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Movement, Distribution, and Passage Behavior of Radio-Tagged Juvenile Chinook Salmon and Steelhead at Bonneville Dam, 2005

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 (USACE), 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 2005, the USACE has contracted the U.S. Geological Survey to evaluate juvenile salmonid behavior in relation to passage improvement tests at Lower Granite, Little Goose, McNary, John Day, The Dalles, and Bonneville Dams.

In 2005, we used radio telemetry to examine the movements and passage behavior of yearling and subyearling Chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* in the forebay of Bonneville Dam. The objectives of this research were to: 1) determine the 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 efficiency and effectiveness for the spillway and corner collector, and 4) provide data to estimate survival of radio tagged fish released above Bonneville Dam. This report covers the study of yearling Chinook salmon and steelhead during spring, 2005 (Chapter 1) and subyearling Chinook salmon during summer, 2005 (Chapter 2).

Spring

From 29 April to 6 June 2005, we radio-tagged and released 5,820 yearling Chinook salmon and 4,278 yearling steelhead upstream of Bonneville Dam at John Day and The Dalles dams. We detected our last radio-tagged fish on 12 June 2005. Mean river discharge at Bonneville Dam during the study period was 216.4 kcfs, with 47.3% of flow discharged at the second powerhouse (B2), 40.3% at the spillway (SPI), and 12.4% at the first powerhouse (B1). Fish were exposed to two different spill conditions throughout the study: (1) A spill discharge goal of 75 kcfs during the day and (2) up to 120% of the total dissolved gas cap (TDG) at night. This BIOP spill treatment averaged 75.1 kcfs during the day and 111.5 kcfs during the night. Median travel times of radio-tagged fish from release to Bonneville Dam were 27.2 – 44.3 h, depending on species and release site, resulting in median travel rates of 2.5 - 2.7 km/h. Of the fish released from John Day and The Dalles Dams, we detected 94% of yearling Chinook salmon and 93% of steelhead at Bonneville Dam. Median forebay residence time for Chinook salmon was shortest at B2 (6 min), compared to 24 min at the spillway and 2.7 h at B1. Median forebay residence time for steelhead was shortest at the spillway (30 min), compared to 36 min at B2 and 5.2 h at B1.

The second powerhouse passed the most fish (56% of Chinook salmon and 53% of steelhead), followed by the spillway (38% of Chinook salmon and 39% of steelhead) and B1 (6% of Chinook salmon and 8% of steelhead). Of the fish that passed at B1, 33% of Chinook salmon and 29% of steelhead passed into the sluiceway, while 65% of Chinook salmon and 70% of steelhead passed through the turbines (unguided). Of the

Chinook salmon that passed at B2, 45% passed unguided through the turbines, 29% passed through the corner collector, and 26% were guided into the downstream salmonid migrants channel (DSM). Of the steelhead that passed at B2, 66% passed through the corner collector, 22% passed unguided through the turbines, and 12% were guided into the DSM.

Fish passage efficiency (FPE: the proportion of fish that passed the dam via non-turbine routes) at Bonneville Dam in spring 2005 was 71% overall for Chinook salmon and 83% for steelhead. During the day, when spill discharge averaged 75.1 kcfs, FPE was 75% for Chinook salmon and 88% for steelhead. During the night, when spill discharge averaged 111.5 kcfs, Chinook salmon had an FPE of 64% and steelhead had an FPE of 77%. At B2, FPE was 55% for Chinook salmon and 79% for steelhead. Fish guidance efficiency (FGE: the proportion of powerhouse entrained fish that are guided by screens into the bypass system) was determined only at B2 since no guidance system operated at B1 during 2005. Overall FGE was 36% for Chinook salmon and 36% for steelhead. Fish Guidance Efficiency during the day was 42% for Chinook salmon and 40% for steelhead. During the night, FGE was 29% for Chinook salmon and 34% for steelhead. Chinook salmon had a spillway efficiency of 37% overall, 33% during the day, and 45% during the night. Spillway efficiency (the proportion of fish passing all routes that passed via spill) for steelhead was 39% overall, 21% during the day, and 62% during the night. Spillway effectiveness (spillway efficiency divided by the proportion of total discharge through the spillway) for Chinook salmon was 0.93 overall, 0.95 during the day, and 0.86 during the night. Spillway effectiveness for steelhead was 0.97 overall, 0.60 during the day, and 1.2 during the night. Corner collector efficiency (CCE: the number of fish that passed through the corner collector divided by the number of fish that passed through all routes at B2) at the second powerhouse for Chinook salmon was 30% overall, 40% during the day, and 8% during the night. Steelhead had a CCE of 66% overall, 81% during the day, and 20% during the night. Corner collector effectiveness (CCF: corner collector efficiency divided by the proportion of discharge at B2 that went through the corner collector) for Chinook salmon was 5.9 overall, 8.7 during the day, and 1.4 during the night. Steelhead had a CCF of 13.2 overall, 17.4 during the day, and 3.3 during the night.

Like in previous years, the proportion of discharge allocated among 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. Since the greatest discharge occurred at B2, more than half of both species entered the forebay of B2 and spent the least amount of time relative to the other forebays before passing. Of the two spill conditions, spill at night (mean = 112kcfs) was the most efficient, passing 45% of Chinook salmon and 62% of steelhead relative to all other passage routes. Conversely, passage through the corner collector was significantly higher during the day than during the night for both yearling Chinook salmon (40%) and steelhead (81%). Another shallow passage route, the sluiceway, was also more efficient during the day (35% for yearling Chinook salmon and 45% for steelhead) than during the night (28% for yearling Chinook salmon and 12% for steelhead).

Passage metrics for both yearling Chinook salmon and steelhead were similar in 2004 and 2005. Surface-oriented passage (corner collector and sluiceway efficiency) was lower in 2005 for both yearling Chinook salmon and steelhead. Project FPE and FPE_{B2}

was similar in 2005 compared to 2004 but FPE_{B1} was much lower for both species. Fish guidance efficiency at B2 was higher in 2005 than in 2004 in yearling Chinook salmon, but lower in steelhead. We hypothesize that lower FGE_{B2} in 2004 and 2005 was due to the corner collector passing the majority of the shallow fish; fish that may otherwise have been guided. Spillway efficiency was lower in 2004 and 2005 because more fish passed at B2, specifically through the corner collector. Although the addition of the corner collector did not increase $FPE_{project}$, it did achieve $FPE_{project}$ similar to that attained in previous years, mainly through spill. Furthermore, the corner collector helped achieve similar $FPE_{project}$ with far less water than would have been used to attain the same FPE without the corner collector. The spillway discharged an average 17 times more water than the corner collector. Consequently, effectiveness of the corner collector relative to the project (5.9 for yearling Chinook salmon and 13.2 for steelhead) was far greater than effectiveness of the spillway (0.93 for yearling Chinook salmon and 0.97 for steelhead). Our results indicate that although the intake screen guidance systems at Bonneville Dam have poor guidance efficiency, project FPE of 70-83%, depending on species, can be attained if sufficient numbers of fish are passed via a combination of non-turbine routes (spill, sluice, turbine guidance systems, and the corner collector).

Summer

From 15 June to 17 July 2005, we radio-tagged and released 6,525 subyearling Chinook salmon upstream of Bonneville Dam at The Dalles Dam and John Day Dam. We detected our last radio-tagged fish on 25 July 2005. Mean river discharge at Bonneville Dam during the study period was 173.6 kcfs, with 52.8% of flow discharged at the spillway, 44.2% at the second powerhouse (B2), and 3.0% at the first powerhouse (B1). Although no spill treatments were designed into the study plan, fish were exposed to two different spill conditions throughout the study: (1) A spill discharge goal of 75 kcfs during the day and (2) up to 120% of the total dissolved gas cap (TDG) at night. This BIOP spill treatment averaged 75.3 kcfs during the day and 124.4 kcfs during the night. The median travel rate of radio-tagged fish from release to Bonneville Dam was 2.29 km/h for fish released from John Day Dam and 2.23 km/h for fish released from The Dalles Dam. Median travel time from the release site to Bonneville Dam was 49.0 h for fish released from John Day Dam and 33.6 h for fish released from The Dalles Dam. Of the fish released, we detected 86% at Bonneville Dam. Median forebay residence time was shortest at B2 (10.2 min), compared to 22.2 min at the spillway and 4.4 h at B1.

The spillway passed the most fish (51%), followed by B2 (48%), and B1 (1%). Of the fish that passed at B1, 30% passed through the turbines (unguided), 59% passed through the sluiceway, and 10% passed through the navigation lock. Of the fish that passed at B2, 46% passed unguided through the turbines, 40% passed through the corner collector, and 14% were guided into the DSM.

Fish passage efficiency at Bonneville Dam during summer 2005 was 77.7% overall, 75.6% during the day, and 82.2% during the night. At B2, FPE was 54.5% overall, 53.1% during the day, and 58.1% during the night. Fish guidance efficiency was calculable only at B2 because the guidance system at B1 was not operated during 2005. Fish guidance efficiency at B2 was 23.9% overall, 15.0% during the day, and 41.7% during the night. Spillway efficiency was 50.6% overall, 47.4% during the day, and 57.5% during the night. Spillway effectiveness was 0.96 overall, 1.08 during the day, and 0.81 during the night. Corner collector efficiency was 40.1% overall, 44.8% during the day, and 28.1% during the night. Corner collector effectiveness was 5.9 overall, 7.8 during the day, and 2.6 during the night.

Similar to previous years, the proportion of discharge allocated among 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. The majority of water was discharged at the spillway (53%) and B2 (44%) and very little water was discharged at B1 (3%). Consequently, most fish entered the forebays of the spillway (48%) and B2 (50%) and very few entered the B1 forebay (2%). At the spillway, the higher nighttime discharge was more efficient (58%) than 75 kcfs spill (47%). However spillway effectiveness was higher during the 75 kcfs day spill (1.1) than during TDG cap spill at night (0.8). Corner collector efficiency (44.8%) and effectiveness (7.8) were also higher during 75 kcfs day spill than during TDG cap spill at night (efficiency = 28.1%; effectiveness = 2.6). Another shallow surface flow type passage route, the B1 sluiceway, was also more efficient (63.8%) and effective (4.0) during 75 kcfs day spill than during TDG cap spill at night (efficiency = 36.4%; effectiveness = 0.7).

Overall passage metrics for subyearling Chinook salmon in 2005 were generally higher than in 2004 and comparable to passage metrics in 2002. Higher spill discharge in 2005 likely resulted in higher spillway efficiency and FPE compared to 2004. Most passage metrics, especially spillway efficiency and FPE, were similar in 2002 and 2005 due to similar spill discharge during those years. Fish guidance efficiency at B2 was lower in 2004 and 2005 than in previous years, likely because of the corner collector. We hypothesize that low FGE at B2 in 2004 and 2005 was due to the corner collector passing the majority of the shallow fish that may otherwise have been guided. Although FGE at B2 has decreased since the addition of the corner collector, FPE at B2 has increased and project FPE has remained about the same when spill levels are adequate. Our results indicate that although the intake screen guidance systems at Bonneville Dam have poor guidance efficiency, project FPE of nearly 80% can be attained for subyearling Chinook salmon under sufficient spill levels in conjunction with the operation of the B2 corner collector. Additionally, by strategically optimizing discharge patterns at the project, passage of juvenile salmonids can be increased temporally and spatially.

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Chapter One

Movement, Distribution, and Passage Behavior of Radio-Tagged Yearling Chinook Salmon and Steelhead at Bonneville Dam, 2005

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1-1.0 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. Options currently being evaluated at Bonneville Dam are the improvement of turbine intake guidance systems and a new corner collector surface-flow bypass system.

In 2000, we conducted the first evaluation of species-specific fish passage efficiency (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 U.S. Army Corps of Engineers (USACE) 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 (Evans et al. 2003a and 2003b). In 2004 (Evans et al. 2005) and 2005, studies of the MGR turbine and spillway flow deflectors continued and evaluations were also conducted for the ice and trash sluiceway at the first powerhouse and the corner collector surface-flow bypass system at the second powerhouse. 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 2005, we used radio telemetry to examine the movements and passage behavior of yearling Chinook salmon *Oncorhynchus tshawytscha* and yearling steelhead *O. mykiss* in the forebay of Bonneville Dam. Our objectives were to:

- Determine the distribution, and approach patterns of fish in the forebay areas of Bonneville Dam.
- Determine the time and route of passage of fish at Bonneville Dam relative to spill, powerhouse operations, and corner collector tests.
- Estimate fish passage efficiency for the entire Bonneville Dam complex, fish guidance efficiency for the second powerhouse, spillway efficiency and effectiveness, corner collector efficiency and effectiveness, and sluiceway efficiency and effectiveness.
- Provide data to estimate survival of radio-tagged fish passing through Bonneville Dam (reported by Counihan et al. 2006).

In addition we examined potential delay in the second powerhouse juvenile bypass and compared passage performance metrics derived from radio telemetry and hydroacoustic studies.

1-2.0 Methods

1-2.1 Study Area

Bonneville Dam is located on the Columbia River at approximately river kilometer (rkm) 233. The dam consists of two powerhouses and a single spillway, each separated by an island. The first powerhouse (B1) consists of 10 turbine units and is located at the south side of the river, spanning from the Oregon shore to Bradford Island. The second powerhouse (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).

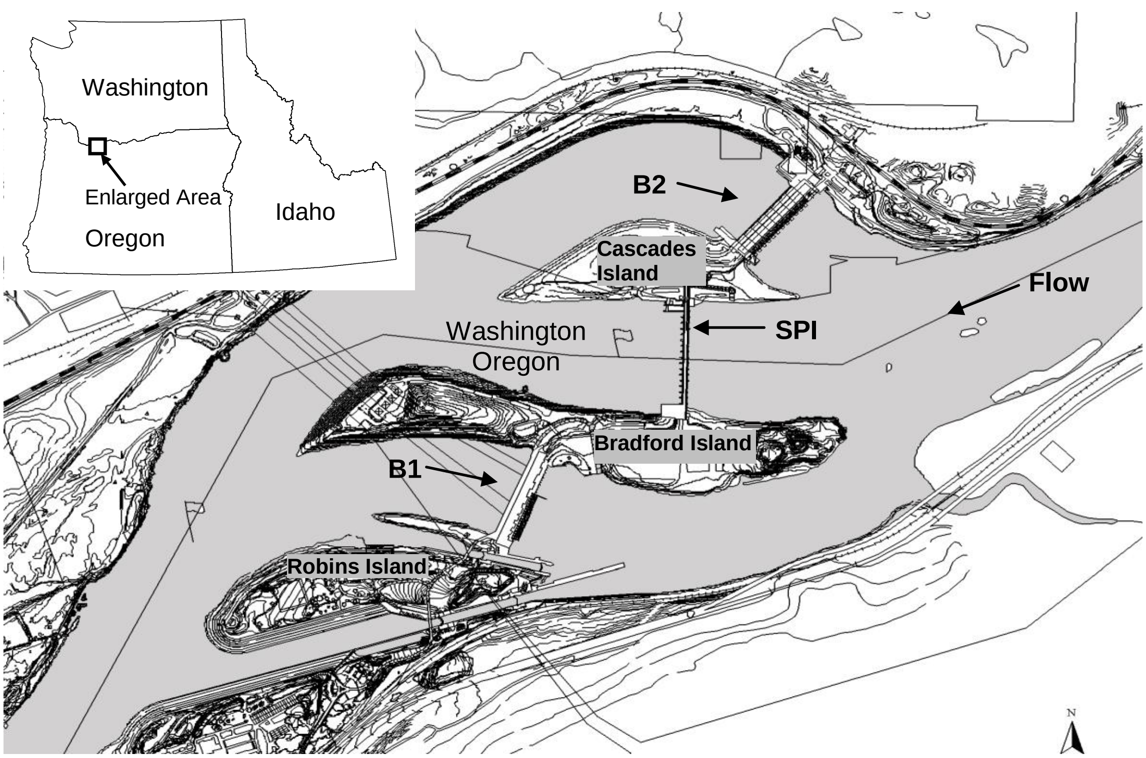


Figure 1.—Plan view of Bonneville Dam on the Columbia River showing the first powerhouse (B1), spillway (SPI), and second powerhouse (B2) during 2005. Image source: U. S. Army Corps of Engineers.

1-2.2 Water Quality

We monitored water temperature (± 0.2ºC), dissolved oxygen (DO; ± 0.2 ppm), and electrical conductivity (EC; 0.5%) throughout the study using a Stevens-Greenspan CS304 multi-parameter sensor (Stevens Water Monitoring Systems, Inc, Beaverton, Oregon). The CS304 was deployed 1.5 m below the water surface in the forebay of the

Bonneville Dam spillway and was programmed to record water temperature, DO, and EC measurements every minute.

1-2.3 Fixed Receiving Equipment

We used four types of fixed telemetry receivers, along with aerial and underwater antennas, to monitor radio-tagged juvenile salmonids at Bonneville Dam in 2005. Eighty-three aerial antennas, 36 stripped coax antennas, and 124 underwater dipole antennas were linked to 34 Lotek SRX-400 receivers (SRX; Lotek Engineering, Newmarket, Ontario), two Lotek DSP-500 digital spectrum processors (DSP; Lotek Engineering, Newmarket, Ontario), three Orion DSP receivers (Orion; Grant Systems Engineering, King City, Ontario, Canada), and three Multiprotocol Integrated Telemetry Acquisition Systems (MITAS; Grant Systems Engineering, King City, Ontario, Canada). Each SRX monitored a maximum of six aerial antennas. Orions and MITASs were used to monitor underwater antennas. Orions and DSPs were also used to monitor aerial antennas in some areas. The combination of these technologies allowed us to monitor fish as they approached and then passed through various routes at Bonneville Dam. Aerial antennas were positioned in three locations: 1) along the periphery of the forebay, 2) along the tailrace shoreline, and 3) along the corner collector flume (Figure 2). Aerial antennas were located in the forebay to detect fish within 100 m of the dam, in the tailrace to confirm fish passage, and in the corner collector flume to detect fish passing through the corner collector. Aerial antennas were connected to SRX receivers programmed to monitor nineteen frequencies in random order. Two aerial antenna monitoring configurations were used depending on location: auxiliary/master switching or combined antennas. In the auxiliary/master configuration, the receiver scans the master antenna (up to 8 unique antennas combined) until a signal is received; at which point the receiver scans the individual 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 in the spillway forebay and all tailraces 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 all locations. 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 location information by limiting the range of signal detection.

Two SRX receivers in the B2 tailrace were each coupled with DSPs. These receivers had essentially no scan time because a DSP acquires signals over a 1 MHz bandwidth almost instantaneously. Using DSPs, rather than a stand-alone SRX, was necessary to determine fish presence in high flow environments because signal acquisition time is limited.

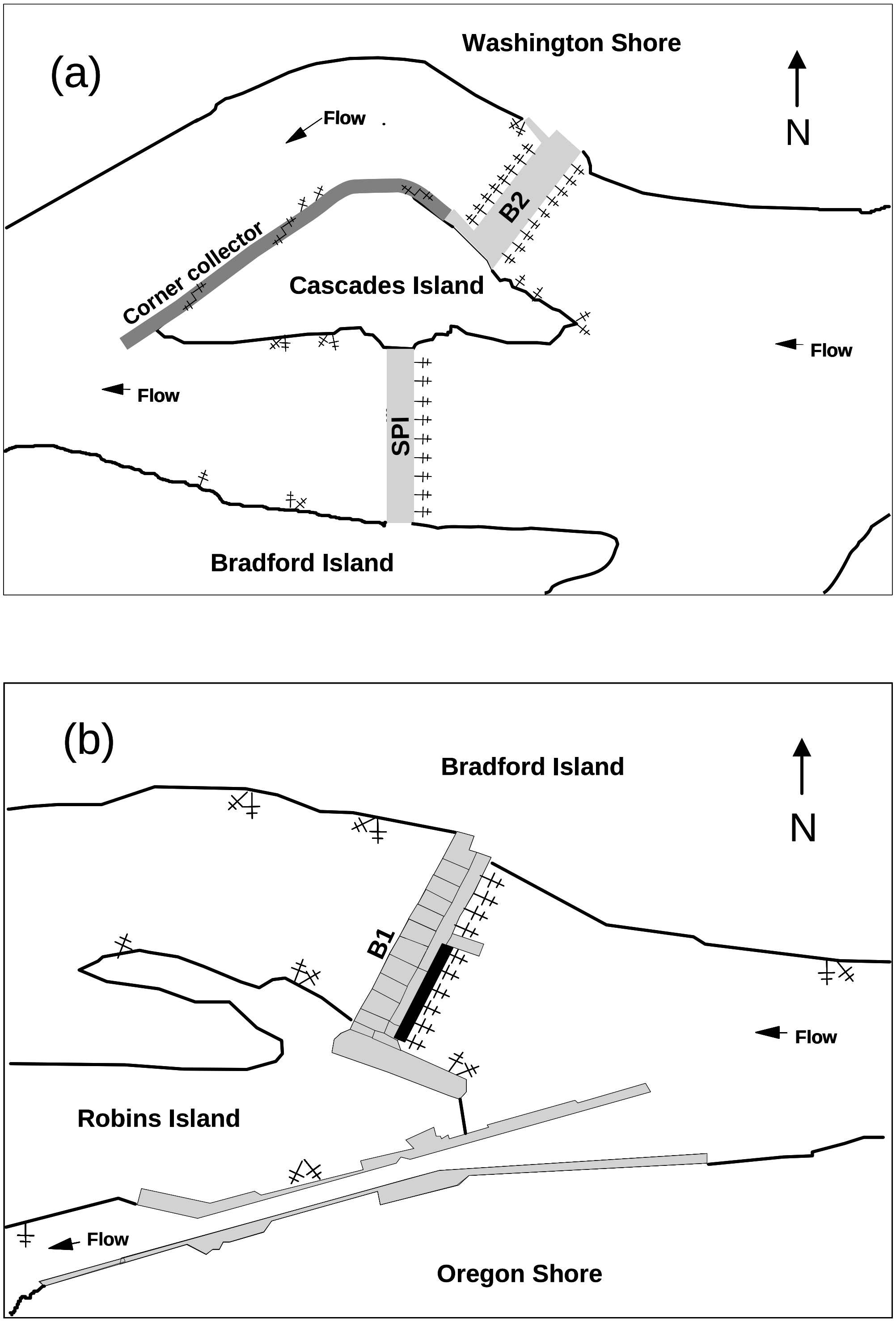


Figure 2.—Plan view of aerial antenna coverage during spring 2005 at Bonneville Dam's: (a) second powerhouse (B2) and spillway (SPI); and (b) first powerhouse (B1).

One Orion receiver at the B2 smolt monitoring facility and two Orion receivers in the corner collector flume were also used. All three of the Orion receivers were monitoring the same frequencies and antennas as the DSPs. The Orion receiver also has essentially no scan time because signals are acquired over a 1 MHz bandwidth.

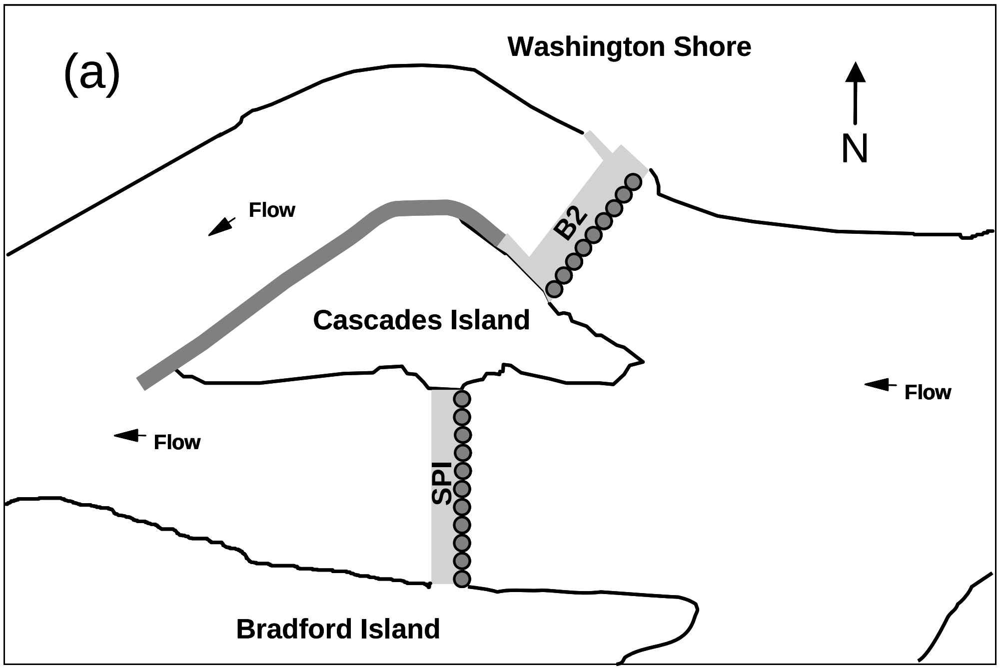
Three MITASs were incorporated at B1, B2, and the spillway (Figure 3). Each MITAS was capable of simultaneously monitoring up to 50 inputs with greater multiple transmitter recognition than the SRX, DSP, or Orion. Although each MITAS was limited to a maximum of 50 inputs, each input could be a horizontal or vertical combination of multiple underwater dipole or stripped coax antennas. In addition to enhanced signal recognition, the MITAS's data displays and on-screen diagnostics allowed the user to identify problems in real-time and avoid potential data loss that otherwise would not have been apparent until post-processing.

The MITAS at B1 was composed of 22 underwater stripped coax antennas and one aerial antenna. Twenty stripped coax antennas were positioned mid-channel in the sluiceway, two at each unit, to monitor unit-specific sluiceway entrance and passage through the sluiceway. In addition, two stripped coax antennas and one aerial antenna were placed at the outfall of the sluiceway to confirm sluiceway passage.

The MITAS at B2 was composed of 61 underwater antennas. Forty-eight dipole underwater antennas attached to the submersible traveling screens monitored unguided turbine passage: Two dipole antennas were mounted to the bottom of each of three submersible traveling screens in front of each of eight turbine units. Antennas from each of three gatewell slots per unit were combined to provide turbine unit specific passage information. Nine stripped coax antennas placed within the downstream salmonids migrant channel (DSM) monitored guided fish passage. One antenna was located just downstream of each "C-slot" gatewell orifice and one additional antenna was located at the terminus of the DSM. Four dipole underwater antennas monitored approach and entrance of fish into the corner collector.

The spillway MITAS consisted of 72 underwater antennas. Seventy-two dipole underwater antennas monitored spillway passage and were attached to the forebay pier noses. Each spillbay had four antennas; two antennas on each piernose at about 4.5 m below mean pool level and 2 antennas at about 10.5 m below mean pool level. All four antennas in each spillbay were combined to one input to provide spillbay-specific passage information.

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.



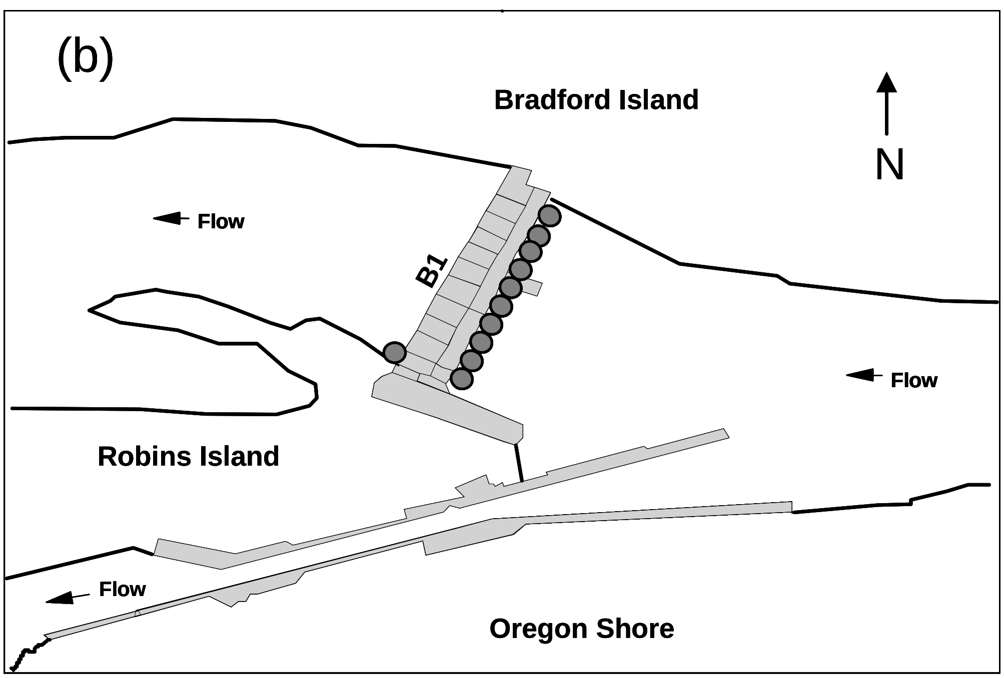


Figure 3.—Plan view of underwater antenna coverage during spring 2005 at Bonneville Dam's: a) second powerhouse (B2) and spillway (SPI), and (b) first powerhouse (B1).

1-2.4 Transmitters

Coded microprocessor transmitters (model NTC-3-1 KMF) manufactured by Lotek Engineering Inc. were implanted in yearling Chinook salmon and steelhead. The transmitters were 7.2 mm (diameter) x 17.0 mm and weighed 1.0 g in air and 0.19 g in water. The antenna length was 22 cm and the pulse rate was 2.0 s, resulting in an estimated minimum tag life of 9 d.

1-2.5 Tagging, Handling, and Release of Fish

Juvenile Chinook salmon and steelhead were collected at the Smolt Monitoring Facility (SMF) at John Day Dam. Employees from the Pacific States Marine Fisheries Commission's Smolt Monitoring Program and the U.S. Geological Survey sorted and identified study fish. Fish were weighed at the time of collection to ensure they met the minimum weight criteria of 21.5 g, keeping the tag weight to fish weight ratio below 5%. Fish collected at John Day Dam were tagged and released into the Columbia River at John Day and The Dalles dams. Although fish were tagged and released at different locations, the fish handling, tagging, transport and release methods were standardized.

Subsequent to collection, fish to be tagged at John Day Dam were held for 12-36 h at the SMF in 114 L circular fiberglass tanks supplied with flow-through river water at a maximum biomass density of 20 g/L. Fish to be tagged and released at The Dalles Dam were collected, loaded into 265 L plastic tanks and transported to The Dalles Dam in temperature-controlled trucks. The tanks were supplied with oxygen throughout transport. Once at The Dalles Dam, the tanks were supplied with flow-through river water and fish were held for 12-36 h before tagging. The holding time for fish prior to tagging allowed the fish to attain a postabsorptive state, minimizing stress throughout the tagging procedure.

All fish were gastrically implanted with a radio transmitter using procedures described by Adams et al. (1998). Fish were anesthetized using MS-222 (tricaine methanosulfate) at a concentration of 50 mg/L of fresh water. An equal amount of buffer solution ($NaHCO_3$) and Stress Coat (Aquarium Pharmaceuticals, Inc, Chalfont, PA), a synthetic slime coating and water conditioner, were added at a concentration of 0.25ml/L. Fish were netted from the holding tanks into the prepared anesthesia bucket with a maximum density of five fish in anesthesia at one time. Timers were used to ensure that fish remained in the anesthesia for no longer than 5 min. Fish were carefully observed to determine when adequate sedation had occurred (evident by loss of equilibrium), then removed from anesthesia and examined for overall condition and fin clip. Fish that met criteria for size and condition were weighed, measured and tagged, then placed in an oxygenated recovery bucket for 5 min. Recovery buckets were modified 19 L buckets that held 7 L of water in the bottom and were perforated above the 7 L reservoir (surface area of 65-103 cm^2). A maximum of two fish were held in each recovery bucket and oxygen was supplied at a minimum flow rate of 50 ml/min. Following the recovery period, fish were checked for regurgitated tags or mortalities. Each bucket was then covered with a locking lid and held for 18-24 h in a 3.6m x 1.2m x 1.2m aluminum tank supplied with flow-through river water to a depth of 61 cm. Each tank was modified with an expanded metal floor that was elevated 33 cm, resulting in a water depth of 28 cm relative to the buckets. The elevated floor provided easier access to the buckets during the holding period, reducing stress induced by bucket movements and collisions. Prior to transporting the fish to the release site, each recovery bucket was checked for mortalities, regurgitated tags, and tag functionality. Releases occurred during day and night (0800 and 2200 hours at John Day Dam, 0700-1400 hours and 1900-0100 hours at The Dalles Dam) to enable tagged fish to mix spatially and temporally with untagged fish in the river before reaching Bonneville Dam. The upstream release locations allowed fish an average of 31 to 45 h, depending on species and release site, to adjust to temperature and hydraulic conditions in the river before reaching the forebay and encountering Bonneville Dam.

1-2.6 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. We utilized an automated proofing program, designed specifically for Bonneville Dam data. The automated proofing program was written in SAS and allowed us to proof and process our data with increased speed. Data were 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. All data records for fish that fell outside of our set criteria for travel time (<1st percentile or > 99th percentile), residence time (<1st percentile or > 99th percentile), and geographical area (upstream location after downstream location) were flagged and subsequently proofed manually. Additionally, a 10% random sub-sample of each auto-proofed file was proofed manually as a quality assurance measure of the auto-proofing program and to ensure accurately proofed data.

Entrance into the forebay area was determined by the location and time an individual fish was first detected by aerial or underwater antennas in the forebay. Similarly, the last detection of a fish by aerial or underwater antennas in the forebay, on the traveling screens, at the corner collector, within the B2 DSM, or the B1 sluiceway, was considered to indicate 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 the passage location (DSM, corner collector, turbine, or sluiceway).

Residence time in the forebay, 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 forebay. Residence times are a minimum estimate of the actual time that radio-tagged fish spent in the forebay 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 could pass the dam undetected.

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

- Spillway efficiency $(SPE) = \dfrac{SP}{B1 + SP + B2}$

- Spillway effectiveness (*SPF*) = $\frac{SPE}{F_{SP} / F_{tot}}$

- Fish guidance efficiency (*FGE*) = $\frac{G_{tot}}{G_{tot} + UG_{tot}}$

- Fish passage efficiency ($FPE_{Project}$) = $\frac{Non-turbine\ passage}{TOT_{pass}}$

- Fish passage efficiency (FPE_{B1})= $\frac{Non-turbine\ passage_{B1}}{B1}$

- Fish passage efficiency (FPE_{B2})= $\frac{Non-turbine\ passage_{B2}}{B2}$

- Corner collector efficiency (CCE_{B2}) = $\frac{CC}{B2}$

- Corner collector efficiency (*CCE*) = $\frac{CC}{Tot_{Pass}}$

- Corner collector effectiveness (CCF_{B2}) = $\frac{CCE}{F_{CC} / F_{B2}}$

- Corner collector effectiveness (*CCF*) = $\frac{CCE}{F_{CC} / F_{Tot}}$

- Sluiceway efficiency (*SLE*) = $\frac{SL}{B1}$

- Sluiceway effectiveness (*SLF*) = $\frac{SLE}{F_{SL} / F_{B1}}$

Where:

SP = Total number of fish passing spillway.
CC = Total number of fish passing through corner collector.
B1 = Total number of fish passing B1.
B2 = Total number of fish passing B2.
SL = Total number of fish passing through B1 sluiceway.
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).

Non-turbine passage=Total fish passing through non-turbine routes (B1 includes sluiceway and navigation lock; B2 includes corner collector and guided passage)
F_{SP} = Average discharge (kcfs) through the spillway during the study period.
F_{CC} = Average discharge (kcfs) through the corner collector during the study period.
F_{B1} = Average discharge (kcfs) through the first powerhouse during the study period.
F_{B2} = Average discharge (kcfs) through the second powerhouse 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 to provide a measure of precision of our estimate. We tested for equality of proportions between passage efficiencies during day and night using a chi-square test (Zar 1999).

1-3.0 Results

1-3.1 Water Quality

Throughout the spring, water temperature increased, and dissolved oxygen and electrical conductivity decreased (Appendix 1). Water temperature in the spillway forebay was a mean 14.8 ºC and ranged from 11.7 to 16.5 ºC. The mean dissolved oxygen was 9.5 ppm and ranged from 8.5 to 10.7 ppm. The mean electrical conductivity was 142.7 µS/cm and ranged from 126.5 to 187.5 µS/cm. Temperature, dissolved oxygen, and electrical conductivity were similar during the day and night (Appendix 2).

