyearling Chinook salmon at Bonneville Dam during summer 2000, 2001 and 2002. B1 = powerhouse one and B2 = powerhouse two.

Metric	2000	2001	2002
Spillway Efficiency	65%	2%	58%
Spillway Effectiveness	1.2	0.8	1.3
FGE_{B1}	29%	57%	43%
FGE_{B2}	25%	35%	47%
FPE	91%	40%	82%
FPE_{B1}	77%	89%	72%
FPE_{B2}	25%	35%	47%

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 utilize 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 44%). The smaller sample sizes utilized by radio telemetry may have contributed to these differences. However, standard errors for radio telemetry estimates were usually under 4%. 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 subyearling Chinook salmon.

5.0 Acknowledgements

We thank Blaine Ebberts, Rock Peters, Jennifer Sturgill, and other COE 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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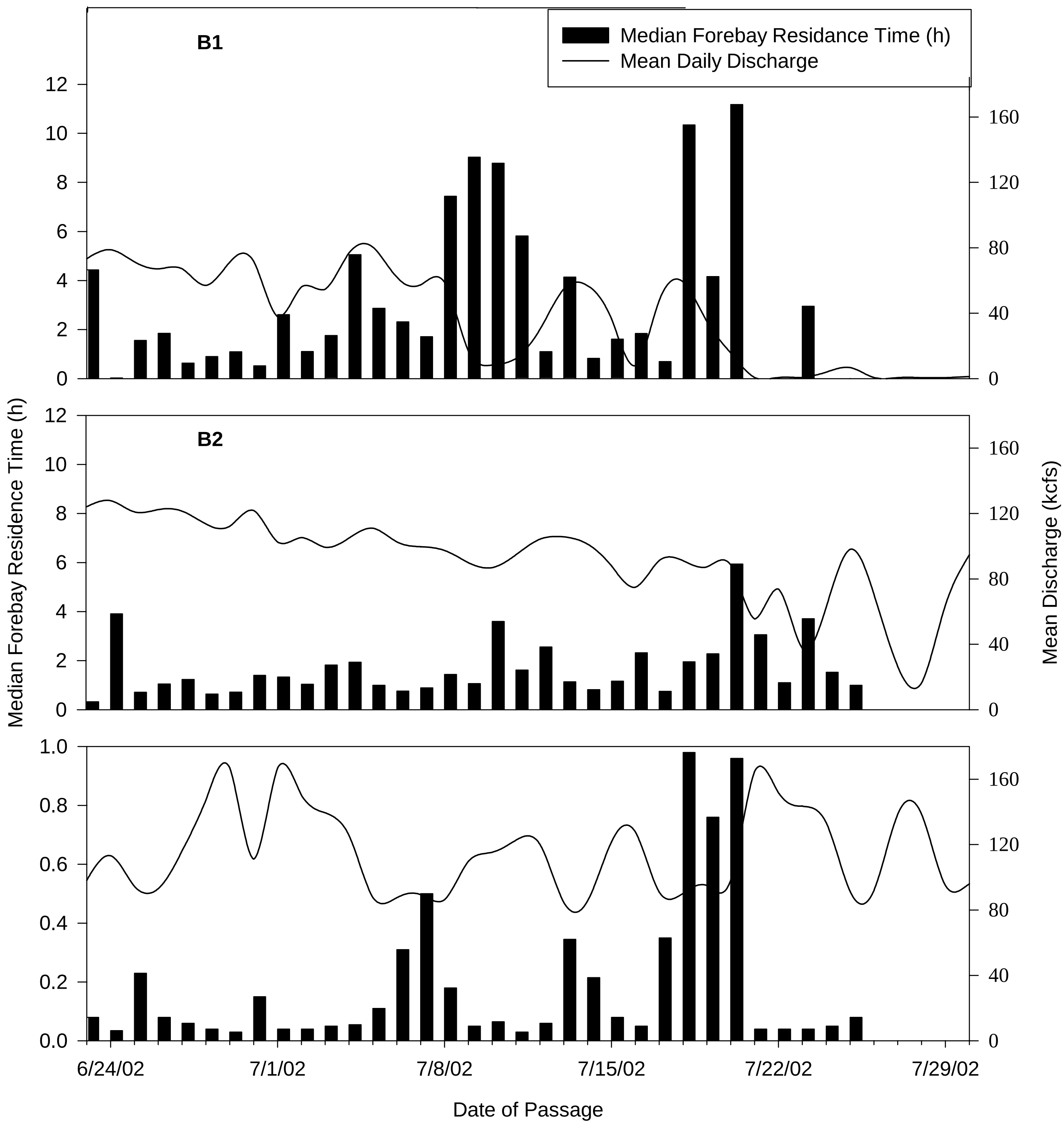
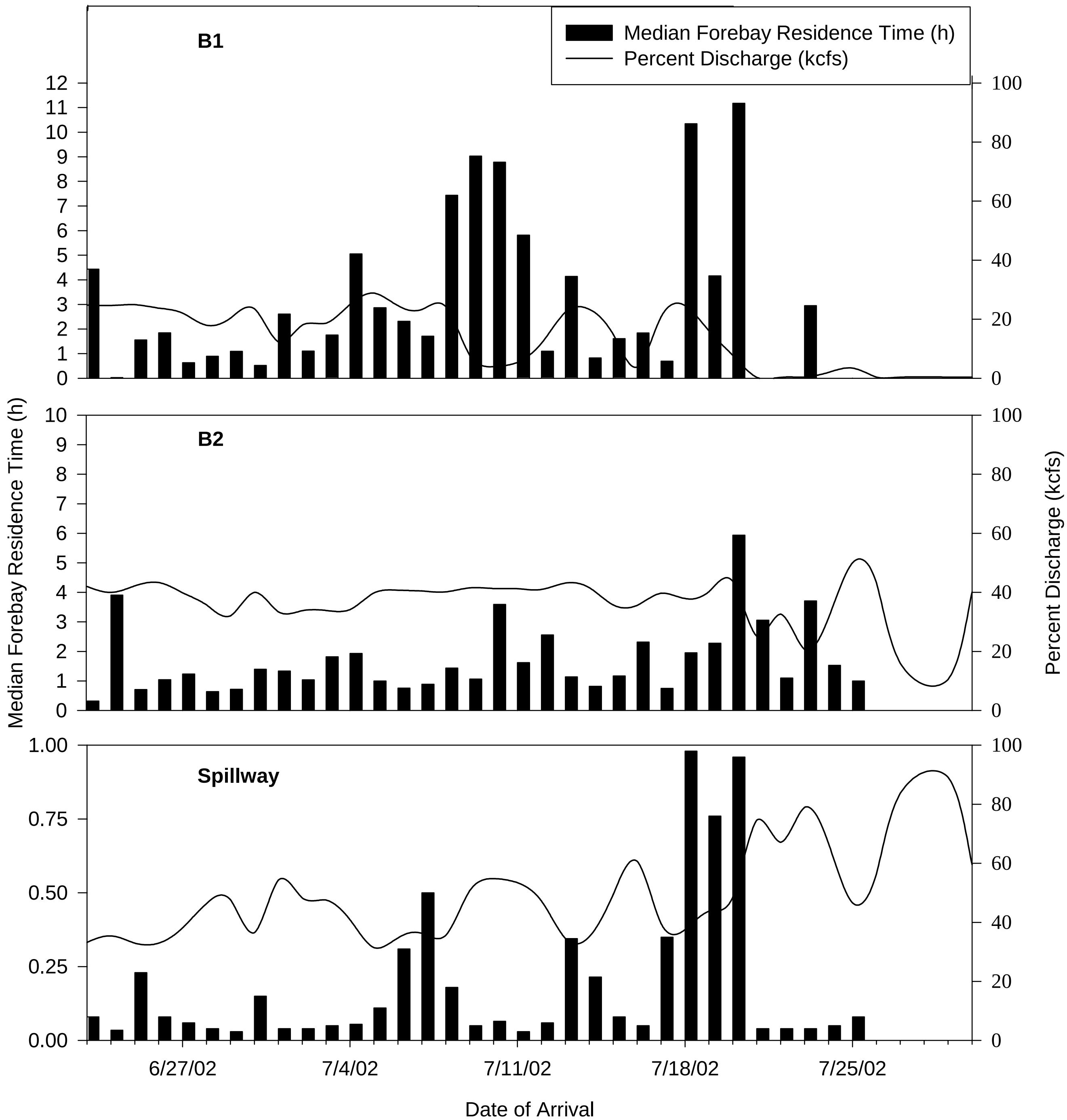
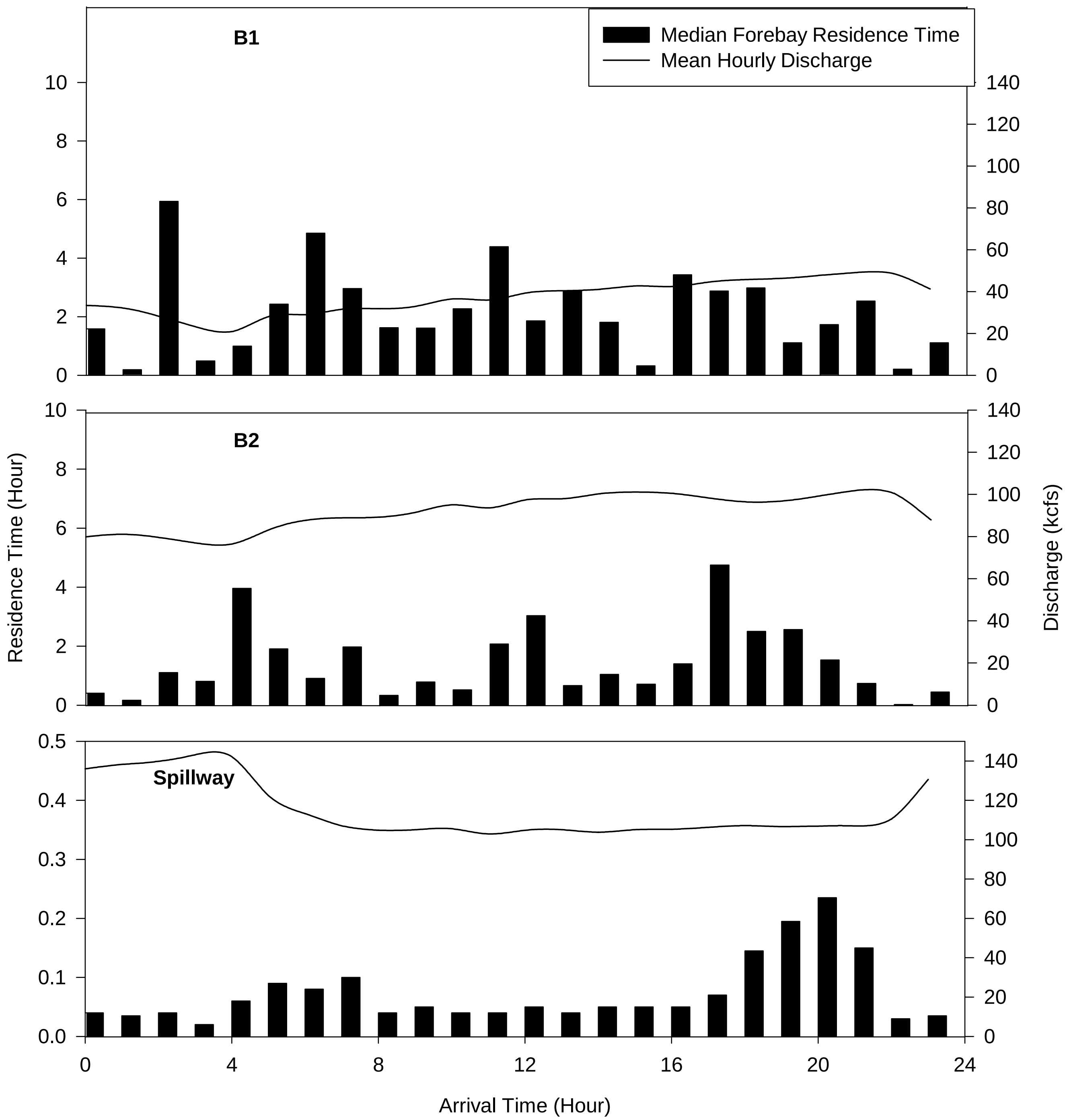
7.0 Appendices



