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ADULT SALMON AND STEELHEAD PASSAGE THROUGH FISHWAYS AND TRANSITION POOLS AT BONNEVILLE DAM, 1997-2002

Report for project MPE-P-95-1

M.L. Keefer, D.C. Joosten, C.L. Williams, C.M. Nauman, M.A. Jepson,
C.A. Peery, T.C. Bjornn, R.R. Ringe, K.R. Tolotti, and S.R. Lee
U.S. Geological Survey, Idaho Cooperative Fish and Wildlife Research Unit
University of Idaho, Moscow, Idaho 83844-1141

and

L.C. Stuehrenberg, M.M. Moser, and B.J. Burke
National Marine Fisheries Service
2725 Montlake Blvd. East, Seattle, Washington 98112

for
U. S. Army Corps of Engineers
Portland and Walla Walla Districts

and
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Preface

Studies of adult salmon and steelhead *Oncorhynchus* spp. migrations past dams, through reservoirs, and into tributaries began in 1990 with planning, purchase, and installation of radio telemetry equipment for studies at the Snake River dams. The focus of adult salmonid passage studies shifted to include the lower Columbia River dams in 1996, when spring–summer Chinook salmon and steelhead were tagged (see Bjornn et al. 2000a, b; Keefer et al. 2003a, and Stuehrenberg et al. 2005 for summary reports of the 1996 migrations). Subsequently, spring–summer Chinook salmon, steelhead and/or sockeye salmon were outfitted with transmitters at Bonneville Dam in 1997, 1998, 2000, 2001 and 2002. In this report we present information on the use of fishway entrances and movements of adult salmon and steelhead through fishways and transition pools and past Bonneville Dam during these migration years.

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Executive Summary

Evaluation of fishway entrance use and passage through fishways by spring–summer Chinook salmon *Oncorhynchus tshawytscha*, steelhead *O. mykiss*, and sockeye salmon *O. nerka* at Bonneville Dam were objectives of the adult salmon and steelhead passage project in 1997, 1998, 2000, 2001, and 2002. Critical parameters studied were times for a fish to first approach and first enter a fishway, total time to pass over the dam, which openings were approached, where fish entered and exited fishways, and fish passage through transition pools and over the dam. We report here on study results from five years of spring–summer Chinook salmon data, four years of steelhead data, and one year of sockeye salmon data.

Passage times for spring Chinook salmon were consistently longer than for summer Chinook salmon and steelhead. Sockeye salmon passed most rapidly. After entering the tailrace, median times to first approach a fishway entrance were 2.3 to 9.6 h for spring–summer Chinook, 2.5 to 3.3 h for steelhead, and 2.2 h for sockeye salmon. Median times from tailrace entry to first fishway entry were 9.6 to 1.75 h for spring-summer Chinook, 5.1 to 7.9 h for steelhead, and 3.0 h for sockeye salmon. Total times to pass Bonneville Dam (tailrace entry to first exit from the top of a ladder) were 23.8 to 41.1 h for spring–summer Chinook, 17.4 to 24.2 h for steelhead, and 15.0 h for sockeye salmon. Fish from all species ascended ladders rapidly.

Median passage times for all segments decreased for spring–summer Chinook salmon as migrations progressed. Time of day was also influential, with longer passage times for fish that entered a passage segment later in the day. Powerhouse II priority in later years appeared to slow total passage times for Chinook salmon and steelhead. By comparison to the above factors, flow and spill levels had relatively limited influence on most passage time calculations compared to behaviors in the fishways and transition pools.

Chinook salmon approached monitored fishway entrances more often (*median* = 7 to 15 times, *mean* = 11 to 24 times) than steelhead (*median* = 6 to 9 times, *mean* = 13 to 17 times) or sockeye salmon (*median* = 7 times, *mean* = 12 times). Fish from all species approached all fishway entrances. Fish from all runs favored the larger shoreline entrances. Total spill volume affected the distribution of approaches, but considerably less so than powerhouse priority. Movements between fishways was extensive for all species in all years.

Fish from all runs entered fishways a median of 1 to 2 times (*mean* = 2 to 4 times). Fish from all runs entered all fishway entrances, again favoring shoreline entrances for first entries. Sockeye salmon were somewhat more likely than the other runs to use Powerhouse I entrances. Chinook salmon were more likely to use the spillway entrances. As with fishway approaches, the distributions of fishway entrances was related to powerhouse priority, with fish attracted to the side of the river with greater discharge.

In all years, 36 to 63% of Chinook salmon, 43 to 64% of steelhead, and 62% of sockeye salmon exited a fishway into the tailrace at least once. Fish from all runs were more likely to exit from openings at Powerhouse II than at other fishways. The proportion of Chinook salmon that exited increased as migrations progressed each year while exit rates for steelhead were more variable.

Fish that exited fishways had significantly longer dam passage times than those that did not exit. An exit typically resulted in considerable dam passage delays for all species during all parts of the migrations. Based on monthly median passage times, minimum delays associated with fishway exit were 3 to 13 h for spring–summer Chinook salmon and steelhead; maximum

delays were 15 to 45 h for Chinook salmon and 7 to 38 h for steelhead. Exiting a fishway added 10 to 15 h to the total passage time of sockeye salmon. Many fish exited fishways after entering transition pools, while very few fish exited fishways after migrating up ladders.

Most fish of all species entered transition pools quickly after entering fishways. After transition pool entry, however, behaviors were quite variable and this section of the fishway appeared to create the most confusion for adults. Fish behavior in transition pools were apportioned into four categories: fish that moved straight through with no downstream movement, fish that delayed (moved downstream) in a pool but did not exit, fish that exited the pools into collection channels but not the tailrace, and fish that exited a pool into the tailrace. Transition pool behaviors were quite consistent across species. From 12 to 27% of each run moved straight through pools, 25 to 45% delayed briefly in pools before passing, 6 to 14% exited pools into collection channels, and the rest (25 to 49%) exited pools into the tailrace. Generally, fish were more likely to exit the Washington-shore transition pool than other pools.

Passage times from first transition pool record to exit a pool into a ladder were significantly different for the four groups for most species–years. Median pool passage times (all species) were rapid (most < 1.0 h) for fish that had any of the first three behaviors. Those that exited to the tailrace had much longer passage times for this segment (medians ranged from ~ 5 h to > 24 h) for fish that exited from each pool. Fish of all species that exited either transition pool to the tailrace had significantly longer median dam passage times (tailrace to exit from top of ladder) than fish that did not exit a pool in most months of most years.

Multivariate analyses identified several factors that influenced transition pool exit. Fish that first entered the Washington-shore pool were more likely to exit, exit rates were higher in years with higher tailwater elevation, exit rates increased with water temperature (particularly for spring–summer Chinook salmon), and fish that entered a pool late in the day were more likely to exit to the tailrace.

Multivariate analyses of total dam passage time (tailrace entry to top of ladder) indicated that an exit from a fishway and water temperature were the most influential predictors. Times were consistently longest for fish that exited fishways, while passage times decreased as water temperatures rose within each year, especially for spring–summer Chinook salmon. Exit from a transition pool was also influential, though this variable was strongly correlated with fishway exit. Steelhead passed more slowly when spill was high. Analyses of the shorter passage segment from first fishway entry to exit from the top of a ladder indicated that fishway exit and time of day were most influential. Passage through the tailrace was most influenced by water temperature, with slow passage during cool periods and again at the highest temperatures. Time of tailrace entry was also influential. For both Chinook salmon, use of the Washington-shore fishway and transition pool contributed to longer passage times, and this led to longer passage times in years with Powerhouse II priority.

In each year, 1 to 2% of Chinook and sockeye salmon and 2 to 3% of steelhead recorded at Bonneville Dam did not pass. Most of these fish were only recorded in the tailrace, though some were recorded inside fishways and transition pools. The majority had unknown fates (were unaccounted for) downstream from the dam, and a portion of these were almost certainly mortalities from pinnipeds or other factors. Some fish likely regurgitated transmitters, and small numbers were reported harvested or were recorded in downstream tributaries or hatcheries.

Introduction

An important aspect of the adult salmon and steelhead *Oncorhynchus* spp. passage project has been to describe how fish moved past dams in the lower Columbia and Snake rivers. Monitoring of fishway entrance use and movements within fishways by adult salmon and steelhead at lower Snake River dams began in the early 1990s and continued through 1994. With receivers and antennas placed near entrances to fishways, within fishways, and at the tops of ladders, we could monitor movements of individual fish outfitted with transmitters as they approached entrances to fishways, determine openings used by fish to enter and exit fishways, document their movements within fishways, and assess the time fish required to pass the dams. Detailed information on fishway use and passage for Chinook salmon in years prior to 1996 was reported in Bjornn et al. (1994, 1995) and in Part III of Bjornn et al. (1998a).

Research objectives were expanded in 1996 to include lower Columbia River dams. Fishway use behaviors and basic passage time metrics for spring–summer Chinook salmon at Bonneville, McNary, Ice Harbor and Lower Granite dams in 1996 were reported in Keefer et al. (2003a). Multi-year and multi-species assessments were also made for The Dalles and John Day dams (Keefer et al. 2007, 2008), and summaries for fall Chinook salmon were reported for the four lower Columbia River dams by Burke et al. (2005). Adult passage behaviors at John Day Dam were further compared to passage at The Dalles Dam for the 1997 and 1998 migration years, with particular emphasis on how fishway water temperatures affected behavior (Keefer et al. 2003b). Steelhead response to fall spill at John Day Dam was evaluated in 1997 (Bjornn et al. 1999a) and the effects of closing orifice gates at Priest Rapids Dam was reported by Peery et al. (1998). In addition, basic dam passage times (from tailrace to top-of-ladder sites) were summarized for all lower Columbia and lower Snake River dams for all studied species in Keefer et al. (2004a).

From 1997 to 2002, adult passage study objectives for Bonneville Dam included assessments of a variety of fish behaviors and passage times. In this report, we present details of fishway entrance use, document fish movements in fishways, transition pools, and ladders, and detail passage times for fish to enter fishways, pass through various fishway segments, and eventually pass Bonneville Dam. Entrances approached and used to enter fishways and entrances and fishways used to pass the dam were also studied, as was delay associated with transition pool behavior and fish responses to Powerhouse priority and spill patterns. Adult fish behaviors and passage metrics are reported for ten migration-years, including for spring–summer Chinook salmon (1997, 1998, 2000, 2001, 2002), steelhead (1997, 2000, 2001, 2002) and sockeye salmon (1997).

While this report addresses many of the adult passage concerns at Bonneville Dam, it is by no means comprehensive. For example, a rigorous evaluation of the effects of the Bonneville spill tests on adult passage are included in Caudill et al. (*Draft report*), and relationships between Bonneville Dam passage times, river environment, and overall adult migration success are reported in Caudill et al. (2007). Evaluations of passage behaviors near Bonneville count window and in vertical-slot weirs are reported in Jepson et al. (2004), adult behaviors in the Bonneville forebay are reported in Bjornn et al. (1999c) and Boggs et al. (2004b), and tailrace migration depths and behaviors in relation to dissolved gas are reported in Johnson et al. 2004). Adult fallback behaviors have been described in a number of publications (e.g., Bjornn et al. 2000a; Reischel and Bjornn 2003; Boggs et al. 2004a). The telemetry array has also been used to help evaluate fish energy use during passage of Bonneville Dam (Brown and Geist 2002) and to evaluate lamprey passage efficiency and behavior (Moser et al. 2002, 2005).

Methods

Salmon and steelhead used for the studies were collected and outfitted with radio transmitters at the adult fish facility at Bonneville Dam on the Columbia River (river kilometer 235.1). Fish with transmitters were monitored in the tailrace of Bonneville Dam using SRX receivers (Lotek Engineering, Newmarket Ontario) connected to nine-element Yagi antennas. SRX/DSP receivers connected to underwater coaxial cable antennas were installed near major fishway entrances, and inside fishways and transition pools, as well as at top-of-ladder exits. Tailrace receivers were used to determine when fish first entered the tailrace area of the dam. The SRX/DSP receivers were used to determine when a fish approached the dam at a fishway entrance, entered a fishway, moved within the fishway, and exited the fishway. A detailed description of tagging and monitoring methods used throughout the basin can be found in Bjornn et al. (2000a).

Dam Passage Times

An important aspect of adult salmon and steelhead behavior at John Day Dam was a breakdown of the time required to pass the dam. Analytical emphasis was placed on determining passage times from tailrace entry to first approach at a fishway entrance, from first approach to first recorded entry into a fishway, passage through transition pools, and total time to pass over the dam. Start times were either the times fish were first recorded at tailrace receivers (~2.8 km downstream), or the times of first approach or entry into a fishway entrance or transition pool. End times were when fish were recorded exiting from each passage segment. Only fish with telemetry records at both sites bracketing the passage areas were included in analyses.

All fishway entrances were monitored in 1997 and 1998, and all except the Powerhouse II floating orifice gates were monitored from 2000-2002. In the later years, therefore, we likely overestimated slightly the time some fish took to first approach or enter a fishway entrance, because some likely first approached or entered at unmonitored orifice gates. In all years, some adult salmon and steelhead with transmitters were recorded inside fishways before being recorded approaching an antenna outside the fishway. In these cases, the location of a fish's first approach at the dam was treated as unknown (most likely if a fish approached at an open orifice gate). However, if a fish's first record inside a fishway clearly indicated which entrance was used, the approach was attributed to that entrance and only the time was unknown (e.g., if the first record was inside the B-Branch fishway, the first approach was designated at the B-Branch ladder entrance, but the approach time was designated unknown). Similarly, the time or exact location of the first entry into fishways was unknown for some fish each year. Many unknown first entrances were likely via unmonitored orifice gates. To avoid bias, fish with unknown approach or entrance times were excluded from passage time analyses; they were included in fishway use summaries if the entrance location was known.

The numbers of radio-tagged fish with known times and locations for first tailrace record, first fishway approach, first fishway entry, first transition pool entry, transition pool exit into a ladder and exit from the tops of ladders are summarized in Table 1. Between 96.9 and 98.8% of all fish recorded at Bonneville Dam eventually passed the dam. Between 70 and 77% of Chinook salmon in all years, 56–78% of steelhead, and 61% of sockeye salmon had known times and locations at all passage points (Table 1). In general, slightly larger percentages of steelhead and sockeye salmon had unrecorded actions. In part this was because some steelhead and all sockeye salmon had smaller, lower-transmission 3-volt transmitters, which had lower detection

Table 1. Number of adult radio-tagged fish recorded at Bonneville Dam that passed the dam, that were recorded on their first passage of the tailrace, first approach at a fishway entrance, first fishway entry, first transition pool entry, last exit from a transition pool into a ladder, and exit from the top of a ladder. Also includes number and percentage of those that passed the dam with telemetry records at all passage points.

	Chinook salmon					Steelhead				SK[1]
	1997	1998	2000	2001	2002	1997	2000	2001	2002	1997
Recorded at dam	968	946	967	866	896	945	826	792	935	570
Known to pass dam	950	932	952	855	884	916	814	776	909	563
Percent known to pass dam	98.1%	98.5%	98.4%	98.7%	98.7%	96.9%	98.5%	98.0%	97.2%	98.8%
Recorded first tailrace passage	930	874	912	722	766	901	760	757	856	567
Recorded first fishway approach[2]	919	918	943	838	870	816	795	762	875	458
Recorded first fishway entrance[2]	768	819	792	752	757	654	712	630	736	368
Recorded first transition pool entry	953	917	943	845	868	884	796	751	880	524
Recorded transition pool exit	894	888	819	810	844	822	770	743	795	500
Recorded ladder exit	935	911	930	829	869	799	787	754	865	507
Recorded ladder exit or navlock exit	941	913	946	838	878	829	812	772	906	559
Recorded all passage points	688	718	668	615	624	510	636	571	603	341
Percent with all passage points[3]	72.4%	77.0%	70.2%	71.9%	70.6%	55.7%	78.1%	73.6%	66.3%	60.6%

[1] *Sockeye salmon*
[2] *Some fish likely approached or entered at unmonitored sites prior to being recorded*
[3] *Percent of all fish known to pass dam*

rates at some sites. In 2001, 85 (10%) spring–summer Chinook salmon had Channel 8 transmitters, which were not monitored at tailrace receivers; most Channel 8 fish were tagged in May and June.

Unless otherwise reported, passage time calculations (time to first approach, time to first entry, time to pass a dam, etc.) were summarized over the entire migration period for all flow and spill conditions and for all fish with known time and location records bracketing both ends of the migration segment. In most cases we present medians because of the tendency for passage time distributions to be right-skewed.

Fishway Use

With the antenna/receiver arrays at Bonneville Dam we were able to determine the movements of adult salmon and steelhead with transmitters in the tailrace, approaches at major entrances to fishways, entrances used to enter and exit the fishway, and the fishway used to pass the dam (Figure 1). Because fish could approach and enter fishways more than once, total approaches, entries, and exits made by fish were also summarized. Bonneville Dam has two fishways, serviced by four ladders. The Washington-shore (WA-shore) ladder passes fish that enter fishways associated with Powerhouse 2; the Cascades Island ladder collects fish from the north spillway entrance, and the ladder joins the WA-shore ladder near the ladder exit. The Bradford Island fishway collects fish that use the entrances associated with Powerhouse 1 (A-Branch ladder) as well as fish that enter at the south end of the spillway (B-branch ladder). Some fish also pass the dam via the navigation lock near the south shore (Figure 1).

The migration history of each fish at the dam was contained in thousands of telemetry records collected as fish passed antenna sites. A program, based on a decision tree, was used to aid in manual and automated coding of telemetry records at the dam. The program helped the person coding fish movements move through site records quickly and presented codes that could be accepted or rejected. Passage at the dams was the most complex and most intensively monitored part of the migration history of most fish. All data were coded once, checked, and then double-checked in the context of the entire migration of each fish.

Movement through Transition Pools

We also collected telemetry data as fish passed through transition pools (the area at the bottom of the fish ladders where weirs are inundated by the tailwater) during dam passage. Underwater antennas were installed in the downstream portion of each transition pool to record when tagged fish entered or exited the pools. One or more antennas were installed at the bottom of each ladder and in sequence up the ladder to record when fish passed through the transition pools and entered ladders. The sequences of antennas were set to accommodate fluctuating water elevations in the fishway and tailrace. Minor coverage differences existed between years, but should not have greatly biased interpretation.

We identified when fish first entered transition pools, how much time fish spent between their first and last records in a pool, whether or not fish passed directly into the ladder from a pool, when fish exited a pool and began to ascend a ladder, and when fish exited the top of a ladder.

Based upon earlier studies at other dams by Bjornn et al. (1998a; 1998b) and Keefer et al. (2003a), fish behavior in transition pools was categorized into four groups:

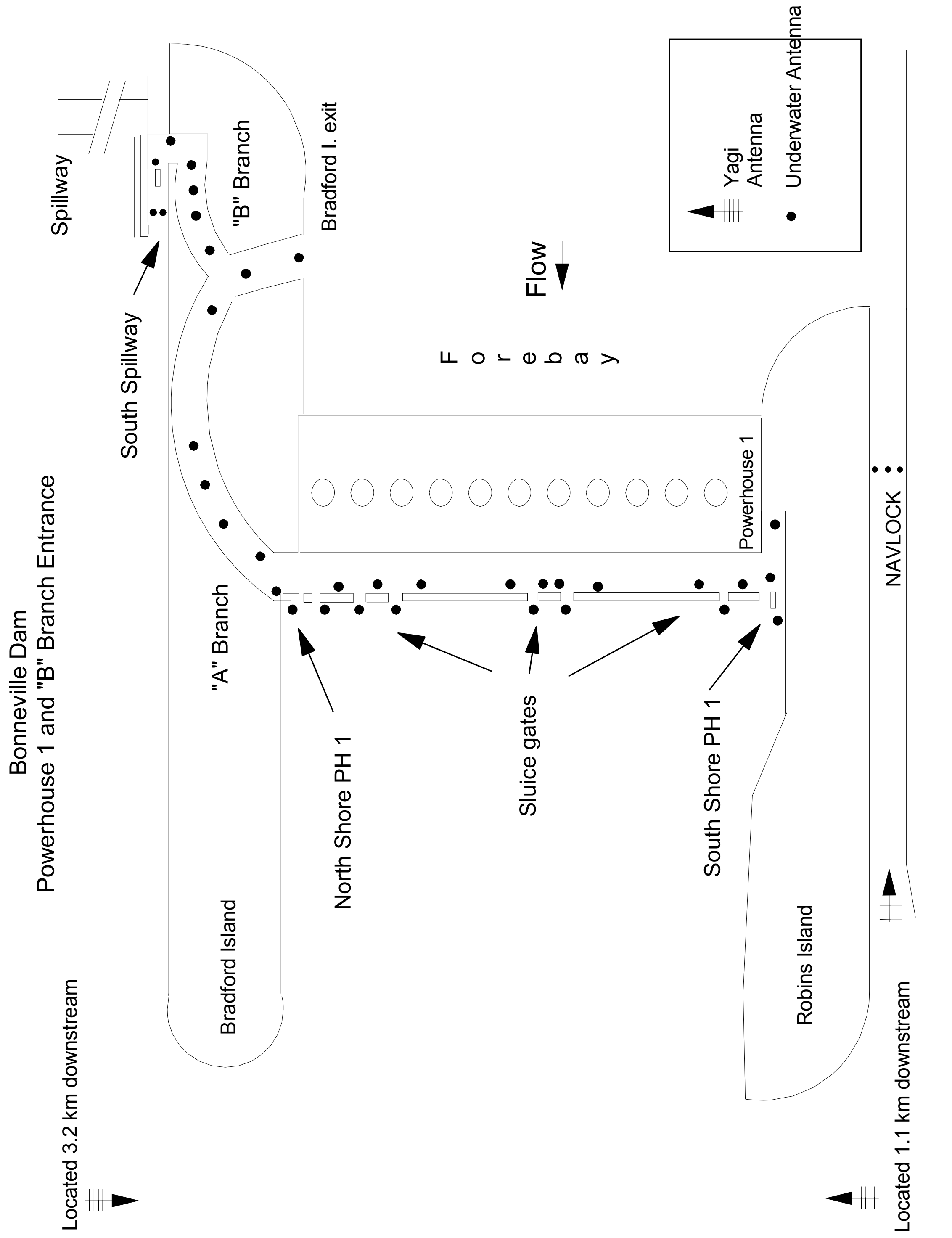

Figure 1-a. Schematic drawing of Bonneville Dam's Powerhouse II and Cascades Island fishways and fishway entrances (Washington-shore fishway), with approximate locations of underwater antennas used for monitoring adult passage behaviors. See Appendix 1 for locations of antennas within each study year.

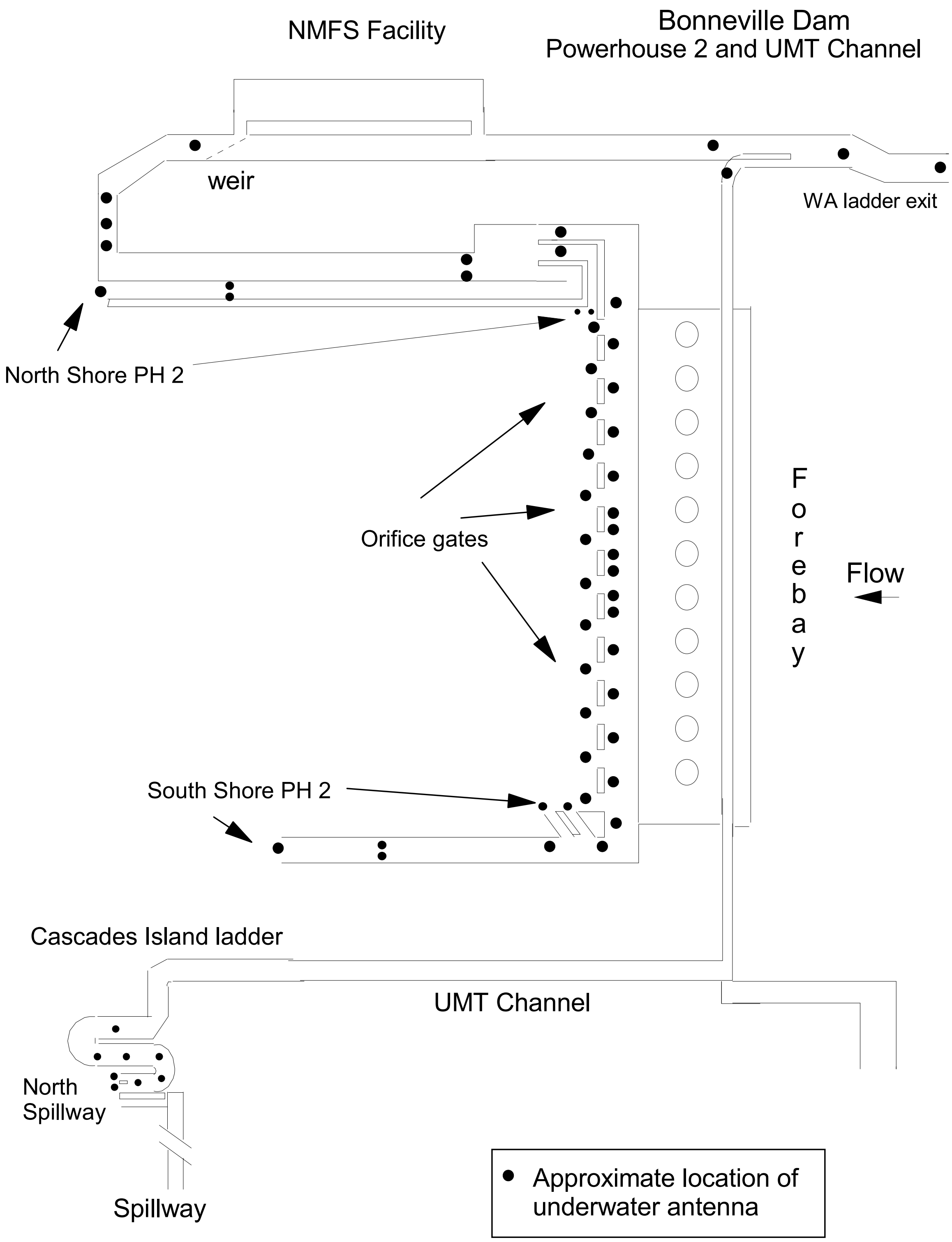

Figure 1-b. Schematic drawing of Bonneville Dam's Powerhouse I and B-branch fishways and fishway entrances (Bradford Island fishway), with approximate locations of aerial and underwater antennas used for monitoring adult passage behaviors. See Appendix 1 for locations of antennas within each study year.

1.) Fish passed through a pool without delay (no downstream movements recorded.)
2.) Fish delayed in a pool (downstream movement detected within the pool, but fish was not recorded at antennas within the collection channel or at a fishway entrance.)
3.) Fish exited the OR-shore pool into a collection channel (fish were detected at antennas inside collection channels, but were not recorded exiting the fishway into the tailrace. Note: some fish may have exited and re-entered the fishway via unmonitored orifice gates.)
4.) Fish that exited a pool into the tailrace of the dam.

Environmental Conditions

Flow and spill at Bonneville Dam during the study ranged from well above average (1997) to one of the lowest runoff years on record (2001) (USACE 1998; USACE 2002 DART electronic database). Peak flows in 1997 were > 550 kcfs and peak spill was > 400 kcfs; in comparison, peak flows were ~ 425 kcfs briefly in 1998, < 400 kcfs in 2000 and 2002, and < 200 kcfs in 2001 (Figure 2). In all years except 2001, spill was continuous from early to mid-April through 31 August. Spill was limited in 2001 to two brief periods (from late May to mid-June and in the second half of August). Peak mean daily temperatures at the dam were between 21 and 24° C in all years, with the highest levels in 1998 (Figure 3).

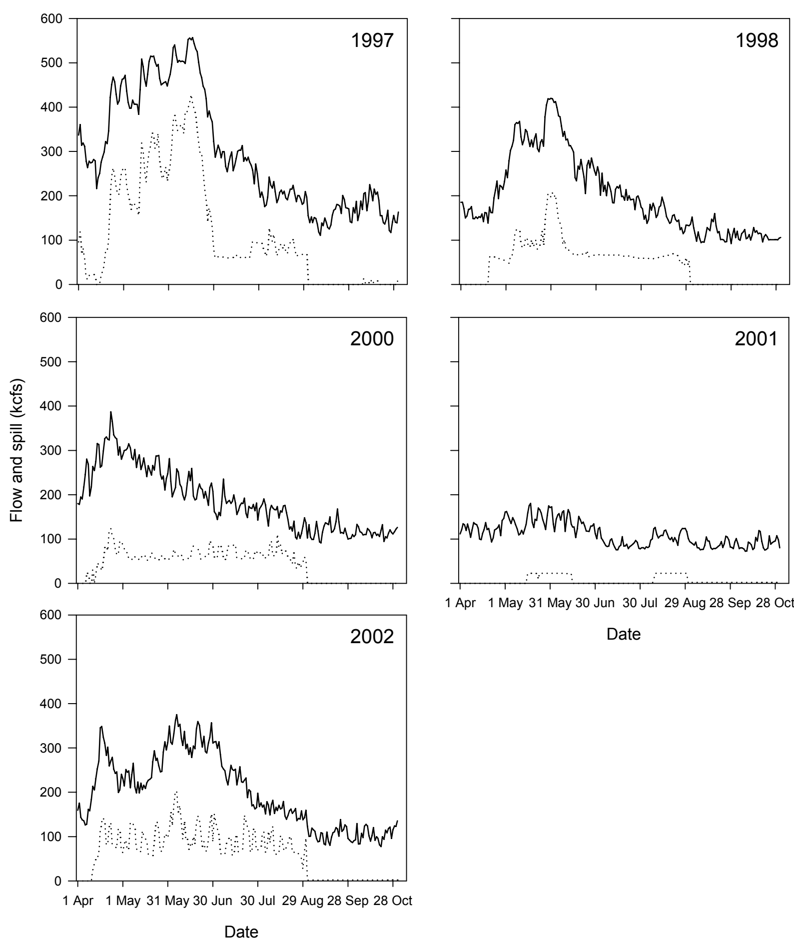

Figure 2. Mean daily flow (solid line) and spill (dotted line in kcfs, uncorrected) at Bonneville Dam during the adult radiotelemetry study years.

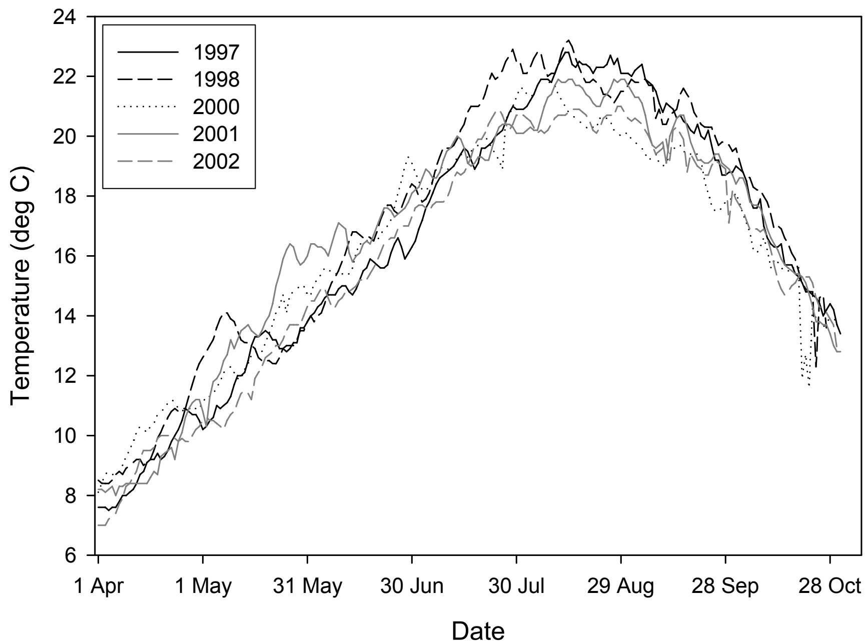

Figure 3. Mean daily water temperature (º C) at the Bonneville Dam water quality monitoring site during the adult radiotelemetry study years.

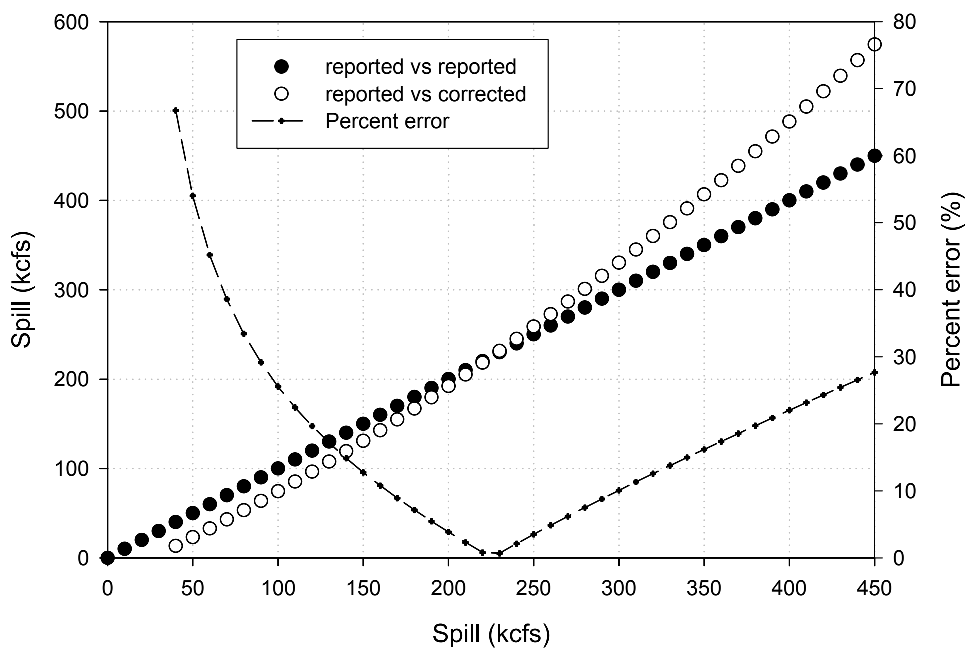

Figure 4. Reported mean daily spill (kcfs) and the corrected mean daily spill at Bonneville Dam, using the USACE-provided formula 0.001*spill^2 + 0.8788-spill - 23.45.

Spill correction -- In 2005, when this report was near completion, the USACE reported that its estimates of spill volume at Bonneville Dam had been incorrectly calibrated for all years of the radiotelemetry study. The magnitude of the calibration error was greatest at low and high spill levels (Figure 4). The error was < 10% when spill was between approximately 175-300 kcfs, and was > 25% when spill was less than 100 kcfs and again when spill was greater than about 400 kcfs. The correction factor ($y = 0.001 \cdot spill^2 + 0.8788 \cdot spill - 23.45$) was for instantaneous spill, and it was therefore inappropriate to apply to mean daily spill values, the metric we used for most spill analyses. Mean daily uncorrected spill was often < 30 kcfs and application of the correction to these values resulted in negative spill. Because all analyses were complete at the time the calibration error was reported, we present only uncorrected values in this report.

Results

Passage Times

Chinook salmon

Median times for all spring–summer Chinook salmon to pass from the tailrace receiver (2.8 km downstream from Bonneville Dam) to their first recorded approach at a fishway entrance were between 2.3 and 3.3 h in the first three years, and then jumped to about 9.6 h in 2001 and 2002 (Table 2). The difference between the two time periods were due, in part, to reduced antenna coverage at Powerhouse II in later years. At least 75% first approached a fishway entrance in < 12 h each year. Less than 3% took > 3 d to approach a fishway in the first three years, while 7-8% took 3 d or more in 2001 and 2002.

From first tailrace record, median times for Chinook salmon to first enter a fishway ranged from 9.6 h in 1998 to 17.5 h in 2002 (Table 2). As with time to first fishway approach, times were longer in later years. One to 9% took > 5 d to first enter a fishway in all years. The percentages that took more than 3 d to first enter were 7% (1997), 2% (1998), 10% (2000), 13% (2001), and 17% (2002).

Median times from first fishway approach to first fishway entry ranged from 1.6 to 5.1 h (Table 2). Time to first enter after first approach was quite variable: 25% of the fish entered a fishway within 0.7 h (42 min) of first approaching in all years, while up to 8% took more than 5 d.

Median times from first tailrace record to exit from the top of a ladder were 24.6 h in 1997, 19.6 h in 1998, 26.5 h in 2000, 23.8 h in 2001, and 41.1 h in 2002 (Table 2). In each year, 25% of the fish passed the dam in ≤ 24 h. Six to 29% passed in > 3 d and 2–16% passed in > 5 d. Proportions that passed the dam in > 3 and > 5 d were highest in 2002 and 1997 and lowest in 1998.

In all passage time measures, distributions were skewed to the right. Consequently, mean passage times were longer than median times and variance estimates were high. Longer passage times occurred when fish spent 1 d (or night) or more in the fishways or spent time migrating up and down powerhouse collection channels, exiting and reentering fishways multiple times, or migrating between fishways. Passage times between the tailrace and exit from the tops of ladders included time used by fish that exited a fishway into the tailrace and then reentered a fishway.

In all years, median passage times for spring–summer Chinook salmon were longest in April, intermediate in May, and were shortest in June and July (Table 3). Monthly differences in

Table 2. Number of adult radio-tagged fish and median and quartile times to pass from first tailrace record to first fishway approach, first fishway entrance and to pass Bonneville Dam, and from first fishway approach to first fishway entry with percentages that took > 3 and > 5 d to pass through the migration segment.

	Chinook salmon					Steelhead				SK[1]
First tailrace to first fishway approach	1997	1998	2000	2001	2002	1997	2000	2001	2002	1997
N	881	850	890	705	743	776	732	728	805	456
1st Quartile (h)	1.7	1.5	1.8	3.1	2.4	2.0	1.6	1.9	2.0	1.6
Median (h)	**2.7**	**2.3**	**3.3**	**9.6**	**9.7**	**3.1**	**2.5**	**2.8**	**3.3**	**2.2**
3rd Quartile (h)	10.3	8.8	12.6	20.0	22.6	11.8	10.2	9.3	12.6	4.1
Percent > 5 d	1.8	0.5	0.3	2.8	3.4	3.1	0.1	0.6	1.7	0.0
Percent > 3 d	2.2	0.5	0.3	7.8	7.3	4.0	0.8	0.8	3.0	0.4
First tailrace to first fishway entry										
N	739	760	750	641	651	625	659	604	679	368
1st Quartile (h)	3.5	3.0	5.9	7.4	7.0	2.6	2.5	2.7	2.9	2.1
Median (h)	**10.7**	**9.6**	**15.5**	**12.8**	**17.5**	**5.1**	**5.3**	**5.6**	**7.9**	**3.0**
3rd Quartile (h)	19.9	17.5	34.9	34.9	48.9	14.8	15.4	12.1	16.5	10.7
Percent > 5 d	4.2	1.1	4.1	4.2	9.4	3.7	0.6	1.2	3.7	0.3
Percent > 3 d	6.6	2.2	9.5	12.5	17.4	5.3	1.7	1.7	6.3	0.8
First tailrace to pass dam										
N	905	846	894	702	749	794	748	737	829	555
1st Quartile (h)	13.7	12.7	16.7	14.7	20.3	8.3	11.0	11.1	13.4	7.6
Median (h)	**24.6**	**19.6**	**26.5**	**23.8**	**41.1**	**17.4**	**19.7**	**18.4**	**24.2**	**15.0**
3rd Quartile (h)	57.2	27.5	56.0	54.7	82.5	28.9	30.6	30.9	55.7	24.6
Percent > 5 d	13.0	2.4	8.1	7.1	15.6	8.1	4.6	3.5	11.2	3.1
Percent > 3 d	21.1	5.9	19.4	16.8	29.1	12.3	9.8	8.1	19.7	6.7
First fishway approach to first entry										
N	767	820	792	752	757	654	711	630	736	368
1st Quartile (h)	0.3	0.4	0.7	0.5	0.6	0.0	0.2	0.2	0.1	0.0
Median (h)	**2.1**	**2.1**	**5.1**	**1.6**	**2.5**	**0.2**	**0.6**	**0.6**	**0.6**	**0.3**
3rd Quartile (h)	11.5	10.2	23.3	6.3	21.4	1.4	3.0	2.1	2.5	1.5
Percent > 5 d	2.4	0.7	2.9	1.1	3.8	0.5	0.4	0.3	1.5	0.3
Percent > 3 d	3.8	1.8	7.5	3.2	8.2	0.6	0.6	1.0	2.6	0.3

Table 3. Number of adult radio-tagged spring–summer Chinook salmon and median times to pass (h) from first tailrace record to first fishway approach, to first fishway entrance, and to pass Bonneville Dam based on month fish were first detected in the tailrace.

	Chinook salmon									
	1997		1998		2000		2001		2002	
First tailrace to first fishway approach	N	Median	N	Median	N	Median	N	Median	N	Median
April	296	**3.4**	337	**3.9**	454	**6.9**	247	**20.3**	241	**17.5**
May	304	**2.6**	271	**2.0**	218	**2.5**	251	**9.0**	268	**12.1**
June	135	**3.9**	147	**1.8**	115	**1.7**	112	**3.7**	157	**2.4**
July	146	**2.1**	95	**1.7**	97	**1.9**	95	**6.3**	76	**2.6**
August					6	**1.2**			1	**14.2**
First tailrace to first fishway entry										
April	226	**17.0**	294	**14.4**	373	**25.3**	228	**37.6**	214	**34.6**
May	271	**10.0**	249	**10.2**	185	**13.2**	231	**11.5**	228	**23.8**
June	115	**12.6**	130	**3.6**	101	**7.1**	100	**8.1**	142	**8.8**
July	127	**4.2**	87	**2.8**	85	**7.3**	82	**8.9**	66	**9.6**
August					6	**2.2**			1	**16.6**
First tailrace to first pass dam										
April	307	**47.6**	330	**23.9**	449	**44.8**	237	**58.7**	248	**52.4**
May	308	**22.7**	267	**19.6**	219	**22.7**	254	**22.2**	267	**50.6**
June	141	**18.0**	152	**15.8**	119	**18.7**	115	**18.7**	158	**24.5**
July	149	**16.1**	97	**17.2**	101	**18.3**	96	**17.1**	75	**23.4**
August					6	**20.8**			1	**23.9**
First fishway approach to first entry										
April	225	**4.8**	294	**4.2**	373	**16.2**	228	**3.0**	214	**3.6**
May	271	**2.3**	249	**2.9**	185	**4.7**	231	**1.2**	228	**4.5**
June	115	**0.4**	130	**0.7**	101	**0.9**	100	**0.7**	142	**1.3**
July	127	**0.6**	87	**0.6**	85	**0.7**	82	**1.4**	66	**1.0**
August					6	**0.4**			1	**2.4**

median full-dam passage times were widely variable. From April to May, passage times decreased by 22–37 h (49–62%) in 1997, 2000, and 2001, but only 2-4 h (3–18%) in 1998 and 2002. Similarly, changes in median times from May to June were 14–26 h (52–60%) in 1997 and 2002, and 4 h (18–20%) in all other years. Differences were smaller between June and July, except in 1997, when times were longer in July by 7 h (79%) (Table 3).

Additional passage time summaries, relating to fishway exits and behavior in transition pools, are included in sections on fishway use and movements through transition pools. Relationships between river environment, operational conditions, and passage times are included in the multivariate analyses section.

Steelhead

Median times for all steelhead to pass from the tailrace receiver to their first recorded approach at a fishway entrance ranged from 2.5 to 3.3 h (Table 2). At least 75% first approached within 13 h. From 1–4% took more than 3 d to first approach. Median times to first enter a fishway after tailrace entry ranged from 5.1 to 7.9 h (Table 2). At least 75% first entered a fishway within 17 h of tailrace entry and 2–6% took more than 3 d to first enter a fishway. Median times from first tailrace record to exit from the top of a ladder were 17.4 h in 1997, 19.7 h in 2000, 18.4 h in 2001, and 24.2 h in 2002 (Table 2). In each year, about a quarter of the steelhead passed the dam in < 14 h; 3rd quartiles of passage times ranged from 28.9 h to 55.7 h. From 4 to 11% passed in > 5 d and 8–20% passed in > 3 d (Table 2).

Median times from first fishway approach to first fishway entry were < 1 h in all years, and 75% took less than 3.0 h to first enter after approaching the dam (Table 2).

As with Chinook salmon, passage time distributions for steelhead were skewed to the right, mean passage times were longer than median times and variance estimates were high. Longer passage times occurred when fish spent 1 d (or night) or more in the fishways or spent time migrating up and down powerhouse collection channels, exiting and reentering fishways multiple times, or migrating between fishways.

Unlike for Chinook salmon, between-month differences in median passage times for steelhead did not show strong seasonal patterns (Table 4). This is not to suggest that passage times were uniform across months. In fact, monthly medians were quite variable, as indicated by annual coefficients of variation (*CV* = (standard deviation/mean of monthly median times)*100). Variation in monthly medians for the tailrace to fishway approach segment was highest in 2002 (*CV* = 31%) and lowest in 2001 (*CV* = 9%). Variability in the tailrace to first fishway entry was highest in 1997 (*CV* = 48%), when August passage times were particularly high (median = 10.5 h) and lowest in 2001 (*CV* = 26%). Monthly variability in total dam passage time was highest in 2000 (*CV* = 21%) and lowest in 2001 (*CV* = 10%).

Additional passage time summaries, relating to fishway exits and behavior in transition pools, are included in sections on fishway use and movements through transition pools. Relationships between river environment, operational conditions, and passage times are included in the multivariate analyses section.

Sockeye salmon

Migration times for sockeye salmon were less variable than for spring–summer Chinook salmon or steelhead. Median times for sockeye salmon to first approach and first enter a

Table 4. Number of adult radio-tagged steelhead and sockeye salmon and median times to pass (h) from first tailrace record to first fishway approach, to first fishway entrance, and to pass Bonneville Dam based on month fish were first detected in the tailrace.