1-3.2 Tagging

From 29 April to 6 June 2005, we radio-tagged and released 5,850 yearling Chinook salmon and 4,278 yearling steelhead. Of the Chinook salmon, 25% (1,469 of 5,850) were released from John Day Dam and 75% (4,381 of 5,850) were released from The Dalles Dam. All 4,278 steelhead were released from The Dalles Dam. The release period coincided with the central portion of the "in river" seaward migration of Chinook salmon and steelhead smolts (Figure 4). Of the fish released from John Day Dam, 49% (717 of 1,469) were released during the day and 51% (752 of 1,469) were released at night. Of the fish released from The Dalles Dam, 55% (4,721 of 8,659) were released during the day and 45% (3,938 of 8,659) were released at night. Mean fork length for Chinook salmon released from all sites was 153.9 mm and the mean weight was 36.3 g (Appendix 3). Mean fork length for steelhead released from all sites was 221.1 mm and the mean weight was 93.0 g (Appendix 4). The radio tag represented an average of 2.9% (1.1%-4.9%) of mean Chinook salmon body weight and 1.1% (0.4%-4.6%) of mean steelhead weight.

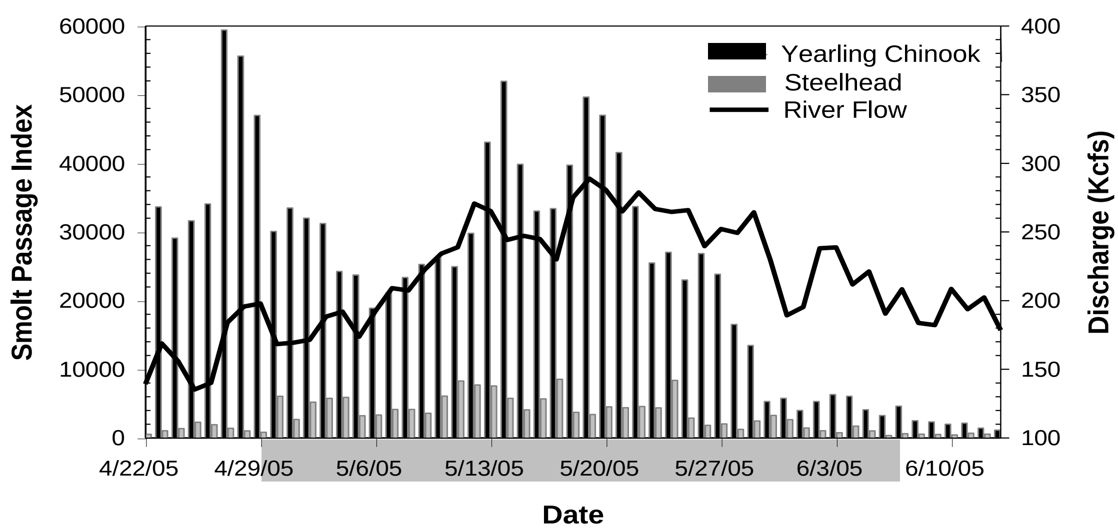
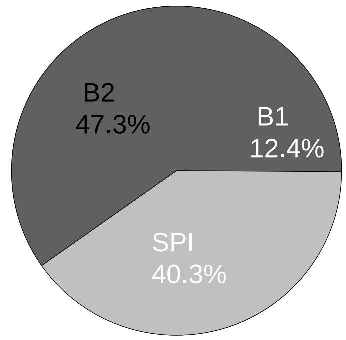


Figure 4.— Smolt Passage index for yearling Chinook salmon and steelhead at Bonneville Dam's Second Powerhouse Smolt Monitoring Facility during spring 2005 (4/22-6/13). Shaded area indicates release period (4/29-6/06). Smolt index data were acquired from www.fpc.org.

1-3.3 River Discharge and Project Operations



During spring 2005 (May 1– June 12), mean river discharge at Bonneville Dam was 216.4 kcfs, and ranged from 157.6 kcfs to 279.2 kcfs. Allocation of mean river discharge among dam areas (i.e., B1, B2, and spillway) during the study period was 12.4% through B1, 47.3% through B2, and 40.3% through spill (Figure 5 and Table 1). Mean daily discharge at B1 (turbines 1 – 10) was 26.8 kcfs and ranged from 0.9 to 70.5 kcfs. B2 displayed the greatest fluctuation in mean daily discharge with a mean of 102.3 kcfs, a minimum of 73.4 kcfs and a maximum of 125.4 kcfs. Mean daily spill was 87.3 kcfs and ranged from 65.1 to 105.4 kcfs (Table 1)[1]. Day and night periods were determined by selecting the middle date of our study period and calculating the period between the start of civil twilight to the end of civil twilight, rounding to the nearest hour. Spill occurred from about 0500 – 2059 hours during the day and from about 2100 – 0459 hours during the night. Discharge at both powerhouses increased in the beginning of the season and then decreased as the season progressed and daily discharge fluctuated more at B1 and B2 than at the spillway (Figure 6).

Only one spill condition was tested in 2005: 75 kcfs spilled during daytime hours (0500 – 2059) and spill to the 120% total dissolved gas (TDG) cap during nighttime hours (2100 – 0459). Mean discharge at B1 went primarily through turbines 1-6 (72%), with the remainder of discharge going through turbines 7-10 (24%) and the sluiceway (4%; Figure 7). Mean discharge at B2 was distributed through the turbines more equally than at B1: 49% through turbines 11-14 and 48% through turbines 15-18. The remaining 3% was discharged through the corner collector (Figure 8). There were considerable differences in discharge between turbine units, although fluctuations in mean daily discharge at B2 and the spillway corresponded with mean daily river discharge. Differences in daily turbine discharge were observed for multiple turbines throughout the study (Figures 9-12). We found that mean discharge was higher during day than night (15% of B1 and 50% of B2) and mean discharge at the spillway was higher at night compared to day (53% of SPI).

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[1] In July of 2004, the U.S. Army Corps of Engineers identified a discrepancy in the amount of water reported to be spilled at Bonneville Dam. An error in the calibration of spill gate openings installed in the early 1970s resulted in up to 30% less water discharged through the spillway than was reported to regional fish and water management officials. This report contains data based on accurate discharge measurements for 2005. Additionally, discharge data from research in 2002 and 2004 presented in this report has been revised for updated spill data.

Table 1.—Descriptive statistics for discharge (kcfs) at Bonneville Dam during spring 2005. Values have been rounded to the nearest tenth and are based on daily totals. Discharge for the sluiceway and corner collector are included in discharge for the first powerhouse and second powerhouse, respectively.

Dam Area	Mean	Median	Min	Max
First Powerhouse	26.8	27.2	0.9	70.5
Sluiceway	1.0	1.1	0.6	1.3
Second Powerhouse	102.3	103.2	73.4	125.4
Corner Collector	5.1	5.2	4.6	5.6
Spillway	87.3	89.2	65.1	105.4
Total	216.4	220.8	157.6	279.2

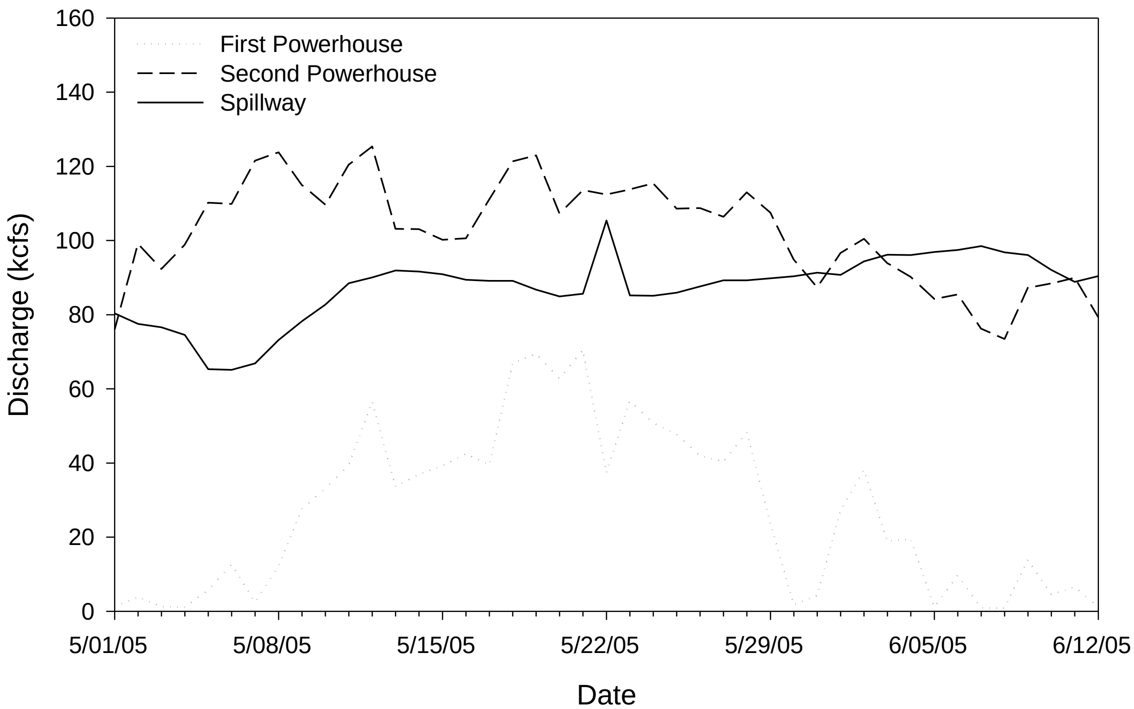

Figure 6.—Mean daily discharge by dam area at Bonneville Dam, spring 2005.

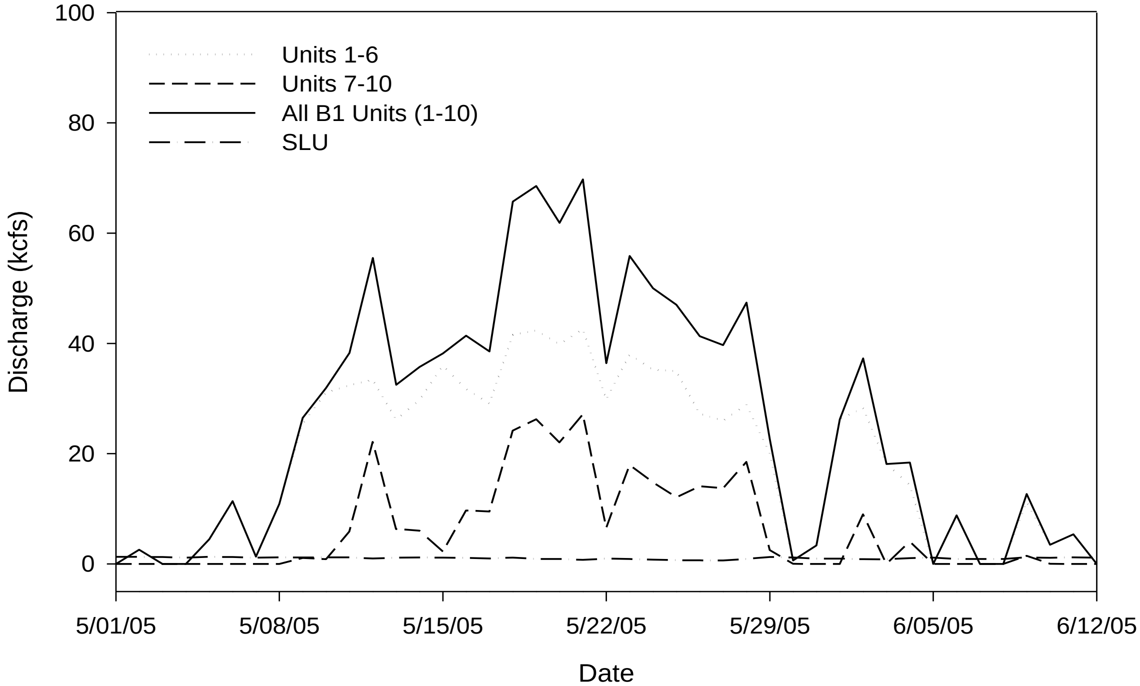

Figure 7.—Mean daily discharge through turbines 1-6, 7-10, and the sluiceway (SLU) at Bonneville Dam's first powerhouse (B1), spring 2005.

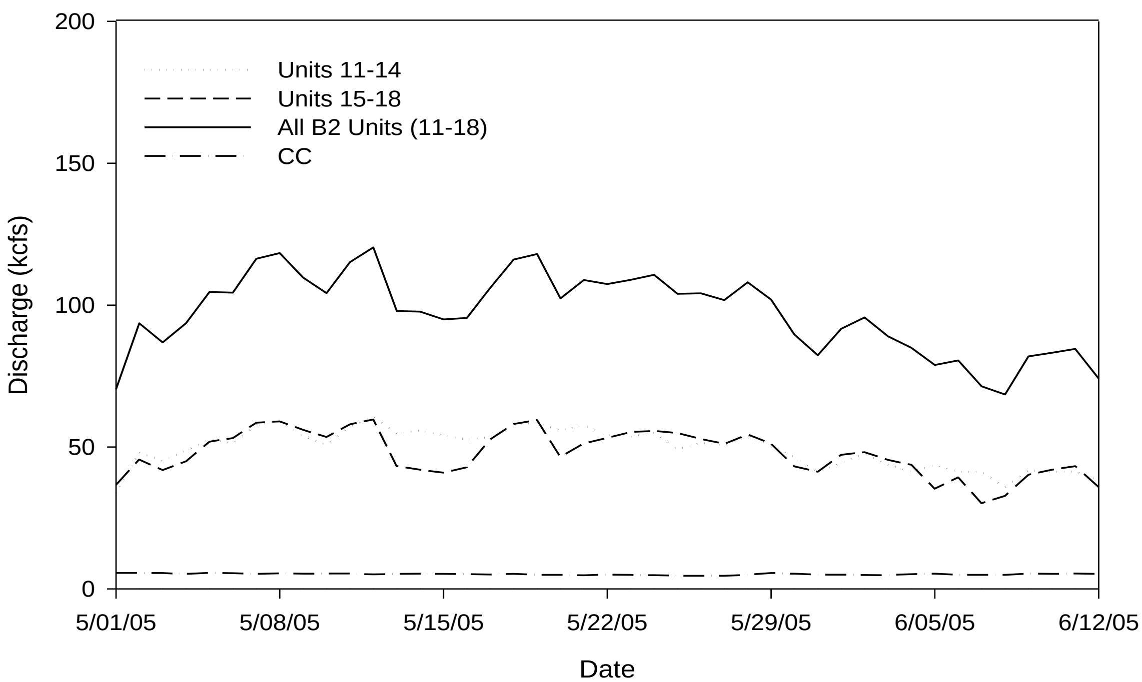

Figure 8.—Mean daily discharge through turbines 11-14, 15-18, and the corner collector (CC) at Bonneville Dam's second powerhouse (B2), spring 2005.

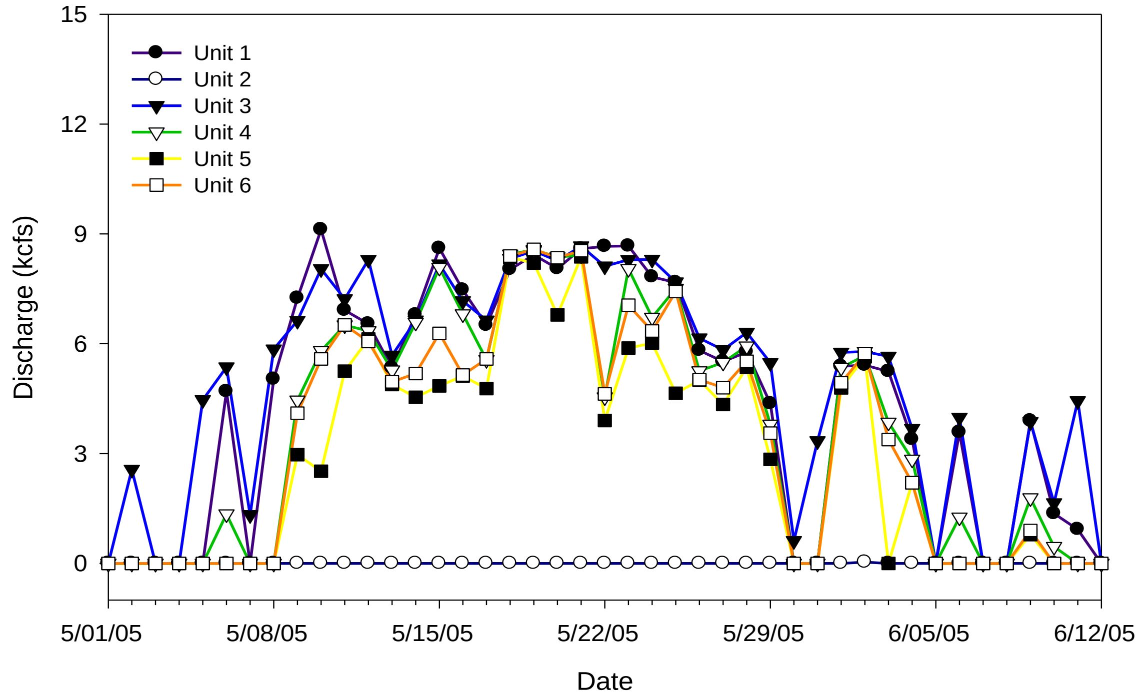

Figure 9.—Mean daily discharge by unit for turbines 1-6 at Bonneville Dam, spring 2005.

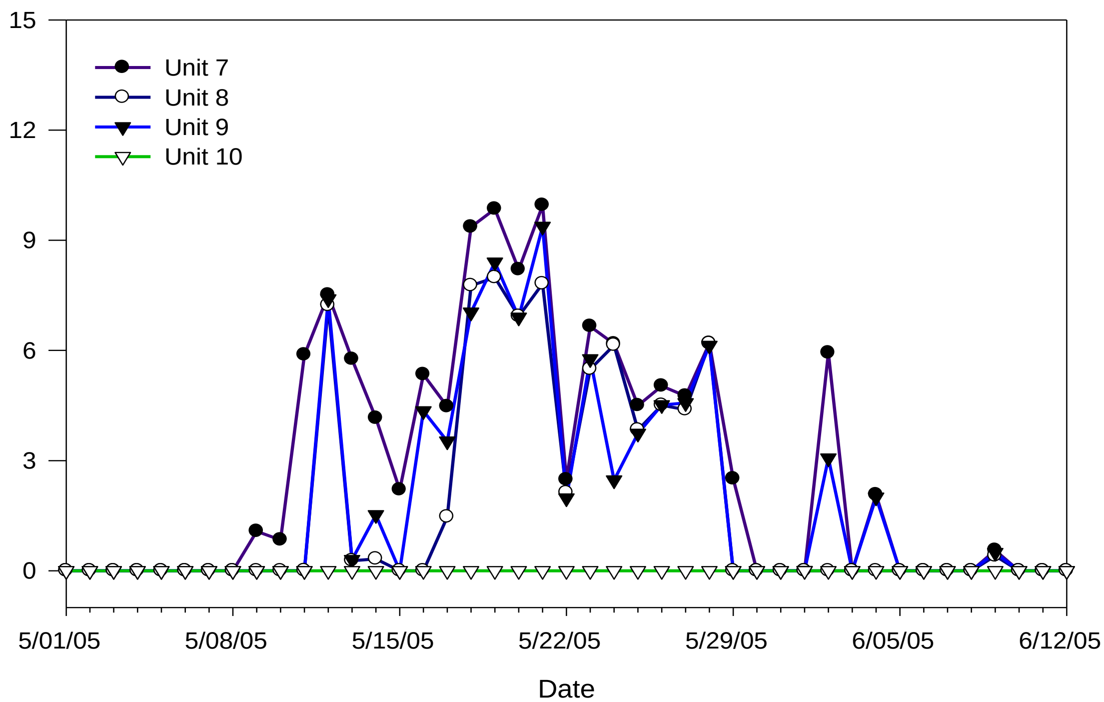

Figure 10.—Mean daily discharge by unit for turbines 7-10 at Bonneville Dam, spring 2005.

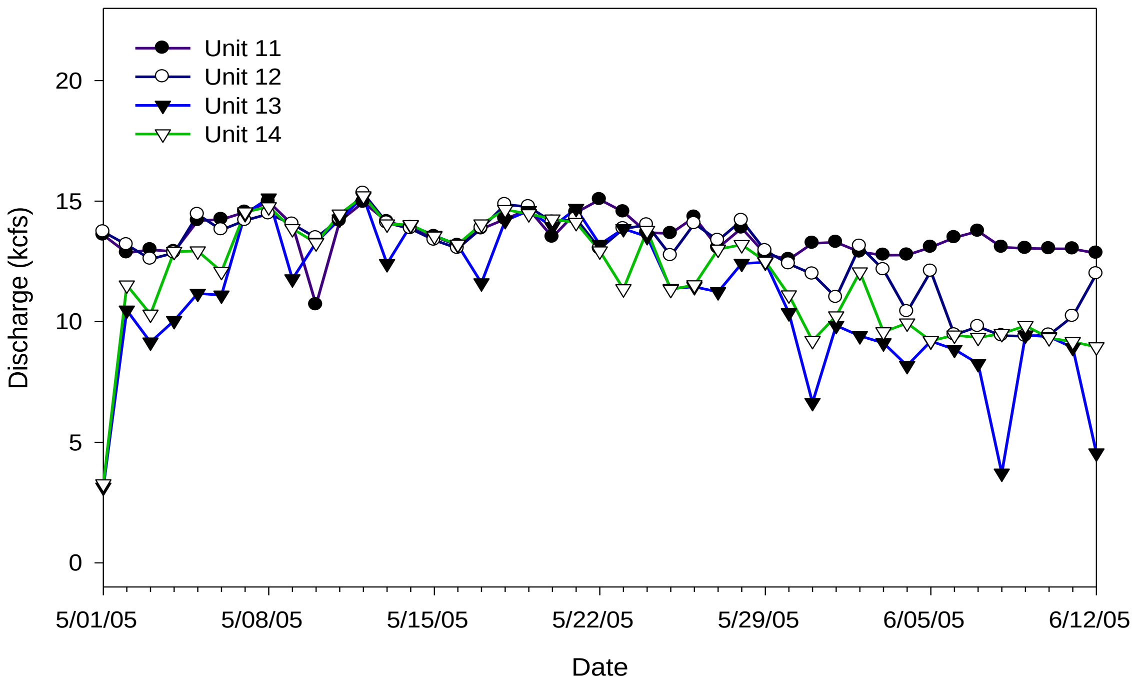

Figure 11.—Mean daily discharge by unit for turbines 11-14 at Bonneville Dam, spring 2005.

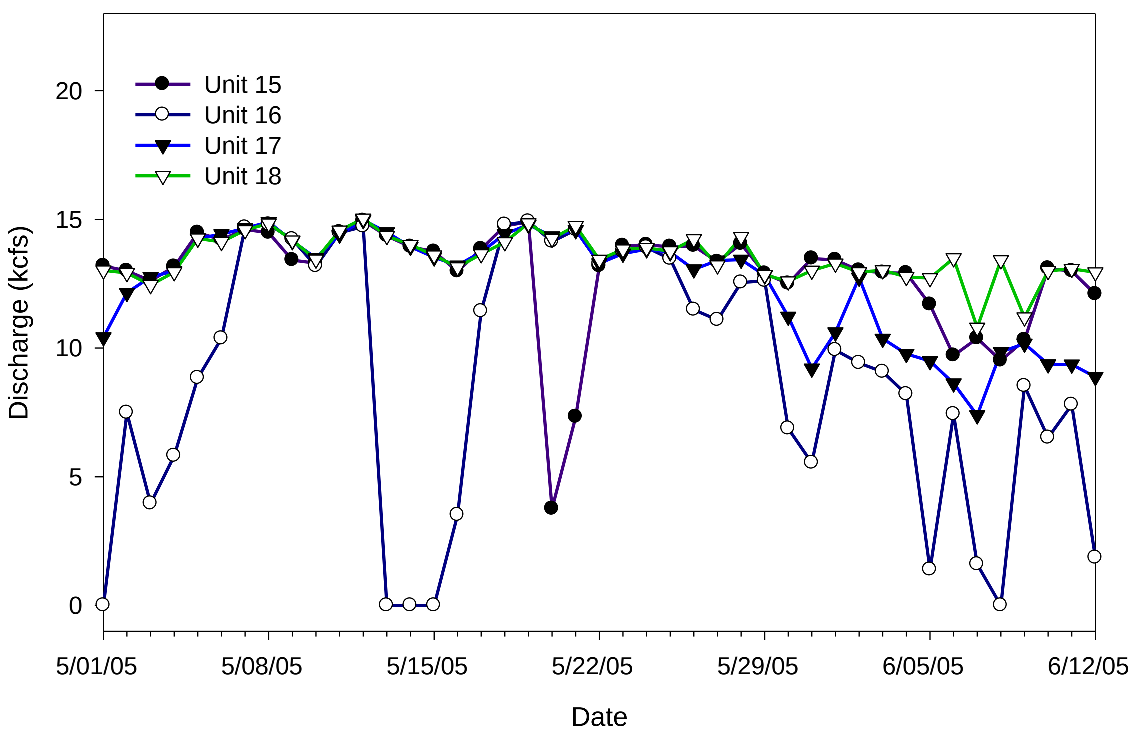

Figure 12.—Mean daily discharge by unit for turbines 15-18 at Bonneville Dam, spring 2005.

Table 2.—Mean discharge (kcfs) during day (0500-2059 hours) and night (2100-0459 hours) by dam area at Bonneville Dam, spring 2005.

Period and dam area	Percent (of period)	Mean	Median	Min	Max
Day					
First Powerhouse	15%	33.4	30.6	0.6	82.3
Second Powerhouse	50%	109.8	110.0	66.9	140.3
Spillway	35%	75.1	75.1	64.1	114.9
Total	100%	218.3	218.1	137.6	291.8
Night					
First Powerhouse	6%	13.8	1.3	0.5	75.9
Second Powerhouse	41%	87.2	94.8	30.8	139.1
Spillway	53%	111.5	115.2	65.2	163.9
Total	100%	212.5	204.1	136.8	313.7

1-3.4 Travel to and Arrival at Bonneville Dam

At Bonneville Dam, we detected 94% (5,452 of 5,820) of the yearling Chinook salmon and 93% (3,996 of 4,278) of the steelhead that were released from John Day Dam and The Dalles Dam. The median travel time for Chinook salmon released from John Day Dam to first detection at Bonneville Dam was 47.2 h and the median travel rate was 2.5 km/h. Chinook salmon released from The Dalles Dam had a median travel time of 30.4 h and a median travel rate of 2.5 km/h. The median travel time for steelhead released from The Dalles Dam was 28.5 h and the median travel rate was 2.7 km/h . (Table 3).

Table 3.— Descriptive statistics for travel time (h) and travel rate (km/h) to Bonneville Dam for yearling Chinook salmon (CH1) and steelhead (HST), spring 2005. Travel rate statistics are represented in parentheses.

Release site	Species	Mean	Median	Min	Max
John Day Dam	CH1	47.2 (2.5)	44.3 (2.5)	31.7 (0.8)	149.2 (3.5)
The Dalles Dam	CH1	30.4 (2.5)	28.9 (2.5)	16.0 (0.5)	160.6 (4.6)
The Dalles Dam	HST	28.5 (2.7)	27.2 (2.7)	18.0 (0.5)	157.6 (4.1)

Fish did not enter dam areas (i.e. B1, B2, and spillway) in equal proportions. Of the Chinook salmon detected at Bonneville Dam, 4% (192 of 5,446) first entered the B1 forebay, 64% (3,494 of 5,446) first entered the B2 forebay, and 32% (1,760 of 5,446) 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, 3% (106 of 3,993) first entered the B1 forebay, 64% (2,548 of 3,993) first entered the B2 forebay, and 33% (1,339 of 3,993) 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 allocation at B1, B2, and the spillway was 13%, 47%, and 40%, respectively. 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 13 and 14).

Similarly, we compared the hourly proportion of fish entering each dam area to the hourly proportion of mean discharge through each dam area. At all three dam areas, fish entrance increased when hourly discharge increased and fish entrance decreased when hourly discharge decreased (Figures 15 and 16).

1-3.5 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=2.7 h) than in the forebays of B2 (median = 0.1 h) or the spillway (median = 0.4 h). Steelhead also resided considerably longer in the forebay of B1 (median = 5.2 h) than in the forebays of B2 (median = 0.6 h) or the spillway (median = 0.5 h; Table 4). We compared median forebay residence time to mean discharge by day of passage, by hour of passage, and by hour of arrival and found that residence times generally decreased as discharge increased (Appendices 5-10).

1-3.6 Route and Time of Passage through Bonneville Dam

We determined the route of passage through Bonneville Dam for 99.9% of yearling Chinook salmon (5,446 of 5,452) and 99.9% of steelhead (3,992 of 3,996) detected at Bonneville Dam. All fish for which passage routes could not be determined were detected downstream of the dam. Among the three dam areas, B2 passed the most fish (53-56%, depending on species), followed by the spillway (38-39%) and B1 (6-8%; Figure 17). The distribution of passage among dam areas was very similar to the distribution of approach (based on first detection of fish) among dam areas.

Passage of Chinook salmon at B1 was highest through turbine routes. Of the 345 Chinook salmon that passed at B1, 65% (224) passed unguided through the turbines and 33% (115) passed through the sluiceway. The remaining 2% (6) passed via the navigation lock. Passage of Chinook salmon at B2 was not equally distributed. Of the 3,062 Chinook salmon with known passage routes at B2, 45% (1,374) passed unguided through the turbines, 29% (902) passed through the corner collector and 26% (786) were guided into the DSM (Figure 17).

Passage of steelhead at B1 was also highest through turbine routes. Of the 326 steelhead that passed B1, 70% (229) passed unguided through the turbines and 29% (93) passed through the sluiceway. The remaining 1% (4) passed via the navigation lock. Steelhead passage at B2 was also not equally distributed. Of the 2,107 steelhead that passed at B2, 66% (1,396) passed through the corner collector, 22% (453) passed unguided through the turbines, and 12% (258) were guided into the DSM (Figure 17).

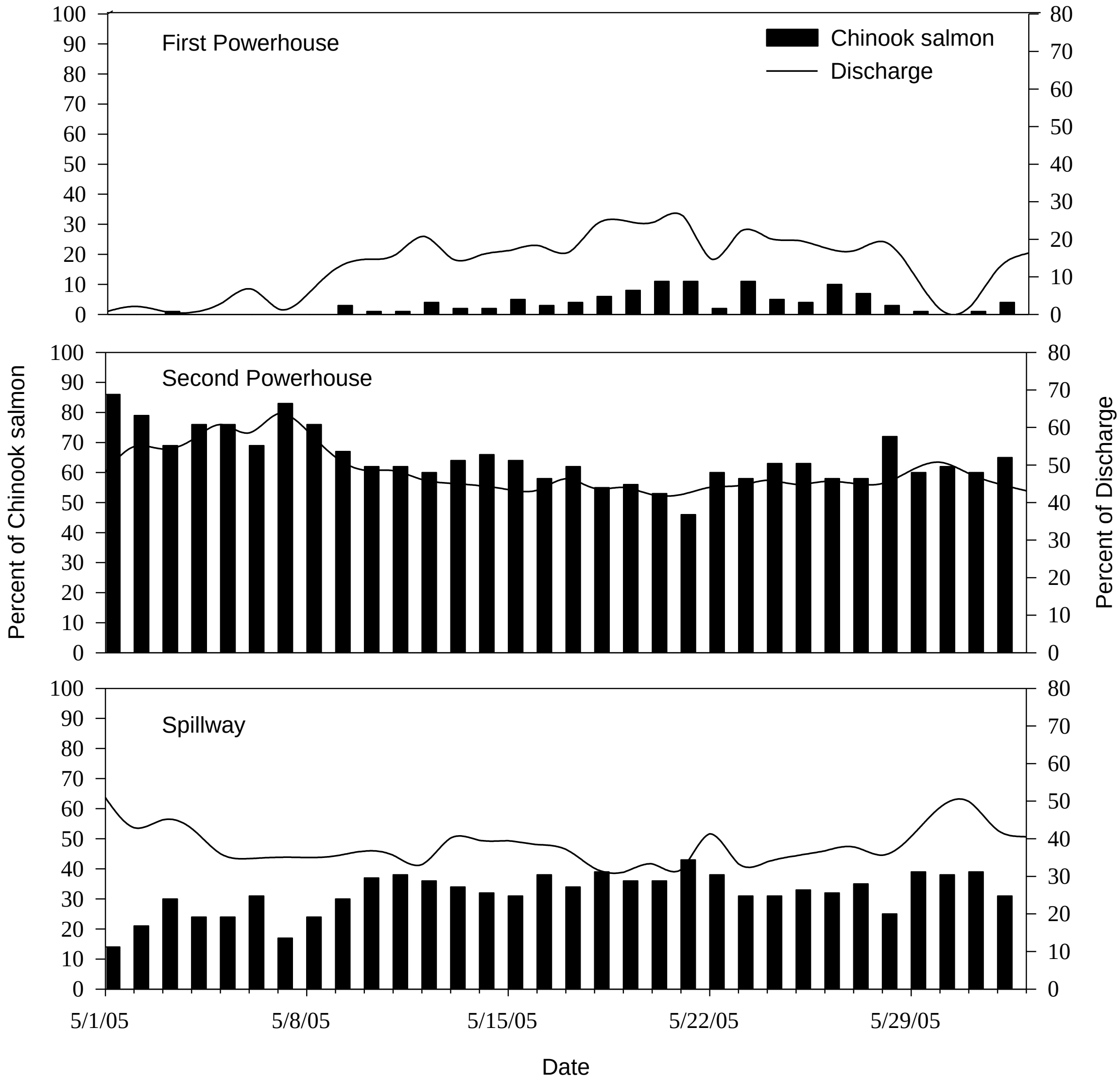

Figure 13.— The percentage of yearling Chinook salmon that entered each dam area versus the percentage of mean daily discharge at each dam area at Bonneville Dam, spring 2005.

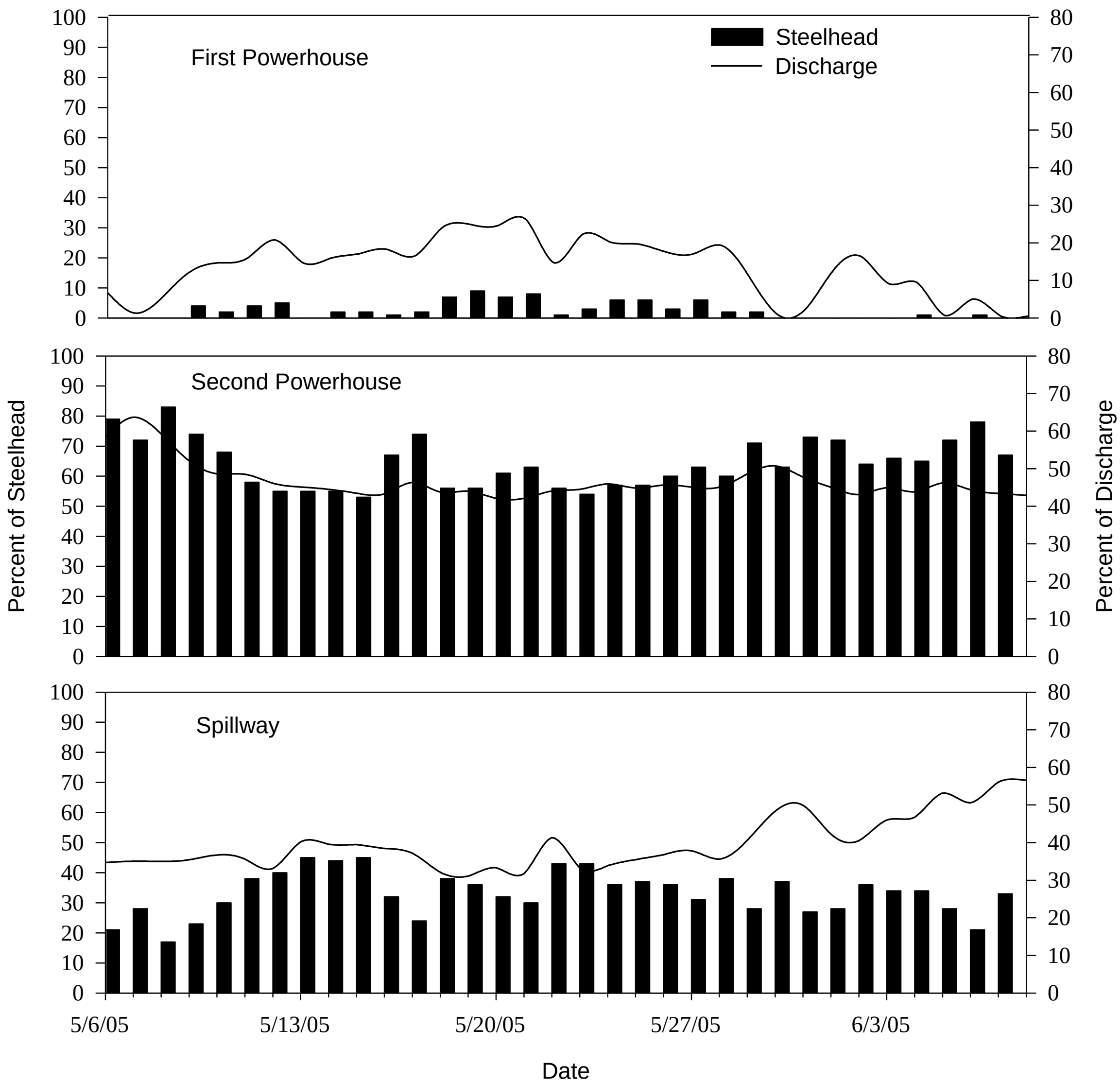

Figure 14. — The percentage of yearling steelhead that entered each dam area versus the percentage of mean daily discharge at each dam area at Bonneville Dam, spring 2005.

