A study of adult salmon and steelhead migrations past dams, through reservoirs, and into tributaries of the Snake River began in 1990 with planning, purchase, and installation of radio telemetry equipment. Adult spring and summer chinook salmon were outfitted with transmitters in 1991-1993, and adult steelhead were outfitted in 1991-1994. Progress reports have been issued periodically (Bjornn et al. 1992; 1994; 1995) and final reports as listed below. Part I of the final report includes a general introduction, methods that apply to all segments of the work, and information on passage of chinook salmon. Other parts of the final report include an introduction and methods section specific to the topic covered.

Part I - Passage of chinook salmon through the lower Snake River and distribution into tributaries - 1991-1993.

Part II - Passage of steelhead through the lower Snake River and distribution into tributaries - 1991-1994.

Part III - Entrances used and passage through fishways for adult chinook salmon and steelhead at Snake River dams.

Part IV - Turbine priority and its effects on passage of steelhead at Snake River dams.

Part V - Movements of steelhead in fishways in relation to transition pools.

Part VI - Evaluation of fishway fences and spill for adult salmon and steelhead passage at Snake River dams.

Part VII - Effects of zero versus normal flow at night on passage of steelhead in summer and fall.

Acknowledgments

Many people assisted with this project and its successful completion was made possible by Teri Barila, the Corps of Engineers project officer. Michelle Feeley, Brian Hastings, Jay Nance and Matthew Keefer played important roles in the study.
# Table of Contents - Part III of Final Report

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td>i</td>
</tr>
<tr>
<td>Abstract</td>
<td>iii</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Methods</td>
<td>1</td>
</tr>
<tr>
<td>Results</td>
<td>2</td>
</tr>
<tr>
<td>Ice Harbor Dam</td>
<td>2</td>
</tr>
<tr>
<td>Steelhead 1993</td>
<td>2</td>
</tr>
<tr>
<td>Steelhead 1994</td>
<td>12</td>
</tr>
<tr>
<td>Chinook Salmon 1993</td>
<td>16</td>
</tr>
<tr>
<td>Lower Monumental Dam</td>
<td>23</td>
</tr>
<tr>
<td>Steelhead 1993</td>
<td>23</td>
</tr>
<tr>
<td>Steelhead 1994</td>
<td>32</td>
</tr>
<tr>
<td>Chinook Salmon 1993</td>
<td>39</td>
</tr>
<tr>
<td>Little Goose Dam</td>
<td>44</td>
</tr>
<tr>
<td>Steelhead 1993</td>
<td>44</td>
</tr>
<tr>
<td>Steelhead 1994</td>
<td>56</td>
</tr>
<tr>
<td>Chinook Salmon 1993</td>
<td>62</td>
</tr>
<tr>
<td>Lower Granite Dam</td>
<td>67</td>
</tr>
<tr>
<td>Steelhead 1993</td>
<td>67</td>
</tr>
<tr>
<td>Steelhead 1994</td>
<td>80</td>
</tr>
<tr>
<td>Chinook Salmon 1993</td>
<td>85</td>
</tr>
<tr>
<td>Discussion</td>
<td>92</td>
</tr>
<tr>
<td>References</td>
<td>99</td>
</tr>
</tbody>
</table>
Abstract

Study of fishway entrance, fishway use, and dam passage by chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* at the four lower Snake River dams was an important aspect of the adult salmon and steelhead passage project. The objectives were to monitor fish movements at Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dams using radio transmitters and receivers. Steelhead were monitored at Lower Granite Dam in 1992 and all four dams during 1993 and 1994; chinook salmon were monitored at all dams during 1993. Critical parameters were passage times for a fish to first approach the dam, first enter a fishway, total time to pass over the dam, which entrances were approached, and where fish entered and exited the fishways.

Median time to first approach each of the fishways was 0.5 to 2 hours (h) throughout the study for both steelhead and chinook salmon (although it was 3.4 h at Lower Granite Dam in 1992). Median times for steelhead to first enter fishways were 2 to 3 h at Ice Harbor, Lower Monumental, and Little Goose dams and 4.5 to 5.5 h at Lower Granite Dam. Median times for chinook salmon to first enter fishways were 1.9 to 2.6 h at Ice Harbor and Lower Granite dams and 3.9 to 4.6 h at Lower Monumental and Little Goose dams.

At Ice Harbor Dam, median passage time from the tailrace to exit from the top of the ladder was about 19 h for steelhead and chinook salmon in 1993. Median passage time for steelhead in 1994 was 12 h.

In both years, steelhead tended to first approach the Ice Harbor fishway at the southern half of the dam, though many first approaches were also made at orifice gates and northern entrances. No entrances were clearly favored by chinook salmon for first approaches. Entrances used by all fish were more restricted than entrances approached. The south-shore entrance (SSE) and north-powerhouse entrance (NPE) were most used to enter fishways by steelhead in 1993 and 1994; chinook salmon used the north-shore entrance (NSE) and NPE most often. The most effective entrances (based on the highest ratio of entrances to exits) for steelhead in 1993 were SSE-1, orifice gate-1 (OG-1), and OG-2. In 1994, SSE-1, NSE, and OG-8 were most effective for steelhead. NSE, OG-1, OG-2, and SSE-1 were the most effective entrances for chinook salmon in 1993. The least effective Ice Harbor entrance (more exits than entries) for each year and run was the NPE.

At Lower Monumental Dam, median passage time from the tailrace to exit from the top of the ladder was 13.4 h for steelhead in 1993, 20.4 h for chinook salmon in 1993, and 12 h for steelhead in 1994.

First fishway approaches for steelhead in 1993 at Lower Monumental Dam were at SPE-2, OG-3, and OG-7; in 1994, steelhead first approached more
often at OG-3, OG-5, and SSE. In 1993 chinook salmon first approached at OG-1, OG-3, and SPE-2. First and total entrances used by all fish were more restricted than entrances approached. South-powerhouse entrances (SPE-1, SPE-2), SSE, and NSE were most used to enter the fishways by steelhead in 1993 and 1994. Chinook salmon used SSE, NSE, SPE-1, and SPE-2 most often. The most effective entrances for steelhead in 1993 were SSE, OG-3, and NSE. In 1994 the SSE and NSE were most effective for steelhead. The SSE, SPE-1, and NSE were the most effective entrances for chinook salmon in 1993. The least effective fishway entrance at Lower Monumental Dam for each year and run was SPE-2.

At Little Goose Dam, median passage time from the tailrace to exit from the top of the ladder was 12 h for steelhead in 1993, 16.9 h for chinook salmon in 1993, and 10.6 h for steelhead in 1994.

First fishway approaches by steelhead at Little Goose Dam in 1993 were mostly at NPE-3, NSE, and SSE. In 1994, steelhead approached the SSEs most often, followed by NPE-3 and NSE. Chinook salmon in 1993 first approached the SSEs, NPE-1 and NSE most often. First and total entrances used by all fish were more restricted than entrances approached. The majority of first and subsequent entrances used to enter the fishways by steelhead in 1993 and 1994 occurred at the SSEs. Chinook salmon used the SSEs and NSE about equally. The most effective entrances for steelhead in 1993 were SSE-1, OG-1, and NPE-2. The SSEs and NPEs were most effective for steelhead in 1994; the SSE, NSE, and OG-1 were most effective for chinook salmon in 1993. The least effective fishway entrances at Little Goose Dam were NSE, NPE-1, and NPE-2 for steelhead in 1993, NPE-1 and OG-10 for chinook salmon in 1993, and NSE and OG-10 for steelhead in 1994.

At Lower Granite Dam, median passage time from the tailrace to exit from the top of the dam was 31.7 h for steelhead in 1993, 18.2 h for chinook salmon in 1993, and 28.8 h for steelhead in 1994.