	Steelhead								Sockeye	
	1997		2000		2001		2002		2002	
First tailrace to first fishway approach	N	Median	N	Median	N	Median	N	Median	N	Median
May					5	**2.3**				
June	36	**3.3**	49	**2.5**	68	**2.6**	77	**2.4**	223	**2.5**
July	171	**2.7**	141	**3.2**	152	**2.8**	171	**3.3**	230	**2.0**
August	216	**4.4**	285	**2.4**	260	**2.7**	309	**4.6**	3	**2.2**
September	280	**2.8**	140	**1.9**	187	**3.0**	208	**2.7**		
October	73	**2.6**	116	**3.4**	56	**3.0**	40	**5.4**		
First tailrace to first fishway entry										
May					5	**2.6**				
June	25	**3.9**	45	**3.4**	59	**4.3**	65	**3.5**	178	**3.2**
July	123	**6.7**	127	**8.7**	122	**5.6**	144	**11.0**	187	**2.7**
August	164	**10.5**	265	**6.9**	225	**5.6**	265	**9.4**	3	**2.9**
September	250	**3.9**	129	**3.0**	145	**5.5**	167	**7.8**		
October	63	**3.2**	92	**6.1**	48	**6.8**	38	**10.0**		
First tailrace to first pass dam										
May					5	**20.0**				
June	48	**14.4**	55	**20.3**	68	**17.4**	81	**27.3**	285	**15.1**
July	193	**19.8**	139	**29.3**	150	**21.9**	178	**32.1**	267	**14.9**
August	215	**20.8**	292	**19.5**	266	**16.0**	317	**26.0**	3	**5.4**
September	267	**15.8**	142	**17.9**	189	**19.5**	212	**21.2**		
October	72	**17.2**	120	**17.3**	59	**17.7**	41	**20.8**		
First fishway approach to first entry										
May					5	**0.4**				
June	25	**0.1**	45	**0.2**	59	**0.5**	65	**0.5**	178	**0.3**
July	123	**0.9**	127	**0.7**	122	**1.2**	144	**0.7**	187	**0.3**
August	164	**0.5**	265	**0.7**	225	**0.5**	265	**0.5**	3	**1.0**
September	250	**0.1**	129	**0.5**	145	**0.4**	167	**0.7**		
October	63	**0.1**	92	**0.6**	48	**0.6**	38	**0.6**		

fishway at Bonneville Dam were 2.2 h and 3.0 h, respectively. Overall, 75% first approached within 4.1 h and first entered within 10.7 h after first passing the tailrace receiver (Table 2). Less than 1% took > 3 d to first approach or first enter a fishway. Time between first fishway approach and first fishway entry was < 1.5 h for most fish. Median passage time from the tailrace over the dam was 15.0 h; 25% passed in < 7.6 h and 25% passed in > 24.6 h. Seven percent took more than 3 d to pass the dam (Table 2).

Sockeye salmon first approached and entered fishways and passed the dam in June and July with just a handful passing in August (Table 4). Median times to pass from the tailrace to first fishway approach, first fishway entry, and to pass the dam were slightly longer in June than in July.

Diel effects

Time of day strongly influenced passage times, particularly over multiple segments. For example, passage times from the tailrace to first fishway entry and from tailrace to pass the dam were shortest for Chinook salmon and steelhead that entered the tailrace early in the day (Figures 5 and 6). Fish, and especially Chinook salmon, that first entered the tailrace in mid-day had considerably longer median passage times. This was likely because the fish that started the passage process early in the day had the time to retreat or exit from a fishway and then re-enter and pass during the same day while those that started later in the day were more likely to encounter nightfall and stop. Ladder passage, a shorter segment, also clearly showed this diel effect. Median ladder passage times were uniformly low for those fish that entered the ladder during daylight, and then jumped for those that entered near dusk or at night, most of which spent the night in the ladder before exiting the following morning (Figures 5 and 6).

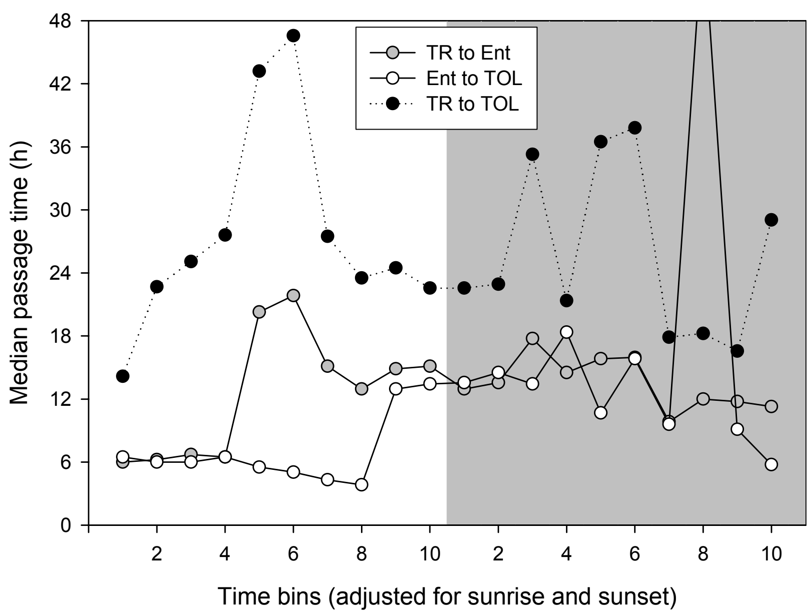

Figure 5. Median passage times (h) for Chinook salmon from first tailrace entry (TR) to first fishway entry (Ent), from first fishway entry to exit from the top of a ladder (TOL), and from first tailrace to top of ladder, based on time of segment entry. All years combined, and time bins adjusted for sunrise and sunset.

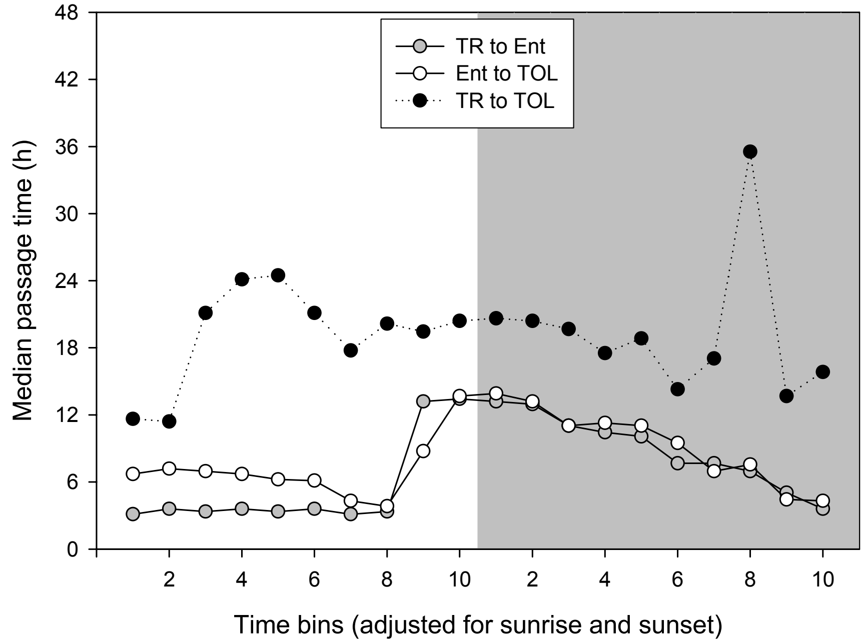

Figure 6. Median passage times (h) for steelhead from first tailrace entry (TR) to first fishway entry (Ent), from first fishway entry to exit from the top of a ladder (TOL), and from first tailrace to top of ladder, based on time of segment entry. All years combined, and time bins adjusted for sunrise and sunset.

Fishway Use

Chinook salmon

In all years, spring–summer Chinook salmon were monitored as they approached and entered the major fishway entrances at both Powerhouses and the spillway at Bonneville Dam. Coverage at Powerhouse II orifice gates was limited to 1997 and 1998, after which fish could enter them undetected. The volumes of discharge from fishways were probably important factors in attracting fish. According to USACE personnel, sluice gates at Powerhouse I were 0.61 m wide and 1.83 m deep with discharges of 60 to 80 cfs and sluice gates were 0.41 m wide with variable depths and discharges. The south-shore and north-powerhouse entrances at Powerhouse 1 were 2.44 m wide and at least 2.44 m deep. North- and south-spillway entrances were all 3.05 m wide and a minimum of 3.05 m deep. The south-shore entrance at Powerhouse 2 was 3.91 m wide and 3.05 m deep, and similar in size at the north shore of Powerhouse 2. Depths of openings varied with tailrace elevation.

Between 854 and 960 Chinook salmon were known to have approached fishways each year, 848 to 956 were known to have entered fishways, and 304 to 602 exited fishways (Table 5). In each year, > 98% of fish that approached fishways subsequently entered and 36 to 63% of the fish that entered eventually exited into the tailrace. Salmon approached fishways a median of 7 to 15 times (means = 11 to 24 times), and entered a median of 1 to 2 times (means = 2 to 3). Fish that exited fishways exited a median of 1 time in 2001 and 2 times in all other years (means = 2 to 4). Because orifice gate entrances were unmonitored in later years, some fish approached, entered and exited through orifice gates undetected, resulting in a loss of

Table 5. Number of radio-tagged spring–summer Chinook salmon, steelhead, and sockeye salmon that approached, entered and exited fishway entrances at Bonneville Dam, and the median and mean number of approaches, entrances and exits per fish. Also includes the percentages that entered after approaching fishways and exited after entering fishways.

		Approached fishways			Entered fishways			Exited fishways			Percent that entered[1]	Percent that exited[2]
Run	Year	N	Med.	Avg.	N	Med.	Avg.	N	Med.	Avg.		
Chinook	1997	960	14	22	956	2	3	602	2	3	99.6%	63.0%
	1998	929	13	23	925	1	2	451	2	3	99.6%	48.8%
	2000	957	15	24	945	1	2	441	2	3	98.7%	46.7%
	2001	854	7	11	848	1	2	304	1	2	99.3%	35.8%
	2002	882	10	18	876	1	3	375	2	4	99.3%	42.8%
Steelhead	1997	909	6	13	904	1	2	392	2	2	99.4%	43.4%
	2000	807	8	15	800	2	3	405	2	4	99.1%	50.6%
	2001	778	8	17	771	2	3	404	3	4	99.1%	52.4%
	2002	908	9	16	895	2	4	575	3	5	98.6%	64.2%
Sockeye	1997	542	7	12	534	2	3	331	2	3	98.5%	62.0%

[1] Number that entered/Number that approached
[2] Number that exited/Number that entered

precision for behavior summaries.

<u>*Approaches to fishways*</u> - Chinook salmon first approached fishways at Bonneville Dam at all monitored entrances (Table 6). No single entrance site was used by a majority of Chinook salmon in any year. Approach sites were at least partially a response to Powerhouse priority—the allocation of discharge through turbines at either Powerhouse I or II. Priority was through Powerhouse I in 1997, 1998, and 2000 and through Powerhouse II in 2001 and 2002. Priority differences resulted in substantial changes in the distribution of fish attraction flows, and these were reflected in the sites salmon used.

When priority was at Powerhouse 1, 52-61% of Chinook salmon first approached fishways at Powerhouse I entrances, 4-7% first approached at the spillway entrances, and 34-41% first approached at Powerhouse 2 entrances (Figure 7). The shift to Powerhouse II priority in 2001-2002 resulted in more than twice as many fish first approaching at the spillway entrances and the majority of first approaches occurred at Powerhouse II entrances.

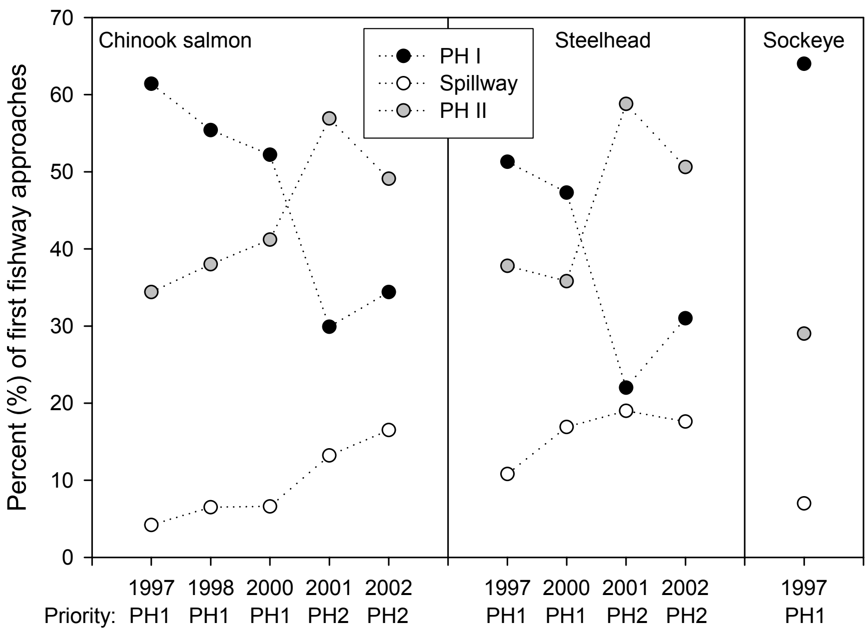

Figure 7. Distributions (%) of first fishway entrance sites approached by radio-tagged fish by species and year. Powerhouse priority indicated under the year. PH I = Powerhouse I entrances, PH II = Powerhouse II entrances, spillway = spillway entrances.

Site preferences for first fishway approaches varied with spill volume and powerhouse priority. At low spill and Powerhouse I priority, the largest percentages of first approaches were at Powerhouse 1 sluice gates and the south-shore entrance (Table 7). The north-shore entrance at Powerhouse II was also approached first by many fish, though the percentage declined as spill increased in 1997. There was also a tendency for more first approaches at spillway entrances as spill increased. Combined, the results for 1997-2000 in Table 7 suggest that Chinook salmon tended to follow shorelines at lower spill levels and first approached at near-shore entrances; as spill increased, more fish appeared to be attracted to the spillway. In

Table 6. Location of first and total fishway approaches by radio-tagged spring–summer Chinook salmon at Bonneville Dam; approaches with unknown times were included at specific entrances if subsequent telemetry records inside fishways clearly identified approach site.

	Chinook salmon									
	1997		1998		2000		2001		2002	
First approaches	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**
South-shore Powerhouse 1	50	**5.2**	243	**26.2**	245	**25.6**	102	**11.9**	117	**13.3**
Sluice gates Powerhouse 1	445	**46.4**	213	**22.9**	190	**19.9**	108	**12.6**	144	**16.4**
North-shore Powerhouse 1	84	**8.8**	56	**6.0**	64	**6.7**	40	**4.7**	37	**4.2**
South spillway	26	**2.7**	43	**4.6**	49	**5.1**	85	**10.0**	75	**8.5**
North spillway	14	**1.5**	17	**1.8**	14	**1.5**	28	**3.3**	70	**8.0**
South-shore Powerhouse 2	95	**9.9**	100	**10.8**	132	**13.8**	262	**30.7**	177	**20.1**
Orifice gates Powerhouse 2	45	**4.7**	44	**4.7**	not monitored					
North-shore Powerhouse 2	190	**19.8**	209	**22.5**	258	**27.0**	220	**25.8**	256	**29.1**
Unknown Powerhouse 1	11	**1.1**	4	**0.4**	3	**0.3**	7	**0.8**	4	**0.5**
Unknown Powerhouse 2	0	**0.0**	0	**0.0**	2	**0.2**	2	**0.2**	0	**0.0**
Unknown	**1**	**0.1**	0	**0.0**	0	**0.0**	0	**0.0**	1	**0.1**
Total	960		929		957		854		880	
Total approaches										
South-shore Powerhouse 1	258	**1.2**	1338	**6.1**	2247	**9.8**	726	**7.6**	953	**6.0**
Sluice gates Powerhouse 1	5217	**24.6**	4204	**19.3**	7882	**34.3**	2104	**22.1**	5160	**32.7**
North-shore Powerhouse 1	1563	**7.4**	1201	**5.5**	2532	**11.0**	749	**7.9**	1786	**11.3**
South spillway	510	**2.4**	490	**2.2**	601	**2.6**	310	**3.3**	436	**2.8**
North spillway	427	**2.0**	286	**1.3**	361	**1.6**	148	**1.6**	477	**3.0**
South-shore Powerhouse 2	3518	**16.6**	4430	**20.3**	4899	**21.3**	3065	**32.2**	3821	**24.2**
Orifice gates Powerhouse 2	6814	**32.1**	6160	**28.2**	not monitored					
North-shore Powerhouse 2	2798	**13.2**	3605	**16.5**	4386	**19.1**	2404	**25.2**	2927	**18.5**
Unknown Powerhouse 1	60	**0.3**	65	**0.3**	16	**0.1**	5	**0.1**	82	**0.5**
Unknown Powerhouse 2	49	**0.2**	35	**0.2**	57	**0.2**	21	**0.2**	155	**1.0**
Unknown	**2**	**0.1**	0	**0.0**	0	**0.0**	0	**0.0**	1	**0.0**
Total	21214		21814		22981		9532		15797	

2001, the year with almost no spill, the south-shore entrance at Powerhouse II was the preferred first approach site. In 2002, with moderate spill and Powerhouse II priority, salmon tended to first approach at Powerhouse I entrances at low spill and shifted to Powerhouse II entrances at higher spill levels (Table 7). Substantial numbers of salmon first approached the dam during zero spill in 1998 and 2001. In 1998, the largest percentage of these fish approached at the south-shore entrance at Powerhouse I, while in 2001 the north-shore entrance at Powerhouse II was favored. This pattern almost certainly reflects powerhouse priority differences between these two years.

Distributions of combined first and subsequent approaches at fishway entrances (total approaches) differed from those for first approaches (Table 6). The highest percentages of total fishway approaches were at the Powerhouse II orifice gates in 1997 and 1998, at Powerhouse I sluice gates in 2000 and 2002, and at the south-shore Powerhouse II entrance in 2001. The second most used sites were the south-shore Powerhouse II entrance in 1998, 2000, and 2002 and the north-shore Powerhouse II entrance in 2001. The total approach numbers reflect the tendency of adult fish to move along the face of the dam powerhouses, approaching (or at least passing very near) all sluice gate and orifice gate entrances. Note that Powerhouse II orifice gates were unmonitored in 2000-2002 and that many fish likely approached those sites, particularly when priority switched to Powerhouse II.

The distribution of total approaches in relation to spill was qualitatively similar to first approaches: the highest percentages of total approaches were at Powerhouse I entrances in 1997, 1998, and 2000 when priority was Powerhouse I and were at Powerhouse II entrances in 2002 when priority had switched (Table 8). Total approaches in 2001 did not quite fit the pattern, as most approaches were at the main Powerhouse 1 entrances. This may have been because most approaches occurred during zero- or low-spill conditions in 2001.

Entries to fishways - Chinook salmon first entered fishways at Bonneville Dam at all monitored entrances (Table 9). No single entrance site was used by a majority of Chinook salmon in any year. Entry sites were at least partially a response to Powerhouse priority—the allocation of discharge through turbines at either Powerhouse I or II. Priority differences resulted in substantial changes in the distribution of fish attraction flows, and these are reflected in the sites salmon used to enter fishways.

The distribution of first and total entry locations was more evenly distributed than for first and total fishway approaches (Figure 8). As with approaches, however, there was a shift away from Powerhouse I entrance sites when powerhouse priority switched to Powerhouse II. Chinook salmon tended to first enter at the larger shoreline entrances at both powerhouses, though relatively high percentages of entries were also at the two spillway entrances (Table 9). No single entrance site had more than 30% of first or total entries in any year.

At zero spill, salmon tended to first enter the south-shore entrance at Power house II (2001) or the south spillway entrance (1998) (Table 10). Powerhouse I entrances were favored at most spill levels in 1997, 1998, and 2000, while more first entrances were at Powerhouse II entrances in 2001 and 2002. These results are consistent with the switch in powerhouse priority.

No strong patterns emerged in the distribution of total fishway entrances among sites (Table 11). The south-shore entrance at Powerhouse II was favored in 1997 and 2001, no site was strongly preferred in either 1998 or 2000, and Powerhouse II sites were most used in 2002. As with first entries, the highest percentages of total entrances were at the south-shore entrance at Power house II (2001) or the south spillway entrance (1998).

Table 7. Percentage of **first** approaches to fishway entrances by radio-tagged spring–summer Chinook salmon at Bonneville Dam based on mean daily spill (kcfs) on the date of the approach. Approaches with unknown times were included at specific sites if subsequent telemetry records clearly identified approach site. (Spill values are uncorrected.)

CK97											
Spill	*n*	SSh PH1	SGs	NSh PH1	SSpill	Unk OR	NSpill	SSh PH2	OGs	NSh PH2	Unk WA
1-49	62	11	**26**	11	3	0	0	18	7	24	0
50-99	216	7	**46**	10	7	0	1	1	9	20	0
100-149	91	4	**41**	9	1	0	1	12	4	28	0
150-199	184	4	**56**	7	1	0	1	5	4	22	1
200-249	219	6	**45**	11	3	0	2	11	3	20	0
250-299	110	7	**57**	6	1	0	2	7	4	16	0
300-349	50	4	**52**	12	2	0	4	10	4	12	0
>350	9	0	**89**	0	0	0	0	11	0	0	0
CK98											
0	149	**38**	16	4	5	0	1	14	7	14	0
1-49	37	14	**35**	0	3	0	0	11	19	19	0
50-99	525	**26**	22	8	6	0	2	10	4	23	0
100-149	181	23	**28**	4	3	0	1	11	2	**28**	0
150-199	10	10	**40**	20	0	0	10	10	0	10	0
200-249	30	17	**37**	10	0	0	0	7	0	30	0
CK00											
0	17	18	29	12	0	0	0	6		**35**	0
1-49	57	16	12	2	5	0	5	12		**47**	0
50-99	582	**26**	21	8	6	0	1	12		25	0
100-149	300	**27**	1	5	3	0	2	17		**27**	0

Table 7. Continued.

Spill	*n*	SSh PH1	SGs	NSh PH1	SSpill	Unk OR	NSpill	SSh PH2	OGs	NSh PH2	Unk WA
CK01											
0	583	16	15	5	3	0	2	**30**		28	1
1-49	271	4	7	3	26	0	5	**34**		21	0
CK02											
0	18	**33**	22	0	6	6	11	11		11	0
1-49	3	**33**	**33**	0	0	0	0	**33**		0	0
50-99	305	15	15	5	11	0	10	17		**26**	0
100-149	443	10	15	5	9	0	7	22		**33**	0
150-199	105	15	23	4	2	0	5	24		**28**	0
200-249	6	**50**	33	17	0	0	0	0		0	0

Table 8. Percentage of **total** approaches to fishway entrances by radio-tagged spring–summer Chinook salmon at Bonneville Dam based on mean daily spill (kcfs) on the date of the approach. Approaches with unknown times were included at specific sites if subsequent telemetry records clearly identified approach site.

CK97											
Spill	*n*	SSh PH1	SGs	NSh PH1	SSpill	Unk OR	NSpill	SSh PH2	OGs	NSh PH2	Unk WA
0	72	1	25	1	0	0	0	**29**	26	17	0
1-49	1352	3	23	7	2	0	1	**25**	24	16	0
50-99	5058	2	20	6	3	0	1	17	**38**	14	0
100-149	1911	2	22	6	2	0	2	22	**26**	18	0
150-199	4781	1	27	8	2	0	2	14	**33**	13	1
200-249	4493	1	26	8	2	0	3	14	**32**	13	0
250-299	2025	1	29	9	3	0	2	11	**33**	12	0
300-349	1024	1	**32**	11	4	0	3	13	29	7	0
>350	318	1	**35**	17	3	0	2	11	23	9	0
CK98											
0	3297	11	**24**	5	3	0	1	22	20	14	0
1-49	954	6	18	4	2	0	1	22	**31**	16	0
50-99	10336	6	19	6	3	0	2	17	**31**	16	0
100-149	6009	3	18	5	2	0	1	24	**29**	18	0
150-199	675	2	9	2	1	0	1	**29**	27	28	0
200-249	567	6	**35**	11	2	0	2	15	15	15	0
CK00											
0	130	9	23	8	5	0	3	8		**45**	0
1-49	757	10	27	6	6	0	3	17		**30**	1
50-99	14012	11	**38**	12	3	0	2	18		17	0
100-149	8065	8	**29**	10	2	0	2	27		22	0

Table 8. Continued.

Spill	*n*	SSh PH1	SGs	NSh PH1	SSpill	Unk OR	NSpill	SSh PH2	OGs	NSh PH2	Unk WA
CK01											
0	6132	9	25	9	2	0	1	**30**		23	0
1-49	3400	5	17	6	6	0	2	**36**		29	0
CK02											
0	125	16	**42**	13	4	1	9	13		3	0
1-49	16	**50**	31	0	0	0	0	13		6	0
50-99	5526	6	**35**	13	3	0	4	22		17	1
100-149	7543	6	**32**	11	3	0	3	26		19	0
150-199	2331	5	**30**	10	2	0	2	28		23	1
200-249	252	12	**43**	10	4	0	1	19		12	1

Table 9. Location of first and total fishway entrances by radio-tagged spring–summer Chinook salmon at Bonneville Dam; entries with unknown times were included at specific entrances if subsequent telemetry records inside fishways clearly identified entry site.

	Chinook salmon									
	1997		1998		2000		2001		2002	
First entrances	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**
South-shore Powerhouse 1	109	**11.4**	151	**16.3**	204	**21.6**	134	**15.8**	42	**4.8**
Sluice gates Powerhouse 1	108	**11.3**	95	**10.3**	59	**6.2**	37	**4.4**	70	**8.0**
North-shore Powerhouse 1	87	**9.1**	71	**7.7**	75	**7.9**	31	**3.7**	68	**7.8**
South spillway	143	**15.0**	186	**20.1**	182	**19.3**	124	**14.6**	150	**17.2**
North spillway	107	**11.2**	82	**8.9**	115	**12.2**	32	**3.8**	169	**19.4**
South-shore Powerhouse 2	147	**15.4**	125	**13.5**	118	**12.5**	234	**27.6**	124	**14.2**
Orifice gates Powerhouse 2	42	**4.4**	65	**7.0**	not monitored					
North-shore Powerhouse 2	159	**16.6**	79	**8.5**	120	**12.7**	187	**21.7**	175	**20.0**
Unknown Powerhouse 1	41	**4.3**	54	**5.8**	31	**3.3**	12	**1.4**	33	**3.8**
Unknown Powerhouse 2	12	**1.3**	17	**1.8**	40	**4.2**	60	**7.1**	41	**4.7**
Unknown	1	**0.1**	0	**0.0**	0	**0.0**	0	**0.0**	1	**0.1**
Total	[1]956		925		944		848		873	
Total entrances										
South-shore Powerhouse 1	185	**6.5**	260	**12.7**	429	**19.7**	180	**11.9**	106	**4.7**
Sluice gates Powerhouse 1	183	**6.4**	169	**8.2**	134	**6.1**	49	**3.2**	18	**9.7**
North-shore Powerhouse 1	167	**5.9**	138	**6.7**	175	**8.0**	47	**3.1**	163	**7.3**
South spillway	392	**13.7**	372	**18.1**	380	**17.4**	217	**14.4**	332	**14.8**
North spillway	304	**10.7**	186	**9.1**	225	**10.3**	73	**4.8**	373	**16.7**
South-shore Powerhouse 2	650	**22.8**	379	**18.5**	356	**16.3**	442	**29.3**	389	**17.4**
Orifice gates Powerhouse 2	270	**9.5**	174	**8.5**	not monitored					
North-shore Powerhouse 2	555	**19.5**	245	**11.9**	308	**14.1**	341	**22.6**	416	**18.6**
Unknown Powerhouse 1	76	**2.7**	89	**4.3**	55	**2.5**	14	**0.9**	84	**3.8**
Unknown Powerhouse 2	69	**2.4**	41	**2.0**	120	**5.5**	147	**9.7**	156	**7.0**
Unknown	2	**0.1**	0	**0.0**	0	**0.0**	0	**0.0**	1	**0.0**
Total	2853		2053		2181		1510		2238	

Table 10. Percentage of **first** fishway entries by radio-tagged spring–summer Chinook salmon at Bonneville Dam based on mean daily spill (kcfs) on the date of the entry. Approaches with unknown times were included at specific sites if subsequent telemetry records clearly identified entry site.

CK97											
Spill	*n*	SSh PH1	OGs	NSh PH1	SSpill	Unk OR	NSpill	SSh PH2	SGs	NSh PH2	Unk WA
0	1	0	**100**	0	0	0	0	0	0	0	0
1-49	62	**34**	5	0	8	0	3	26	7	18	0
50-99	221	**19**	9	11	17	0	6	17	8	14	0
100-149	75	20	7	5	9	1	15	19	1	**21**	1
150-199	216	9	12	11	16	0	7	13	7	**20**	6
200-249	219	9	17	7	14	0	15	13	4	**22**	0
250-299	105	3	**23**	15	18	0	14	11	5	11	0
300-349	52	12	17	**19**	15	0	15	15	4	2	0
>350	7	**43**	0	14	29	0	0	0	14	0	0
CK98											
0	140	16	19	7	**30**	0	9	12	5	3	0
1-49	32	16	**31**	9	28	0	6	0	9	0	0
50-99	531	**19**	14	9	16	0	9	16	7	11	0
100-149	185	12	11	10	**24**	0	9	10	17	7	0
150-199	9	11	11	11	11	0	**22**	**22**	11	0	0
200-249	34	**18**	9	**18**	12	0	9	9	12	15	0
CK00											
0	13	**46**	0	0	0	0	15	0		23	15
1-49	41	22	2	0	**34**	0	17	7		15	2
50-99	582	18	10	10	**22**	0	11	14		14	3
100-149	308	**27**	9	7	14	0	14	17		11	1

Table 10. Continued.

Spill	*n*	SSh PH1	OGs	NSh PH1	SSpill	Unk OR	NSpill	SSh PH2	SGs	NSh PH2	Unk WA
CK01											
0	576	20	6	4	7	0	4	**33**		22	5
1-49	272	7	4	3	**31**	0	4	25		22	4
CK02											
0	12	8	**33**	0	8	8	25	8		8	0
1-49	1	0	0	0	0	0	0	0		**100**	0
50-99	354	4	9	9	21	0	**25**	11		18	3
100-149	408	4	9	10	17	0	17	18		**22**	3
150-199	91	9	12	14	6	0	9	**24**		22	4
200-249	7	**29**	14	**29**	**29**	0	0	0		0	0

Table 11. Percentage of **total** fishway entries by radio-tagged spring–summer Chinook salmon at Bonneville Dam based on mean daily spill (kcfs) on the date of the entry. Approaches with unknown times were included at specific sites if subsequent telemetry records clearly identified entry site.

CK97											
Spill	*n*	SSh PH1	OGs	NSh PH1	SSpill	Unk OR	NSpill	SSh PH2	SGs	NSh PH2	Unk WA
0	10	10	10	0	0	0	0	**50**	10	20	0
1-49	167	22	2	0	9	0	4	**35**	7	19	1
50-99	728	11	7	7	14	0	7	**22**	13	21	0
100-149	213	15	3	6	11	1	14	**28**	5	18	1
150-199	672	5	6	5	14	0	9	**24**	13	21	4
200-249	602	5	9	6	14	0	14	**22**	10	20	1
250-299	257	2	14	7	**18**	0	11	15	14	20	0
300-349	152	7	13	13	16	0	15	**20**	10	6	1
>350	40	8	3	**23**	20	0	10	13	8	18	0
CK98											
0	216	14	19	5	**30**	1	11	13	5	4	0
1-49	48	10	27	6	**29**	0	8	6	10	2	0
50-99	1325	14	10	7	16	0	9	**21**	9	15	0
100-149	354	10	11	10	**20**	0	7	15	**20**	7	0
150-199	43	7	5	7	9	2	19	**26**	9	16	0
200-249	74	8	11	**15**	**15**	0	14	12	11	**15**	0
CK00											
0	16	**38**	0	0	0	0	13	0		**38**	13
1-49	66	20	2	0	**32**	0	15	8		17	8
50-99	1442	18	8	9	**19**	0	10	**19**		14	3
100-149	653	**23**	9	8	14	0	12	20		13	2

Table 11. Continued.

Spill	*n*	SSh PH1	OGs	NSh PH1	SSpill	Unk OR	NSpill	SSh PH2	SGs	NSh PH2	Unk WA
CK01											
0	884	16	5	4	8	0	5	**35**		21	7
1-49	626	6	3	3	23	0	5	**30**		25	6
CK02											
0	16	6	**31**	0	13	6	**31**	6		6	0
1-49	1	0	0	0	0	0	0	0		**100**	0
50-99	869	5	11	9	17	0	**19**	17		17	5
100-149	1000	4	13	10	14	0	17	**21**		18	3
150-199	320	6	8	10	10	0	11	24		**27**	4
200-249	31	7	7	7	26	0	7	**32**		10	7

Exits from fishways – The distribution of first and total fishway exits was related to the distribution of entries (i.e., fish tended to exit at or near where they entered). There was also a strong tendency for Chinook salmon to exit at the larger entrances at the ends of collection channels, such as the north- and south-shore entrances at both powerhouses (Table 12). Many exits at these sites occurred after fish entered at sluice or orifice gate, moved down collection channels, and then exited at the shoreline sites. The largest percentages of exits occurred at the south-shore entrance at Powerhouse I in 1998 and 2000 and at the south-shore entrance at Powerhouse II in 2001 and 2002 (Table 12).

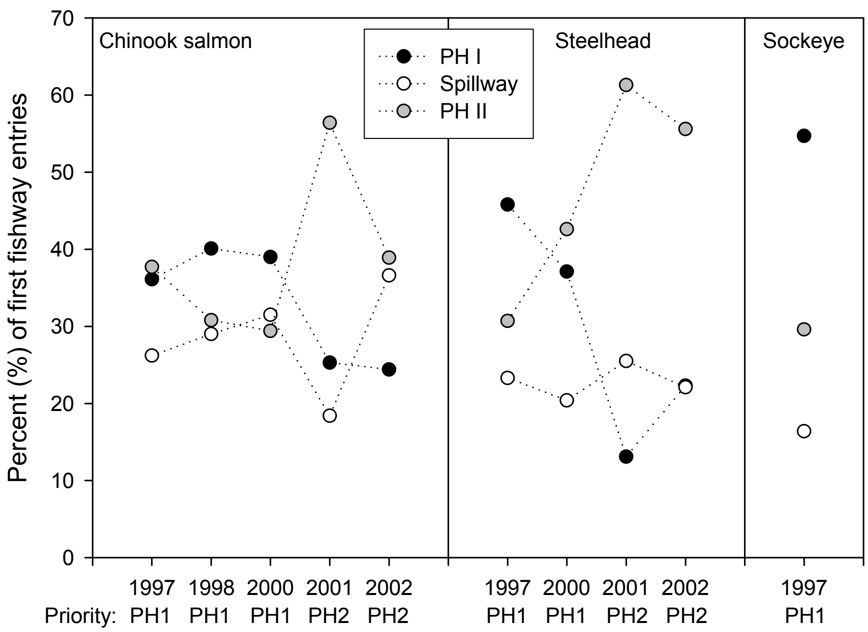

Figure 8. Distributions (%) of first fishway entrance sites used by radio-tagged fish by species and year. Powerhouse priority indicated under the year. PH I = Powerhouse I entrances, PH II = Powerhouse II entrances, spillway = spillway entrances.

Most upstream point reached before first fishway exit – We estimated where spring–summer Chinook salmon turned around in fishways and ladders before their first fishway exit to the tailrace (Table 13). This metric provided a good estimate of where fish first encountered unfavorable conditions and retreated back to the tailrace, a behavior that greatly increased dam passage times. Relatively sparse telemetry coverage in some portions of fishways, particularly in ladders upstream from transition pools, limited resolution in this analysis. Between 20-35% of salmon that exited did so after being inside the Powerhouse I collection channel, and 3-21% did so after being inside the Powerhouse II collection channel, though the latter was likely an underestimate given the relatively few antenna sites deployed there in later years. Most of the remaining fish that exited did so after entering transition pools at the base of ladders: 10-26% after entering the A-Branch pool, 8-13% after entering the B-Branch pool, 5-14% after entering the Cascades Island pool, and 16-27% after entering the Washington-shore pool. Another 1-13% first exited after being recorded on antennas near the transition between the upper end of the Powerhouse II collection channel and the transition pool there (Table 13). Small proportions

Table 12. Location of first and total fishway exits by radio-tagged spring–summer Chinook salmon at Bonneville Dam; exits with unknown times were included at specific entrances if telemetry records inside fishways clearly identified exit site.

	Chinook salmon									
	1997		1998		2000		2001		2002	
First exits	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
South-shore Powerhouse 1	110	**18.3**	100	**22.2**	121	**27.4**	9	**3.0**	31	**8.3**
Sluice gates Powerhouse 1	8	**1.3**	9	**2.0**	9	**2.0**	10	**3.3**	32	**8.5**
North-shore Powerhouse 1	28	**0.7**	46	**10.2**	29	**6.6**	15	**4.9**	38	**10.1**
South spillway	67	**11.1**	61	**13.5**	48	**10.9**	38	**12.5**	29	**7.7**
North spillway	37	**6.2**	24	**5.3**	25	**5.4**	14	**4.6**	51	**13.6**
South-shore Powerhouse 2	132	**22.0**	97	**21.5**	92	**20.9**	108	**35.5**	77	**20.5**
Orifice gates Powerhouse 2	9	**1.5**	13	**2.9**	not monitored					
North-shore Powerhouse 2	161	**26.8**	64	**14.2**	75	**17.0**	77	**25.3**	74	**19.7**
Unknown Powerhouse 1	35	**5.8**	32	**7.1**	21	**4.8**	6	**2.0**	23	**6.1**
Unknown Powerhouse 2	14	**2.3**	5	**1.1**	22	**5.0**	27	**8.9**	20	**5.3**
Unknown	0	**0.0**	0	**0.0**	0	**0.0**	0	**0.0**	0	**0.0**
Total	601		451		441		304		375	
Total exits										
South-shore Powerhouse 1	197	**10.3**	183	**16.1**	340	**27.2**	23	**3.5**	134	**9.8**
Sluice gates Powerhouse 1	18	**0.9**	22	**1.9**	21	**1.7**	14	**2.1**	114	**8.3**
North-shore Powerhouse 1	52	**2.7**	87	**7.7**	80	**6.4**	25	**3.8**	79	**5.8**
South spillway	202	**10.6**	156	**13.7**	138	**11.0**	65	**9.8**	120	**8.8**
North spillway	111	**5.8**	67	**5.9**	70	**5.6**	35	**5.3**	198	**14.5**
South-shore Powerhouse 2	554	**29.1**	303	**26.7**	277	**22.1**	271	**40.8**	315	**23.0**
Orifice gates Powerhouse 2	69	**3.6**	29	**2.6**	not monitored					
North-shore Powerhouse 2	576	**30.2**	213	**18.8**	231	**18.5**	181	**27.2**	256	**18.7**
Unknown Powerhouse 1	58	**3.0**	57	**5.0**	40	**3.2**	6	**0.9**	82	**6.0**
Unknown Powerhouse 2	69	**3.6**	18	**1.6**	54	**4.3**	45	**6.8**	72	**5.3**
Unknown	0	**0.0**	0	**0.0**	0	**0.0**	0	**0.0**	0	**0.0**
Total	1906		1135		1251		665		1370	

Table 13. Most upstream point reached in fishways before Chinook salmon first exited into the tailrace.

	Chinook salmon									
	1997		1998		2000		2001		2002	
Antenna location	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**
Inside Powerhouse 1 collection channel	90	**15.0**	66	**14.8**	85	**19.5**	9	**3.0**	79	**21.2**
Inside A-Branch transition pool	82	**13.7**	115	**25.7**	89	**20.5**	29	**9.6**	41	**11.0**
Above A-Branch transition pool	6	**1.0**	4	**0.9**	1	**0.2**	0	**0.0**	1	**0.3**
Inside B-Branch transition pool	67	**11.2**	59	**13.2**	47	**10.8**	34	**11.2**	28	**7.5**
Above B-Branch transition pool	3	**0.5**	4	**0.9**	3	**0.7**	6	**2.0**	2	**0.5**
Inside Cascade Island transition pool	33	**5.5**	23	**5.2**	23	**5.3**	14	**4.6**	51	**13.7**
Above Cascade Island transition pool	3	**0.5**	1	**0.2**	1	**0.2**	0	**0.0**	1	**0.3**
Inside Powerhouse 2 collection channel	128	**21.4**	88	**19.7**	87	**20.0**	106	**35.0**	75	**20.1**
Below Powerhouse 2 transition pool	79	**13.2**	11	**2.5**	16	**3.7**	4	**1.3**	11	**3.0**
Inside Powerhouse 2 transition pool	98	**16.4**	74	**16.6**	80	**18.4**	84	**27.7**	71	**19.0**
Above Powerhouse 2 transition pool	10	**1.7**	2	**0.5**	3	**0.7**	17	**5.6**	13	**3.5**
Total Powerhouse 1 fishway	178	**29.7**	185	**41.4**	175	**40.2**	38	**12.5**	121	**32.4**
Total B-Branch fishway	70	**11.7**	63	**14.1**	50	**11.5**	40	**13.2**	30	**8.0**
Total Cascade Island fishway	36	**6.0**	24	**5.4**	24	**5.5**	14	**4.6**	52	**13.9**
Total Powerhouse 2 fishway	315	**52.6**	175	**39.2**	186	**42.8**	211	**69.6**	170	**45.6**
Total	599		447		435		303		373	

(mostly < 1%) retreated to the tailrace after being recorded on sites upstream from transition pools. The one exception was that about 6% of the salmon that exited in 2001 did so after passing through the Washington-shore transition pool. The upper end of transition pools was determined by daily tailwater elevation. Given the detection range of antennas, it was possible that some fish recorded at antennas upstream from the submerged-weirs were still in the transition pool. Relatively few fish were recorded for extended periods at the upper antennas before being recorded at downstream sites, suggesting that few fish moved far up the ladder.

Fishway entrance effectiveness - In each year almost all fishway entrances had more entries than exits by spring–summer Chinook salmon (Table 14). Negative net entry rates occurred only in 1997 and 2002 at the south-shore entrance at Powerhouse I, likely reflecting the tendency for fish to enter at sluice gate entrances and then move downstream and exit at the south-shore entrance. The highest net first entry sites were sluice gates and the spillway entrances in 1997, 1998, 2000, and 2002; the south-shoreline entrances at both powerhouses had the highest net first entries in 2001. Net total entries followed similar patterns, although the sluice gates had the highest net total in 1997. Again, the lack of monitoring of orifice gates in later years likely resulted in underestimates for those sites.

A negative net entry rate at a fishway entrance did not mean that the entrance did not produce dam passages, as Chinook salmon successfully passed the dam following entries at all sites (Table 15). Majorities of successful fish last entered the Bradford Island fishways in years with Powerhouse I priority and the Washington-shore fishways in years with Powerhouse II priority. The entry sites used by the highest percentages of successful passages were at the spillway entrances in 1997 and 1998, the south spillway or south-shore Powerhouse I entry in 2000, the shoreline entrances at Powerhouse II in 2001, and the south spillway and north-shore Powerhouse II entrance in 2002 (Table 15). As with many other entrance use metrics, these estimates likely reflected the shift in powerhouse priority.

The probability of Chinook salmon exiting a fishway to the tailrace varied with the location of first fishway entry. On average, fish that first entered the spillway entrances were the least likely to exit (32% exited) (Figure 9). About 43% of the fish that entered the south- or north-shore entrances or the sluice gates at Powerhouse I exited. Salmon were more likely to exit if they first entered at Powerhouse II: mean exit percentages were 69% for the south-shore Powerhouse II entrance, 67% for the orifice entrances (1997-1998 only), and 57% for the north-shore entrance at Powerhouse II. Note that fish did not necessarily exit via the same site where they first entered for this summary.

Movements between fishways - In all years, Chinook salmon moved between entrances and between fishways at high rates before passing the dam (Table 16). Of those salmon that first approached at the south-shore entrance at Powerhouse I, 20-41% first entered at either spillway or Powerhouse II entrances. Similarly, 24-51% of those that first approached at sluice gates and 30-47% of those that first approached at the north-shore Powerhouse I entrance first entered spillway or Powerhouse II entrances. Fourteen to 31% of those that first approached at the south spillway entrance first entered at other sites, as did 7-61% of those that first entered at the north spillway entrance (Table 16). It is not clear why variability was so high for the north spillway site, though sample sizes were relatively small. Majorities of the fish that first approached at the various Powerhouse II entrances also subsequently entered fishways at other sites.

Despite considerable movement between fishways, Chinook salmon tended to pass the dam via the fish ladder adjoining the fishway they first approached: 57 to 82% of fish that first

Table 14. Net first and total fishway entrances and exits by radio-tagged spring–summer Chinook salmon, steelhead, and sockeye salmon at Bonneville Dam; entrances and exits with unknown times were included at specific entrances if telemetry records inside fishways clearly identified the site.

	Chinook salmon									
	1997		1998		2000		2001		2002	
Net entrances	First	Total	First	Total	First	Total	First	Total	First	Total
South-shore Powerhouse 1	-1	-12	51	77	83	89	125	157	11	-28
Sluice gates Powerhouse 1	100	165	86	147	50	113	27	35	38	104
North-shore Powerhouse 1	59	115	25	51	46	95	16	22	30	84
South spillway	76	190	125	216	134	242	86	152	121	212
North spillway	70	193	58	119	91	154	18	38	118	175
South-shore Powerhouse 2	15	96	28	76	26	79	126	171	47	74
Orifice gates Powerhouse 2	33	201	52	145	not monitored					
North-shore Powerhouse 2	-2	-21	15	32	45	77	107	160	101	160
Unknown Powerhouse 1	6	18	22	32	10	15	6	8	10	2
Unknown Powerhouse 2	-2	0	12	23	18	66	33	102	21	84
Unknown	1	2	0	0	0	0	0	0	1	1
	Steelhead								Sockeye	
	1997		2000		2001		2002		1997	
	First	Total	First	Total	First	Total	First	Total	First	Total
South-shore Powerhouse 1	36	25	30	-21	31	34	-3	-119	48	55
Sluice gates Powerhouse 1	106	183	57	140	10	27	48	202	19	62
North-shore Powerhouse 1	50	76	47	125	24	55	9	54	47	93
South spillway	61	129	63	117	95	193	83	195	30	89
North spillway	84	131	31	61	51	112	48	114	18	55
South-shore Powerhouse 2	-2	5	38	128	55	143	58	243	-11	-52
Orifice gates Powerhouse 2	3	11	not monitored						12	36
North-shore Powerhouse 2	96	186	113	183	52	-35	63	-56	25	96
Unknown Powerhouse 1	55	78	17	24	-2	0	31	-62	19	27
Unknown Powerhouse 2	22	58	0	31	52	223	-17	286	-4	43
Unknown	1	2	-1	-1	0	0	0	0	0	1

Table 15. Last fishway entrance used by radio-tagged Chinook salmon at Bonneville Dam and ladder used to pass the dam; entrances with unknown times were included at specific entrances if telemetry records inside fishways clearly identified the site.

	Chinook salmon									
	1997		1998		2000		2001		2002	
Last entrances	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**
South-shore Powerhouse 1	59	**6.2**	121	**13.1**	179	**19.0**	139	**16.4**	44	**5.0**
Sluice gates Powerhouse 1	104	**11.0**	79	**8.6**	52	**5.5**	37	**4.4**	59	**6.7**
North-shore Powerhouse 1	85	**9.0**	74	**8.0**	71	**7.5**	37	**4.4**	50	**5.7**
South spillway	188	**19.9**	213	**23.1**	241	**25.6**	152	**18.0**	209	**23.9**
North spillway	192	**20.3**	122	**13.2**	154	**16.4**	39	**4.6**	174	**19.9**
South-shore Powerhouse 2	92	**9.7**	101	**11.0**	70	**7.4**	166	**19.6**	84	**9.6**
Orifice gates Powerhouse 2	58	**6.1**	71	**7.7**	not monitored					
North-shore Powerhouse 2	111	**11.7**	88	**9.5**	116	**12.3**	191	**22.6**	192	**21.9**
Unknown Powerhouse 1	39	**4.1**	38	**4.1**	18	**1.9**	9	**1.1**	13	**1.5**
Unknown Powerhouse 2	16	**1.7**	15	**1.6**	40	**4.3**	75	**8.9**	49	**5.6**
Unknown	2	**0.2**	0	**0.0**	0	**0.0**	0	**0.0**	1	**0.1**
Total	946		922		941		845		875	
Ladder used to pass dam										
Bradford Island	474	**50.1**	524	**56.3**	557	**58.8**	374	**43.8**	376	**42.6**
Washington shore	470	**49.7**	397	**42.7**	379	**40.0**	470	**55.0**	496	**56.2**
Navigation lock	2	**0.2**	1	**0.1**	8	**0.8**	9	**1.1**	9	**1.0**
Unknown[1]	0	**0.0**	8	**0.9**	3	**0.3**	1	**0.1**	1	**0.1**

Table 16. Location of first fishway entrances by radio-tagged spring–summer Chinook salmon at Bonneville Dam based on first approach site; approaches and entries with unknown times were included at specific entrances if subsequent telemetry records inside fishways clearly identified approach site.