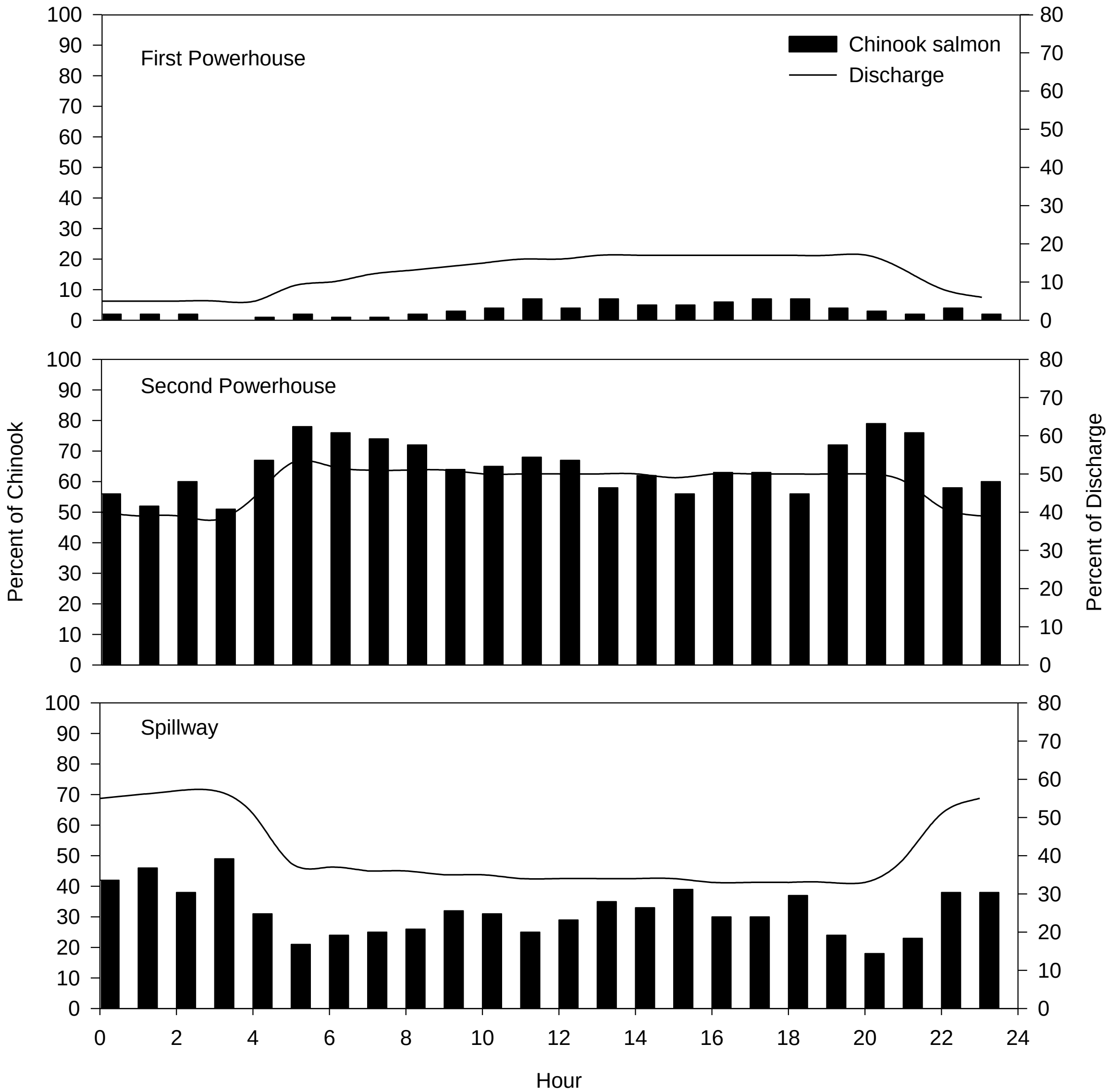

Figure 15.—The percent of yearling Chinook salmon that entered each dam area versus the percentage of mean hourly discharge at each dam area at Bonneville Dam, spring 2005.

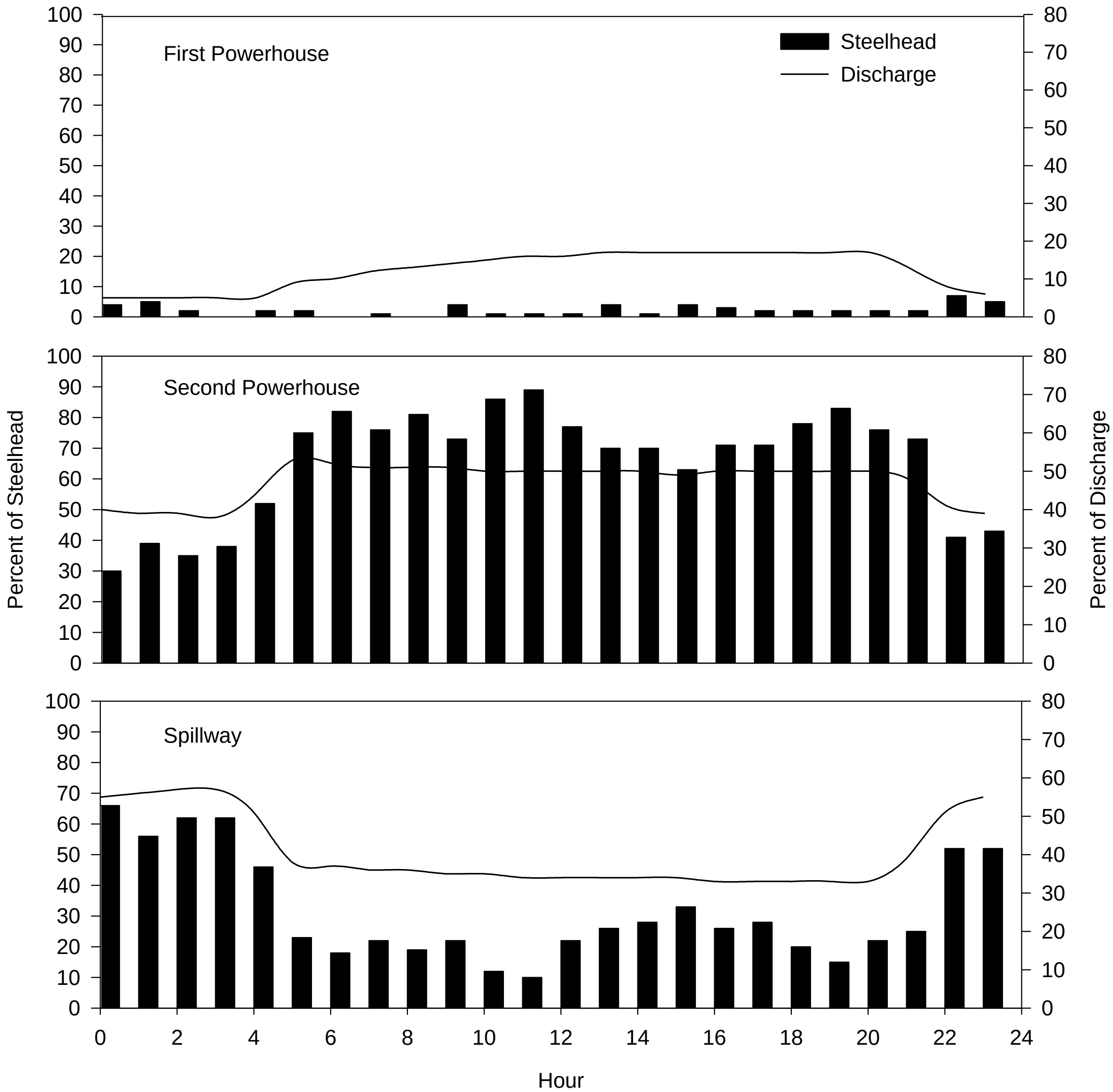

Figure 16. —The percent of yearling steelhead that entered each dam area versus the percentage of mean hourly discharge at each dam area at Bonneville Dam, spring 2005.

Table 4. —Descriptive statistics of forebay residence time (h) by dam area of yearling Chinook salmon and steelhead at Bonneville Dam, spring 2005.

Dam area	N	Mean	Median	Min	Max
Chinook salmon					
First Powerhouse	342	11.8	2.7	0.0	171.9
Second Powerhouse	2752	0.7	0.1	0.0	141.5
Spillway	1999	1.0	0.4	0.0	142.9
Total	5093	1.5	0.3	0.0	171.9
Steelhead					
First Powerhouse	321	13.2	5.2	0.0	138.4
Second Powerhouse	2034	2.1	0.6	0.0	140.9
Spillway	1516	2.3	0.5	0.0	144.9
Total	3871	3.1	0.6	0.0	144.9

Project passage of both Chinook salmon and steelhead peaked at sunset (2100-2200 hours) and was lowest just after sunrise (0500-0700 hours; Figure 18). Diurnal passage distributions of Chinook salmon and steelhead were similar to overall passage distributions. During the day, the majority of both species passed at B2 (59-72%) compared to the spillway (21-33%) and B1 (7-8%). At night, more yearling Chinook salmon passed B2 (51%) compared to the spillway (45%) and B1 (4%). For steelhead, night passage was highest at the spillway (62%) compared to B2 (29%) and B1 (9%; Table 5). Upon comparison of the number of fish that passed each dam area during day and night, we found that a higher proportion of fish passed during day (Table 6). This was true for both Chinook salmon and steelhead at all dam areas, the only exception being at the spillway where 71% (1103 of 1,559) 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 yearling Chinook salmon were higher during the day at B1 and higher during the night at the spillway. For steelhead, passage rates were higher during the night at B1 and the spillway but higher during the day at B2 (Table 7). Hourly passage data for each species by route of passage and by spill treatment are provided in Appendices 11-23.

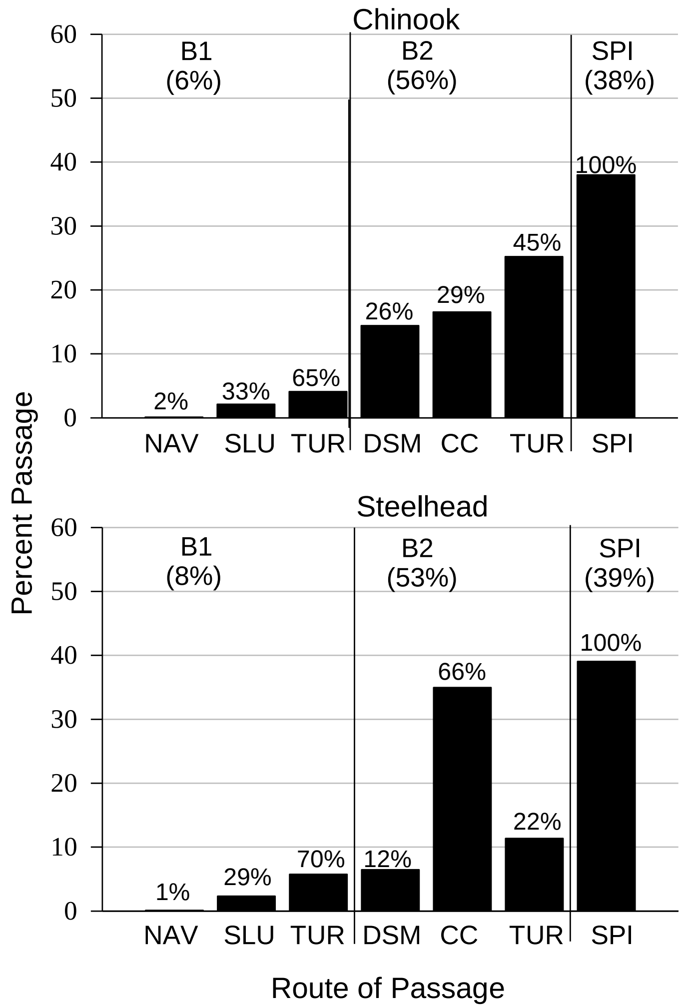

Figure 17. —Percent fish passage by dam area and route of passage for yearling Chinook salmon and steelhead at Bonneville Dam, spring 2005. B1 = first powerhouse; B2 = second powerhouse; SPI = spillway; NAV = navigation lock; SLU = sluiceway; TUR = turbine; DSM = downstream salmonid migrants channel; and CC = corner collector. Percentages in parentheses designate proportions among dam areas, percentages without parentheses designate proportions within each dam area, and the percent value of each bar represents proportions of all routes at Bonneville Dam.

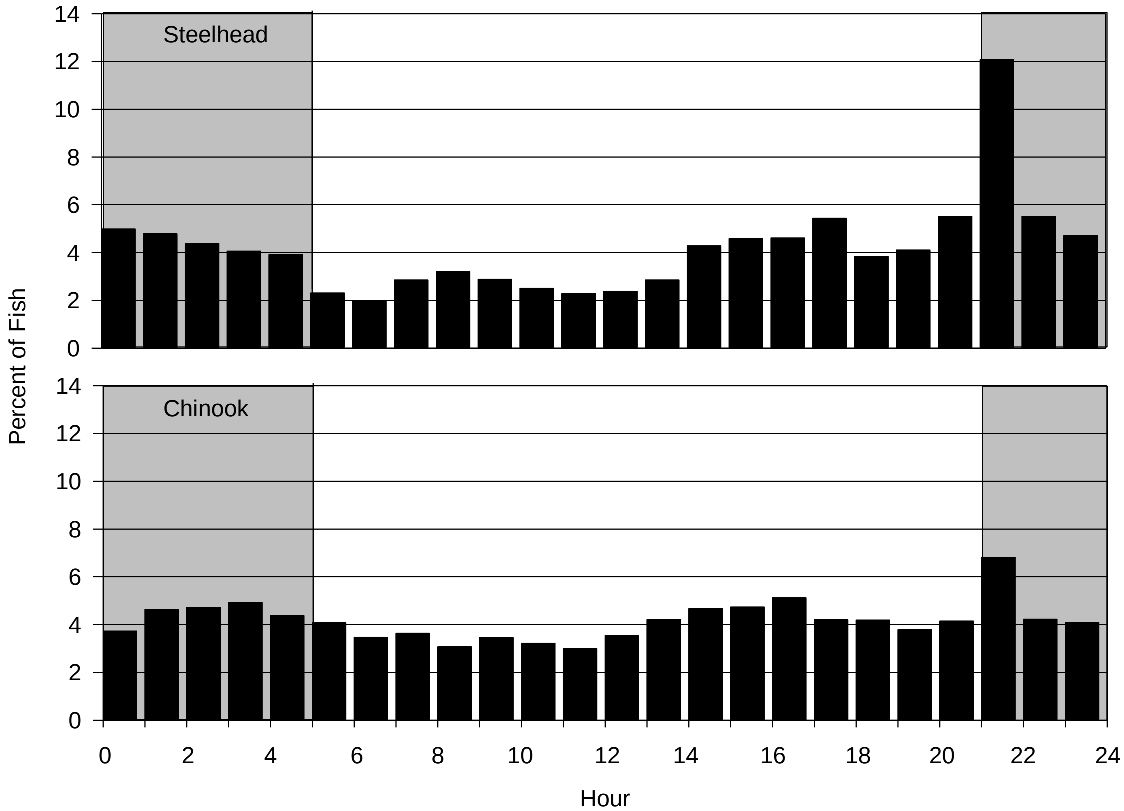

Figure 18. —Percent passage by hour during day (0500-2059 hours; unshaded) and night (2100-0459 hours; shaded) for yearling Chinook salmon and steelhead at Bonneville Dam, spring 2005.

Table 5. — Percentage of yearling Chinook salmon and steelhead that passed each area of Bonneville Dam during the day (0500-2059 hours) and night (2100-0459 hours), spring 2005. Percentages are based on the total number of fish that passed each route during each diel period.

Species and period	Route of passage		
	First Powerhouse	Second Powerhouse	Spillway
Chinook salmon			
Day	8% (262 of 3404)	59% (2029 of 3404)	33% (1113 of 3404)
Night	4% (83 of 2042)	51% (1033 of 2042)	45% (926 of 2042)
Steelhead			
Day	7% (163 of 2219)	72% (1600 of 2219)	21% (456 of 2219)
Night	9% (163 of 1773)	29% (507 of 1773)	62% (1103 of 1773)

Table 6.—Percentage of yearling Chinook salmon and steelhead that passed each area of Bonneville Dam during daytime hours (0500-2059 hours) and nighttime hours (2100-0459 hours), spring 2005. Percentages are based on the total number of fish that pass each Dam area.

Species and period	Route of passage		
	First Powerhouse	Second Powerhouse	Spillway
Chinook salmon			
Day	76% (262 of 345)	66% (2029 of 3062)	55% (1113 of 2039)
Night	24% (83 of 345)	34% (1033 of 3062)	45% (926 of 2039)
Steelhead			
Day	50% (163 of 326)	76% (1600 of 2107)	29% (456 of 1559)
Night	50% (163 of 326)	24% (507 of 2107)	71% (1103 of 1559)

Table 7.—Passage rates for yearling Chinook salmon and steelhead that passed Bonneville Dam during the day (0500-2059 hours) and night (2100-0459 hours), spring 2005. Rates are based on 16 h per 24 h over 40 d for day passage and 8 h per 24 h over 40 d for night passage.

Species and period	Route of passage		
	First Powerhouse	Second Powerhouse	Spillway
Chinook salmon			
Day	0.4 fish/h	3.2 fish/h	1.7 fish/h
Night	0.3 fish/h	3.2 fish/h	2.9 fish/h
Steelhead			
Day	0.3 fish/h	2.5 fish/h	0.7 fish/h
Night	0.5 fish/h	1.6 fish/h	3.4 fish/h

1-3.7 Passage Metrics

1-3.7.1 Spillway Efficiency

Spillway efficiency is the number of fish that passed through the spillway divided by the number of fish that passed through all routes at all dam areas (spillway, B1, and B2). Overall, 37% of Chinook salmon and 38% of steelhead passed through the spillway. Spillway efficiency was significantly higher for both yearling Chinook salmon (X^2 = 87.2, df = 1, $P < 0.0001$) and steelhead (X^2 = 718.7, df = 1, $P < 0.0001$) during the night, when spill was discharged up to the total dissolved gas cap (TDG; mean = 111.5 kcfs), than during the day, when an average of 75.1 kcfs was discharged through the spillway (Table 8).

Table 8.—Spillway Efficiency at Bonneville Dam for yearling Chinook salmon and steelhead during spring 2005. Mean discharge spilled during each period is shown in parentheses. SE = standard error of spillway efficiency estimate, B1 = first powerhouse, and B2 = second powerhouse.

Species and period	Spillway efficiency	SE	B1 passage	B2 passage	SPI passage
Chinook salmon					
Overall (87.3)	37%	0.7	345	3062	2039
Day (75.1)	33%	0.8	262	2029	1113
Night (111.5)	45%	1.1	83	1033	926
Steelhead					
Overall (87.3)	39%	0.8	326	2107	1559
Day (75.1)	21%	0.9	163	1600	456
Night (111.5)	62%	1.2	163	507	1103

1-3.7.2 Spillway Effectiveness

Spillway effectiveness is the proportion of fish that passed through spill relative to the proportion of project discharge spilled. Chinook salmon had an overall spillway effectiveness of 0.93 and steelhead had an overall spillway effectiveness of 0.97 (Table 9). Spill was more effective during the day (0.95), than night (0.86), for yearling Chinook salmon. Conversely, spill was more effective during the night (1.19), than during the day (0.60), for steelhead.

Table 9.—Spillway effectiveness and efficiency at Bonneville Dam for yearling Chinook salmon and steelhead during spring 2005. F_{sp} = mean spillway discharge (kcfs). F_{tot} = mean project discharge (kcfs).

Species and period	Spillway effectiveness	Spillway efficiency	F_{sp}	F_{tot}
Chinook salmon				
Overall	0.93	37%	87.3	216.4
Day	0.95	33%	75.1	218.3
Night	0.86	45%	111.5	212.5
Steelhead				
Overall	0.97	39%	87.3	216.4
Day	0.60	21%	75.1	218.3
Night	1.19	62%	111.5	212.5

1-3.7.3 Fish Guidance Efficiency

Fish guidance efficiency at B2 (FGE; proportion of fish entering turbine intakes that were guided by turbine intake screens) overall was 36% for Chinook salmon and 36% for steelhead. Since no guidance screens were deployed at B1 in 2005 we could not calculate FGE at B1. Fish guidance efficiency at B2 was significantly higher (X^2 = 36.8, df = 1, P < 0.0001) for Chinook salmon during the day (42%) compared to night (29%). Fish guidance efficiency at B2 was significantly higher (X^2 = 2.33, df = 1, P < 0.0001) for steelhead during the day (40%) compared to night (34%; Table 10). Turbine unit 11 was the most efficient (43%) at guiding Chinook salmon and turbine unit 16 was the most efficient (50%) at guiding steelhead (Table 11). Over twice as many fish of both species passed at the southern half of B2, at units 11-14, compared to the northern half, at units 15-18. Unit 18 passed the least amount of fish and had the lowest guidance. Units 12-17 had similar FGE for Chinook salmon, ranging from 35-43%. Units 12-15 had similar FGE for steelhead, ranging from 36-38%. Unit 13, although it didn't have the highest FGE, guided the most yearling Chinook salmon.

Table 10.—Estimates of fish guidance efficiency (FGE) and corresponding standard error at Bonneville Dam's second powerhouse for yearling Chinook salmon and steelhead during spring 2005. Mean discharge spilled during each period and numbers of fish guided of total guided plus unguided are shown in parentheses.

Species and period	Fish guidance efficiency	Standard error
Chinook salmon		
Overall (87.3 kcfs)	36% (786 of 2160)	1.0
Day (75.1 kcfs)	42% (508 of 1211)	1.4
Night (111.5 kcfs)	29% (278 of 949)	1.5
Steelhead		
Overall (87.3 kcfs)	36% (258 of 711)	1.8
Day (75.1 kcfs)	40% (120 of 304)	2.8
Night (111.5 kcfs)	34% (138 of 407)	2.3

Table 11.—Estimates of fish guidance efficiency (FGE) by turbine unit at Bonneville Dam's second powerhouse for yearling Chinook salmon and steelhead, spring 2005.

Turbine Unit	FGE	
	Chinook salmon	Steelhead
11	43% (108 of 252)	48% (60 of 124)
12	40% (106 of 265)	38% (36 of 94)
13	40% (162 of 403)	38% (43 of 113)
14	35% (121 of 349)	38% (35 of 92)
15	41% (114 of 278)	36% (32 of 90)
16	40% (76 of 191)	50% (26 of 52)
17	42% (69 of 164)	37% (14 of 38)
18	23% (27 of 117)	33% (11 of 33)

1-3.7.4 Fish Passage Efficiency

Fish passage efficiency (FPE: the proportion of fish that passed the dam via non-turbine routes) at Bonneville Dam was 71% (SE = 0.6) for Chinook salmon and 83% (SE = 0.6) for steelhead (Table 12). Fish passage efficiency was highest during the day for both Chinook salmon (75%) and steelhead (91%). Differences in FPE between day and night were significant for both yearling Chinook salmon (X^2 = 64.7, df = 1, P < 0.0001) and steelhead (X^2 = 85.3, df = 1, P < 0.0001).

Table 12.—Fish passage efficiency (FPE) at Bonneville Dam for yearling Chinook salmon and steelhead during spring 2005. Does not include six Chinook salmon and four steelhead that passed through the navigation lock that were used in FPE calculations. B1 = first powerhouse and B2 = second powerhouse.

Species and period	FPE	Sluiceway	B2 guided	Corner collector	Spillway	B1 unguided	B2 unguided
Chinook salmon							
Overall	71%	115	786	902	2039	224	1374
Day	75%	92	508	818	1113	165	703
Night	64%	23	278	84	926	59	671
Steelhead							
Overall	83%	93	258	1396	1559	229	453
Day	91%	73	120	1296	456	86	184
Night	77%	20	138	100	1103	143	269

1-3.7.5 Corner Collector Efficiency

Corner collector efficiency (CCE) is the number of fish that passed through the corner collector divided by the number of fish that passed through all routes at B2. Overall, 30% of Chinook salmon and 66% of steelhead that passed at B2 went through the corner collector. Passage through the corner collector was significantly higher during the day, than night, for both yearling Chinook salmon (X^2 = 341.2, df = 1, P < 0.0001) and steelhead (X^2 = 646.6, df = 1, P < 0.0001; Table 13).

Table 13.—Corner collector efficiency (CCE) and effectiveness (CCF) at Bonneville Dam for yearling Chinook salmon and steelhead during spring 2005. SE = standard error of corner collector efficiency estimate. F_{cc} = mean corner collector discharge (kcfs). F_{B2} = mean second powerhouse discharge (kcfs).

Species and period	CCE	SE	CCF	F_{cc}	F_{B2}
Chinook salmon					
Overall	30%	0.8	5.9	5.1	102.3
Day	40%	1.1	8.7	5.1	109.8
Night	8%	0.9	1.4	5.2	87.2
Steelhead					
Overall	66%	1.0	13.2	5.1	102.3
Day	81%	1.0	17.4	5.1	109.8
Night	20%	1.8	3.3	5.2	87.2

1-3.7.6 Corner Collector Effectiveness

Corner collector effectiveness (CCF) is the proportion of fish that passed through the corner collector relative to the proportion of B2 discharge that went through the corner collector. Chinook salmon had an overall effectiveness of 5.9 and steelhead had an overall effectiveness of 13.2 (Table 13).

1-3.7.7 Sluiceway Efficiency

Sluiceway efficiency is the number of fish that passed through the B1 sluiceway divided by the number of fish that passed through all routes at B1. Overall, 33% of yearling Chinook salmon and 29% of steelhead that passed at B1 passed through the sluiceway. For yearling Chinook salmon, differences in passage through the sluiceway during day and night were not significant ($X^2 = 1.55$, df = 1, $P = 0.21$). Steelhead passage through the sluiceway was significantly ($X^2 = 42.3$, df = 1, $P < 0.0001$; Table 14) higher during the day than during the night.

Table 14.—Sluiceway efficiency (SLE) and effectiveness (SLF) at Bonneville Dam for yearling Chinook salmon and steelhead during spring 2005. SE = standard error of sluiceway efficiency estimate. F_{SL} = mean sluiceway discharge (kcfs). F_{B1} = mean first powerhouse discharge (kcfs).

Species and period	SLE	SE	SLF	F_{SL}	F_{B1}
Chinook salmon					
Overall	33%	2.5	8.8	1.0	26.8
Day	35%	3.0	11.7	1.0	33.4
Night	28%	4.9	3.6	1.1	13.8
Steelhead					
Overall	29%	2.5	7.5	1.0	26.8
Day	45%	3.9	14.9	1.0	33.4
Night	12%	2.6	1.6	1.1	13.4

1-3.7.8 Sluiceway Effectiveness

Sluiceway effectiveness (SLF) is the proportion of fish that passed through the B1 sluiceway relative to the proportion of B1 discharge that went through the sluiceway. Chinook salmon had an overall sluiceway effectiveness of 8.8 and steelhead had an overall effectiveness of 7.5 (Table 14).

1-3.8 Comparisons 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) used fixed hydroacoustics to monitor fish passage and estimate passage performance metrics for the run-at-large (Ploskey et al. 2006). The spring monitoring period for hydroacoustics (April 17 – May 31) was slightly different than it was for our radio telemetry study (May 1 – June 12). We therefore calculated passage metrics during the overlapping period of May 1 – May 31 to directly compare estimates and minimize the effects of variables such as discharge that may have differed during non-overlapping time periods. Because PNNL's estimates were based on the run-at-large and incorporated both yearling Chinook salmon and steelhead, we also weighted our passage estimates based on the passage index (Fish Passage Center, 2005). The passage index from May 1 through May 31, 2005 was 894,378 (86%) yearling Chinook salmon and 141,589 (14%) steelhead. Rather than simply adding passage numbers for each species to get a combined total from which to calculate passage metrics, we multiplied passage proportions for each species by the index proportions: 86% for yearling Chinook salmon and 14% for steelhead. We then added the adjusted proportions to get a combined estimate for the run-at-large. Differences in passage performance metrics, as estimated by radio telemetry and hydroacoustics, ranged from 0-7%. Estimates of $FPE_{Project}$, FPE_{B2}, FPE_{B1}, spillway efficiency, sluiceway efficiency $_{B1,}$ and corner collector $efficiency_{B2}$ differed by 3% or less (Table 15). Corner collector efficiency $_{Project}$ and Sluiceway efficiency $_{Project}$ differed by 6% or less. Estimates of FGE by unit at B2 were most similar for the southern units and differed considerably at the northern units (Table 16). Although sample sizes for radio telemetry estimates of FGE by unit were relatively small compared to those for hydroacoustics, standard errors of radio telemetry passage metric estimates ranged from 0.5% to 1.8%.

Table 15.— 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) during the overlapping period of May 1-May 31, 2005, at Bonneville Dam. Radio telemetry estimates are weighted by the proportion of run size for each species based on the equation: RT estimate = (RT estimateCH1 x proportion of runCH1) + (RT $estimate_{STH}$ x proportion of run_{STH}). Powerhouse one = B1 and powerhouse two = B2.

Passage metric	RT estimate	HA estimate	Difference
Corner collector $efficiency_{B2}$	34%	31%	3%
Corner collector $effectiveness_{B2}$	7.2	6.5	0.7
Corner collector $efficiency_{Project}$	19%	13%	6%
Corner collector $effectiveness_{Project}$	8.2	5.7	2.5
Spillway efficiency	38%	39%	1%
Spillway effectiveness	1.0	1.0	0.0
Sluiceway $efficiency_{B1}$	31%	34%	3%
Sluiceway effectiveness $_{B1}$	9.9	10.4	0.5
Sluiceway $efficiency_{Project}$	2%	7%	5%
Sluiceway $effectiveness_{Project}$	4.6	13.6	9.0
FGE_{B2}	36%	43%	7%
$FPE_{Project}$	72%	71%	1%
FPE_{B1}	33%	34%	1%
FPE_{B2}	58%	61%	3%

Table 16.— Estimates of Fish Guidance Efficiency (FGE), by turbine unit, at Bonneville Dam'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 the overlapping period of May 1-May 31, 2005. Radio telemetry estimates are weighted by the proportion of run size for each species based on the equation: RT FGE= (RT FGE_{CH1}xproportion of run_{CH1}) + (RT FGE_{STH} x proportion of run_{STH}).

Location	RT FGE	HA FGE	Difference
Unit 11	43%	42%	1%
Unit 12	38%	42%	4%
Unit 13	40%	38%	2%
Unit 14	35%	48%	13%
Unit 15	40%	56%	16%
Unit 16	40%	50%	10%
Unit 17	41%	54%	13%
Unit 18	24%	35%	11%

1-3.9 Residence Times at Areas of Potential Delay

According to survey data gathered by the USACE early in 2002, the second powerhouse's Juvenile Bypass System (B2 JBS) conveyance 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 B2 JBS conveyance pipe transported juvenile salmonids rather quickly in 1999-2001 (Holmberg et al. 2001a, 2001b; Evans et al. 2001a, 2001b) and again in 2002 and 2004, after the discovery of the ovality issue (Evans et al. 2003a, 2003b, 2005, Reagan et al. 2005). Travel times of juvenile salmonids through the conveyance pipe were monitored again in 2005. The median travel time of guided fish through the B2 JBS conveyance pipe in 2005 was 36.0 minutes for yearling Chinook salmon and 36.1 minutes for steelhead. These travel times were similar to travel times through the pipe in 1999-2002 and 2004, indicating that fish were not delayed in the pipe (Table 17).

Table 17.—Median travel times (min) for yearling Chinook salmon and steelhead passing through Bonneville Dam's second powerhouse juvenile bypass system conveyance pipe during spring study periods of 1999-2005.

	1999	2000	2001	2002	2004	2005
Chinook salmon	50.3[a]	41.3	37.9	37.0	36.4	36.0
Steelhead	56.6[a]	47.7	No Data	38.2	37.0	36.1

[a] Residence times in 1999 were based on travel from the top of the pipe to the outfall. Residence times in 2000-2005 were based on travel from the top of the pipe to the fish sampling facility, which was not yet completed in 1999.

1-4.0 Discussion

The proportion of discharge allocated to each dam area likely determined the forebay that fish entered, and therefore the dam area that fish subsequently passed. Based on our analysis of daily percent discharge per dam area related to percent of fish that entered each dam area, fish appeared to follow the bulk flow, entering the dam area that had the highest proportion of discharge. Since B2 discharged the greatest amount of water during the study (47.3%), most fish entered the B2 forebay (64% of both Chinook salmon and steelhead). Since flows were lowest at B1 (12.4% of project discharge), only 4% of Chinook salmon and 3% of steelhead entered that dam area.

Higher discharge reduced forebay residence times. Chinook salmon and steelhead resided the least amount of time at structures with the highest discharge (B2 and the spillway, respectively) and both species spent the most time in the B1 forebay, the structure with the lowest discharge. Comparisons of residence times and discharge patterns based on date of fish passage, hour of fish passage, and hour of forebay arrival, indicated that residence times generally decreased with increased discharge. These observations indicate that project operations and the resulting discharge per dam area influence approach paths of migrating yearling Chinook salmon and steelhead and consequently determine which dam area smolts enter and pass. Discharge per dam area also affected how long fish resided in the forebay of Bonneville Dam before passing.

Although surface passage routes were available at both powerhouses, most fish passed through deeper routes of passage. At B1, the largest percentage of both species (65% of Chinook salmon and 70% of steelhead) passed through the deeper turbine intakes, followed by the shallow, weir-type entrances of the sluiceway (33% of Chinook salmon and 29% of steelhead). Likewise at B2, yearling Chinook salmon passed more readily through the deeper turbine intakes (45% unguided, 26% guided) than through the corner collector (29%). However, most steelhead (66%) did pass through the surface-oriented entrance of the corner collector. At the spillway, where fish must descend about 15 m to pass, yearling Chinook salmon and steelhead had a similar passage distribution (38% and 39%, respectively). The data at B2 indicates that yearling Chinook salmon were likely distributed deeper in the water column than steelhead, similar to past years.