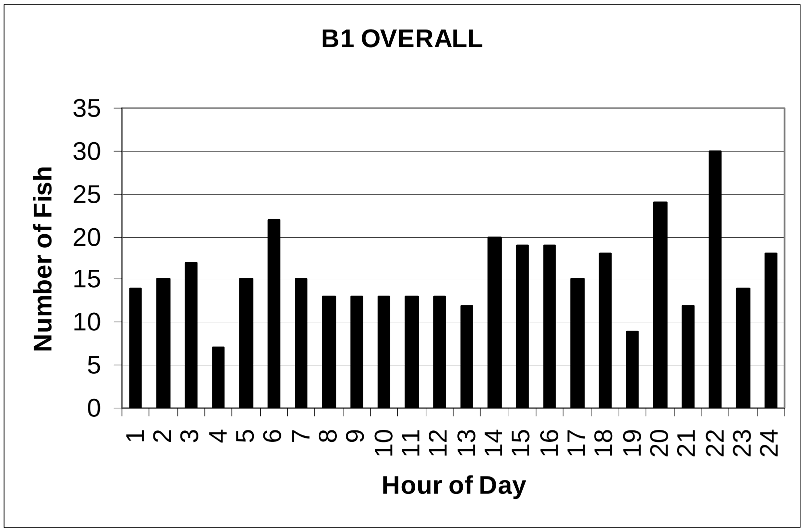
Appendix 1. Median forebay residence time by day of passage versus mean discharge by dam area for radio-tagged subyearling Chinook salmon at Bonneville Dam during summer 2002.

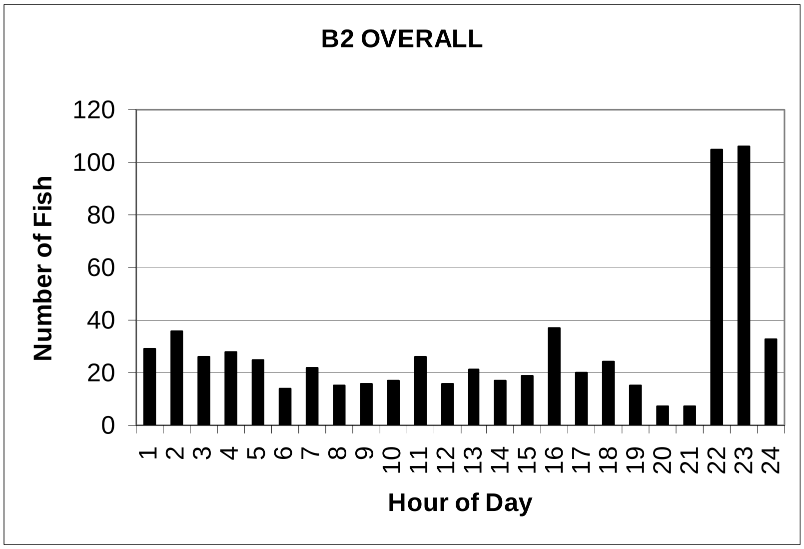


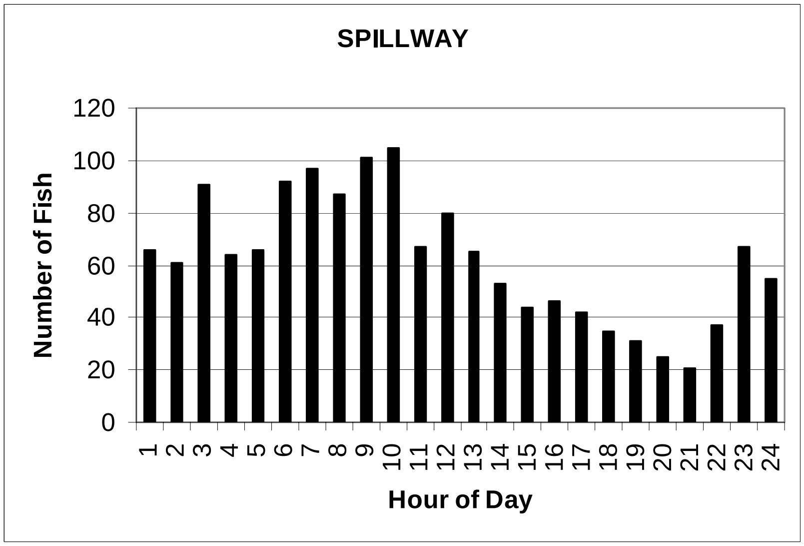
Appendix 2. Median forebay residence time by day of arrival versus mean discharge by dam area for radio-tagged subyearling Chinook salmon at Bonneville Dam during summer 2002



Appendix 3. Median forebay residence time by hour of arrival versus mean discharge by dam area for radio-tagged subyearling Chinook salmon at Bonneville Dam during summer 2002