			First fishway entry site									
			Powerhouse 1			Spillway		Powerhouse 2			Unknown	
First approach site	Year	*n*	1	2	3	4	5	6	7	8	South	North
1) South-shore Powerhouse 1	1997	50	60.0	14.0	6.0	14.0	2.0	2.0	0.0	2.0	0.0	0.0
	1998	243	31.9	16.0	12.3	14.0	7.0	6.6	2.5	1.6	8.2	0.8
	2000	240	40.0	10.0	11.3	14.2	7.1	6.6		5.0	3.8	2.5
	2001	101	60.4	7.9	6.9	3.0	0.0	12.9		6.9	1.0	1.0
	2002	114	14.0	22.8	14.0	14.0	8.8	7.0		11.4	7.0	0.9
2) Sluice gates Powerhouse 1	1997	443	12.9	17.4	14.9	19.6	9.9	7.4	2.7	11.3	3.6	0.2
	1998	211	22.3	15.2	13.3	17.5	6.6	6.2	5.7	3.3	9.5	0.5
	2000	190	27.4	10.5	15.3	15.3	7.9	10.0		6.8	4.7	2.1
	2001	108	41.7	17.6	11.1	2.8	0.9	7.4		13.0	5.6	0.0
	2002	144	7.3	20.1	24.3	12.5	13.2	9.0		6.3	6.3	0.7
3) North-shore Powerhouse 1	1997	84	17.9	22.6	17.9	9.5	8.3	6.0	1.2	7.1	8.3	0.0
	1998	56	23.2	19.6	17.9	14.3	3.6	5.4	1.8	8.9	5.4	0.0
	2000	64	21.9	6.3	18.8	17.2	15.6	4.7		9.4	6.3	0.0
	2001	37	32.4	24.3	10.8	8.1	0.0	8.1		13.5	2.7	0.0
	2002	37	8.1	16.2	32.4	10.8	2.7	5.4		16.2	8.1	0.0
4) South spillway	1997	26	0.0	7.7	0.0	76.9	0.0	3.8	0.0	7.7	3.8	0.0
	1998	42	2.4	2.4	0.0	78.6	9.5	2.4	0.0	0.0	4.8	0.0
	2000	49	6.1	2.0	4.1	77.6	0.0	4.1		2.0	4.1	0.0
	2001	85	0.0	0.0	0.0	85.9	7.1	0.0		3.5	0.0	3.5
	2002	74	2.7	1.4	2.7	68.9	10.8	4.1		4.1	4.1	1.4

Table 16. Continued.

			First fishway entry site									
			Powerhouse 1			Spillway		Powerhouse 2			Unknown	
First approach site	Year	*n*	1	2	3	4	5	6	7	8	South	North
5) North spillway	1997	14	0.0	0.0	0.0	14.3	78.6	7.1	0.0	0.0	0.0	0.0
	1998	17	11.8	0.0	0.0	23.5	58.8	0.0	0.0	5.9	0.0	0.0
	2000	14	0.0	0.0	0.0	7.1	92.9	0.0		0.0	0.0	0.0
	2001	26	3.8	0.0	0.0	30.8	38.5	7.7	n/a	15.4	0.0	3.8
	2002	70	2.9	1.4	0.0	7.1	81.4	1.4		5.7	0.0	0.0
6) South-shore Powerhouse 2	1997	95	1.1	1.1	1.1	6.3	10.5	43.2	10.5	14.7	3.2	6.3
	1998	99	3.0	2.0	0.0	14.1	13.1	37.4	13.1	11.1	0.0	6.1
	2000	128	10.9	4.7	1.6	15.6	10.9	30.5		14.8	1.6	9.4
	2001	261	4.2	0.0	2.7	7.7	4.2	45.2	n/a	24.9	0.0	11.1
	2002	175	2.3	2.3	1.1	16.6	16.6	25.7		24.6	2.3	8.6
7) Orifice gates Powerhouse 2	1997	44	9.1	2.3	0.0	6.8	11.4	38.6	15.9	13.6	2.3	0.0
	1998	44	0.0	11.4	0.0	18.2	4.5	13.6	20.5	18.2	6.8	6.8
8) North-shore Powerhouse 2	1997	188	1.1	1.1	1.1	5.3	15.4	25.5	5.9	42.6	0.0	1.6
	1998	209	4.8	2.4	1.4	23.0	9.6	23.4	11.5	20.6	1.0	2.4
	2000	255	9.8	1.6	1.2	19.2	18.0	15.7		27.1	1.2	6.3
	2001	219	1.8	0.5	0.5	6.4	1.8	41.1	n/a	39.3	0.0	8.7
	2002	255	1.6	1.2	0.4	10.6	17.6	20.4		38.0	1.2	9.0

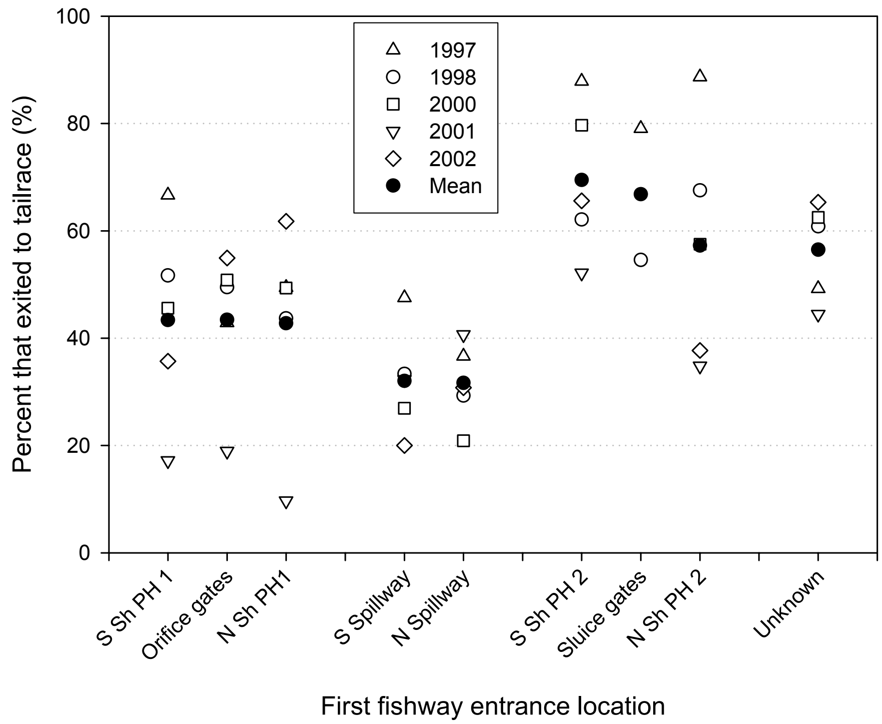

Figure 9. Percentages of radio-tagged Chinook salmon that exited to the tailrace from each major fishway entrance. First entries only.

approached the north- or south-shore Powerhouse I entrance or sluice gates eventually passed the dam via the Bradford Island ladder (Table 17). Between 69-79% of salmon that first approached the south spillway entrance passed the Bradford Island fishway, while 46-86% that first approached the north spillway entrance passed via the Washington-shore fishway. For those that first approached at Powerhouse II entrances, 49-84% eventually passed via the Washington-shore fishway (Table 17).

Some Chinook salmon that approached Bonneville Dam did not pass the dam, but where fish first approached the dam did not appear to be related to non-passage. It was more likely that fish had migrated past tributaries downstream from Bonneville Dam, died (e.g., were killed by pinnipeds), were recaptured in fisheries near the dam after first approaching, or lost transmitters (see Table 67 for fates of non-passing fish).

Fishway exits and dam passage time – Spring–summer Chinook salmon that exited a fishway into the tailrace one or more times at Bonneville Dam had longer dam passage times than fish that did not exit in all months of all years (Table 18). Exiting fish had significantly longer passage times (P < 0.005, K-W χ^2 tests) than non-exiting fish in all months. In each year, delays associated with exiting a fishway into the tailrace in April ranged from 13 to 45 h, or 66-146% of the dam passage times for those fish that did not exit to the tailrace. Differences ranged from 5 to 26 h (27-93%) in May, 8 to 16 h (69-122%) in June, and 4 to 15 h (18-290%) in July. The largest percentage difference (290%) occurred in July 1998, when dam passage times were 5.1 h for 25 non-exiting fish versus 19.9 h for 72 fish that exited (Table 18).

Table 17. Route of dam passage by radio-tagged Chinook salmon, steelhead, and sockeye salmon at Bonneville Dam based on first approach site. BI = Bradford Island fishway; WA = Washington-shore fishway; Nav = navigation lock; Unk = unknown route; DNP = did not pass.

				Dam passage route				
First approach site	Run	Year	*n*	BI	WA	Nav	Unk	DNP
South-shore Powerhouse 1	Chinook salmon	1997	50	82.0	18.0	0.0	0.0	0.0
		1998	243	73.7	26.3	0.0	0.0	0.0
		2000	245	71.3	27.9	1.7	1.3	1.3
		2001	102	79.2	20.8	1.0	0.0	0.0
		2002	117	63.2	36.8	0.9	1.8	1.8
	Steelhead	1997	121	86.8	11.6	0.8	0.0	0.8
		2000	214	69.6	27.1	2.3	0.0	0.9
		2001	65	63.1	33.8	1.5	0.0	1.5
		2002	148	59.5	31.8	5.4	0.0	3.4
	Sockeye salmon	1997	95	77.9	18.9	3.2	0.0	0.0
Sluice gates Powerhouse 1	Chinook salmon	1997	445	60.0	39.1	0.2	0.0	1.1
		1998	213	63.0	36.5	0.5	0.0	0.9
		2000	190	65.8	33.2	0.5	0.0	0.5
		2001	108	75.0	24.1	0.0	0.0	0.9
		2002	144	60.4	39.6	0.0	0.0	0.0
	Steelhead	1997	214	66.4	30.4	0.5	0.0	2.8
		2000	108	66.7	33.3	0.0	0.0	0.0
		2001	60	58.3	36.7	1.7	0.0	3.3
		2002	104	51.9	45.2	1.9	0.0	1.0
	Sockeye salmon	1997	163	69.3	22.1	7.4	0.0	1.2
North-shore Powerhouse 1	Chinook salmon	1997	84	57.1	42.9	0.0	0.0	0.0
		1998	56	66.1	33.9	0.0	0.0	0.0
		2000	64	67.2	32.8	0.0	0.0	0.0
		2001	38	73.0	27.0	0.0	0.0	2.7
		2002	37	59.5	40.5	0.0	0.0	0.0

Table 17. Continued.

				Dam passage route				
First approach site	Run	Year	*n*	BI	WA	Nav	Unk	DNP
	Steelhead	1997	84	77.4	19.0	1.2	0.0	2.4
		2000	58	65.5	27.6	6.9	0.0	0.0
		2001	47	66.0	29.8	0.0	0.0	4.3
		2002	24	58.3	37.5	0.0	0.0	4.2
	Sockeye salmon	1997	77	75.3	20.8	3.9	0.0	0.0
South spillway	Chinook salmon	1997	26	69.2	30.8	0.0	0.0	0.0
		1998	43	78.6	21.4	0.0	0.0	2.4
		2000	49	69.4	26.5	0.0	0.0	4.1
		2001	85	70.6	25.9	0.0	1.2	2.4
		2002	74	78.4	21.6	0.0	0.0	1.4
	Steelhead	1997	62	67.7	30.6	1.6	0.0	0.0
		2000	99	57.6	40.4	2.0	0.0	0.0
		2001	102	68.6	30.4	0.0	0.0	1.0
		2002	116	70.7	24.1	3.4	0.0	1.7
	Sockeye salmon	1997	32	56.3	37.5	3.1	0.0	3.1
North spillway	Chinook salmon	1997	14	14.3	78.6	0.0	0.0	7.1
		1998	17	47.1	52.9	0.0	0.0	0.0
		2000	14	14.3	85.7	0.0	0.0	0.0
		2001	28	23.8	46.2	3.8	0.0	3.8
		2002	70	21.4	78.6	0.0	0.0	0.0
	Steelhead	1997	36	25.0	72.2	0.0	0.0	2.8
		2000	37	24.3	75.7	0.0	0.0	0.0
		2001	46	34.8	63.0	0.0	0.0	2.2
		2002	44	18.2	81.8	0.0	0.0	0.0
	Sockeye salmon	1997	6	0.0	100.0	0.0	0.0	0.0

Table 17. Continued.

				Dam passage route				
First approach site	Run	Year	*n*	BI	WA	Nav	Unk	DNP
South-shore Powerhouse 2	Chinook salmon	1997	95	30.5	68.4	0.0	0.0	1.1
		1998	100	35.4	64.6	0.0	0.0	1.0
		2000	132	50.8	49.2	0.0	0.0	3.1
		2001	262	26.8	73.2	0.0	0.0	0.4
		2002	177	33.7	65.7	1.1	0.0	0.6
	Steelhead	1997	33	15.2	81.8	0.0	0.0	3.0
		2000	75	18.7	78.7	0.0	0.0	2.7
		2001	203	25.1	70.0	3.1	0.0	1.5
		2002	187	28.9	67.9	2.7	0.0	0.5
	Sockeye salmon	1997	32	37.2	56.3	6.3	0.0	0.0
Orifice gates Powerhouse 2	Chinook salmon	1997	45	38.6	63.6	0.0	0.0	0.0
	Chinook salmon	1998	44	31.8	68.2	0.0	0.0	0.0
	Steelhead	1997	29	34.5	65.3	0.0	0.0	0.0
	Sockeye salmon	1997	27	44.4	51.9	3.7	0.0	0.0
North-shore Powerhouse 2	Chinook salmon	1997	190	24.5	72.3	0.5	0.0	3.7
		1998	209	38.8	59.8	0.5	0.0	1.0
		2000	258	45.1	52.9	2.0	0.4	0.8
		2001	220	16.0	84.0	0.0	0.0	0.5
		2002	256	23.5	76.1	0.8	0.0	0.0
	Steelhead	1997	274	24.8	71.9	1.1	0.0	2.2
		2000	210	20.5	77.1	0.5	0.5	1.4
		2001	247	25.1	73.7	0.8	0.0	0.4
		2002	272	28.3	67.6	2.2	0.0	1.8
	Sockeye salmon	1997	97	37.1	55.7	4.1	0.0	3.1

Table 18. Number of adult radio-tagged spring–summer Chinook salmon, and median times (h) to pass from first tailrace record to pass Bonneville Dam based on month fish were first detected in the tailrace and whether or not fish exited from a fishway into the tailrace.

		Chinook salmon									
		1997		1998		2000		2001		2002	
	Month	*n*	Med (h)	*n*	Med (h)	*n*	Med (h)	*n*	Med (h)	*n*	Med (h)
Did not exit fishway	April	109	27.4	209	18.8	291	32.6	196	52.8	183	45.9
	May	135	17.2	155	15.7	114	19.7	165	18.8	166	37.3
	June	55	10.6	49	11.4	39	12.8	51	13.6	44	13.5
	July	42	10.5	25	5.1	35	11.9	46	14.9	23	15.9
	August					1	4.9				
Exited a fishway	April	198	**67.5	121	**31.6	158	**69.8	41	**97.5	65	**76.4
	May	173	**33.2	112	**21.9	105	**25.0	89	**26.8	101	**62.9
	June	86	**23.5	103	**19.3	80	**22.9	64	**23.1	114	**29.4
	July	107	**18.9	72	**19.9	66	**23.8	50	**19.3	53	**30.1
	August										

* $P < 0.05$, ** $P < 0.005$ Kruskal-Wallis χ^2 test

Steelhead

Steelhead were monitored as they approached and entered the major fishway entrances at both Powerhouses and the spillway at Bonneville Dam in all years. Coverage at Powerhouse II orifice gates was limited to 1997, after which fish could enter them undetected. The size of and discharge from fishways were probably important factors in attracting fish. (See Chinook salmon section for fishway entrance dimensions.)

Between 778 and 909 steelhead were known to have approached fishways each year, 771 to 904 were known to have entered fishways, and 392 to 575 exited fishways (Table 5). In each year, > 98% of fish that approached fishways subsequently entered and 43 to 64% of the fish that entered eventually exited into the tailrace. Steelhead approached fishways a median of 6 to 9 times (means = 13 to 17 times), and entered a median of 1 to 2 times (means = 2 to 4). Fish that exited fishways exited a median of 2 to 3 times in all years (means = 2 to 5). Because orifice gate entrances were unmonitored in later years, some fish approached, entered and exited through orifice gates undetected, resulting in a loss of precision for behavior summaries.

Approaches to fishways - Steelhead first approached fishways at Bonneville Dam at all monitored entrances (Table 19). No single entrance site was used by a majority of steelhead in any year. As with Chinook salmon, approach sites were at least partially a response to powerhouse priority. Priority differences resulted in substantial changes in the distribution of fish attraction flows, and these were reflected in the sites steelhead used.

When priority was at Powerhouse 1 (1997 and 2000), 47-51% of steelhead first approached fishways at Powerhouse I entrances, 11-17% first approached at the spillway entrances, and 36-38% first approached at Powerhouse 2 entrances (Figure 7). The shift to Powerhouse II priority in 2001-2002 resulted in decreased percentages of fish first approaching at Powerhouse I entrances (22-31%), and an increase in the numbers first approaching the spillway entrances (18-19%) and Powerhouse II entrances (51-59%).

Site preferences for first fishway approaches varied somewhat with spill volume and powerhouse priority, but the north-shore Powerhouse II was most approached under most conditions (Table 20). The south-shore entrance at Powerhouse I and sluice gates were also frequently used, particularly in 1997. When priority was at Powerhouse II, most fish first approached there in 2001 and 2002. As spill increased there was a tendency for increasing percentages of first approaches at spillway entrances.

Distributions of combined first and subsequent approaches at fishway entrances (total approaches) differed from those for first approaches (Table 19). The highest percentages of total fishway approaches were at the Powerhouse II orifice gates in 1997 (when they were monitored), and were at Powerhouse I sluice gates in subsequent years. The second most used sites were orifice gates in 1997 and either the north- or south-shore Powerhouse II entrances in subsequent years. The total approach numbers reflected the tendency of adult fish to move along the face of the dam powerhouses, approaching (or at least passing very near) orifice gate and sluice gate entrances, as well as the priority switch. Note that Powerhouse II orifice gates were unmonitored in 2000-2002 and that many fish likely approached those sites, particularly when priority switched to Powerhouse II.

No clearly different patterns emerged in regard to the distribution of total approaches in relation to spill (Table 21). Orifice gates and/or sluice gates were most approached. When priority switched (and monitoring of orifice gates ended) more fish approached at the

Table 19. Location of first and total fishway approaches by radio-tagged steelhead and sockeye salmon at Bonneville Dam; approaches with unknown times were included at specific entrances if subsequent telemetry records inside fishways clearly identified approach site.

	Steelhead								Sockeye	
	1997		2000		2001		2002		1997	
First approaches	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**
South-shore Powerhouse 1	121	**13.3**	214	**26.5**	65	**8.3**	148	**16.3**	95	**17.5**
Sluice gates Powerhouse 1	214	**23.5**	108	**13.4**	60	**7.7**	104	**11.5**	163	**30.1**
North-shore Powerhouse 1	84	**9.2**	58	**7.2**	47	**6.0**	24	**2.6**	77	**14.2**
South spillway	62	**6.8**	99	**12.3**	102	**13.1**	116	**12.8**	32	**5.9**
North spillway	36	**4.0**	37	**4.6**	46	**5.9**	44	**4.8**	6	**1.1**
South-shore Powerhouse 2	33	**3.6**	75	**9.3**	203	**26.1**	187	**20.6**	32	**5.9**
Orifice gates Powerhouse 2	29	**3.2**	not monitored						27	**5.0**
North-shore Powerhouse 2	274	**30.1**	210	**26.0**	247	**31.7**	272	**30.0**	97	**17.9**
Unknown Powerhouse 1	48	**5.3**	2	**0.2**	0	**0.0**	5	**0.6**	12	**2.2**
Unknown Powerhouse 2	8	**0.9**	4	**0.5**	8	**1.0**	8	**0.9**	1	**0.2**
Unknown	0	**0.0**	0	**0.0**	0	**0.0**	0	**0.0**	0	**0.0**
Total	909		807		778		908		542	
Total approaches										
South-shore Powerhouse 1	273	**2.3**	1589	**12.9**	1206	**9.0**	1107	**7.5**	228	**3.5**
Sluice gates Powerhouse 1	2041	**17.4**	5134	**41.6**	3602	**26.8**	4239	**28.8**	1256	**19.6**
North-shore Powerhouse 1	683	**5.8**	1468	**11.9**	1221	**9.1**	1329	**9.0**	534	**8.3**
South spillway	285	**2.4**	444	**3.6**	584	**4.3**	671	**4.6**	202	**3.1**
North spillway	243	**2.1**	332	**2.7**	409	**3.0**	401	**2.7**	96	**1.5**
South-shore Powerhouse 2	1497	**12.8**	1538	**12.5**	3108	**23.1**	3551	**24.1**	727	**11.3**
Orifice gates Powerhouse 2	4892	**41.8**	not monitored						2506	**39.0**
North-shore Powerhouse 2	1677	**14.3**	1764	**14.3**	3179	**23.6**	2831	**19.2**	802	**12.5**
Unknown Powerhouse 1	94	**0.8**	10	**0.1**	0	**0.0**	205	**1.4**	45	**0.7**
Unknown Powerhouse 2	30	**0.3**	64	**0.5**	133	**1.0**	382	**2.6**	27	**0.4**
Unknown	2	**0.0**	1	**0.0**	1	**0.0**	0	**0.0**	0	**0.0**
Total	11717		12344		13433		14716		6423	

Table 20. Percentage of **first** approaches to fishway entrances by radio-tagged steelhead and sockeye salmon at Bonneville Dam based on mean daily spill (kcfs) on the date of the approach. Approaches with unknown times were included at specific sites if subsequent telemetry records clearly identified approach site.

SK97											
Spill	*n*	SSh PH1	OGs	NSh PH1	SSpill	Unk OR	NSpill	SSh PH2	SGs	NSh PH2	Unk WA
50-99	254	16	**24**	18	8	0	2	5	7	21	0
100-149	77	20	**38**	10	5	0	0	10	4	13	0
150-199	133	22	**35**	12	7	0	1	6	4	14	0
200-249	27	4	**63**	15	0	0	0	0	0	19	0
250-299	8	25	**50**	25	0	0	0	0	0	0	0
300-349	30	27	**30**	13	0	0	0	10	3	17	0
>350	16	25	13	6	6	0	0	6	6	**38**	0
SH97											
0	421	23	20	12	6	0	4	4	5	**25**	1
1-49	11	18	9	0	9	0	9	0	0	**55**	0
50-99	183	8	**37**	6	8	1	3	3	2	33	0
100-149	255	10	29	9	6	0	6	4	2	**35**	0
150-199	22	14	18	14	9	0	5	0	0	**41**	0
200-249	4	25	**50**	0	0	0	0	0	0	25	0
250-299											
300-349	12	**58**	17	8	0	0	0	0	0	17	0
>350											
SH00											
0	299	19	12	6	8	0	5	17		**33**	0
50-99	386	**31**	15	10	14	0	4	6		21	0
100-149	121	**32**	11	3	18	0	6	5		25	0

Table 20. Continued.

Spill	*n*	SSh PH1	OGs	NSh PH1	SSpill	Unk OR	NSpill	SSh PH2	SGs	NSh PH2	Unk WA
SH01											
0	140	9	14	4	10	0	4	28		**31**	0
1-49	638	8	6	6	14	0	6	26		**32**	1
SH02											
1-49	301	13	11	2	3	0	4	33		**34**	1
50-99	332	15	12	3	18	0	7	18		**26**	1
100-149	232	20	11	3	19	0	4	13		**29**	0
150-199	40	30	18	3	10	0	0	5		**35**	0
200-249	3	0	0	0	0	0	0	33		**67**	0

Table 21. Percentage of **total** approaches to fishway entrances by radio-tagged steelhead and sockeye salmon at Bonneville Dam based on mean daily spill (kcfs) on the date of the approach. Approaches with unknown times were included at specific sites if subsequent telemetry records clearly identified approach site.

SK97											
Spill	*n*	SSh PH1	OGs	NSh PH1	SSpill	Unk OR	NSpill	SSh PH2	SGs	NSh PH2	Unk WA
50-99	2766	4	21	9	3	0	2	9	**41**	12	0
100-149	983	4	18	7	3	0	1	14	**39**	12	0
150-199	1533	3	16	7	2	0	1	16	**39**	15	0
200-249	373	1	24	9	3	0	2	9	**38**	14	0
250-299	109	8	**42**	23	5	0	1	3	10	8	0
300-349	394	5	24	11	5	0	1	11	**34**	10	0
>350	268	4	17	5	4	0	1	13	**44**	13	0
SH97											
0	4536	5	17	6	2	0	2	10	**44**	13	0
1-49	92	4	5	2	5	1	2	25	**39**	12	3
50-99	2190	1	22	7	3	0	2	9	**40**	16	0
100-149	4573	1	16	5	2	0	2	17	**41**	15	0
150-199	163	4	20	6	2	0	6	11	**34**	18	0
200-249	29	3	**41**	7	0	0	0	10	24	14	0
250-299	2	0	0	0	0	0	0	**100**	0	0	0
300-349	109	7	23	6	9	0	3	14	**31**	6	0
>350											
SH00											
0	4555	11	**34**	11	3	0	3	18		21	1
50-99	6229	14	**47**	13	4	0	3	9		11	0
100-149	1556	14	**43**	12	5	0	3	10		11	0

Table 21. Continued.

Spill	*n*	SSh PH1	OGs	NSh PH1	SSpill	Unk OR	NSpill	SSh PH2	SGs	NSh PH2	Unk WA
SH01											
0	3066	11	**31**	12	3	0	3	18		23	1
1-49	10377	9	**26**	8	5	0	3	25		24	1
SH02											
1-49	6369	7	26	8	4	0	3	**30**		20	4
50-99	4536	7	**29**	9	5	0	3	24		20	2
100-149	3105	9	**34**	11	6	0	3	19		17	1
150-199	591	14	**35**	12	3	0	2	15		19	0
200-249	106	11	**52**	9	1	0	2	9		13	2

Powerhouse II entrances. Again, note that steelhead almost certainly moved along the face of Powerhouse II, approaching entrances there.

Entries to fishways - Steelhead first entered fishways at Bonneville Dam at all monitored entrances (Table 22). No single entrance site was used by a majority of steelhead in any year. Entry sites were at least partially a response to powerhouse priority—the allocation of discharge through turbines at either Powerhouse I or II. Priority differences resulted in substantial changes in the distribution of fish attraction flows, and these were reflected in the sites steelhead used to enter fishways (Figure 8).

As with fishway approaches, there was a shift in entrance use away from Powerhouse I entrance sites when powerhouse priority switched to Powerhouse II. Steelhead tended to first enter at the larger shoreline entrances at both powerhouses, though relatively high percentages of entries were also at the two spillway entrances, particularly after the powerhouse priority shift (Table 22). No single entrance site had more than 35% of first or total entries in any year, though about 31% of total entrances were at the south-shore entrance at Powerhouse II in 2001 and 2002.

At zero spill, the highest percentages of steelhead first entered the north-shore entrance at Powerhouse II (1997, 2000) or the south-shore entrance at Powerhouse II (2001) (Table 23). There was no zero spill in 2002, though many days had spill < 5 kcfs and steelhead again favored the south-shore entrance at Powerhouse II. Patterns were similar at higher spill, though more steelhead entered the spillway entrances during moderate spill levels and the percentage first using the south-shore entrance at Powerhouse I increased as spill increased (Table 23).

When all entrances were considered, steelhead continued to favor shoreline entrances and those at the ends of powerhouses (Table 22). The north-shore entrance at Powerhouse II was favored in 1997 at all spill levels, while the south-shore entrance at Powerhouse II was favored in 2002 (Table 24). Patterns otherwise were generally similar to those for first entries.

Exits from fishways – The distribution of first and total fishway exits was related to the distribution of entries (i.e., fish tended to exit at or near where they entered). There was also a strong tendency for steelhead to exit at the larger entrances at the ends of collection channels, such as the north- and south-shore entrances at both powerhouses (Table 25). Many exits at these sites occurred after fish entered at orifice or sluice gate, moved down collection channels, and then exited at the shoreline sites. In general, the largest percentages of both first and total exits occurred at the north- and south-shore entrances at Powerhouse II and the south-shore entrance at Powerhouse I. However, in 1997 relatively few steelhead exited the south-shore entrance at Powerhouse II and relatively few exited the south-shore entrance at Powerhouse I in 2001 (Table 25).

Most upstream point reached before first fishway exit – We estimated where steelhead turned around in fishways and ladders before their first fishway exit to the tailrace (Table 26). This metric provided a good estimate of where fish first encountered unfavorable conditions and retreated back to the tailrace, a behavior that greatly increased dam passage times. Relatively sparse telemetry coverage in some portions of fishways, particularly in ladders upstream from transition pools, limited resolution in this analysis. Between 5-17% of steelhead that exited did so after being inside the Powerhouse I collection channel, and 7-33% did so after being inside the Powerhouse II collection channel, though the latter was likely an underestimate given the relatively few antenna sites after 1997. Most of the remaining fish that exited did so after entering transition pools at the base of ladders: 4-25% after entering the A-Branch pool, 7-11%

Table 22. Location of first and total fishway entrances by radio-tagged steelhead and sockeye salmon at Bonneville Dam; entries with unknown times were included at specific entrances if subsequent telemetry records inside fishways clearly identified entry site.

	Steelhead								Sockeye	
	1997		2000		2001		2002		1997	
First entrances	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**
South-shore Powerhouse 1	103	**11.4**	110	**13.8**	46	**6.0**	76	**8.5**	124	**23.4**
Sluice gates Powerhouse 1	112	**12.4**	76	**9.5**	15	**1.9**	62	**6.9**	34	**6.4**
North-shore Powerhouse 1	86	**9.5**	80	**10.0**	39	**5.1**	21	**2.3**	87	**16.4**
South spillway	104	**11.5**	105	**13.1**	125	**16.2**	121	**13.5**	66	**12.4**
North spillway	107	**11.8**	58	**7.3**	72	**9.3**	77	**8.6**	21	**4.0**
South-shore Powerhouse 2	13	**1.4**	116	**14.5**	189	**24.5**	230	**25.7**	55	**10.4**
Orifice gates Powerhouse 2	8	**0.9**	not monitored						16	**3.0**
North-shore Powerhouse 2	217	**24.0**	193	**24.1**	168	**21.8**	185	**20.7**	78	**14.7**
Unknown Powerhouse 1	113	**12.5**	30	**3.8**	1	**0.1**	41	**4.6**	45	**8.5**
Unknown Powerhouse 2	40	**4.4**	32	**4.0**	116	**15.0**	82	**9.2**	8	**1.5**
Unknown	1	**0.1**	0	**0.0**	1	**0.1**	0	**0.0**	0	**0.0**
Total										
Total entrances										
South-shore Powerhouse 1	164	**9.0**	284	**12.5**	131	**5.1**	258	**6.7**	185	**13.7**
Sluice gates Powerhouse 1	199	**11.0**	191	**8.4**	45	**1.8**	261	**6.8**	84	**6.2**
North-shore Powerhouse 1	157	**8.7**	202	**8.9**	95	**3.7**	114	**3.0**	158	**11.7**
South spillway	234	**12.9**	257	**11.3**	335	**13.1**	417	**10.9**	156	**11.6**
North spillway	189	**10.4**	212	**9.4**	204	**8.0**	284	**7.4**	75	**5.6**
South-shore Powerhouse 2	61	**3.4**	455	**20.1**	798	**31.1**	1220	**31.8**	242	**18.0**
Orifice gates Powerhouse 2	29	**1.6**	not monitored						60	**4.5**
North-shore Powerhouse 2	460	**25.4**	472	**20.8**	475	**18.5**	668	**17.4**	226	**16.8**
Unknown Powerhouse 1	196	**10.8**	44	**1.9**	7	**0.3**	102	**2.7**	79	**5.9**
Unknown Powerhouse 2	122	**6.7**	147	**6.5**	474	**18.5**	517	**13.5**	81	**6.0**
Unknown	2	**0.1**	1	**0.0**	1	**0.0**	0	**0.0**	1	**0.1**
Total	1811		2265		2565		3841		1347	

Table 23. Percentage of **first** fishway entries by radio-tagged steelhead and sockeye salmon at Bonneville Dam based on mean daily spill (kcfs) on the date of the entry. Approaches with unknown times were included at specific sites if subsequent telemetry records clearly identified entry site.

SK97											
Spill	*n*	SSh PH1	OGs	NSh PH1	SSpill	Unk OR	NSpill	SSh PH2	SGs	NSh PH2	Unk WA
50-99	255	17	15	16	13	0	4	10	4	**20**	0
100-149	80	**35**	4	16	14	3	6	5	4	14	0
150-199	128	**26**	10	21	13	0	3	15	7	5	0
200-249	27	15	15	**30**	7	0	7	15	0	11	0
250-299	10	**40**	10	30	0	0	0	0	0	20	0
300-349	29	**41**	3	14	14	0	0	14	0	14	0
>350	15	**27**	0	13	13	0	0	20	0	20	7
SH97											
0	422	16	22	15	8	0	6	0	0	**28**	5
1-49	11	18	0	0	18	9	9	0	0	**36**	9
50-99	184	9	21	9	13	1	9	6	3	**26**	**3**
100-149	244	16	14	7	18	0	**23**	0	2	16	3
150-199	22	18	9	18	5	0	9	5	9	**23**	5
200-249	4	0	**50**	25	0	0	0	0	25	0	0
250-299											
300-349	12	**58**	0	8	8	0	8	8	0	8	0
SH00											
0	301	10	9	10	7	0	6	22		**29**	7
50-99	378	19	11	12	17	0	8	11		**21**	2
100-149	120	9	15	10	18	0	8	15		**22**	3

Table 23. Continued.

Spill	*n*	SSh PH1	OGs	NSh PH1	SSpill	Unk OR	NSpill	SSh PH2	SGs	NSh PH2	Unk WA
SH01											
0	138	10	2	9	7	0	10	**30**		23	9
1-49	634	5	2	4	18	0	9	**30**		22	10
SH02											
1-49	307	5	7	2	5	0	8	**38**		21	14
50-99	336	9	10	2	19	0	10	**25**		19	9
100-149	216	12	11	4	19	1	9	17		**24**	3
150-199	36	**28**	8	11	6	0	3	17		25	3
200-249	3	0	0	0	0	0	0	**67**		0	33

Table 24. Percentage of **total** fishway entries by radio-tagged steelhead and sockeye salmon at Bonneville Dam based on mean daily spill (kcfs) on the date of the entry. Approaches with unknown times were included at specific sites if subsequent telemetry records clearly identified entry site.

SK97											
Spill	*n*	SSh PH1	OGs	NSh PH1	SSpill	Unk OR	NSpill	SSh PH2	SGs	NSh PH2	Unk WA
50-99	654	11	11	12	12	0	7	17	9	**21**	2
100-149	167	**25**	14	13	14	2	5	11	5	11	1
150-199	318	15	7	14	10	0	4	**26**	11	13	1
200-249	54	9	11	17	9	0	11	**22**	7	13	0
250-299	26	**35**	12	27	4	0	0	0	4	19	0
300-349	87	**25**	5	15	15	0	2	20	5	14	0
>350	61	15	2	16	16	0	2	**33**	3	12	2
SH97											
0	828	14	19	12	10	0	7	0	1	**30**	7
1-49	26	12	0	4	19	4	8	0	0	**35**	19
50-99	405	8	17	9	14	1	9	9	5	**24**	4
100-149	442	13	16	8	17	0	18	1	3	**19**	4
150-199	49	14	8	12	4	0	12	18	6	**20**	4
200-249	6	0	**33**	17	0	0	0	17	17	17	0
250-299	2	0	0	0	0	0	0	**100**	0	0	0
300-349	38	**21**	11	11	**21**	0	5	**21**	3	8	0
SH00											
0	887	10	7	8	7	0	6	**32**		25	6
50-99	1068	15	11	11	15	0	12	15		**19**	3
100-149	308	13	14	8	13	0	10	**21**		16	5

Table 24. Continued.

Spill	*n*	SSh PH1	OGs	NSh PH1	SSpill	Unk OR	NSpill	SSh PH2	SGs	NSh PH2	Unk WA
SH01											
0	455	10	4	9	8	0	8	**30**		21	10
1-49	2110	4	2	3	14	0	8	**41**		18	11
SH02											
1-49	1469	4	5	2	8	0	7	**43**		15	16
50-99	1300	8	9	4	12	0	7	**35**		18	9
100-149	879	8	14	5	16	1	9	**25**		20	4
150-199	162	19	11	11	5	1	4	**24**		25	1
200-249	30	27	10	10	3	0	7	**23**		13	7

Table 25. Location of first and total fishway exits by radio-tagged steelhead and sockeye salmon at Bonneville Dam; exits with unknown times were included at specific entrances if subsequent telemetry records inside fishways clearly identified exit site.

	Steelhead								Sockeye	
	1997		2000		2001		2002		1997	
First exits	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**
South-shore Powerhouse 1	67	**17.1**	80	**19.8**	15	**3.7**	79	**13.7**	76	**23.0**
Sluice gates Powerhouse 1	6	**1.5**	19	**4.7**	5	**1.2**	14	**2.4**	15	**4.5**
North-shore Powerhouse 1	36	**9.2**	33	**8.1**	15	**3.7**	12	**2.1**	40	**12.1**
South spillway	43	**11.0**	42	**10.4**	30	**7.4**	38	**6.6**	36	**10.9**
North spillway	23	**5.9**	27	**6.7**	21	**5.2**	29	**5.0**	3	**0.9**
South-shore Powerhouse 2	15	**3.8**	78	**19.3**	134	**33.2**	172	**29.9**	66	**19.9**
Orifice gates Powerhouse 2	5	**1.3**	not monitored						4	**1.2**
North-shore Powerhouse 2	121	**30.9**	80	**19.8**	116	**28.7**	122	**21.2**	53	**16.0**
Unknown Powerhouse 1	58	**14.8**	13	**3.2**	3	**0.7**	10	**1.7**	26	**7.9**
Unknown Powerhouse 2	18	**4.6**	32	**7.9**	64	**15.8**	99	**17.2**	12	**3.6**
Unknown	0	**0.0**	1	**0.3**	1	**0.3**	0	**0.0**	0	**0.0**
Total	392		405		404		575		331	
Total exits										
South-shore Powerhouse 1	139	**15.0**	305	**20.6**	97	**5.4**	377	**12.6**	130	**15.4**
Sluice gates Powerhouse 1	16	**1.7**	51	**3.5**	18	**1.0**	59	**2.0**	22	**2.6**
North-shore Powerhouse 1	81	**8.7**	77	**5.2**	40	**2.2**	60	**2.0**	65	**7.7**
South spillway	105	**11.3**	140	**9.5**	142	**7.8**	222	**7.4**	67	**8.0**
North spillway	58	**6.2**	151	**10.2**	92	**5.1**	170	**5.7**	20	**2.4**
South-shore Powerhouse 2	56	**6.0**	327	**22.1**	655	**36.1**	977	**32.7**	294	**34.9**
Orifice gates Powerhouse 2	18	**1.9**	not monitored						24	**2.9**
North-shore Powerhouse 2	274	**29.5**	289	**19.6**	510	**28.1**	724	**24.3**	130	**15.4**
Unknown Powerhouse 1	118	**12.7**	20	**1.4**	7	**0.4**	164	**5.5**	52	**6.2**
Unknown Powerhouse 2	64	**6.9**	116	**7.8**	251	**13.8**	231	**7.7**	38	**4.5**
Unknown	0	**0.0**	2	**0.1**	1	**0.1**	0	**0.0**	0	**0.0**
Total	929		1478		1813		2984		842	

Table 26. Most upstream point reached in fishways before steelhead and sockeye salmon first exited into the tailrace.

	Steelhead								Sockeye	
	1997		2000		2001		2002		1997	
Antenna location	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**
Inside Powerhouse 1 collection channel	50	**17.3**	49	**12.2**	19	**4.7**	66	**11.5**	95	**29.0**
Inside A-Branch transition pool	71	**24.6**	78	**19.5**	15	**3.7**	46	**8.0**	55	**16.8**
Above A-Branch transition pool	4	**1.4**	5	**1.3**	1	**0.3**	4	**0.7**	5	**1.5**
Inside B-Branch transition pool	33	**11.4**	41	**10.2**	29	**7.2**	37	**6.5**	37	**11.3**
Above B-Branch transition pool	0	**0.0**	1	**0.3**	2	**0.5**	0	**0**	0	**0**
Inside Cascade Island transition pool	12	**4.2**	23	**5.7**	15	**3.7**	26	**4.6**	2	**0.6**
Above Cascade Island transition pool	1	**0.4**	1	**0.3**	3	**0.8**	0	**0.0**	1	**0.3**
Inside Powerhouse 2 collection channel	20	**6.9**	70	**17.5**	134	**33.3**	167	**29.2**	76	**23.2**
Below Powerhouse 2 transition pool	21	**7.3**	1	**0.3**	8	**2.0**	22	**3.9**	30	**9.2**
Inside Powerhouse 2 transition pool	70	**24.2**	99	**24.7**	18	**29.4**	163	**28.5**	26	**7.9**
Above Powerhouse 2 transition pool	7	**2.4**	33	**8.2**	58	**14.4**	41	**7.2**	1	**0.3**
Total Powerhouse 1 fishway	125	**43.3**	132	**32.9**	35	**8.7**	116	**20.3**	155	**40.6**
Total B-Branch fishway	33	**11.4**	42	**10.5**	31	**7.7**	37	**6.5**	37	**11.3**
Total Cascade Island fishway	13	**4.5**	24	**6.0**	18	**4.5**	26	**4.6**	3	**0.9**
Total Powerhouse 2 fishway	118	**40.8**	203	**50.6**	318	**79.1**	393	**68.7**	133	**47.3**
Total	289		401		402		572		328	

after entering the B-Branch pool, 4-6% after entering the Cascades Island pool, and 24-29% after entering the Washington-shore pool. The largest percentages of first turnaround locations were at the A-Branch or Washington-shore transition pools in 1997 and 2000, and in the Powerhouse II collection channel or Washington-shore pool in 2001 and 2002 (Table 26). Again, the change in telemetry coverage likely influenced these estimates. Small proportions (mostly < 2%) retreated to the tailrace after being recorded on sites upstream from transition pools, except that 2-14% did so after passing through the Washington-shore transition pool.

Fishway entrance effectiveness - In each year the majority of fishway entrances had more entries than exits by steelhead (Table 14). Negative net entry rates occurred at the south-shore entrance at Powerhouse I in 2000 and 2002, likely reflecting the tendency for fish to enter at sluice gate entrances and then move downstream and exit at the south-shore entrance. Negative entry rates also occurred at the north-shore entrance at Powerhouse II in 2001 and 2002. The highest net first entry sites were sluice gates in 1997, the north-shore entrance at Powerhouse II in 2000, and at the south spillway entrance in 2001 and 2002 (Table 14). Net total entries were highest at the north-shore entrance at Powerhouse II in 1997 and 2000.

A negative net entry rate at a fishway entrance did not mean that the entrance did not produce dam passages, as steelhead successfully passed the dam following entries at all sites (Table 27). Majorities of successful fish last entered the Bradford Island fishways in 1997, 2000, and 2001, while more passed the Washington-shore fishway in 2002. This was somewhat in contrast to observations for Chinook salmon, for which passage mirrored powerhouse priority patterns. The difference between species was most likely a factor of run timing: most steelhead passed after peak spill and flow, and were thus less affected by the distribution of attractive flows in the tailrace. The entry sites used by the highest percentages of successful passages were at the spillway entrances in 1997, 2000, and 2001 and was at the north-shore Powerhouse II entrance in 2002 (Table 27).

The probability of steelhead exiting a fishway to the tailrace varied with the location of first fishway entry. Fish that first entered the spillway entrances were the least likely to exit (30-33% exited, on average) (Figure 10). On average, 50% of the fish that entered the south-shore entrance at Powerhouse I, 45% that first entered sluice gates, and 43% that first entered the north-shore entrance at Powerhouse I subsequently exited. The likelihood of exit was higher for the Washington-shore fishway, with an average of 55% exiting after first entry at the north-shore entrance at Powerhouse II and 83% exiting after entry at the north-shore entrance (Figure 10). Note that fish did not necessarily exit via the same site where they first entered for this summary.

Movement between fishways - In all years, steelhead moved between entrances and between fishways at high rates before passing the dam (Table 28). On average, 25% of those steelhead that first approached at the south-shore entrance at Powerhouse I first entered at either spillway or Powerhouse II entrances. An average of 35-40% of those that first approached at sluice gates or at the north-shore Powerhouse I entrance first entered spillway or Powerhouse II entrances. Nineteen to 32% of those that first approached at the south spillway entrance first entered at other sites, as did 14-35% of those that first entered at the north spillway entrance (Table 28). Majorities of the fish that first approached at the various Powerhouse II entrances also subsequently entered fishways at other sites, except that 53% of the steelhead that first approached the south-shore entrance entered there in 2002 and 56-64% that first approached the north-shore entrance entered there in 1997 and 2000.

Table 27. Last fishway entrance used by radio-tagged steelhead and sockeye salmon at Bonneville Dam and ladder used to pass the dam; entrances with unknown times were included at specific entrances if telemetry records inside fishways clearly identified the site.