First approaches to the Lower Granite fishway by steelhead in 1993 were mostly at NPE-3, OG-7, and NPE-3. In 1994, steelhead also first approached at NPE-3, then OG-1 and OG-4. Chinook salmon in 1993 first approached at NPE-2, SSE-1, and OG-10 with few approaches at NPE-3. First and total entrances used to enter the fishways by all fish were more restricted than entrances approached. Steelhead in 1993 and 1994 used the SSEs and NPEs most often. In 1993 chinook salmon used the NSE, SSEs, and NPEs most often. The most effective entrance was SSE-2 for all fish in both 1993 and 1994. The NPEs were also effective for steelhead in both years, and OG-1 and NPE-2 were effective for chinook salmon in 1993. The NSE and SSE-1 were the least effective entrances for steelhead in both years, and NPE-1 was the least effective entrance for chinook salmon.
Most fishway entrances had more entries than exits during the study. Exits from the collection channels were mostly from entrances closest to the bottom of the ladder and from entrances adjacent to the spillways, as well as the NSL at Ice Harbor Dam, the SSL at Lower Monumental Dam, and the NSEs at Little Goose and Lower Granite dams. Overall, steelhead and chinook salmon successfully used shoreline and powerhouse entrances most often; these entrances were larger had greater depth and higher flow volumes than other entrances. Orifice gates and entrances adjacent to the spillways, which received a proportionate number of fishway approaches, were used relatively infrequently to enter the fishways.
Introduction

An important aspect of the adult salmon and steelhead passage project was to describe how fish moved past Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dams in the lower Snake River. Accurately monitoring movements at the dams of fish outfitted with transmitters was significantly enhanced with the development of the digital spectrum processors (DSP), which, when combined with SRX radio receivers (SRX/DSP units), allowed simultaneous monitoring of all transmitter frequencies. The SRX/DSP radio receivers were first used to monitor entrance use by steelhead at Lower Granite Dam in the fall of 1992 (Bjornn et al. 1994).

In 1993 and 1994, antennas connected to SRX/DSP receivers were placed near entrances to fishways, within fishways, and at the top of ladders at all four lower Snake River dams in early spring. With the new telemetry system, it was possible to monitor the movements of individual fish outfitted with transmitters as they approached entrances to fishways, determine openings used by fish to enter and exit fishways and movements within fishways, and calculate the total time for fish to pass the dams. Steelhead with transmitters were monitored at the four dams during 1993 and 1994, and at Lower Granite dam during 1992; chinook salmon were monitored at all dams during 1993. The emphasis of this report will be on the results from monitoring steelhead during 1993 and 1994, and chinook salmon behavior will be included where appropriate for comparison. Detailed information on fishway use and passage for chinook salmon was reported in Bjornn et al. (1995). Results from this study will be used to determine where changes may be needed to improve passage of salmon and steelhead at the lower Snake River dams.

Methods

Steelhead used for the study were collected and outfitted with radio transmitters at Ice Harbor Dam (river kilometer, RKM, 537.7) in 1994. Chinook salmon and steelhead were collected and outfitted with radio transmitters at John Day Dam (RKM 346.9) on the Columbia River in 1993. Fish with transmitters were monitored at the four Snake River dams using SRX receivers connected to 9-element Yagi antennas in the tailrace (1.5-2.7 km downstream from the dams), and SRX/DSP receivers connected to underwater coaxial cable antennas positioned near fishway entrances, exits, and inside fishways at the dams. The tailrace SRX 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.

Emphasis on analysis was placed on determining passage times for a fish to first approach the dam, first enter a fishway, and total time to pass over the dam. Because fish could approach and enter fishways more than once, total approaches and entrances (and exits) made by fish were also summarized. All passage times were determined from the time of last record of a fish at the tailrace receiver sites prior to the first approach at the dam. Detailed description of tagging and monitoring methods used for the study can be found in Part I of the final report (Bjornn et al. 1998a).
Results

Passage of steelhead and chinook salmon with transmitters at the four lower Snake River dams during 1993 and 1994 is summarized below. Passage variables (time to first approach, time to first entry, time to pass a dam) were summarized over the whole migration periods in 1993 and 1994 for all flow and spill conditions. In most cases we present medians of variables because of the tendency for passage values to be skewed to the right.

Ice Harbor Dam

Steelhead 1993. - Use of fishway entrances (Figure 1) and movements within the fishway at Ice Harbor Dam in 1993 were monitored by recording movements of 371 steelhead outfitted with transmitters. Median passage times of steelhead from the tailrace receiver (about 2 km downstream from the dam) to first recorded approach at an entrance, first entry into fishways, and passage from the top of the ladder were 1.7 h, 2.2 h, and 19.0 h (Figure 2). The distribution of passage times was skewed to the right, with a few fish taking several days to approach the entrances, enter the fishways, or pass over the dam. Consequently, mean passage times were longer than median times. Most fish entered fishways within 6 to 12 h after passing the tailrace receiver, but several fish took up to 8 d to pass the dam because they spent 1 d or more in the fishways or spent time exiting and reentering fishways. Some fish were in the fishways at nightfall and usually stayed there until morning, and some fish spent time migrating up and down the powerhouse collection channel during daylight (Figure 3). Passage times between the tailrace and passage from the top of a ladder also included time some fish used when they exited a fishway via one of the entrances, moved out into the tailrace, and then reentered a fishway.

Steelhead had a tendency to first approach along the powerhouse at the southern half of the dam, including 43 and 50 of 371 fish recorded that approached orifice gate 10 (OG-10) and the north-powerhouse entrance (NPE) first (Figure 4). Number of turbine units operating was low in the fall and was alternated between the southern and northern ends of the powerhouse as part of the turbine priority test (see Part IV of final report, Bjornn et al. 1998b). First approaches at the NPE were an indication that significant numbers of steelhead moved up to the dam north of the powerhouse, perhaps circled through the spillway stilling basin, and passed by NPE and OG-10 before entering the fishway.

When all approaches at fishway entrances made by steelhead in fall 1993 were considered, most approaches were along the powerhouse and relatively few were at the north-shore entrance (NSE, Figure 4). The large number of approaches to entrances (averaged 20 per fish, 7,309 total) is an indication that steelhead moved back and forth along the dam and did not readily enter a fishway.

The 371 steelhead monitored had a median of 8 approaches to the dam versus a median of 16 approaches per fish for chinook salmon in 1993. Fifty steelhead approached the dam only once
Figure 1. Fishway entrances and locations of antennas used at Ice Harbor Dam during 1993 and 1994 chinook salmon and steelhead migration seasons.
Figure 2. Numbers of steelhead and days to passage from the Ice Harbor Dam tailrace to first approach at a fishway entrance, first entry into fishway, and passage from the top of the ladders in fall 1993.
and 211 (57%) steelhead approached the dam 1 to 10 times, but several fish approached various entrances 50 or more times (Figure 5). Although steelhead moved back and forth along the dam and approached entrances several times, the time between first approach and first entry into the fishway was about 0.5 h (based on median passage times, Figure 2).

Entrances used by steelhead in the fall of 1993 for first-time entries were more restricted than entrances approached. The highest number of first and repeated entries into the fishway occurred at south-shore entrance-1 (SSE-1) and NPE (Figure 6), whereas many approaches to the dam were at floating orifice-gate entrances, in addition to SSE-1 and NPE (Figure 4). Where fish approached the dam was probably related to location of discharges, but this was not the only factor as illustrated by higher than average numbers of fish that approached the dam and entered at NPE. Where a fish entered the fishway was probably related to amount of discharge, size of opening, and ease of following attractive flow to the opening. Discharge from NPE may have been easier to find and follow for steelhead approaching the dam near the middle of the channel because the discharge curled around the north end of the powerhouse and into the spillway stilling basin when there was no spill. Although many fish approached the orifice-gate entrances, relatively few entered the fishway through those

Figure 3. Illustration of the types of movements made by some steelhead in fall 1993 when approaching Ice Harbor Dam, entering and exiting the fishway, and passing through the fishway.
Figure 4. Number of first and total approaches by steelhead at Ice Harbor Dam fishway entrances in fall 1993. See Figure 1 for location of entrances.
openings. Orifice-gate entrances were used less than others because of their smaller capacity (design of 60-80 cfs), mixing of discharges with those from turbines, and smaller size and shallower depth of the orifice-gate openings. The NPE was 3.66 m wide and 2.44 m deep and designed to discharge 700 cfs. Orifice gate entrances at Ice Harbor Dam were 0.61 m high and 1.83 m wide, with the top of the opening 1.37 m below the surface. The SSE and NSEs were 12 ft (3.66 m) wide and 8 ft (2.44 m) deep with a discharge of about 650 cfs.

Of the 371 steelhead monitored at Ice Harbor Dam, four did not enter and one entered at an unknown location. Of the fish with known entrances, 106 (29%) entered a fishway at Ice Harbor Dam only once (Figure 7), the remainder exited and reentered the fishway from 1 to 63 times. There was a median of three entrances and two exits for the 371 steelhead monitored at Ice Harbor Dam in 1993 versus a median of two entries and one exit per fish for chinook salmon.