The distribution of passage among dam areas fluctuated with diurnal periods but was confounded because discharge also varied diurnally. Project passage of both Chinook salmon and steelhead peaked at sunset (2100-2200 hours) and was lowest just after sunrise (0500-0700 hours). Passage distributions were greatest for both species at B2 during the day. At night, passage was highest for Chinook salmon and steelhead at the spillway. However, discharge was also greatest (50% of project flow) at B2 during the day and at the spillway during the night (53% of project flow). Thus, it is difficult to determine whether diurnal periods or discharge were most responsible for fluctuating passage distributions. During spring 2002, when discharge was similar during day and night for all dam areas and when the only passage route through B2 was through the turbines or bypass system, fish passage increased during the night at both the spillway and B2, and increased during the day at B1 (Evans et al. 2003a). Therefore, past and present research at Bonneville Dam shows that fish passage increases at night through deep routes of passage like the turbines and spillway, and increases during the day through shallow routes of passage like the sluiceway and corner collector. These findings 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. Surface-oriented passage of juvenile salmonids has been shown to increase during the day at Bonneville Dam (Willis and Uremovich 1981; Magne et al.1989; 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). These data suggest that since fish tend to both follow flow and pass in a diurnal pattern, if discharge is optimized in the appropriate area at the right time, passage of fish through non-turbine routes can be increased.

Passage metrics for both yearling Chinook salmon and steelhead were generally similar in 2005 compared to 2004 (Table 18). Surface-oriented passage (corner collector and sluiceway efficiency) was lower in 2005 for both yearling Chinook salmon and steelhead. Project FPE and FPE_{B2} was similar in 2005 compared to 2004 but FPE_{B1} was much lower for both species. If guidance screens had been deployed at B1 in 2005, FPE_{B1} and $FPE_{project}$ would have been higher. However, due to low discharge at B1 in 2005, relatively few fish passed there and the increase would have been minimal. Fish guidance efficiency at B2 was slightly higher in 2005 than 2004 in yearling Chinook salmon, but lower for steelhead. Spillway efficiency was lower in 2004 and 2005 compared to 2002 because more fish passed at B2, specifically through the corner collector. Although the addition of the corner collector did not increase $FPE_{project}$, it did achieve $FPE_{project}$ similar to that attained in previous years, mainly through spill. Furthermore, the corner collector helped achieve similar $FPE_{project}$ with far less water than would have been used to attain the same FPE without the corner collector. The spillway discharged on average 17 times more water than the corner collector. Consequently, effectiveness of the corner collector relative to the project (5.9 for yearling Chinook salmon and 13.2 for steelhead) was far greater than effectiveness of the spillway (0.93 for yearling Chinook salmon and 0.97 for steelhead). These results indicate that although the intake screen guidance systems at Bonneville Dam have poor guidance efficiency, project FPE of 70-83%, depending on species, can be attained if sufficient numbers of fish are passed via a combination of non-turbine routes (spill, sluice, turbine guidance systems, and the corner collector). Additionally, by strategically optimizing discharge patterns at the project, non-turbine passage of juvenile salmonids can be increased.

Table 18.—Passage performance metrics for yearling Chinook salmon and steelhead at Bonneville Dam during spring study periods of 2000, 2001, 2002, 2004, and 2005. B1 = first powerhouse and B2 = second powerhouse.

Species and Passage Metric	2000	2001[c]	2002	2004	2005
Chinook salmon					
Spillway efficiency	44%	16%	57%	33%	37%
Spillway effectiveness	1.3	0.7	1.2	0.9	0.9
FGE_{B1} [a]	50%	45%	50%	-----	-----
FGE_{B2}	39%	46%	37%	33%	36%
$FPE_{Project}$	73%	56%	76%	71%	71%
FPE_{B1}	65%	87%	69%	54%	35%
FPE_{B2}	40%	46%	37%	57%	55%
Sluiceway $efficiency_{B1}$	29%	77%	35%	53%	33%
Sluiceway $effectiveness_{B1}$ [b]	-----	-----	18.6	14.6	8.8
Corner collector $efficiency_{B2}$	-----	-----	-----	37%	30%
Corner collector $effectiveness_{B2}$	-----	-----	-----	7.0	5.9
Corner collector $efficiency_{Project}$	-----	-----	-----	22%	17%
Corner collector $effectiveness_{Project}$	-----	-----	-----	8.4	7.0
Steelhead					
Spillway efficiency	33%	-----	55%	26%	39%
Spillway effectiveness	1.0	-----	1.2	0.7	1.0
FGE_{B1} [a]	59%	-----	75%	-----	-----
FGE_{B2}	55%	-----	59%	40%	36%
$FPE_{Project}$	78%	-----	84%	86%	83%
FPE_{B1}	77%	-----	91%	58%	30%
FPE_{B2}	55%	-----	59%	84%	79%
Sluiceway $efficiency_{B1}$	44%	-----	65%	55%	29%
Sluiceway $effectiveness_{B1}$ [b]	-----	-----	34.1	15.1	7.5
Corner collector $efficiency_{B2}$	-----	-----	-----	74%	66%
Corner collector $effectiveness_{B2}$	-----	-----	-----	14.2	13.2
Corner collector $efficiency_{Project}$	-----	-----	-----	49%	35%
Corner collector $effectiveness_{Project}$	-----	-----	-----	19.1	14.7

[a] In 2004 and 2005, FGE_{B1} could not be estimated due to the absence of guidance screens.
[b] Sluiceway discharge data were not provided in 2000 and 2001 so sluiceway effectiveness could not be calculated.
[c] Steelhead were not evaluated in 2001.

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. 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. Differences in passage metric estimates for radio telemetry and hydroacoustics were typically 3% or less, with only a few instances as high as 7%. The smaller sample sizes utilized by radio telemetry may have contributed to these differences. However, standard errors for radio telemetry estimates were very low, never exceeding 1.8%. Equally plausible is that, because hydroacoustics sampled the run-at-large, passage estimates were based on a mixture of species with different passage behavior than yearling Chinook salmon or steelhead.

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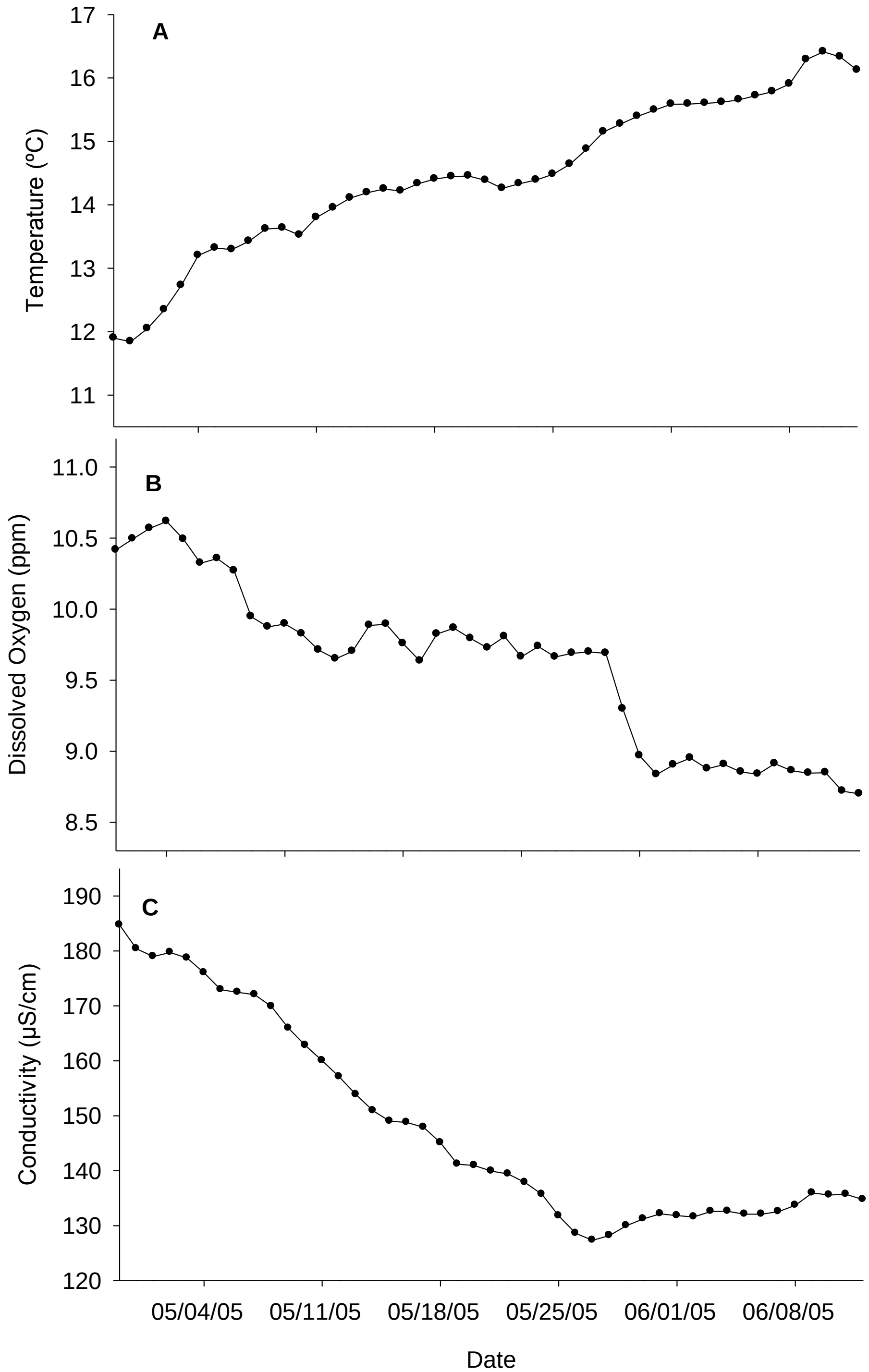
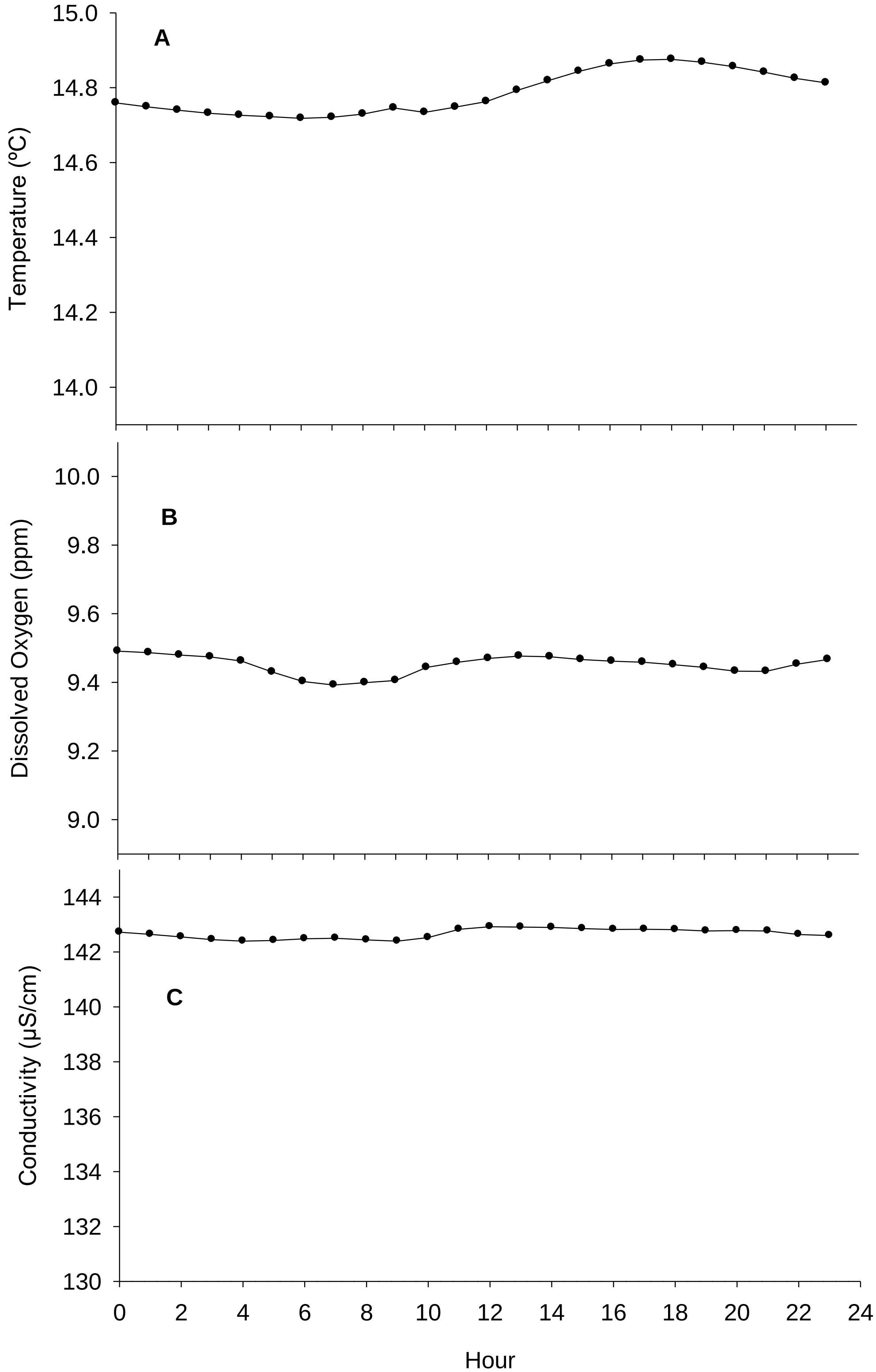
1-6.0 Appendices



Appendix 1. —Mean daily temperature (A), dissolved oxygen (B), and conductivity (C) at Bonneville Dam 1.5 m below water surface in the forebay of the spillway from 25 April to 12 June, 2005.



Appendix 2. —Mean hourly temperature (A), Dissolved oxygen (B), and conductivity (C) at Bonneville Dam 1.5 m below water surface in the forebay of the spillway from 25 April to 12 June, 2005.

Appendix 3.—Mean weight and forklength, and their associated standard deviations (SD), for yearling Chinook salmon released from The Dalles Dam (TDA) and John Day Dam (JDA), spring 2005.

Release	Release		Weight			Forklength	
Date	Time	Dam	N	Mean (g)	SD	Mean (mm)	SD
4/29/2005	8:00	JDA	24	36.5	4.7	158	6.8
4/29/2005	22:00	JDA	24	33.1	3.5	154	5.1
4/30/2005	0:00	TDA	42	35.5	6.2	154	7.6
4/30/2005	8:00	JDA	21	36.7	8.2	156	11.0
4/30/2005	14:00	TDA	47	33.1	5.1	152	6.9
4/30/2005	19:00	TDA	46	34.8	6.8	154	9.8
4/30/2005	21:00	JDA	24	35.3	5.7	157	7.8
5/1/2005	0:00	TDA	47	33.0	6.3	151	8.3
5/1/2005	6:00	TDA	24	37.8	9.9	157	12.6
5/1/2005	7:00	TDA	23	34.0	6.5	152	9.2
5/1/2005	8:00	JDA	24	33.1	7.1	153	11.0
5/1/2005	13:00	TDA	46	34.6	5.7	154	9.0
5/1/2005	21:00	JDA	23	32.0	5.3	151	6.9
5/2/2005	0:00	TDA	38	33.7	7.4	152	8.9
5/2/2005	8:00	JDA	26	36.0	8.3	155	11.8
5/2/2005	13:00	TDA	47	34.9	7.2	154	9.5
5/2/2005	14:00	TDA	43	31.4	5.6	149	8.3
5/2/2005	21:00	JDA	24	32.2	7.7	151	11.2
5/2/2005	23:00	TDA	22	34.0	6.5	151	10.7
5/3/2005	0:00	TDA	23	33.8	10.7	150	13.0
5/3/2005	1:00	TDA	46	35.0	10.9	152	13.4
5/3/2005	8:00	JDA	22	32.6	6.6	150	9.7
5/3/2005	14:00	TDA	45	32.5	9.2	147	11.3
5/3/2005	22:00	JDA	20	33.5	7.6	153	10.3
5/4/2005	0:00	TDA	43	37.1	11.1	152	13.4
5/4/2005	8:00	JDA	24	35.3	8.0	155	11.2
5/4/2005	13:00	TDA	24	34.4	6.1	151	7.4
5/4/2005	14:00	TDA	21	34.2	7.1	153	10.6
5/4/2005	18:00	TDA	10	35.3	9.7	154	11.4
5/4/2005	19:00	TDA	31	34.0	10.0	149	13.1
5/4/2005	21:00	JDA	24	34.3	7.2	151	9.9
5/5/2005	0:00	TDA	48	33.6	7.3	149	9.0
5/5/2005	1:00	TDA	40	34.4	8.2	150	10.8
5/5/2005	8:00	JDA	21	33.8	7.1	152	11.2
5/5/2005	13:00	TDA	43	32.7	7.2	149	10.7
5/5/2005	21:00	JDA	23	32.9	5.9	151	7.6
5/6/2005	0:00	TDA	45	33.9	7.1	150	9.9
5/6/2005	8:00	JDA	22	35.0	7.2	154	10.2
5/6/2005	13:00	TDA	45	34.2	6.2	149	8.5
5/6/2005	14:00	TDA	45	35.4	10.8	150	13.6
5/6/2005	22:00	JDA	26	34.0	7.0	151	10.4
5/7/2005	0:00	TDA	37	38.4	9.0	154	11.3
5/7/2005	7:00	TDA	46	36.2	8.6	152	10.5
5/7/2005	8:00	JDA	25	34.6	7.0	153	9.1
5/7/2005	14:00	TDA	37	34.9	6.7	150	9.8
5/7/2005	22:00	JDA	22	35.3	8.9	154	11.7
5/7/2005	23:00	TDA	43	36.4	11.4	152	14.2

Appendix 3 (continued).—Mean weight and forklength, and their associated standard deviations (SD), for yearling Chinook salmon released from The Dalles Dam (TDA) and John Day Dam (JDA), spring 2005.

Release Date	Release Time	Dam	Weight N	Weight Mean (g)	Weight SD	Forklength Mean (mm)	Forklength SD
5/8/2005	8:00	JDA	22	32.2	9.5	150	11.7
5/8/2005	13:00	TDA	46	35.4	7.6	153	10.1
5/8/2005	14:00	TDA	44	33.1	7.9	151	10.4
5/8/2005	21:00	JDA	22	31.7	5.7	149	8.3
5/9/2005	0:00	TDA	44	34.8	9.2	152	12.9
5/9/2005	1:00	TDA	43	34.8	7.7	152	10.6
5/9/2005	8:00	JDA	20	32.9	7.3	150	9.5
5/9/2005	14:00	TDA	43	36.0	8.7	154	11.0
5/9/2005	21:00	JDA	21	38.0	11.4	155	13.7
5/10/2005	0:00	TDA	46	30.8	4.9	146	7.4
5/10/2005	7:00	JDA	24	36.4	11.4	154	15.7
5/10/2005	14:00	TDA	41	33.8	9.6	149	13.3
5/10/2005	18:00	TDA	24	37.8	12.3	155	16.9
5/10/2005	19:00	TDA	23	33.0	12.2	148	15.9
5/10/2005	22:00	JDA	24	34.5	10.8	152	14.6
5/10/2005	23:00	TDA	31	34.0	11.2	149	14.6
5/11/2005	0:00	TDA	12	32.5	11.8	149	14.3
5/11/2005	7:00	TDA	44	34.5	8.6	153	20.6
5/11/2005	8:00	JDA	18	31.3	6.9	148	10.5
5/11/2005	14:00	TDA	43	37.0	14.2	153	17.9
5/11/2005	21:00	JDA	23	40.9	15.0	160	17.4
5/12/2005	0:00	TDA	44	37.2	12.3	154	14.8
5/12/2005	8:00	JDA	26	32.7	6.9	150	11.6
5/12/2005	14:00	TDA	44	35.5	10.6	152	13.1
5/12/2005	19:00	TDA	46	36.7	10.6	155	14.9
5/12/2005	22:00	JDA	24	41.3	11.5	160	15.5
5/12/2005	23:00	TDA	45	38.2	13.2	156	16.6
5/13/2005	1:00	TDA	45	40.6	12.4	159	16.3
5/13/2005	8:00	JDA	26	42.8	12.2	163	16.8
5/13/2005	14:00	TDA	44	33.2	8.7	149	11.6
5/13/2005	21:00	JDA	22	40.6	7.3	157	11.9
5/14/2005	0:00	TDA	43	35.0	10.2	152	13.8
5/14/2005	8:00	JDA	25	37.0	11.3	155	15.0
5/14/2005	13:00	TDA	45	32.5	9.4	150	12.8
5/14/2005	14:00	TDA	47	34.5	7.7	152	10.9
5/14/2005	22:00	JDA	23	38.8	11.0	158	14.8
5/14/2005	23:00	TDA	46	36.6	10.1	152	14.8
5/15/2005	6:00	TDA	19	32.4	7.0	150	10.9
5/15/2005	7:00	TDA	28	32.1	8.9	149	12.5
5/15/2005	8:00	JDA	22	30.3	8.6	146	12.1
5/15/2005	14:00	TDA	46	34.9	13.5	151	17.0
5/15/2005	22:00	JDA	23	33.3	9.6	151	13.1
5/16/2005	0:00	TDA	47	36.9	9.0	156	12.7
5/16/2005	6:00	TDA	6	39.7	8.4	157	13.0
5/16/2005	7:00	TDA	42	33.9	6.6	150	10.2
5/16/2005	8:00	JDA	22	37.3	7.8	156	12.3
5/16/2005	13:00	TDA	39	34.5	7.6	151	11.3

Appendix 3 (continued).—Mean weight and forklength, and their associated standard deviations (SD), for yearling Chinook salmon released from The Dalles Dam (TDA) and John Day Dam (JDA), spring 2005.

Release	Release		Weight			Forklength	
Date	Time	Dam	N	Mean (g)	SD	Mean (mm)	SD
5/16/2005	14:00	TDA	7	37.6	15.1	154	19.5
5/16/2005	22:00	JDA	25	38.9	11.7	156	16.7
5/16/2005	23:00	TDA	39	34.9	13.1	152	15.9
5/17/2005	0:00	TDA	7	36.4	9.1	154	13.7
5/17/2005	1:00	TDA	47	37.4	10.5	156	13.8
5/17/2005	8:00	JDA	23	41.7	18.2	161	21.1
5/17/2005	13:00	TDA	40	37.7	12.6	155	16.6
5/17/2005	14:00	TDA	6	37.8	11.1	155	14.4
5/17/2005	21:00	JDA	24	41.5	14.7	158	18.1
5/18/2005	0:00	TDA	45	37.6	13.8	155	17.6
5/18/2005	8:00	JDA	23	39.0	12.2	160	17.6
5/18/2005	13:00	TDA	47	37.0	11.9	154	15.7
5/18/2005	18:00	TDA	12	32.8	9.5	147	12.6
5/18/2005	19:00	TDA	35	37.4	11.6	155	14.7
5/18/2005	21:00	JDA	23	31.5	11.8	149	15.5
5/19/2005	0:00	TDA	47	34.7	10.4	152	14.3
5/19/2005	8:00	JDA	23	34.1	8.6	151	11.7
5/19/2005	13:00	TDA	94	35.1	8.8	151	12.5
5/19/2005	22:00	JDA	23	35.4	11.0	155	14.9
5/19/2005	23:00	TDA	38	39.5	15.4	158	19.6
5/20/2005	0:00	TDA	25	35.3	10.9	152	14.5
5/20/2005	1:00	TDA	30	37.7	16.6	153	20.2
5/20/2005	8:00	JDA	22	32.1	6.0	150	9.0
5/20/2005	13:00	TDA	46	36.0	11.0	155	15.7
5/20/2005	22:00	JDA	23	36.7	12.9	157	15.8
5/20/2005	23:00	TDA	32	35.1	11.3	153	15.4
5/21/2005	0:00	TDA	14	29.5	8.3	145	12.7
5/21/2005	8:00	JDA	23	34.2	12.1	154	17.9
5/21/2005	13:00	TDA	46	32.7	12.0	150	16.2
5/21/2005	18:00	TDA	12	41.8	24.3	155	25.8
5/21/2005	19:00	TDA	36	32.5	10.9	149	14.3
5/21/2005	22:00	JDA	25	39.6	17.7	159	23.0
5/22/2005	0:00	TDA	46	36.7	17.1	154	21.1
5/22/2005	6:00	TDA	2	28.7	0.1	147	2.8
5/22/2005	7:00	TDA	44	31.0	10.4	147	14.3
5/22/2005	8:00	JDA	24	31.4	12.6	149	15.6
5/22/2005	14:00	TDA	46	35.9	13.1	153	18.4
5/22/2005	22:00	JDA	23	36.4	10.6	156	13.6
5/23/2005	0:00	TDA	47	36.6	14.8	154	18.1
5/23/2005	8:00	JDA	25	33.3	10.2	152	13.6
5/23/2005	12:00	TDA	4	33.0	7.4	150	11.1
5/23/2005	13:00	TDA	44	37.7	16.0	154	20.2
5/23/2005	14:00	TDA	46	37.3	15.4	154	18.9
5/23/2005	22:00	JDA	24	36.9	16.3	154	19.6
5/24/2005	0:00	TDA	47	40.6	14.5	160	18.6
5/24/2005	7:00	JDA	24	37.3	9.4	155	13.8
5/24/2005	12:00	TDA	22	38.8	18.3	155	20.3

Appendix 3 (continued).—Mean weight and forklength, and their associated standard deviations (SD), for yearling Chinook salmon released from The Dalles Dam (TDA) and John Day Dam (JDA), spring 2005.

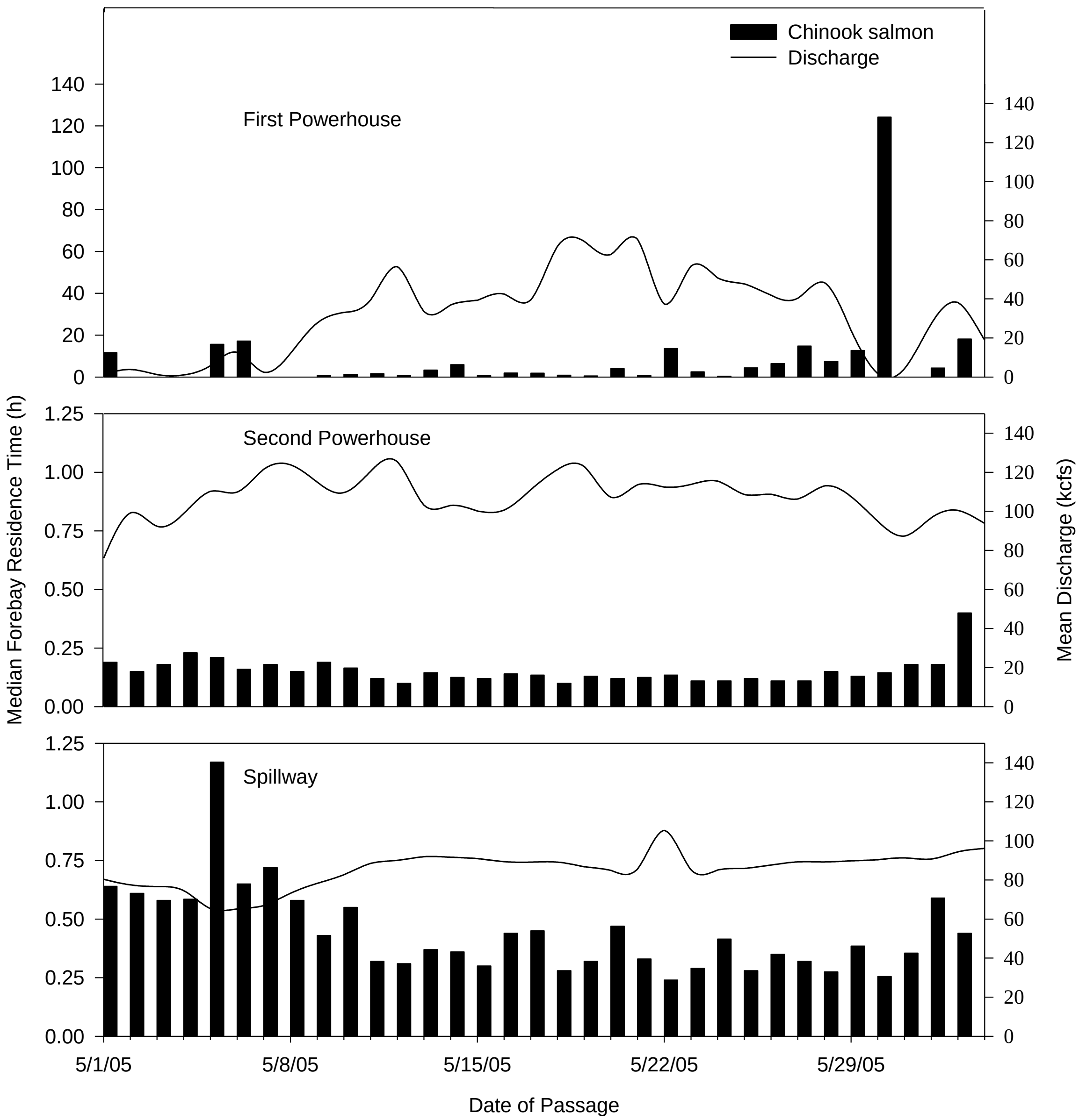
Release	Release		Weight			Forklength	
Date	Time	Dam	N	Mean (g)	SD	Mean (mm)	SD
5/24/2005	13:00	TDA	26	36.4	15.9	155	19.7
5/24/2005	14:00	TDA	45	35.0	14.6	153	18.0
5/24/2005	21:00	JDA	24	44.6	15.9	166	20.3
5/25/2005	0:00	TDA	47	42.0	14.5	160	17.4
5/25/2005	7:00	TDA	48	40.2	12.0	160	15.4
5/25/2005	8:00	JDA	23	40.7	13.6	160	17.6
5/25/2005	14:00	TDA	46	40.7	14.4	160	18.8
5/25/2005	21:00	JDA	21	41.7	12.8	157	15.9
5/25/2005	23:00	TDA	42	41.7	15.4	160	18.9
5/26/2005	1:00	TDA	42	37.8	11.4	155	15.4
5/26/2005	8:00	JDA	23	35.0	8.8	153	13.0
5/26/2005	13:00	TDA	46	40.1	11.8	160	15.1
5/26/2005	21:00	JDA	21	37.7	14.4	156	17.2
5/27/2005	0:00	TDA	44	38.6	12.4	156	15.5
5/27/2005	7:00	JDA	22	39.5	11.4	159	15.3
5/27/2005	14:00	TDA	47	38.4	11.6	157	16.4
5/27/2005	19:00	TDA	47	42.3	13.3	163	16.6
5/27/2005	22:00	JDA	23	41.9	10.8	163	14.5
5/28/2005	0:00	TDA	46	38.5	10.6	157	15.1
5/28/2005	8:00	JDA	21	38.4	11.8	159	15.5
5/28/2005	13:00	TDA	45	45.6	14.3	165	16.1
5/28/2005	19:00	TDA	47	38.6	9.8	156	11.7
5/28/2005	22:00	JDA	23	35.7	7.3	156	10.2
5/28/2005	23:00	TDA	47	39.9	13.4	158	17.0
5/29/2005	1:00	TDA	47	38.9	10.3	158	14.0
5/29/2005	14:00	TDA	47	42.2	16.2	160	19.8
5/29/2005	21:00	JDA	27	41.3	11.4	162	15.0
5/29/2005	23:00	TDA	47	37.7	11.6	155	16.0
5/30/2005	6:00	TDA	7	38.2	10.0	157	13.6
5/30/2005	7:00	TDA	40	37.5	10.2	156	14.5
5/30/2005	8:00	JDA	27	41.6	11.2	160	14.5
5/30/2005	14:00	TDA	47	38.4	13.2	157	16.3
5/30/2005	21:00	JDA	31	35.4	7.8	154	11.2
5/31/2005	0:00	TDA	47	40.8	13.4	158	16.2
5/31/2005	12:00	TDA	23	35.8	8.6	152	12.0
5/31/2005	13:00	TDA	24	37.5	11.4	154	15.1
5/31/2005	14:00	TDA	47	39.4	10.9	157	15.1

Appendix 4.—Mean weight and forklength, and their associated standard deviations (SD), for yearling steelhead released from The Dalles Dam (TDA) and John Day Dam (JDA), spring 2005.

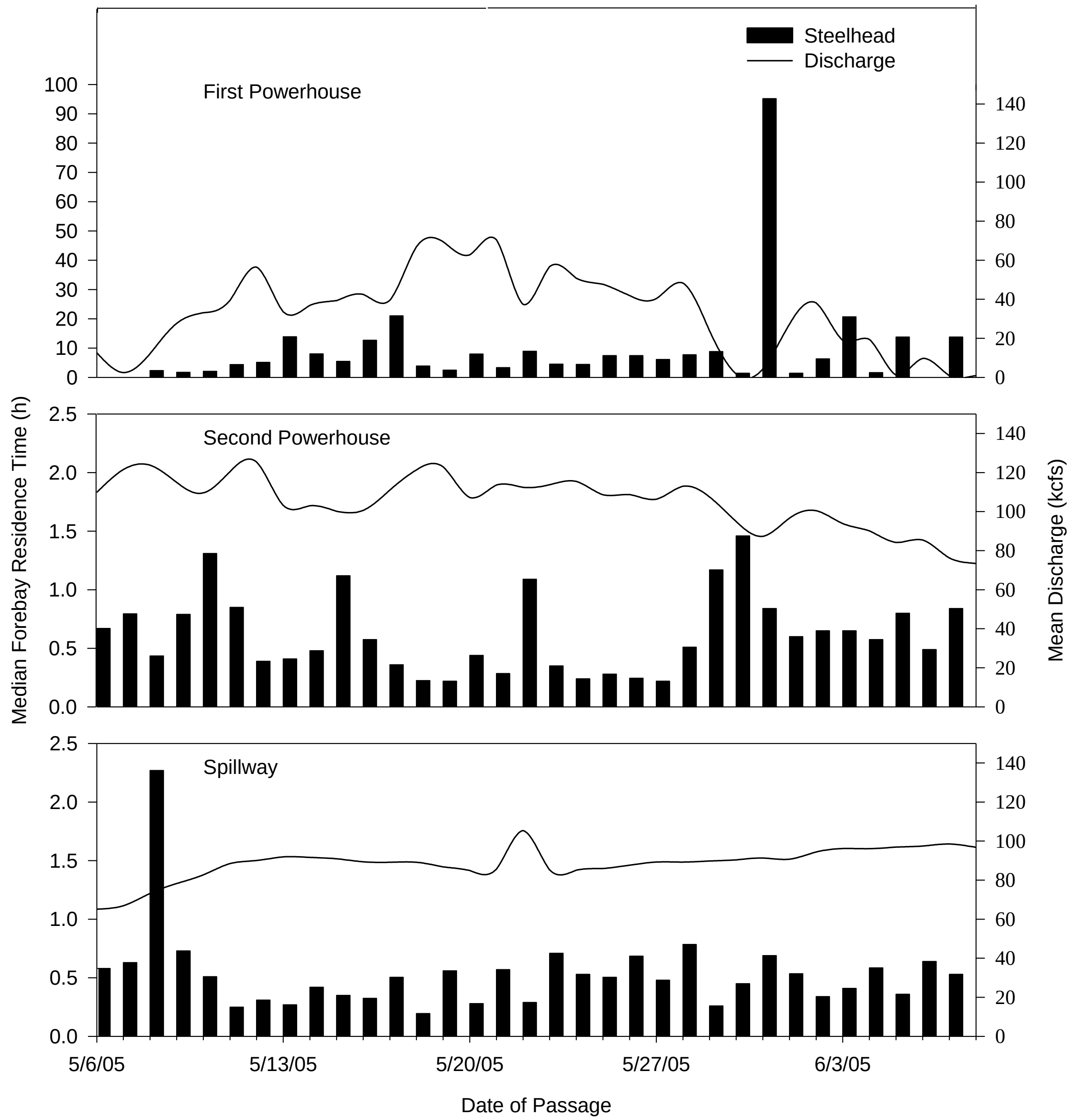
Release	Release		Weight			Forklength	
Date	Time	Dam	N	Mean (g)	SD	Mean (mm)	SD
5/5/2005	14:00	TDA	64	94.3	23.4	221	20.4
5/6/2005	0:00	TDA	64	92.4	20.3	220	21.0
5/6/2005	14:00	TDA	17	96.5	25.2	224	21.6
5/7/2005	0:00	TDA	52	94.8	22.4	224	16.1
5/7/2005	14:00	TDA	31	103.9	26.5	230	16.4
5/7/2005	15:00	TDA	17	105.4	20.2	228	10.1
5/7/2005	23:00	TDA	26	106.1	26.9	227	21.1
5/8/2005	0:00	TDA	37	94.3	27.2	220	20.7
5/8/2005	14:00	TDA	27	103.3	28.2	229	19.7
5/8/2005	15:00	TDA	38	92.4	32.9	217	31.0
5/9/2005	0:00	TDA	65	107.6	38.9	225	30.4
5/9/2005	14:00	TDA	64	103.0	28.0	226	18.5
5/10/2005	0:00	TDA	64	106.8	34.9	226	23.1
5/10/2005	14:00	TDA	31	101.7	29.3	227	19.7
5/10/2005	15:00	TDA	31	108.6	28.6	228	18.5
5/10/2005	23:00	TDA	41	112.2	34.0	234	21.2
5/11/2005	0:00	TDA	25	113.7	28.2	231	17.1
5/11/2005	14:00	TDA	62	100.2	30.1	220	28.0
5/12/2005	0:00	TDA	57	103.2	38.6	226	26.3
5/12/2005	1:00	TDA	4	97.3	9.3	225	9.9
5/12/2005	14:00	TDA	65	100.2	29.5	223	24.0
5/13/2005	0:00	TDA	67	100.5	33.4	223	23.1
5/13/2005	14:00	TDA	65	92.3	31.4	220	25.4
5/14/2005	0:00	TDA	65	95.7	33.7	221	24.0
5/14/2005	14:00	TDA	66	107.2	32.5	228	21.3
5/15/2005	0:00	TDA	65	95.2	28.4	223	22.7
5/15/2005	14:00	TDA	67	96.0	33.3	221	25.7
5/16/2005	0:00	TDA	31	100.4	28.7	226	22.6
5/16/2005	1:00	TDA	37	91.5	29.3	219	23.3
5/16/2005	14:00	TDA	66	93.8	28.5	217	30.5
5/17/2005	0:00	TDA	67	98.4	33.9	225	24.5
5/17/2005	14:00	TDA	68	95.0	26.4	223	20.0
5/18/2005	0:00	TDA	68	86.5	25.7	216	25.8
5/18/2005	13:00	TDA	33	94.1	26.0	223	22.1
5/18/2005	14:00	TDA	34	95.5	26.2	224	22.1
5/19/2005	0:00	TDA	69	92.9	30.3	223	21.2
5/19/2005	14:00	TDA	67	94.0	25.2	223	20.9
5/20/2005	0:00	TDA	70	88.8	30.3	220	24.0
5/20/2005	14:00	TDA	66	86.3	28.0	218	23.3
5/21/2005	0:00	TDA	70	91.0	30.3	223	24.3
5/21/2005	14:00	TDA	67	90.6	28.9	221	25.0
5/22/2005	0:00	TDA	70	84.7	26.2	217	21.0
5/22/2005	13:00	TDA	32	81.1	30.8	215	24.5
5/22/2005	14:00	TDA	30	96.1	22.1	225	17.0
5/23/2005	0:00	TDA	67	83.6	28.7	216	23.9
5/23/2005	14:00	TDA	66	91.6	26.8	221	22.6
5/24/2005	0:00	TDA	65	91.6	33.1	220	26.5
5/24/2005	14:00	TDA	33	89.9	25.4	224	21.5

Appendix 4 (continued).—Mean weight and forklength, and their associated standard deviations (SD), for yearling steelhead released from The Dalles Dam (TDA) and John Day Dam (JDA), spring 2005.