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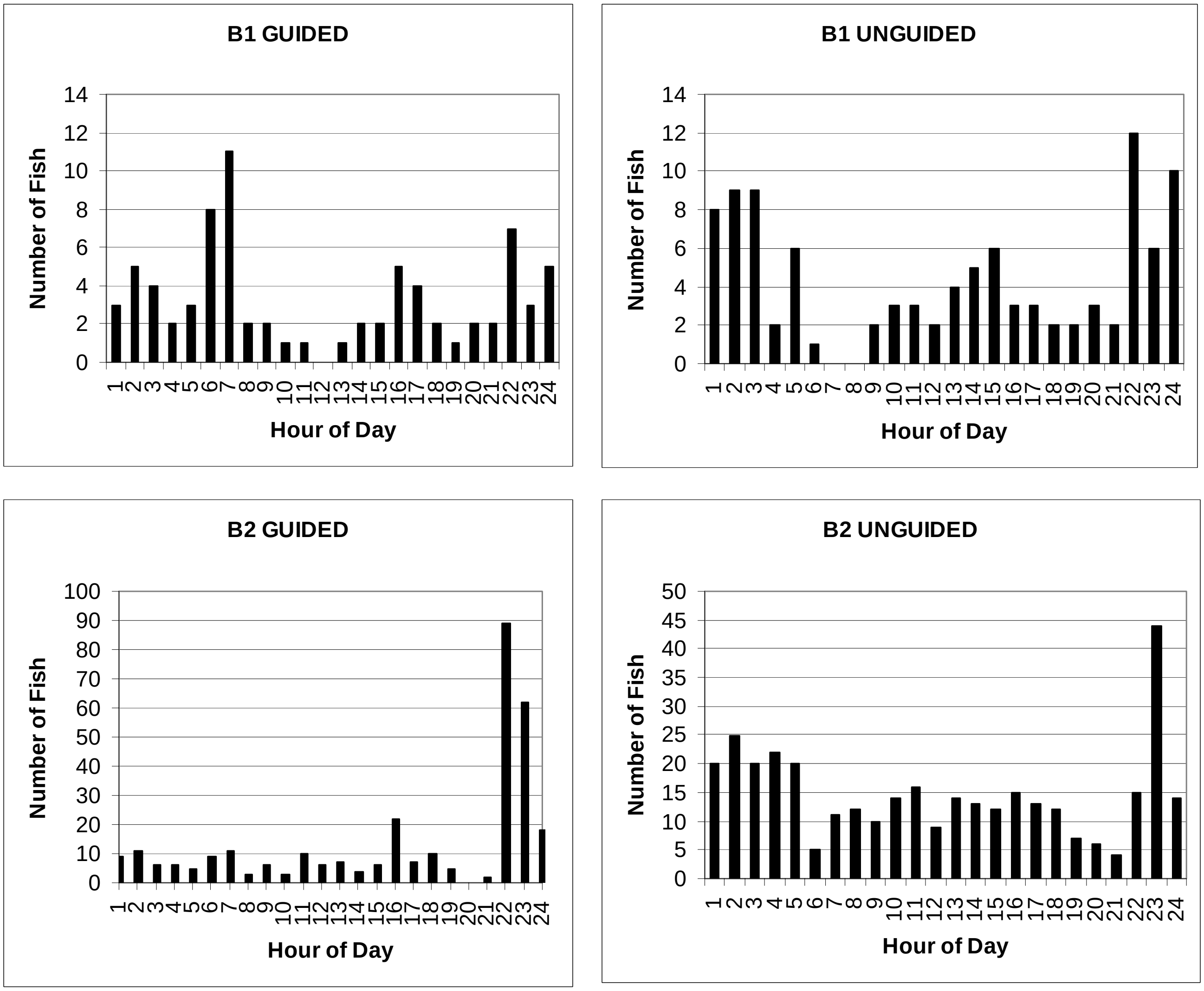
Appendix 4. Overall diurnal passage of radio-tagged subyearling Chinook salmon at Bonneville Dam during summer 2002. Note the y-axis scales differ among graphs.



Appendix 5. Diurnal passage of guided and unguided radio-tagged subyearling Chinook salmon at Bonneville Dam during summer 2002. Note the y-axis scales differ among graphs.

U.S. Army Corps of Engineers
Portland District

ADDENDUM 1

To

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

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Revised: July 20, 2006

This addendum is issued in response to a request for additional information regarding radio-telemetry data collected and reported on subyearling Chinook salmon at Bonneville Dam during summer 2002. The annual report titled "Passage Behavior of Radio-Tagged Subyearling Chinook Salmon 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 between the two spill treatments, spillway efficiency did not differ significantly for subyearling Chinook salmon (X^2 = 1.9, df = 1, P =0.16; Table 1). As stated on page 19 of the annual report, using the three spill treatments, spillway efficiency varied significantly among spill treatments (X^2 = 126.82, df = 2, P < 0.001) and the TDG Day spill treatment was significantly greater than both the Day Cap (Tukey test; q =15,00, df = 3, P < 0.05) and the TDG Night (Tukey test; q = 11.70, df = 3, P < 0.05) treatments.] Fish passage efficiency (FPE) relative to the project was significantly greater (X^2 = 4.3, df = 1, P = 0.038) for subyearling Chinook salmon during the 57 kcfs spill treatment (Table 3). Likewise, FGE at the second powerhouse (X^2 = 12.8, df = 1, P< 0.001) and sluiceway efficiency (X^2 = 10.0, df = 1, P = 0.002) were significantly greater for subyearling Chinook salmon during the 57 kcfs spill treatment (Table 4). Fish guidance efficiency at the first powerhouse was not significantly different (X^2 = 2.3, df = 1, P = 0.13 between spill treatments (Table 4).

Diel passage data was reported on page 17 (Figure 17) 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 1-12 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 subyearling Chinook salmon during summer 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
Overall	0.58	1.0%	383	692	1498
57 kcfs (81 kcfs)	0.55	2.6%	52	117	206
TDG Cap (118 kcfs)	0.59	1.1%	331	575	1292

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

Treatment	Spillway Effectiveness	Spillway Efficiency	F_{sp}	F_{tot}
Overall	1.3	0.58	98.7	228.5
57 kcfs (81 kcfs)	1.5	0.55	81.3	219.8
TDG Cap (118 kcfs)	1.2	0.59	117.7	231.7

Table 3. Fish passage efficiency (FPE) at Bonneville Dam for radio-tagged subyearling Chinook salmon during summer 2002. Numbers shown that were used to calculate FPE do not include eight fish that passed through the navigation lock and one fish that passed through the adult ladder at B2. 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
Overall	0.82	78	175	317	1498	103	364
57 kcfs	0.86	3	35	71	206	10	44
TDG Cap	0.81	75	140	246	1292	93	320

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

Treatment	B1	SE	B2	SE
Overall	43% (78 of 181)	3.7%	47% (317 of 681)	1.9%
57 kcfs	23% (3 of 13)	12.2%	62% (71 of 115)	4.6%
TDG Cap	45% (75 of 168)	3.8%	44% (246 of 566)	2.1%