Steelhead exited the fishways via all entrances, but more did so at NPE and SSE-1 than at other entrances (Figure 8). Net entry rates (known entrances minus exits) for fishway entrances ranged from -50 to 50 for first entries and exits, and -250 to 190 for all entries and exits (Figure 9). The SSE-1 was the most effective entrance (fewest exits per entrance), followed by OG-2 and OG-4. There were
Figure 6. Number of first and total entries by steelhead at Ice Harbor Dam fishway entrances in fall 1993. See Figure 1 for location of entrances.
Figure 7. Frequency distributions of entries (top) and exits (bottom) into or from the fishway entrances at Ice Harbor Dam by steelhead in fall 1993. Steelhead listed as having zero entries did enter the fishway but the entrance used was unknown.
Figure 8. Number of first and total exits from each fishway entrance by steelhead at Ice Harbor Dam in fall 1993. See Figure 1 for location of entrances.
Figure 9. Net number of first and total exits from each fishway entrance by steelhead at Ice Harbor Dam in fall 1993. See Figure 1 for location of entrances.
Steelhead 1994. - Entrance use and movements within fishways at Ice Harbor Dam in 1994 were monitored by recording movements of 287 steelhead outfitted with transmitters. Median passage times of steelhead from the tailrace receiver (about 2 km downstream from the dam) at Ice Harbor Dam to the first recorded approach at an entrance, first entry into fishways, and passage from the top of the ladder were 1.2 h, 1.9 h, and 12.0 h, respectively (Figure 10). Most fish entered the fishways within 6 to 12 h after passing the tailrace receiver, but several fish took more than 10 d to pass the dam because they spent 1 d or more in the fishways or spent time exiting and reentering fishways. Some fish were in fishways at nightfall and usually stayed there until morning, and some fish spent time migrating up and down the powerhouse collection channel during daylight (Figure 11). Passage times between the tailrace and passage from the top of a ladder also included time some fish used when they exited fishways via one of the entrances, moved out into the tailrace, and then reentered the fishways.

Steelhead had a tendency to first approach the southern half of the dam, although 50 and 37 of 287 fish recorded first approached the NSE and OG-8, respectively (Figure 12). Turbine unit operations were low in fall and primarily from the southern end of the powerhouse. Protracted turbine outages caused the turbine priority test to fail and turbine operation reverted to the south priority as established by the Fish Passage Plan (see Part IV of final report). Fish first approaching the north-shore entrance (NSE) was an indication that significant numbers of fish first moved toward the dam along the north shore and some fish first approached the dam midchannel, north of the powerhouse. When all approaches at fishway entrances were considered, most were along the powerhouse (Figure 12). The large number of approaches to all entrances (averaged 14 per fish, 4,065 total) is an indication that steelhead moved back and forth along the dam before entering the fishway. Of the 287 steelhead monitored at Ice Harbor Dam in 1994, 22 approached the dam only once, 173 (60%) approached the dam 1 to 10 times, but several fish approached various entrances 50 or more times (Figure 13). Although steelhead moved back and forth along the dam and approached the entrances several times, the time between first approach and first entry into the fishway was about 42 min (based on median passage times, Figure 10).

Entrances used for first-time entries by steelhead in fall 1994 were more restricted than entrances approached. For example, a majority of first and repeated entries into fishways occurred at SSE-1, NPE, and NSE (Figure 14), whereas many first approaches at the dam were at floating orifice-gate entrances, in addition to the most used entrances (Figure 12). Although many fish approached orifice-gate entrances, relatively few entered the fishway through those openings. Turbine unit operation was an important factor in where fish approached the dam, but not the only factor, as illustrated by higher than average numbers of fish that approached the dam and entered at NSE and NPE. Discharge from NSE may have been easier for
Figure 10. Numbers of steelhead and days to passage from the Ice Harbor Dam tailrace to first approach at a fishway entrance, first entry into fishways, and passage from the top of the ladders in fall 1994.
Almost half of the steelhead (132 of 287 monitored, 46%) entered the fishway at Ice Harbor Dam only once in 1994 (Figure 15) and the remainder exited and reentered the fishways 1 to 27 times. Median entrances and exits per fish were two and one for the 287 steelhead monitored at Ice Harbor Dam in 1994.

Steelhead exited the fishway via all entrances, but more did so at SSE-1, the NPE, and NSE than at other entrances (Figure 16). Many fish failed to ascend a ladder after entering the transition pool located at the bottom of ladders. These fish traveled downstream in the fishways and may not have exited, or they may have exited and then had to reenter before ascending a ladder. Net entry rates (entrances minus exits) for fishway entrances ranged from -3 to 77 for first entries and exits, and -30 to 165 for all entries and exits (Figure 17). The SSE was the most effective entrance, followed by NSE and OG-8. There were more exits than entries by steelhead at NPE and OG-1.

Figure 11. Illustration of the types of movements made by some steelhead in fall 1994 when approaching Ice Harbor Dam, entering and exiting the fishway, and passing through the fishway.
Figure 12. Number of first and total approaches by steelhead at Ice Harbor Dam fishway entrances in fall 1994. See Figure 1 for location of entrances.
Chinook salmon 1993. - Summary information on fishway entrance use and passage by chinook salmon in 1993 is presented in this report so that passage information for both salmon and steelhead would be readily available for comparison. Detailed analyses of chinook salmon passage through fishways was reported in Bjornn et al. (1995). Entrances (Figure 1) used and movements within the fishways at Ice Harbor Dam in 1993 were monitored by recording movements of 340 chinook salmon outfitted with transmitters. Spring and summer chinook salmon with transmitters had median passage times from the tailrace receiver to first recorded approach at an entrance, first entry into fishways, and passage from the top of the ladders at Ice Harbor Dam of 1.2 h, 2.6 h, and 20.6 h in 1993 (Figure 18). The distribution of passage time was skewed to the right, with a few fish taking several days to approach the entrances, enter the fishways, or pass over the dam.

First approaches to Ice Harbor Dam by chinook salmon were made at all entrances (fewest at OG-12), including a high number of first approaches at the NSE and OG-2 (Figure 19). When all approaches at fishway entrances made by chinook salmon in 1993 were considered (average 30 per fish, median 16 per fish, 10,093 total), most approaches were concentrated at entrances near the south shore (Figure 19). By comparison, total steelhead approaches (average 20 per

Figure 13. Number of steelhead approaching fishway entrances one or more times at Ice Harbor Dam in fall 1994.

![Number of steelhead approaching fishway entrances](image_url)
Figure 14. Number of first and total entries by steelhead into Ice Harbor Dam fishway entrances in fall 1994. See Figure 1 for location of entrances.
Figure 15. Frequency distributions of entries (top) and exits (bottom) into or from fishway entrances at Ice Harbor Dam by steelhead in fall 1994.
Figure 16. Number of first and total exits from each fishway entrance by steelhead at Ice Harbor Dam in fall 1994. See Figure 1 for location of entrances.
Figure 17. Net number of first and total exits from each fishway entrance by steelhead at Ice Harbor Dam in fall 1994. See Figure 1 for location of entrances.
Figure 18. Number of chinook salmon and days to passage from the Ice Harbor Dam tailrace to first approach at a fishway entrance, first entry into fishways, and passage from the top of a ladder in fall 1993.
Figure 19. Number of first and total approaches by chinook salmon at Ice Harbor Dam fishway entrances in 1993. See Figure 1 for location of entrances.
fish, 7,309 total) were more distributed among entrances.

Entrances used for first-time entries by chinook salmon in 1993 were more restricted than entries approached. The highest numbers of first entries for spring and summer chinook salmon were at the NSE, followed by the NPE and SSE (Figure 20). For steelhead in 1993, more than one-third of the fish entered first at the SSE, 14% at the NPE, and the remainder at the orifice gates and NSE (Figure 11). When all entries were considered, the pattern for chinook salmon was similar to that of steelhead; most entries occurred at the SSE, NPE, and NSE, and relatively few occurred at orifice gates (Figures 11 and 20). Where a fish entered the fishway was probably related to the amount of discharge, size of fishway opening, and ease of following attractive flow to the opening. Although many fish approached the orifice-gate entrances, relatively few entered the fishway through those openings. Orifice-gate entrances were used less than others because of their smaller capacity (design of 60-80 cfs), mixing of discharges with those from turbines, and smaller size and shallower depth of the orifice-gate opening.

Of the 340 chinook salmon monitored in 1993 at Ice Harbor Dam, 147 (43%) entered the fishways only once and they did not exit before passing over the dam. The remainder of the salmon exited and then reentered the fishways one or more times before they passed over the dam (means for all fish of 3.4 entries and 2.5 exits). Net entry rates (entries minus exits) for chinook salmon at Ice Harbor Dam in 1993 were positive for all entrances except the NPE (Figure 21). For first entries and exits, the NSE, and OG-2 had the highest net number of entries, but for all entries the NSE and OG-1 had the highest net number of entries. The least effective entrance for chinook salmon in 1993 was the NPE, where chinook had many more exits than entries.