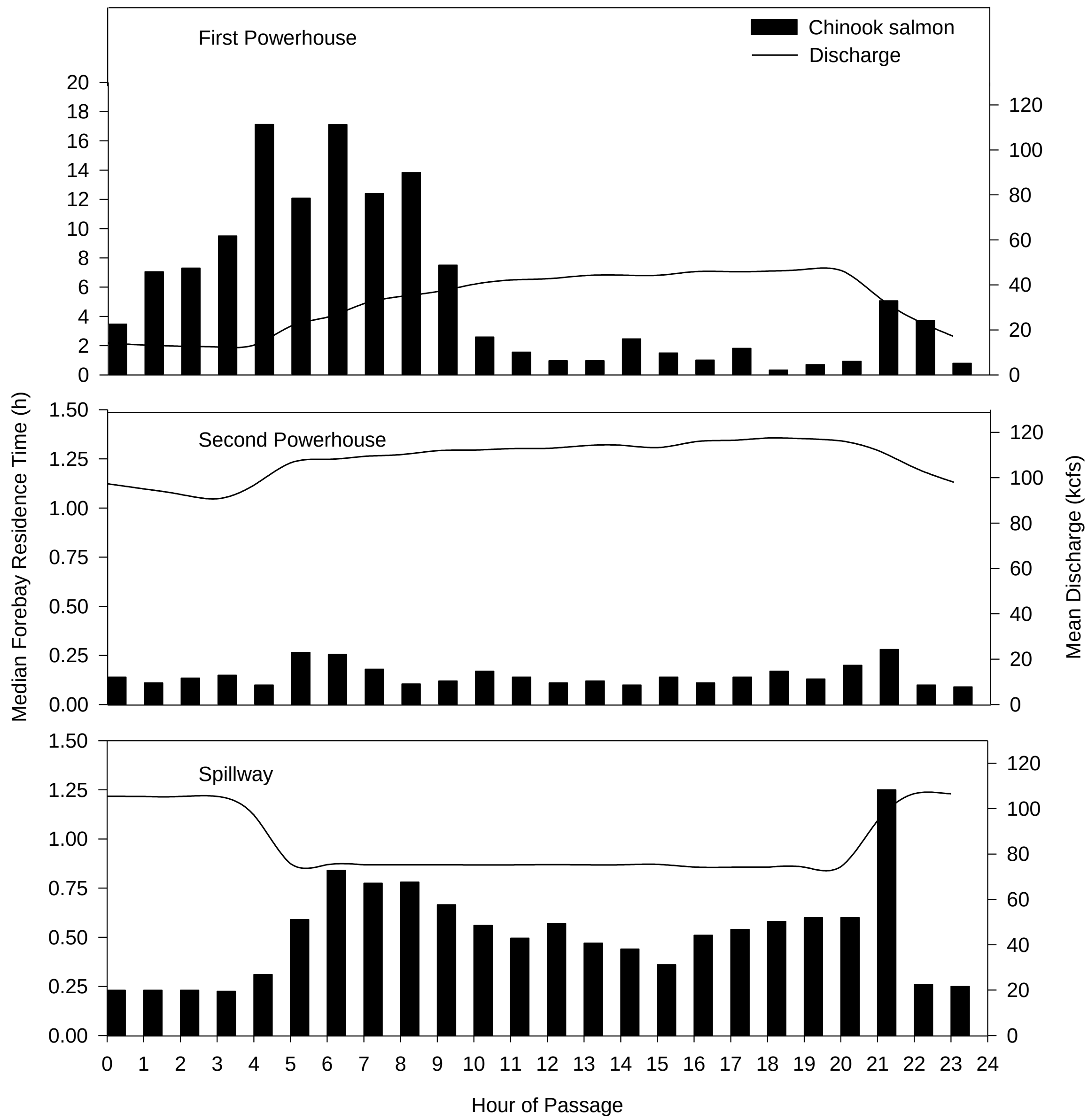
Release	Release		Weight			Forklength	
Date	Time	Dam	N	Mean (g)	SD	Mean (mm)	SD
5/24/2005	15:00	TDA	33	85.8	27.7	218	23.7
5/25/2005	0:00	TDA	67	85.7	31.4	218	26.8
5/25/2005	14:00	TDA	68	90.1	29.0	220	22.8
5/26/2005	0:00	TDA	67	90.3	30.8	219	24.8
5/26/2005	13:00	TDA	3	61.0	6.3	199	5.6
5/26/2005	14:00	TDA	85	84.7	26.7	217	22.6
5/27/2005	0:00	TDA	81	90.6	35.5	221	29.4
5/27/2005	14:00	TDA	90	85.3	25.1	217	22.6
5/28/2005	0:00	TDA	82	85.4	28.4	217	24.2
5/28/2005	14:00	TDA	41	97.4	31.6	224	26.6
5/28/2005	15:00	TDA	50	92.4	28.9	221	22.7
5/28/2005	23:00	TDA	39	82.8	27.8	213	30.3
5/29/2005	0:00	TDA	45	88.9	34.5	219	27.5
5/29/2005	14:00	TDA	88	93.0	33.2	222	26.2
5/30/2005	0:00	TDA	83	90.8	39.2	220	30.8
5/30/2005	14:00	TDA	87	93.3	31.5	223	25.1
5/31/2005	0:00	TDA	82	81.7	30.9	215	28.2
5/31/2005	14:00	TDA	89	87.9	31.3	219	27.1
6/1/2005	0:00	TDA	72	82.8	31.2	214	28.8
6/1/2005	14:00	TDA	77	99.7	38.5	227	27.6
6/2/2005	0:00	TDA	48	84.1	33.5	214	30.2
6/2/2005	14:00	TDA	57	86.1	35.8	214	33.6
6/3/2005	0:00	TDA	52	75.1	35.5	207	31.2
6/3/2005	14:00	TDA	50	89.2	32.9	220	26.1
6/3/2005	23:00	TDA	37	89.0	41.7	218	32.4
6/4/2005	13:00	TDA	26	97.1	36.7	224	31.7
6/4/2005	14:00	TDA	22	88.2	27.7	221	24.1
6/4/2005	23:00	TDA	39	96.6	42.1	226	32.9
6/5/2005	0:00	TDA	36	92.0	39.6	221	33.9
6/5/2005	14:00	TDA	75	100.4	29.9	231	23.2
6/6/2005	0:00	TDA	54	90.8	39.8	217	35.6



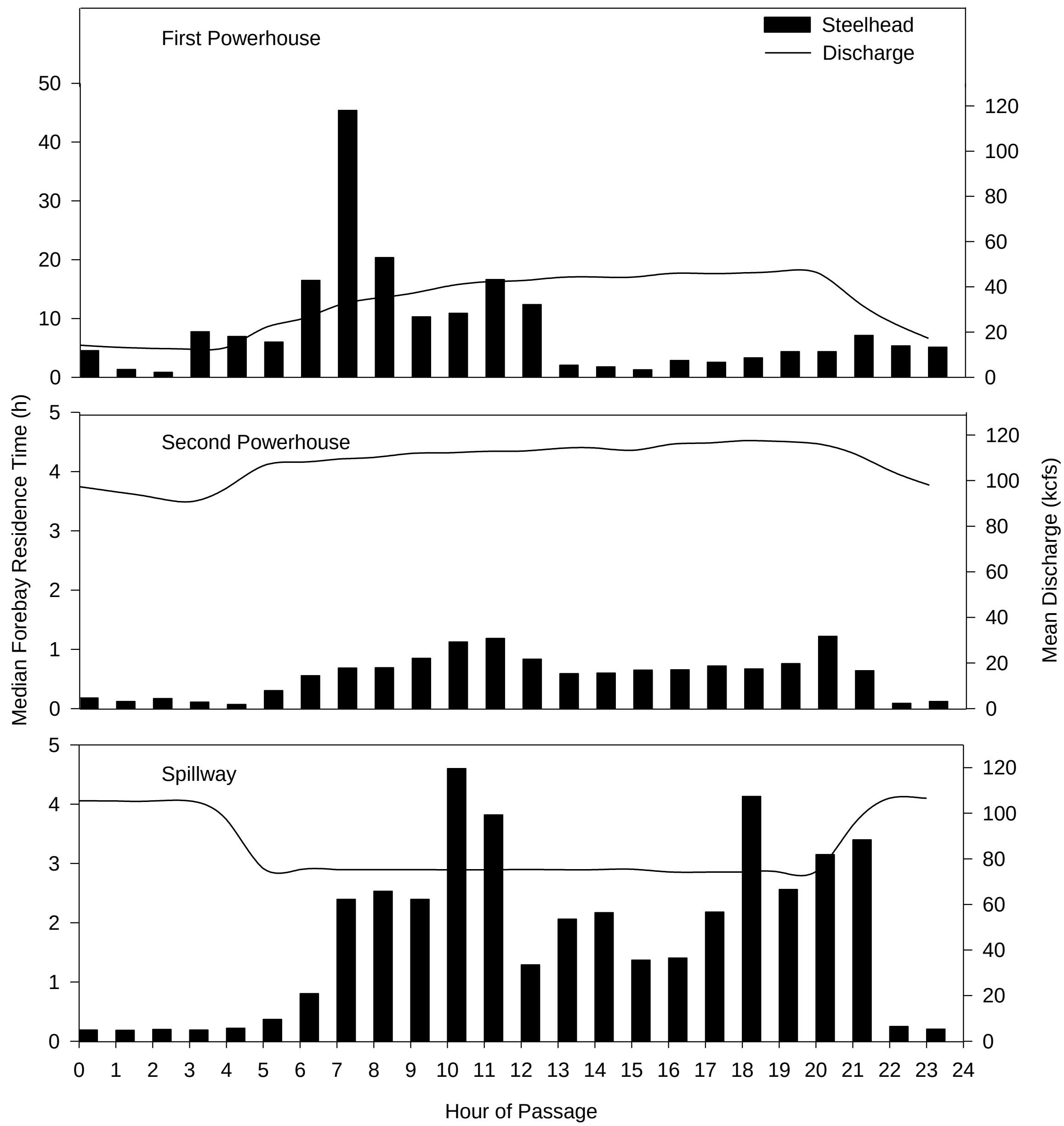
Appendix 5.—Median forebay residence time by day of passage versus mean discharge by dam area for yearling Chinook salmon at Bonneville Dam, spring 2005. Scale of y-axis for first powerhouse graph differs from graphs for second powerhouse and spillway for visual clarity of residence time data.



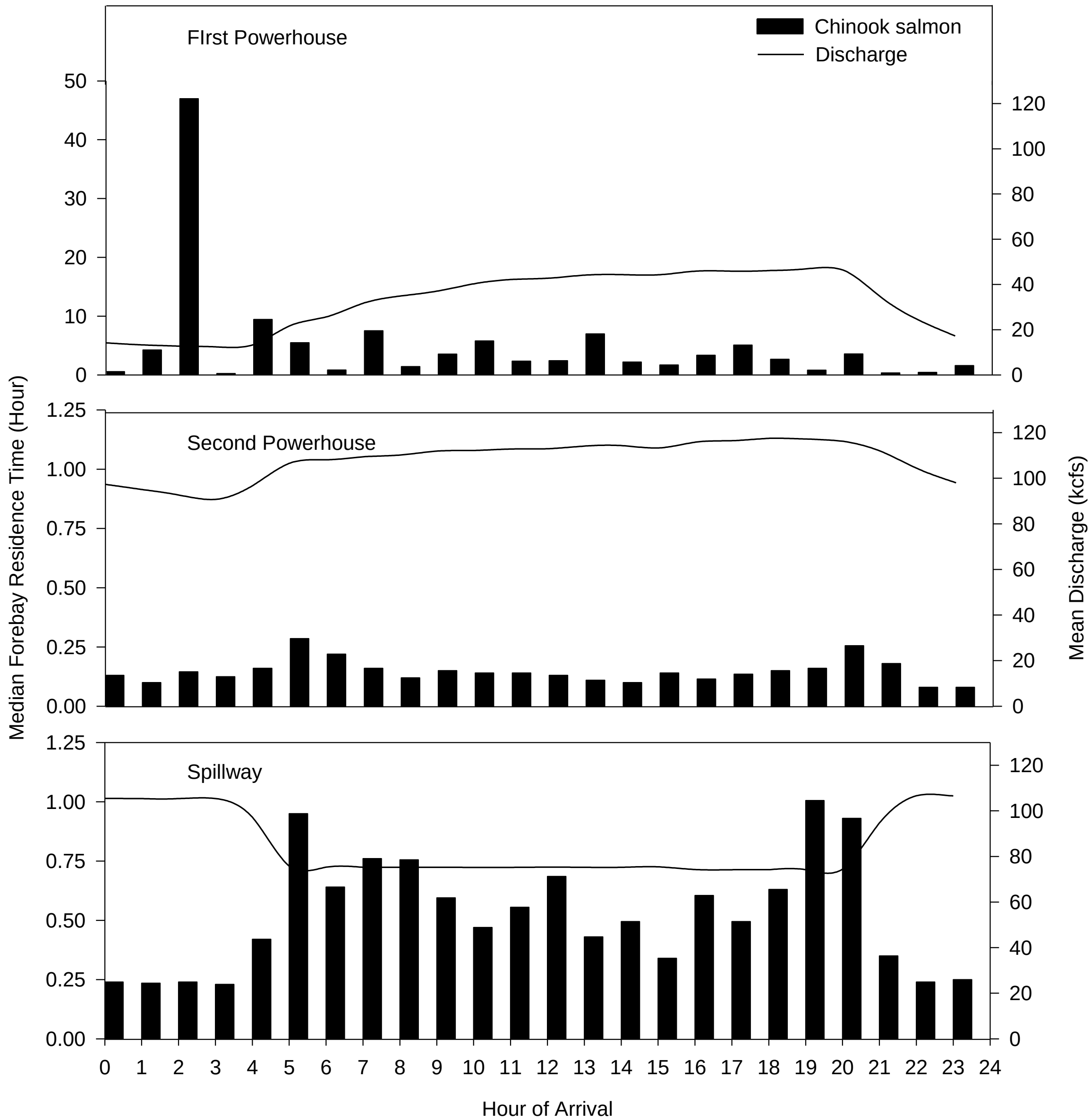
Appendix 6.—Median forebay residence time by day of passage versus mean discharge by dam area for yearling steelhead at Bonneville Dam, spring 2005. Scale of y-axis for first powerhouse graph differs from graphs for second powerhouse and spillway for visual clarity of residence time data.



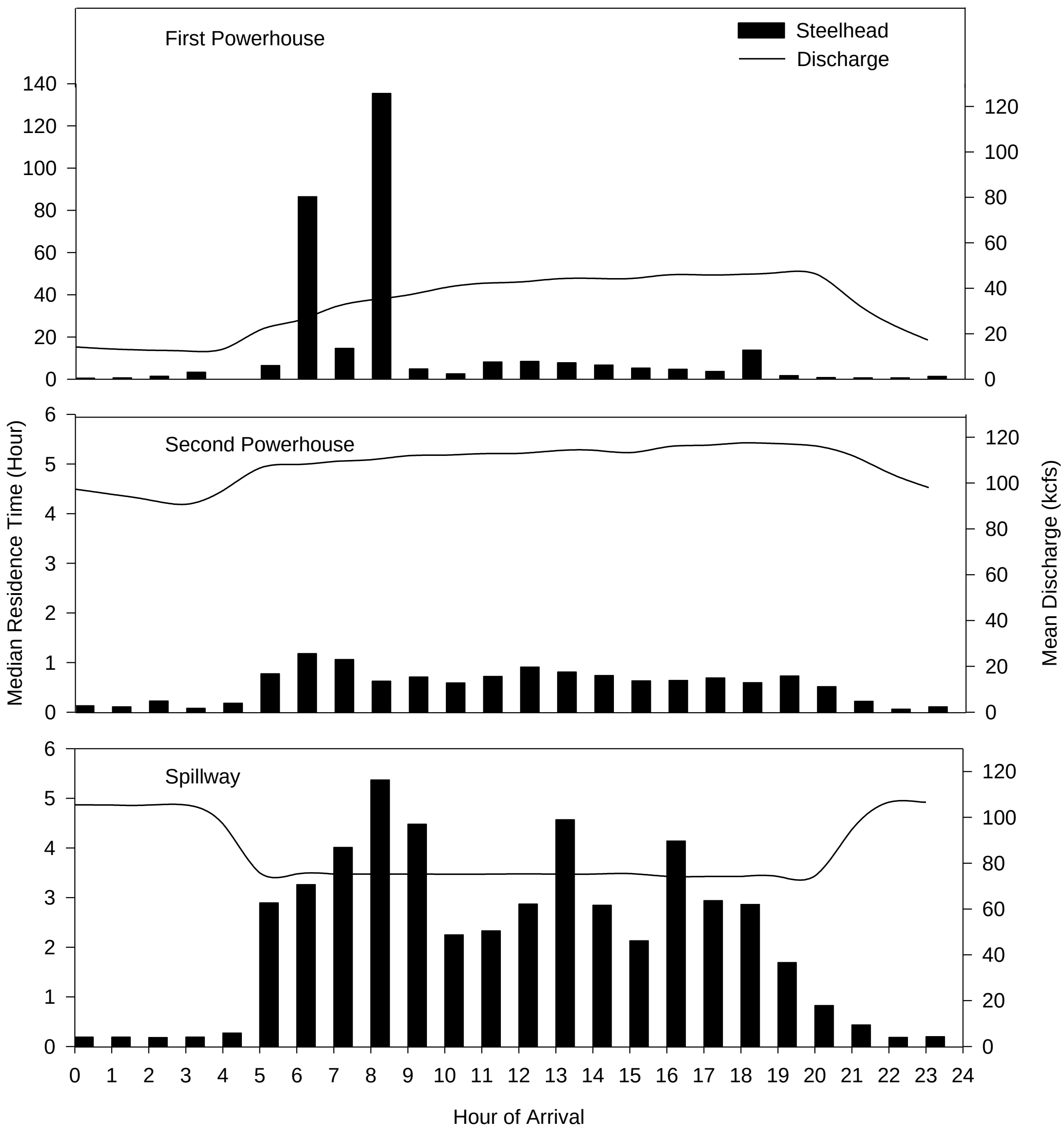
Appendix 7.—Median forebay residence time by hour of passage versus mean discharge by dam area for yearling Chinook salmon at Bonneville Dam, spring 2005. Scale of y-axis for first powerhouse graph differs from graphs for second powerhouse and spillway for visual clarity of residence time data.



Appendix 8.—Median forebay residence time by hour of passage versus mean discharge by dam area for yearling steelhead at Bonneville Dam, spring 2005. Scale of y-axis for first powerhouse graph differs from graphs for second powerhouse and spillway for visual clarity of residence time data.



Appendix 9.—Median forebay residence time by hour of arrival versus mean discharge by dam area for yearling Chinook salmon at Bonneville Dam, spring 2005. Scale of y-axis for first powerhouse graph differs from graphs for second powerhouse and spillway for visual clarity of residence time data.



Appendix 10.—Median forebay residence time by hour of arrival versus mean discharge by dam area for yearling steelhead at Bonneville Dam, spring 2005. Scale of y-axis for first powerhouse graph differs from graphs for second powerhouse and spillway for visual clarity of residence time data.

Chapter Two

Movement, Distribution, and Passage Behavior of Radio-Tagged Subyearling Chinook Salmon at Bonneville Dam, 2005

by:

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2-1.0 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. Options currently being evaluated at Bonneville Dam are the improvement of turbine intake guidance systems and a new corner collector surface-flow bypass system.

In 2000, we conducted the first evaluation of species-specific fish passage efficiency (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 (Evans et al. 2003a and 2003b). In 2004 and 2005, studies of the MGR turbine and spillway flow deflectors continued and evaluations were also conducted for the ice and trash sluiceway at the first powerhouse and the corner collector surface-flow bypass system at the second powerhouse (Evans et al. 2005). 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 2005, we used radio telemetry to examine the movements and passage behavior of subyearling Chinook salmon, *Oncorhynchus tshawytscha,* in the forebay of Bonneville Dam. Our objectives were to:

- Determine the distribution, and approach patterns of fish in the forebay areas of Bonneville Dam.
- Determine the time and route of passage of fish at Bonneville Dam relative to spill, powerhouse operations, and corner collector tests.
- Estimate fish passage efficiency for the entire Bonneville Dam complex, fish guidance efficiency for the second powerhouse, spillway efficiency and effectiveness, corner collector efficiency and effectiveness, and sluiceway efficiency and effectiveness.
- Provide data to estimate survival of radio-tagged fish passing through Bonneville Dam (reported by Counihan et al. 2006).

2-2.0 Methods

2-2.1 Study Area

Bonneville Dam is located on the Columbia River at approximately river kilometer (rkm) 233. The dam consists of two powerhouses and a single spillway, each separated by an island. The first powerhouse (B1) consists of 10 turbine units and is located at the south side of the river, spanning from the Oregon shore to Bradford Island. The second powerhouse (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 19).

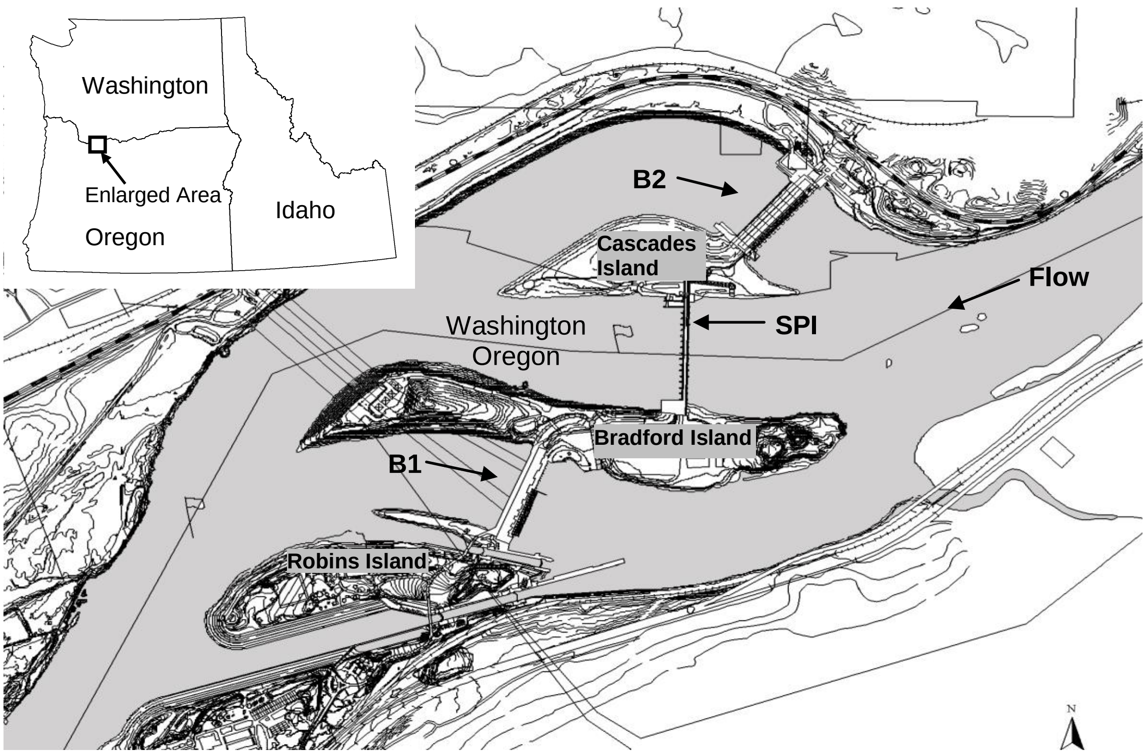


Figure 19.—Plan view of Bonneville Dam on the Columbia River, showing first powerhouse (B1), the spillway (SPI), and second powerhouse (B2). Image source: U.S. Army Corps of Engineers.

2-2.2 Water quality

We monitored water temperature ($\pm$ 0.2ºC), dissolved oxygen (DO; $\pm$ 0.2 ppm), and electrical conductivity (EC; 0.5%) throughout the study using a Stevens-Greenspan CS304 multi-parameter sensor (Stevens Water Monitoring Systems, Inc, Beaverton, Oregon). The CS304 was deployed 1.5 m below the water surface in the forebay of the Bonneville Dam spillway and was programmed to record water temperature, DO, and EC measurements every minute.

2-2.3 Fixed Receiving Equipment

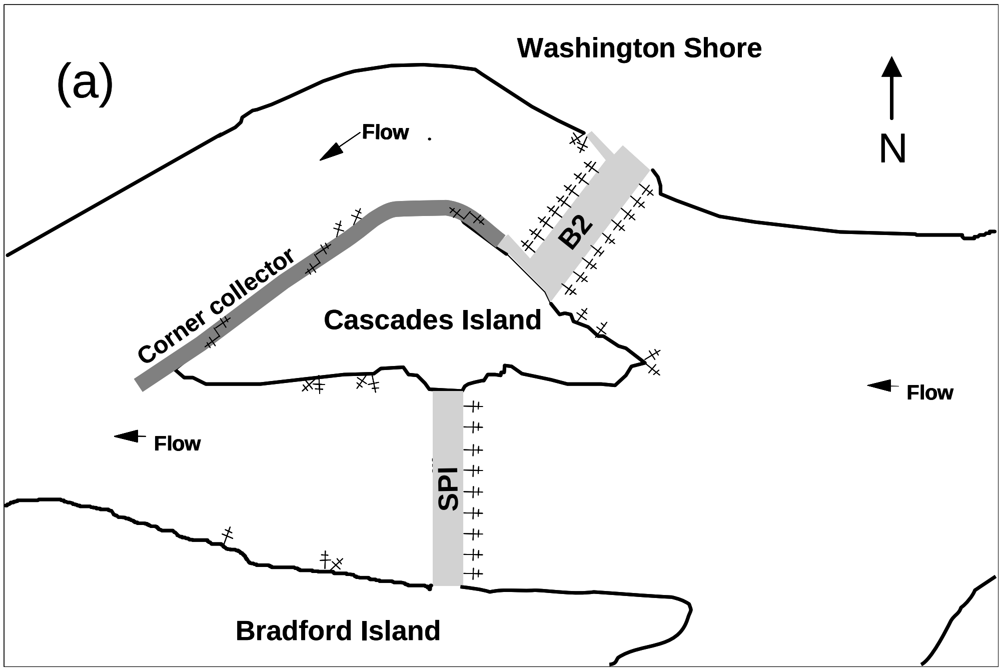
We used four types of fixed telemetry receivers, along with aerial and underwater antennas, to monitor radio-tagged juvenile salmonids at Bonneville Dam in 2005. Eighty-three aerial antennas, 36 stripped coax antennas, and 124 underwater dipole antennas were linked to 34 Lotek SRX-400 receivers (SRX; Lotek Engineering, Newmarket, Ontario), two Lotek DSP-500 digital spectrum processors (DSP; Lotek Engineering, Newmarket, Ontario), three Orion DSP receivers (Grant Systems Engineering, King City, Ontario, Canada), and three Multiprotocol Integrated Telemetry Acquisition Systems (MITAS; Grant Systems Engineering, King City, Ontario, Canada). Each SRX monitored a maximum of six aerial antennas. Orions and MITASs were used to monitor underwater antennas. Orions and DSPs were also used to monitor aerial antennas in some areas. The combination of these technologies allowed us to monitor fish as they approached and then passed through various routes at Bonneville Dam.

Aerial antennas were positioned in three locations: 1) along the periphery of the forebay, 2) along the tailrace shoreline, and 3) along the corner collector flume (Figure 20). Aerial antennas were located in the forebay to detect fish within 100 m of the dam, in the tailrace to confirm fish passage, and in the corner collector flume to detect fish passing through the corner collector. Aerial antennas were connected to SRX receivers programmed to monitor nineteen frequencies in random order. Two aerial antenna monitoring configurations were used depending on location: auxiliary/master switching or combined antennas. In the auxiliary/master configuration, the receiver scans the master antenna (up to 8 unique antennas combined) until a signal is received; at which point the receiver scans the individual 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 in the spillway forebay and all tailraces 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 all locations. 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 antenna gain). Underwater antennas allowed us to obtain fine scale fish location information by limiting the range of signal detection.

Two SRX receivers in the B2 tailrace were each coupled with DSPs. These receivers had essentially no scan time because a DSP acquires signals over a 1 MHz bandwidth almost instantaneously. Using a DSP, rather than a stand-alone SRX, was necessary to determine fish presence in high flow environments where signal acquisition time is limited.

One Orion receiver at the B2 smolt monitoring facility and two Orion receivers in the corner collector flume were also used. The Orion receiver, like the DSP, has essentially no scan time because signals are acquired over a 1 MHz bandwidth and is ideal for locations that have limited signal acquisition time.

Three MITASs were incorporated at B1, B2, and the spillway (Figure 21). Each MITAS was capable of simultaneously monitoring up to 50 inputs with greater multiple transmitter recognition than the SRX, DSP, or Orion. Although each MITAS was limited to a maximum of 50 inputs, each input could be a horizontal or vertical combination of



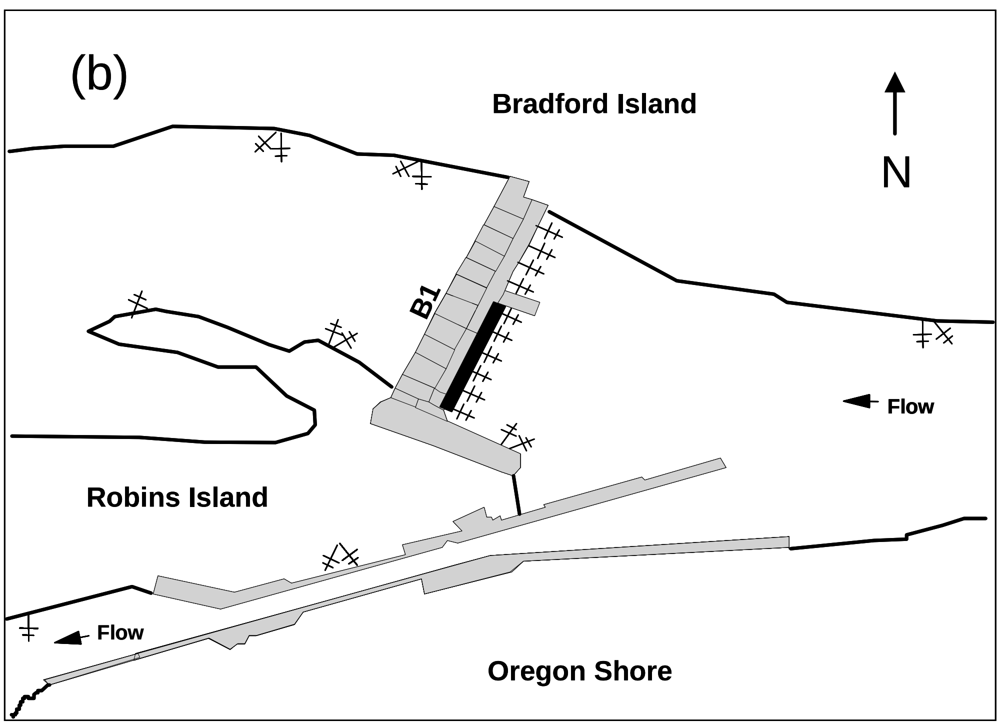


Figure 20.—Plan view of aerial antenna coverage during summer 2005 at Bonneville Dam's: (a) second powerhouse (B2) and spillway (SPI); and (b) first powerhouse (B1).