	Steelhead								Sockeye	
	1997		2000		2001		2002		1997	
Last entrances	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**
South-shore Powerhouse 1	71	**8.0**	97	**12.1**	51	**6.6**	69	**7.7**	75	**14.0**
Sluice gates Powerhouse 1	99	**11.1**	68	**8.5**	17	**2.2**	64	**7.2**	46	**8.6**
North-shore Powerhouse 1	91	**10.2**	92	**11.5**	47	**6.1**	29	**3.2**	99	**18.5**
South spillway	134	**15.0**	113	**14.1**	191	**24.8**	199	**22.2**	91	**17.0**
North spillway	141	**15.8**	69	**8.6**	118	**15.3**	125	**14.0**	56	**10.5**
South-shore Powerhouse 2	15	**1.7**	86	**10.8**	80	**10.4**	101	**11.3**	10	**1.9**
Orifice gates Powerhouse 2	4	**0.4**	not monitored						7	**1.3**
North-shore Powerhouse 2	183	**20.5**	208	**26.0**	135	**17.5**	159	**17.8**	93	**17.4**
Unknown Powerhouse 1	101	**11.3**	17	**2.1**	2	**0.3**	31	**3.5**	38	**7.1**
Unknown Powerhouse 2	50	**5.6**	50	**6.3**	130	**16.9**	118	**13.2**	18	**3.4**
Unknown	2	**0.2**	0	**0.0**	0	**0.0**	0	**0.0**	1	**0.2**
Total	891		800		771		895		534	
Ladder used to pass dam										
Bradford Island	487	**53.2**	385	**47.3**	308	**39.7**	381	**41.9**	334	**59.4**
Washington shore	396	**43.2**	402	**49.4**	449	**57.9**	487	**53.6**	176	**31.3**
Navigation lock	30	**3.3**	25	**3.1**	18	**2.3**	41	**4.5**	52	**9.3**
Unknown[1]	3	**0.3**	2	**0.2**	1	**0.1**	0	**0.0**	0	**0.0**

Table 28. Location of first fishway entrances by radio-tagged steelhead and sockeye salmon at Bonneville Dam based on first approach site; approaches and entries with unknown times were included at specific entrances if subsequent telemetry records inside fishways clearly identified approach site.

			First fishway entry site									
			Powerhouse 1			Spillway		Powerhouse 2			Unknown	
First approach site	Year	*n*	1	2	3	4	5	6	7	8	South	North
1) South-shore Powerhouse 1	1997	120	59.2	17.5	13.3	2.5	0.0	0.0	0.0	3.3	4.2	0.0
	2000	211	33.2	19.4	17.5	4.3	2.8	7.6		9.0	4.3	1.9
	2001	63	33.3	7.9	17.5	6.3	11.1	11.1	n/a	6.3	0.0	6.3
	2002	142	36.6	20.4	8.5	2.1	4.9	6.3		7.0	9.2	4.9
	1997[1]	95	83.2	3.2	9.5	1.1	0.0	0.0	0.0	3.2	0.0	0.0
2) Sluice gates Powerhouse 1	1997	213	7.5	30.5	16.0	8.9	11.3	2.3	0.9	4.2	16.4	1.4
	2000	108	20.4	22.2	19.4	9.3	5.6	4.6		15.7	0.9	1.9
	2001	58	15.5	10.3	32.8	15.5	3.4	6.9	n/a	8.6	0.0	6.9
	2002	103	7.8	22.3	6.8	10.7	8.7	15.5		18.4	6.8	2.9
	1997[1]	155	20.6	9.7	28.4	14.2	5.2	3.2	0.6	6.5	11.6	0.0
3) North-shore Powerhouse 1	1997	83	9.6	22.9	36.1	6.0	2.4	0.0	1.2	2.4	18.1	1.2
	2000	56	17.9	16.1	26.8	5.4	7.1	8.9		5.4	7.1	5.4
	2001	45	24.4	8.9	17.8	13.3	4.4	8.9	n/a	8.9	2.2	11.1
	2002	23	17.4	17.4	8.7	13.0	4.3	8.7		13.0	8.7	8.7
	1997[1]	77	10.4	18.2	41.6	13.0	0.0	0.0	0.0	1.3	15.6	0.0
4) South spillway	1997	62	0.0	3.2	1.6	80.6	9.7	0.0	0.0	4.8	0.0	0.0
	2000	98	3.1	2.0	2.0	68.4	12.2	1.0		9.2	1.0	1.0
	2001	102	2.9	0.0	0.0	71.6	14.7	6.9	n/a	1.0	0.0	2.9
	2002	112	2.7	2.7	0.0	76.8	7.1	4.5		5.4	0.0	0.9
	1997[1]	32	3.1	0.0	0.0	87.5	0.0	0.0	0.0	9.4	0.0	0.0

[1] Sockeye salmon

Table 28. Continued.

			First fishway entry site									
			Powerhouse 1			Spillway		Powerhouse 2			Unknown	
First approach site	Year	*n*	1	2	3	4	5	6	7	8	South	North
5) North spillway	1997	36	0.0	0.0	0.0	8.3	86.1	0.0	0.0	0.0	5.6	0.0
	2000	37	2.7	0.0	0.0	10.8	64.9	8.1		10.8	0.0	2.7
	2001	46	2.2	0.0	0.0	21.7	67.4	6.5	n/a	0.0	0.0	2.2
	2002	44	0.0	0.0	0.0	6.8	79.5	6.8		6.8	0.0	0.0
	1997[1]	6	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0
6) South-shore Powerhouse 2	1997	33	0.0	0.0	0.0	6.1	6.1	15.2	0.0	51.5	3.0	18.2
	2000	74	2.7	0.0	5.4	6.8	2.7	32.4		32.4	0.0	17.6
	2001	203	0.5	0.0	0.5	3.9	4.9	44.8	n/a	21.7	0.0	23.2
	2002	186	3.2	1.1	0.0	4.3	5.4	52.7		17.2	0.0	16.1
	1997[1]	32	3.1	0.0	3.1	3.1	3.1	53.1	9.4	18.8	3.1	3.1
7) Orifice gates Powerhouse 2	1997	29	0.0	10.3	10.3	6.9	20.7	0.0	3.4	37.9	3.4	6.9
	1997[1]	27	11.1	0.0	3.7	3.7	11.1	37.0	14.8	11.1	3.7	3.7
8) North-shore Powerhouse 2	1997	272	2.9	0.7	0.7	7.4	13.2	1.5	1.5	64.0	1.1	7.0
	2000	210	1.0	0.0	0.5	3.3	1.9	29.5		55.7	0.5	7.6
	2001	247	0.0	0.0	0.0	6.1	2.0	29.6	n/a	44.5	0.0	17.8
	2002	272	1.1	0.4	0.0	2.6	2.6	35.7		41.2	0.7	15.8
	1997[1]	997	0.0	2.1	0.0	3.1	3.1	23.7	8.2	53.6	1.0	5.2

[1] Sockeye salmon

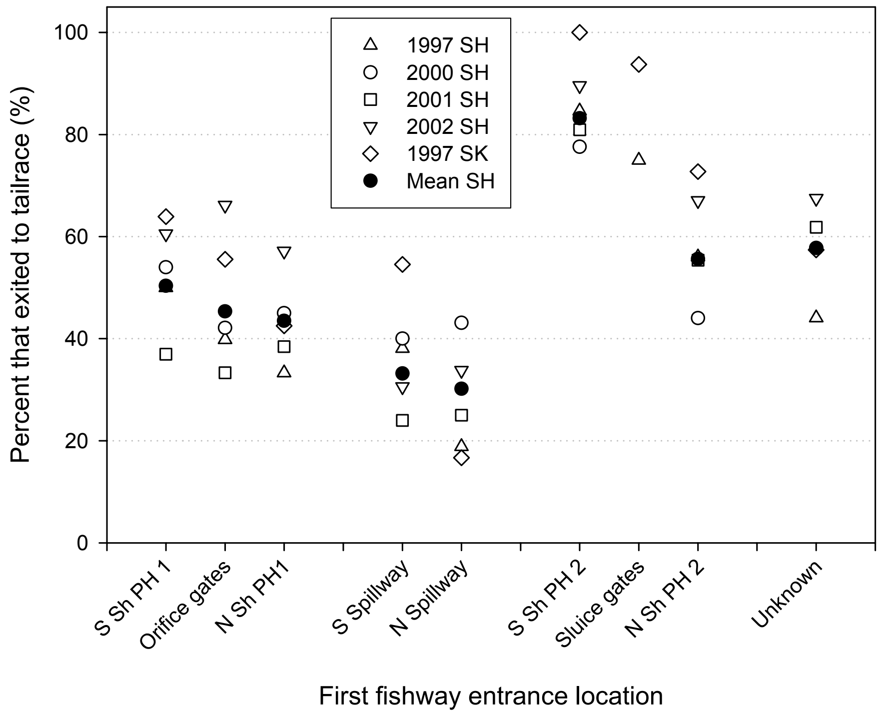

Figure 10. Percentages of radio-tagged steelhead and sockeye salmon that exited to the tailrace from each major fishway entrance. First entries only.

Despite considerable movement between fishways, steelhead tended to pass the dam via the fish ladder adjoining the fishway they first approached: 52-87% of fish that first approached the north- or south-shore Powerhouse I entrance or sluice gates eventually passed the dam via the Bradford Island ladder (Table 17). Between 58-71% of steelhead that first approached the south spillway entrance passed the Bradford Island fishway, while 63-82% that first approached the north spillway entrance passed via the Washington-shore fishway. For those that first approached at Powerhouse II entrances, 68-82% eventually passed via the Washington-shore fishway (Table 17).

Some steelhead that approached Bonneville Dam did not pass the dam, but where fish first approached the dam did not appear to be related to non-passage. It was more likely that fish had migrated past tributaries downstream from Bonneville Dam, died (e.g., were killed by pinnipeds), were recaptured in fisheries near the dam after first approaching, or lost transmitters (see Table 67 for fates of non-passing fish).

Fishway exits and dam passage time – Steelhead that exited a fishway into the tailrace one or more times at Bonneville Dam had longer dam passage times than fish that did not exit in almost all months of all years (Table 29). Exiting fish had significantly longer passage times (P < 0.005, K-W χ^2 tests) than non-exiting fish in 18 of 20 months; the remaining two showed significance in the same direction at lower levels (P < 0.05). In each year, delays associated with exiting a fishway into the tailrace in June ranged from 5 to 38 h, or 44-608% of the dam passage times for those fish that did not exit to the tailrace. The very large difference (608%)

Table 29. Number of adult radio-tagged steelhead and sockeye salmon, and median times (h) to pass from first tailrace record to pass Bonneville Dam based on month fish were first detected in the tailrace and whether or not fish exited from a fishway into the tailrace.

		Steelhead								Sockeye	
		1997		2000		2001		2002		1997	
	Month	*n*	Med (h)	*n*	Med (h)	*n*	Med (h)	*n*	Med (h)	*n*	Med (h)
Did not exit fishway	June	17	10.8	21	8.7	20	15.1	22	6.3	130	9.2
	July	114	16.1	53	17.5	68	11.1	50	22.4	104	7.4
	August	127	18.1	166	16.2	147	12.8	138	17.9	1	5.4
	September	170	12.8	67	8.8	87	16.0	73	15.8		
	October	41	15.9	70	15.0	40	17.3	25	17.7		
Exited a fishway	June	31	*15.6	34	**24.3	53	*20.0	59	**44.6	156	**23.7
	July	78	**28.7	86	**45.9	82	**31.8	128	**38.0	163	**17.8
	August	88	**28.5	126	**25.6	119	**24.8	179	**43.9	2	12.6
	September	97	**21.3	75	**23.1	102	**25.4	139	**25.4		
	October	31	**18.6	50	**21.6	19	**23.8	16	*23.8		

* $P < 0.05$, ** $P < 0.005$ Kruskal-Wallis χ^2 test

occurred in 2002, when 22 fish that did not exit passed the dam in a median time of 6.3 h while 59 fish that exited had a median of 44.6 h. Differences ranged from 13 to 28 h (70-186%) in July, 9 to 26 h (54-163%) in August, 9 to 14 h (54-163%) in September, and 3 to 7 h (17-44%) in October (Table 29).

Sockeye salmon

Of the 542 sockeye salmon that approached fishways in 1997, 98.2% entered and 62% of those eventually exited back to the tailrace (Table 5). Sockeye salmon approached fishways a median of 7 times (mean = 12 times), and entered a median of 2 times (mean = 3). Fish that exited fishways exited a median of 2 times (mean = 3).

Approaches to fishways - Sockeye salmon first approached fishways at Bonneville Dam at all monitored entrances (Table 19). No single entrance site was used by a majority of sockeye salmon in any year. The highest percentage (30%) first approached at sluice gates, followed by the north-shore entrance at Powerhouse II (18%) and the south-shore entrance at Powerhouse I (18%). Under almost all spill conditions, the highest percentages of first approaches were at sluice gates (Table 20). The larger shoreline entrances were also approached first by many fish. Small numbers of sockeye salmon first approached at spillway entrances at low spill levels; no fish first approached the spillway sites when spill was > 200 kcfs.

Distributions of combined first and subsequent approaches at fishway entrances (total approaches) differed from those for first approaches (Table 19). Much like steelhead, the highest percentages of total fishway approaches by sockeye salmon were at the Powerhouse II orifice gates (39%) followed by Powerhouse I sluice gates (20%). The total approach numbers reflect the tendency of adult fish to move along the face of the dam powerhouses, approaching (or at least passing very near) orifice gate and sluice gate entrances.

No clearly different patterns emerged in regard to the distribution of total approaches in relation to spill (Table 21). Sluice gates and/or orifice gates were most approached. There was also an increase in approaches at the north-shore Powerhouse II entrance as spill increased.

Entries to fishways - Sockeye salmon first entered fishways at Bonneville Dam at all monitored entrances (Table 22). No single entrance site was used by a majority of sockeye salmon in any year, though entrances at Powerhouse I were preferred relative to Chinook salmon or steelhead (Figure 8). The most used first entrance site was the south-shore entrance at Powerhouse I (23%), followed by the north-shore entrance at Powerhouse I (16%) and the north-shore entrance at Powerhouse II (15%). First entry locations did not vary widely with different spill levels, except that use of spillway entrances tended to decrease as spill increased (Table 23).

When all entrances were considered, sockeye salmon continued to favor shoreline entrances and those at the ends of powerhouses (Table 22). However, there was a shift away from Powerhouse I entrances and to Powerhouse II entrances. The distribution of total entries by spill level (Table 24) showed the greatest use was at the south-shore entrances at both powerhouses, with no apparent pattern in regards to spill.

Exits from fishways – The distribution of first and total fishway exits was related to the distribution of entries (i.e., fish tended to exit at or near where they entered). There was also a strong tendency for sockeye salmon to exit at the larger entrances at the ends of collection channels, such as the north- and south-shore entrances at both powerhouses (Table 25). Many exits at these sites occurred after fish entered at orifice or sluice gate, moved down collection channels, and then exited at the shoreline sites. In general, the largest percentages of both first and total exits occurred at the north- and south-shore entrances at Powerhouse II and the south-shore entrance at Powerhouse I. These results were similar to those for steelhead.

Most upstream point reached before first fishway exit – We estimated where sockeye salmon turned around in fishways and ladders before their first fishway exit to the tailrace (Table 26). The largest percentage of first turnarounds occurred in the Powerhouse I collection channel (29%), followed by the Powerhouse II collection channel (23%), the A-Branch transition pool (17%) and the B-Branch transition pool (11%). A total of 17% first turned at the base of or in the Washington-shore transition pool (Table 26).

Fishway entrance effectiveness - All fishway entrances except the south-shore entrance at Powerhouse II had more entries than exits by sockeye salmon (Table 14). The negative net entry rate at this site likely reflects the tendency for fish to enter at sluice gate entrances and then move downstream and exit at the south-shore entrance. The highest net first entry sites were at the north- and south-shore entrances at Powerhouse I (Table 14). Net total entries were highest at the north-shore entrances at both powerhouses, followed by the south spillway entrance. It is interesting to note that each of these entrances leads directly into a ladder.

A negative net entry rate at a fishway entrance did not mean that the entrance did not produce dam passages, as sockeye salmon successfully passed the dam following entries at all sites (Table 27). The majority (59%) of successful fish last entered the Bradford Island fishways, while 31% passed the Washington-shore fishway and 9% passed via the navigation lock. Sockeye salmon used the lock to pass the dam more than either Chinook salmon (0-1%) or steelhead (2-5%). Last fishway entries for successful fish were evenly distributed, with 11-19% each at both spillway entrances, both shoreline entrances at Powerhouse I and at the north-shore entrance at Powerhouse II. Sluice and orifice gates as well as the south-shore entrance at Powerhouse II produced relatively few successful passages.

The probability of sockeye salmon exiting a fishway to the tailrace varied with the location of first fishway entry. Fish that first entered the north spillway entrance were the least likely to exit (17% exited) (Figure 10). Exit percentages following first fishway entry were 43-64% at the Powerhouse I entrances, 73-100% at the Powerhouse II entry, and 55% at the south spillway entrance. Sockeye salmon were more likely to exit to the tailrace than either Chinook salmon or steelhead, though we emphasize that only one year of sockeye salmon data was collected. Note that fish did not necessarily exit via the same site where they first entered for this summary.

Movement between fishways - Sockeye salmon moved between entrances and between fishways before passing the dam, but they were more likely than either Chinook salmon or steelhead to first enter at the same location where they first approached fishways (Table 28). For example, more than 80% of the sockeye salmon that first approached at the south-shore entrance at Powerhouse I and the two spillway entrances made their first entrances at those same sites. In contrast, only 10-15% of those fish that first approached orifice and sluice gates first entered at those sites (10-15%).

Sockeye salmon also tended to pass the dam via the fish ladder adjoining the fishway they first approached: 69-78% of fish that first approached the north- or south-shore Powerhouse I entrance or sluice gates eventually passed the dam via the Bradford Island ladder (Table 17).

Fifty-six percent of salmon that first approached the south spillway entrance passed the Bradford Island fishway, while 100% that first approached the north spillway entrance passed via the Washington-shore fishway (though $n = 6$). For those that first approached at Powerhouse II entrances, 52-56% eventually passed via the Washington-shore fishway (Table 17).

Some sockeye salmon that approached Bonneville Dam did not pass the dam. Non-passers approached at only three sites: sluice gates, the south spillway entrance, or the north-shore Powerhouse II entrance. There is nothing to indicate, however, that the location of first approach affected the likelihood of passage. It was more likely that fish had migrated past tributaries downstream from Bonneville Dam, died (i.e., were killed by pinnipeds), were recaptured in fisheries near the dam after first approaching, or lost transmitters (see Table 67 for fates of non-passing fish).

Fishway exits and dam passage time – Sockeye salmon that exited a fishway into the tailrace one or more times at Bonneville Dam had longer dam passage times than fish that did not exit in both June and July (Table 29). Exiting fish had significantly longer passage times ($P < 0.005$, K-W χ^2 tests). Delays associated with exiting a fishway into the tailrace were 14.5 h in June and 10.4 h in July. These delays (based on median times) represented 141-158% of the dam passage times for those fish that did not exit to the tailrace.

Movements Through Fishways and Transition Pools

Chinook salmon

Transition pool selection and behavior in pools -- We analyzed behavior of 614 to 718 Chinook salmon with complete passage histories as they moved into fishways, through transition pools and up ladders at Bonneville Dam in each of five years (Table 30). A total of 842 to 940 fish had recorded first transition pool entries. Passage behaviors for fish that missed antennas appeared to be similar to fish with complete records.

The locations of first transition pool entries varied with powerhouse priority. In 1997, 1998, and 2000, first entry locations were 34-38% at the A-Branch pool, 19-25% at the B-Branch pool, 11-15% at the Cascades Island pool, and 25-32% at the Washington shore pool. In 2001 and 2002, first entry locations were 20-25% at the A-Branch pool, 17-21% at the B-Branch pool, 5-22% at the Cascades Island pool, and 37-53% at the Washington shore pool. Most fish (81 to 90%) passed the dam via the fishway (Bradford Island vs. Washington shore) associated with the transition pool they first entered, while the remainders (10 to 19%) exited the first transition pool they entered, crossed the spillway tailrace and passed the dam via the other fishway (Figure 11).

For between-year consistency, summaries below are only for fish with complete passage histories. Fifteen to 27% of fish with complete passage histories moved straight through a transition pool and entered a ladder with no downstream movement (Table 30). Twenty-six to 45% moved downstream in a transition pool before entering the ladder but were not recorded at antennas inside the collection channel downstream from the transition pool and were not recorded exiting into the tailrace. Seven to 14% exited transition pools and were recorded at antennas in the collection channel but did not exit into the tailrace. (This behavior was likely underestimated in later years, when the Powerhouse II collection channel had more limited

Table 30. Transition pool behavior by adult radio-tagged spring–summer Chinook salmon at Bonneville Dam for fish with telemetry records at all passage points (tailrace, first fishway entry, first transition pool entry, transition pool exit into a ladder and exit from the top of a ladder). All transition pools combined.

	Chinook salmon									
	1997		1998		2000		2001		2002	
Behavior in transition pool	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Moved straight through	116	**16.9**	108	**15.0**	163	**24.4**	111	**18.1**	169	**27.1**
Moved downstream, but did not exit	177	**25.7**	231	**32.2**	203	**30.2**	276	**45.0**	220	**35.3**
Exited pool into collection channel	66	**9.6**	98	**13.6**	72	**10.8**	76	**12.4**	43	**6.9**
Exited pool into tailrace	329	**47.8**	281	**39.1**	29	**34.3**	151	**24.6**	192	**30.8**
Total	688		718		667		614		624	

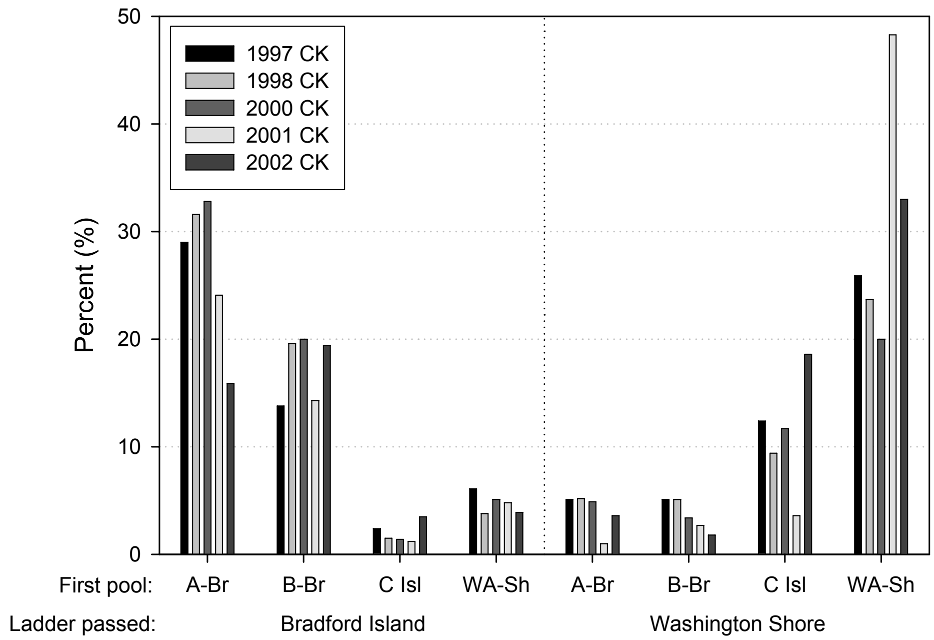

Figure 11. First transition pool entered by radio-tagged Chinook salmon and eventual ladder passed.

antenna coverage.) The remaining fish exited a transition pool into the tailrace before passing the dam: 48% in 1997, 39% in 1998, 34% in 2000, 25% in 2001, and 31% in 2002 (Table 30).

Mean annual percentages that exited to the tailrace from each transition pool after first entry were 31% from the A-Branch pool, 32% from the B-Branch pool, 35% from the Cascades Island pool, and 41% from the Washington-shore pool (Table 31). Mean annual percentages that moved straight through pools with no downstream movement were 28% for the A-Branch pool, 13% for the B-Branch pool, 14% for the Cascades Island pool, and 19% for the Washington-shore pool. Transition pool delay (fish turned around in submerged-weir area, but did not exit to the collection channel or tailrace) was the most common behavior in both the B-Branch (mean = 52%) and Cascades Island (50%) pools; 36% of salmon that first entered the Washington-shore pool and 10% that entered the A-Branch pool had this behavior. Percentages that moved downstream into collection channels (but not the tailrace) after transition pool entry averaged 8% at the Washington-shore pool (1997 and 1998 only) and 31% at the A-Branch pool (Table 31).

Passage time from first fishway entry to first transition pool entry – Chinook salmon passage times from first fishway entry to first entry into a transition pool varied little between years. Median times to first enter the B-Branch and Cascades Island pools, which were almost immediately inside the fishways was ≤ 1 min (0.02 h) in all years. Median times were 0.11 to 0.22 h to first enter the A-Branch transition pool for all fishway entrances combined ranged and 0.07 to 0.54 h to first enter the Washington-shore pool (note that the lack of monitoring at orifice gate entrances likely reduced the median in later years). Less than 5% of the salmon took more than 24 h from first fishway entry to first transition pool entry at any site, except at the Washington-shore pool in 1997 (8.3% took > 24 h) and at the B-Branch pool in 2000 (5.8%)

Table 31. Transition pool behavior by adult radio-tagged spring–summer Chinook salmon at Bonneville Dam for fish with telemetry records at all passage points (tailrace, first fishway entry, first transition pool entry, transition pool exit into a ladder and exit from the top of a ladder) based on transition pool first entered.

	Chinook salmon									
	1997		1998		2000		2001		2002	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
First entered WA-shore pool										
Moved straight through	50	**19.8**	34	**16.4**	23	**12.8**	50	**15.3**	61	**28.5**
Moved downstream, but did not exit	41	**16.2**	64	**30.9**	74	**41.3**	180	**55.2**	81	**37.9**
Exited pool into collection channel[1]	11	**4.3**	24	**11.6**	3	**1.7**	7	**2.1**	0	**0.0**
Exited pool into tailrace	151	**59.7**	85	**41.1**	79	**44.1**	89	**27.3**	72	**33.6**
Total	253		207		179		326		214	
First entered Cascades Island pool										
Moved straight through	5	**4.7**	7	**9.9**	8	**26.7**	3	**13.0**	25	**18.0**
Moved downstream, but did not exit	57	**53.8**	44	**62.0**	16	**53.3**	9	**39.1**	60	**43.2**
Exited pool into tailrace	44	**41.5**	20	**28.2**	6	**20.0**	11	**47.8**	4	**38.8**
Total	106		71		30		23		139	
First entered B-Branch pool										
Moved straight through	14	**10.1**	36	**19.4**	38	**22.0**	7	**6.7**	32	**24.1**
Moved downstream, but did not exit	57	**41.3**	86	**46.2**	90	**52.0**	66	**63.5**	76	**57.1**
Exited pool into tailrace	67	**48.6**	64	**34.4**	45	**26.0**	31	**29.8**	25	**18.8**
Total	138		183		173		104		133	
First entered A-Branch pool										
Moved straight through	47	**24.6**	31	**12.2**	94	**33.0**	51	**31.7**	51	**37.0**
Moved downstream, but did not exit	22	**11.5**	37	**14.6**	23	**8.1**	21	**13.0**	3	**2.2**
Exited pool into collection channel[1]	55	**28.8**	74	**29.1**	69	**24.2**	69	**42.9**	43	**31.2**
Exited pool into tailrace	67	**35.1**	112	**44.1**	99	**34.7**	20	**12.4**	41	**29.7**
Total	191		254		285		161		138	

[1] Monitoring of Powerhouse 2 collection channel was limited starting in 2000

Table 32. Number of adult radio-tagged spring–summer Chinook salmon and median and quartile times to pass from first fishway entry to first transition pool entry at Bonneville Dam, based on first transition pool entered and for all fish.

	Chinook salmon										
	WA-shore transition pool						**Cascades Island transition pool**				
	1997	1998	2000	2001	2002		1997	1998	2000	2001	2002
n	253	207	179	326	214		106	71	30	23	139
1st quartile (h)	0.23	0.10	0.02	0.04	0.02		0.01	0.01	0.01	0.01	0.01
Median (h)	0.54	0.23	0.17	0.16	0.07		0.02	0.01	0.02	0.01	0.02
3rd quartile (h)	2.24	0.74	0.55	0.49	0.65		1.12	0.08	0.04	0.04	0.08
Percent that took > 24 h (%)	8.3%	1.5%	3.9%	0.9%	3.3%		2.8%	0.0%	0.0%	0.0%	4.3%
	B-Branch transition pool						**A-Branch transition pool**				
	1997	1998	2000	2001	2002		1997	1998	2000	2001	2002
n	138	186	176	104	133		191	254	285	161	138
1st quartile (h)	0.01	0.01	0.01	0.01	0.00		0.02	0.04	0.06	0.13	0.03
Median (h)	0.02	0.02	0.02	0.01	0.01		0.11	0.18	0.22	0.20	0.19
3rd quartile (h)	0.07	0.08	0.07	0.04	0.06		0.31	0.31	0.52	0.28	0.40
Percent that took > 24 h (%)	1.5%	1.1%	5.8%	2.9%	6.0%		3.7%	0.4%	2.8%	0.6	4.4%
	All transition pools combined										
	1997	1998	2000	2001	2002						
n	688	718	667	614	624						
1st quartile (h)	0.02	0.02	0.02	0.02	0.01						
Median (h)	0.16	0.12	0.10	0.13	0.04						
3rd quartile (h)	0.86	0.34	0.46	0.32	0.35						
Percent that took > 24 h (%)	4.8%	0.8%	3.8%	1.1%	4.3%						

(Table 32). Longer passage times for this segment were almost all for fish that exited a fishway back to the tailrace one or more times prior to entering a transition pool.

Passage time from first transition pool entry to exit a pool into a ladder – Chinook salmon passage times from first transition pool entry to exit a pool into a ladder were the most variable of all dam passage segments. For all fish with telemetry records at each passage point, median pool passage times ranged from 0.4 to 1.9 h for all pools combined (Table 33). Medians tended to be highest for those fish that first entered the Cascades Island pool (medians = 1.0-1.8 h) and shortest for those that entered the A-Branch pool (0.2-1.2 h). Longer times for those that first entered the Cascades Island pool may have been because many of the fish that exited at that location subsequently passed through another pool. With all transition pools combined, from 8 to 20% of Chinook salmon took more than 24 h to pass through a pool and into a ladder.

Fish that moved straight through a transition pool on their first attempt, with no recorded downstream movements, had median passage times ≤ 0.80 h (48 min) at all transition pools in all years (Table 34). In fact, few fish that moved straight through transition pool had pool passage times > 30 min except at the Cascades Island pool. Fish that delayed in a transition pool by moving downstream (but were not recorded at antennas in the collection channel or tailrace) had median passage times ≤ 1.00 h at all sites in all years, except at the Cascades Island pool in 1997 (median = 1.05 h) and 2002 (1.34 h). Fish that delayed in the A-Branch pool and exited into the collection channel—but not into the tailrace—had median times of ≤ 0.80 h (48 min) from first pool entry to exit the pool into the A-Branch ladder. Those that exited the Washington-shore pool into the collection channel had median times of 1.1-1.2 h in 1997 and 1998. Median times for those that exited pool into the tailrace were much higher: 4.9 to 18.8 h for those that exited the Washington-shore pool, 4.9-29.4 h for those that exited the Cascades Island pool, 7.4-21.6 h for those that exited the B-Branch pool, and 2.6-24.1 h for those that exited the A-Branch pool (Table 34). On average, 36% of the salmon that exited a transition pool took more than 24 h to pass though a pool into a ladder (all years and pools combined). For comparison, for almost all other years and behaviors < 2% of all fish that did not exit took > 24 h to pass through a pool (Table 34).

Passage time to ascend a ladder – After exiting transition pools into ladders, Chinook salmon ascended ladders relatively quickly at Bonneville Dam in all years. Median times to ascend from the top-of-pool sites ranged from 2.7 to 4.6 h from the Washington-shore pool, 2.9-4.3 h from the Cascades Island pool, 2.0-3.0 h from the B-Branch pool, and 2.2-2.9 h from the A-Branch pool (Table 35). Less than 1.5% took more than 24 h to ascend from any site in any year.

Passage time from first tailrace record to pass the dam – Within years, Chinook salmon behavior in transition pools was a good predictor of overall time to pass Bonneville Dam (Totals in Table 36). When all fish and all transition pools were combined, median passage times from first tailrace record to exit from the top of a ladder were highest for fish that exited transition pools into the tailrace in each year. Median times in 1997 were 17.2-20.0 h for fish that did not exit versus 37.2 h for fish that did exit, a difference of 16.9-20.0 h (Table 36). Exiting fish took 6.5-9.5 h longer, on median, in 1998, and 9.3-13.0 h longer in 2000. Differences were smallest in 2001 (0.9-3.5 h), perhaps because of the low flow and spill conditions in that year. Times were most variable in 2002, with medians ranging from 22.8 h for fish that moved straight through, to 40.6 h for fish that delayed in pools, to 49.2 h for fish that exited to the tailrace (Table 36). There was a strong seasonal effect for all years and behaviors, with median monthly passage times decreasing as water temperatures increased (Table 36).

Table 33. Number of adult radio-tagged spring–summer Chinook salmon and median and quartile times to pass from first transition pool entry to last exit from a transition pool into a ladder at Bonneville Dam, based on first transition pool entered and for all fish.

	Chinook salmon										
	WA-shore transition pool						**Cascades Island transition pool**				
	1997	1998	2000	2001	2002		1997	1998	2000	2001	2002
n	253	207	179	326	214		106	71	30	23	139
1st quartile (h)	0.32	0.24	0.31	0.24	0.31		0.78	0.71	0.80	0.73	0.85
Median (h)	3.40	0.68	0.95	0.38	0.64		1.73	1.18	1.01	1.33	1.83
3rd quartile (h)	24.31	4.06	9.54	1.76	7.19		22.97	2.42	1.60	5.27	16.08
Percent that took > 24 h (%)	25.3%	6.3%	14.5%	5.5%	15.4%		22.6%	11.3%	10.0%	13.0%	20.9%
	B-Branch transition pool						**A-Branch transition pool**				
	1997	1998	2000	2001	2002		1997	1998	2000	2001	2002
n	138	186	173	104	133		191	254	285	161	138
1st quartile (h)	0.68	0.40	0.35	0.38	0.39		0.30	0.39	0.33	0.08	0.30
Median (h)	2.73	0.79	0.64	0.72	0.73		0.78	1.24	0.70	0.17	0.48
3rd quartile (h)	19.99	5.48	2.81	5.88	2.21		7.15	10.01	5.09	0.39	8.74
Percent that took > 24 h (%)	22.5%	6.5%	8.1%	9.6%	8.3%		10.5%	10.6%	12.3%	2.5%	15.2%
	All transition pools combined										
	1997	1998	2000	2001	2002						
n	688	718	667	614	624						
1st quartile (h)	0.49	0.38	0.34	0.21	0.39						
Median (h)	1.88	0.99	0.75	0.37	0.84						
3rd quartile (h)	17.79	5.84	5.31	1.31	7.82						
Percent that took > 24 h (%)	20.2%	8.4%	11.7%	5.7%	15.1%						

Table 34. Number of adult radio-tagged spring–summer Chinook salmon and median and quartile times to pass from first transition pool entry to exit a transition pool into a ladder at Bonneville Dam based on fish behavior in each pool.

		Behavior in transition pool first entered											
		Straight through			Downstream, no exit			Exit to collection chan.[1]			Exit to tailrace		
			Med	> 24 h		Med	> 24 h		Med	> 24 h		Med	> 24 h
Transition pool	Year	*n*	(h)	(%)	*n*	(h)	(%)	*n*	(h)	(%)	*n*	(h)	(%)
WA-shore	1997	50	0.16	0.0%	41	0.39	0.0%	11	1.13	0.0%	151	18.81	42.4%
	1998	34	0.12	0.0%	64	0.34	0.0%	24	1.19	0.0%	85	4.93	15.3%
	2000	23	0.14	0.0%	74	0.39	1.4%	3	5.69	0.0%	79	11.03	31.6%
	2001	50	0.17	0.0%	180	0.33	0.0%	7	1.88	0.0%	89	5.94	20.2%
	2002	61	0.26	0.0%	81	0.57	0.0%	0	--	--	72	17.44	45.8%
Cascades Island	1997	5	0.49	0.0%	57	1.05	1.8%	N/A			44	27.56	52.3%
	1998	7	0.37	0.0%	44	0.98	0.0%				20	16.54	40.0%
	2000	8	0.76	0.0%	16	0.99	0.0%				6	23.68	66.7%
	2001	3	0.63	0.0%	9	0.94	0.0%				11	4.87	27.3%
	2002	25	0.73	0.0%	60	1.34	0.0%				54	29.35	53.7%
B-Branch	1997	14	0.46	0.0%	57	0.79	7.0%	N/A			67	12.19	40.3%
	1998	36	0.31	0.0%	86	0.64	0.0%				64	10.97	18.8%
	2000	38	0.34	0.0%	90	0.55	1.1%				45	7.35	28.9%
	2001	7	0.29	0.0%	66	0.53	0.0%				31	10.61	32.3%
	2002	32	0.37	0.0%	76	0.73	1.3%				25	21.64	40.0%
A-Branch	1997	47	0.27	0.0%	22	0.31	4.5%	55	0.68	0.0%	67	11.80	28.4%
	1998	31	0.27	0.0%	37	0.33	0.0%	74	0.77	1.4%	112	11.72	23.2%
	2000	94	0.29	0.0%	23	0.35	0.0%	69	0.78	0.0%	99	14.02	35.4%
	2001	51	0.08	0.0%	21	0.14	0.0%	69	0.24	0.0%	20	2.61	20.0%
	2002	51	0.31	0.0%	3	0.33	0.0%	43	0.43	0.0%	41	24.14	51.2%

[1] Monitoring of Powerhouse 2 collection channel was limited starting in 2000

Table 35. Number of adult radio-tagged spring–summer Chinook salmon and median and quartile times to pass from the last record in a transition pool to exit from the top of a ladder at Bonneville Dam, based on first transition pool entered and for all fish.

	Chinook salmon										
	WA-shore transition pool						**Cascades Island transition pool**				
	1997	1998	2000	2001	2002		1997	1998	2000	2001	2002
n	253	207	179	326	214		106	71	30	23	139
1st quartile (h)	2.11	2.13	2.01	3.08	2.66		2.14	2.33	3.06	3.39	2.34
Median (h)	2.76	2.86	2.66	4.62	4.14		2.94	3.02	3.70	4.31	2.91
3rd quartile (h)	4.07	4.11	3.71	9.20	7.14		4.94	4.39	9.12	6.38	6.60
Percent that took > 24 h (%)	0.8%	0.0%	0.6%	1.5%	0.9%		0.0%	0.0%	0.0%	0.0%	0.0%
	B-Branch transition pool						**A-Branch transition pool**				
	1997	1998	2000	2001	2002		1997	1998	2000	2001	2002
n	138	186	173	104	133		191	254	285	161	138
1st quartile (h)	1.89	1.78	1.60	2.20	1.89		1.77	1.84	1.79	2.29	2.12
Median (h)	2.40	2.21	1.96	3.00	2.28		2.16	2.22	2.25	2.91	2.59
3rd quartile (h)	3.24	3.14	2.86	5.08	3.07		3.00	3.16	3.33	5.60	4.59
Percent that took > 24 h (%)	0.0%	0.5%	0.0%	0.0%	0.0%		1.1%	0.8%	1.1%	0.0%	0.7%
	All transition pools combined										
	1997	1998	2000	2001	2002						
n	688	718	667	614	624						
1st quartile (h)	1.95	1.93	1.79	2.56	2.19						
Median (h)	2.53	2.42	2.29	3.81	2.90						
3rd quartile (h)	3.76	3.65	3.40	7.55	5.95						
Percent that took > 24 h (%)	0.6%	0.4%	0.6%	0.8%	0.5%						

Table 36. Numbers of adult radio-tagged Chinook salmon and median times (h) to pass from first tailrace record to pass Bonneville Dam based on month fish were first detected in the tailrace and transition pool behavior.

		1997		1998		2000		2001		2002	
Behavior	Month	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)
Moved straight through	April	31	28.6	35	18.0	95	29.8	49	41.8	82	47.0
	may	24	23.6	34	14.7	36	17.3	34	23.5	60	37.3
	June	32	11.0	25	13.6	15	14.2	16	13.7	23	16.1
	July	29	13.7	14	5.1	16	13.1	13	13.4	4	15.8
	August	0	--	0	--	1	4.1	0	--	0	--
	Total	116	17.3	108	14.2	163	22.4	111	24.2	169	36.6
Moved downstream, did not exit	April	49	28.3	96	22.0	99	36.6	104	58.1	95	44.7
	may	81	17.7	93	18.5	68	19.9	111	18.3	90	45.2
	June	18	18.5	30	14.6	19	16.0	34	15.1	18	16.8
	July	29	10.4	12	15.1	14	15.9	27	6.0	17	19.2
	August	0	--	0	--	3	15.2	0	--	0	--
	Total	177	20.0	231	17.2	203	22.5	276	22.5	220	40.6
Exited to collection channel	April	19	28.0	50	20.4	46	48.1	34	53.6	6	32.1
	may	30	15.0	35	15.7	12	23.4	24	17.5	16	30.3
	June	13	10.6	8	5.9	8	17.5	10	12.7	15	12.8
	July	4	6.7	5	12.9	6	11.8	8	13.9	5	18.4
	August	0	--	0	--	0	--	0	--	1	23.9
	Total	66	17.2	98	16.6	72	26.1	76	21.8	43	22.8
Exited to tailrace	April	115	67.8	90	33.1	75	58.8	21	97.5	23	92.5
	may	104	36.7	79	22.7	55	26.2	58	28.9	54	61.0
	June	52	24.0	62	20.5	53	23.7	38	24.9	79	34.6
	July	58	20.5	50	21.4	44	26.5	34	19.8	36	30.6
	August	0	--	0	--	4	44.1	0	--	0	--
	Total	329	37.2	281	23.7	229	35.4	151	25.3	192	49.2

Fish that exited to the tailrace had longer dam passage times than fish that moved straight through a pool or those that delayed in a pool or fishway in almost all months of all years (Table 36). In most comparisons within months and years, fish that exited a pool to the tailrace had significantly longer ($P < 0.05$) median dam passage times than those that moved straight through or delayed.

Similar patterns emerged when we considered each transition pool separately (Figure 12, Table 37). Fish that exited transition pools into the tailrace had longer passage times than fish that moved straight through a pool or delayed in a pool or collection channel each year. The following comparisons are for groups with > 10 fish in each behavior category: salmon that exited the Washington-shore pool to the tailrace took 3-28 h (11-150%) longer (medians) to pass the dam than fish that moved straight through the pool. Exit fish also took 0-22 h (0-91%) longer than fish that delayed in the pool before passing (Table 37). Salmon that exited the Cascades Island pool took 18-30 h (38-146%) longer than fish that delayed in the pool before passing. Those that exited the B-Branch pool took 1-21 h (4-63%) longer than those that moved straight through that pool and 3-24 h (14-84%) longer than those that delayed in the pool before passing. Salmon that exited the A-Branch pool took 2-15 h (6-148%) longer to pass the dam than those that moved straight through, except fish that exited passed faster by 7 h (24%) in 2001 (Table 37). Exit fish took 5-10 h (21-72%) longer to pass than fish that delayed in the pool before passing and 1-12 h (5-62%) longer than fish that exited to the collection channel before passing.

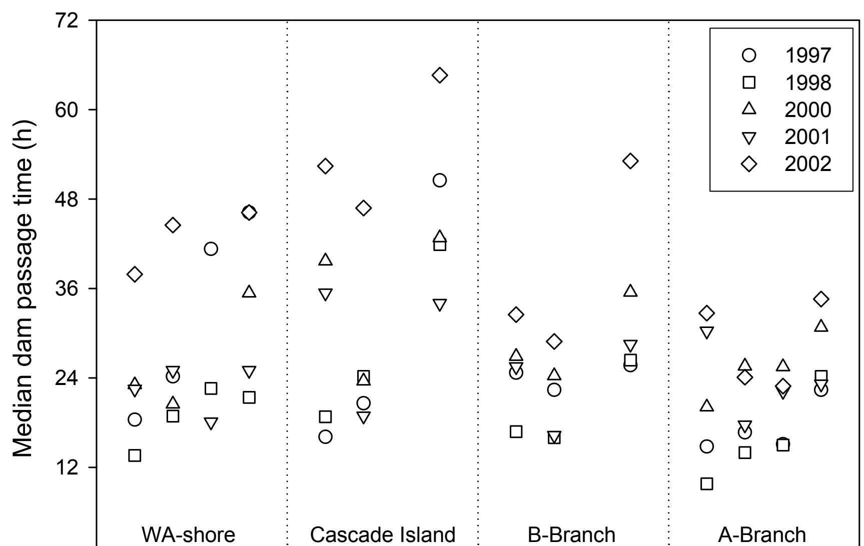

Figure 12. Median dam passage times (first tailrace to top of ladder) for radio-tagged Chinook salmon, by year and location of first transition pool entry. Behaviors were: 1) moved straight through, 2) hesitated, but did not exit the pool, 3) exited the pool to a collection channel, 4) exited the pool into the tailrace.

Table 37. Number of adult radio-tagged spring–summer Chinook salmon and median and quartile times to pass from first tailrace record to pass Bonneville Dam based on fish behavior in each pool.

		Behavior in transition pool first entered											
		Straight through			Downstream, no exit			Exit to collection chan.[1]			Exit to tailrace		
			Med	> 24 h		Med	> 24 h		Med	> 24 h		Med	> 24 h
Transition pool	Year	*n*	(h)	(%)	*n*	(h)	(%)	*n*	(h)	(%)	*n*	(h)	(%)
WA-shore	1997	50	18.4	40.0%	41	24.2	51.2%	11	41.3	72.7%	151	46.2	74.2%
	1998	34	13.6	8.8%	64	18.9	25.0%	224	22.6	45.8%	85	21.4	30.8%
	2000	23	23.1	47.8%	74	20.5	33.8%	3	153.7	66.7%	79	35.4	67.1%
	2001	50	22.5	44.0%	180	25.0	53.9%	7	18.1	42.9%	89	25.0	52.8%
	2002	61	37.9	68.9%	81	44.5	75.3%	0	--	--	72	46.2	72.2%
Cascades Island	1997	5	16.1	20.0%	57	20.6	35.1%				44	50.5	79.5%
	1998	7	18.8	14.3%	44	24.2	52.3%				20	41.9	80.0%
	2000	8	39.7	87.5%	16	23.6	50.0%		N/A		6	42.8	100.0%
	2001	3	35.4	66.7%	9	18.9	33.3%				11	34.0	63.6%
	2002	25	52.4	72.0%	60	46.8	75.0%				54	64.6	75.9%
B-Branch	1997	14	24.7	57.1%	57	22.4	49.1%				67	25.7	53.7%
	1998	36	16.8	22.2%	86	16.0	27.9%				64	26.4	26.3%
	2000	38	26.9	55.3%	90	24.3	53.3%		N/A		45	35.5	62.2%
	2001	7	25.5	57.1%	6	16.3	31.8%				31	28.5	61.3%
	2002	32	32.5	75.0%	76	28.9	55.3%				25	53.1	76.0%
A-Branch	1997	47	14.8	29.8%	22	16.7	18.2%	55	15.1	23.6%	67	22.4	43.3%
	1998	31	9.8	6.5%	37	14.0	18.9%	74	15.0	25.7%	112	24.2	50.9%
	2000	94	20.1	36.2%	23	25.6	52.2%	69	25.5	53.6%	99	30.8	62.6%
	2001	51	30.3	54.9%	21	17.7	38.1%	69	22.2	46.4%	20	23.2	50.0%
	2002	51	32.7	56.9%	3	24.1	66.7%	43	22.9	39.5%	41	34.6	75.6%

[1] Monitoring of Powerhouse 2 collection channel was limited starting in 2000

Patterns were similar within individual months at each pool (Tables 38-41). Seasonal effects were also apparent at this scale, with the longest passage times in April in most years and progressively shorter times as the migrations progressed. In some instances there was a slight increase in passage times from June to July, such as at the Washington-shore pool, but these differences were generally small.