**Lower Monumental Dam**

**Steelhead 1993.** - Entrance use and movements within fishways at Lower Monumental Dam (Figure 22) in 1993 were monitored by recording movements of 339 steelhead outfitted with transmitters. Median passage times of steelhead from the tailrace receiver (about 2 km downstream from dam) at Lower Monumental Dam to first recorded approach at an entrance, first entry into fishways, and passage from the top of a ladder were 2.2 h, 3.4 h, and 13.4 h (Figure 23). Most fish entered fishways within 6 to 12 h after passing the tailrace receiver, but several fish took up to 9 d to pass the dam because they spent 1 d or more in the fishways or spent time exiting and reentering fishways. Some fish were in fishways at nightfall and usually stayed there until morning, and some fish spent time migrating up and down the powerhouse collection channel during daylight (Figure 24). Passage times between the tailrace and passage from the top of a ladder also included time some fish used when they exited fishways via one of the entrances, moved into the tailrace, and then reentered a fishway.

Highest number of first approaches to the dam for steelhead occurred at the south-powerhouse entrance-2 (SPE-2) and OG-3, and 38 of 339 fish first approached OG-7 (Figure 25). Number of turbine units operating was low in the fall
Figure 20. Number of first and total entries by chinook salmon at Ice Harbor Dam fishway entrances in spring and early summer 1993. See Figure 1 for location of entrances.
Figure 21. Net number of first and total exits by chinook salmon into Ice Harbor Dam fishway entrances in spring and early summer 1993. See Figure 1 for location of entrances.
Figure 22. Fishway entrances and locations of antennas used at Lower Monumental Dam during 1993 and 1994 chinook salmon and steelhead migration seasons.
Figure 23. Numbers of steelhead and days to passage from the Lower Monumental Dam tailrace to first approach at a fishway entrance, first entry into fishways, and passage from the top of a ladder in fall 1993.
and was alternated between the northern and southern ends of the powerhouse as part of the turbine priority test. First approaches at the SPEs are an indication that significant numbers of fish moved toward the dam in the midchannel south of the powerhouse, perhaps circled through the spillway stilling basin, and passed by SPE-1 and SPE-2 before entering the fishway.

When all approaches at fishway entrances made by steelhead in fall 1993 were considered, most were along the powerhouse entrances and relatively few were at the SSL or NSL (Figure 25). The large number of approaches to entrances (averaged 16 per fish, 5,557 total) is an indication that steelhead moved back and forth along the dam before entering the fishway. Thirteen percent, 45 of the 339 steelhead monitored, approached the dam once, and 207 (61%) steelhead approached the dam 1 to 10 times (Figure 26). Several steelhead approached various entrances 50 or more times. Median number of approaches per steelhead was seven compared to a median of 39 for chinook salmon in 1993. Although steelhead moved back and forth along the dam and approached the entrances severaltimes, the time between first approach and first entry into the fishway was about 1 h (based on median passage times, Figure 23).

Entrances used by steelhead in fall 1993 for first-time entries were more

Figure 24. Illustration of the types of movements made by some steelhead in fall 1993 when approaching Lower Monumental Dam, entering and exiting, and passing through a fishway.
Figure 25. Number of first and total approaches by steelhead at Lower Monumental Dam fishway entrances in fall 1993. See Figure 22 for location of entrances.
restricted than entrances approached. For example, a majority of first and repeated entries into a fishway occurred at SPE-1 and SPE-2, SSE, and NSE (Figure 27), whereas many first approaches at the dam were at floating orifice-gate entrances in addition to the most used entrances (Figure 25). Although many fish approached orifice-gate entrances, relatively few entered the fishway through those openings. Turbine unit operation was an important factor in where fish approached the dam, but not the only factor as illustrated by higher than average numbers of fish that approached the dam and entered at the SSE where there was no flow to attract fish other than that coming from the ladder. Discharge from the SSE may have been easier for steelhead to find and follow when there was no spill, because the discharge was directed into the spillway stilling basin. Orifice-gate entrances were used less than others because of their lower capacity (design of 60-80 cfs), mixing of discharges with those from turbines, and smaller size and shallower depth of the orifice-gate openings. The SSL consisted of two openings that were 3.33 m wide and 2.44 m deep and designed to discharge 320 cfs. Orifice-gate entrances were 0.61 m high and 1.83 m wide, with the top of the opening 1.22 m below the surface. The SPEs were 1.83 m wide and 2.44 m deep, with a discharge of 680 cfs. The NSEs were 1.22 m wide and 2.44 m deep, with a discharge of 400 cfs. In the spring and summer, the majority of first
First entrances into fishway

n = 337 fish

All entrances into fishway

n = 337 fish

Mean = 3.7/fish

Total entrances = 1,261

Figure 27. Number of first and total entries by steelhead into Lower Monumental Dam fishway entrances in fall 1993. See Figure 22 for location of entrances.
entries occurred at the NSE and SSE, and relatively few entered at the powerhouse (Figure 27).

Of 339 steelhead monitored at Lower Monumental Dam, two did not enter the fishway. Of the steelhead that entered, 152 (45%) entered the fishway at Lower Monumental Dam only once (Figure 28) and the remainder exited and reentered the fishway from 1 to 40 times. The median number of entrances per steelhead was two versus a median of one exit per fish, similar to the values found for chinook salmon in 1993.

Steelhead exited fishways via all entrances, but more did so at the SPEss and the SSEthan at other entrances (Figure 29). A net fallout was observed previously at the SPEs(Turner et al. 1983; 1984). Many fish moved up the collection channel to the transition pool located at the bottom of the ladder, and then moved down the channel and exited at the SPEs.

Net entry rates (known entrances minus exits) for fishway entrances ranged from -2 to 23 for first entries and exits, and -55 to 50 for all entries and exits (Figure 30). The SSE was the most effective entrance for steelhead followed by OG-3 and NSE. There were more exits than entries by steelhead at SPE-2 and OG-9.

**Steelhead 1994.** - Entrance use and movements within fishways at Lower Monumental Dam in 1994 were monitored in fall 1994 by recording movements of 274 steelhead outfitted with transmitters. Median passage times of steelhead from the tailrace receiver (about 2 km downstream from the dam) to first recorded approach at an entrance, first entry into fishways, and passage from the top of the ladder were 1.7 h, 2.4 h, and 12.0 h (Figure 31). Most fish entered the fishways within 6 to 12 h after passing the tailrace receiver, but several fish took up to 6.25 d to pass the dam. Some fish were in the fishway at nightfall and usually stayed there until morning, and some fish spent time migrating up and down the powerhouse collection channel during daylight (Figure 32). Passage times between the tailrace and passage from the top of the ladders also included time some fish used when they exited the fishways via one of the entrances, moved out into the tailrace, and then reentered the fishway.

Steelhead had a tendency to first approach the dam at OG-3 and OG-5 and the SSE, although 35 fish approached the NSE and 50 fish approached the SPEsfirst (Figure 33). Turbine operations were low in the fall and primarily from the northern end of the powerhouse. First approaches at SPEs are an indication that significant numbers of fish moved up to the dam along the south shore, perhaps circled through the spillway stilling basin, and passed by SPE-1 and SPE-2 before entering the fishway.

When all approaches at fishway entrances were considered, most were at the SSE, and along the north end of the powerhouse, from OG-5 to the NSE, with the exception of OG-1 (Figure 33). The large number of approaches to entrances (averaged 16 per fish, 4,366 total) is an indication that steelhead moved back and forth along the dam before entering the fishway. Of the 274 steelhead monitored at Lower Monumental Dam in 1994, 28 approached the dam only once, 154 (56%) approached the dam 1 to 10 times,
Figure 28. Frequency distribution of entries (top) and exits (bottom) into or from the fishway entrances at Lower Monumental Dam by steelhead in fall 1993. Steelhead listed as having zero entries did enter the fishway but the entrance used was unknown.
Figure 29. Number of first and total exits from each fishway entrance by steelhead at Lower Monumental Dam in fall 1993. See Figure 22 for location of entrances.
Figure 30. Net number of first and total exits from each fishway entrance by steelhead at Lower Monumental Dam in fall 1993. See Figure 22 for location of entrances.
Figure 31. Number of steelhead and days to pass from the Lower Monumental Dam tailrace to first approach at a fishway entrance, first entry into fishway, and passage from the top of the ladders in fall 1994.
but several fish approached various entrances 50 or more times (Figure 34). Although steelhead moved back and forth along the dam and approached the entrances several times, the time between first approach and first entry into the fishway was 42 min (based on median passage times, Figure 31).