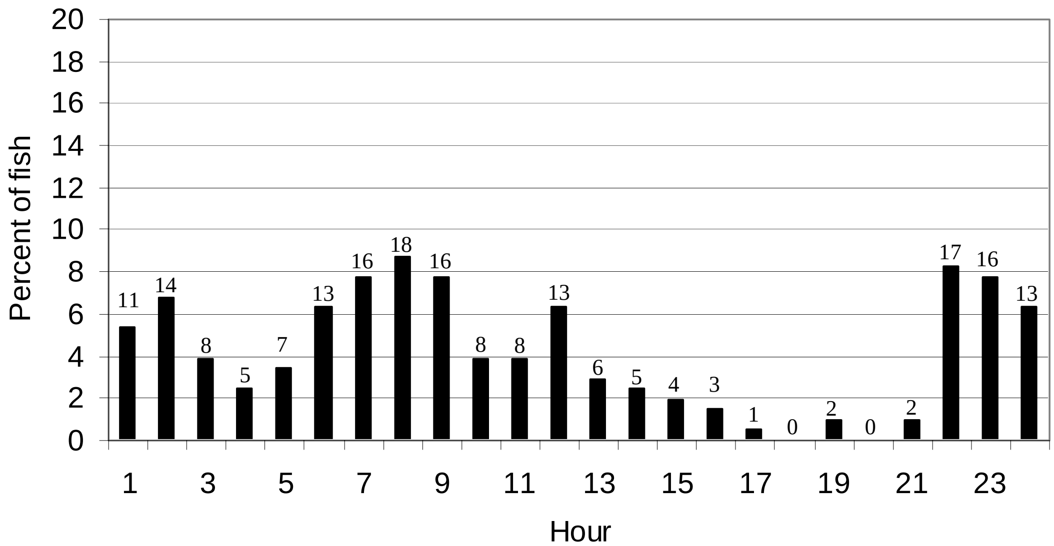

Figure 1. Hourly spillway passage of subyearling Chinook salmon during 57 kcfs spill treatment blocks at Bonneville Dam during summer 2002. Numbers above the bars represent number of fish that passed during that hour.

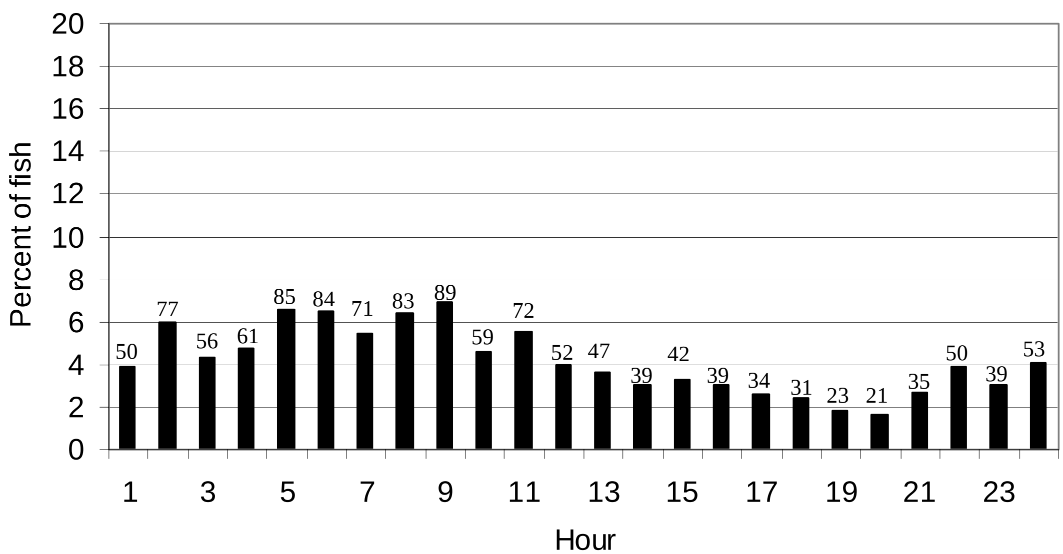

Figure 2. Hourly spillway passage of subyearling Chinook salmon during TDG Cap spill treatment blocks at Bonneville Dam during summer 2002. Numbers above the bars represent number of fish that passed during that hour.

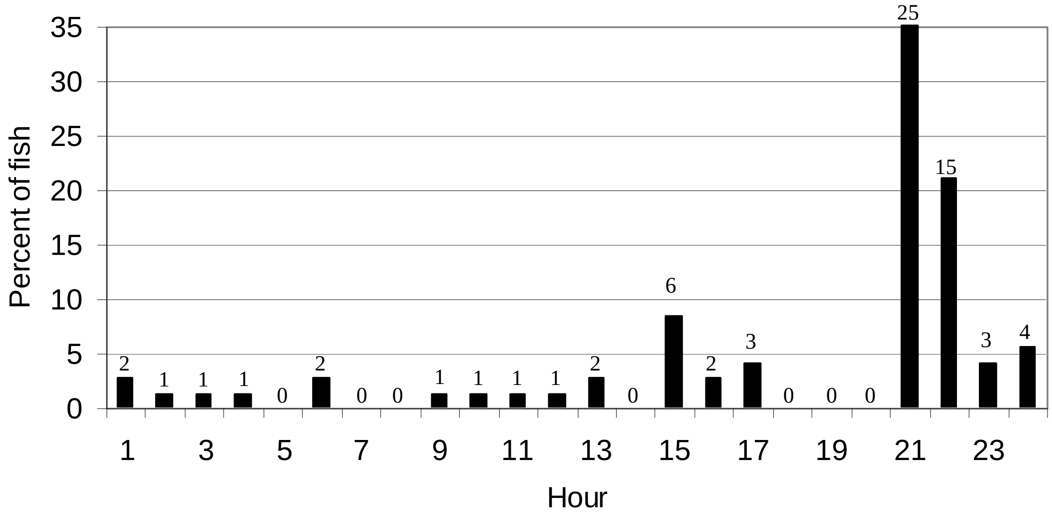

Figure 3. Hourly guided passage at the second powerhouse for subyearling Chinook salmon during 57 kcfs spill treatment blocks at Bonneville Dam during summer 2002. Numbers above the bars represent number of fish that passed during that hour.