Factors that affected the likelihood of transition pool exit are examined further in the multivariate section below.

Steelhead

Transition pool selection and behavior in pools -- We analyzed behavior of 510 to 634 steelhead with complete passage histories as they moved into fishways, through transition pools and up ladders at Bonneville Dam in each of four years (Table 42). A total of 746 to 874 steelhead were recorded on first transition pool entry. Passage behaviors for fish that missed antennas appeared to be similar to fish with complete records.

The locations of first transition pool entries varied among years, and likely reflected differences in powerhouse priority (Table 43). In 1997, the highest percentage of first pool entries was at the A-Branch pool (42%), followed by the Washington-shore pool (30%); 14% first entered each of the spillway pools. In 2000-2003, the largest percentages first entered the Washington-shore pool (43-57%), while 8-18% first entered spillway pools and 13-33% first entered the A-Branch pool. Most fish (77 to 85%) passed the dam via the fishway (Bradford Island vs. Washington shore) associated with the transition pool they first entered, while the remainders (15 to 23%) exited the first transition pool they entered, crossed the spillway tailrace and passed the dam via the other fishway (Figure 13).

For between-year consistency, summaries below are only for fish with complete passage histories. Twelve to 27% of fish with complete passage histories moved straight through a transition pool and entered a ladder with no downstream movement (Table 42). Twenty-five to 40% moved downstream in a transition pool before entering the ladder but were not recorded at antennas inside the collection channel downstream from the transition pool and were not recorded exiting into the tailrace. Six to 11% exited transition pools and were recorded at antennas in the collection channel but did not exit into the tailrace. (This behavior was likely underestimated in later years, when the Powerhouse II collection channel had more limited antenna coverage.) The remaining fish exited a transition pool into the tailrace before passing the dam: 35% in 1997, 42% in 2000, 42% in 2001, and 49% in 2002 (Table 42).

Mean annual percentages that exited to the tailrace from each transition pool after first entry were 34% from the A-Branch pool, 34% from the B-Branch pool, 31% from the Cascades Island pool, and 52% from the Washington-shore pool (Table 43). Mean annual percentages that moved straight through pools with no downstream movement were 30% for the A-Branch pool, 11% for the B-Branch pool, 19% for the Cascades Island pool, and 19% for the Washington-shore pool. Transition pool delay (fish turned around in submerged-weir area, but did not exit to the collection channel or tailrace) was the most common behavior in both the B-Branch (mean = 55%) and Cascades Island (49%) pools; on average, 28% of steelhead that first entered the Washington-shore pool and 7% that entered the A-Branch pool had this behavior. Percentages that moved downstream into collection channels (but not the tailrace) after transition pool entry averaged 29% at the A-Branch pool (Table 43).

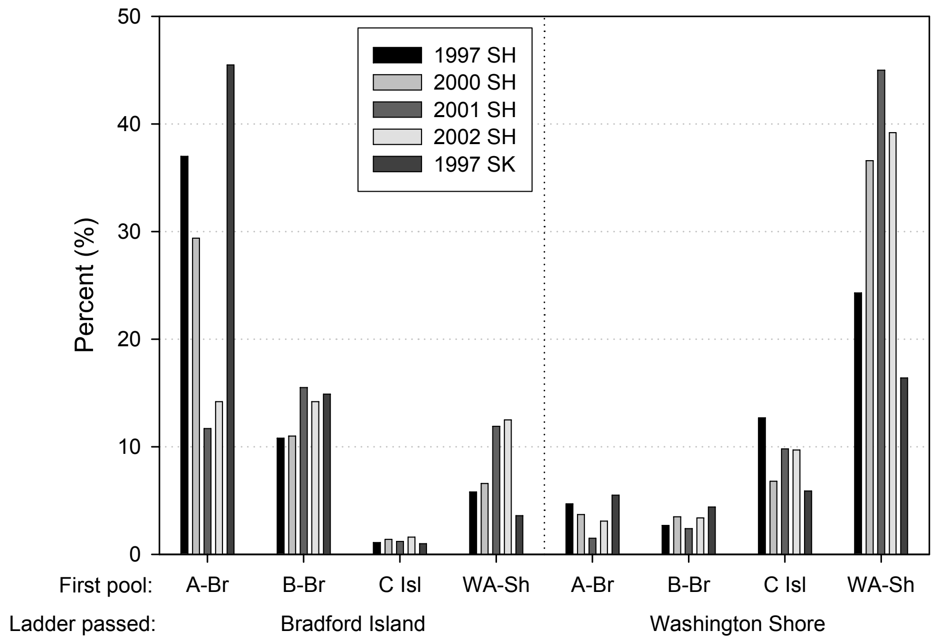

Figure 13. First transition pool entered by radio-tagged steelhead and sockeye salmon and eventual ladder passed.

Passage time from first fishway entry to first transition pool entry – Steelhead passage times from first fishway entry to first entry into a transition pool varied little between years (Table 44). Median times to first enter the B-Branch and Cascades Island pools, which were almost immediately inside the fishways was ≤ 3 min (0.04 h) in all years. Median times were 0.15 to 0.27 h to first enter the A-Branch transition pool for all fishway entrances combined ranged and 0.06 to 0.23 h to first enter the Washington-shore pool (note that the lack of monitoring at orifice gate entrances likely affected the median in later years). Less than 3% of the steelhead took more than 24 h from first fishway entry to first transition pool entry at any site, except at the Cascades Island pool in 2002 (5.6% took > 24 h). Longer passage times for this segment were almost all for fish that exited a fishway back to the tailrace one or more times prior to entering a transition pool.

Passage time from first transition pool entry to exit a pool into a ladder – Steelhead passage times from first transition pool entry to exit a pool into a ladder were the most variable of all dam passage segments. For all fish with telemetry records at each passage point, median pool passage times ranged from 0.6 to 1.3 h for all pools combined (Table 45). Medians tended to be highest for those fish that first entered either the Cascades Island pool (medians = 0.7-2.9 h) or the Washington-shore pool (0.8-2.3 h) and shortest for those that entered the A-Branch pool (0.3-0.6 h). With all transition pools combined, from 9 to 23% of steelhead took more than 24 h to pass through a pool and into a ladder, and percentages did not vary greatly by transition pool (Table 45).

Fish that moved straight through a transition pool on their first attempt, with no recorded downstream movements, had median passage times ≤ 0.70 h (42 min) at all transition pools in all years (Table 46). In fact, few fish that moved straight through transition pools had pool passage times > 30 min except at the Cascades Island pool. Fish that delayed in a transition

Table 38. Numbers of adult radio-tagged Chinook salmon and median times (h) to pass from first tailrace record to pass Bonneville Dam based on month fish were first detected in the tailrace and behavior in the **WA-shore transition pool**.

		1997		1998		2000		2001		2002	
Behavior	Month	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)
Moved straight through	April	16	28.1	3	25.4	9	23.1	20	52.1	28	47.6
	May	5	57.0	10	15.0	13	29.9	13	20.0	22	38.9
	June	13	11.3	12	14.5			9	15.0	10	21.6
	July	15	14.2	9	5.0	1	12.4	8	12.3	1	18.4
	Total	50	18.4	34	13.6	23	23.1	50	22.5	61	37.9
Moved downstream, did not exit	April	12	42.8	19	22.2	29	21.9	80	59.5	36	46.4
	May	18	22.1	27	20.6	32	20.3	65	21.5	33	44.9
	June	2	9.5	14	14.6	5	13.7	11	19.0	5	13.8
	July	9	10.6	4	14.8	8	16.3	24	16.8	7	19.2
	Total	41	24.2	64	18.9	74	20.5	180	25.0	81	44.5
Exited to collection channel	April	7	41.3	13	24.7	2	182.4	3	24.7		
	May	3	15.3	10	22.4	1	14.3	2	22.1		
	June	1	50.6								
	July			1	16.4			2	18.1		
	Total	11	41.3	24	22.6	3	153.7	7	18.1		
Exited to tailrace	April	73	54.1	19	31.6	38	60.0	16	101.4	12	89.9
	May	45	49.1	20	18.0	18	25.8	34	27.9	22	53.3
	June	14	37.1	23	19.3	8	15.5	13	23.2	20	19.8
	July	19	21.1	23	19.9	15	25.9	26	19.8	18	38.4
	Total	151	46.2	85	21.4	79	35.4	89	25.0	72	46.2

Table 39. Numbers of adult radio-tagged Chinook salmon and median times (h) to pass from first tailrace record to pass Bonneville Dam based on month fish were first detected in the tailrace and behavior in the **Cascades Island transition pool**.

		1997		1998		2000		2001		2002	
Behavior	Month	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)
Moved straight through	April	1	6.8	4	17.8	7	38.9	1	35.4	19	61.1
	May	2	23.7	3	22.0	1	167.1	1	14.3	6	24.9
	June	2	12.5					1	57.7		
	July										
	Total	5	16.1	7	18.8	8	39.7	3	35.4	15	27.2
Moved downstream, did not exit	April	15	29.9	20	24.2	8	25.1	2	142.5	30	48.5
	May	30	17.3	18	25.1	5	22.0	3	21.8	22	65.6
	June	5	13.8	5	17.0	2	15.1	2	11.6	4	23.6
	July	7	8.1	1	21.9	1	10.9	2	15.8	4	20.8
	Total	57	20.5	44	24.2	16	23.6	9	18.9	60	46.8
Exited to tailrace	April	16	72.9	10	42.5	4	87.2			9	122.1
	May	22	40.5	5	32.1			4	38.7	20	80.5
	June	4	29.9	4	40.1	1	37.1	4	29.6	18	67.6
	July	2	28.7	1	71.0	1	27.4	3	23.4	7	19.3
	Total	44	50.5	20	41.9	6	42.8	11	34.0	54	64.6

Table 40. Numbers of adult radio-tagged Chinook salmon and median times (h) to pass from first tailrace record to pass Bonneville Dam based on month fish were first detected in the tailrace and behavior in the **B-Branch transition pool**.

		1997		1998		2000		2001		2002	
Behavior	Month	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)
Moved straight through	April	7	24.9	16	19.2	29	44.1	3	74.1	21	29.2
	May	3	7.0	14	15.4	1	7.8	2	21.6	10	41.0
	June			4	16.2	3	16.7	1	25.5	1	31.2
	July	4	25.2	2	9.8	5	13.0	1	11.2		
	Total	14	24.6	36	16.8	38	26.9	7	25.5	32	32.5
Moved downstream, did not exit	April	17	28.1	36	23.2	43	45.5	10	32.2	29	42.1
	May	25	22.4	38	14.8	30	19.7	36	16.3	33	33.2
	June	6	36.3	9	14.2	9	16.1	19	14.3	9	16.1
	July	9	10.0	3	15.7	5	15.7	1	7.9	5	14.7
	August					3	15.2				
	Total	57	22.4	86	16.0	90	24.3	66	16.3	76	28.9
Exited to tailrace	April	15	77.1	18	41.2	10	59.6			2	52.2
	May	19	22.8	21	25.8	15	22.5	13	36.3	8	74.7
	June	13	36.9	10	21.7	9	36.9	16	28.0	11	33.5
	July	20	18.2	15	22.5	11	35.5	2	20.4	4	27.6
	Total	67	25.7	64	26.4	45	35.5	31	28.5	25	53.0

Table 41. Numbers of adult radio-tagged Chinook salmon and median times (h) to pass from first tailrace record to pass Bonneville Dam based on month fish were first detected in the tailrace and behavior in the **A-Branch transition pool**.

		1997		1998		2000		2001		2002	
Behavior	Month	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)
Moved straight through	April	7	89.5	12	12.3	50	25.8	25	31.2	14	44.5
	May	13	19.2	7	8.4	21	13.4	18	34.6	22	66.9
	June	17	9.9	9	9.7	12	12.1	5	11.6	12	10.3
	July	10	12.6	3	5.1	11	13.2	3	16.6	3	13.5
	Total	47	14.8	31	9.7	94	20.1	51	30.3	51	32.7
Moved downstream, did not exit	April	5	22.0	21	14.2	19	37.4	12	39.3		
	May	8	13.0	10	12.8	1	17.7	7	13.7	2	125.0
	June	5	23.8	2	9.7	3	15.7	2	14.2		
	July	4	11.1	4	11.4					1	14.2
	Total	22	16.7	37	14.0	23	25.6	21	17.7	3	24.1
Exited to collection channel	April	12	26.6	37	18.4	44	45.6	31	54.7	6	32.1
	May	27	14.9	25	14.5	11	23.6	22	17.1	16	30.3
	June	12	9.0	8	5.9	8	17.5	10	12.7	15	12.8
	July	4	6.7	4	8.6	6	11.8	6	13.2	5	18.4
	August									1	23.9
	Total	55	15.1	74	15.0	69	25.5	39	22.2	43	22.8
Exited to tailrace	April	11	167.6	43	31.4	23	57.6	5	92.3		
	May	18	22.7	33	22.7	22	37.8	7	21.3	4	81.8
	June	21	19.6	25	20.4	35	23.6	5	16.6	30	35.9
	July	17	20.6	11	21.0	17	24.2	3	14.2	7	34.0
	August					2	70.3				
	Total	67	22.4	112	24.2	99	30.8	20	23.2	41	34.6

Table 42. Transition pool behavior by adult radio-tagged steelhead and sockeye salmon at Bonneville Dam for fish with telemetry records at all passage points (tailrace, first fishway entry, first transition pool entry, transition pool exit into a ladder and exit from the top of a ladder). All transition pools combined.

	Steelhead								Sockeye	
	1997		2000		2001		2002		1997	
Behavior in transition pool	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**	*n*	**%**
Moved straight through	136	**26.7**	132	**20.8**	66	**11.6**	127	**21.1**	93	**27.3**
Moved downstream, but did not exit	157	**30.8**	169	**26.7**	229	**40.2**	149	**24.7**	98	**28.7**
Exited pool into collection channel	40	**7.8**	69	**10.9**	37	**6.5**	34	**5.6**	25	**7.3**
Exited pool into tailrace	177	**34.7**	264	**41.6**	238	**41.8**	293	**48.6**	124	**36.4**
Total	510		634		570		603		341	

Table 43. Transition pool behavior by adult radio-tagged steelhead and sockeye salmon at Bonneville Dam for fish with telemetry records at all passage points (tailrace, first fishway entry, first transition pool entry, transition pool exit into a ladder and exit from the top of a ladder) based on transition pool first entered.

	Steelhead								Sockeye	
	1997		2000		2001		2002		1997	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
First entered WA-shore pool										
Moved straight through	61	**34.3**	44	**17.1**	11	**3.9**	64	**21.8**	34	**26.2**
Moved downstream, but did not exit	32	**18.0**	90	**34.9**	110	**38.7**	56	**19.0**	22	**23.4**
Exited pool into collection channel[1]	2	**1.1**	2	**0.8**	2	**0.7**	0	**0.0**	1	**1.1**
Exited pool into tailrace	83	**46.6**	122	**47.3**	161	**56.7**	174	**59.2**	37	**39.4**
Total	178		258		284		294		94	
First entered Cascades Island pool										
Moved straight through	19	**24.4**	8	**14.5**	12	**16.2**	16	**22.5**	2	**6.5**
Moved downstream, but did not exit	48	**61.5**	22	**40.0**	41	**55.4**	29	**40.8**	19	**61.3**
Exited pool into tailrace	11	**14.1**	25	**45.5**	21	**28.4**	26	**36.6**	10	**32.3**
Total	78		55		74		71		31	
First entered B-Branch pool										
Moved straight through	8	**10.3**	9	**9.4**	14	**11.8**	13	**10.7**	13	**15.7**
Moved downstream, but did not exit	40	**51.3**	51	**53.1**	75	**63.0**	64	**52.9**	36	**43.4**
Exited pool into tailrace	30	**38.5**	36	**37.5**	30	**25.2**	44	**36.4**	34	**41.0**
Total	78		96		119		121		83	
First entered A-Branch pool										
Moved straight through	48	**27.3**	71	**31.6**	29	**31.2**	34	**29.1**	44	**33.1**
Moved downstream, but did not exit	37	**21.0**	7	**3.1**	3	**3.2**	0	**0.0**	22	**16.5**
Exited pool into collection channel[1]	38	**21.6**	66	**29.3**	35	**37.6**	34	**29.1**	24	**18.0**
Exited pool into tailrace	53	**30.1**	81	**36.0**	26	**28.0**	49	**41.9**	43	**32.3**
Total	176		225		93		117		133	

[1] Monitoring of Powerhouse 2 collection channel was limited starting in 2000

Table 44. Number of adult radio-tagged steelhead and sockeye salmon (SK) and median and quartile times to pass from first fishway entry to first transition pool entry at Bonneville Dam, based on first transition pool entered and for all fish.

	WA-shore transition pool						Cascades Island transition pool				
	Steelhead				SK		Steelhead				SK
	1997	2000	2001	2002	1997		1997	2000	2001	2002	1997
n	178	258	284	294	94		78	55	74	71	31
1st quartile (h)	0.05	0.03	0.04	0.06	0.10		0.01	0.01	0.00	0.02	0.01
Median (h)	0.09	0.06	0.18	0.23	0.63		0.03	0.02	0.01	0.04	0.02
3rd quartile (h)	0.20	0.42	0.62	0.91	2.56		0.06	0.04	0.03	0.12	1.19
Percent that took > 24 h (%)	1.7%	1.2%	1.1%	2.7%	5.3%		1.3%	1.8%	2.7%	5.6%	3.2%
	B-Branch transition pool						A-Branch transition pool				
	Steelhead				SK		Steelhead				SK
	1997	2000	2001	2002	1997		1997	2000	2001	2002	1997
n	78	96	119	121	83		176	225	93	117	133
1st quartile (h)	0.02	0.01	0.00	0.00	0.01		0.05	0.04	0.03	0.08	0.02
Median (h)	0.04	0.03	0.01	0.01	0.02		0.15	0.17	0.20	0.27	0.25
3rd quartile (h)	0.08	0.04	0.02	0.08	1.08		0.30	0.42	0.59	0.93	1.02
Percent that took > 24 h (%)	1.3%	1.0%	0.8%	2.5%	2.4%		0.0%	0.9%	2.2%	1.7%	1.5%
	All transition pools combined										
	Steelhead				SK						
	1997	2000	2001	2002	1997						
n	510	634	570	603	341						
1st quartile (h)	0.03	0.02	0.01	0.03	0.02						
Median (h)	0.07	0.07	0.05	0.13	0.14						
3rd quartile (h)	0.22	0.33	0.41	0.79	1.5						
Percent that took > 24 h (%)	1.0%	1.1%	1.4%	2.8%	2.9%						

Table 45. Number of adult radio-tagged steelhead and sockeye salmon (SK) and median and quartile times to pass from first transition pool entry to last exit from a transition pool into a ladder at Bonneville Dam, based on first transition pool entered and for all fish.

	WA-shore transition pool						**Cascades Island transition pool**				
	Steelhead				SK		Steelhead				SK
	1997	2000	2001	2002	1997		1997	2000	2001	2002	1997
n	178	258	284	294	94		78	55	74	71	31
1st quartile (h)	0.22	0.25	0.32	0.30	0.24		0.48	0.80	0.37	0.57	0.44
Median (h)	0.76	0.93	2.28	1.84	0.51		0.69	2.90	0.71	1.10	0.88
3rd quartile (h)	4.97	15.12	19.59	26.96	3.07		1.46	16.30	1.57	8.05	9.94
Percent that took > 24 h (%)	7.9%	17.8%	19.4%	27.9%	8.5%		5.1%	12.7%	8.1%	15.5%	19.4%
	B-Branch transition pool						**A-Branch transition pool**				
	Steelhead				SK		Steelhead				SK
	1997	2000	2001	2002	1997		1997	2000	2001	2002	1997
n	78	96	119	121	83		176	225	93	117	133
1st quartile (h)	0.38	0.29	0.32	0.43	0.37		0.15	0.10	0.09	0.23	0.21
Median (h)	0.98	0.64	0.64	1.22	0.95		0.41	0.35	0.31	0.56	0.36
3rd quartile (h)	14.62	9.31	3.59	18.79	8.96		2.53	2.62	1.19	14.06	4.15
Percent that took > 24 h (%)	15.4%	13.5%	6.7%	18.2%	8.4%		8.0%	11.6%	7.5%	19.7%	7.5%
	All transition pools combined										
	Steelhead				SK						
	1997	2000	2001	2002	1997						
n	510	634	570	603	341						
1st quartile (h)	0.24	0.23	0.29	0.33	0.26						
Median (h)	0.64	0.63	0.73	1.29	0.60						
3rd quartile (h)	4.37	10.52	7.01	21.13	4.41						
Percent that took > 24 h (%)	8.6%	14.5%	13.3%	22.9%	9.1%						

Table 46. Number of adult radio-tagged steelhead and sockeye salmon and median and quartile times to pass from first transition pool entry to exit a transition pool into a ladder at Bonneville Dam based on fish behavior in each pool.

		Behavior in transition pool first entered											
		Straight through			Downstream, no exit			Exit to collection chan.[2]			Exit to tailrace		
			Med	> 24 h		Med	> 24 h		Med	> 24 h		Med	> 24 h
Transition pool	Year	*n*	(h)	(%)	*n*	(h)	(%)	*n*	(h)	(%)	*n*	(h)	(%)
WA-shore	1997	61	0.14	0.0%	32	0.43	0.0%	2	0.94	0.0%	83	5.28	16.9%
	2000	44	0.20	0.0%	90	0.32	0.0%	2	0.51	0.0%	122	16.72	37.7%
	2001	11	0.20	0.0%	110	0.29	0.0%	2	1.01	0.0%	161	12.52	34.2%
	2002	64	0.18	0.0%	56	0.34	0.0%	0	--	--	174	21.50	47.1%
	1997[1]	34	0.21	0.0%	22	0.42	0.0%	1	1.84	0.0%	37	4.06	21.6%
Cascades Island	1997	19	0.50	0.0%	48	0.71	2.1%				11	14.65	27.3%
	2000	8	0.64	0.0%	22	0.94	0.0%				25	17.50	28.0%
	2001	12	0.32	0.0%	41	0.51	0.0%		N/A		21	6.52	28.6%
	2002	16	0.47	0.0%	29	0.77	0.0%				26	19.32	42.3%
	1997[1]	2	0.46	0.0%	19	0.53	0.0%				10	29.36	60.0%
B-Branch	1997	8	0.36	0.0%	40	0.57	0.0%				30	17.97	40.0%
	2000	9	0.24	0.0%	51	0.35	0.0%				36	18.14	36.1%
	2001	14	0.37	0.0%	75	0.51	0.0%		N/A		30	9.44	26.7%
	2002	13	0.34	0.0%	64	0.61	0.0%				44	24.28	50.0%
	1997[1]	13	0.28	0.0%	36	0.41	0.0%				35	11.28	20.6%
A-Branch	1997	48	0.12	0.0%	37	0.30	0.0%	38	0.46	0.0%	53	14.43	26.4%
	2000	71	0.07	0.0%	7	0.13	0.0%	66	0.34	0.0%	81	14.00	32.1%
	2001	29	0.07	0.0%	3	0.26	0.0%	35	0.29	0.0%	26	5.52	26.9%
	2002	34	0.18	0.0%	0	--	0.0%	34	0.38	0.0%	49	18.56	46.9%
	1997[1]	44	0.19	0.0%	22	0.26	0.0%	24	0.65	0.0%	43	14.10	23.3%

[1] Sockeye salmon
[2] Monitoring of Powerhouse 2 collection channel was limited starting in 2000

pool by moving downstream (but were not recorded at antennas in the collection channel or tailrace) had median passage times ≤ 0.80 h (48 min) at all sites in all years. Fish that delayed in the A-Branch pool and exited into the collection channel—but not into the tailrace—had median times of ≤ 0.50 h (30 min) from first pool entry to exit the pool into the A-Branch ladder. Median times for those that exited pool into the tailrace were much higher: 5.3 to 21.5 h for those that exited the Washington-shore pool, 6.5-19.3 h for those that exited the Cascades Island pool, 9.4-24.3 h for those that exited the B-Branch pool, and 5.5-18.6 h for those that exited the A-Branch pool (Table 46). On average, 34% of the steelhead that exited a transition pool took more than 24 h to pass though a pool into a ladder (all years and pools combined). For comparison, almost no fish that did not exit took > 24 h to pass through a pool (Table 46).

Passage time to ascend a ladder – After exiting transition pools into ladders, steelhead ascended ladders relatively quickly at Bonneville Dam in all years. Median times to ascend from the top-of-pool sites ranged from 2.6 to 4.4 h from the Washington-shore pool, 2.8-4.8 h from the Cascades Island pool, 2.1-3.0 h from the B-Branch pool, and 2.1-3.0 h from the A-Branch pool (Table 47). More steelhead than Chinook salmon took more than 24 h to ascend from ladders: with all sites combined 0.4-2.8% took 24 h or more to ascend in each year. The highest percentages were from the B-Branch pool in 2001 (10.8%) and from the Washington-shore pool in 2002 (4.1%).

Passage time from first tailrace record to pass the dam – Within years, steelhead behavior in transition pools was a good predictor of overall time to pass Bonneville Dam (Totals in Table 48). When all fish and all transition pools were combined, median passage times from first tailrace record to exit from the top of a ladder were highest for fish that exited transition pools into the tailrace in each year. Median times in 1997 were 6.7-17.1 h for fish that did not exit versus 22.5 h for fish that did exit, a difference of 5.4-15.8 h (Table 48). Exiting fish took 11.9-18.8 h longer, on median, in 2000, 11.8-13.8 h longer in 2001, and 22.6-26.4 h in 2002. Although there was a slight tendency for faster passage times in June and July, steelhead did not show the same strong seasonal effect as Chinook salmon (Table 48).

Fish that exited to the tailrace had longer dam passage times than fish that moved straight through a pool or those that delayed in a pool or fishway in almost all months of all years (Table 48). In most comparisons within months and years, fish that exited a pool to the tailrace had significantly longer ($P < 0.05$) median dam passage times than those that moved straight through or delayed.

Similar patterns emerged when we considered each transition pool separately (Figure 14, Table 49). Fish that exited transition pools into the tailrace had longer passage times than fish that moved straight through a pool or delayed in a pool or collection channel each year. The following comparisons are for groups with > 10 fish in each behavior category: steelhead that exited the Washington-shore pool to the tailrace took 6-24 h (44-137%) longer (medians) to pass the dam than fish that moved straight through the pool. Exit fish also took 6-23 h (35-121%) longer than fish that delayed in the pool before passing (Table 49). Steelhead that exited the Cascades Island pool took 4-27 h (19-153%) longer than fish that moved straight through and 4-24 h (23-120%) longer than those that delayed in the pool before passing. Steelhead that exited the B-Branch pool took 14-19 h (96-113%) longer than those that moved straight through that pool and 9-20 h (53-106%) longer than those that delayed in the pool before passing. Steelhead that exited the A-Branch pool took 10-32 h (71-268%) longer to pass the dam than those that moved straight through (Table 49). Exit fish took 7-28 h (52-228%) longer to pass than fish that exited to the collection channel before passing. The time delays associated with

Table 47. Number of adult radio-tagged steelhead and sockeye salmon (SK) and median and quartile times to pass from the last record in a transition pool to exit from the top of a ladder at Bonneville Dam, based on first transition pool entered and for all fish.

	WA-shore transition pool						**Cascades Island transition pool**				
	Steelhead				SK		Steelhead				SK
	1997	2000	2001	2002	1997		1997	2000	2001	2002	1997
n	178	258	284	294	94		78	55	74	71	31
1st quartile (h)	1.95	1.87	2.65	2.30	1.97		2.18	2.43	3.36	2.60	2.42
Median (h)	2.57	2.99	4.44	3.48	2.44		2.81	3.21	4.75	3.87	3.34
3rd quartile (h)	4.83	5.88	10.46	7.85	3.96		4.17	7.82	12.53	13.71	5.10
Percent that took > 24 h (%)	0.6%	2.3%	2.8%	3.4%	1.1%		0.0%	0.0%	1.4%	1.4%	3.2%
	B-Branch transition pool						**A-Branch transition pool**				
	Steelhead				SK		Steelhead				SK
	1997	2000	2001	2002	1997		1997	2000	2001	2002	1997
n	78	96	119	121	83		176	225	93	117	133
1st quartile (h)	1.81	1.68	2.34	1.97	1.34		1.75	1.83	2.44	1.93	1.30
Median (h)	2.37	2.12	2.98	2.47	1.74		2.12	2.31	2.96	2.28	1.66
3rd quartile (h)	3.99	4.96	5.70	4.80	2.68		3.00	3.92	4.30	3.15	2.09
Percent that took > 24 h (%)	0.0%	1.0%	0.8%	4.1%	1.2%		0.6%	1.3%	10.8%	0.9%	0.8%
	All transition pools combined										
	Steelhead				SK						
	1997	2000	2001	2002	1997						
n	510	634	570	603	341						
1st quartile (h)	1.86	1.84	2.54	2.12	1.43						
Median (h)	2.37	2.60	3.72	2.95	1.96						
3rd quartile (h)	3.86	5.30	8.63	6.46	3.17						
Percent that took > 24 h (%)	0.4%	1.6%	2.3%	2.8%	1.2%						

Table 48. Numbers of adult radio-tagged steelhead and sockeye salmon and median times (h) to pass from first tailrace record to pass Bonneville Dam based on month fish were first detected in the tailrace and transition pool behavior.

		Steelhead								Sockeye	
		1997		2000		2001		2002		1997[1]	
Behavior	Month	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)
Moved straight through	June	6	5.6	11	13.1	7	10.7	14	6.1	43	9.2
	July	26	10.7	12	14.0	10	9.2	21	11.8	49	7.6
	August	14	18.2	71	16.1	27	11.7	61	20.5	1	24.0
	September	73	14.8	19	9.2	13	16.3	24	14.3	0	--
	October	17	16.0	19	16.2	9	17.3	7	20.8	0	--
	Total	136	14.8	132	14.6	66	13.3	127	15.8	93	7.8
Moved downstream, did not exit	June	8	14.8	11	20.3	11	16.4	6	19.3	43	14.1
	July	46	18.5	37	20.8	48	12.5	32	22.9	56	14.0
	August	57	19.2	62	19.1	89	12.9	69	18.3	0	--
	September	31	15.4	28	8.2	55	16.3	26	18.7	0	--
	October	15	15.9	32	16.7	26	16.9	16	8.6	0	--
	Total	157	17.1	170	17.4	229	15.3	149	18.9	99	14.1
Exited to collection channel	June	1	3.9	1	6.9	9	12.4	4	9.1	17	14.1
	July	5	6.1	7	13.7	4	14.9	3	9.7	8	8.3
	August	7	13.6	32	13.8	17	16.0	9	16.3	0	--
	September	21	6.5	20	5.6	6	18.0	14	16.2	0	--
	October	6	15.6	8	11.1	1	25.2	4	17.0	0	--
	Total	40	6.7	68	10.5	37	13.6	34	15.1	25	12.9
Exited to tailrace	June	9	15.6	21	25.8	35	20.0	36	58.3	64	24.6
	July	33	26.4	64	50.0	52	35.4	74	49.2	59	21.3
	August	46	25.4	94	27.8	83	26.4	98	46.5	1	20.9
	September	70	22.0	57	24.4	56	27.2	74	30.1	0	--
	October	19	18.3	28	22.0	12	31.5	11	27.0	0	--
	Total	177	22.5	264	29.3	238	27.1	293	41.5	124	23.0

Table 49. Number of adult radio-tagged steelhead and sockeye salmon and median and quartile times to pass from first tailrace record to pass Bonneville Dam based on fish behavior in each pool.

		Behavior in transition pool first entered											
		Straight through			Downstream, no exit			Exit to collection chan.[2]			Exit to tailrace		
			Med	> 24 h		Med	> 24 h		Med	> 24 h		Med	> 24 h
Transition pool	Year	*n*	(h)	(%)	*n*	(h)	(%)	*n*	(h)	(%)	*n*	(h)	(%)
WA-shore	1997	61	14.7	8.2%	32	15.6	34.4%	2	9.3	0.0%	83	21.1	39.8%
	2000	44	13.6	15.9%	90	18.3	21.1%	2	19.8	0.0%	122	32.2	66.4%
	2001	11	16.3	18.2%	110	16.3	13.6%	2	24.2	50.0%	161	29.8	59.6%
	2002	64	17.7	35.9%	56	18.7	19.6%	0	-	-	174	41.3	71.8%
	1997[1]	34	11.7	17.6%	22	19.1	40.9%	1	9.0	0.0%	37	21.1	35.1%
Cascades Island	1997	19	19.6	26.3%	48	18.9	35.4%				11	23.4	45.5%
	2000	8	19.5	12.5%	22	20.0	36.4%				25	28.1	52.0%
	2001	12	17.3	16.7%	41	18.9	31.7%		N/A		21	23.2	47.6%
	2002	16	17.7	37.5%	29	20.3	34.5%				26	44.7	73.1%
	1997[1]	2	207.2	50.0%	19	14.3	15.8%				10	42.6	70.0%
B-Branch	1997	8	12.3	12.5%	40	17.1	17.5%				30	26.1	45.0%
	2000	9	5.5	0.0%	51	16.1	21.6%				36	26.0	63.9%
	2001	14	12.3	7.1%	75	13.2	10.7%		N/A		30	26.2	63.3%
	2002	13	19.5	38.5%	64	18.6	34.4%				44	38.3	86.4%
	1997[1]	13	6.9	7.7%	36	12.4	8.3%				34	23.8	44.1%
A-Branch	1997	48	11.2	6.3%	37	15.0	24.3%	38	6.7	10.5%	53	22.0	41.5%
	2000	71	14.9	9.9%	7	16.0	14.3%	66	8.7	10.6%	81	25.5	53.1%
	2001	29	9.8	10.3%	3	5.1	0.0%	35	13.2	28.6%	26	20.1	38.5%
	2002	34	11.8	20.6%	0	-	-	34	15.1	17.6%	49	43.4	59.2%
	1997[1]	45	5.1	8.9%	22	9.5	9.1%	24	13.4	8.3%	43	22.8	44.2%

[1] Sockeye salmon
[2] Monitoring of Powerhouse 2 collection channel was limited starting in 2000

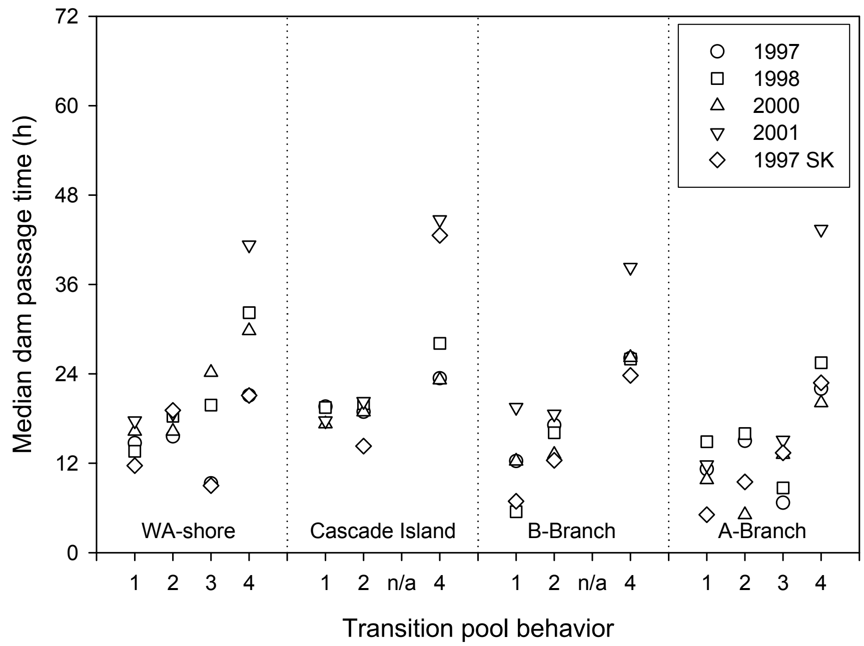

Figure 14. Median dam passage times (first tailrace to top of ladder) for radio-tagged steelhead and sockeye salmon, by year and location of first transition pool entry. Behaviors were: 1) moved straight through, 2) hesitated, but did not exit the pool, 3) exited the pool to a collection channel, 4) exited the pool into the tailrace.

exiting all transition pools were greatest in 2002. Patterns were similar within individual months at each pool (Tables 50-53), though sample sizes were often limited.

Factors that affected the likelihood of transition pool exit are examined further in the multivariate section below.

Sockeye salmon

Transition pool selection and behavior in pools – We analyzed behavior of 341 sockeye salmon with complete passage histories as they moved into fishways, through transition pools and up ladders at Bonneville Dam in 1997 (Table 42). A total of 523 fish had recorded first transition pool entries. The highest percentage of first pool entries by sockeye salmon was at the A-Branch pool (51%), followed by the Washington-shore pool (20%), B-Branch pool (19%), and Cascades Island pool (7%) (Figure 13). Most fish (83%) passed the dam via the fishway (Bradford Island vs. Washington shore) associated with the transition pool they first entered, while the remainder (17%) exited the first transition pool they entered, crossed the spillway tailrace and passed the dam via the other fishway.

Twenty-seven percent of sockeye salmon with complete passage histories moved straight through a transition pool and entered a ladder with no downstream movement (Table 42). Twenty-nine percent moved downstream in a transition pool before entering the ladder but were not recorded at antennas inside the collection channel downstream from the transition pool and were not recorded exiting into the tailrace. Seven percent exited transition pools and were

Table 50. Numbers of adult radio-tagged steelhead and sockeye salmon and median times (h) to pass from first tailrace record to pass Bonneville Dam based on month fish were first detected in the tailrace and behavior in the **WA-shore transition pool**.

		Steelhead								Sockeye	
		1997		2000		2001		2002		1997[1]	
Behavior	Month	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)
Moved straight through	June	1	7.0					3	13.9	10	12.0
	July	6	10.9	5	14.6	1	10.3	10	19.9	24	11.7
	August	7	15.9	20	17.7	2	19.2	27	19.6		
	September	34	14.8	6	9.3	6	17.8	19	13.5		
	October	13	15.2	13	12.6	2	20.0	5	24.2		
	Total	61	14.7	44	13.6	1	16.3	64	17.7	34	11.7
Moved downstream, did not exit	June	1	14.2	6	20.9	7	22.8	5	18.9	1	7.8
	July	6	20.7	16	22.7	26	11.0	14	12.7	1	406.5
	August	1	12.9	24	19.6	27	12.7	7	19.3		
	September	6	17.0	20	7.2	35	17.5	17	21.2		
	October	8	10.4	24	15.7	15	17.4	13	7.3		
	Total	32	15.6	90	18.3	110	16.2	56	18.7	2	207.2
Exited to tailrace	June	4	13.1	11	25.8	17	15.5	15	68.1	15	54.6
	July	12	23.8	24	49.7	37	42.5	38	50.14	21	48.9
	August	25	22.2	36	32.7	50	26.7	56	55.4	1	58.6
	September	34	22.2	31	27.5	47	29.1	58	30.4		
	October	8	17.5	20	23.7	10	26.8	7	24.0		
	Total	83	21.1	122	32.2	161	29.8	174	41.2	37	50.3

Table 51. Numbers of adult radio-tagged steelhead and sockeye salmon and median times (h) to pass from first tailrace record to pass Bonneville Dam based on month fish were first detected in the tailrace and behavior in the **Cascades Island transition pool**.

		Steelhead								Sockeye	
		1997		2000		2001		2002		1997[1]	
Behavior	Month	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)
Moved straight through	June	1	8.0	1	28.3					11	32.1
	July	9	19.5			4	23.8	3	9.0	11	16.9
	August	4	30.8	6	18.6	2	10.3	11	21.7		
	September	4	18.2			3	16.0				
	October	1	20.8	1	19.1	3	17.3	2	11.6		
	Total	19	19.6	8	19.5	12	17.3	16	17.7	22	19.1
Moved downstream, did not exit	June	2	10.9	2	47.8			1	19.7	5	14.1
	July	21	23.5	6	20.3	13	24.0	7	25.2	14	14.9
	August	17	21.0	10	20.0	13	15.4	17	19.4		
	September	7	17.1	1	18.2	8	18.7	2	8.9		
	October	1	16.6	3	17.3	7	16.5	2	14.7		
	Total	48	18.9	22	20.0	41	18.8	29	20.3	19	14.3
Exited to tailrace	June					2	31.4	5	96.9	5	61.6
	July	1	270.5	7	28.1	6	25.7	7	38.5	5	20.5
	August	3	509.7	8	36.8	7	23.2	7	49.1		
	September	6	19.7	7	22.3	5	22.2	5	39.1		
	October	1	16.8	3	14.3	1	40.3	2	31.2		
	Total	11	23.4	25	28.1	21	23.2	26	44.7	10	42.6

Table 52. Numbers of adult radio-tagged steelhead and sockeye salmon and median times (h) to pass from first tailrace record to pass Bonneville Dam based on month fish were first detected in the tailrace and behavior in the **B-Branch transition pool**.

		Steelhead								Sockeye	
		1997		2000		2001		2002		1997[1]	
Behavior	Month	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)
Moved straight through	June					1	10.7	1	4.1	6	11.6
	July	3	8.6			1	4.5	2	22.4	7	5.7
	August	1	262.2	5	18.1	11	12.8	9	20.5		
	September	2	15.4	4	4.6			1	19.5		
	October	2	11.2			1	19.0				
	Total	8	12.3	9	5.5	14	12.3	13	19.5	13	6.9
Moved downstream, did not exit	June	2	22.9	3	11.5	3	14.4			14	12.0
	July	13	17.1	13	17.4	9	7.4	11	35.7	22	12.5
	August	16	18.1	26	16.8	47	12.2	45	18.0		
	September	7	16.1	4	11.9	12	14.4	7	8.0		
	October	2	9.1	5	13.7	4	15.5	1	20.8		
	Total	40	17.1	51	16.1	75	13.2	64	18.6	36	12.4
Exited to tailrace	June	3	55.4	1	73.4	3	26.2	3	37.0	22	25.7
	July	11	50.2	13	59.9	6	23.3	11	73.0	12	20.0
	August	16	22.8	14	23.2	18	24.6	23	34.8		
	September	5	22.5	7	22.5	3	38.3	5	32.6		
	October	6	34.4	1	24.2			2	107.7		

Table 53. Numbers of adult radio-tagged steelhead and sockeye salmon and median times (h) to pass from first tailrace record to pass Bonneville Dam based on month fish were first detected in the tailrace and behavior in the **A-Branch transition pool**.

		Steelhead								Sockeye	
		1997		2000		2001		2002		1997[1]	
Behavior	Month	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)	*n*	Med(h)
Moved straight through	June	4	4.1	10	12.4	6	11.6	10	5.7	26	5.6
	July	8	5.8	7	13.3	4	6.5	6	13.0	17	4.9
	August	2	13.5	40	14.4	12	10.8	14	17.2	1	4.2
	September	33	14.3	9	15.9	4	12.1	4	14.9		
	October	1	16.0	5	17.3	3	9.8				
	Total	48	11.2	71	14.9	29	9.8	34	11.8	44	5.1
Moved downstream, did not exit	June	3	14.7			1	5.1			13	10.0
	July	6	12.0	2	9.4					9	9.0
	August	13	22.1	2	42.7	2	6.1				
	September	11	9.2	3	5.7						
	October	4	54.0								
	Total	37	15.0	7	16.0	3	5.1			22	9.5
Exited to collection channel	June	1	3.9	1	6.9	9	12.4	4	9.1	17	14.1
	July	3	5.0	7	13.7	4	14.9	3	9.7	7	7.5
	August	7	13.6	32	13.8	17	16.0	9	16.3		
	September	21	3.5	19	5.4	5	12.8	14	16.2		
	October	6	15.6	7	7.0			4	17.0		
	Total	38	6.7	66	8.7	35	13.2	34	15.1	21	13.4
Exited to tailrace	June	2	17.1	9	20.4	13	20.0	13	28.0	22	21.6
	July	9	22.1	20	47.1	3	25.2	18	50.4	21	22.8
	August	13	26.7	36	24.9	8	20.7	12	44.9		
	September	25	22.0	12	21.2	1	5.5	6	16.6		
	October	4	18.7	4	16.1	1	42.2				
	Total	53	22.0	81	25.5	26	20.1	49	43.4	43	22.8

recorded at antennas in the collection channel but did not exit into the tailrace. The remaining fish (36%) exited a transition pool into the tailrace before passing the dam (Table 42).

Percentages that exited to the tailrace from each transition pool after first entry ranged from 32 to 41% (Table 43). Percentages that moved straight through pools with no downstream movement were 33% for the A-Branch pool, 16% for the B-Branch pool, 7% for the Cascades Island pool, and 26% for the Washington-shore pool. Transition pool delay (fish turned around in submerged-weir area, but did not exit to the collection channel or tailrace) was the most common behavior in both the B-Branch (43%) and Cascades Island (61%) pools. Percentages that moved downstream into collection channels (but not the tailrace) after transition pool entry were 18% at the A-Branch pool and 1% at the Washington-shore pool (Table 43).

Passage time from first fishway entry to first transition pool entry – Median sockeye salmon passage times from first fishway entry to first entry into a transition pool were ≤ 2 min (0.02 h) for those that entered the B-Branch and Cascades Island pools, 15 min (0.25 h) for those that entered the A-Branch pool and 38 min (0.63 h) for those at the Washington-shore pool (Table 44). Longer passage times for this segment were almost all for fish that exited a fishway back to the tailrace one or more times prior to entering a transition pool.

Passage time from first transition pool entry to exit a pool into a ladder – Sockeye salmon passage times from first transition pool entry to exit a pool into a ladder were the most variable of all dam passage segments. For all fish with telemetry records at each passage point, median pool passage times ranged from 0.5 to 1.0 h for all pools combined (Table 45). Medians were highest for those fish that first entered either the Cascades Island or B-Branch pools. Transition pool passage times were strongly right skewed, and from 7.5 to 19.4% of sockeye salmon took more than 24 h to pass through a pool and into a ladder (Table 45).

Fish that moved straight through a transition pool on their first attempt, with no recorded downstream movements, had median passage times ≤ 0.50 h (30 min) at all transition pools (Table 46). In fact, few fish that moved straight through transition pools had pool passage times > 15 min. Fish that delayed in a transition pool by moving downstream (but were not recorded at antennas in the collection channel or tailrace) had median passage times ≤ 0.60 h (36 min) at all sites in all years. Fish that delayed in the A-Branch pool and exited into the collection channel—but not into the tailrace—had a median time of 0.65 h (39 min) from first pool entry to exit the pool into the A-Branch ladder. Median times for those that exited pool into the tailrace were much higher: 4.1 for those that exited the Washington-shore pool, 29.4 h for those that exited the Cascades Island pool, 11.3 h for those that exited the B-Branch pool, and 14.1 h for those that exited the A-Branch pool (Table 46). On average, 31% of the sockeye salmon that exited a transition pool took more than 24 h to pass though a pool into a ladder. For comparison, no fish that did not exit took > 24 h to pass through a pool (Table 46).