Entrances used by steelhead for first-time entries were more restricted than entrances approached. For example, a majority of first and repeated entries into the fishways occurred at SPE-1 and SPE-2, SSE, and NSE (Figure 35), whereas many first approaches at the dam were at floating orifice-gate entrances, in addition to the most used entrances (Figure 33). Although many fish approached orifice-gate entrances, relatively few entered the fishway through those openings. Location of discharges was an important factor in where fish approached the dam, but not the only factor. For example, higher than average numbers of fish approached the dam and entered the fishway from the south shore, where the only other attractive flow was 1.1 kcfs from spillbay 1, adjacent to the SSE, 2 d out of every 4d, from 0500-2000 h, during the fall.

Of the 274 steelhead monitored at Lower Monumental Dam in 1994, two did not enter the fishway. Of fish that entered, 124 (45%) entered a fishway at Lower Monumental Dam only once (Figure 36), while the remainder exited and reentered

Figure 32. Illustration of the types of movements made by some steelhead in fall 1994 when approaching Lower Monumental Dam, entering and exiting the fishway, and passing through the fishway.
Figure 33. Number of first and total approaches by steelhead at Lower Monumental Dam fishway entrances in fall 1994. See Figure 22 for location of entrances.
the fishway from 1 to 43 times. Median entrances and exits per fish were two and one for the 272 steelhead monitored at Lower Monumental Dam in 1994.

Steelhead exited fishways via all entrances, but more did so at the SPEs, SSE, and NSE than at other entrances (Figure 37). A net fallout rate was previously observed at the SPEs at Lower Monumental Dam (Turner et al. 1984). Many fish failed to ascend a ladder after first entering the transition pool located near the bottom of the ladders. The fish traveled downstream in the fishway and some exited and reentered the fishway before they returned to the transition pool and ascended the ladder.

Net entry rates (known entrances minus exits) for fishway entrances ranged from -2 to 29 for first entries and exits, and -30 to 68 for all entries and exits (Figure 38). The SSE was the most effective entrance, followed by SPE-1 and NSE. There were more total exits than entries of steelhead at SPE-2.

**Chinook salmon 1993.** - Summary information on fishway entrance use and passage of chinook salmon in 1993 is presented in this report so that passage information for both salmon and steelhead would be readily available for comparison. Detailed analyses of chinook salmon passage through fishways was reported in Bjornn et al. (1995). Entrances used and
First entrances into fishway
n = 272 fish

All entrances into fishway
n = 272 fish
Mean = 3.4/fish
Total entrances = 933

Figure 35. Number of first and total entries by steelhead into the Lower Monumental Dam fishway in fall 1994. See Figure 22 for location of entrances.
Figure 36. Frequency distributions of entries (top) and exits (bottom) into or from fishway entrances at Lower Monumental Dam by steelhead in fall 1994. Fish with zero entries did enter the fishway but the entrance used was unknown.
Figure 37. Number of first and total exits from each fishway entrance by steelhead at Lower Monumental Dam in fall 1994. See Figure 22 for location of entrances.
Figure 38. Net number of first and total exits from each fishway entrance by steelhead at Lower Monumental Dam in fall 1994. See Figure 22 for location of entrances.
movements within the fishways at Lower Monumental Dam in 1993 were monitored by recording movements of 310 chinook salmon outfitted with transmitters. Median passage times of chinook salmon from the tailrace receiver (about 2 km downstream from the dam) to first recorded approach at an entrance, first entry into fishways, and passage from the top of the ladders were 1.9 h, 4.6 h, and 18.0 h (Figure 39). The distribution of passage time was skewed to the right, with a few fish taking several days to approach the entrances, enter the fishways, or pass over the dam.

First approaches to Lower Monumental Dam for chinook salmon in 1993 were highest at the north end of the powerhouse at OG-1, OG-3, and SPE-2 (Figure 40). The fewest number of first approaches were at OG-9 and SPE-1. When total approaches at fishway entrances made by chinook salmon were considered, most approaches occurred at OG-5, OG-7, and OG-3. Median number of approaches for chinook salmon in 1993 was 39 per fish compared to a median of seven approaches for each steelhead.

First and total entries by chinook salmon at Lower Monumental Dam occurred mostly at the SSE, SPEs, and the NSE, with few entries at orifice gates (Figure 41). Where a fish entered the fishway was probably related to the amount of discharge, size of fishway opening, and ease of following attractive flow to the opening. Orifice-gate entrances were used less than others because of their lower capacity (design of 60-80 cfs), mixing of discharges with those from turbines, and smaller size and shallower depth of the orifice-gate openings. The SSE consisted of two openings that were 6 ft (3.33 m) wide and 8 ft (2.44 m) deep and designed to discharge 320 cfs. Orifice-gate entrances were 2 ft (0.61 m) high and 6 ft (1.83 m) wide, with the top of the opening 4 ft (1.22 m) below the surface. The SPEs were 6 ft (1.83 m) wide and 8 ft (2.44 m) deep with a discharge of 680 cfs. The NSEs were 4 ft (1.22 m) wide with a discharge of 400 cfs at a depth of 8 ft (2.44 m).

Net entry rates (entries minus exits) for chinook salmon at Lower Monumental Dam in 1993 were positive for all entrances except SPE-1 (Figure 42). For first and total entries and exits, SSE and NSE were the most effective (Figure 42). The least effective entrances for salmon in 1993 were the SPEs, where fish had many more exits than entries.

**Little Goose Dam Steelhead 1993.** - Entrance use and movements within the fishway at Little Goose Dam (Figure 43) in 1993 were monitored by recording movements of 305 steelhead outfitted with transmitters. Median passage times of steelhead from the tailrace receiver (about 2 km downstream from the dam) to first recorded approach at an entrance, first entry into the fishway, and passage from top of the ladder were 1.0 h, 1.7 h, and 12 h (Figure 44). Most fish entered the fishway within 6 to 12 h after passing the tailrace receiver, but several fish took up to 8.25 d to pass the dam because they spent 1 d or more in the fishway or spent time exiting and reentering the fishway. Some fish were in the fishway at nightfall and stayed there until morning, and some fish spent time migrating up and down the powerhouse collection channel during daylight (Figure 45). Passage times between the tailrace and passage from
Figure 39. Number of chinook salmon and days to pass from the Lower Monumental Dam tailrace to first approach at a fishway entrance, first entry into the fishway, and passage from the top of the ladders in spring and summer 1993.
Figure 40. Number of first and total approaches by chinook salmon at Lower Monumental Dam fishway entrances in spring and early summer 1993. See Figure 22 for location of entrances.
Figure 41. Number of first and total entries by chinook salmon at Lower Monumental Dam to fishway entrances in spring and summer 1993. See Figure 22 for location of entrances.
Figure 42. Net number of first and total exits from each fishway entrance by chinook salmon at Lower Monumental Dam in spring and summer 1993. See Figure 22 for location of entrances.
Figure 43. Fishway entrances and locations of antennas used at Little Goose Dam during 1993 and 1994 chinook salmon and steelhead migration seasons.
Little Goose tailrace to first approach
n = 194 fish
Median = 0.04 d (1.0 h)
Mean = 0.34 d (8.2 h)

Little Goose tailrace to first entrance
n = 187 fish
Median = 0.07 d (1.7 h)
Mean = 2.5 d (60.0 h)

Little Goose tailrace to passage from ladder
n = 182 fish
Median = 0.5 d (12.0 h)
Mean = 3.7 d (88.8 h)

Figure 44. Number of steelhead and days to passage from Little Goose Dam tailrace to first approach at a fishway entrance, first entry into fishway, and passage from the top of the ladder in fall 1993.
the top of the ladder also included time some fish used when they exited the fishway via one of the entrances, moved out into the tailrace, and then reentered the fishway.

Steelhead had a tendency to first approach the dam at NPE-3, although 53 of 305 fish recorded first approached the NSE, 47 at the SSE, and 43 at NPE-1 (Figure 46). Turbine unit operation was low in the fall and was alternated between northern and southern ends of the powerhouse as part of the turbine priority test. First approaches at NPEs and NSE are an indication that significant numbers of fish moved up to the dam north of the powerhouse, perhaps circled through the spillway stilling basin, and passed NPE-3 and NPE-1 before entering the fishway.