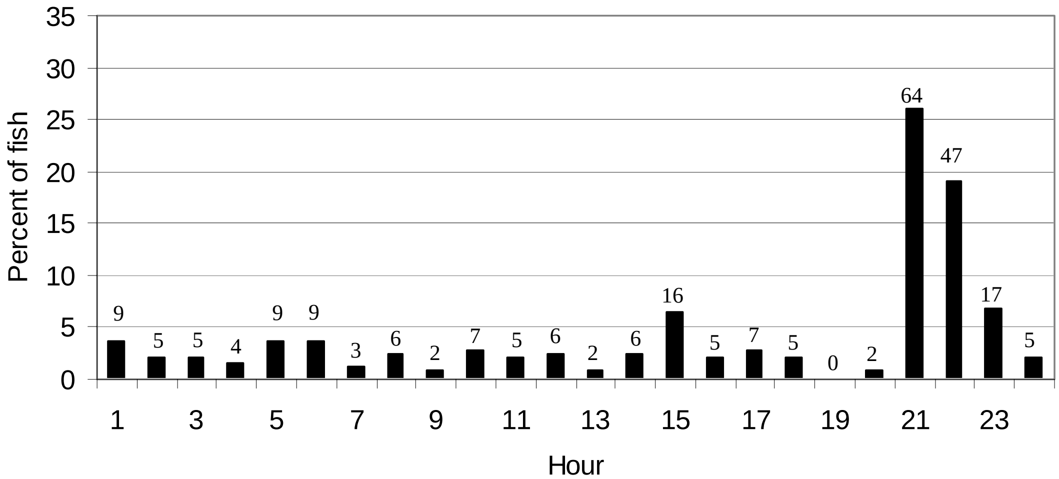

Figure 4. Hourly guided passage at the second powerhouse for subyearling Chinook salmon during TDG Cap spill treatment blocks at Bonneville Dam during summer 2002. Numbers above the bars represent number of fish that passed during that hour.

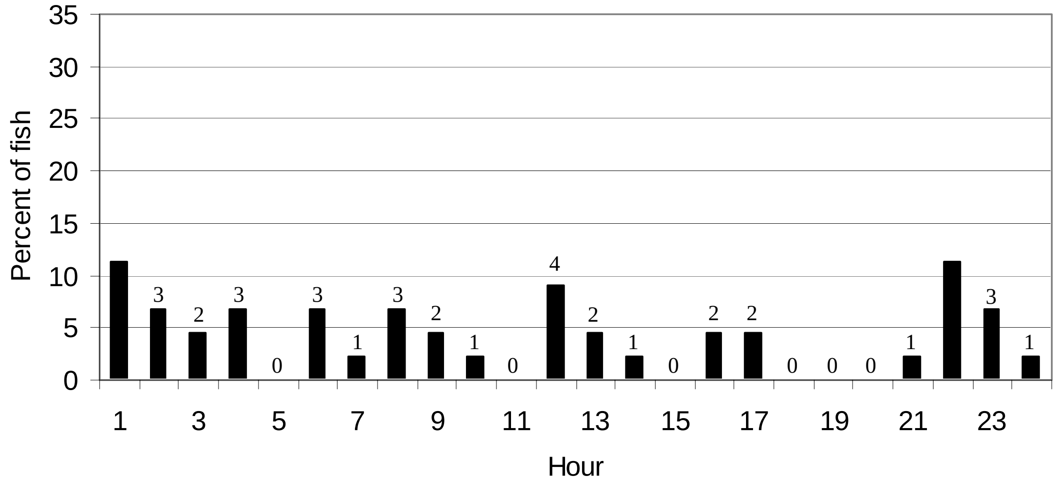

Figure 5. Hourly unguided passage at the second powerhouse for subyearling Chinook salmon during 57 kcfs spill treatment blocks at Bonneville Dam during summer 2002. Numbers above the bars represent number of fish that passed during that hour.

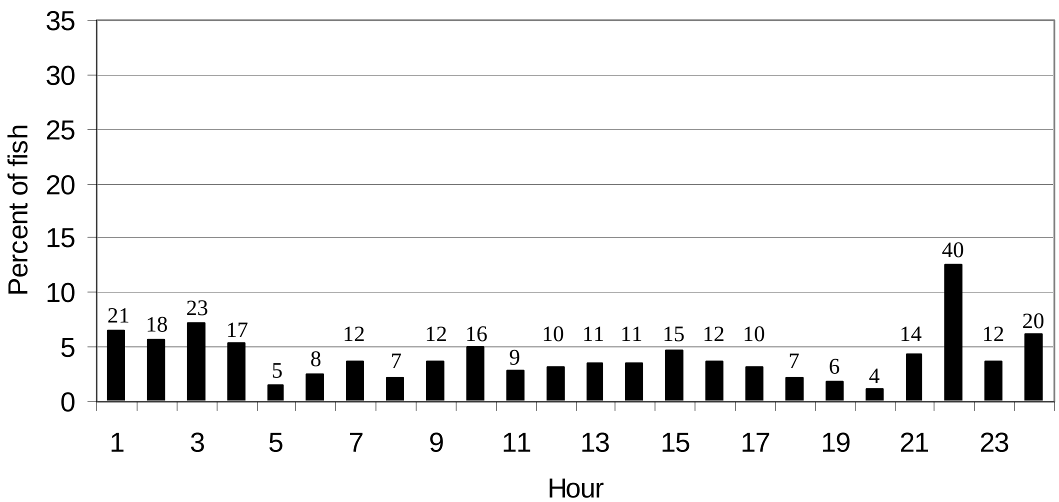

Figure 6. Hourly unguided passage at the second powerhouse for subyearling Chinook salmon during TDG Cap spill treatment blocks at Bonneville Dam during summer 2002. Numbers above the bars epresent number of fish that passed during that hour.

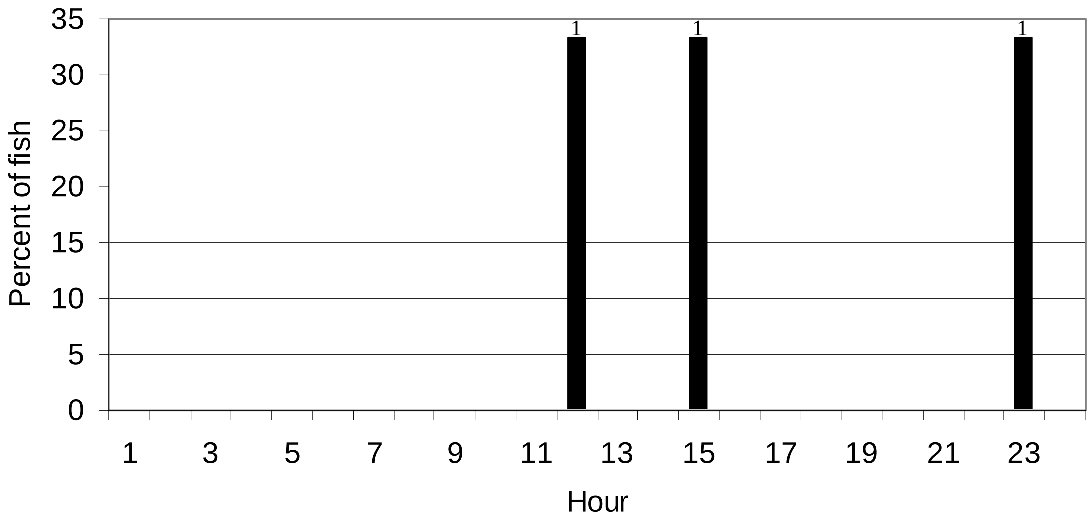

Figure 7. Hourly guided passage at the first powerhouse for subyearling Chinook salmon during 57 kcfs spill treatment blocks at Bonneville Dam during summer 2002. Numbers above the bars represent number of fish that passed during that hour.