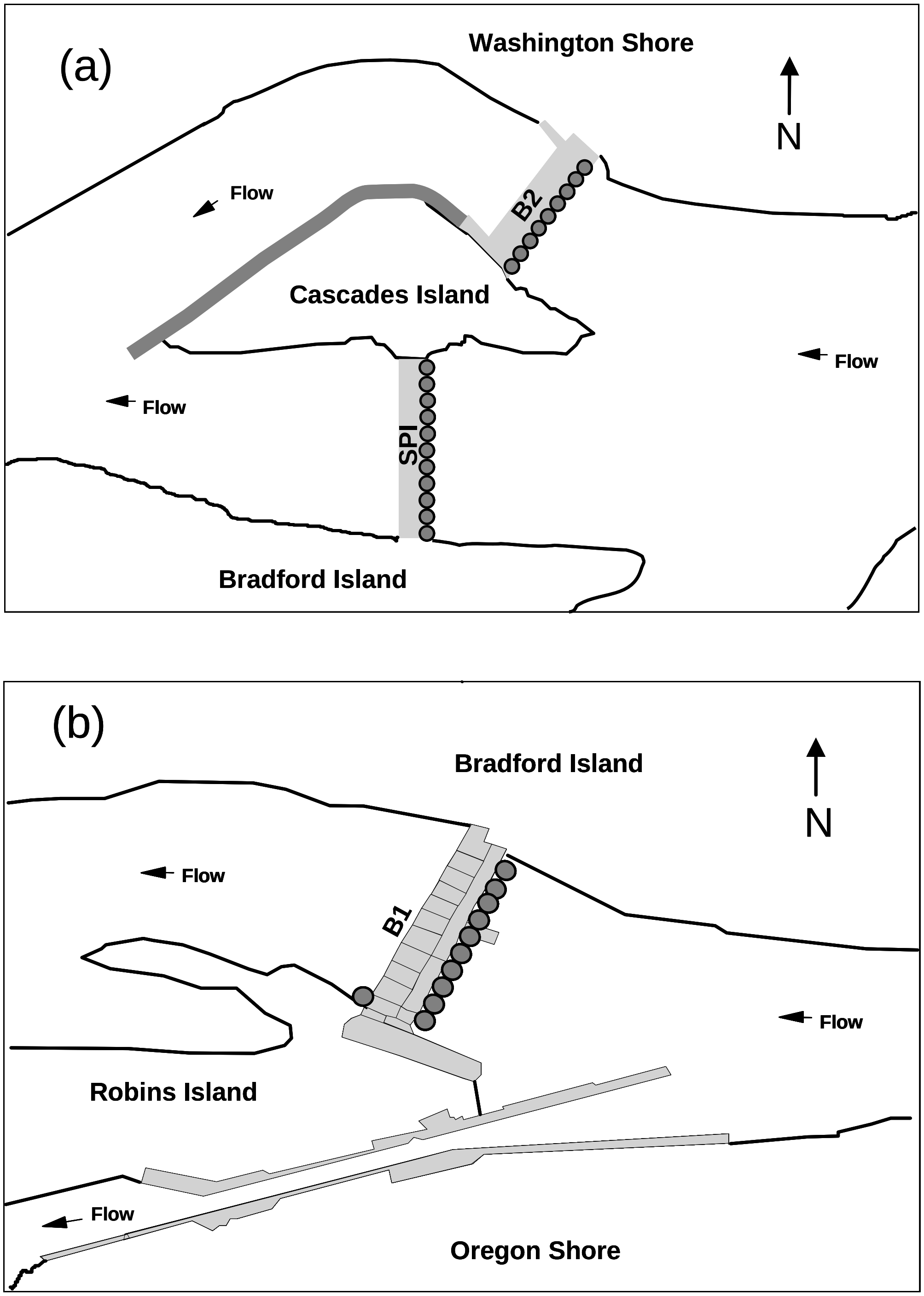


Figure 21.—Plan view of underwater antenna coverage during summer 2005 at Bonneville Dam's: (a) second powerhouse (B2) and spillway (SPI); and (b) first powerhouse (B1).

multiple underwater dipole or stripped coax antennas. In addition to enhanced signal recognition, the MITAS's data displays and on-screen diagnostics allowed the user to identify problems in real-time and avoid potential data loss that otherwise would not have been apparent until post-processing.

The MITAS at B1 was composed of 22 underwater stripped coax antennas and one aerial antenna. Twenty stripped coax antennas were positioned mid-channel in the sluiceway, two at each unit, to monitor unit-specific sluiceway entrance and passage through the sluiceway. In addition, two stripped coax antennas and one aerial antenna were placed at the outfall of the sluiceway to confirm sluiceway passage.

The MITAS at B2 was composed of 61 underwater antennas. Forty-eight dipole underwater antennas attached to the submersible traveling screens monitored unguided turbine passage. Two dipole antennas were mounted to the bottom of each of three submersible traveling screens in front of each of eight turbine units. Antennas from each of three gatewell slots per unit were combined to provide turbine unit specific passage information. Nine stripped coax antennas placed within the downstream salmonids migrant channel (DSM) monitored guided fish passage. One antenna was located just downstream of each "C-slot" gatewell orifice and one additional antenna was located at the terminus of the DSM. Four dipole underwater antennas monitored approach and entrance of fish into the corner collector.

The spillway MITAS consisted of 72 underwater antennas. Seventy-two dipole underwater antennas monitored spillway passage and were attached to the forebay pier noses. Each spillbay had four antennas; two antennas on each piernose at about 4.5 m below mean pool level and 2 antennas at about 10.5 m below mean pool level. All four antennas in each spillbay were combined to one input to provide spillbay-specific passage information.

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.

2-2.4 Transmitters

Coded microprocessor transmitters (model NTC-M-2) manufactured by Lotek Engineering Inc. were implanted in subyearling Chinook salmon. The transmitters were 5.6 mm x 3.7 mm x 13.9 mm and weighed 0.43 g in air. The antenna length was 18 cm and the pulse rate was 2.5 s, resulting in an estimated minimum tag life of 9 d.

2-2.5 Tagging, Handling, and Release of Fish

Juvenile Chinook salmon and steelhead were collected at the Smolt Monitoring Facility (SMF) at John Day Dam. Employees from the Pacific States Marine Fisheries Commission's Smolt Monitoring Program and the U.S. Geological Survey sorted and identified study fish. Fish were weighed at the time of collection to ensure they met the minimum weight criteria of 10.0 g, keeping the tag weight to fish weight ratio below 5%. Fish collected at John Day Dam were tagged and released into the Columbia River at John Day Dam and at The Dalles Dam. Although fish were tagged and released at different locations, the fish handling, tagging, transport, and release methods were standardized.

Subsequent to collection, fish to be tagged at John Day Dam were held for 12-36 h at the SMF in 114 L circular fiberglass tanks supplied with flow-through river water at a maximum biomass density of 20 g/L. Fish to be tagged and released at The Dalles Dam were collected, loaded into 265 L plastic tanks and transported to The Dalles Dam in temperature-controlled trucks. The tanks were supplied with oxygen throughout transport. Once at The Dalles Dam, the tanks were supplied with flow-through river water and fish were held for 12-36 h before tagging. The holding time for fish prior to tagging allowed fish to attain a postabsorptive state, minimizing stress throughout the tagging procedure.

All fish were gastrically implanted with a radio transmitter using procedures described by Adams et al. (1998). Fish were anesthetized using MS-222 (tricaine methanosulfate) at a concentration of 50 mg/L of fresh water. An equal amount of buffer solution ($NaHCO_3$) and Stress Coat (Aquarium Pharmaceuticals, Inc, Chalfont, PA), a synthetic slime coating and water conditioner, were added at a concentration of 0.25ml/L. Fish were netted from the holding tanks into the prepared anesthesia bucket with a maximum density of 5 fish in anesthesia at one time. Timers were used to ensure that fish remained in the anesthesia for no longer than 5 min. Fish were carefully observed to determine when adequate sedation had occurred (evident by loss of equilibrium), then removed from anesthesia and examined. Fish that were absent of external tags, fin clips, descaling, injuries, or signs of disease were weighed, measured, and tagged, then placed in an oxygenated recovery bucket for 5 min. Recovery buckets were modified 19 L buckets that held 7 L of water and were perforated above the 7 L reservoir (surface area of 65-103 cm^2). A maximum of two fish were held in each recovery bucket and oxygen was supplied at a minimum flow rate of 50 ml/min. Following the recovery period, fish were checked for regurgitated tags or mortalities. Each bucket was then covered with a locking lid and held for 18-24 h in a 3.6 m x 1.2 m x 1.2 m aluminum tank supplied with flow-through river water to a depth of 61 cm. Each tank was modified with an expanded metal floor that was elevated 33 cm, resulting in a water depth of 28 cm relative to the buckets. The elevated floor provided easier access to the buckets during the holding period, reducing stress induced by bucket movements and collisions. Prior to transporting the fish to the release site, each recovery bucket was checked for mortalities, regurgitated tags, and tag functionality. Releases occurred during day and night (0800 and 2000 hours at John Day Dam, 0700-1400 and 1900-0100 hours at The Dalles Dam) to enable tagged fish to mix spatially and temporally with untagged fish in the river before reaching Bonneville Dam. The upstream release locations allowed fish an average of 33 to 50 h, depending on release site, to adjust to temperature and hydraulic conditions in the river before reaching the forebay and encountering Bonneville Dam.

2-2.6 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. We utilized an automated proofing program, designed specifically for Bonneville Dam data. The automated proofing program was written in SAS and allowed us to proof and process our data with increased speed. Data were 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. All data records for fish that fell outside of our set criteria for travel time (<1st percentile or > 99th percentile), residence time (<1st percentile or > 99th percentile), and geographical area (upstream location after downstream location) were flagged and subsequently proofed manually. Additionally, a 10% random sub-sample of each auto-proofed file was proofed manually as a quality assurance measure of the auto-proofing program and to ensure accurately proofed data.

Entrance into the forebay area was determined by the location and time an individual fish was first detected by aerial or underwater antennas in the forebay. Similarly, the last detection of a fish by aerial or underwater antennas in the forebay, on the traveling screens, at the corner collector, within the B2 DSM, or the B1 sluiceway, was considered to indicate 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 the passage location (DSM, corner collector, turbine, or sluiceway).

Residence time in the forebay, 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 forebay. Residence times are a minimum estimate of the actual time that radio-tagged fish spent in the forebay 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 could pass the dam undetected.

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

- Spillway efficiency (SPE) = $\dfrac{SP}{B1 + SP + B2}$
- Spillway effectiveness (SPF) = $\dfrac{SPE}{F_{SP} / F_{tot}}$
- Fish guidance efficiency (FGE) = $\dfrac{G_{tot}}{G_{tot} + UG_{tot}}$

- Fish passage efficiency ($FPE_{Project}$) = $\frac{Non-turbine\ passage}{TOT_{pass}}$

- Fish passage efficiency (FPE_{B1})= $\frac{Non-turbine\ passage_{B1}}{B1}$

- Fish passage efficiency (FPE_{B2})= $\frac{Non-turbine\ passage_{B2}}{B2}$

- Corner collector efficiency (CCE_{B2}) = $\frac{CC}{B2}$

- Corner collector efficiency (CCE) = $\frac{CC}{Tot_{Pass}}$

- Corner collector effectiveness (CCF_{B2}) = $\frac{CCE}{F_{CC} / F_{B2}}$

- Corner collector effectiveness (CCF) = $\frac{CCE}{F_{CC} / F_{Tot}}$

- Sluiceway efficiency (SLE) = $\frac{SL}{B1}$

- Sluiceway effectiveness (SLF) = $\frac{SLE}{F_{SL} / F_{B1}}$

Where:
SP = Total number of fish passing spillway.
CC = Total number of fish passing through corner collector.
B1 = Total number of fish passing B1.
B2 = Total number of fish passing B2.
SL = Total number of fish passing through B1 sluiceway.
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).
Non-turbine passage=Total fish passing through non-turbine routes (B1 includes sluiceway and navigation lock; B2 includes corner collector and guided passage)
F_{SP} = Average discharge (kcfs) through the spillway during the study period.
F_{CC} = Average discharge (kcfs) through the corner collector during the study period.
F_{B1} = Average discharge (kcfs) through the first powerhouse during the study period.
F_{B2} = Average discharge (kcfs) through the second powerhouse 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 to provide a measure of precision of our estimate. We tested for equality of proportions between passage efficiencies during day and night using a chi-square test (Zar 1999).

2-3.0 Results

2-3.1 Water Quality

Over the course of the summer study period, water temperature and conductivity increased and dissolved oxygen decreased. Water temperature in the spillway forebay was a mean 19.2 ºC and ranged from 16.2 ºC to 21.5 ºC. The mean dissolved oxygen was 8.2 ppm and ranged from 7.6 to 8.9 ppm. The mean electrical conductivity was 162.5 µS/cm and ranged from 129.4 to 218.4 µS/cm (Appendix 11). Temperature, electrical conductivity, and dissolved oxygen fluctuated very little diurnally (Appendix 12).

2-3.2 Tagging

From 15 June to 17 July 2005, we radio-tagged and released 6,525 subyearling Chinook salmon, 70% of which were released from The Dalles Dam and 30% from John Day Dam (Appendix 13). The release period coincided with the central portion of the "in river" seaward migration of subyearling Chinook salmon (Figure 22). Of the fish released from John Day Dam, 57% (1,121 of 1,959) were released during the day and 43% (838 of 1,959) were released at night. Of the fish released from The Dalles Dam, 61% (2,790 of 4,566) were released during the day and 39% (1,776 of 4,566) were released at night. The mean fork length for fish released from all sites was 108 mm and the mean weight was 13.9 g. The mean tag/fish weight ratio was 3.0% (1.0% - 4.2%).

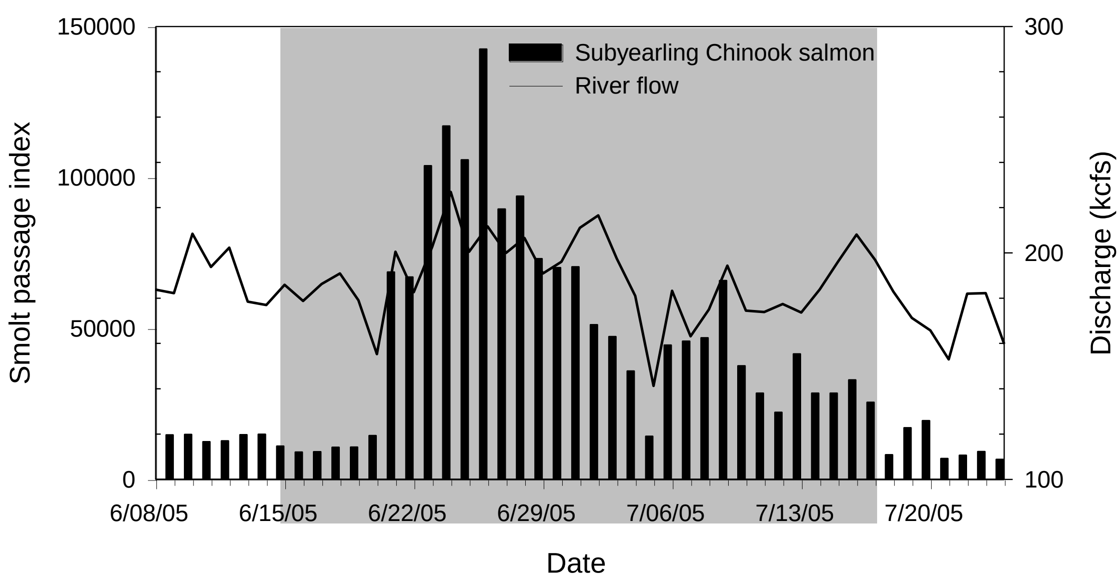
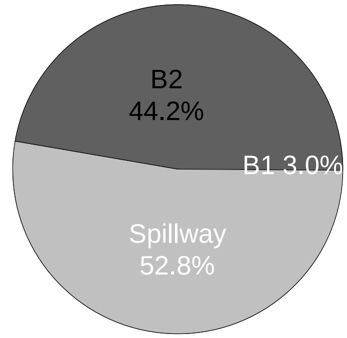


Figure 22.—Smolt Passage Index for subyearling Chinook salmon at Bonneville Dam's second powerhouse (B2) fish collection facility during summer 2005 (6/8 – 7/24). Shaded area indicates release period (6/15-7/17). Smolt index data were acquired from www.fpc.org.

2-3.3 River Discharge and Project Operations



During summer 2005 (15 June–25 July), mean river discharge at Bonneville Dam was 173.6 kcfs, and ranged from 135.9 kcfs to 213.2 kcfs. Allocation of mean river discharge among dam areas (i.e., B1, B2, and spillway) during the study period was 3% through B1, 44% through B2, and 53% through spill (Figure 23 and Table 19). Mean daily discharge at B1 (turbines 1–10) was 4.1 kcfs and ranged from 0 to 20.7 kcfs. The second powerhouse displayed the greatest fluctuation in mean daily discharge with a mean of 71.4 kcfs, a minimum of 40.5 kcfs and a maximum of 95.3 kcfs. Mean daily spill was 91.7 kcfs and ranged from 83.7 to 97.2 kcfs (Table 19)[2]. Day and night periods were determined by selecting the middle date of our study period and calculating the period between the beginning of civil twilight to the end of civil twilight, rounding to the nearest hour. Spill occurred from about 0500–2059 hours during the day and from about 2100–0459 hours during the night. Discharge at B2 decreased as the season progressed and daily discharge fluctuated more at B1 and B2 than at the spillway (Figure 24).

Only one spill treatment, called BIOP spill, was tested in 2005. The BIOP spill treatment consisted of 75 kcfs spill during the day (0500–2059) and spill to the 120% total dissolved gas (TDG) cap during the night (2100–0459). Discharge at B1 primarily occurred through turbines 1-6 (mean=78%) and the remainder of discharge went through turbines 7-10 (mean=1%) and the sluiceway (mean=21%; Figure 25). Discharge at B2 was distributed through the turbines more equally than at B1: 46% through turbines 11-14 and 47% through turbines 15-18. The remaining 7% was discharged through the corner collector (Figure 26). There were considerable differences in discharge between turbines, although fluctuations in mean daily discharge at B2 and the spillway corresponded with mean daily river discharge. Differences in daily turbine discharge were observed for multiple turbines throughout the study (Figures 27-30). Mean discharge at both powerhouses was higher during the day than night (74% of B1 and 65% of B2) and mean discharge at the spillway was higher at night compared to day (62% of SPI). During the day, 56% of water discharged at Bonneville Dam went through the powerhouses (4% at B1 and 52% at B2) and 44% was discharged through the spillway (Table 20). Conversely, during the night, mean discharge was highest at the spillway (71%) and lowest at the powerhouses (1% at B1 and 28% at B2).

[2]In July of 2004, the U.S. Army Corps of Engineers identified a discrepancy in the amount of water reported to be spilled at Bonneville Dam. An error in the calibration of spill gate openings installed in the early 1970s resulted in up to 30% less water discharged through the spillway than was reported to regional fish and water management officials. This report contains data based on accurate discharge measurements for 2005. Additionally, discharge data from research in 2002 and 2004 presented in this report has been revised for updated spill data.

Table 19.—Descriptive statistics for discharge (kcfs) at Bonneville Dam during summer 2005. Values have been rounded to the nearest tenth and are based on daily total. Discharge for the sluiceway and corner collector is included in discharge for first powerhouse and second powerhouse, respectively.

Dam Area	*Mean*	*Median*	*Min*	*Max*
First Powerhouse	*5.2*	*3.7*	*0.9*	*21.8*
Sluiceway	*1.1*	*1.2*	*0.6*	*1.3*
Second Powerhouse	*76.7*	*78.1*	*45.8*	*100.4*
Corner Collector	*5.2*	*5.3*	*4.6*	*5.7*
Spillway	*91.7*	*91.9*	*83.9*	*97.2*
Total	*173.6*	*175.5*	*135.9*	*213.2*

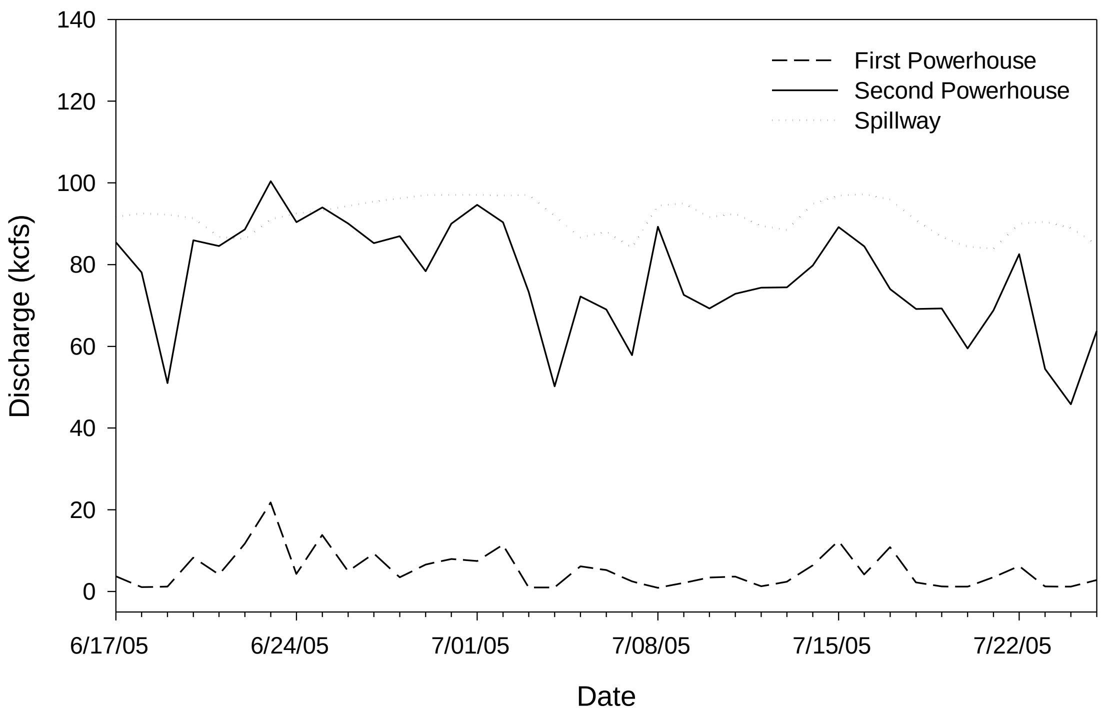


Figure 24.—Mean daily discharge by dam area at Bonneville Dam, summer 2005.

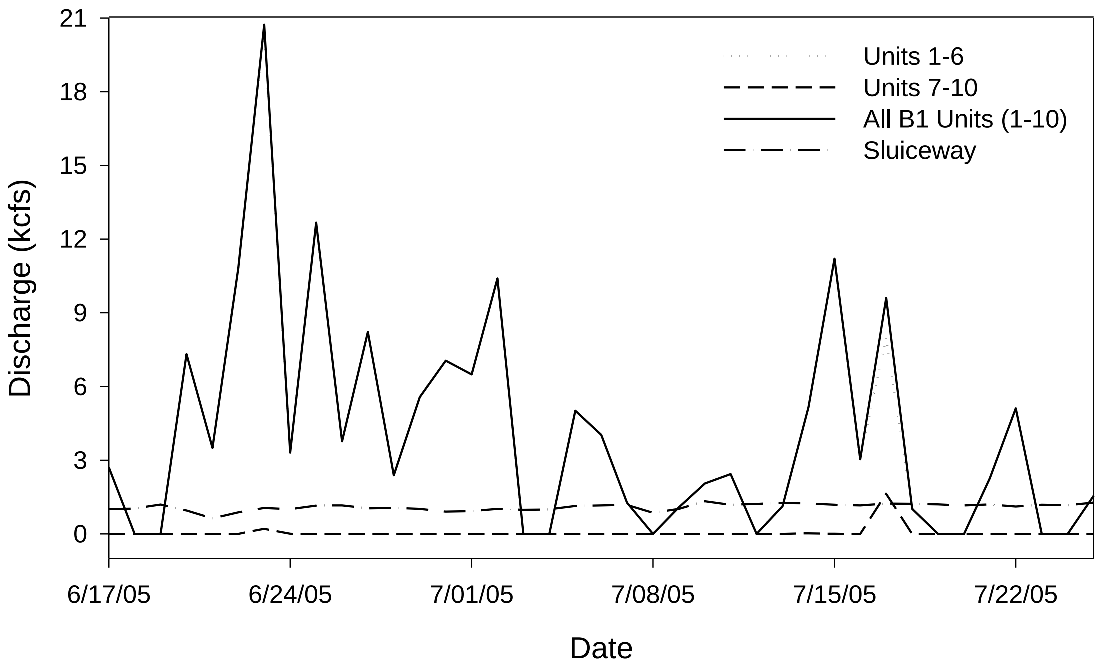


Figure 25.—Mean daily discharge through turbines 1-6, 7-10, and the sluiceway at Bonneville Dam's first powerhouse (B1), summer 2005.

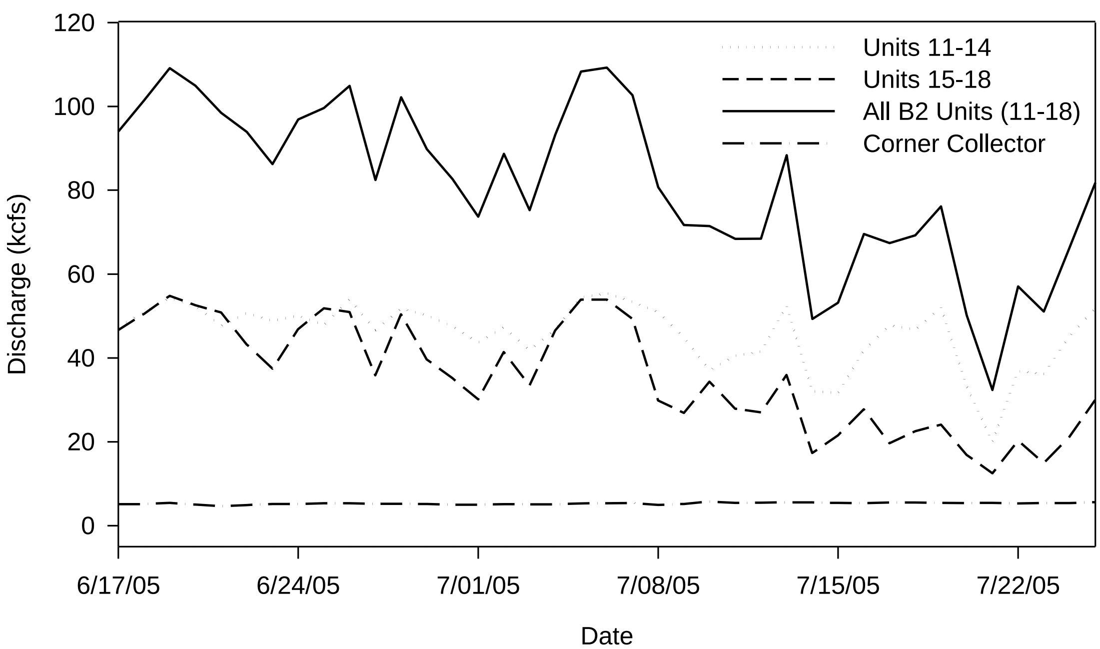


Figure 26.—Mean daily discharge through turbines 11-14, 15-18, and the corner collector at Bonneville Dam's second powerhouse (B2), summer 2005.

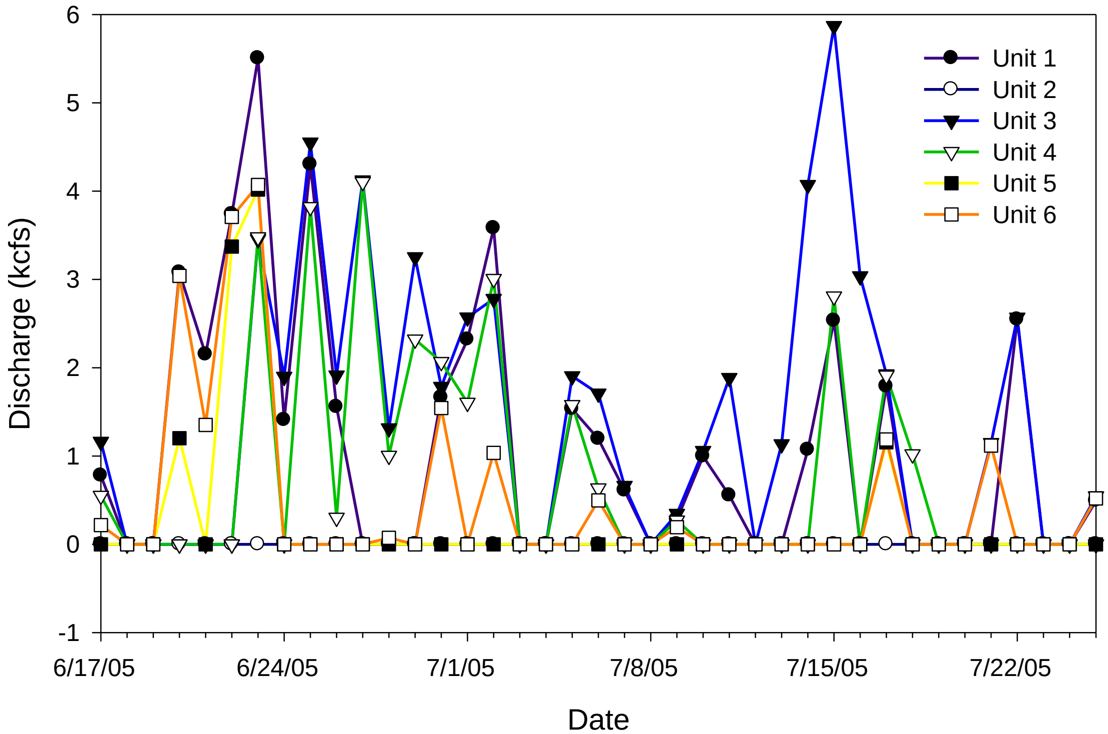


Figure 27.—Mean daily discharge by unit for turbines 1-6 at Bonneville Dam, summer 2005.

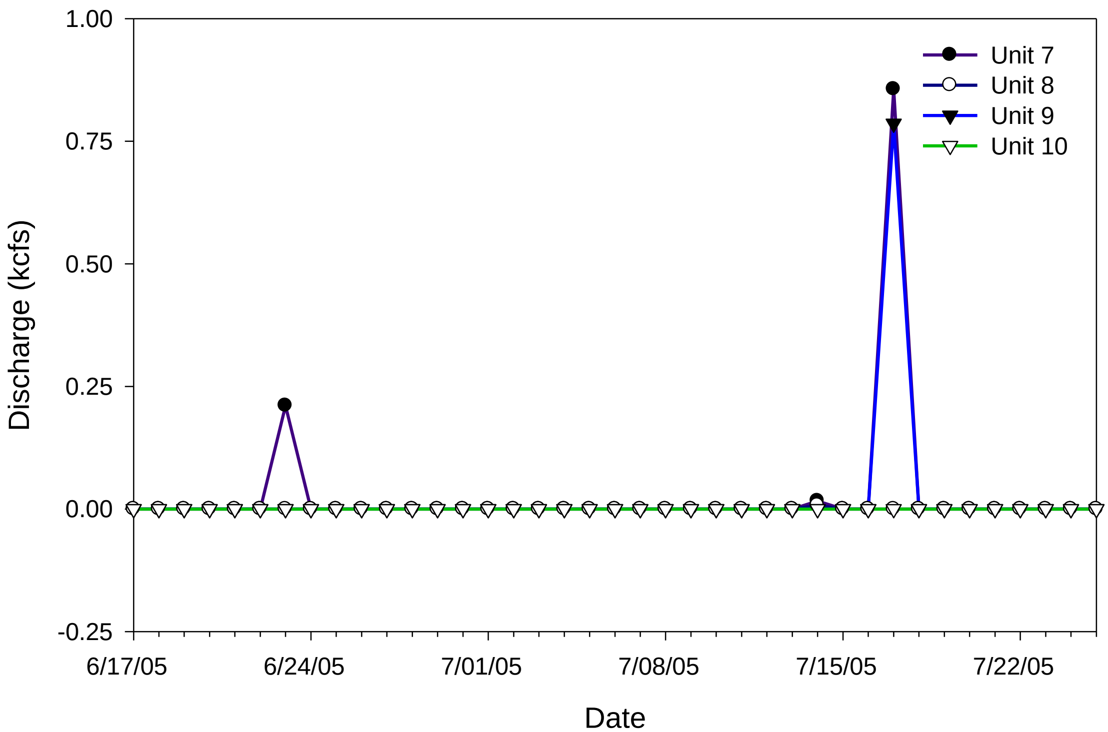


Figure 28.—Mean daily discharge by unit for turbines 7-10 at Bonneville Dam, summer 2005.

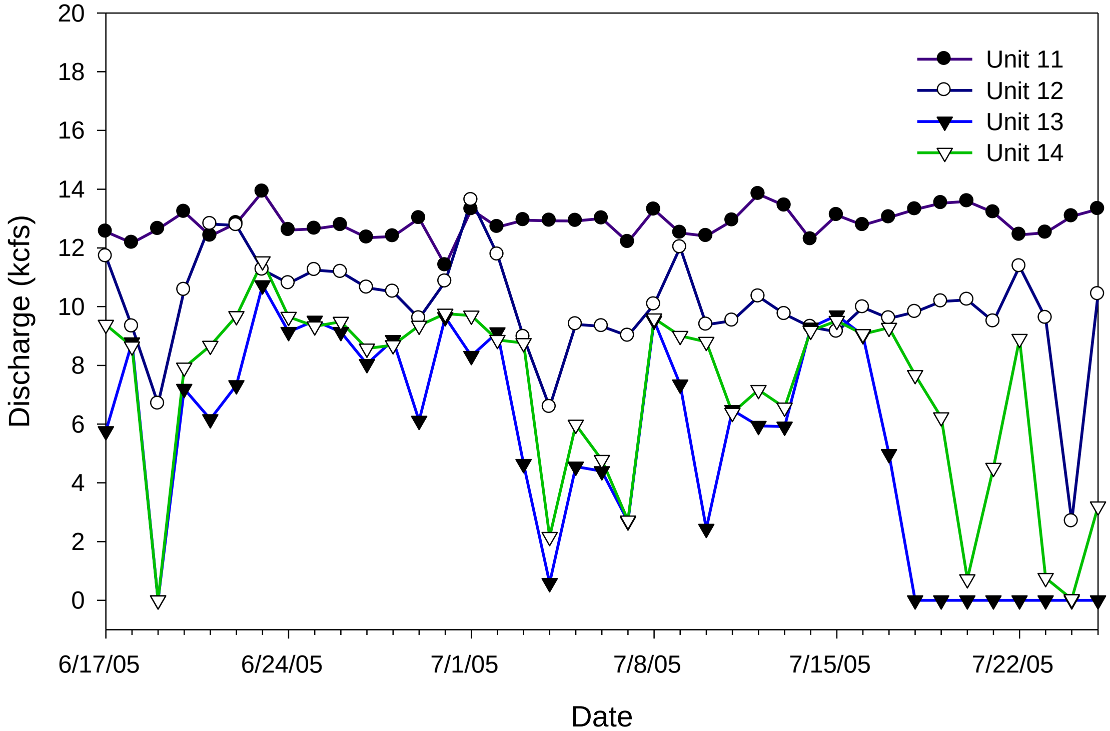


Figure 29.—Mean daily discharge by unit for turbines 11-14 at Bonneville Dam, summer 2005.

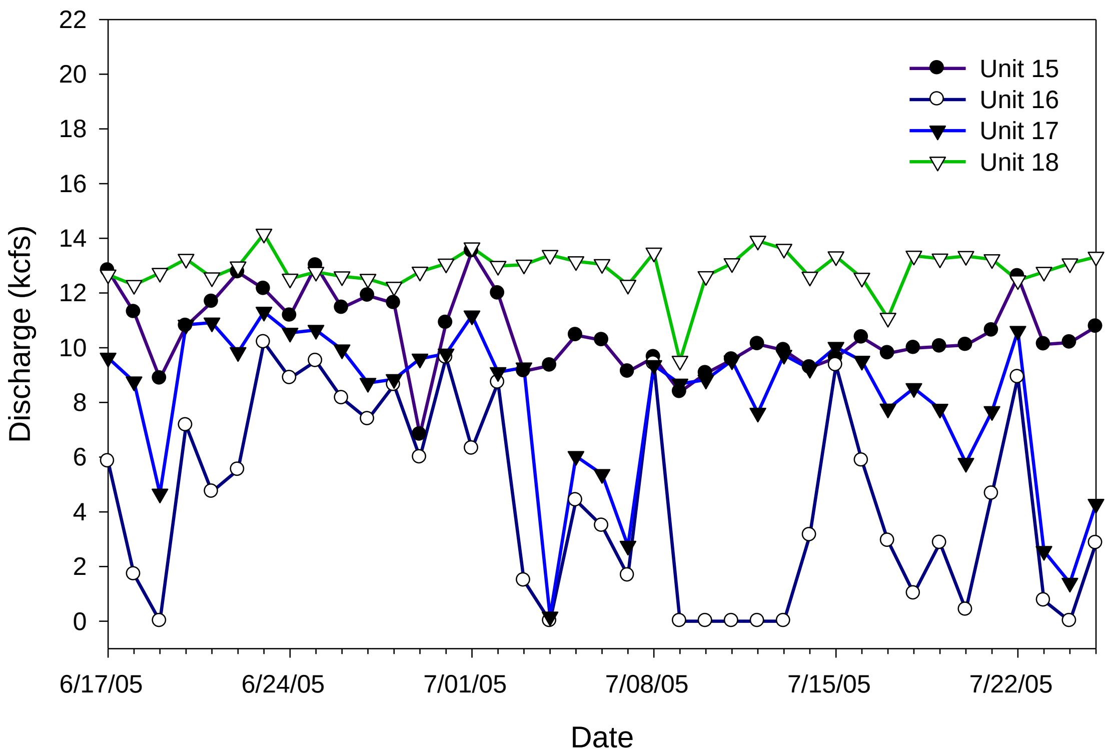


Figure 30.—Mean daily discharge by unit for turbines 15-18 at Bonneville Dam, summer 2005.