Passage time to ascend a ladder – After exiting transition pools into ladders, sockeye salmon ascended ladders relatively quickly. Median times to ascend from the top-of-pool sites were 2. 4 h from the Washington-shore pool, 3.3 h from the Cascades Island pool, 1.7 h from the B-Branch pool, and 1.7 h from the A-Branch pool (Table 47). One to 3% of sockeye salmon took more than 24 h to ascend a ladder.

Passage time from first tailrace record to pass the dam – Sockeye salmon behavior in transition pools was a good predictor of overall time to pass Bonneville Dam (Totals in Table 48). When all fish and all transition pools were combined, median passage times from first tailrace record to exit from the top of a ladder were highest for fish that exited transition pools into the tailrace. Median times were 7.8 h for fish that moved straight through, 14.1 h for fish that delayed, 12.9 h for fish that exited to collection channels, and 23.0 h for those that exited to the tailrace. Sockeye salmon tended to pass more quickly in July compared to June, but patterns were similar in regard to the effects of transition pool behavior (Table 48).

Similar patterns emerged when we considered each transition pool separately (Figure 14, Table 49). The following comparisons are for groups with > 10 fish in each behavior category: sockeye salmon that exited the Washington-shore pool to the tailrace took 9.4 h (80%) longer (medians) to pass the dam than fish that moved straight through the pool. Exit fish also took 2 h (10%) longer than fish that delayed in the pool before passing (Table 49). Salmon that exited the Cascades Island pool took 28.3 h (198%) longer than fish that delayed in the pool before passing. Those that exited the B-Branch pool took 16.9 h (245%) longer than those that moved straight through that pool and 11.4 h (92%) longer than those that delayed in the pool before passing. Those that exited the A-Branch pool took 17.7 h (347%) longer to pass the dam than those that moved straight through, 13.3h (140%) longer to pass than fish that delayed in the pool, and 9.4 h (70%) longer than those that exited to the collection channel before passing. Patterns were similar within individual months at each pool (Tables 50-53), though sample sizes were often limited.

Factors that affected the likelihood of transition pool exit are examined further in the multivariate section below.

Factors Associated with Transition Pool Exits by Salmon and Steelhead

The largest dam passage delays for all studied runs occurred when fish exited transition pools into the tailrace. We used univariate χ^2 tests and multiple logistic regression models to evaluate how several variables may have affected pool exit behavior including transition pool entered, date, transition pool entry time, tailwater elevation, total flow, spill, and water temperature. Given strong correlations among some variables (e.g., between date and temperature or flow and tailwater elevation during the spring–summer Chinook salmon migrations) some variables were excluded *a priori*. Logistic models were selected because exit behavior is binary: fish either exited or did not exit a transition pool.

Tailwater elevation at Bonneville Dam fluctuates with discharge continuously during all migrations. As elevations increase, additional overflow weirs are completely submerged inside fishways, and concerns have been raised that resulting changes in flows through weir sluices and over overflow portions of weirs may contribute to fish turn-around in the transition pools. Tailwater elevation is strongly positively correlated with total discharge at Bonneville Dam, but while elevation affects conditions inside fishways, total flow likely has limited direct impacts. Elevated temperatures could also create passage deterrents in the pools as at John Day Dam (described in Keefer et al. 2003a). We did not monitor fishway temperatures at Bonneville, and so used temperatures collected at the water quality monitoring site. These should be a reasonable surrogate for fishway temperatures, though intra-daily fluctuations and any systematic warming were likely missed.

Chinook salmon

Univariate analyses - With all years combined, Chinook salmon that first entered the Washington-shore transition pool had the highest exit rate (40.4%), followed by those that entered the Cascades Island pool (36.6%), the A-Branch pool (32.9%) and the B-Branch pool

(31.9%). These differences were significant (χ^2 = 20.1, P = 0.0002). With all transition pools combined, among-year differences in exit percentages were also significant (χ^2 = 87.9, P < 0.0001), ranging from 24.6% in 2001 to 47.8% in 1997. Comparisons of exit percentages across years by pool and across pools by year produced similar significant results (P < 0.05 in all but one test). However, the pools with the highest exit proportions differed among years (Figure 15).

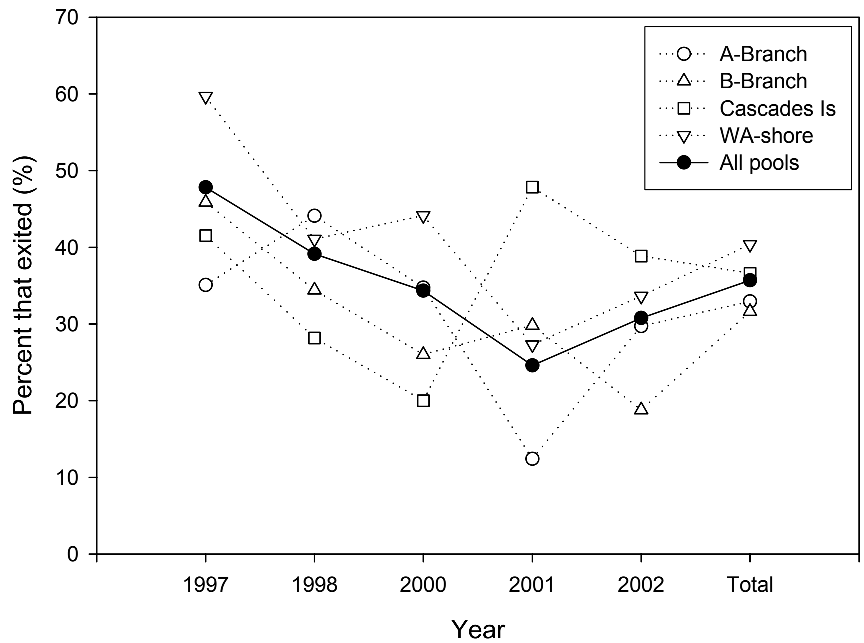

Figure 15. Percent of radio-tagged Chinook salmon that exited transition pools into the tailrace at Bonneville Dam, by year and transition pool.

Time of day that Chinook salmon first entered transition pools was also influential (Figure 16). With all pools and years combined, salmon were less likely to exit to the tailrace if they first entered a pool in the afternoon (χ^2 = 47.1, P < 0.0001). For individual pools, time of day differences were significant only for fish that first entered the A-Branch pool (χ^2 = 18.4, P = 0.0025) or the Washington-shore pool (χ^2 = 25.9, P < 0.0001).

To facilitate interpretation of the effects of environmental variables on transition pool exit probabilities we converted these continuous variables to categorical variables. For temperature, this resulted in 8 increments of 2 ºC each. With all years and pools combined, pool exit percentages strongly increased as temperature increased (χ^2 = 178.8, P < 0.0001) (Figure 17). This pattern was consistent for each transition pool separately (P < 0.0001) and within each year with all pools combined (P < 0.0001 in all but 1997 when P = 0.0155) (Figure 18). Tailwater elevation was categorized into 8 groups with 4 ft (1.2 m) intervals. With all years and pools combined, exit percentages increased as tailwater elevation rose (χ^2 = 62.8, P < 0.0001), though the small number of fish at the lowest elevation also had a high exit percentage (Figure 19). Patterns were similar for individual transition pools (P < 0.05) except for the Cascades Island pool (P = 0.1033), and within each year (P < 0.06). Secchi depth visibility was converted

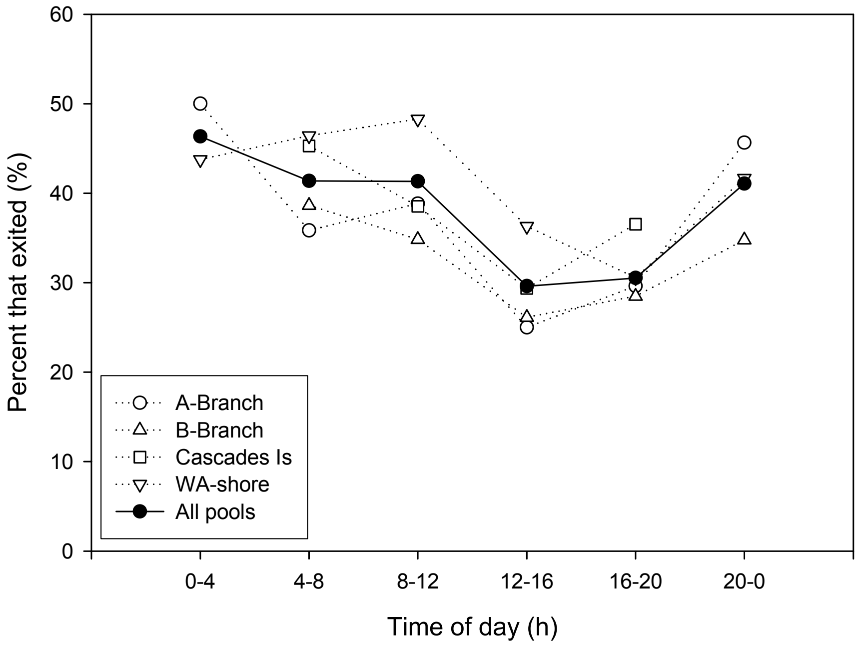

Figure 16. Percent of radio-tagged Chinook salmon that exited transition pools into the tailrace at Bonneville Dam, by time of day and first transition pool entered. All years combined.

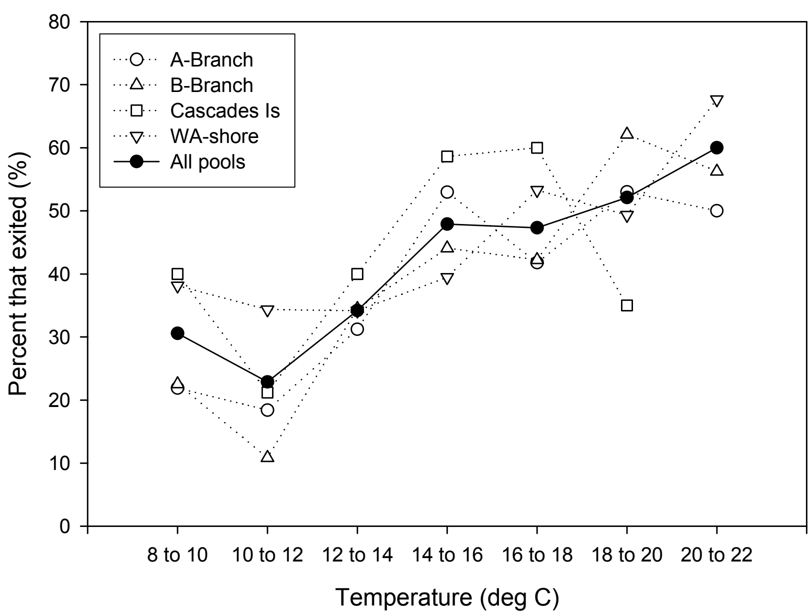

Figure 17. Percent of radio-tagged Chinook salmon that exited transition pools into the tailrace at Bonneville Dam, by water temperature and transition pool first entered. All years combined.

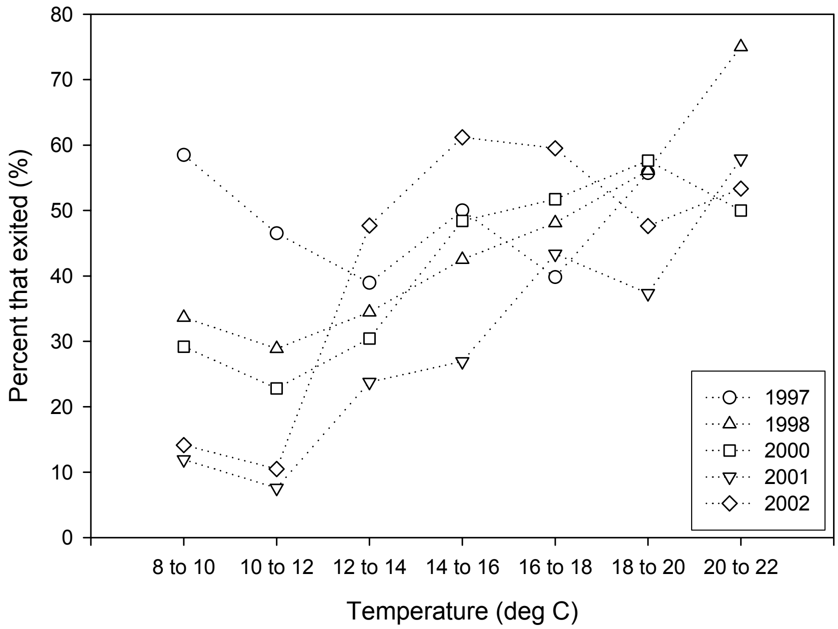

Figure 18. Percent of radio-tagged Chinook salmon that exited transition pools into the tailrace at Bonneville Dam, by water temperature and year. All transition pools combined.

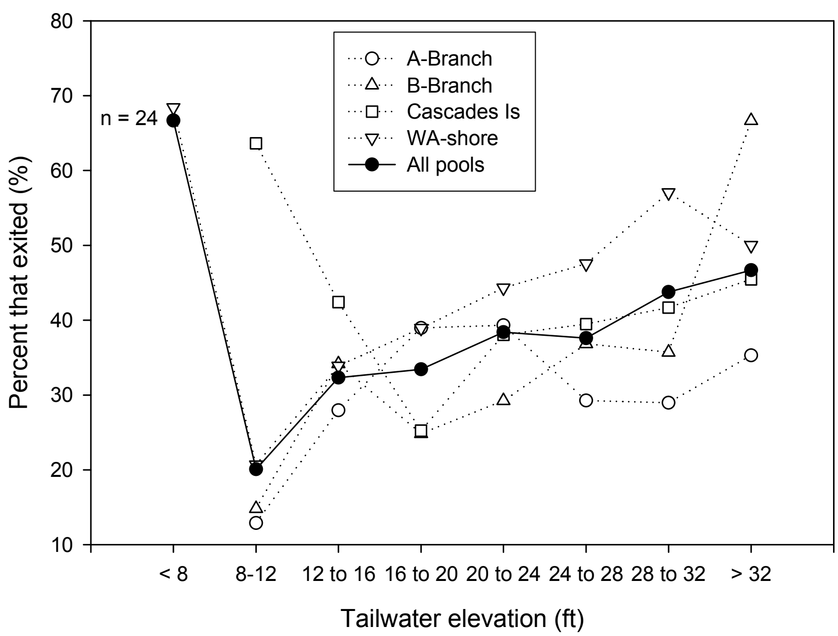

Figure 19. Percent of radio-tagged Chinook salmon that exited transition pools into the tailrace at Bonneville Dam, by tailwater elevation and transition pool first entered. All years combined.

into 6 categories of 1 ft (0.3 m) increments. With all years and pools combined, exit percentages decreased as visibility increased ($\chi^2 = 41.7$, $P < 0.0001$) (Figure 20). The pattern was similarly significantly for fish that first entered the B-Branch or Washington-shore pools ($P <$ 0.0001). Within years, the relationship between Secchi depth and exit percentage was significant only in 2000, when an opposite pattern was observed: more fish exited when visibility was high ($P < 0.0001$). In 2000 the runoff peak was earlier than average, with corresponding higher turbidity earlier in the migration season.

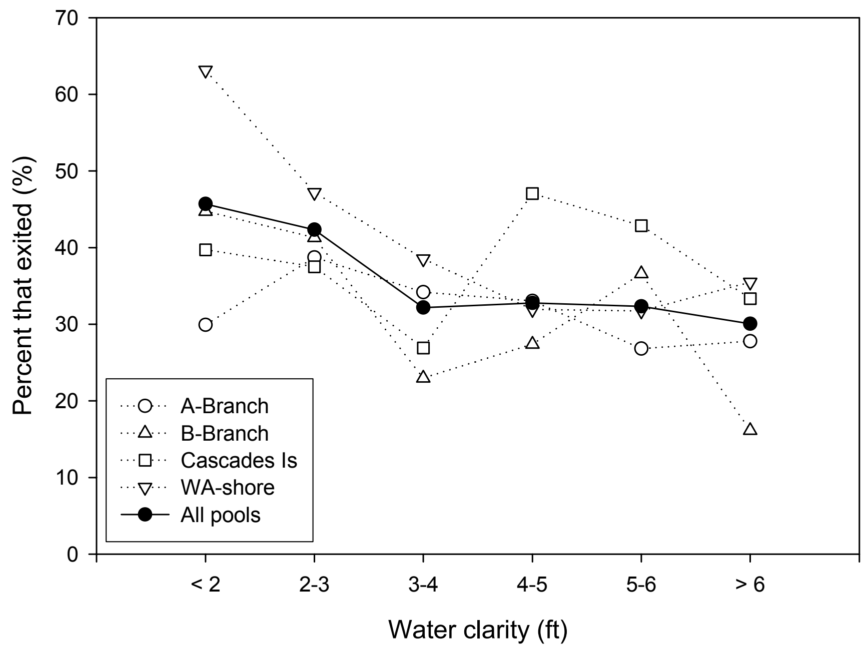

Figure 20. Percent of radio-tagged Chinook salmon that exited transition pools into the tailrace at Bonneville Dam, by water clarity (Secchi depth visibility) and transition pool first entered. All years combined.

Multiple logistic regression analyses - In a multiple stepwise logistic regression model with all Chinook salmon included, water temperature was selected first followed by year, the temperature×year interaction, first transition pool entered, two more interaction terms, and time of day (Table 54). Temperature was also the first variable selected in models that considered each transition pool separately, except that year was selected first for fish first entering the Washington-shore pool. The selection of year for the Washington-shore pool probably reflected the large difference in exit percentages between 1997 (59.7%) and 2001 (27.3%) (Figure 15). The year and/or temperature×year terms were also selected in the separate transition pool models (Table 54). These results suggest that temperature (or the closely related migration date) was the most influential factor in transition pool exits. The strong year effects suggest that inter-annual differences in total discharge are likely important, or that the switch in Powerhouse priority may have played a role. Notably, tailwater elevation, a strong correlate with total discharge, was not selected in any of these models.

Table 54. Results of multiple logistic regression models (stepwise, descending) predicting the likelihood of spring–summer Chinook salmon exiting the first transition pool they entered into the tailrace at Bonneville Dam, for all fish and by transition pool first entered. Predictor variables included: year (categorical, *n* = 5), first transition pool entered (categorical, *n* = 4), time of transition pool entry (categorical, *n* = 6 4 h increments), tailwater elevation (continuous, 4 ft [1.2 m] increments), turbidity (continuous, 1 ft [0.3 m] increments), and temperature (continuous, 2 ºC increments) as well as all single interaction terms. Includes fish with records at all passage points.

Data	Step	Variable entered	*df*	χ^2	*P*
All salmon (*n* = 3,311)	1	Temperature	1	139.4	<0.0001
	2	Year	4	99.4	<0.0001
	3	Temperature×Year	4	87.6	<0.0001
	4	Transition pool	3	28.3	<0.0001
	5	Transition pool×Year	12	61.8	<0.0001
	6	Temperature×Transition pool	3	18.6	0.0003
	7	Time of day	5	14.5	0.0126
A-Branch (*n* = 1,029)	1	Temperature	1	67.7	<0.0001
	2	Year	4	45.4	<0.0001
	3	Temperature×Year	4	10.6	0.0313
B-Branch (*n* = 734)	1	Temperature	1	64.8	<0.0001
	2	Year	4	30.4	<0.0001
Cascades Island (*n* = 369)	1	Temperature	1	8.0	0.0046
Washington Shore (*n* = 1,179)	1	Year	4	67.4	<0.0001
	2	Temperature	1	33.4	<0.0001
	3	Temperature×Year	4	64.5	<0.0001
	4	Time of day	5	14.8	0.0113

Models that looked at each year independently produced generally similar results (Table 55). An exception was in 1997, when the first transition pool entered was the first and only variable selected, reflecting large differences in exit percentages for the Washington-shore pool (59.7%) and A-Branch pool (35.1%) that year (Figure 15). In 1998, temperature was the only variable selected. In 2000 and 2001, temperature was selected first followed by the first transition pool entered. In 2002, temperature was again first, followed by tailwater elevation.

Steelhead

Univariate analyses - With all years combined, steelhead that first entered the Washington-shore transition pool had the highest exit rate (53.3%), followed by those that entered the A-Branch pool (34.2%), the B-Branch pool (33.9%) and the Cascades Island pool (29.9%). These differences were significant (χ^2 = 95.9, P < 0.0001). With all transition pools combined, among-year differences in exit percentages were also significant (χ^2 = 22.2, P < 0.0001), ranging from 34.7% in 1997 to 48.7% in 2002. Comparisons of exit percentages across years by pool and across pools by year produced generally similar results (Figure 21).

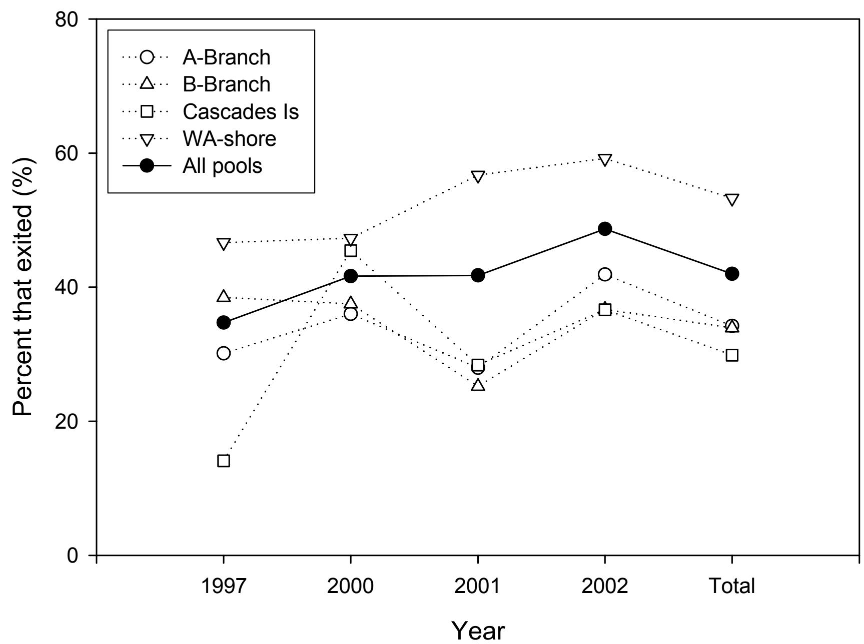

Figure 21. Percent of radio-tagged steelhead that exited transition pools into the tailrace at Bonneville Dam, by year and transition pool.

Time of day that steelhead first entered transition pools was also influential (Figure 22). With all pools and years combined, steelhead were less likely to exit to the tailrace if they first entered a pool in late morning (χ^2 = 11.8, P = 0.0376). For individual pools, time of day differences were significant only for fish that first entered the Washington-shore pool (χ^2 = 11.7, P = 0.0396).

To facilitate interpretation of the effects of environmental variables on transition pool exit probabilities we converted these continuous variables to categorical variables. For temperature,

Table 55. Results of multiple logistic regression models (stepwise, descending) predicting the likelihood of spring–summer Chinook salmon exiting transition pools into the tailrace at Bonneville Dam, by year. Predictor variables included: first transition pool entered (categorical, *n* = 4), time of transition pool entry (categorical, *n* = 6 4 h increments), tailwater elevation (continuous, 4 ft [1.2 m] increments), turbidity (continuous, 1 ft [0.3 m] increments), and temperature (continuous, 2 ºC increments) as well as all single interaction terms. Includes fish with records at all passage points.

Data	Step	Variable entered	*df*	χ^2	*P*
1997 (*n* = 688)	1	Transition pool	3	28.4	<0.0001
1998 (*n* = 718)	1	Temperature	1	26.0	<0.0001
2000 (*n* = 667)	1	Temperature	1	47.9	<0.0001
	2	Transition pool	3	17.5	0.0006
2001 (*n* = 614)	1	Temperature	1	59.0	<0.0001
	2	Transition pool	3	12.7	0.0054
	3	Time of day	5	14.1	0.0147
	4	Turbidity	1	5.0	0.0251
2002 (*n* = 624)	1	Temperature	1	103.5	<0.0001
	2	Tailwater elevation	1	20.9	<0.0001
	3	Transition pool	3	28.9	<0.0001

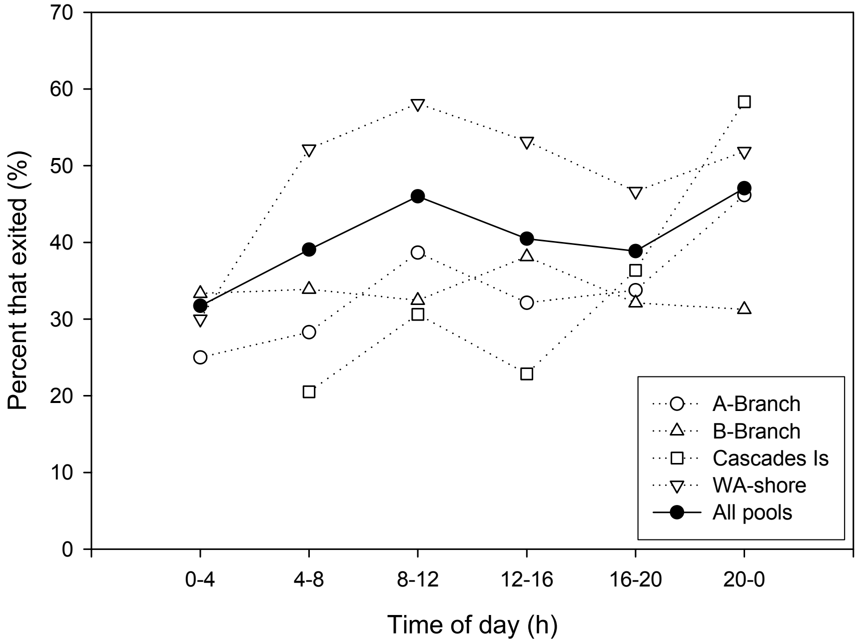

Figure 22. Percent of radio-tagged Chinook salmon that exited transition pools into the tailrace at Bonneville Dam, by time of day and first transition pool entered. All years combined.

this resulted in 7 increments of 2 ºC each. With all years and pools combined, pool exit percentages did not differ among temperature intervals (χ^2 = 9.0, P = 0.1747) (Figure 23). This pattern of non-significance was consistent for each transition pool separately (P > 0.05) and within each year with all pools combined (P > 0.05) except in 1997 when no consistent pattern emerged but P = 0.0375 (Figure 24). Tailwater elevation was categorized into 8 groups with 4 ft (1.2 m) intervals. With all years and pools combined, there was not a significant change in exit percentages as tailwater elevation rose (χ^2 = 5.6, P = 0.5869), though the small number of fish at the highest elevation had the lowest exit percentage (Figure 25). When individual transition pools were considered, some differences were significant (P < 0.05) with a general tendency toward higher exit percentages at higher tailwater elevations. Secchi depth visibility was converted into 6 categories of 1 ft (0.3 m) increments. With all years and pools combined, exit percentages did not vary with visibility (χ^2 = 7.7, P = 0.1727) (Figure 26). The pattern was similarly non-significant for fish that first entered the B-Branch, Cascades Island or Washington-shore pools (P > 0.05). Variability in exit percentages for those that entered the A-Branch pool was significant (P < 0.05) but no clear pattern emerged. Within years, the relationship between Secchi depth and exit percentage was not significant in any year.

Multiple logistic regression analyses - In a multiple stepwise logistic regression model with all steelhead included, first transition pool entered was selected first followed by year, tailwater elevation, and two interaction terms (Table 56). Tailwater elevation was the first and only variable selected in models that considered separately those fish that used the A-Branch and B-Branch transition pools. Year was the first and only variable selected for fish that used the Cascades Island pool. For those that used the Washington-shore pool first, year was selected first, followed by temperature and tailwater elevation (Table 56). Both year and tailwater elevation effects likely reflect differences in total discharge among years.

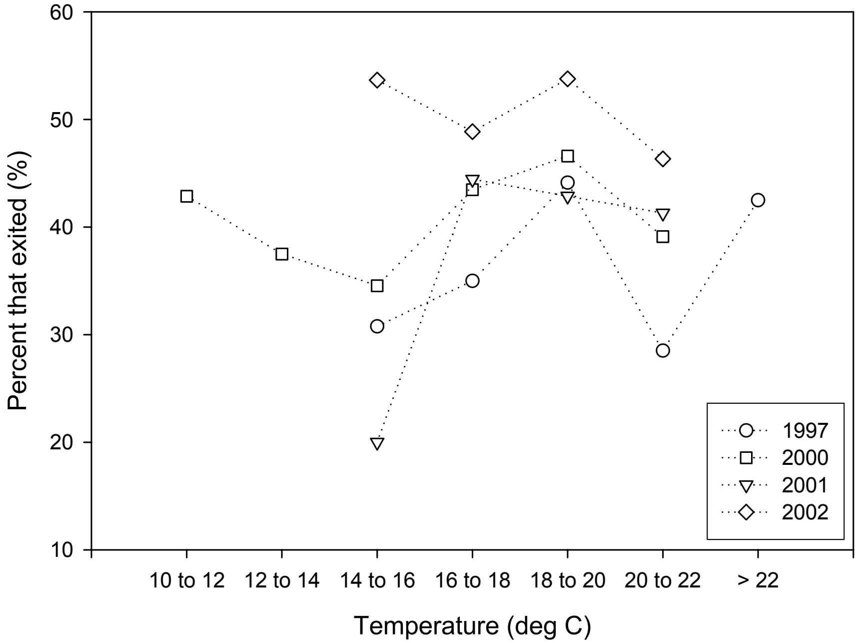

Figure 23. Percent of radio-tagged steelhead that exited transition pools into the tailrace at Bonneville Dam, by water temperature and year. All transition pools combined.

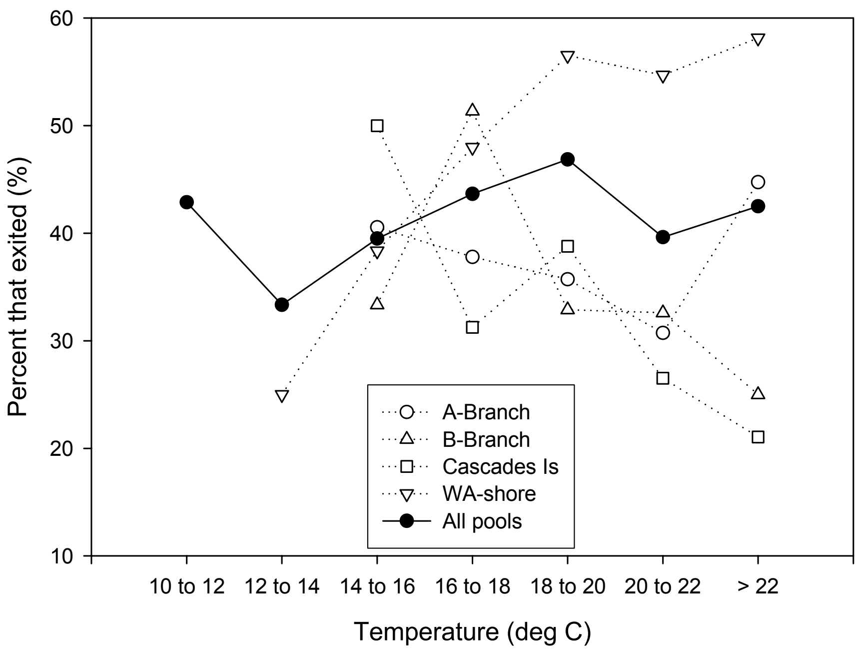

Figure 24. Percent of radio-tagged steelhead that exited transition pools into the tailrace at Bonneville Dam, by water temperature and transition pool first entered. All years combined.

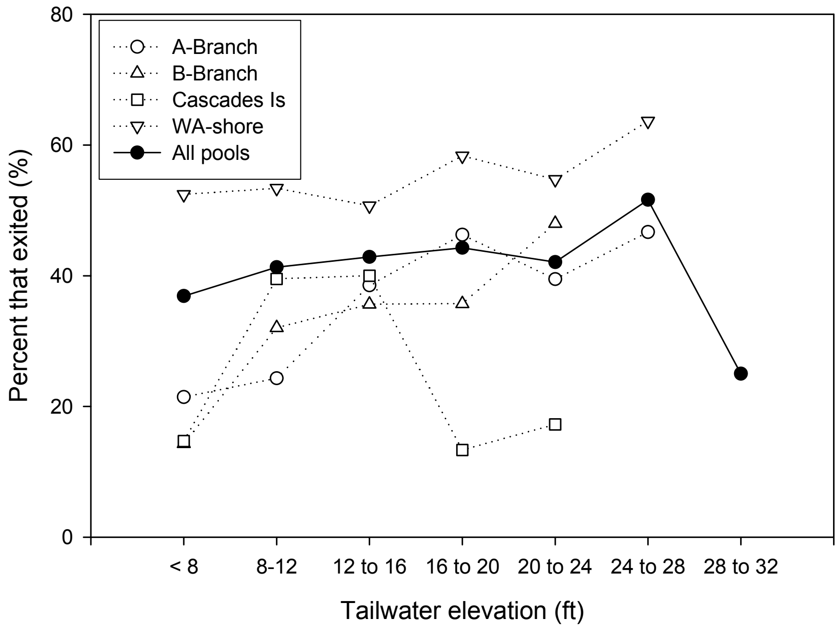

Figure 25. Percent of radio-tagged steelhead that exited transition pools into the tailrace at Bonneville Dam, by tailwater elevation and transition pool first entered. All years combined.

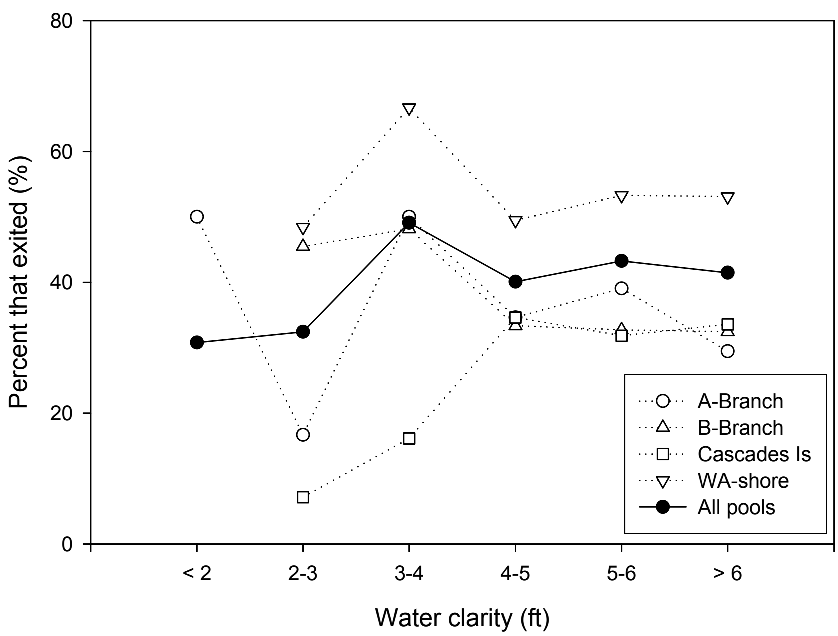

Figure 26. Percent of radio-tagged steelhead that exited transition pools into the tailrace at Bonneville Dam, by water clarity (Secchi depth visibility) and transition pool first entered. All years combined.

Table 56. Results of multiple logistic regression models (stepwise, descending) predicting the likelihood of steelhead exiting the first transition pool they entered into the tailrace at Bonneville Dam, for all fish and by transition pool first entered. Predictor variables included: year (categorical, *n* = 5), first transition pool entered (categorical, *n* = 4), time of transition pool entry (categorical, *n* = 6 4 h increments), tailwater elevation (continuous, 4 ft [1.2 m] increments), turbidity (continuous, 1 ft [0.3 m] increments), and temperature (continuous, 2 ºC increments) as well as all single interaction terms. Includes fish with records at all passage points.

Data	Step	Variable entered	*df*	χ^2	*P*
All salmon (*n* = 2,316)	1	Transition pool	3	95.9	<0.0001
	2	Year	3	15.6	0.0014
	3	Tailwater elevation	1	12.7	0.0004
	4	Transition pool×Year	9	27.5	0.0012
	5	Tailwater elevation×Year	3	9.5	0.0231
A-Branch (*n* = 611)	1	Tailwater elevation	1	8.1	0.0045
B-Branch (*n* = 413)	1	Tailwater elevation	1	6.7	0.0095
Cascades Island (*n* = 278)	1	Year	3	17.3	0.0006
Washington Shore (*n* = 1,014)	1	Year	3	12.3	0.0063
	2	Temperature	1	5.7	0.0168
	3	Tailwater elevation	1	6.1	0.0135

Models that looked at each year independently produced generally similar results (Table 57). First transition pool entered was selected first in 1997, 2001, and 2002. Tailwater elevation was first in 2000, and second in 2001, while Secchi depth was second in 2002. Transition pool exit percentages were consistently highest from the Washington-shore pool, and this pattern was reflected in multivariate results.

Sockeye salmon

Univariate analyses - Exit percentages did not differ by first transition pool entered for sockeye salmon in 1997 ($\chi^2 = 2.3$, $P = 0.5155$). Time of day that sockeye salmon first entered transition pools was also non significant ($P > 0.05$), with all pools combined or for any individual pool. Sockeye salmon encountered four temperature categories. Exit percentages decreased from 44.6% at 14-16 ºC to 26.7% at 20-22 ºC, but differences among categories were not significant ($\chi^2 = 2.6$, $P = 0.4622$). Sample sizes for some individual temperature/transition pool categories were small, limiting statistical tests. Exit percentages from individual pools were quite variable, but no differences were identified as significant. Six tailwater elevation intervals and four Secchi depth intervals were encountered by sockeye salmon. While there was a tendency for increasing exit probabilities as elevation increased, tests of these variables were not significant with all pools combined. Sample sizes for individual pools were again limited.

Multiple logistic regression analyses - In a multiple stepwise logistic regression model with all sockeye salmon included, no variables were selected as predictive of transition pool exit behavior. In addition, no variables were selected for any individual pool model. The lack of significant findings for sockeye salmon may have been related to the relatively narrow passage window for these fish, the small sample sizes at individual transition pools, and limited variability in predictive variables relative to Chinook salmon or steelhead.

Modeling Bonneville Dam Passage Times

We used multiple regression analyses (PROC GLM, SAS) to identify which continuous variables (date, flow, spill, turbidity, temperature) and categorical variables (fishway exit, transition pool first entered, transition pool exit, time of day) most influenced Bonneville Dam passage times. Times modeled were from first tailrace entry to pass over the dam, from first tailrace to first fishway entry, and from first fishway entry to pass the dam. These segments were selected so that fishway and transition pool behaviors could be included as predictor variables. All times were log-transformed to improve normality.

Correlations among predictor variable were high in some cases, particularly among date and temperature and among flow and spill, and tailwater elevation. Similarly, the fishway exit term (0 exits, 1 exit, > 1 exit) was similar to transition pool exit (exit, no exit). Nonetheless, all variables were retained and both Type I and Type III sums of squares were reported. The latter take into account the variability explained by all other variables in the model.

Significant year effects were detected in models that included fish from all years, reflecting inter-annual differences in river environment, dam operations (e.g., Powerhouse priority, spill tests), and the timing and size of samples. In general, between-year differences for Chinook salmon indicated that passage times were longest in 1997 (high flow) and 2002 (moderate flow, Powerhouse II priority, spill test) and were shortest in 1998 or 2000, two years with near-average flow conditions (Figure 27). Seasonal effects were also evident for both Chinook salmon and steelhead. Spring Chinook generally had longer passage times than summer

Table 57. Results of multiple logistic regression models (stepwise, descending) predicting the likelihood of steelhead exiting transition pools into the tailrace at Bonneville Dam, by year. Predictor variables included: first transition pool entered (categorical, *n* = 4), time of transition pool entry (categorical, *n* = 6 4 h increments), tailwater elevation (continuous, 4 ft [1.2 m] increments), turbidity (continuous, 1 ft [0.3 m] increments), and temperature (continuous, 2 ºC increments) as well as all single interaction terms. Includes fish with records at all passage points.

Data	Step	Variable entered	*df*	χ^2	*P*
1997 (*n* = 510)	1	Transition pool	3	27.9	<0.0001
2000 (*n* = 634)	1	Tailwater elevation	1	7.2	0.0072
	2	Transition pool	3	8.2	0.0426
2001 (*n* = 570)	1	Transition pool	3	52.2	<0.0001
	2	Tailwater elevation	1	9.3	0.0023
2002 (*n* = 602)	1	Transition pool	3	26.2	<0.0001
	2	Turbidity	1	10.7	0.0011

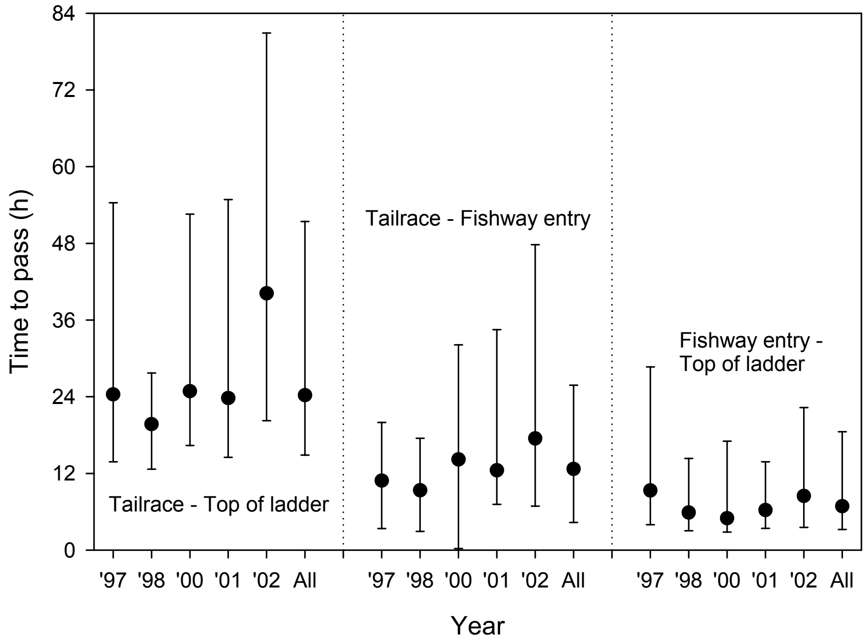

Figure 27. Summary of median passage times for radio-tagged Chinook salmon for selected passage segments at Bonneville Dam, by year.

Chinook (Figure 28), while some steelhead had long passage times during the warmest months (Figure 29).

Chinook salmon

Tailrace to top of ladder - Multiple regression models were highly significant ($P < 0.0001$) for Chinook salmon in each year, and the predictor variables explained between 24 and 40% of the variability in passage times (Table 58). When all variables were considered together, fishway exits into the tailrace of Bonneville Dam was the most influential variable in 1997, 2000, and 2002; temperature was most influential in 1998 and 2001, reflecting a seasonal effect. Time of tailrace entry was also significant in all years except 2000, reflecting longer passage times for salmon that entered the tailrace in mid- to late in the day and then spent a night in the tailrace or a fishway. Exit from a transition pool (as opposed to exit from a fishway) was also significant in several years (Table 58). Figure 30 shows the relationships, with continuous variables (flow, spill, temperature) reduced to intervals.

Tailrace to first fishway entry - Water temperature and time of tailrace entry were the variables that most influenced Chinook salmon passage times through the tailrace and into a fishway (Figure 31, Table 59). Multiple regression models explained 17 to 41% of the variability in this passage segment. Passage was slowest for those fish migrating during the coolest period, though times again slowed slightly at the highest temperatures. The time of day effect was not the same in all years, though times were most consistently low for those fish that entered the tailrace between 4 a.m. and noon. Greater variability for those fish that arrived in late afternoon likely reflected seasonal differences in day length. Total flow was significant in

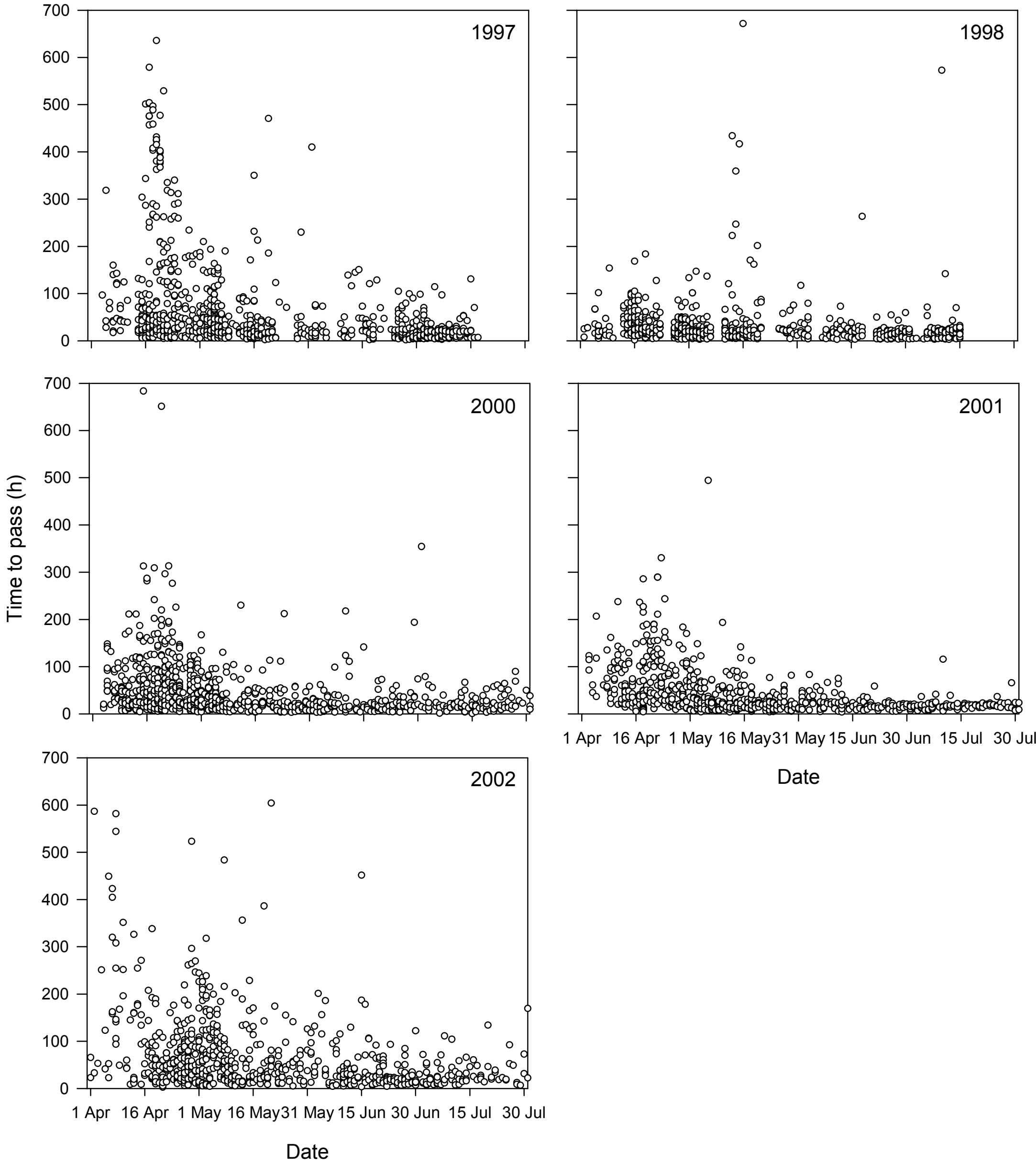

Figure 28. Full-dam (tailrace to top of ladder) passage times of radio-tagged Chinook salmon at Bonneville Dam, by year.