When all approaches at fishway entrances in fall 1993 were considered, most approaches were along SSE, NPE-1 and -3, and OG-1 (Figure 46). The large number of approaches to entrances (averaged 15 per fish, 4,545 total) was an indication that steelhead moved back and forth along the dam before entering the fishway. Twenty-nine of the 305 steelhead monitored (9.5%) approached the dam only once and 183 (60%) steelhead approached the dam 1 to 10 times, but several fish approached various entrances 50 or more times (Figure 47). Median number of approaches were eight
First approaches to fishway entrances
\(n = 305\) fish

All approaches to fishway entrances
\(n = 305\) fish
Mean = 14.9/fish
Total approaches = 4,545

Figure 46. Number of first and total approaches by steelhead at Little Goose Dam fishway entrances in fall 1993. See Figure 43 for location of entrances.
per steelhead, as compared to 17 approaches per fish for chinook salmon in 1993. Although some steelhead moved back and forth along the dam and approached entrances several times, the time between first approach and first entry into the fishway was about 42 minutes (based on median passage times, Figure 44).

Entrances used by steelhead in fall 1993 for first-time entries were more restricted than entrances approached. Most first and repeated entries into the fishway occurred at SSE which is 1.22 m wide, 2.44 m deep (Figure 48). Many first approaches at the dam were at NPEs which were 1.83 m wide, 2.44 m deep, NSE(1.83 m wide, 2.44 m deep), and SSE (Figure 46). Although fish approached orifice-gate entrances, relatively few entered the fishway through those openings.

Of 306 steelhead monitored at Little Goose Dam, seven did not enter the fishway and one entered at an unknown location. Of the fish that used known entrances, 125 (42%) entered the fishway at Little Goose Dam only once, while the remainder exited and reentered 1 to 32 times. The median number of entrances per fish was two versus a median of one exit per fish for the 306 steelhead monitored at Little Goose Dam (Figure 49), similar to the median values for chinook salmon in 1993.
Figure 48. Number of first and total entries by steelhead into the Little Goose Dam fishway entrances in fall 1993. See Figure 43 for location of entrances.
Figure 49. Frequency distribution of entries (top) or exits (bottom) into or from the fishway at Little Goose Dam by steelhead in fall 1993. Steelhead listed as having zero entries did enter the fishway but the entrance used was unknown.
Steelhead exited the fishway via all entrances, but more did so at NSE, SSE, and NPEs than at other entrances (Figure 50). A high exit rate was observed previously at the NPEs (Turner et al. 1984). Many fish moved up the collection channel to the transition pool, located at the bottom of the ladder, and then returned down the channel and exited out the north-powerhouse entrances. If a fish traveled downstream in the fishway as far as NPE-1 or NPE-2 and was on the tailrace side of the fishway, the fish would encounter the fishway fence and could be guided out of the fishway via the open NPE (see Part VI of final report for results of study with fishway fences).

Net entry rates (known entrances minus exits) for fishway entrances ranged from -20 to 80 for first entries and exits and -70 to 200 for all entries and exits (Figure 51). The SSE-1 was the most effective entrance for steelhead, followed by OG-1 and NPE-3. There were more exits than entries of steelhead at NSE, NPE-1, and NPE-2.

**Steelhead 1994.** - Entrance use and movements within the fishway at Little Goose Dam in 1994 were monitored in fall 1994 by recording movements of 255 steelhead outfitted with transmitters. Median passage times of steelhead from the tailrace receiver (about 2 km downstream from the dam) to first recorded approach at an entrance, first entry into the fishway, and passage from the top of the ladder were 1.0 h, 2.2 h, and 10.6 h (Figure 52). Most fish entered the fishway within 6 to 12 h after passing the tailrace receiver, but several fish took more than 10 d to pass the dam because they spent 1 d or more in the fishway or spent time exiting and reentering the fishway. Some fish were in the fishway at nightfall and usually stayed there until morning, and some fish spent time migrating up and down the powerhouse collection channel during daylight (Figure 53). Passage time between the tailrace and passage from the top of the ladder also included time some fish used when they exited the fishway via one of the entrances, moved into the tailrace, and then reentered the fishway.

Steelhead had a tendency to first approach the dam at the SSE, NPE-3, and at the NSE (Figure 54). Turbine unit operation was low in the fall and was alternated between the northern and southern ends of the powerhouse as part of the turbine priority test. First approaches at the NPEs and NSE are an indication that significant numbers of fish moved up to the dam midchannel and north of the powerhouse, perhaps circled through the spillway stilling basin, and passed by NPE-3 and NPE-1 before entering the fishway.

When all approaches at fishway entrances were considered, most were at the SSE and along the northern half of the powerhouse from OG-6 to NPE-3 (Figure 54). The large number of approaches to entrances (averaged 18 per fish, 4,570 total) is an indication that steelhead moved back and forth along the dam before entering the fishway. Of the 255 steelhead monitored at Little Goose Dam, 24 approached the dam only once, 134 (53%) approached the dam 1 to 10 times, and several fish approached various entrances 50 or more times (Figure 55). Although steelhead moved back and forth along the dam and approached the entrances several times, the time between
Figure 50. Number of first and total exits from fishway for each entrance by steelhead at Little Goose Dam in fall 1993. See Figure 43 for location of entrances.
Figure 51. Net number of first and total exits from each fishway entrance by steelhead at Little Goose Dam in fall 1993. See Figure 43 for location of entrances.
Figure 52. Numbers of steelhead and days to passage from the Little Goose Dam tailrace to first approach at a fishway entrance, first entry into fishway, and passage from the top of the ladders in fall 1994.
first approach and first entry into the fishway was 1 h (based on median passage times, Figure 52).

Entrances used by steelhead for first-time entries were more restricted than entrances approached. A majority of first and repeated entries into the fishway occurred at the SSE (Figure 56), whereas many first approaches were at NPEs and NSE in addition to the SSE (Figure 54). Although fish approached orifice-gate entrances, relatively few entered the fishway through those openings. Turbine unit operation was an important factor in where fish approached the dam, but not the only factor as illustrated by higher than average numbers of fish that approached the dam and entered NPE-3, where there was no attractive flow other than that coming from the fishway. Discharge from NPE-3 may have been easier for steelhead approaching the dam to find and follow because the discharge was into the spillway stilling basin when there was no spill.

Of the 255 steelhead monitored at Little Goose Dam in 1994, two did not enter the fishway. Of the fish that entered, 110 (43.5%) entered the fishway at Little Goose Dam only once (Figure 57) and the remainder exited and reentered the fishway from 1 to 19 times.

Steelhead exited the fishway via all entrances, but more did so at the SSE, NSE, and NPE-3 than at other entrances.
Figure 54. Number of first and total approaches by steelhead at Little Goose Dam fishway entrances in fall 1994. See Figure 43 for location of entrances.
A high exit rate was observed previously at the NPEs (Turner et al. 1983; 1984). Many fish moved downstream in the collection channel after entering the transition pool located at the bottom of the ladder, and some then exited and reentered the fishway before they returned to the transition pool and ascended the ladder.

Net entry rates (known entrances minus exits) for fishway entrances ranged from -20 to 60 for first entries and exits, and -90 to 125 for all entries and exits (Figure 59). The SSE was the most effective entrance followed by the NPEs. There were more exits than entries of steelhead at NSE and OG-10.

**Chinook salmon 1993.** Summary information on fishway entrance use and passage by chinook salmon in 1993 is presented in this report so that passage information for both salmon and steelhead would be readily available for comparison. Detailed analyses of chinook salmon passage through fishways was reported in Bjornn et al. (1995). Entrances used and movements within the fishways at Little Goose Dam in 1993 were monitored by recording movements of 306 chinook salmon outfitted with transmitters. Median chinook salmon passage times from the tailrace receiver (about 2 km downstream from the dam) to first recorded approach at an entrance, first entry into the fishway, and passage from the top of the ladder at

---

**Figure 55.** Number of steelhead approaching fishway entrances one or more times at Little Goose Dam in fall 1994.
First entrances into fishway
n = 253 fish

All entrances into fishway
n = 253 fish
Mean = 3.2/fish
Total entrances = 823

Figure 56. Number of first and total entries by steelhead into the Little Goose Dam fishway in fall 1994. See Figure 43 for location of entrances.
Figure 57. Frequency distributions of entries (top) and exits (bottom) into or from the fishway at Little Goose Dam by steelhead in fall 1994. Fish that passed over the dam with unknown number of entries were listed as zero entries.
Figure 58. Number of first and total exits from fishway for each entrance by steelhead at Little Goose Dam in fall 1994. See Figure 43 for location of entrances.
Figure 59. Net number of first and total exits from each fishway entrance by steelhead at Little Goose Dam in fall 1994. See Figure 43 for location of entrances.
Little Goose Dam were 0.7 h, 3.9 h, and 14.4 h (Figure 60).