Table 20.—Mean discharge (kcfs) during day (0500-2059 hours) and night (2100-0459 hours) by dam area at Bonneville Dam, summer 2005.

Period and dam area	Percent (of period)	Mean	Median	Min	Max
Day					
First Powerhouse	4%	7.7	6.9	3.8	13.5
Second Powerhouse	54%	95.5	98.4	884.7	102.6
Spillway	42%	75.3	75.3	75.0	75.6
Total	100%	178.5	180.5	164.1	190.1
Night					
First Powerhouse	2%	3.5	2.4	2.2	11.4
Second Powerhouse	30%	54.7	47.2	41.4	101.5
Spillway	68%	124.4	133.4	76.5	137.0
Total	100%	182.7	184.0	172.8	189.4

2-3.4 Travel to and Arrival at Bonneville Dam

At Bonneville Dam, we detected 86% (5,572 of 6,495) of the subyearling Chinook salmon that were released from John Day Dam and The Dalles Dam. The median travel times from release to first detection at Bonneville Dam were 49.0 h from John Day Dam and 32.7 h from the Dalles Dam. The median travel rates from release to first detection at Bonneville Dam were 2.3 km/h for fish released from John Day Dam and 2.2 km/h for fish released from the Dalles Dam (Table 21).

Table 21.—Descriptive statistics for travel time (h) and travel rate (km/h) to Bonneville Dam for subyearling Chinook salmon, summer 2005. Travel rate statistics are represented in parentheses.

Release site	*Mean*	*Median*	*Min*	*Max*
John Day Dam	*50.3 (2.3)*	*49.0 (2.3)*	*32.5 (0.7)*	*154.0 (3.5)*
The Dalles Dam	*33.6 (2.2)*	*32.7 (2.2)*	*21.8 (0.8)*	*87.5 (3.4)*

Fish did not enter dam areas (i.e., B1, B2, and spillway) in equal proportions. Of the fish detected in the forebay of Bonneville Dam, 50% (2683 of 5348) first entered the B2 forebay, 48% (2587 of 5348) first entered the spillway, and 2% (78 of 5348) first entered the B1 forebay. Differences in the number of fish entering each forebay appeared to be related to allocation of river discharge among dam areas. Discharge allocation at the spillway, B2, and B1 was 53%, 44%, and 3%, respectively. To further investigate this relation, we compared the proportion of mean daily discharge though each dam area to the daily proportion of radio-tagged fish that entered each dam area. 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 (Figure 31).

Similarly, we compared the hourly proportion of fish entering each dam area to the hourly proportion of mean discharge through each dam area. At the spillway and second powerhouse, the number of fish entering the forebay increased during hours of increased discharge and decreased during hours of decreased discharge (Figure 32).

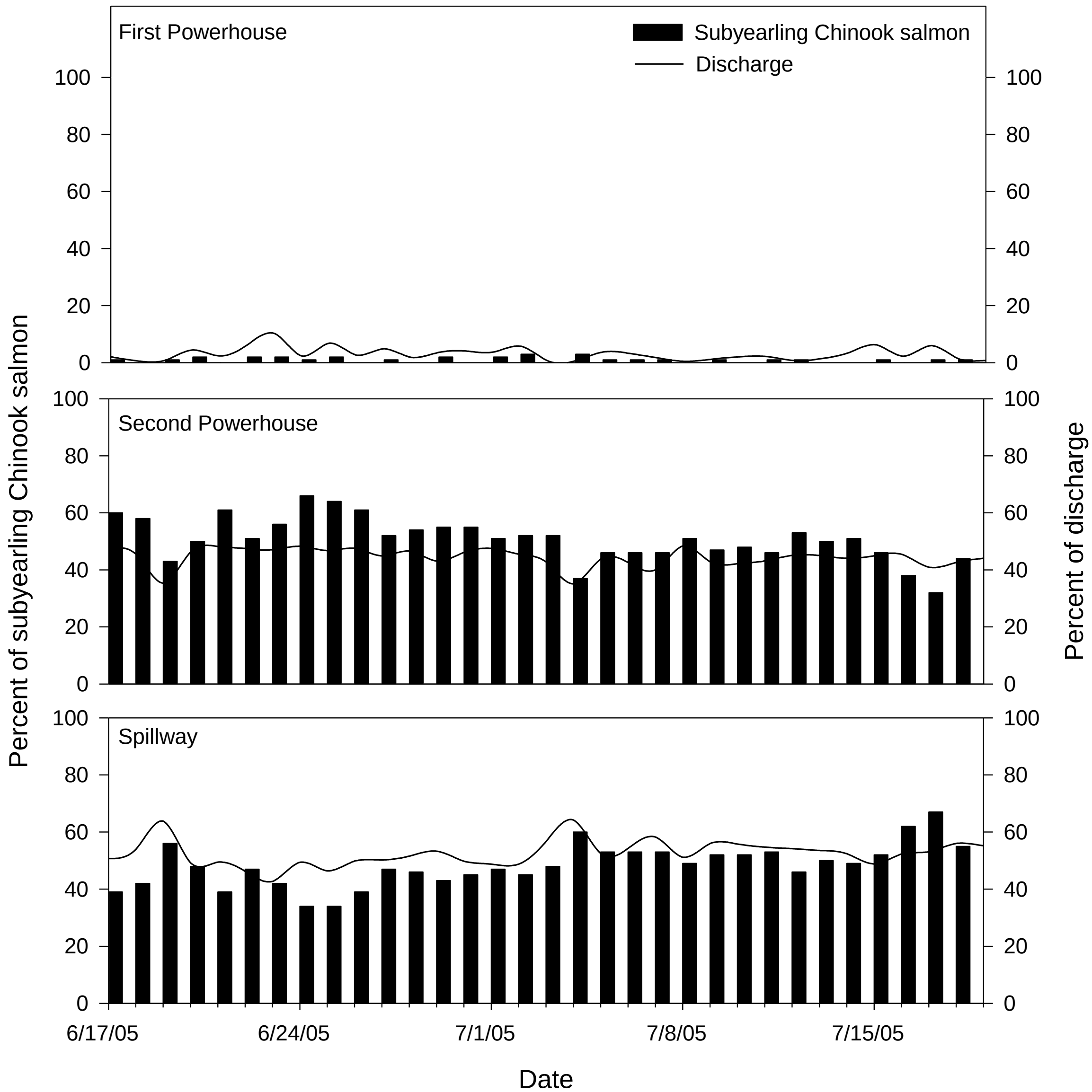


Figure 31.—The percentage of subyearling Chinook salmon that entered each dam area versus the percentage of mean daily discharge at each dam area at Bonneville dam, summer 2005.

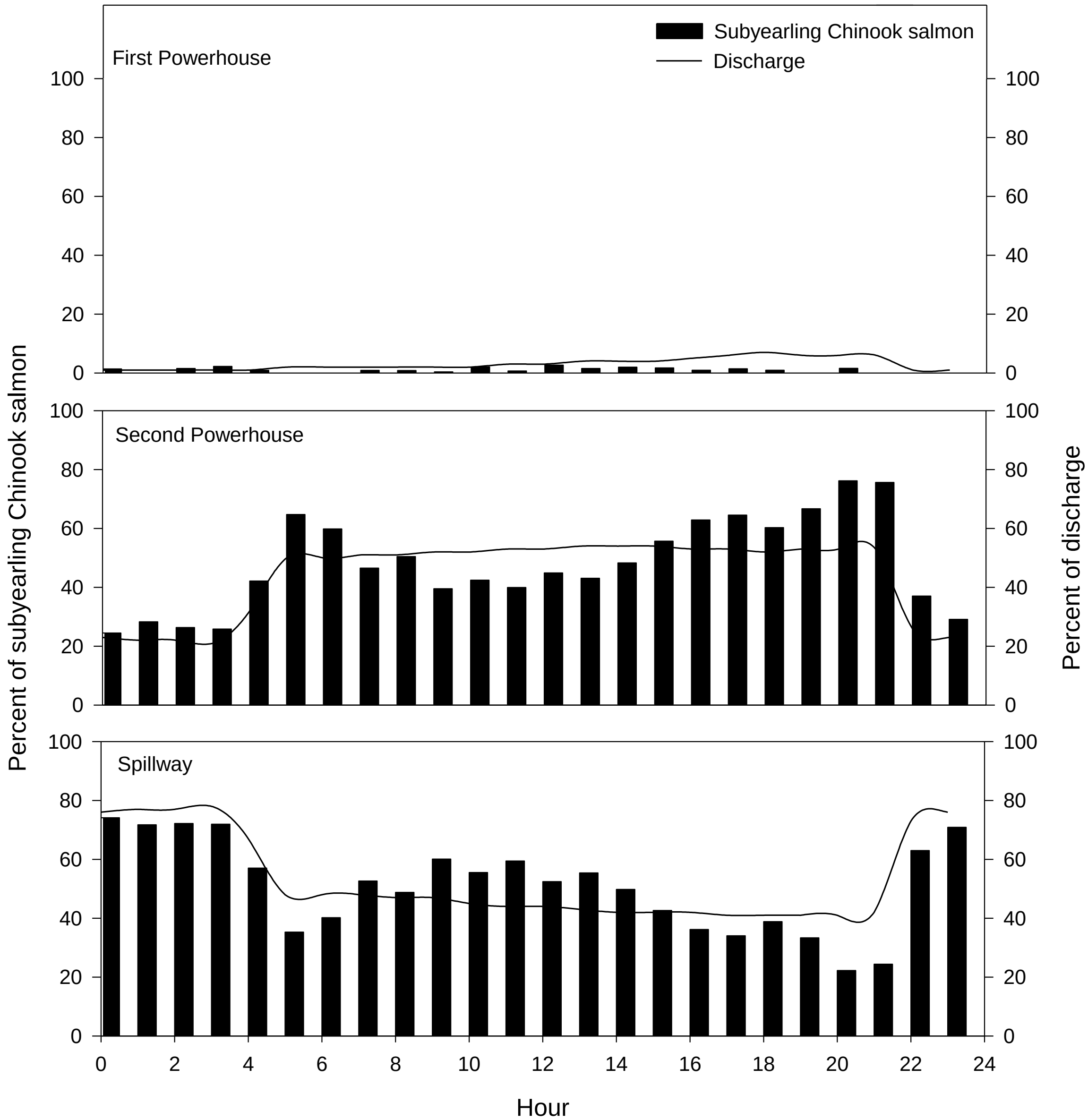


Figure 32.—The percentage of subyearling Chinook salmon that entered each dam area versus the percentage of mean hourly discharge at each dam area at Bonneville Dam, summer 2005.

2-3.5 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 forebay of B1 (median = 4.4 h) than in the forebays of B2 (median = 0.2 h) or the spillway (0.4 min; Table 22). We compared median forebay residence times by day of passage, by hour of passage, and by hour of arrival to mean discharge and found that residence times generally decreased as discharge increased (Appendices 14-16).

Table 22.—Descriptive statistics of forebay residence time (h) by dam area for subyearling Chinook salmon at Bonneville Dam, summer 2005.

Dam area	*N*	*Mean*	*Median*	*Min*	*Max*
First Powerhouse	*69*	*7.1*	*4.4*	*0.2*	*30.5*
Second Powerhouse	*2284*	*1.1*	*0.2*	*0.0*	*140.8*
Spillway	*2634*	*0.8*	*0.4*	*0.0*	*98.9*
Total	*4987*	*1.0*	*0.3*	*0.0*	*140.8*

2-3.6 Route and Time of Passage through Bonneville Dam

We determined the route of passage through Bonneville Dam for 98% of the tagged fish (5,454 of 5,572 subyearling Chinook) detected at Bonneville Dam. All 118 fish for which passage routes could not be determined were detected downstream of the dam. Among the three dam areas, the spillway passed the most fish (51%), 48% passed at B2, and 1% passed at B1 (Figure 33). The distribution of passage among dam areas was identical to the distribution of approach (based on first detection of fish) among dam areas and was very similar to the proportion of water discharged through each dam area.

The distribution of passage of subyearling Chinook salmon at each dam area varied and was dependant on the type of passage route available. Of the 69 fish that passed B1, 30% (21) passed unguided through the turbines, 59% (41) passed through the sluiceway, and 10% (7) passed through the navigation lock. Of the 2,626 fish that passed at B2, 46% (1,196) passed unguided through the turbines, 40% (1,054) passed through the corner collector, and 14% (376) were guided into the DSM. The remaining 2,759 fish passed through the spillway (Figure 33).

Diurnal passage distributions of subyearling Chinook salmon were similar to overall passage distributions. During the day, more fish passed B2 (51%), than through the spillway (47%), and B1 (2%). Passage distributions of fish at night were similar to day with 57% of the fish passing the spillway, compared to 42% passing B2, and 1% passing B1 (Table 23). Passage of subyearling Chinook salmon peaked at sunset (2200 hours) and was lowest at 0200 hours (Figure 34). Of the total number of fish that passed each dam area during day and night, a higher number of fish passed during the day (Table 24). However, there was a difference in the number of hours in each diel period (16 day, 8 night); therefore we also calculated passage rates (fish/hour) for each dam area and diel period. Passage rates were higher during the day at B1 and B2, but at the spillway passage rates were higher at night (Table 25).

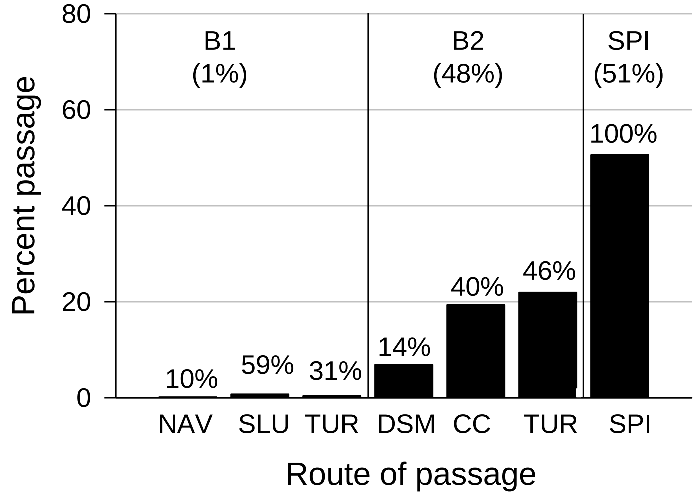


Figure 33.—Percent fish passage by dam area and route of passage for subyearling Chinook salmon at Bonneville Dam, summer 2005. B1 = first powerhouse, B2 = second powerhouse, SPI = spillway, NAV = navigation lock, SLU = sluiceway, TUR = turbine, DSM = downstream salmonid migrants channel, and CC = corner collector. Percentages in parentheses designate proportions among dam area, percentages without parentheses designate proportions within each dam area, and the percent value of each bar represents proportion of all routes at Bonneville Dam.

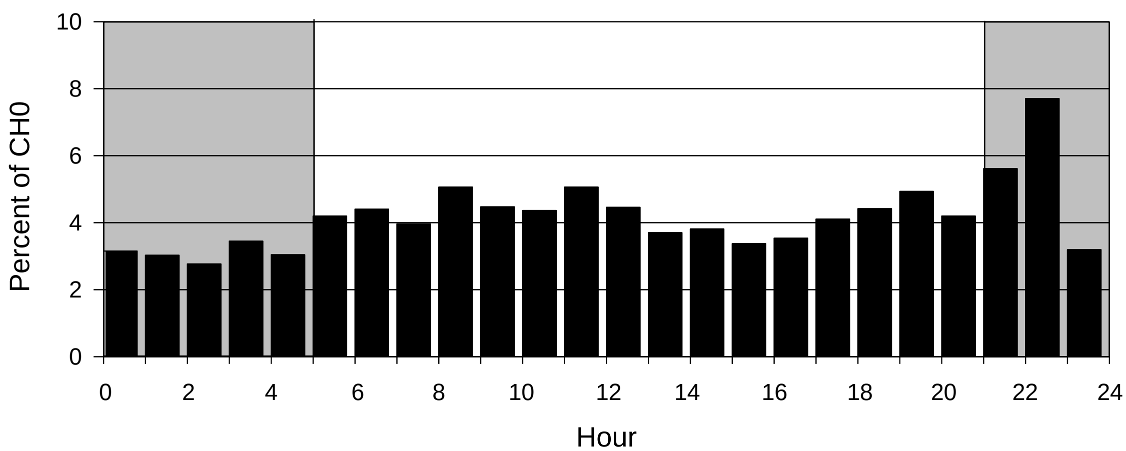


Figure 34.—Percent passage during the day (0500-2059 hours; unshaded) and night (2100-0459 hours) for subyearling Chinook salmon at Bonneville Dam, summer 2005.

Table 23.—Percentage of subyearling Chinook salmon that passed each area of Bonneville Dam during daytime hours (0500-2059) and nighttime hours (2100-0459), summer 2005. Percentages are based on the total number of fish that passed each route during each diel period.

Diel period	*Route of passage*		
	First Powerhouse	*Second Powerhouse*	*Spillway*
Day	*2% (58 of 3,712)*	*51% (1,896 of 3,712)*	*47% (1,758of 3,712)*
Night	*1% (11 of 1,742)*	*42% (730 of 1,742)*	*57% (1,001 of 1,742)*

Table 24.—Percentage of subyearling Chinook salmon that passed each area of Bonneville Dam during daytime hours (0500-2059) and nighttime hours (2100-0459), summer 2005. Percentages are based on the total number of fish that passed each dam area.

Diel period	*Route of passage*		
	First Powerhouse	*Second Powerhouse*	*Spillway*
Day	*84% (58 of 69)*	*72% (1,896 of 2,626)*	*64% (1,758of 2,759)*
Night	*16% (11 of 69)*	*28% (730 of 2,626)*	*36% (1,001 of 2,759)*

Table 25.—Passage rates for subyearling Chinook salmon that passed Bonneville Dam during daytime hours (0500-2059) and nighttime hours (2100-0459), summer 2005. Rates are based on 16 h per 24 h over 40 d for day passage and 8 h per 24 h over 40 d for night passage.

Diel period	*Route of passage*		
	First Powerhouse	*Second Powerhouse*	*Spillway*
Day	*0.1 fish/h*	*3.0 fish/h*	*2.7 fish/h*
Night	*0.03 fish/h*	*2.3 fish/h*	*3.1 fish/h*

2-3.7 Passage Metrics

2-3.7.1 Spillway Efficiency

Spillway efficiency is the number of fish that passed through the spillway divided by the number of fish that passed through all routes at all dam areas (spillway, B1, and B2). Overall, 51% of subyearling Chinook salmon passed through the spillway. Spillway efficiency was significantly higher ($\chi^2 = 48.4$, df = 1, $P < 0.0001$) during the night spill condition (mean 124.4 kcfs), than during the day when spill was discharged at a mean 124.4 kcfs (Table 26).

Table 26. — Spillway Efficiency at Bonneville Dam for subyearling Chinook salmon during summer 2005. Mean discharge (kcfs) spilled is shown in parenthesis. SE = standard error of spillway efficiency estimate, B1 = first powerhouse, and B2 = second powerhouse.

Diel period	Spillway efficiency	SE	B1 passage	B2 passage	SPI passage
Overall (91.7)	51%	0.7	69	2626	2759
Day (75.3)	47%	0.8	58	1896	1758
Night (124.4)	58%	1.2	11	730	1001

2-3.7.2 Spillway Effectiveness

Spillway effectiveness is the proportion of fish that passed through spill relative to the proportion of project discharge spilled. Overall spillway effectiveness was 0.96 for subyearling Chinook salmon (Table 27). Spill during the 75 kcfs day condition was more effective (1.08) than during the TDG night condition (0.81).

Table 27.—Spillway effectiveness and efficiency at Bonneville Dam for subyearling Chinook salmon during summer 2005. Mean discharge (kcfs) spilled is shown in parenthesis. F_{sp} = mean spillway discharge (kcfs). F_{tot} = mean project discharge (kcfs).

Diel period	Spillway effectiveness	Spillway efficiency	F_{sp}	F_{tot}
Overall (91.7)	0.96	51%	91.7	173.6
Day (75.3)	1.08	47%	75.3	172.3
Night (124.4)	0.81	58%	124.4	176.2

2-3.7.3 Fish Guidance Efficiency

Fish guidance efficiency at B2 (FGE; proportion of fish entering turbine intakes that were guided by turbine intake screens) overall was 24% for subyearling Chinook salmon (Table 28). We could not calculate FGE at B1 because there were no guidance screens deployed at B1 during 2005. Fish guidance efficiency at B2 was significantly higher (χ^2 = 137.2, df = 1, P < 0.0001) during the TDG gas cap condition at night (42%) than during the 75 kcfs day condition (15%). Turbine unit 17 was the most efficient (53%) at guiding subyearling Chinook salmon (Table 29). Over twice as many fish passed the southern half of B2 through units 11-14 than the northern half through units 15-18. Unit 16 had the lowest guidance efficiency (21%) and guided and passed the least number of fish. Unit 13 guided and passed the highest number of fish.

Table 28.—Estimates of fish guidance efficiency (FGE) and corresponding standard error at Bonneville Dam's second powerhouse for subyearling Chinook salmon during summer 2005. Mean discharge (kcfs) spilled and number of fish guided of total fish guided plus unguided are shown in parentheses.

Diel period	Fish guidance efficiency	Standard error
Overall (91.7)	24% (376 of 1,572)	1.1
Day (75.3)	15% (157 of 1,047)	1.1
Night (124.4)	42% (219 of 525)	2.2

Table 29.—Estimates of fish guidance efficiency (FGE) by turbine unit at Bonneville Dam's second powerhouse for subyearling Chinook salmon, summer 2005.

Turbine Unit	*FGE*
11	*32% (60 of 185)*
12	*25% (47 of 192)*
13	*27% (69 of 256)*
14	*27% (56 of 207)*
15	*37% (66 of 180)*
16	*21% (13 of 63)*
17	*53% (42 of 80)*
18	*27% (21 of 78)*

2-3.7.4 Fish Passage Efficiency

Fish passage efficiency (FPE: the proportion of fish that passed the dam via non-turbine routes) at Bonneville Dam was 78% (SE = 0.01) overall for subyearling Chinook salmon (Table 30). Fish passage efficiency was higher ($\chi^2 = 30.1$, df = 1, $P < 0.0001$) at night during the TDG gas cap (82%) than during the 75 kcfs day condition (76%).

Table 30.—Fish passage efficiency (FPE) at Bonneville Dam for subyearling Chinook salmon during summer 2005. Does not show seven fish that passed through the navigation lock that were used in FPE calculations. B2 = first powerhouse and B2 = second powerhouse.

Diel period	FPE	Sluiceway	B2 guided	Corner collector	Spillway	B1 unguided	B2 unguided
Overall	78%	41	376	1054	2759	21	1196
Day	76%	37	157	849	1758	17	890
Night	82%	4	219	205	1001	4	306

2-3.7.5 Corner Collector Efficiency

Corner collector efficiency (CCE) is the number of fish that passed through the corner collector divided by the number of fish that passed through all routes at B2. Overall, 40% of subyearling Chinook salmon that passed at B2 went though the corner collector (Table 31). Passage through the corner collector was significantly higher ($\chi^2 = 61.2$, df = 1, $P < 0.0001$) during the day (45%), when a mean 75 kcfs was spilled, than during the night (28%), when a mean 124 kcfs was spilled.

Table 31.—Corner collector efficiency (CCE) and effectiveness (CCF) at Bonneville Dam for subyearling Chinook salmon during summer 2005. SE = standard error of corner collector efficiency estimate. F_{cc} = mean corner collector discharge (kcfs). F_{B2} = mean second powerhouse discharge (kcfs).

Diel period	*CCE*	*SE*	*CCF*	F_{cc}	F_{B2}
Overall	*40%*	*1.0*	*5.9*	*5.2*	*76.7*
Day	*45%*	*1.1*	*7.8*	*5.2*	*90.3*
Night	*28%*	*1.7*	*2.6*	*5.4*	*49.4*

2-3.7.6 Corner Collector Effectiveness

Corner collector effectiveness (CCF) is the proportion of fish that passed through the corner collector relative to the proportion of discharge at B2 that went through the corner collector. Overall effectiveness of the corner collector was 5.9 and was higher during the day (7.8) than during the night (2.6; Table 31).

2-3.7.7 Sluiceway Efficiency

Sluiceway efficiency is the number of fish that passed through the B1 sluiceway divided by the number of fish that passed through all routes at B1. Overall, more than half of the subyearling Chinook salmon that passed at B1 passed through the sluiceway (59%; Table 32). Sluiceway efficiency was significantly greater during the day (64%; $\chi^2 = 2.9$, df = 1, $P = 0.09$) than during the night (36%).

Table 32. — Sluiceway efficiency (SLE) and effectiveness (SLF) at Bonneville Dam for subyearling Chinook salmon during summer 2005. SE = standard error of sluiceway efficiency estimate. F_{SL} = mean sluiceway discharge (kcfs). F_{B1} = mean first powerhouse discharge (kcfs).

Diel period	*SLE*	*SE*	*SLF*	F_{SL}	F_{B1}
Overall	*59%*	*6.0*	*2.8*	*1.1*	*5.2*
Day	*64%*	*6.4*	*4.0*	*1.1*	*6.7*
Night	*36%*	*15.2*	*0.7*	*1.2*	*2.4*

2-3.7.8 Sluiceway Effectiveness

Sluiceway effectiveness (SLF) is the proportion of fish that passed through the B1 sluiceway relative to the proportion of discharge at B1 that went through the sluiceway. Subyearling Chinook salmon had an overall sluiceway effectiveness of 2.8 (Table 32). Effectiveness of the sluiceway was higher during the day (4.0) than during the night (0.7).

2-3.8 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) used fixed hydroacoustics to monitor fish passage and estimate passage performance metrics for the run-at-large (Ploskey et al. 2006). The summer monitoring period for hydroacoustics (June 1 – July 15) was slightly different than it was for our radio telemetry study (June 15 – July 25). We therefore calculated passage metrics during the overlapping period of June 15 – July 15 to directly compare estimates and minimize the effects of variables such as discharge that may have differed during non-overlapping time periods. Differences in passage performance metrics, as estimated by radio telemetry and hydroacoustics, ranged from 0.5 – 20.5% (Table 33). Estimates of corner collector efficiency were within 0.5-1.3% of each other. Estimates of sluiceway efficiency$_{B1}$ had the greatest disparity between the two methods. Estimates of FGE by unit at B2 were most similar for units 14 and 17 and differed considerably at units 11 and 16 (Table 34). Although sample sizes for radio-telemetry estimates were relatively small compared to those for hydroacoustics, standard errors of radio telemetry passage metric estimates ranged from 0.1% to 6.1%. Standard errors for FGE by unit ranged from 2.8% to 5.6%.

Table 33.—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) during the overlapping period of June 15 – July 15, 2005, at Bonneville Dam. Hydroacoustic data were provided by Gene Ploskey, Pacific Northwest National Laboratory (27 April 2006).

Metric	RT estimate	HA estimate	Difference
Corner Collector Efficiency$_{B2}$	40%	41.3%	-1.3%
Corner Collector Effectiveness $_{B2}$	7.2	6.3	0.9
Corner Collector Efficiency$_{Project}$	20%	20.5%	-0.5%
Corner Collector Effectiveness$_{Project}$	6.8	7.0	-0.2
Spillway efficiency	49%	44.7%	4.3%
Spillway effectiveness	1.2	0.9	0.3
Sluiceway efficiency$_{B1}$	62%	82.5%	-20.5%
Sluiceway effectiveness$_{B1}$	7.8	4.2	3.6
Sluiceway efficiency$_{Project}$	0.8%	4.7%	-3.9%
Sluiceway effectiveness$_{Project}$	1.4	7.7	-6.3
FGE$_{B2}$	24%	38.1%	-14.1%
FPE	77%	81.0%	-4%
FPE$_{B1}$	72%	82.5%	-10.5%
FPE$_{B2}$	54%	63.7%	-9.7%

Table 34.—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 the overlapping period of June 15 – July 15, 2005. Hydroacoustic data were provided by Gene Ploskey, Pacific Northwest National Laboratory (27 April 2006).

Location	RT FGE	HA FGE	Difference
Unit 11	33%	54%	-21%
Unit 12	24%	40%	-16%
Unit 13	27%	38%	-11%
Unit 14	26%	33%	-7%
Unit 15	36%	46%	-10%
Unit 16	20%	44%	-24%
Unit 17	53%	48%	5%
Unit 18	25%	13%	12%

2-3.9 Residence Times at Areas of Potential Delay

According to survey data gathered by the USACE early in 2002, the second powerhouse's Juvenile Bypass System (B2 JBS) conveyance 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 B2 JBS conveyance pipe transported juvenile salmonids rather quickly in 1999 – 2001 (Holmberg et al. 2001a, 2001b; Evans et al. 2001a, 2001b) and again in 2002-2004, after the discovery of the ovality issue (Evans et al. 2003a, 2003b, 2005, Reagan et al. 2005). Travel times of juvenile salmonids through the conveyance pipe were monitored again in 2005. The median travel time of guided subyearling Chinook salmon through the B2 JBS conveyance pipe in 2005 was, 34.7 minutes, slightly less than travel times through the pipe in 1999 – 2002 and 2004, indicating that fish were not delayed in the pipe (Table 35).

Table 35.—Median travel times (min) for subyearling Chinook salmon passing through Bonneville Dam's second powerhouse juvenile bypass system conveyance pipe during summer study periods 1999 – 2005.

	1999	*2000*	*2001*	*2002*	*2004*	*2005*
Chinook salmon	*41.3*[a]	*36.5*	*38.1*	*35.9*	*35.0*	*34.8*

[a] Residence times in 1999 were based on travel from the top of the pipe to the outfall.
Residence times in 2000-2005 were based on travel from the top of the pipe to the fish sampling facility, which was not yet completed in 1999.

2-4.0 Discussion

The proportion of discharge allocated to each dam area likely determined the forebay that fish entered, and therefore, the dam area that fish subsequently passed. Based on our analysis of daily percent discharge per dam area 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 and B2 discharged the greatest amount of water (53 and 44%, respectively) during the study, most fish entered the spillway (48%) and B2 (50%) forebays. Only 3% of project discharge was allocated to B1 and, consequently, only 2% of subyearling Chinook salmon entered the B1 forebay.

High discharge reduced forebay residence times. Subyearling Chinook salmon spent the least amount of time in the forebays of B2 (median = 12 min) and the spillway (median = 24 min), the areas with the highest project discharge. Residence time was longest for fish in the forebay of B1 (median = 4.4 h) where project discharge was lowest. Comparisons of residence times and discharge patterns based on date of fish passage, hour of fish passage, and hour of forebay arrival, indicated that residence times generally decreased with increased discharge. These observations indicate that project operations and the resulting discharge per dam area influence approach paths of migrating subyearling Chinook salmon and consequently determine which dam area smolts enter and pass. Discharge per dam area also affected how long fish resided in the forebay of Bonneville Dam before passing.

Of all radio-tagged subyearling Chinook salmon with known passage routes, 80% passed Bonneville Dam through relatively deep routes of passage (the spillway or the turbine intakes). Half of all subyearling Chinook salmon that passed Bonneville Dam went through the spillway, where fish must descend about 15 m to pass. At B2, subyearling Chinook salmon passed more readily through the deeper turbine intakes (46% unguided, 14% guided) than through the surface-oriented corner collector (40%). Conversely, at B1, a greater proportion of radio-tagged fish passed through the shallow, weir-type entrances of the sluiceway (59%) and the navigation lock (10%) than through the deeper turbine intakes (31% unguided). These data indicate that (deep) discharge per dam area likely affected whether subyearling Chinook salmon passed through shallow or deep passage routes. Higher discharge at the spillway and B2 seemed to result in most fish passing through deep passage routes, such as the spillway and turbine intakes. The relatively low discharge at B1 may have allowed fish the opportunity to discover the sluiceway more readily than they would have during higher turbine discharge at B1.

The distribution of passage among dam areas fluctuated with diurnal periods but was confounded because discharge also varied diurnally. During the night, when a mean 124 kcfs was spilled, most radio-tagged subyearling Chinook salmon (58%) passed the spillway, which had the highest proportion of project discharge (68%) during TDG cap spill. During the 75 kcfs day spill condition, most fish (51%) passed at B2, which had the highest proportion of project discharge (54%) during 75 kcfs spill. A similar pattern between fish passage and discharge was observed in 2004. During summer 2004, 50% of subyearling Chinook salmon passed through spill during the Biop spill treatment (mean = 100.2 kcfs) and 72% of fish passed through routes at B2 during the lower 50 kcfs spill treatment (Evans et al. 2005). During summer 2002, when discharge was nearly equal during day and night for all dam areas and when the only passage route through B2 was through the turbines or bypass system, fish passage increased during the night at all dam areas (Evans et al. 2003a). Daytime passage during summer 2004 at both powerhouses was primarily through the shallow sluiceway (49% of B1) and corner collector (47% of B2), while nighttime passage at both powerhouses was primarily through the deeper turbines (B1 = 58% unguided and B2 = 56% unguided, 26% guided). Therefore, past and present research at Bonneville Dam shows that fish passage increases at night through deep routes of passage like the turbines and spillway, and increases during the day through shallow routes of passage like the sluiceway and corner collector. These findings concur with 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. Surface-oriented passage of juvenile salmonids has been shown to increase during the day at Bonneville Dam (Willis and Uremovich 1981; Magne et al.1989; 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). These data suggest that since fish tend to both follow flow and pass in a diurnal pattern, if discharge is optimized in the appropriate area at the right time, passage of fish through non-turbine routes can be increased.

Overall passage metrics for subyearling Chinook salmon in 2005 were generally higher than in 2004 and comparable to passage metrics in 2002 (Table 36). Higher spill discharge in 2005 likely resulted in higher spillway efficiency and FPE compared to 2004. Most passage metrics, especially spillway efficiency and FPE, were similar in 2002 and 2005 due to similar spill discharge during those years. Fish guidance efficiency at B2 was lower in 2004 and 2005 than in previous years, likely because of the corner collector. We hypothesize that low FGE at B2 in 2004 and 2005 was due to the corner collector passing the majority of the shallow fish that may otherwise have been guided. Although FGE at B2 has decreased since the addition of the corner collector, FPE at B2 has increased and project FPE has remained about the same when spill levels are adequate. Our results indicate that although the intake screen guidance systems at Bonneville Dam have poor guidance efficiency, project FPE of nearly 80% can be attained for subyearling Chinook salmon under sufficient spill levels in conjunction with the operation of the B2 corner collector. Additionally, by strategically optimizing discharge patterns at the project, non-turbine passage of subyearling Chinook salmon can be increased.

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 so great (between 10% and 21%) for the sluiceway and guidance screens at B2 (and therefore FPE at both powerhouses). The smaller sample sizes utilized by radio telemetry may have contributed to these differences. However, standard errors for radio telemetry estimates were less than 1% except for estimates for B1 (6%) where sample size was low. Equally plausible is the possibility that because hydroacoustics sampled the run-at-large, passage estimates were based on a mixture of species with different passage behavior than subyearling Chinook salmon.

Table 36.—Passage performance metrics for subyearling Chinook salmon at Bonneville Dam during summer study periods of 2000, 2001, 2002, 2004, and 2005. B1 = first powerhouse and B2 = second powerhouse.