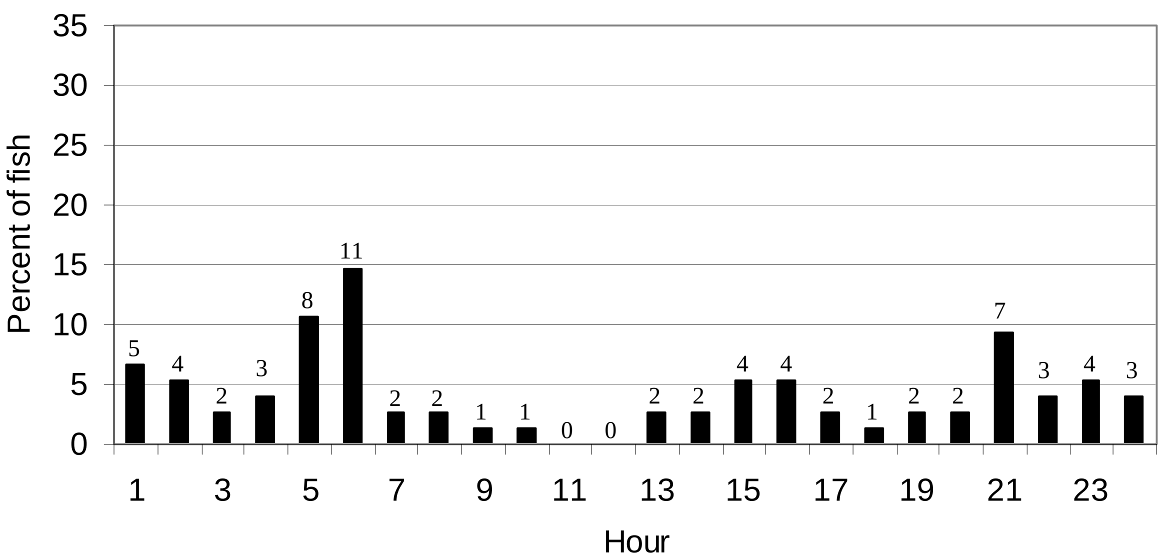

Figure 8. Hourly guided passage at the first powerhouse for subyearling Chinook salmon during TDG Cap spill treatment blocks at Bonneville Dam during summer 2002. Numbers above the bars represent number of fish that passed during that hour.

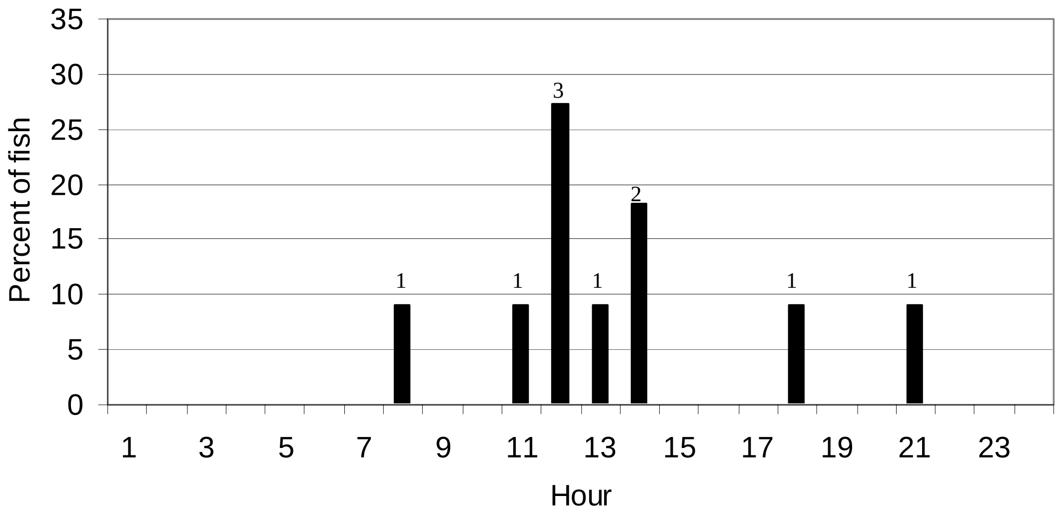

Figure 9. Hourly unguided passage at the first powerhouse for subyearling Chinook salmon during 57 kcfs spill treatment blocks at Bonneville Dam during summer 2002. Numbers above the bars represent number of fish that passed during that hour.

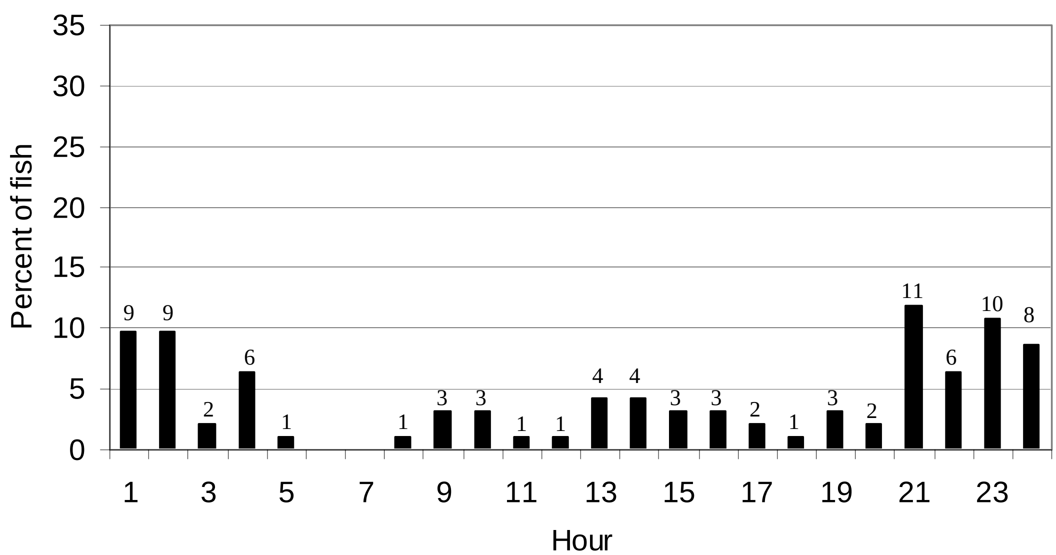

Figure 10. Hourly unguided passage at the first powerhouse for subyearling Chinook salmon during TDG Cap spill treatment blocks at Bonneville Dam during summer 2002. Numbers above the bars represent number of fish that passed during that hour.