2001 and 2002, but the relationship between flow and passage time differed in these years, with slow passage at low-flow conditions in 2002 and a slight increase in times at higher flow in 2001.

First fishway entry to top of ladder - The multiple regression models for the first fishway entry to top of ladder section explained more of the variability (40-58%) than models for the other segments (Figure 32, Table 60). In all years, fishway exit and time of first fishway entry variables were the most influential. As would be expected, fish with more fishway exits had

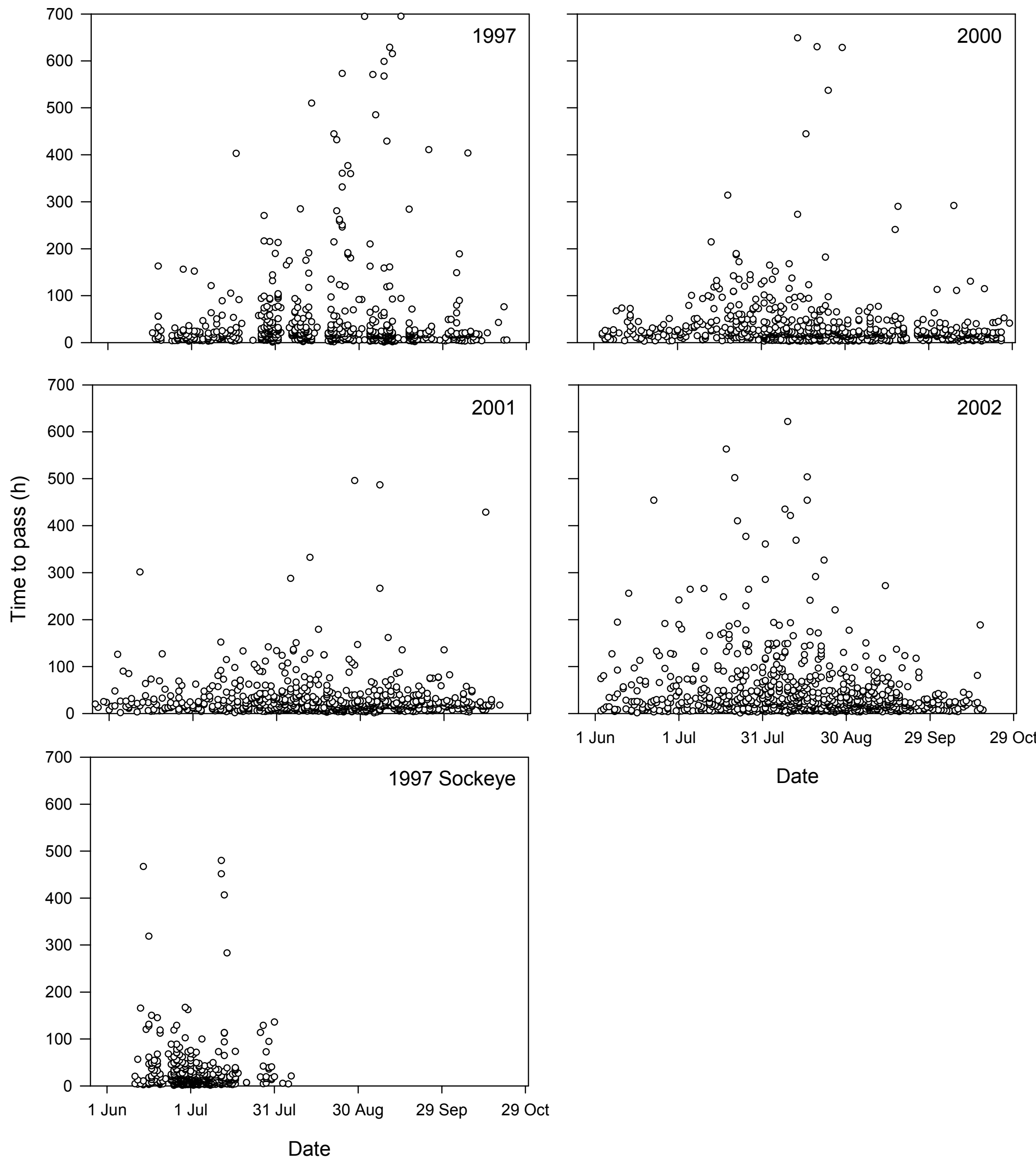

Figure 29. Full-dam (tailrace to top of ladder) passage times of radio-tagged steelhead and sockeye salmon at Bonneville Dam, by year.

longer passage times. Chinook salmon that first entered a fishway in the late afternoon or evening had longer passage times than those that arrived earlier in the day, as a greater proportion of the late entries spent the night in the tailrace or in a fishway. Exit from a transition pool and the first transition pool entry location were also significant variables in 1997 and 2000, most likely indicating greater exit rates from some transition pools.

Table 58. Results of multiple regression analysis, where Chinook salmon time to pass Bonneville Dam (tailrace to top of ladder, log-transformed) was the dependent variable and independent variables included date, time of day, fishway exit to tailrace (0,1,>1), transition pool exit to tailrace (0,1), location of first fishway approach (PH1,PH2,spillway), location of first transition pool entry, flow, spill, tailwater elevation, turbidity, and temperature. Type III sum of squares adjust for all other variables in the model. Only includes fish with records at all passage points.

Year	Source	Type I SS	*F*	*P*	Type III SS	*F*	*P*
1997	Date	26.6	174.8	<0.0001	0.0	0.0	0.9836
	Time	3.2	4.3	0.0008	3.1	4.1	0.0011
	Fishway approach	0.6	2.1	0.1237	0.3	0.91	0.4049
	Transition pool	4.0	8.9	<0.0001	0.7	1.63	0.1812
	Fishway exits	18.6	61.2	<0.0001	5.7	18.8	<0.0001
	Pool exit	0.8	5.5	0.0199	0.8	5.5	0.0194
	Flow	0.0	0.2	0.6263	0.0	0.1	0.7330
	Spill	0.0	0.0	0.9974	0.0	0.1	0.7143
	Temperature	0.4	3.0	0.0864	0.4	3.0	0.0864
	Turbidity	0.0	0.2	0.6999	0.1	0.4	0.5566
Model r^2 = 0.35; F = 19.9; P < 0.0001							
1998	Date	4.7	53.8	< 0.0001	0.4	4.4	0.0370
	Time	3.7	8.4	< 0.0001	3.8	8.7	< 0.0001
	Fishway approach	1.1	6.0	0.0026	0.5	3.1	0.0462
	Transition pool	2.1	8.1	< 0.0001	2.7	10.3	< 0.0001
	Fishway exits	12.4	70.58	< 0.0001	3.0	16.9	< 0.0001
	Pool exit	0.4	4.3	0.0392	0.3	3.1	0.0786
	Flow	0.3	3.3	0.0713	0.0	0.3	0.5697
	Spill	0.1	0.9	0.3513	0.0	0.5	0.4919
	Temperature	1.5	17.5	< 0.0001	1.5	17.5	< 0.0001
	Turbidity	0.4	4.4	0.0357	0.1	1.2	0.2668
Model r^2 = 0.30; F = 16.8; P < 0.0001							

Table 58. Continued.

Year	Source	Type I SS	F	P	Type III SS	F	P
2000	Date	8.3	63.1	< 0.0001	0.4	3.2	0.0726
	Time	1.8	2.7	0.0207	1.2	1.9	0.1008
	Fishway approach	0.0	0.1	0.8857	0.0	0.1	0.8981
	Transition pool	0.1	0.3	0.8502	1.1	2.8	0.0375
	Fishway exits	14.8	56.3	< 0.0001	4.4	16.9	< 0.0001
	Pool exit	0.3	2.5	0.1169	0.4	3.3	0.0693
	Flow	0.8	6.0	0.0147	0.0	0.4	0.5460
	Spill	0.4	2.9	0.0909	0.4	3.2	0.0746
	Temperature	0.0	0.0	0.8680	0.0	0.0	0.8680
	Turbidity	0.4	3.3	0.0693	0.4	3.3	0.0692
							Model r^2 = 0.24; F = 11.4; P < 0.0001
2001	Date	20.2	223.2	< 0.0001	0.0	0.1	0.7583
	Time	3.1	7.0	< 0.0001	2.2	4.8	0.0002
	Fishway approach	0.5	2.8	0.0605	0.1	0.7	0.5066
	Transition pool	1.7	6.4	0.0003	0.6	2.3	0.0770
	Fishway exits	5.0	27.4	< 0.0001	1.2	6.5	0.0016
	Pool exit	0.4	5.5	0.0195	0.4	4.9	0.0274
	Flow	3.3	36.1	< 0.0001	1.1	12.4	0.0005
	Spill	0.1	0.7	0.4177	0.1	0.7	0.4126
	Temperature	1.3	14.0	0.4374	1.3	14.0	0.0002
	Turbidity	0.1	0.6	0.0002	0.0	0.2	0.6967
							Model r^2 = 0.40; F = 21.9; P < 0.0001
2002	Date	15.1	121.2	< 0.0001	0.3	2.1	0.1439
	Time	3.2	5.1	0.0001	2.6	4.2	0.0010
	Fishway approach	1.0	4.1	0.0176	1.6	6.3	0.0020
	Transition pool	2.5	6.7	0.0002	1.3	3.4	0.0185
	Fishway exits	11.8	47.2	< 0.0001	4.0	15.9	< 0.0001
	Pool exit	0.3	2.6	0.1086	0.7	5.3	0.0212
	Flow	3.8	30.4	< 0.0001	1.3	10.3	0.0014
	Spill	0.0	0.2	0.6477	0.0	0.1	0.8148
	Temperature	0.0	0.0	0.8606	0.0	0.0	0.8606
	Turbidity	0.25	1.4	0.2420	0.2	1.2	0.2730
							Model r^2 = 0.33; F = 16.9; P < 0.0001

Table 59. Results of multiple regression analysis, where Chinook salmon time to pass from tailrace to first fishway entry (log-transformed) was the dependent variable and independent variables included date, time of day, fishway exit to tailrace (0,1,>1), transition pool exit to tailrace (0,1), location of first fishway approach (PH1,PH2,spillway), location of first transition pool entry, flow, spill, tailwater elevation, turbidity, and temperature. Type III sum of squares adjust for all other variables in the model. Only includes fish with records at all passage points.

Year	Source	Type I SS	*F*	*P*	Type III SS	*F*	*P*
1997	Date	22.2	87.9	< 0.0001	1.4	5.4	0.0200
	Time	8.6	6.8	< 0.0001	8.5	6.7	< 0.0001
	Fishway approach	0.2	0.3	0.7365	0.1	0.1	0.8722
	Flow	0.1	0.3	0.5978	0.3	1.3	0.2592
	Spill	0.1	0.3	0.5973	0.4	1.4	0.2383
	Temperature	3.4	13.5	0.0003	3.5	13.8	0.0002
	Turbidity	0.1	0.4	0.5299	0.1	0.4	0.5299
Model r^2 = 0.17; F = 11.4; P < 0.0001							
1998	Date	24.1	135.3	< 0.0001	0.6	3.4	0.0656
	Time	9.1	10.2	< 0.0001	9.1	10.3	< 0.0001
	Fishway approach	1.3	3.6	0.0267	1.2	3.3	0.0362
	Flow	0.5	3.0	0.0818	0.4	2.2	0.1428
	Spill	0.4	2.1	0.1462	0.3	1.5	0.2205
	Temperature	3.4	18.9	< 0.0001	2.5	14.2	0.0002
	Turbidity	0.7	4.1	0.0430	0.7	4.1	0.0430
Model r^2 = 0.24; F = 18.5; P < 0.0001							
2000	Date	41.6	180.1	< 0.0001	0.4	1.8	0.1760
	Time	2.8	2.5	0.0320	3.5	3.1	0.0099
	Fishway approach	0.5	1.1	0.3282	0.7	1.5	0.2268
	Flow	2.0	8.7	0.0033	0.2	0.7	0.3998
	Spill	1.4	5.9	0.0157	1.6	6.8	0.0095
	Temperature	0.5	2.0	0.1582	0.1	0.5	0.4681
	Turbidity	2.9	12.4	0.0005	2.9	12.4	0.0005
Model r^2 = 0.25; F = 18.6; P < 0.0001							

Table 59. Continued.

Year	Source	Type I SS	*F*	*P*	Type III SS	*F*	*P*
2001	Date	46.5	290.8	< 0.0001	0.0	0.2	0.6691
	Time	11.4	14.3	< 0.0001	9.8	12.3	< 0.0001
	Fishway approach	1.0	3.2	0.0404	0.0	0.1	0.9512
	Flow	5.8	36.5	< 0.0001	1.6	9.7	0.0019
	Spill	0.4	2.8	0.0965	0.0	0.0	0.9115
	Temperature	1.7	10.7	0.0011	2.1	12.9	0.0004
	Turbidity	0.4	2.5	0.1152	0.4	2.5	0.1152
Model $r^2 = 0.41$; $F = 35.1$; $P < 0.0001$							
2002	Date	52.1	237.6	< 0.0001	0.2	1.0	0.3225
	Time	10.8	9.8	< 0.0001	9.4	8.6	< 0.0001
	Fishway approach	0.4	1.0	0.3645	1.0	2.3	0.0977
	Flow	8.8	40.1	< 0.0001	4.3	19.6	< 0.0001
	Spill	0.8	3.5	0.0605	0.6	2.5	0.1123
	Temperature	0.1	0.7	0.4106	0.1	0.4	0.5375
	Turbidity	0.1	0.7	0.4214	0.1	0.7	0.4214
Model $r^2 = 0.35$; $F = 27.8$; $P < 0.0001$							

Table 60. Results of multiple regression analysis, where Chinook salmon time to pass Bonneville Dam (first fishway entry to top of ladder, log-transformed) was the dependent variable and independent variables included date, time of day, fishway exit to tailrace (0,1,>1), transition pool exit to tailrace (0,1), location of first fishway approach (PH1,PH2,spillway), location of first transition pool entry, flow, spill, tailwater elevation, turbidity, and temperature. Type III sum of squares adjust for all other variables in the model. Only includes fish with records at all passage points.

Year	Source	Type I SS	*F*	*P*	Type III SS	*F*	*P*
1997	Date	18.6	113.5	< 0.0001	0.3	2.0	0.1631
	Time	7.8	9.5	< 0.0001	5.2	6.4	< 0.0001
	Fishway approach	3.5	10.6	< 0.0001	0.1	0.3	0.7567
	Transition pool	4.8	9.8	< 0.0001	1.6	3.3	0.0193
	Fishway exits	75.1	228.5	< 0.0001	19.2	58.5	< 0.0001
	Pool exit	1.7	28.3	< 0.0001	4.7	28.5	< 0.0001
	Flow	0.5	2.9	0.0921	0.0	0.2	0.6279
	Spill	0.6	0.4	0.5319	0.1	0.6	0.4560
	Temperature	0.6	0.4	0.9451	0.6	0.4	0.5604
	Turbidity	0.0	0.0	0.5304	0.0	0.0	0.8876
							Model r^2 = 0.51; F = 38.9; P < 0.0001
1998	Date	0.6	6.5	0.0108	0.5	4.8	0.0295
	Time	8.8	17.8	< 0.0001	7.1	14.3	< 0.0001
	Fishway approach	1.2	6.0	0.0026	0.2	1.2	0.2903
	Transition pool	0.6	2.0	0.1142	1.3	4.3	0.0053
	Fishway exits	56.5	285.9	< 0.0001	15.3	77.5	< 0.0001
	Pool exit	0.1	1.1	0.2883	0.1	0.7	0.4012
	Flow	0.3	3.4	0.0674	0.0	0.2	0.6758
	Spill	0.0	0.1	0.7237	0.0	0.1	0.8195
	Temperature	1.2	12.6	0.0004	1.2	11.9	0.0006
	Turbidity	0.0	0.0	0.9589	0.0	0.0	0.9589
							Model r^2 = 0.50; F = 39.0; P < 0.0001

Table 60. Continued.

Year	Source	Type I SS	*F*	*P*	Type III SS	*F*	*P*
2000	Date	4.1	34.5	< 0.0001	0.4	3.1	0.0806
	Time	1.2	10.2	< 0.0001	3.4	5.7	< 0.0001
	Fishway approach	0.4	3.8	0.0240	0.5	1.9	0.1511
	Transition pool	1.0	8.6	< 0.0001	1.7	4.9	0.0023
	Fishway exits	45.2	380.0	< 0.0001	31.0	130.2	< 0.0001
	Pool exit	0.1	0.8	0.3668	0.1	0.8	0.3868
	Flow	0.0	0.0	0.8413	0.0	0.1	0.7368
	Spill	0.1	0.4	0.5312	0.0	0.4	0.5517
	Temperature	0.0	0.0	0.9574	0.0	0.0	0.1799
	Turbidity	0.2	1.8	0.1761	0.2	1.8	0.9574
							Model r^2 = 0.58; F = 49.0; P < 0.0001
2001	Date	0.1	0.6	0.4559	0.0	0.0	0.9685
	Time	2.9	5.6	< 0.0001	3.3	6.4	< 0.0001
	Fishway approach	4.5	22.1	< 0.0001	0.1	0.5	0.6145
	Transition pool	3.4	11.0	< 0.0001	1.4	4.5	0.0038
	Fishway exits	27.3	133.0	< 0.0001	6.0	29.3	< 0.0001
	Pool exit	1.0	9.3	0.0024	1.0	9.4	0.0023
	Flow	0.4	3.9	0.0485	0.5	4.7	0.0307
	Spill	0.3	2.9	0.0909	0.4	3.9	0.0495
	Temperature	0.2	1.9	0.1664	0.1	1.3	0.2544
	Turbidity	0.0	0.4	0.5437	0.0	0.4	0.5437
							Model r^2 = 0.40; F = 21.7; P < 0.0001
2002	Date	3.0	24.4	< 0.0001	0.7	5.3	0.0213
	Time	8.6	13.7	< 0.0001	9.1	14.6	< 0.0001
	Fishway approach	1.1	4.4	0.0124	0.1	0.5	0.6010
	Transition pool	5.4	14.5	< 0.0001	1.2	3.1	0.0255
	Fishway exits	78.7	315.2	< 0.0001	26.1	104.6	< 0.0001
	Pool exit	0.8	6.2	0.0131	0.7	5.3	0.0220
	Flow	0.0	0.0	0.8563	0.1	0.5	0.4844
	Spill	0.2	1.5	0.2166	0.1	1.2	0.2840
	Temperature	0.3	2.3	0.1327	0.4	3.2	0.0756
	Turbidity	0.2	1.8	0.1834	0.2	1.8	0.1834
							Model r^2 = 0.57; F = 43.8; P < 0.0001

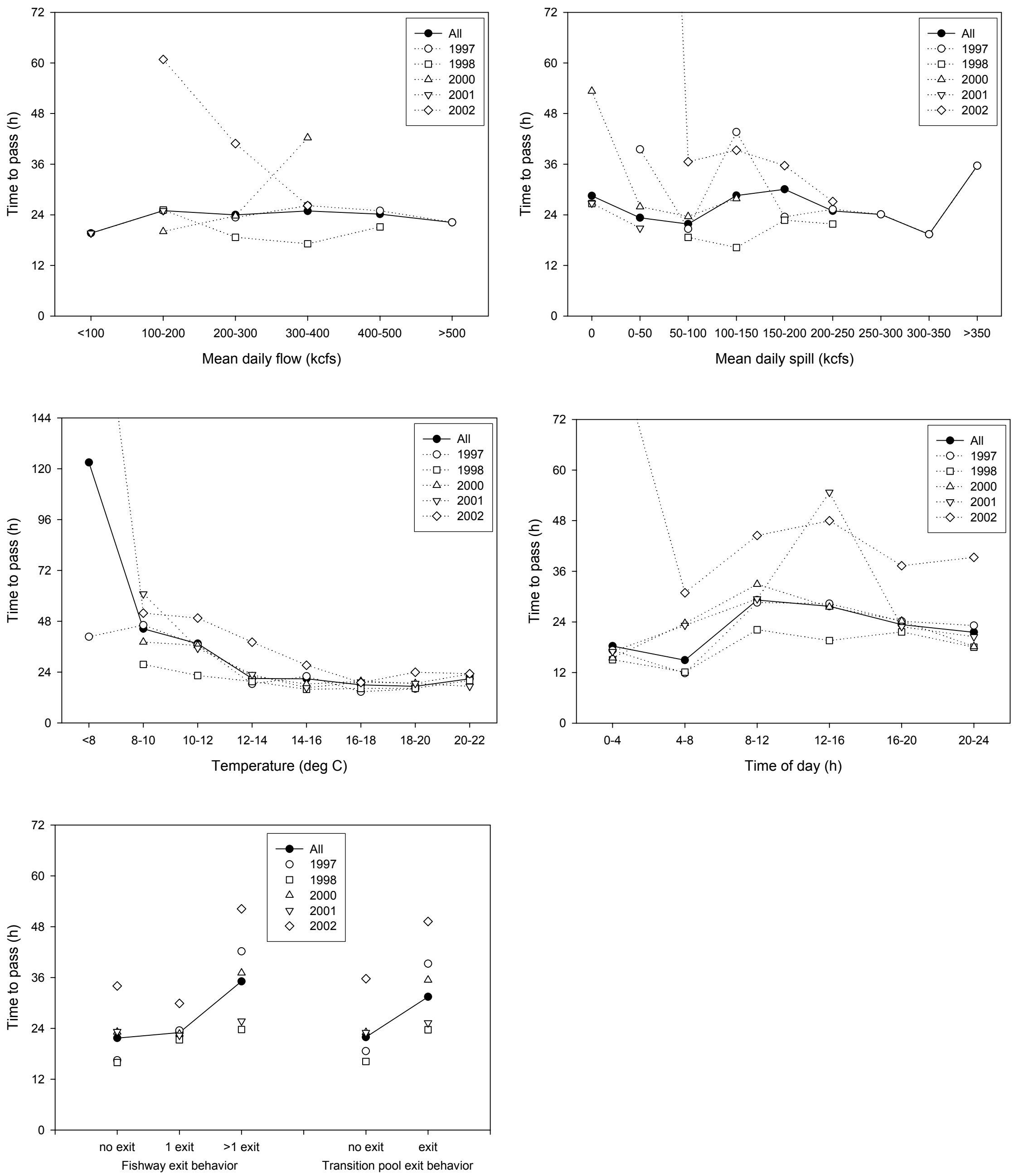

Figure 30. Summary of full-dam (tailrace to top of ladder) passage times for radio-tagged Chinook salmon at Bonneville Dam, based on categories of flow, spill, water temperature, time of day, and fishway and tailrace exit behaviors.

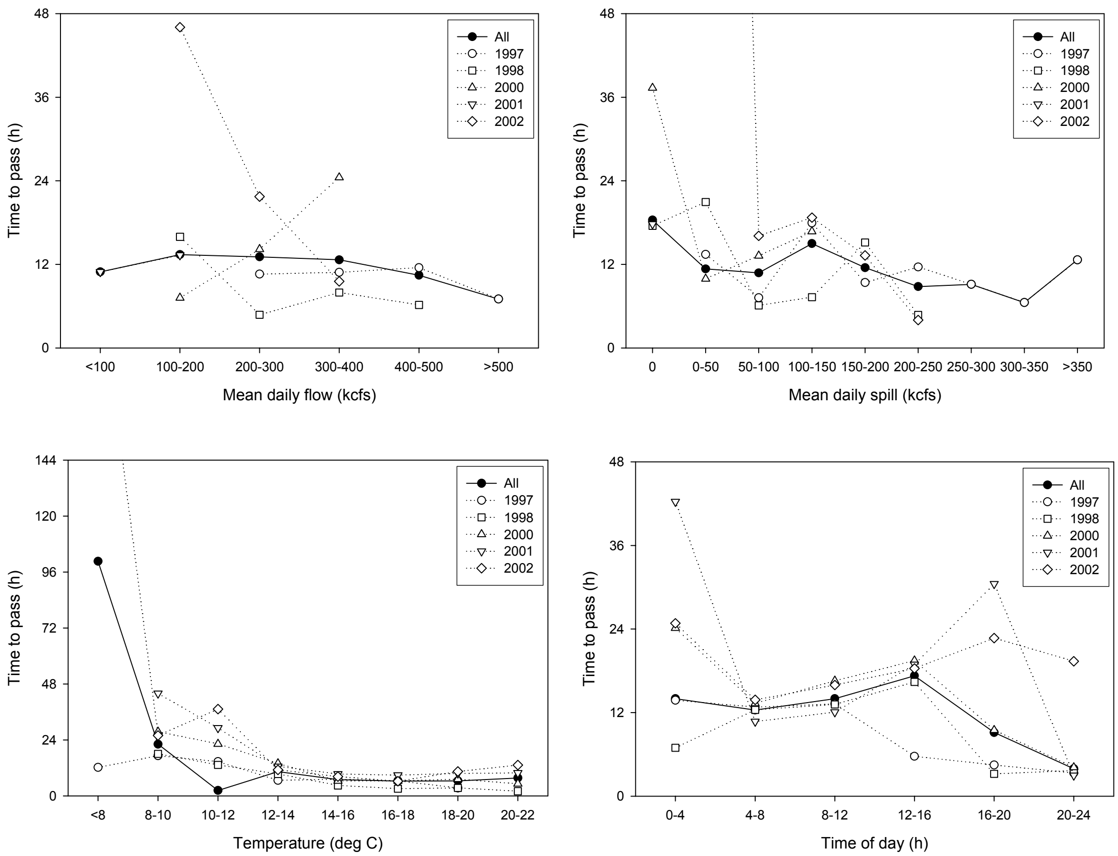

Figure 31. Summary of passage times (first tailrace to first fishway entry) for radio-tagged Chinook salmon at Bonneville Dam, based on categories of flow, spill, water temperature, time of day, and fishway and tailrace exit behaviors.

Steelhead

Tailrace to top of ladder - Multiple regression models were highly significant ($P < 0.0001$) for steelhead in each year, and the predictor variables explained between 26 and 38% of the variability in passage times (Table 61). When all variables were considered together, fishway exits into the tailrace of Bonneville Dam was the most influential variable in 1997, 2000, and 2001; transition pool exit into the tailrace was most influential in 2002. Time of tailrace entry was also significant in all years except 2002, reflecting longer passage times for steelhead that entered the tailrace in mid- to late in the day and then spent a night in the tailrace or a fishway. Spill was an influential variable in 1997, 2000, and 2002, with generally longer passage times at higher spill (Table 61). The first transition pool entered was a significant predictor in 2000-2002, with faster passage for those fish that first entered the A-Branch pool and slower passage for those that first entered either the Cascades Island pool (2000) or the Washington-shore pool (2001, 2002). Figure 33 shows the relationships, with continuous variables (flow, spill, temperature) reduced to intervals.

Tailrace to first fishway entry - Time of tailrace entry and spill were the variables that most influenced steelhead passage times through the tailrace and into a fishway (Figure 34, Table

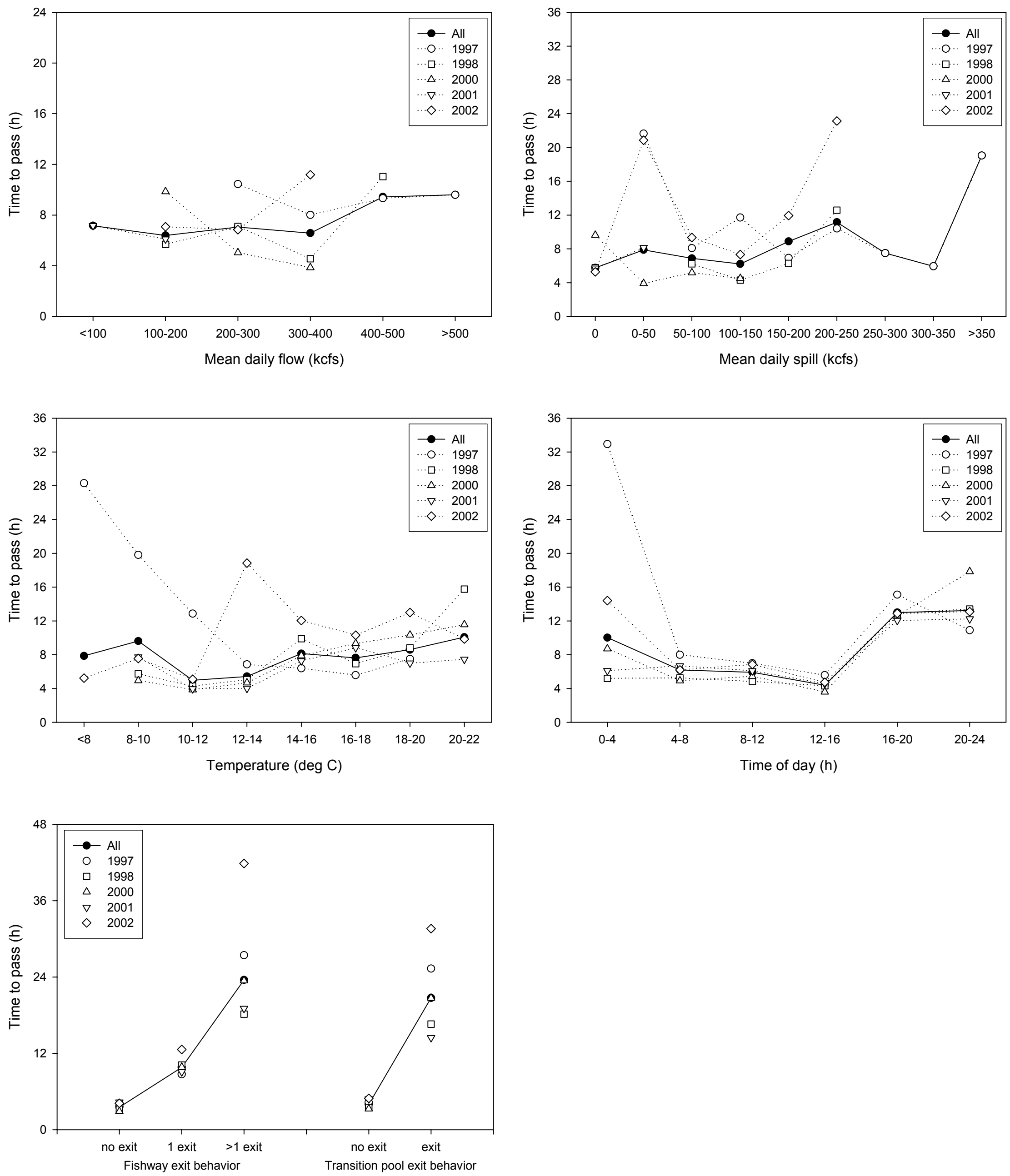

Figure 32. Summary of passage times (first fishway entry to top of ladder) for radio-tagged Chinook salmon at Bonneville Dam, based on categories of flow, spill, water temperature, time of day, and fishway and tailrace exit behaviors.

62). Passage times were most consistently low for those fish that entered the tailrace in late afternoon or at night. Spill was significant in all years, with slightly slower passage under higher spill conditions.

First fishway entry to top of ladder - The multiple regression models for the first fishway entry to top of ladder section explained more of the variability (46-51%) than models for the

Table 61. Results of multiple regression analysis, where steelhead time to pass Bonneville Dam (tailrace to top of ladder, log-transformed) was the dependent variable and independent variables included date, time of day, fishway exit to tailrace (0,1,>1), transition pool exit to tailrace (0,1), location of first fishway approach (PH1,PH2,spillway), location of first transition pool entry, flow, spill, tailwater elevation, turbidity, and temperature. Type III sum of squares adjust for all other variables in the model. Only includes fish with records at all passage points.

Year	Source	Type I SS	*F*	*P*	Type III SS	*F*	*P*
1997	Date	0.1	0.8	0.3627	0.2	1.3	0.2521
	Time	5.3	6.1	<0.0001	6.9	7.9	<0.0001
	Fishway approach	0.9	2.7	0.0710	0.0	0.1	0.8840
	Transition pool	1.4	2.7	0.0432	1.3	2.4	0.0640
	Fishway exits	17.2	49.0	<0.0001	4.0	11.4	<0.0001
	Pool exit	0.4	2.4	0.1218	0.1	0.8	0.3636
	Flow	0.5	3.0	0.0861	0.5	2.8	0.0957
	Spill	5.9	33.5	<0.0001	2.4	13.8	0.0002
	Temperature	0.2	1.0	0.3109	1.2	1.1	0.3026
	Turbidity	0.0	0.1	0.7490	0.1	0.1	0.7490
Model r^2 = 0.27; F = 10.2; P < 0.0001							
2000	Date	3.3	26.3	<0.0001	0.0	0.1	0.7396
	Time	7.9	12.7	<0.0001	5.3	8.5	<0.0001
	Fishway approach	0.0	0.2	0.8205	2.1	8.5	0.0002
	Transition pool	6.7	17.8	<0.0001	3.7	9.9	<0.0001
	Fishway exits	26.2	104.9	<0.0001	4.7	18.9	<0.0001
	Pool exit	1.2	9.6	0.0021	1.0	8.1	0.0045
	Flow	0.0	0.1	0.7056	0.2	1.8	0.1784
	Spill	1.7	13.5	0.0003	1.3	10.2	0.0015
	Temperature	0.0	0.0	0.8771	0.0	0.0	0.9804
	Turbidity	0.0	0.1	0.7553	0.0	0.1	0.7553
Model r^2 = 0.38; F = 20.9; P < 0.0001							

Table 61. Continued.

Year	Source	Type I SS	*F*	*P*	Type III SS	*F*	*P*
2001	Date	0.1	0.6	0.4240	0.2	2.4	0.1244
	Time	3.0	5.8	<0.0001	3.2	6.3	<0.0001
	Fishway approach	2.8	13.5	<0.0001	1.1	5.4	0.0047
	Transition pool	3.1	9.9	<0.0001	1.4	4.6	0.0034
	Fishway exits	14.1	68.6	<0.0001	3.0	14.8	<0.0001
	Pool exit	0.5	5.0	0.0252	0.6	5.5	0.0192
	Flow	0.6	5.5	0.0195	1.1	10.3	0.0014
	Spill	0.1	1.4	0.2328	0.4	3.8	0.0521
	Temperature	0.3	3.0	0.0824	0.3	3.4	0.0667
	Turbidity	0.1	1.1	0.2944	0.1	1.1	0.2944
Model r^2 = 0.30; F = 13.3; P < 0.0001							
2002	Date	2.0	11.1	0.0009	0.2	1.1	0.2906
	Time	1.7	1.8	0.1033	1.9	2.1	0.0649
	Fishway approach	0.7	1.8	0.1605	1.0	2.7	0.0663
	Transition pool	4.7	8.6	<0.0001	2.8	5.1	0.0017
	Fishway exits	20.2	55.7	<0.0001	2.3	6.3	0.0021
	Pool exit	4.5	24.6	<0.0001	5.0	27.4	<0.0001
	Flow	1.1	6.0	0.0147	0.5	2.6	0.1088
	Spill	3.1	16.8	<0.0001	2.2	11.8	0.0006
	Temperature	0.0	0.0	0.8551	0.0	0.0	0.8776
	Turbidity	0.0	0.1	0.7225	0.0	0.1	0.7225
Model r^2 = 0.26; F = 11.6; P < 0.0001							

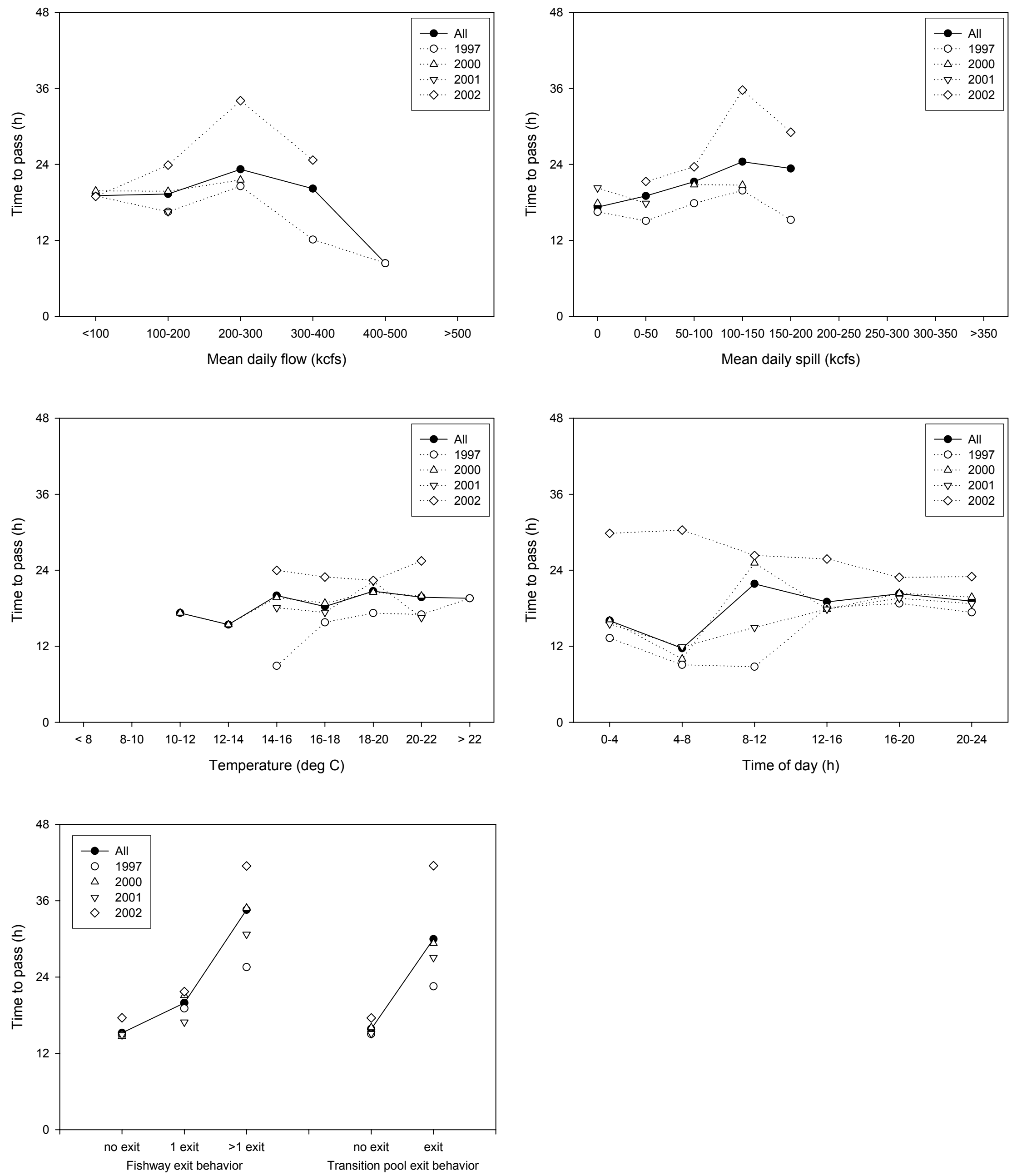

Figure 33. Summary of full-dam (tailrace to top of ladder) passage times for radio-tagged steelhead at Bonneville Dam, based on categories of flow, spill, water temperature, time of day, and fishway and tailrace exit behaviors.

other segments (Figure 35, Table 63). In all years, the number of fishway exits (0, 1, >1) was the most influential variable. As would be expected, fish with more fishway exits had longer passage times. Time of tailrace entry was also significant in all years, and steelhead that first entered a fishway in the late afternoon or evening had longer passage times than those that arrived earlier in the day, as a greater proportion of the late entries spent the night in the tailrace or in a fishway. Exit from a transition pool was also significant, though at lower levels, in all years. As for Chinook and sockeye salmon, transition pool exit and fishway exit variables had considerable overlap for steelhead.

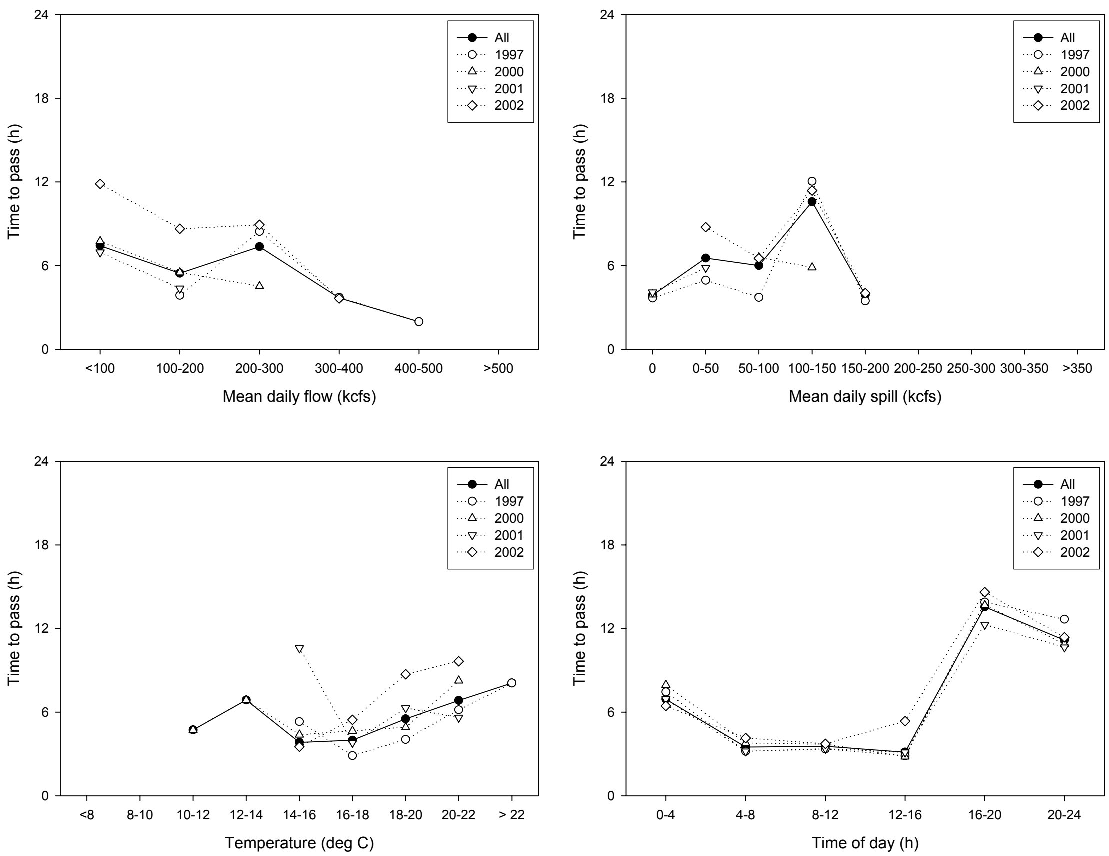

Figure 34. Summary of passage times (first tailrace to first fishway entry) for radio-tagged steelhead at Bonneville Dam, based on categories of flow, spill, water temperature, time of day, and fishway and tailrace exit behaviors.

Sockeye salmon

Tailrace to top of ladder - The multiple regression model was significant ($P < 0.0001$) for sockeye salmon in 1997, with the predictor variables explaining 36% of the variability in passage times (Table 64). When all variables were considered together, fishway exits into the tailrace of Bonneville Dam and exits from transition pools were the most influential variables. The transition pool first entered was also significant: passage times were longest for fish that first entered the Cascades Island pool and were shortest for those that first entered the A-Branch pool. Environmental variables were not significant when the effects of behaviors were considered (Table 64).

Tailrace to first fishway entry - Time of tailrace entry was the only variable that was a significant ($P < 0.05$) predictor of sockeye salmon passage times through the tailrace and into a fishway (Figure 34, Table 65). Multiple regression models explained 16% of the variability in this passage segment. Fish that entered the tailrace in the evening or at night had the longest passage times.

Table 62. Results of multiple regression analysis, where steelhead time to pass from tailrace to first fishway entry (log-transformed) was the dependent variable and independent variables included date, time of day, fishway exit to tailrace (0,1,>1), transition pool exit to tailrace (0,1), location of first fishway approach (PH1,PH2,spillway), location of first transition pool entry, flow, spill, tailwater elevation, turbidity, and temperature. Type III sum of squares adjust for all other variables in the model. Only includes fish with records at all passage points.

Year	Source	Type I SS	*F*	*P*	Type III SS	*F*	*P*
1997	Date	0.8	3.5	0.0631	0.5	2.1	0.1477
	Time	18.3	16.2	<0.0001	18.8	16.6	<0.0001
	Fishway approach	1.1	2.5	0.0797	1.2	2.7	0.0670
	Flow	0.3	1.3	0.2522	1.0	4.4	0.0376
	Spill	11.5	50.9	<0.0001	5.4	24.1	<0.0001
	Temperature	0.1	0.6	0.4257	0.2	0.7	0.3987
	Turbidity	0.2	0.9	0.3461	0.2	0.9	0.3461
							Model r^2 = 0.22; F = 12.0; P < 0.0001
2000	Date	0.3	1.5	0.2156	0.6	3.0	0.0830
	Time	18.5	19.5	<0.0001	18.5	19.5	<0.0001
	Fishway approach	0.9	2.5	0.0837	0.5	1.3	0.2800
	Flow	0.3	1.4	0.2385	0.1	0.3	0.5684
	Spill	2.2	11.5	0.0007	0.8	4.1	0.0422
	Temperature	0.5	2.4	0.1235	0.5	2.4	0.1226
	Turbidity	0.0	0.1	0.7484	0.0	0.1	0.7840
							Model r^2 = 0.16; F = 9.9; P < 0.0001
2001	Date	0.2	1.5	0.2149	0.9	6.7	0.0097
	Time	19.5	29.3	<0.0001	20.8	31.2	<0.0001
	Fishway approach	1.6	6.0	0.0028	2.6	9.7	<0.0001
	Flow	3.6	26.9	<0.0001	3.4	25.2	<0.0001
	Spill	0.2	1.3	0.2594	0.2	1.4	0.2434
	Temperature	0.0	0.3	0.5785	0.1	0.5	0.4873
	Turbidity	0.2	1.8	0.1809	0.2	1.8	0.1809

Table 62. Continued.