Passage Metric	*2000*	*2001*	*2002*	*2004*	*2005*
Spillway efficiency	*65%*	*2%*	*58%*	*35%*	*51%*
Spillway effectiveness	*1.2*	*0.8*	*1.3*	*0.9*	*1.0*
FGE_{B1} [a]	*29%*	*57%*	*43%*	-----	-----
FGE_{B2}	*25%*	*35%*	*47%*	*22%*	*24%*
FPE	*91%*	*40%*	*82%*	*68%*	*78%*
FPE_{B1}	*77%*	*89%*	*72%*	*52%*	*70%*
FPE_{B2}	*25%*	*35%*	*47%*	*50%*	*55%*
Sluiceway efficiency$_{B1}$	*68%*	*70%*	*48%*	*47%*	*59%*
Sluiceway effectiveness$_{B1}$ [b]	-----	-----	*28.0*	*3.7*	*2.8*
Corner collector efficiency$_{B2}$	-----	-----	-----	*37%*	*40%*
Corner collector effectiveness $_{B2}$	-----	-----	-----	*5.6*	*5.9*
Corner collector efficiency$_{Project}$	-----	-----	-----	*22%*	*19%*
Corner collector effectiveness $_{Project}$	-----	-----	-----	*5.9*	*6.4*

[a] In 2004 and 2005 , FGE_{B1} could not be estimated due to the absence of guidance screens.

[b] In 2000 and 2001, sluiceway effectiveness could not be estimated due to the absence of sluiceway discharge data.

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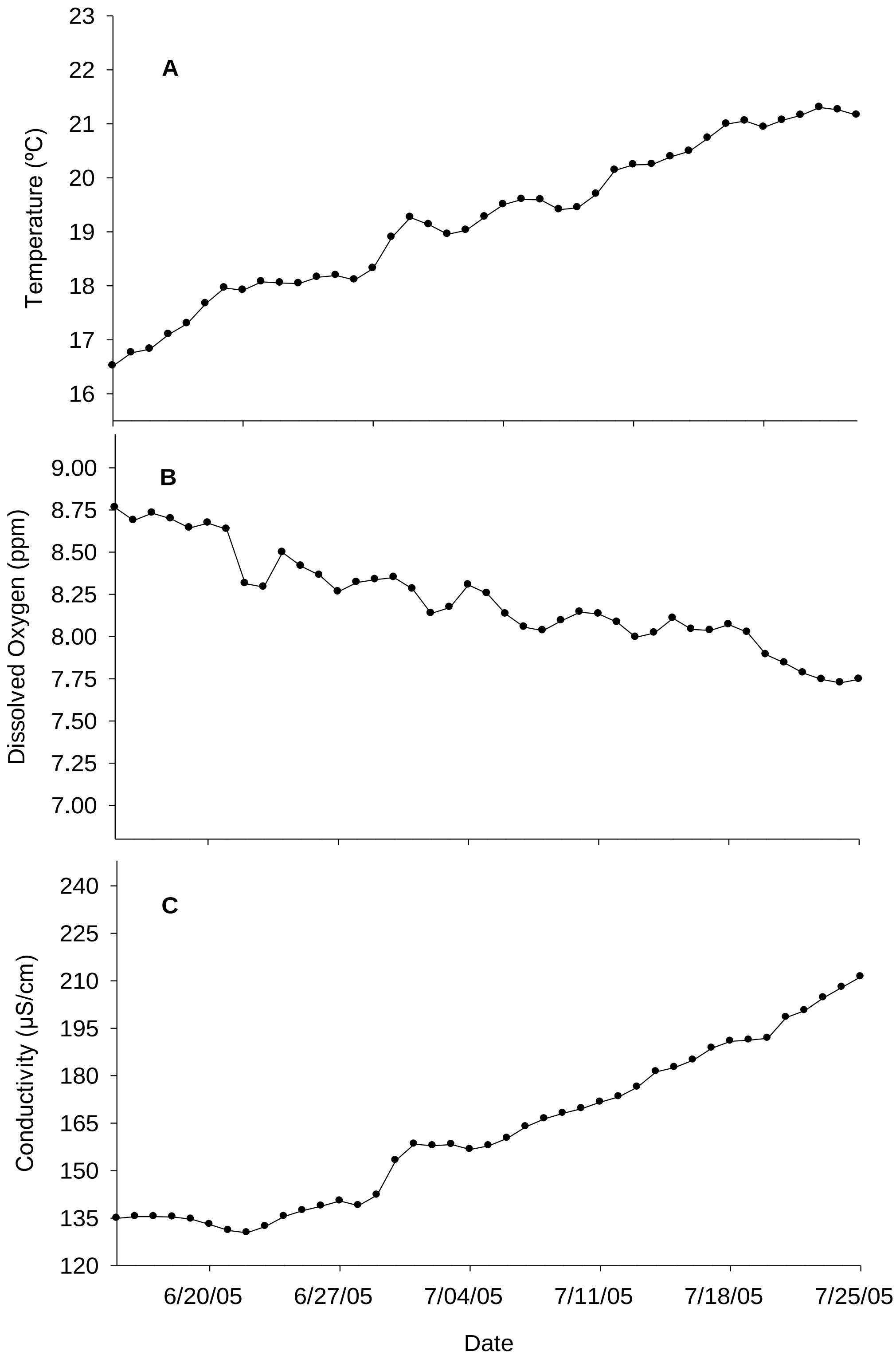
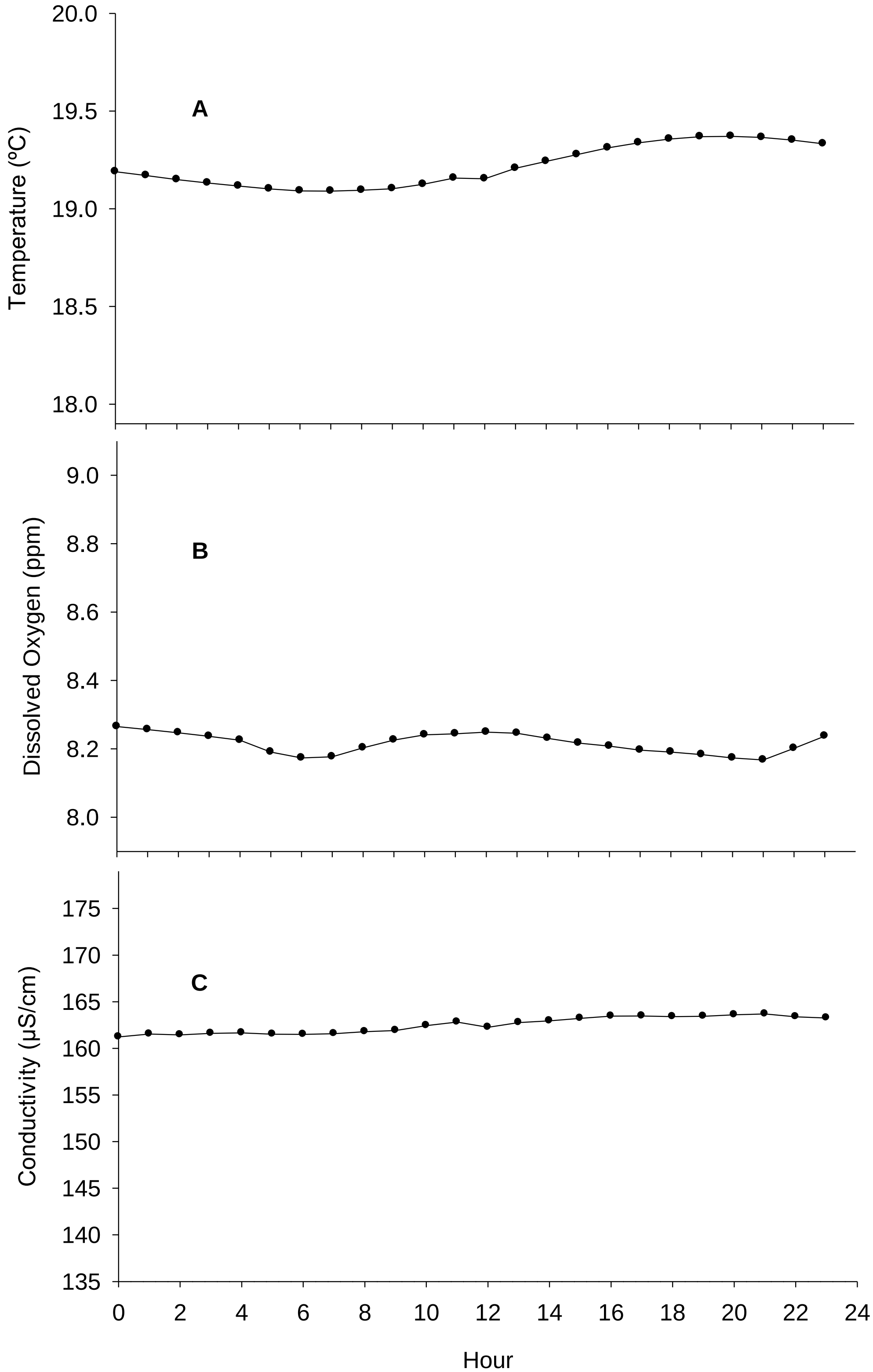
2-6.0 Appendices



Appendix 11.—Mean daily temperature (A), Dissolved oxygen (B), and conductivity (C) at Bonneville Dam 1.5 m below water surface in the forebay of the spillway from 15 June to 25 July, 2005.



Appendix 12.—Mean hourly temperature (A), Dissolved oxygen (B), and conductivity (C) at Bonneville Dam 1.5 m below water surface in the forebay of the spillway from 15 June to 25 July, 2005.

Appendix 13.—Mean weight and fork length, and their associated standard deviations (SD), for subyearling Chinook salmon released from The Dalles Dam (TDA) and John Day Dam (JDA), summer 2005.

Release	Release		Weight			Forklength	
Date	Time	Dam	N	Mean (g)	SD	Mean (mm)	SD
6/15/2005	8:00	JDA	31	14.0	3.4	110	7.7
6/15/2005	20:00	JDA	30	13.5	2.0	110	5.0
6/16/2005	0:00	TDA	39	14.2	2.7	108	6.3
6/16/2005	1:00	TDA	60	14.1	3.4	109	7.4
6/16/2005	8:00	JDA	31	16.1	3.2	112	5.3
6/16/2005	14:00	TDA	40	14.1	2.4	108	5.5
6/16/2005	20:00	JDA	31	16.3	3.9	115	7.3
6/16/2005	23:00	TDA	19	15.6	2.7	111	6.3
6/17/2005	0:00	TDA	21	14.6	2.1	112	4.9
6/17/2005	6:00	TDA	23	15.9	4.4	113	8.8
6/17/2005	7:00	TDA	38	15.0	3.1	111	7.4
6/17/2005	8:00	JDA	27	17.2	3.0	114	6.0
6/17/2005	13:00	TDA	41	15.2	2.9	112	7.0
6/17/2005	20:00	JDA	30	13.2	2.2	108	5.3
6/18/2005	0:00	TDA	41	15.2	2.5	112	5.8
6/18/2005	8:00	JDA	32	13.8	2.9	108	7.0
6/18/2005	14:00	TDA	40	15.7	3.5	111	6.7
6/18/2005	19:00	TDA	62	13.6	2.0	108	5.7
6/18/2005	20:00	JDA	29	14.6	3.3	111	7.3
6/19/2005	0:00	TDA	41	14.2	2.9	109	6.4
6/19/2005	8:00	JDA	29	14.2	3.2	108	7.7
6/19/2005	13:00	TDA	61	14.9	4.0	111	7.3
6/19/2005	14:00	TDA	41	15.3	3.0	113	6.5
6/19/2005	20:00	JDA	32	13.8	1.9	111	4.8
6/20/2005	0:00	TDA	39	15.0	2.8	111	6.0
6/20/2005	6:00	TDA	12	14.2	1.9	115	14.1
6/20/2005	7:00	JDA	30	14.2	1.5	111	3.7
6/20/2005	7:00	TDA	49	14.5	2.4	109	4.9
6/20/2005	13:00	TDA	41	14.9	2.7	111	5.2
6/20/2005	20:00	JDA	31	14.2	2.6	112	5.1
6/20/2005	23:00	TDA	41	13.5	1.8	108	4.6
6/21/2005	8:00	JDA	33	13.4	2.4	110	5.9
6/21/2005	13:00	TDA	41	14.2	2.2	108	5.0
6/21/2005	18:00	TDA	4	12.2	0.5	105	1.3
6/21/2005	19:00	TDA	54	12.1	1.3	104	3.5
6/21/2005	20:00	JDA	29	12.3	1.5	107	3.4
6/21/2005	23:00	TDA	20	12.9	1.2	107	3.6
6/22/2005	0:00	TDA	25	12.7	2.8	106	6.7
6/22/2005	1:00	TDA	53	13.2	2.4	107	5.7
6/22/2005	8:00	JDA	31	12.7	1.6	108	4.5
6/22/2005	14:00	TDA	40	12.2	1.3	107	3.7
6/22/2005	20:00	JDA	28	13.2	1.8	109	5.0
6/23/2005	0:00	TDA	40	14.0	3.0	109	6.1
6/23/2005	8:00	JDA	30	13.5	2.1	110	4.5
6/23/2005	13:00	TDA	62	12.5	1.5	107	4.4
6/23/2005	14:00	TDA	41	13.0	2.4	108	5.8
6/23/2005	20:00	JDA	31	13.0	3.3	107	7.9

Appendix 13 (continued).—Mean weight and forklength, and their associated standard deviations (SD), for subyearling Chinook salmon released from The Dalles Dam (TDA) and John Day Dam (JDA), summer 2005.

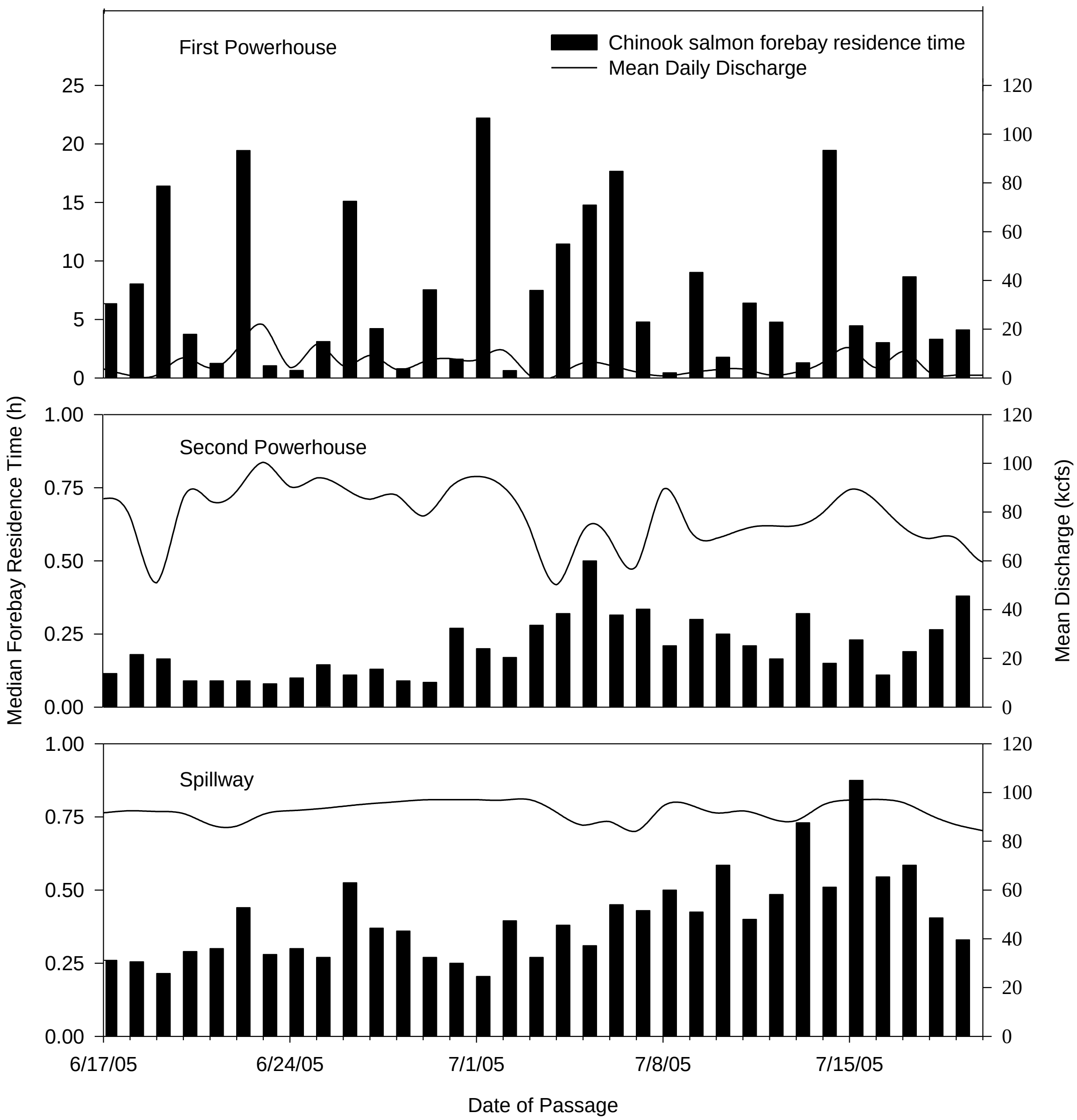
Release	Release		Weight			Forklength	
Date	Time	Dam	N	Mean (g)	SD	Mean (mm)	SD
6/24/2005	0:00	TDA	40	13.2	1.9	108	5.2
6/24/2005	7:00	TDA	62	12.7	2.5	106	5.2
6/24/2005	8:00	JDA	33	11.8	1.8	106	4.4
6/24/2005	14:00	TDA	40	12.8	2.6	107	6.6
6/24/2005	20:00	JDA	31	12.5	2.4	107	4.6
6/25/2005	0:00	TDA	38	14.2	3.3	107	7.1
6/25/2005	8:00	JDA	32	12.1	1.7	107	4.1
6/25/2005	14:00	TDA	41	14.8	3.5	110	7.1
6/25/2005	19:00	TDA	60	12.9	2.8	106	6.3
6/25/2005	20:00	JDA	33	11.5	0.8	105	2.3
6/26/2005	0:00	TDA	40	13.3	2.9	107	6.5
6/26/2005	7:00	JDA	30	12.4	1.3	107	3.2
6/26/2005	13:00	TDA	62	14.0	2.1	108	3.9
6/26/2005	14:00	TDA	39	14.2	2.7	107	4.7
6/26/2005	20:00	JDA	30	12.9	1.2	107	2.8
6/27/2005	0:00	TDA	72	13.5	4.0	108	8.1
6/27/2005	1:00	TDA	31	13.1	2.0	107	4.3
6/27/2005	8:00	JDA	31	13.4	2.3	110	5.8
6/27/2005	13:00	TDA	20	13.0	1.6	108	4.4
6/27/2005	14:00	TDA	21	15.3	2.1	108	4.9
6/27/2005	20:00	JDA	29	13.5	3.2	108	8.5
6/28/2005	0:00	TDA	29	12.4	2.8	105	5.2
6/28/2005	7:00	TDA	61	12.1	1.8	103	4.6
6/28/2005	8:00	JDA	27	11.5	1.4	105	3.7
6/28/2005	14:00	TDA	41	12.0	1.9	103	5.0
6/28/2005	20:00	JDA	33	12.9	2.9	107	6.7
6/28/2005	23:00	TDA	20	13.0	3.8	108	7.7
6/29/2005	0:00	TDA	20	13.7	2.6	108	6.1
6/29/2005	8:00	JDA	31	14.2	4.3	110	9.2
6/29/2005	13:00	TDA	20	13.0	2.2	107	5.3
6/29/2005	14:00	TDA	20	12.9	1.8	106	4.8
6/29/2005	18:00	TDA	31	13.8	3.9	107	8.3
6/29/2005	19:00	TDA	31	12.3	1.5	105	3.4
6/29/2005	20:00	JDA	29	12.6	2.0	108	5.6
6/30/2005	0:00	TDA	41	12.1	1.5	104	3.7
6/30/2005	8:00	JDA	30	12.8	2.5	108	5.0
6/30/2005	12:00	TDA	31	13.7	4.5	109	9.2
6/30/2005	13:00	TDA	30	12.0	1.8	106	5.3
6/30/2005	14:00	TDA	40	12.4	2.2	107	5.0
6/30/2005	20:00	JDA	32	14.5	3.7	110	7.8
6/30/2005	23:00	TDA	40	15.1	3.4	109	6.1
7/1/2005	0:00	TDA	30	16.7	4.6	111	7.6
7/1/2005	1:00	TDA	31	15.7	3.5	109	6.1
7/1/2005	7:00	JDA	31	13.8	2.3	110	5.4
7/1/2005	14:00	TDA	40	13.4	3.4	106	7.1
7/1/2005	20:00	JDA	31	13.0	2.6	108	6.1
7/2/2005	0:00	TDA	40	13.8	3.3	106	6.8

Appendix 13 (continued).—Mean weight and forklength, and their associated standard deviations (SD), for subyearling Chinook salmon released from The Dalles Dam (TDA) and John Day Dam (JDA), summer 2005.

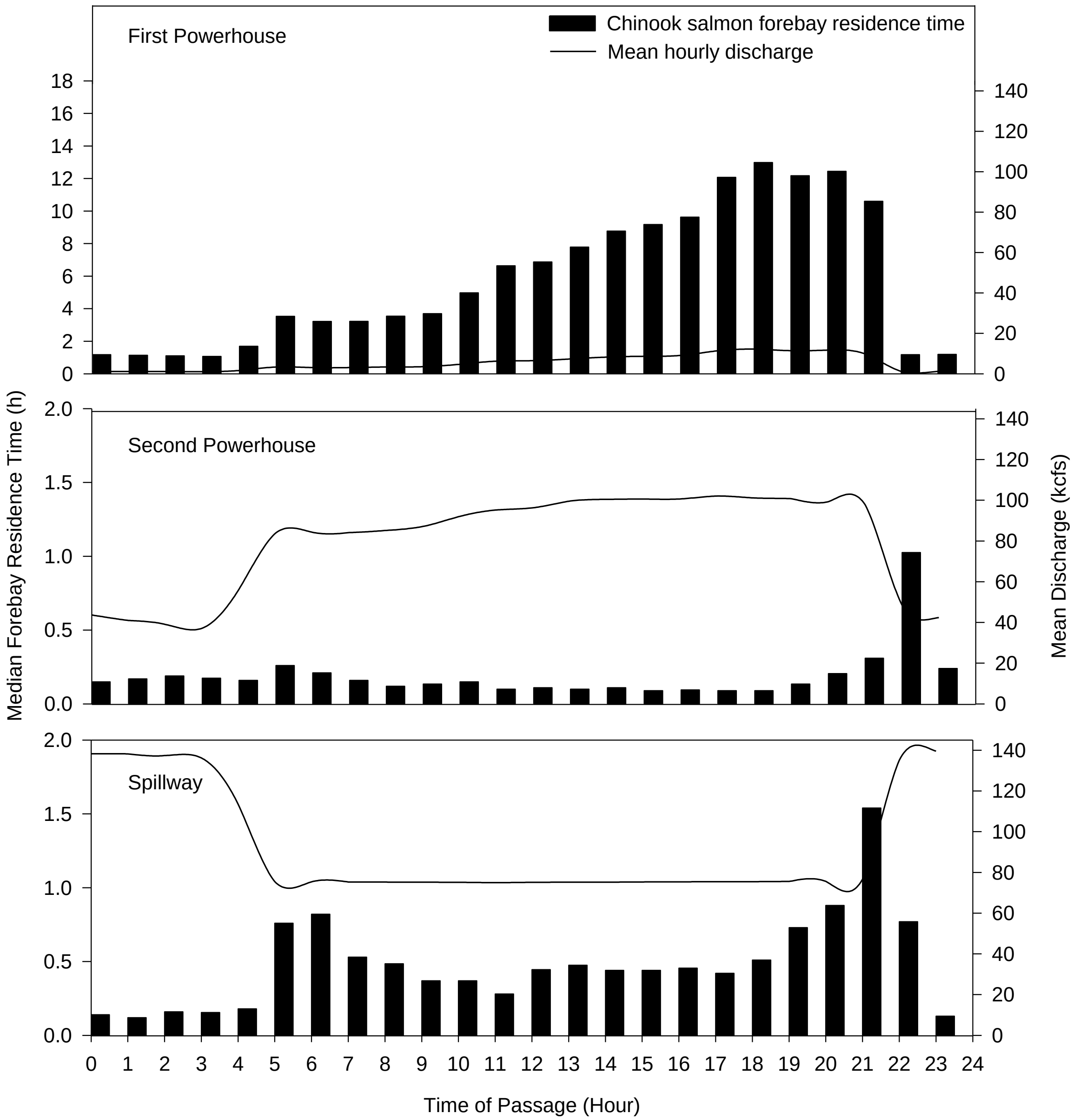
Release	Release		Weight			Forklength	
Date	Time	Dam	N	Mean (g)	SD	Mean (mm)	SD
7/2/2005	7:00	JDA	32	13.8	3.2	109	7.2
7/2/2005	7:00	TDA	62	13.7	3.3	109	6.7
7/2/2005	13:00	TDA	19	15.8	5.3	114	9.8
7/2/2005	14:00	TDA	22	12.8	2.2	106	5.6
7/2/2005	19:00	JDA	33	15.4	3.3	113	6.5
7/3/2005	0:00	TDA	40	15.2	3.3	108	7.3
7/3/2005	8:00	JDA	30	13.7	2.5	109	5.9
7/3/2005	12:00	TDA	29	15.8	4.1	111	8.5
7/3/2005	13:00	TDA	31	15.4	4.0	111	7.1
7/3/2005	14:00	TDA	41	15.2	2.8	109	6.9
7/3/2005	20:00	JDA	31	15.3	3.9	110	8.4
7/4/2005	0:00	TDA	40	13.1	2.1	106	5.5
7/4/2005	8:00	JDA	31	14.0	4.4	110	8.4
7/4/2005	13:00	TDA	40	13.9	4.0	106	8.0
7/4/2005	19:00	JDA	31	15.9	5.7	114	11.5
7/4/2005	19:00	TDA	61	14.3	3.8	109	8.1
7/4/2005	23:00	TDA	21	14.9	5.0	110	10.5
7/5/2005	0:00	TDA	19	15.2	2.7	110	6.6
7/5/2005	1:00	TDA	61	14.5	3.9	108	9.0
7/5/2005	8:00	JDA	30	15.5	3.9	113	8.3
7/5/2005	14:00	TDA	40	15.8	4.1	112	8.8
7/5/2005	20:00	JDA	31	14.2	2.5	110	6.3
7/5/2005	23:00	TDA	20	14.4	3.8	107	8.6
7/6/2005	0:00	TDA	20	15.0	3.4	110	7.1
7/6/2005	8:00	JDA	32	13.6	2.5	108	6.5
7/6/2005	12:00	TDA	31	16.0	4.1	112	9.0
7/6/2005	13:00	TDA	31	13.9	2.7	107	6.5
7/6/2005	14:00	TDA	41	14.7	2.2	110	6.2
7/6/2005	20:00	JDA	31	14.4	2.6	110	6.8
7/6/2005	23:00	TDA	41	15.0	3.0	107	6.5
7/7/2005	7:00	TDA	61	14.3	4.3	108	8.9
7/7/2005	8:00	JDA	28	13.4	2.1	108	4.8
7/7/2005	14:00	TDA	40	14.9	4.0	110	8.5
7/7/2005	20:00	JDA	31	13.1	2.2	107	5.7
7/7/2005	23:00	TDA	21	15.6	3.1	108	8.1
7/8/2005	0:00	TDA	24	15.5	4.0	109	9.0
7/8/2005	1:00	TDA	58	14.2	2.7	106	6.7
7/8/2005	7:00	JDA	31	13.2	3.9	107	7.9
7/8/2005	14:00	TDA	41	13.2	3.9	105	8.6
7/8/2005	19:00	JDA	31	13.0	2.5	108	5.5
7/9/2005	0:00	TDA	39	13.0	2.7	104	6.5
7/9/2005	8:00	JDA	30	13.2	2.3	105	5.9
7/9/2005	13:00	TDA	40	14.7	4.0	107	9.2
7/9/2005	18:00	TDA	31	12.7	2.1	105	5.8
7/9/2005	19:00	JDA	31	12.3	2.3	105	5.7
7/9/2005	19:00	TDA	31	13.7	3.0	107	7.9
7/9/2005	23:00	TDA	21	12.6	2.1	106	5.8

Appendix 13 (continued).—Mean weight and forklength, and their associated standard deviations (SD), for subyearling Chinook salmon released from The Dalles Dam (TDA) and John Day Dam (JDA), summer 2005.

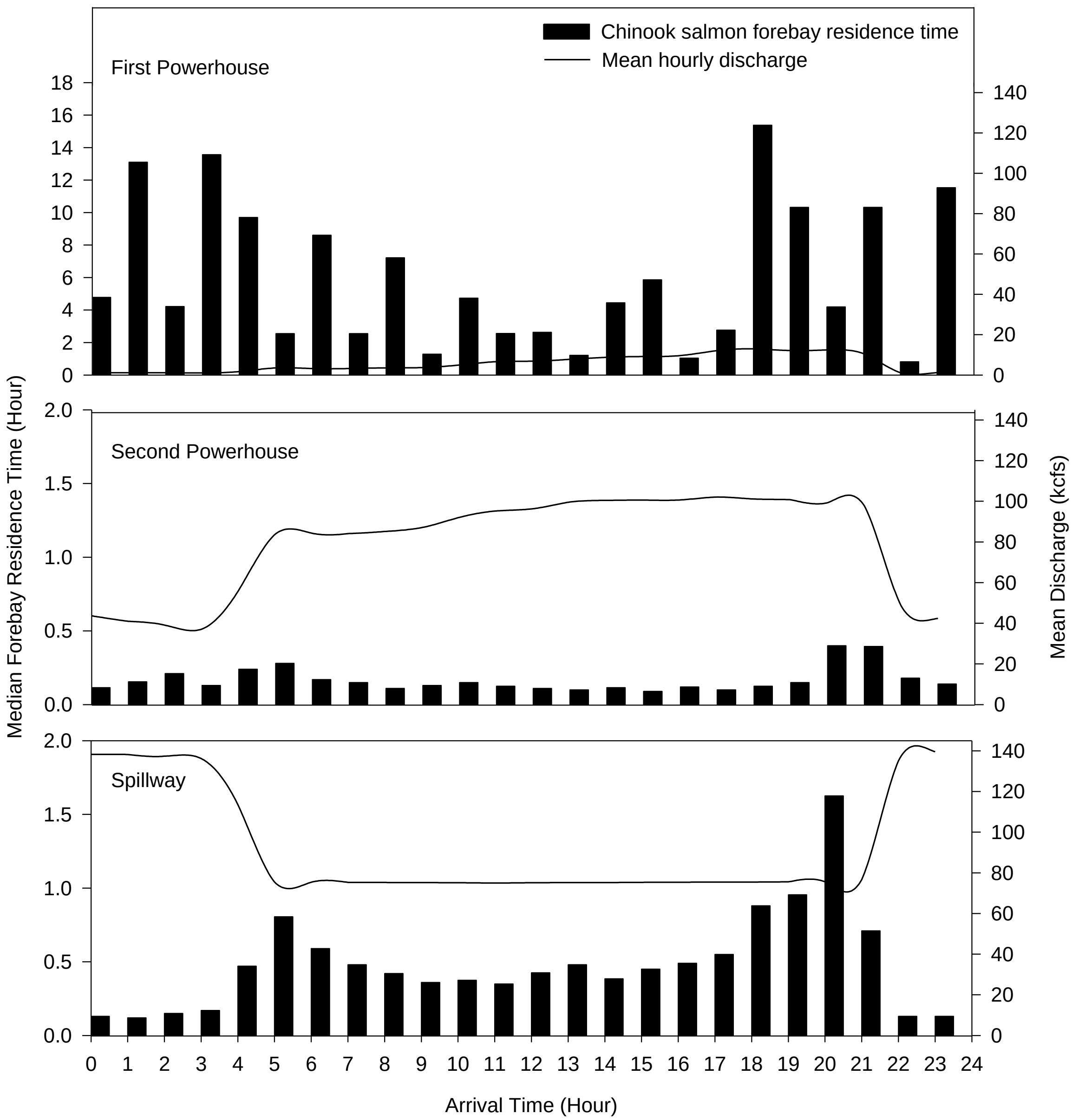
Release	Release		Weight			Forklength	
Date	Time	Dam	N	Mean (g)	SD	Mean (mm)	SD
7/10/2005	0:00	TDA	37	12.8	2.7	104	6.1
7/10/2005	1:00	TDA	42	12.4	1.7	104	4.9
7/10/2005	8:00	JDA	32	15.4	3.0	108	7.0
7/10/2005	14:00	TDA	41	13.7	3.6	106	8.9
7/10/2005	20:00	JDA	31	12.6	2.7	105	6.9
7/11/2005	0:00	TDA	39	13.5	2.1	105	5.9
7/11/2005	7:00	TDA	59	14.7	4.2	106	8.4
7/11/2005	8:00	JDA	31	14.2	5.5	108	11.4
7/11/2005	13:00	TDA	21	15.3	4.8	111	9.9
7/11/2005	14:00	TDA	20	15.1	2.6	106	5.3
7/11/2005	20:00	JDA	30	14.2	3.4	108	8.9
7/11/2005	23:00	TDA	21	14.1	3.2	109	8.7
7/12/2005	0:00	TDA	19	14.7	4.8	107	11.2
7/12/2005	8:00	JDA	31	13.2	3.3	106	7.9
7/12/2005	12:00	TDA	31	12.4	1.5	102	3.9
7/12/2005	13:00	TDA	29	12.6	2.4	103	5.0
7/12/2005	14:00	TDA	39	13.2	2.6	105	6.4
7/12/2005	20:00	JDA	31	13.3	2.8	108	7.3
7/13/2005	0:00	TDA	39	13.9	4.6	106	10.8
7/13/2005	7:00	JDA	30	13.1	3.2	107	8.3
7/13/2005	14:00	TDA	41	14.3	5.5	106	10.8
7/13/2005	18:00	TDA	30	14.4	3.4	108	8.0
7/13/2005	19:00	TDA	31	15.0	5.8	109	12.2
7/13/2005	20:00	JDA	31	14.8	5.4	109	11.1
7/13/2005	23:00	TDA	40	14.9	5.0	108	10.6
7/14/2005	6:00	TDA	29	13.9	4.3	107	10.3
7/14/2005	7:00	TDA	32	12.4	2.0	103	5.4
7/14/2005	8:00	JDA	31	14.1	3.9	109	8.8
7/14/2005	13:00	TDA	41	13.7	3.6	107	8.5
7/14/2005	20:00	JDA	31	15.8	2.7	109	7.0
7/15/2005	0:00	TDA	40	13.9	2.3	106	7.0
7/15/2005	8:00	JDA	30	14.6	3.7	109	9.0
7/15/2005	13:00	TDA	42	14.3	3.2	109	8.2
7/15/2005	19:00	JDA	19	14.9	3.2	112	8.0
7/15/2005	19:00	TDA	63	15.9	4.8	110	10.0
7/15/2005	20:00	JDA	12	14.9	2.5	112	6.9
7/15/2005	23:00	TDA	20	13.6	2.8	109	7.2
7/16/2005	0:00	TDA	20	16.8	3.3	109	6.9
7/16/2005	1:00	TDA	63	14.9	3.6	108	8.7
7/16/2005	8:00	JDA	28	14.1	4.7	109	11.3
7/16/2005	13:00	TDA	21	15.1	3.6	113	8.8
7/16/2005	14:00	TDA	21	14.5	3.8	107	9.5
7/16/2005	20:00	JDA	29	15.6	2.7	109	7.8
7/17/2005	0:00	TDA	45	14.1	3.5	107	8.8
7/17/2005	12:00	TDA	30	13.7	3.2	107	8.8
7/17/2005	13:00	TDA	33	12.8	3.0	103	7.7
7/17/2005	14:00	TDA	49	12.8	3.0	104	6.7



Appendix 14.—Median forebay residence time by day of passage versus mean discharge by dam area for subyearling Chinook salmon at Bonneville Dam, summer 2005. Note the scale of y-axis for first powerhouse graph differs from graphs for second powerhouse and spillway for visual clarity of residence time data.



Appendix 15.—Median forebay residence time by hour of passage versus mean discharge by dam area for subyearling Chinook salmon at Bonneville Dam, summer 2005. Note the scale of y-axis for first powerhouse graph differs from graphs for second powerhouse and spillway for visual clarity of residence time data.



Appendix 16.—Median forebay residence time by hour of arrival versus mean discharge by dam area for subyearling Chinook salmon at Bonneville Dam, summer 2005. Note the scale of y-axis for first powerhouse graph differs from graphs for second powerhouse and spillway for visual clarity of residence time data.