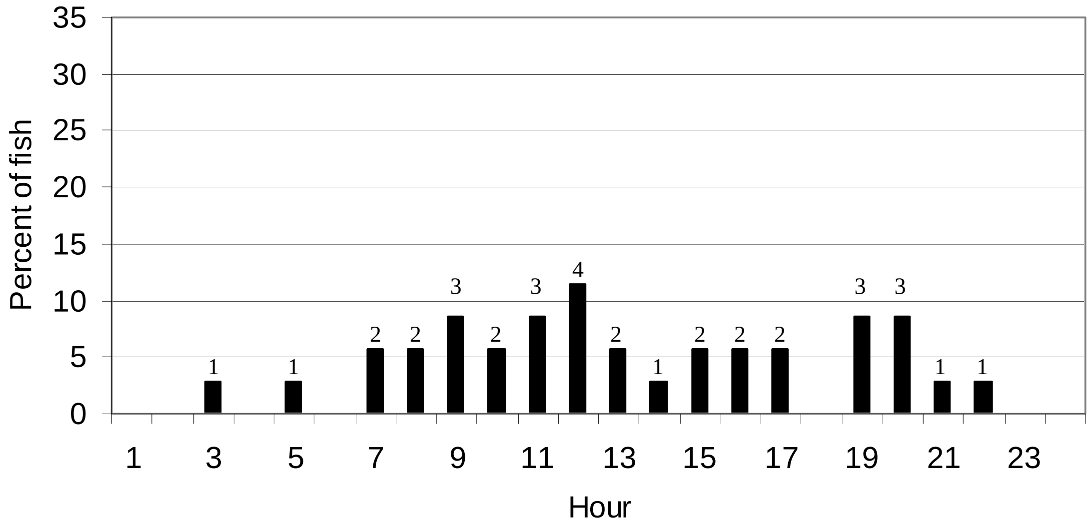

Figure 11. Hourly sluiceway passage at the first powerhouse for subyearling Chinook salmon during 57 kcfs spill treatment blocks at Bonneville Dam during summer 2002. Numbers above the bars represent number of fish that passed during that hour.

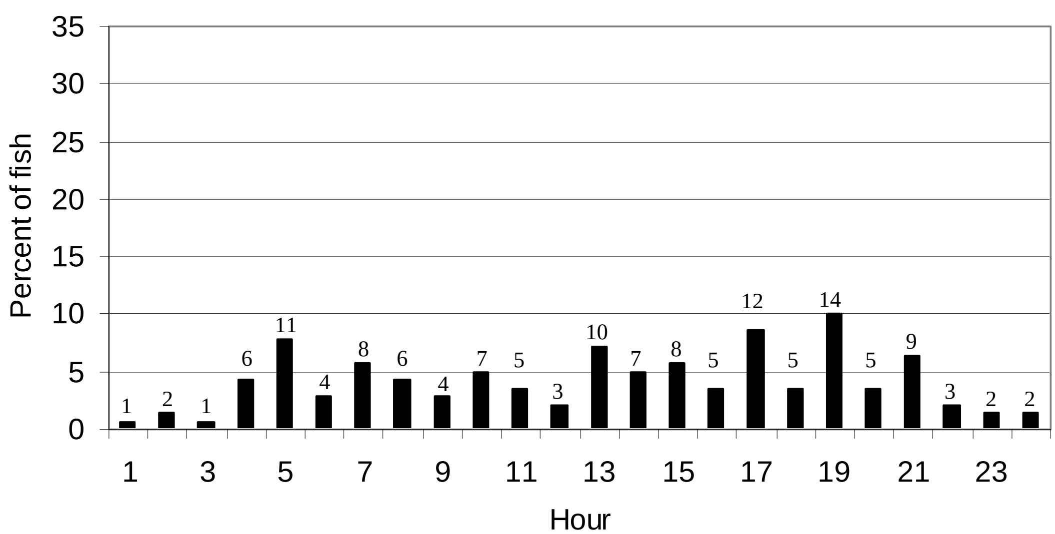

Figure 12. Hourly sluiceway passage at the first powerhouse for subyearling Chinook salmon during TDG Cap spill treatment blocks at Bonneville Dam during summer 2002. Numbers above the bars represent number of fish that passed during that hour.

Table 5. The proportion of radio-tagged subyearling Chinook salmon that passed each dam area of Bonneville Dam during day (0500-2059 hours) and night (2100-0459 hours) during summer 2002. Percentages are based on the 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
Day	66% (239 of 364)	42% (287 of 682)	66% (991 of 1498)
Night	34% (125 of 364)	58% (395 of 682)	34% (507 of 1498)

Table 6. The proportion of radio-tagged subyearling Chinook salmon that passed each dam area of Bonneville Dam during day (0500-2059 hours) and night (2100-0459 hours) during the 57 kcfs spill treatment, summer 2002. Percentages are based on the 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
Day	86% (44 of 51)	35% (40 of 115)	58% (120 of 206)
Night	14% (7 of 51)	65% (75 of 115)	42% (86 of 206)

Table 7. The proportion of radio-tagged subyearling Chinook salmon that passed each dam area of Bonneville Dam during day (0500-2059 hours) and night (2100-0459 hours) during the TDG Cap spill treatment, summer 2002. Percentages are based on the 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
Day	62% (195 of 313)	44% (247 of 567)	67% (871 of 1292)
Night	38% (118 of 313)	56% (320 of 567)	33% (421 of 1292)