Chinook salmon had a tendency to first approach Little Goose Dam about equally at SSE, NPE-1, and NSE with few first approaches at the remaining entrances (Figure 61). When all chinook salmon approaches (median of 17 approaches per fish) at fishway entrances were considered, most were at SSEs, OG-1, and NPE-1.

Entrances used by chinook salmon in 1993 for first-time and subsequent entries were divided between NSE and SSE (Figure 62). Although fish approached orifice-gate entrances, relatively few entered the fishway through those openings. Where a fish entered the fishway was probably related to the amount of discharge, size of fishway opening, and ease of following attractive flow to the opening. Orifice-gate entrances were used less than others because of their smaller capacity (design 60-80 cfs), mixing of discharges with those from turbines, and smaller size and shallower depth of the orifice-gate opening. The SSEs at Little Goose Dam were 1.22 m wide by 2.44 m deep. The NSEs were 1.83 m wide by 2.44 m deep.

Net entry rates (entries minus exits) for chinook salmon at Ice Harbor Dam in 1993 were positive for all entrances except the NPE (Figure 63). For first and subsequent entries and exits, the SSE, NSE, and OG-1 openings had the highest net number of entries. The least effective entrances for salmon in 1993 were at the north powerhouse, where there were many more exits than entries (Figure 63).

**Steelhead 1993.** - Entrance use and movements within the fishway at Lower Granite Dam (Figure 64) in 1993 were monitored by recording movements of 288 steelhead outfitted with transmitters. Behavior of steelhead in the transition pool was monitored using an additional antenna installed at the base of the ladder (Figure 64). Median passage times of steelhead from the tailrace receiver (about 2 km downstream from the dam) to first recorded approach at an entrance, first entry into the fishway, and passage from top of the ladder were 1.2 h, 4.8 h, and 1.32 d (Figure 65). Most fish entered the fishway within 6 to 18 h after passing the tailrace receiver, but several fish took up to 9.25 d to pass the dam because they spent 1 d or more in the fishway or spent time exiting and reentering the fishway. Some fish were in the fishway at nightfall and usually stayed until morning, and some fish spent time migrating up and down the powerhouse collection channel during daylight (Figure 66). Passage times between the tailrace and passage from top of the ladder also included time some fish used when they made multiple entries to the ladder and any delay resulting from operation of the National Marine Fisheries Service trap located in the ladder.

Steelhead had a tendency to first approach the dam at NPE-3, although 37 fish first approached both OG-7 and SSE-2, and approximately 30 fish first approached NPE-1 and NPE-2 (Figure 67). Turbine unit operation was low in the fall and was alternated between northern and southern ends of the powerhouse as part of the turbine priority test. When all approaches at fishway entrances made by steelhead in fall 1993 were considered,
Figure 60. Numbers of chinook salmon and days to passage from Little Goose Dam tailrace to first approach at a fishway entrance, first entry into fishway, and passage from the top of the ladder in spring and summer 1993.
First approaches to fishway entrances

n = 305 fish

All approaches to fishway entrances

n = 305 fish

Mean approaches per fish = 35
Total approaches = 10,714

Figure 61. Number of first and total approaches by chinook salmon at Little Goose Dam fishway entrances in spring and summer 1993. See Figure 43 for location of entrances.
Figure 62. Number of first and total entries by chinook salmon into the Little Goose Dam fishway entrances in spring and summer 1993. See Figure 43 for location of entrances.
Figure 63. Net numbers of first and total exits from each fishway entrance by chinook salmon at Little Goose Dam in spring and summer 1993. See Figure 43 for location of entrances.
Figure 64. Fishway entrances and locations of antennas used at Lower Granite Dam during 1993 and 1994 chinook salmon and steelhead migration seasons.
Figure 65. Numbers of steelhead and days to passage from the Lower Granite Dam tailrace to first approach at a fishway entrance, first entry into fishway, and passage from the top of the ladder in fall 1993.
approaches were along the NPEs and OG-10, and OG-7 (Figure 67). The large number of approaches to entrances (averaged 17 per fish, 4,920 total) is an indication that steelhead moved back and forth along the dam before entering the fishway. Of 288 steelhead monitored at Lower Granite Dam, one did not approach the dam, one approached at an unknown location, 31 approached the dam only once, 131 (57%) approached the dam 1 to 10 times, and several approached various entrances 50 or more times (Figure 68). Although some steelhead moved back and forth along the dam and approached entrances several times, the time between first approach and first entry into the fishway was about 3.5 h (based on median passage times, Figure 65).

The majority of first and repeated entries into the fishway occurred at SSEs and NPEs (Figure 69), whereas many first approaches at the dam were at orifice gates, in addition to the NPEs and SSEs (Figure 67). Although fish approached orifice-gate entrances, relatively few entered the fishway through those openings. Location of discharges was an important factor in where fish approached the dam, but this was not the only factor as illustrated by higher than average numbers of fish that approached the dam and entered the fishway at NPE-3, where the only attractive flow was that coming

Figure 66. Illustration of the types of movements made by some steelhead in fall 1993 when approaching Lower Granite Dam, entering and exiting the fishway, and passing through the fishway.
Figure 67. Number of first and total approaches by steelhead at Lower Granite Dam fishway entrances in fall 1993. See Figure 64 for location of entrances.
from the fishway. Discharge from NPE-3 may have been easier for steelhead approaching the dam to find and follow because the discharge was into the spillway stilling basin during no spill.

Orifice-gate entrances were used less than others because of their lower capacity (design of 60-80 cfs), mixing of discharges with those from turbines, and smaller size and shallower depth of orifice-gate openings. North-powerhouse entrances were 1.83 m wide and 2.44 m deep and discharged 620 cfs. Orifice-gate entrances at Lower Granite Dam were 0.61 m high and 1.83 m wide, with the center of the opening 1.22 m below the surface. There were two SSEs, each 1.22 m wide and 2.44 m deep, with a total discharge of 400 cfs. The NSE had two openings, both were 1.83 m wide and 2.14 m deep with total discharge of 560 cfs. Of the 288 steelhead monitored at Lower Granite Dam, three did not enter the fishway. Of the steelhead that entered, 163 (57%) entered the fishway at Lower Granite Dam only once while the remainder exited and reentered 1 to 27 times (Figure 70). Median entries and exits per fish for steelhead at Lower Granite Dam in 1993 were one and zero and were two and one per fish for chinook salmon.

Steelhead exited the fishway via all entrances, but more did so at the NSE, SSEs, and the NPEs than at orifice gates (Figure 71). High exit rates were observed previously at the NPEs (Turner et al. 1983; 1984). Many fish moved up

Figure 68. Number of steelhead approaching fishway entrances one or more times at Lower Granite Dam in fall 1993.
Figure 69. Number of first and total entries by steelhead into Lower Granite Dam fishway entrances in spring and summer 1993. See Figure 64 for location of entrances.
Figure 70. Frequency distribution of entries (top) or exits (bottom) into or from the fishway at Lower Granite Dam by steelhead in fall 1993. Steelhead listed as having zero entries did enter the fishway but the entrance used was unknown.
First exit from fishway
n = 124 fish

All exits from fishway
n = 124 fish
Mean = 3.4/fish
Total exits = 427

Figure 71. Number of first and total exits from each fishway entrance by steelhead at Lower Granite Dam in fall 1993. See Figure 64 for location of entrances.
the collection channel to the transition pool located at the bottom of the ladder, and then returned down the channel and exited out the NPEs.

Net entry rates (known entrances minus exits) for fishway entrances ranged from -5 to 47 for first entries and exits, and -20 to 130 for all entries and exits (Figure 72). The SSE-2 was the most effective entrance followed by NPE-3, NPE-2, and NPE-1. There were more exits than entries of steelhead at NSE and SSE-1.

**Steelhead 1994.** - Entrance use and movements within the fishway at Lower Granite Dam in fall 1994 were monitored by recording movements of 244 steelhead outfitted with transmitters. Median passage times of steelhead from the tailrace receiver (about 2 km downstream from the dam) to first recorded approach at an entrance, first entry into the fishway, and passage from the top of the ladder were 2.4 h, 4.8 h, and 1.2 d (Figure 73). Most fish entered the fishway within 6 to 18 h after passing the tailrace receiver, but several fish took up to 6.75 d to pass the dam because they spent 1 d or more in the fishway or spent time exiting and reentering the fishway. Some fish were in the fishway at nightfall and usually stayed there until morning, and some fish spent time migrating up and down the powerhouse collection channel during daylight (Figure 74). Passage times between the tailrace and passage from top of the ladder also included time some fish used when they exited the fishway via an entrance, moved into the tailrace, then reentered the fishway, and delays associated with operation of the trap located in the ladder by National Marine Fisheries Service personnel.