Year	Source	Type I SS	F	P	Type III SS	F	P
2002	Date	0.1	0.2	0.6453	0.1	0.2	0.6790
	Time	12.4	10.0	<0.0001	15.1	12.2	<0.0001
	Fishway approach	5.8	11.6	<0.0001	2.9	5.9	0.0029
	Flow	2.4	9.8	0.0018	1.2	4.6	0.0317
	Spill	8.1	32.8	<0.0001	6.0	24.4	<0.0001
	Temperature	0.0	0.0	0.9398	0.0	0.0	0.8855
	Turbidity	0.2	0.8	0.3664	0.2	0.8	0.3664
							Model $r^2 = 0.17$; $F = 9.8$; $P < 0.0001$

Table 63. Results of multiple regression analysis, where steelhead time to pass Bonneville Dam (first fishway entry to top of ladder, log-transformed) was the dependent variable and independent variables included date, time of day, fishway exit to tailrace (0,1,>1), transition pool exit to tailrace (0,1), location of first fishway approach (PH1,PH2,spillway), location of first transition pool entry, flow, spill, tailwater elevation, turbidity, and temperature. Type III sum of squares adjust for all other variables in the model. Only includes fish with records at all passage points.

Year	Source	Type I SS	*F*	*P*	Type III SS	*F*	*P*
1997	Date	0.2	0.2	0.6917	0.0	0.0	0.9471
	Time	12.5	15.6	<0.0001	9.5	11.8	<0.0001
	Fishway approach	1.1	3.3	0.0381	0.1	0.3	0.7381
	Transition pool	1.5	3.1	0.0264	1.6	3.4	0.0172
	Fishway exits	51.3	159.9	<0.0001	9.7	30.4	<0.0001
	Pool exit	0.5	3.2	0.0745	0.3	2.2	0.1403
	Flow	0.5	2.9	0.0890	0.3	1.7	0.1992
	Spill	0.5	3.4	0.0646	0.3	1.9	0.1704
	Temperature	0.0	0.0	0.9517	0.0	0.0	0.9435
	Turbidity	0.0	0.0	0.8700	0.0	0.0	0.8700
							Model r^2 = 0.46; F = 23.5; P < 0.0001
2000	Date	6.1	39.9	<0.0001	0.4	2.8	0.0960
	Time	1.6	2.0	0.0716	1.8	2.4	0.0393
	Fishway approach	0.7	2.4	0.0945	0.3	1.0	0.3749
	Transition pool	5.9	12.9	<0.0001	1.9	4.1	0.0068
	Fishway exits	79.7	260.1	<0.0001	13.9	45.4	<0.0001
	Pool exit	1.8	12.1	0.0006	2.0	12.8	0.0004
	Flow	0.1	0.7	0.4020	0.6	4.0	0.0472
	Spill	0.5	3.1	0.0799	1.2	7.9	0.0052
	Temperature	1.0	6.3	0.0125	0.6	4.1	0.0434
	Turbidity	0.1	0.5	0.4690	0.1	0.5	0.490

Table 63. Continued.

Year	Source	Type I SS	*F*	*P*	Type III SS	*F*	*P*
2001	Date	0.9	7.7	0.0057	0.2	1.8	0.1851
	Time	3.1	5.2	0.0001	3.2	5.3	<0.0001
	Fishway approach	10.9	45.2	<0.0001	0.4	4.6	0.1991
	Transition pool	4.8	13.2	<0.0001	1.8	5.0	0.0021
	Fishway exits	36.2	149.4	<0.0001	7.8	32.4	<0.0001
	Pool exit	0.7	6.1	0.0140	0.7	6.1	0.0142
	Flow	0.0	0.4	0.5563	0.3	2.5	0.1134
	Spill	0.3	2.2	0.1412	0.4	3.3	0.0713
	Temperature	0.1	1.1	0.2856	0.1	1.2	0.2740
	Turbidity	0.0	0.1	0.7500	0.0	0.1	0.7500
Model r^2 = 0.46; F = 26.2; P < 0.0001							
2002	Date	4.5	24.6	<0.0001	0.1	0.4	0.5258
	Time	2.3	2.6	0.0254	2.5	2.8	0.0180
	Fishway approach	8.8	24.4	<0.0001	0.3	0.9	0.3959
	Transition pool	4.0	7.4	<0.0001	2.8	5.2	0.0015
	Fishway exits	66.8	184.4	<0.0001	11.2	30.9	<0.0001
	Pool exit	6.3	34.9	<0.0001	6.5	35.9	<0.0001
	Flow	0.1	0.3	0.5873	0.0	0.0	0.8627
	Spill	0.3	1.4	0.2349	0.1	0.7	0.3996
	Temperature	0.0	0.2	0.6311	0.0	0.3	0.6033
	Turbidity	0.0	0.3	0.6032	0.0	0.3	0.6032
Model r^2 = 0.47; F = 28.6; P < 0.0001							

Table 64. Results of multiple regression analysis, where sockeye salmon time to pass Bonneville Dam (tailrace to top of ladder, log-transformed) was the dependent variable and independent variables included date, time of day, fishway exit to tailrace (0,1,>1), transition pool exit to tailrace (0,1), location of first fishway approach (PH1,PH2,spillway), location of first transition pool entry, flow, spill, tailwater elevation, turbidity, and temperature. Type III sum of squares adjust for all other variables in the model. Only includes fish with records at all passage points.

Year	Source	Type I SS	*F*	*P*	Type III SS	*F*	*P*
1997	Date	0.8	7.2	0.0076	0.2	2.2	0.1428
	Time	0.9	1.7	0.1461	0.8	1.4	0.2184
	Fishway approach	0.9	4.2	0.0165	0.0	0.1	0.9460
	Transition pool	1.9	5.6	0.0010	1.9	5.7	0.0009
	Fishway exits	11.3	50.2	< 0.0001	3.0	13.2	< 0.0001
	Pool exit	1.7	15.1	0.0001	1.5	13.2	0.0003
	Flow	2.4	20.9	< 0.0001	0.2	1.4	0.2407
	Spill	0.0	0.0	0.8648	0.0	0.0	0.9365
	Temperature	0.1	0.6	0.4379	0.1	0.6	0.4379
	Turbidity	0.1	0.5	0.4822	0.1	0.7	0.4206
Model $r^2 = 0.36$; $F = 9.9$; $P < 0.0001$							

Table 65. Results of multiple regression analysis, where sockeye salmon time to pass from tailrace to first fishway entry (log-transformed) was the dependent variable and independent variables included date, time of day, fishway exit to tailrace (0,1,>1), transition pool exit to tailrace (0,1), location of first fishway approach (PH1,PH2,spillway), location of first transition pool entry, flow, spill, tailwater elevation, turbidity, and temperature. Type III sum of squares adjust for all other variables in the model. Only includes fish with records at all passage points.

Year	Source	Type I SS	*F*	*P*	Type III SS	*F*	*P*
1997	Date	0.2	1.0	0.3226	0.1	0.9	0.3505
	Time	5.7	7.2	< 0.0001	6.5	8.2	< 0.0001
	Fishway approach	1.2	3.8	0.0242	0.6	2.0	0.1385
	Flow	2.3	14.4	0.0002	0.0	0.2	0.6230
	Spill	0.5	3.0	0.0870	0.4	2.7	0.1048
	Temperature	0.0	0.3	0.5876	0.1	0.5	0.5024
	Turbidity	0.1	0.7	0.4082	0.1	0.7	0.4082
Model $r^2 = 0.16$; $F = 5.2$; $P < 0.0001$							

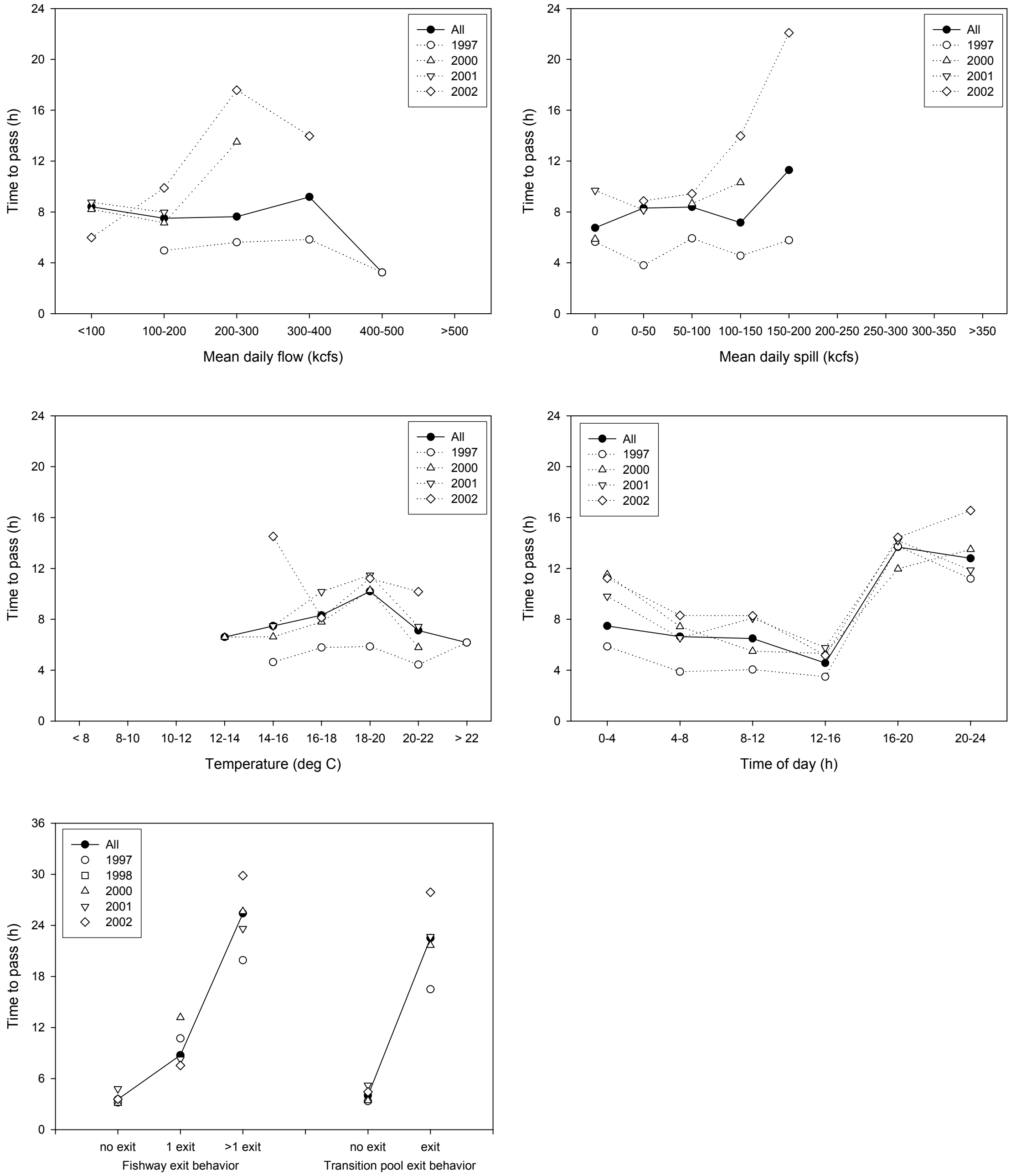

Figure 35. Summary of passage times (first fishway entry to top of ladder) for radio-tagged steelhead at Bonneville Dam, based on categories of flow, spill, water temperature, time of day, and fishway and tailrace exit behaviors.

First fishway entry to top of ladder - The multiple regression models for the first fishway entry to top of ladder section explained 57% of the variability in this passage segment (Figure 35, Table 66). Fishway exit, transition pool exit, and first transition pool entered were the most influential. As would be expected, fish with more fishway exits had longer passage times. Fish that first entered the Cascades Island transition pool had the longest passage times, while those

Table 66. Results of multiple regression analysis, where sockeye salmon time to pass Bonneville Dam (first fishway entry to top of ladder, log-transformed) was the dependent variable and independent variables included date, time of day, fishway exit to tailrace (0,1,>1), transition pool exit to tailrace (0,1), location of first fishway approach (PH1,PH2,spillway), location of first transition pool entry, flow, spill, tailwater elevation, turbidity, and temperature. Type III sum of squares adjust for all other variables in the model. Only includes fish with records at all passage points.

Year	Source	Type I SS	*F*	*P*	Type III SS	*F*	*P*
1997	Date	1.0	8.5	0.0038	0.0	0.4	0.5315
	Time	4.9	8.2	< 0.0001	1.8	3.0	0.0126
	Fishway approach	3.6	15.0	< 0.0001	0.5	2.3	0.1053
	Transition pool	1.5	4.3	0.0056	3.4	9.4	< 0.0001
	Fishway exits	36.8	153.7	< 0.0001	11.8	49.1	< 0.0001
	Pool exit	2.5	21.0	< 0.0001	2.4	19.7	< 0.0001
	Flow	0.5	4.5	0.0342	0.2	1.6	0.2097
	Spill	0.1	0.6	0.4325	0.1	0.6	0.4226
	Temperature	0.0	0.1	0.7985	0.0	0.2	0.7013
	Turbidity	0.1	0.8	0.3636	0.1	0.8	0.3636
Model r^2 = 0.57; F = 23.7; P < 0.0001							

that first entered the A-Branch pool were fastest. Time of first fishway entry was also influential, with faster passage by those salmon that entered during daylight

Behavior and Fate of Fish that Did Not Pass the Dam

Chinook salmon

Between 1.3 and 1.9% of the spring–summer Chinook salmon recorded in the tailrace or at Bonneville Dam did not pass the dam (Table 67). Of those that did not pass, 13 to 67% were only recorded in the tailrace, 21 to 60% were recorded approaching fishway entrances, 0 to 11% were recorded inside fishways (but not in transition pools), and 8 to 44% were recorded inside transition pools. Six to 9% were recorded near the tops of ladders in all years except 2002.

In all years except 2000, the majority (57 to 91%) of the fish that did not pass the dam were unaccounted for downstream; 47% were unaccounted for in 2000 (Table 67). A few fish were reported recaptured in downstream fisheries in 2001 and 2002, and a small number were last recorded in downstream tributaries in 1997 and 1998. The remainders were known or presumed to have spit tags, based either on tag recoveries or repeated detections of stationary tags. We note that some of the latter were likely natural mortalities or mortalities associated with fisheries in the area.

Steelhead

Between 1.5% (2000) and 3.1% (1997) of the steelhead recorded in the tailrace of Bonneville Dam or at the dam did not pass (Table 67). Of these, 31 to 42% were only recorded in the tailrace, 14 to 35% were recorded approaching fishway entrances, 0 to 13% were recorded inside fishways (but not in transition pools), and 15 to 31% were recorded inside transition pools. Six to 17% were recorded near the tops of ladders, but did not pass the dam (Table 67).

In the four years, 50 to 75% of the steelhead that did not pass the dam were unaccounted for downstream, 0 to 13% were recaptured in fisheries downstream, and 3 to 8% were last recorded in downstream tributaries (Table 67). An estimated 17 to 25% that did not pass may have regurgitated tags or the fish died and the transmitter was not recovered.

Sockeye salmon

Seven sockeye salmon (1.2%) did not pass Bonneville Dam in 1997 (Table 67). About 29% were recorded only in the tailrace, and the rest (71%) entered a fishway or transition pool.

The majority (71%) of sockeye salmon that did not pass were unaccounted for downstream, and the rest (29%) had presumed spit tags or possible mortalities.

Table 67. Final fate, most upstream point reached at dam, and last fishway detection for radio-tagged fish that did not pass Bonneville Dam.

	Chinook salmon					Steelhead				Sockeye
	1997	1998	2000	2001	2002	1997	2000	2001	2002	1997
Recorded at dam	968	946	967	866	896	945	826	792	935	570
Did not pass dam	18	14	15	11	12	29	12	16	26	7
Percent that did not pass dam	1.9%	1.5%	1.6%	1.3%	1.3%	3.1%	1.5%	2.0%	2.8%	1.2%
Fate of fish that did not pass:										
Unaccounted for	**89%**	**57%**	47%	**91%**	**58%**	**66%**	**75%**	**50%**	**62%**	**71%**
Recaptured in fisheries				9%	33%	3%		13%	8%	
Entered downstream tributary	6%	7%				3%	8%	6%	8%	
Known or presumed spit tags[1]		36%	**53%**		8%	24%	17%	25%	23%	29%
Other	6%					3%		6%		
Most upstream point at dam:										
Tailrace	22%	**57%**	13%	**36%**	**67%**	**41%**	**42%**	**31%**	**38%**	29%
Approached fishway only	22%	21%	**60%**	**36%**	25%	14%	25%	25%	35%	
Inside fishway, no trans. pool	11%		7%			3%		13%	4%	**43%**
Inside transition pool	**44%**	14%	13%	18%	8%	31%	**17%**	25%	15%	29%
Near top of ladder	6%	7%	7%	9%		10%	17%	6%	8%	
Last fishway detection[2]:										
A-Branch fishway	14%	**33%**	15%	**29%**	**75%**	**59%**	29%	**45%**	**63%**	40%
B-Branch fishway	14%	**33%**	23%	**29%**			14%	18%	13%	
Cascades Island fishway	21%	17%	23%	14%			14%			
WA-shore fishway	**50%**	17%	**38%**	**29%**	25%	41%	**43%**	36%	25%	**60%**

[1] *Some may have been mortalities*

[2] *Percent of those that approached dam*

Discussion

This multi-year, multi-species evaluation of adult salmonid passage behaviors at Bonneville Dam was designed to describe fine-scale fish behaviors at the dam and inside fishways, identify potential areas of passage difficulty, and quantify passage times and behaviors under various operational and environmental conditions. The results provide important baseline metrics for adult passage at the dam and can be used to evaluate future operational changes (e.g., spill patterns, powerhouse priority), construction (e.g., pinniped exclusion devices), or environmental shifts (e.g., warming main stem water temperature).

Bonneville Dam—with two powerhouses, a spillway, and four fishways servicing two fish ladders—is the most complex Columbia River project encountered by returning adult salmonids. Operations at the project during the study years varied widely, with a major shift in the allocation of flow among powerhouses (from Powerhouse I to Powerhouse II priority) and semi-controlled spill manipulations for juvenile passage. Operations changed within migration season and on a day-to-day basis, making strict evaluations of specific conditions challenging. Operations at the dam often change at a time scale that is similar to or shorter than the passage times for individual adult migrants, making strict evaluation of the effects of specific operations difficult. The river environment is also constantly changing. Water temperatures predictably increase over the course of the spring–summer Chinook salmon migrations, while steelhead encounter warm and then peak temperatures before fall cooling begins. Given the strong effects of temperature on salmonid physiology and behavior, these seasonal patterns directly influence behaviors and passage metrics, and particularly passage times. River discharge during the study ranged from far above average flow in 1997 to near-record low flow in 2001. Within-season fluctuations were often large, particularly during the spring–summer Chinook salmon migration, which overlaps with the snowmelt flood. This variability, both within and among years, presents additional analytical challenges, as total flow has a large effect on adult migration rates (e.g., Keefer et al. 2004a, 2004b; Salinger and Anderson 2006). We have addressed these sources of variability with multivariate statistical methods as well as more basic summaries based on groups of fish that encountered similar conditions.

Adult radiotelemetry studies at Bonneville Dam differ from those at upstream projects (e.g., Keefer et al. 2007, 2008) in one important way: tagged fish were not naïve. All fish were trapped in the adult facility adjacent to the Washington-shore ladder and then released downstream at sites on both sides of the river. As such, all fish had previously approached, entered, and moved up fish ladders at least once before the telemetry data was collected. We would expect that this prior experience could improve passage efficiency at the dam. It is possible that our calculations of passage times for some segments may be underestimates relative to naïve fish approaching and entering fishways for the first time. Similarly, the distribution of use among fishway entrances and ladders may also differ relative to naïve fish. We have observed, for example, that fish that fallback at Bonneville Dam behave differently on their second passage attempt, typically passing more quickly, with fewer fishway entrances and exits (Keefer et al. 2003a). We recommend that managers take a conservative view, in that passage time results presented here may represent a ‘best case’ for many fish. There is also the possibility that handling and radio-tagging may in some way affect behaviors at the dam, but our results have indicated that tagged fish migrate at similar rates as untagged fish (Matter and Sandford 2003) and survival to spawning grounds is high (Keefer et al. 2005).

Passage Efficiency: Passage efficiency of radio-tagged adults at Bonneville Dam (before fallback) was very high. On average, 98.5% of spring–summer Chinook salmon, 98.8% of sockeye salmon, and 97.7% of steelhead recorded at the dam eventually passed. These efficiencies were higher than those reported for fall Chinook salmon at Bonneville Dam (*mean* = 92.1%, Burke et al. 2005), perhaps because more fall Chinook spawn at sites downstream from the dam or return to the hatchery just downstream. Passage efficiency for the studied runs was also higher at Bonneville Dam than at upstream dams (Keefer et al. 2007, 2008), again likely reflecting the distribution of spawning grounds and tributaries downstream from the upper dams. For the most part, fish that did not pass the dam had unknown fate downstream; a few were reported harvested or recorded entering downstream tributaries. Predation by pinnipeds was also a possibility.

Passage Times: One of the primary objectives of the adult passage project was to identify sources of slowed adult passage at dams (NMFS 2000). In this report, we have summarized passage behaviors—including passage times —through tailrace, fishway, transition pool, and full-project passage segments at Bonneville Dam. Median full-dam passage times during the study years (1997, 1998, 2000, 2001, 2002) were longest for radio-tagged spring–summer Chinook salmon (19 to 41 h), intermediate for steelhead (17 to 24 h) and shortest for sockeye salmon (15 h). In a companion study, Burke et al. (2005) found Bonneville Dam passage times for fall Chinook salmon (medians = 17 to 22 h) were very similar to those for steelhead in this study. Results from similar multi-species passage time studies at The Dalles and John Day dams (Keefer et al. 2007, 2008) were broadly similar to those reported here. In previous Bonneville evaluations, median full-dam passage times were 17.0 h for steelhead (Stuehrenberg et al. 2005) and 23.1 h for spring–summer Chinook salmon (Keefer et al. 2003a), within the ranges reported in the current study. At all three lower Columbia River dams, spring–summer Chinook salmon have consistently passed most slowly, steelhead have had intermediate passage times, and sockeye salmon pass most quickly. Spring Chinook passage is especially slow, likely because of low water temperatures.

As in other adult passage time studies, mean times at Bonneville Dam were longer than medians for all species/years because some fish delayed for days or weeks and/or moved downstream temporarily. As a result, all passage time distributions were right-skewed. Passage times were also highly variable through most study segments. It is likely that salmonid migration times under pre-dam conditions were also quite variable and skewed, with some fish migrating more slowly than the bulk of the run, particularly in areas with natural constrictions like falls and rapids (e.g., Jensen et al. 1989; Gilhousen 1990; Rand and Hinch 1998). Among-fish passage time variability was also relatively high, for example, for the studied spring–summer Chinook salmon populations in unimpounded reaches and free-flowing tributaries in the basin (Keefer et al. 2004b).

To best determine where fish slowed at Bonneville Dam, we partitioned passage by radio-tagged fish into five primary components: 1) first tailrace entry to first fishway approach, 2) first fishway approach to first fishway entry, 3) first fishway entry to first transition pool entry, 4) first transition pool entry to exit a pool into a ladder, and 5) ladder ascension. These passage segments capture the major fish passage environments at the dam, with segment endpoints marking transitions between environments. Some segments, such as transition pools, have been previously identified as sources of confusion for adult migrants at other hydrosystem dams (e.g., Bjornn et al. 1998b; Keefer et al. 2003a). Defining 'delay' through any passage segment was an arbitrary decision, because fish may have temporarily stopped upstream migration or moved downstream for a variety of reasons, including nightfall (e.g. Naughton et al. 2005), route-searching behavior, response to environmental change, the number of fish passing a site, or difficult passage conditions. By way of summary, one measure of delay that was useful for classifying and comparing groups of fish was a time gap of > 24 h through any of the five passage segments listed above.

Two passage segments—first fishway entry to first transition pool entry and ladder ascension—were rapid for all species in all years, with relatively few fish taking more than 12 h to pass (Figure 36). Passage from first fishway approach to first fishway entry was also relatively efficient for steelhead and sockeye salmon, while many Chinook salmon took more than 12 h for this segment.

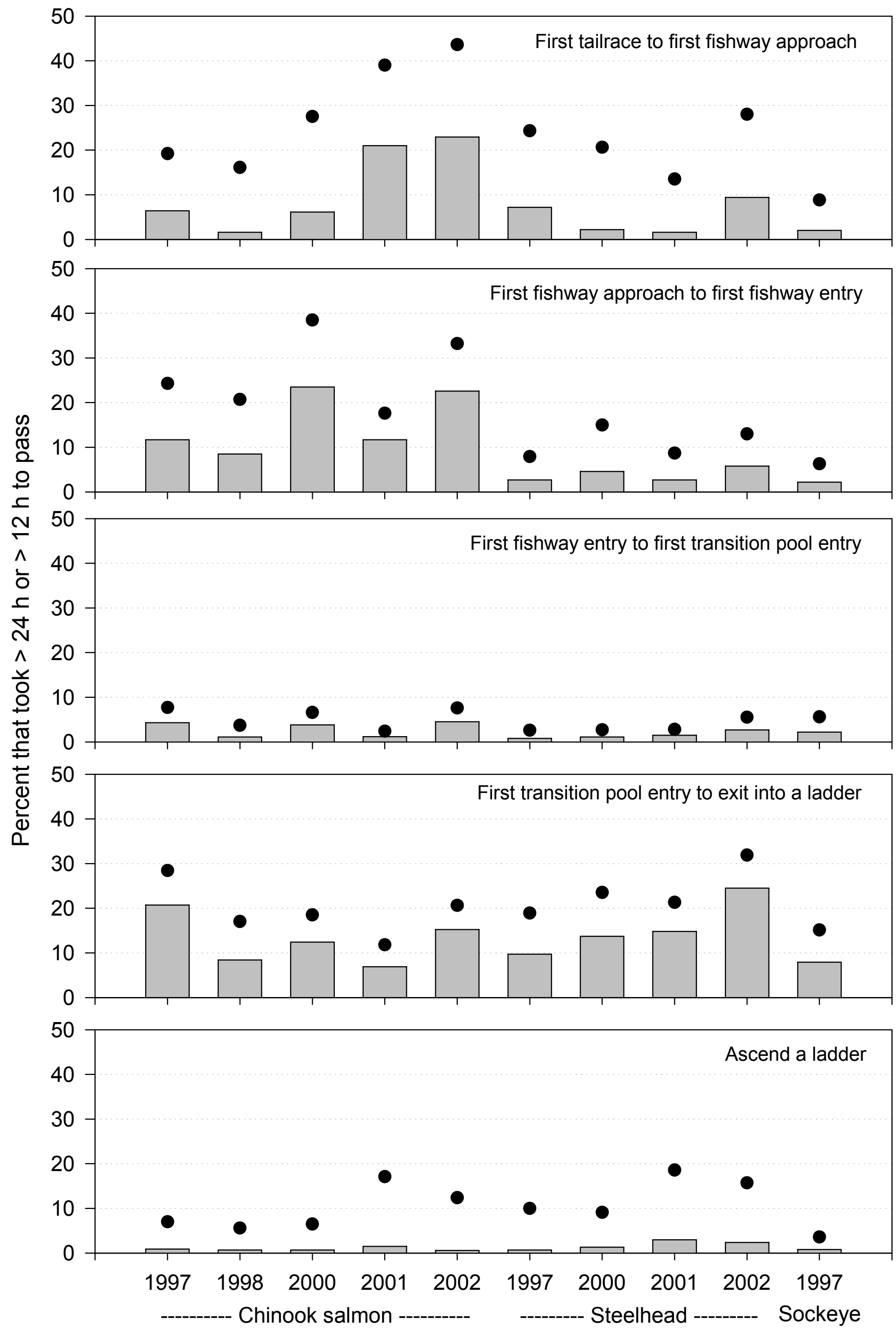

Figure 36. Percent of radio-tagged adult fish from each run-year that took more than 12 h (closed circles) and more than 24 h (bars) to pass through each migration segment at Bonneville Dam.

In contrast, many fish from all runs required more than 24 h to pass through the remaining two passage segments—1) first tailrace entry to first fishway approach and 2) first transition pool entry to exit into a ladder (Figure 36). The transition pool segment had the highest variability in adult passage times for all pre-defined segments. In part, this is because of our definition for this section, which was from first transition pool entry to first entry into the ladder. Salmon and steelhead were generally not inside the transition pools for most of the elapsed time for this segment, but instead were in the tailrace or actively entering and exiting the fishways. As described in Burke et al. (2005) and Brown and Geist (2002), apportioning the time for the transition pool passage segment into tailrace, fishway, and transition pool components shows that fish spend the majority of the elapsed time in the tailrace. Even though fish do not spend much time in the transition pool itself, however, it is clear that failed passage attempts through the pools contribute significantly to passage 'delays'. Exiting the transition pool into the tailrace is particularly costly given that energetic costs are highest in the tailrace (Brown and Geist 2002). The longest full-dam passage times for all runs in all years almost always included one or more exits from a transition pool into the tailrace.

The relatively long passage times through the tailrace to first fishway approach segment appears to have been largely related to the time of tailrace entry. Many fish that arrived in the tailrace in afternoon or evening did not approach the dam until the following day. This is consistent with many other adult salmonid studies, which indicate reluctance by fish to pass through complex environments during darkness. The adult tagging and release schedule (daytime only) likely affected tailrace entry times somewhat, although most fish first passed the tailrace receiver on the day following tagging and release. It is difficult to assess the timing of tailrace entry for naïve fish, though we note again the tendency for adult fish to slow or stop migration at night in complex environments like the Bonneville tailrace.

Results from the multivariate analyses suggested that exiting from fishways and transition pools into the tailrace were the most influential predictors of overall dam passage time. Fish of all species that exited a fishway into the tailrace had longer full-dam passage times than fish that did not exit in almost all months of all years. For spring–summer Chinook salmon, increases in median passage time associated with exiting a fishway ranged 4-13 h (monthly minimum differences) to 15-45 h (monthly maximum differences). Exiting steelhead, took 3-13 h (monthly minimums) to 7-38 h (monthly maximums) longer to pass the dam in each month. Sockeye that exited took 10-15 h longer to pass the dam than those that did not exit in June and July. Similar delays were observed for fish that exited transition pools into the tailrace—overlap between fish that exited fishways and those that exited transition pools to the tailrace was extensive, because many fish migrated upstream in fishways to transition pool areas before turning around and exiting fishways. Not surprisingly, fish with multiple fishway exits had the longest passage times.

The strong link between exit behavior and passage 'delay' is consistent with previous studies that showed fishway and transition pool and fishway exits slow passage for adult migrants (Bjornn et al. 1998a, 1998b; Keefer et al. 2003a). At John Day Dam, for example, water temperatures in the fishways and ladders were implicated in adult exit behavior in a detailed study in 1997 and 1998 (Keefer et al. 2003b). Fishway exit rates at John Day Dam were strongly positively correlated with mean and maximum water temperatures in the ladders (Keefer et al. 2003b). At Lower Granite Dam, low water velocity in the transition pool was associated with transition pool exit and slow passage. Modifications there appear to have improved overall passage efficiency (Naughton et al. 2006).

Exiting fishways and transition pool may be an intrinsic salmonid behavior, where fish test, retreat, and then retest novel passage environments. If so, large reductions in these behaviors may not be possible. However, it is probable that at least some exiting could be reduced by making the environments inside fishways and transition pools more attractive to upstream migrants. Managers should focus attention on possible non-uniform flow, lack of sufficient attractive flow, abrupt water temperature changes, turbulence, confusing conditions created by floor diffusers, fishway configurations (i.e., sharp turns), and inconsistent light conditions (i.e., adjacent open and covered fishway sections). Some, or a combination of these or other variables may all contribute to the exit behaviors we observed.

Spring–summer Chinook passage times at Bonneville Dam tended to decrease as water temperatures warmed each year, but transition pool exits rates also tended to increase as temperatures increased. These responses were countervailing to some degree. Behavioral responses to temperature change were consistent with dam passage at other dams and migration times through longer hydrosystem reaches (Bjornn et al. 2000a; Keefer et al. 2004a, 2007, 2008). Increasing passage rates were likely due to increased metabolic activity at warmer temperatures (Erkinaro 1999; Økland 2001), longer periods of daylight, or increased pressure to reach spawning grounds. The seasonal increase in passage rates may also have been related to increased proportions of fish destined for upriver spawning areas (e.g., Snake and mid-Columbia River tributaries) as migrations progressed. The physiological or spawning imperatives seem most likely, as increasing passage rates by Chinook salmon also occur as temperatures rise in unimpounded reaches and tributaries, independent of river discharge (Keefer et al. 2004b). It is not clear why exit rates increased as temperatures rose, though temperature differences within the fishway or between the fishway and the tailrace certainly have the potential to influence behavior (Peery et al. 2003). At John Day Dam, similar exit behaviors were attributed to elevated fishway temperatures relative to tailrace temperatures (Keefer et al. 2003b). Chinook salmon were more likely to exit transition pool at Bonneville Dam at higher tailwater elevations, when more weirs were submerged. These conditions may provide confusing cues, areas of slack water, or other passage challenges. Increasing exit rates with temperature may also have reflected increased overall activity, with elevated searching behaviors.

In general, steelhead passage times did not appear to be strongly related to water temperature. This may be because steelhead passed Bonneville Dam during a relatively narrow range of warm temperatures compared to spring–summer Chinook salmon. Flow also appeared to have a relatively limited effect on steelhead passage times compared to salmon, in part because study fish mostly passed during moderate to low flows. There was some indication that steelhead passage times were longer at higher spill levels, suggesting that the spilling basin and/or the fishway entrances adjacent to the spillway may be unattractive to steelhead when spill volumes are high. As with Chinook salmon, steelhead were more likely to exit transition pools into the tailrace when tailwater elevations were higher.

Our results suggest that the best opportunities for improving adult passage efficiency at Bonneville Dam include reducing fallout from fishways and transition pools and improving attraction to fishway entrances. The overwhelming majority of 'efficient' (i.e., fast) dam passages by all three species were by fish that did not exit. Modifications to transition pool weirs, including increasing hydraulic head at lower weirs and raising velocities through orifices, may increase the proportions of fish that pass directly through transition pool areas. Other fishway modifications, such as fishway fences, have reduced fishway exit rates at Snake River dams (Bjornn et al. 1999b). Closing orifice/sluice gates may also help reduce exit rates. Evaluations of entrance closures will require within-year controlled experiments, if possible, because comparing passage times and exit rates among years are problematic given the many operational and environmental differences among years. Earlier studies of orifice gate closures at Priest Rapids and Wanapum dams (Bjornn et al. 1997; Peery et al. 1998) were equivocal in terms of adult passage. Analyses of the effects of sluice/orifice gate closure tests at Bonneville Dam are currently underway.

Efforts to reduce the time adult migrants spend in the tailrace—the most energetically expensive passage environment (Brown et al. 2006)—should provide stable and easily detectable attraction flow from the major fishway entrances. Operations that produce turbulence, back eddies, and other non-linear-flow cues should be minimized. The relatively long passage times during spill test years (e.g., Caudill et al. *Draft report*) also suggest that regular switching of operations like spill provides confusing cues to adults. Changes in spillway discharge may have less of an impact on adults if they occur at night or if they are incrementally ramped up and down. The results also suggest that Powerhouse II priority may be somewhat less preferable for adult passage than a more equitable distribution of flow that attracts more fish to Powerhouse I and spillway fishways. Exit rates tended to be highest from the entrances at Powerhouse II, intermediate from entrances at Powerhouse I, and lowest from spillway entrances, so a shift away from Powerhouse II may be beneficial. We note, however, that while attracting more fish to the Bradford Island fishway may reduce overall dam passage times for adults, increased fallback associated with this fishway (Bjornn et al. 2000a; Reischel and Bjornn 2003) may negate any passage time benefits. Increasing attraction to Powerhouse I and spillway entrances would likely have the greatest net gain during low-spill or no-spill periods, when fallback risk is reduced.

Fishway Entrance Use: Powerhouse priority had a large impact on the distribution of fishway entrance use by adult migrants. At the broadest scale, fish were attracted to the powerhouse with the greatest discharge. This was Powerhouse I in the early study years and Powerhouse II in later years. Attraction to entrances adjacent to the spillway was greater in years with Powerhouse II priority, though it is possible that the very high spill in 1997 may have deterred fish from the spillway entrances in that year. In general, fishway use measures (including approaches, entries and exits) tracked powerhouse priority.

Fish from all runs approached fishway entrances (or at least swam very close to them) multiple times. Average numbers of approaches were 11 to 24 for spring–summer Chinook salmon and 12 to 17 times for steelhead and sockeye salmon. These are likely slight underestimates, as the floating orifice gate entrances at Powerhouse II were not monitored in later years. Multiple approaches by many fish may indicate that some fish may have had difficulty locating or entering fishways. Alternately, the numbers of approaches may be related to the many available fishway entrances and the tendency for fish to move along the face of the powerhouse collection channels. Between 36% and 64% of each run also exited at least once to the tailrace, and this behavior results in additional fishway approaches and entries.

In general, fish from all runs were more likely to first approach the high-discharge shoreline entrances at the powerhouses, while proportionately more of the total approaches were at sluice and orifice gates. Again, this likely reflects the tendency for adults to be attracted to discharge but also to move along the face of the dam searching for entries.

On average, adult fish entered fishways between 2 and 4 times. The distributions of first and total entrances were much more evenly spread across entrances sites than were approaches. Major entrances were still favored. Fish from all runs tended to first enter a fishway near where they first approached, as has been observed at other dams (Bjornn et al.

1998a; Keefer et al. 2003a, 2007, 2008).

Majorities of fish passed Bonneville Dam via the fishway they first approached, but movement between Powerhouse I, Powerhouse II, and the spillway entrances was very high. Extensive movements across the tailrace often followed fishway exits, though this was by no means the rule. Some fish moved between fishways without entering, sometimes more than once.

On average, 47% of spring–summer Chinook salmon, 53% of steelhead, and 62% of sockeye salmon exited a fishway into the tailrace at least once. Exit percentages tended to increase as migrations progressed each year for Chinook salmon, and may have been related to increasing temperatures. Exit percentages were highest for those fish that first entered the fishways at Powerhouse II, especially for steelhead. Fish were least likely to exit from the spillway entrances. As a result of this pattern, overall exit rates were higher in years with Powerhouse II priority.

Many fish from all runs migrated upstream in the fishways to the transition pool areas before turning around and exiting fishways and many exited after being inside collection channels only at the powerhouse fishways. Relatively few adult fish exited to the tailrace after entering ladders upstream from transition pools, and almost no fish backed down ladders after being recorded at top-of-ladder sites. Fish exited from all sites, but the larger entrances near shorelines tended to have more total exits, probably because some fish entered sluice or orifice gates, moved down collection channels, and then exited after encountering transition pools.

We did not identify major shifts in fish behaviors in and near fishway entrances that were clearly related to spill volume. One exception, however, was that moderate spill appeared to attract fish to the spillway entrances. This attraction was diminished at high spill for steelhead, who may have avoided high water velocity or turbulence in the spilling basin.

Transition Pool Use: Between 25-48% for spring–summer Chinook salmon exited from transition pools into the tailrace in each year, as did 35-49% of steelhead and 36% of sockeye salmon. For Chinook salmon, the Washington-shore pool had the highest overall exit rate (40%) while the B-Branch pool had the lowest exit rate (33%). However, there was considerable within- and among-year variability in the percentages that exited from each of the four transition pools, and exit rates from the Washington-shore pool were not the highest in all years. Spring–summer Chinook salmon were significantly more likely to exit from transition pools as water temperatures increased, and the behavior was consistent across years and pools. Exit rates were also higher at high tailwater elevations, particularly from the Washington-shore pool. Temperature and tailwater elevation are partially correlated during the spring–summer Chinook run, so these effects are likely complimentary. Routes through transition pools may be less clearly defined at high tailwater elevations, when many weirs are submerged. Time of day was also an influential predictor of transition pool exit for Chinook salmon. In 1996, a high-flow year, 65% of the spring–summer Chinook salmon that entered the Washington-shore pool exited to the tailrace (Keefer et al. 2003a), further supporting the potential negative effect of high tailwater elevation at that site. Between 32-50% of Chinook salmon exited from the other transition pools in 1996, levels that were slightly higher than the ranges recorded in later years.

Steelhead were also most likely to exit from the Washington-shore pool. Overall, 53% of steelhead exited from this pool, versus 34% from the A- and B-Branch pools and 30% from the Cascades Island pool. It is not clear why the Washington-shore pool was somewhat less efficient at passing steelhead as compared to Chinook salmon. In 1996, about 46% of steelhead exited the Washington-shore pool, compared to 50% from the A-Branch pool, 42% from the B-Branch pool, and 39% from the Cascades Island pool (Stuehrenberg et al. 2005). These numbers were generally consistent with the current study.

The combination of Powerhouse II priority and high exit rates from the Washington-shore transition pool has the potential to produce in considerable 'delay' for steelhead. Additional review of water velocities in transition pools and through submerged orifices may be warranted for this site. Temperature discontinuities within the fishways may also be an issue given that peak steelhead passage at Bonneville Dam typically coincides with the warmest system temperatures. We note, however, that temperature, as recorded at the water quality monitoring (WQM) site, was not a good predictor of transition pool exit for steelhead. And, although the Washington-shore site produces proportionately more exits than the other transition pools, differences among pools were relatively small. Generally a third to half of the fish that enter each pool exited to the tailrace. Reductions in these rates could substantially improve overall passage times for each of the studied runs.

General Conclusions: There appear to be several basic factors that explain adult salmon and steelhead passage behaviors at Bonneville Dam: 1) environmental variability, including migration timing, 2) dam operations, 3) cues inside fishways, 4) time of day, and 5) variability among species and individual fish.

Total flow and spill, as well as powerhouse priority, appear to have the largest effect on fish while they are in the dam tailrace. These factors affect the distribution of attraction flows and therefore the distribution of fishway entrance use. Temperature and closely related migration timing are correlated somewhat with discharge, particularly for spring–summer Chinook salmon. However, these variables also affect the physiology and behavior of adult migrants in different ways than flow alone. The distribution of flow, as well as spill patterns, can be directly manipulated by managers, and there is potential for reducing passage metrics such as passage time through modified discharge. Frequent changes in operations, especially during daylight, almost certainly contribute to adult passage delays. In addition, decisions regarding flow and spill manipulations at Bonneville Dam must be balanced against the potential for increased fallback once fish pass the dam.

We did not measure cues inside fishways, but these appear to have a large effect on fishway and transition pool exits and consequently overall dam passage times. Fish turnarounds in transition pools and collection channels are almost certainly not random behaviors, particularly in light of the relatively rapid and direct ascension of ladders. It may be possible to improve overall dam passage efficiency by modifying fishway environments where exits are common, perhaps by improving attraction flow, reducing turbulence, changing light conditions, or increasing other positive stimuli in these areas. Fishway configurations that include bends and turns may also have an effect, as might provision of resting areas.

Time of day plays an important part in adult fish behavior at Bonneville Dam. Most fish slow or stop migrating in most of the dam's passage environments at nightfall, as has been documented at many other dams (Bjornn et al. 1995; Keefer et al. 2003a, 2007, 2008). Therefore, day length is an important feature in passage behavior—this may partially explain the tendency for longer passage times for spring Chinook salmon as compared to summer Chinook salmon, fall Chinook salmon, sockeye salmon and steelhead (though temperature also plays a role). Fish from all species that entered the tailrace, transition pools, or ladders late in the day or after dark had longer passage times than their counterparts that entered early in the day. This strong diel effect should be considered in all future passage time evaluations.

Finally, the studied runs did not respond to environmental and operational conditions in exactly the same way. Differences can likely be attributed to fish physiology (e.g., steelhead are not as strong swimmers as Chinook salmon). Within species, there are almost certainly among-stock differences in behavior as well, perhaps related to the distance to natal sites, hatchery versus wild origins, juvenile history, and etc. Differences in individual condition may also affect behavior. Injuries—such as those from marine mammals or encounters with fisheries—and energetic reserves have the potential for large impacts on individual performance. Because energetic reserves are fixed and more or less finite upon river entry, behaviors that result in extended passage time, including multiple fishway entries and exits, may contribute to eventual prespawn mortality. The link between passage time, energetic costs, and migration success has been clearly implicated by Geist et al. (2000), Brown and Geist (2002), and Caudill et al. (2007). These relationships certainly warrant further attention.

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Appendix

Table 1. Locations of antennas used to monitor behaviors and passage times for radio-tagged adult Chinook and sockeye salmon and steelhead at Bonneville Dam, 1997-2002. Only includes those sites used in summaries (i.e., forebay monitoring sites not included).

Site code	Antenna location	Number	Type	1997	1998	2000	2001	2002
1BO	Tailrace - south	1	A	x	x	x	x	x
2BO	Tailrace - north	1	A	x	x	x	x	x
3BO	Navigation lock	1	A	x	x			
QBO	Navigation lock	3	U	x	x	x	x	x
4BO	PH1 - south-shore entrance	3	U	x	x	x	x	x
5BO	PH1 - sluice gate 9	3	U	x	x	x	x	x
6BO	PH1 - sluice gate 21, 34	6	U	x	x	x	x	x
7BO	PH1 - sluice gate 58, 62	4	U	x	x	x	x	x
8BO	PH1 - sluice gate 64, north-shore entrance	4-5	U	x	x	x	x	x
9BO	A-branch/B-branch junction pool	3	U	x	x	x	x	x
ABO	Bradford ladder exit	1	U	x	x	x	x	x
BBO	Spillway - B-branch entrance	3-4	U	x	x	x	x	x
CBO	Spillway - Cascades Island entrance	3-4	U	x	x	x	x	x
DBO	PH2 - south-shore entrance	6-7	U	x	x	x	x	x
EBO	PH2 - floating orifice gate 1, 2	2-5	U	x	x	x[1]	x[1]	
FBO	PH2 - floating orifice gate 3, 4	4-6	U	x	x	x[1]	x[1]	
GBO	PH2 - floating orifice gate 5, 7	5-7	U	x	x	x[1]	x[1]	
HBO	PH2 - floating orifice gate 10, 12	5	U	x	x			
JBO	PH2 - floating orifice gate 13, 14	4-6	U	x	x			x[1]
KBO	PH2 - floating orifice gate 15, 16	5-7	U	x	x			x[1]

Table 1. Continued.

Site code	Antenna location	Number	Type	1997	1998	2000	2001	2002
LBO	PH2 - north-shore entrances	3-5	U	x	x	x	x	x
MBO	PH2 - north-shore channel, transition pool	4	U	x	x	x	x	x
NBO	PH2 - north-shore ladder, turn pool	4	U	x	x	x	x	x
OBO	PH2 - near ladder junction pool	3	U	x	x	x	x	x
PBO	Washington-shore ladder exit	1	U	x	x	x	x	x
TBO	PH1 - ice and trash sluiceway	4	U	x	x	x	x	x
UBO	PH2 - ice and trash sluiceway	1	U	x	x			
VBO	PH1- A-branch transition pool	3	U	x	x	x	x	x
WBO	Spillway - B-branch transition pool	3	U	x	x	x	x	x
XBO	Spillway - Cascades Island transition pool	3-4	U	x	x	x	x	x

[1] antennas inside collection channel in 2000-2001, but none outside fishway entrances