Steelhead had a tendency to first approach the dam at NPE-3 or OG-1, although 28 of 244 fish first approached OG-4 (Figure 75). Turbine operation was low in the fall and alternated between the northern and southern ends of the powerhouse as part of the turbine priority test. First approaches at NPE-3 is an indication that significant numbers of fish moved toward the dam in midchannel, north of the powerhouse, perhaps circled through the spillway stilling basin, and passed by the NPEs before entering the fishway.

When all approaches at fishway entrances were considered, most approaches were along the powerhouse entrances, OG-1, and OG-4 (Figure 75). The large number of approaches to entrances (averaged 18 per fish, 4,526 total) is an indication that steelhead moved back and forth along the dam before entering the fishway. Twenty-one of the 244 steelhead monitored approached the dam only once, and 119 (49%) steelhead approached the dam 1 to 10 times, but several fish approached various entrances 50 or more times (Figure 76). Although steelhead moved back and forth along the dam and approached the entrances several times, the time between first approach and first entry into the fishway was 2.4 h (based on median passage times, Figure 73).

A majority of first and repeated entries into the fishway occurred at SSE-2 and the NPEs (Figure 77), whereas many first approaches at the dam were at NPEs, OG-1, and OG-4 (Figure 75). Although fish approached orifice-gate entrances, relatively few entered the fishway through those openings. Location of operating turbines was an important factor in where
Figure 72. Net number of first and total exits from each fishway entrance by steelhead at Lower Granite Dam in fall 1993. See Figure 64 for location of entrances.
Figure 73. Number of steelhead and days to passage from the Lower Granite Dam tailrace to first approach at a fishway entrance, first entry into fishway, and passage from the top of the ladder in fall 1994.
Fish approached the dam, but not the only
factor, as illustrated by higher than
average numbers of fish that approached
the dam and entered NPE-3, where there
was no attractive flow other than that
coming from the fishway. Discharge from
NPE-3 may have been easier for
steelhead approaching the dam to find
and follow because the discharge was into
the spillway stilling basin when there was
no spill.

Of the 244 steelhead monitored at
Lower Granite Dam in 1994, five did not
enter the fishway. Of the fish that entered,
133 (55.6%) entered the fishway at Lower
Granite Dam only once (Figure 78) and
the remainder exited and reentered the
fishway from 1 to 11 times. Median
entrances and exits per fish were one and
zero for steelhead at Lower Granite Dam
in 1994.

Steelhead exited the fishway via all
entrances, but more did so at SSEs,
NPE-1, and NPE-2 than at other
entrances (Figure 79). A high exit rate
was previously observed at the NPEs at
Lower Granite Dam (Turner et al. 1984).
Many fish moved downstream in the
fishway after entering the transition pool
located at the bottom of the ladder, and
may or may not have exited during this
trip. Net entry rates (known entrances
minus exits) for fishway entrances ranged
from -8 to 32 for first entries and exits, and
-20 to 60 for all entries and exits (Figure
80). The SSE-2 was the most effective

Figure 74. Illustration of the types of movements made by some steelhead in fall
1994 when approaching Lower Granite Dam, entering and exiting the fishway, and
passing through the fishway.

Figure 74: Illustration of the types of movements made by some steelhead in fall
1994 when approaching Lower Granite Dam, entering and exiting the fishway, and
passing through the fishway.
Figure 75. Number of first and total approaches by steelhead at Lower Granite Dam fishway entrances in fall 1994. See Figure 64 for location of entrances.
entrance followed by NPEs. There were more exits than entries by steelhead at NSE and SSE-1.

**Chinook salmon 1993.** - Summary information on fishway entrance use and passage by chinook salmon in 1993 is presented in this report so that passage information for both salmon and steelhead would be readily available for comparison. Detailed analyses of chinook salmon passage through fishways was reported in Bjornn et al. (1995). Entrances used and movements within the fishways at Lower Granite Dam in 1993 were monitored by recording movements of 321 chinook salmon outfitted with transmitters. Median passage times of chinook salmon from the tailrace receiver (about 2 km downstream from the dam) to first recorded approach at an entrance, first entry into the fishway, and passage from the top of the ladders were 0.7 h, 1.9 h, and 27.6 h (Figure 81).

Chinook salmon in 1993 had a tendency to first approach Lower Granite Dam at NPE-2, with more limited first approaches at SSE-1 and OG-10. Total approaches for chinook salmon were relatively higher at the south end of the powerhouse than for steelhead, but most were at OG-10, NPE-2, OG-7, and OG-1 (Figure 82). Chinook salmon also made more approaches to the dam than steelhead, a median of 25 approaches per

Figure 76. Number of steelhead approaching fishway entrances one or more times at Lower Granite Dam in fall 1994.
Number of entrances by steelhead

First entrances into fishway
n = 239 fish

All entrances into fishway
n = 239 fish
Mean = 2.1/fish
Total entrances = 501

Figure 77. Number of first and total entries by steelhead into the Lower Granite Dam fishway in fall 1994. See Figure 64 for location of entrances.
Figure 78. Frequency distributions of total number of entries (top) and exits (bottom) into or from the fishway at Lower Granite Dam by steelhead in fall 1994. Fish that passed over the dam with unknown number of entries were listed as zero entries.
Figure 79. Number of first and total exits from fishway for each entrance by steelhead at Lower Granite Dam in fall 1994. See Figure 64 for location of entrances.
Entrances minus exits by steelhead

Figure 80. Net number of first and total exits from each fishway entrance by steelhead at Lower Granite Dam in fall 1994. See Figure 64 for location of entrances.
Figure 81. Number of chinook salmon and days to passage from the Lower Granite Dam tailrace to first approach at a fishway entrance, first entry into fishway, and passage from the top of the ladder in spring and summer 1993.
Figure 82. Number of first and total approaches by chinook salmon at Lower Granite Dam fishway entrances in spring and summer 1993. See Figure 64 for location of entrances.
fish for chinook salmon versus 9 per fish for steelhead.

Entrances to the Lower Granite fishway used by chinook salmon in 1993 for first-time and total entries were concentrated at the NSE, SPEs, and NPEs (Figure 83). Although fish approached orifice-gate entrances, relatively few entered the fishways through those openings. Orifice-gate entrances were used less than others because of their lower capacity (design of 60-80 cfs), mixing of discharges with those from turbines, and smaller size and shallower depth of orifice-gate openings. The NPEs were 1.83 m wide and 2.44 m deep and discharged 620 cfs. Orifice-gate entrances at Lower Granite Dam were 0.61 m high and 1.83 m wide, with the center of the opening 1.22 m below the surface. There were two SSEs, each 1.22 m wide and 2.44 m deep, with a total discharge of 400 cfs. The NSE was made up of two openings, 1.83 m wide and 2.14 m deep, with a total discharge of 560 cfs.

Net entry rates (entries minus exits) for chinook salmon at Lower Granite Dam in 1993 were positive for all entrances except the SSE and NPEs (Figure 84). For first entries and exits, SSE-2, OG-1, NPE-2, and NSE had the highest net number of entries. For all entrances and exits, SSE-2 and OG-1 were most effective. The least effective entrance for salmon in 1993 was SSE-1 which had many more exits than entries.

Discussion

Adult chinook salmon and steelhead approached fishways at lower Snake River dams at all available entrances, but entered and exited mostly at the largest (in size and discharge) entrances. The largest entrances to the fishways were located at both ends of the powerhouse collection channels and at entrances on the spillway side of the dams. Relatively few fish used the smaller orifice-gates to enter or exit the fishways.

Steelhead that approached the powerhouses in the fall were probably attracted by turbine discharges as indicated by the large number of first approaches along the powerhouse. Many steelhead first approached fishways at the powerhouse entrances closest to the spillways, an indication that significant numbers of fish moved toward the dams on the opposite side of the river from the powerhouse, then passed through the spillway stilling basins, and passed by the entrances at the midriver end of the powerhouses before entering the fishways.

We successfully monitored fishway entrance use by steelhead outfitted with radio transmitters first at Lower Granite Dam in fall 1992. Powerhouse discharge was south priority configuration (turbines one, then two, then three if needed) as established by the Fish Passage Plan. In 1992, more than half of the approaches by steelhead were along the south half of the powerhouse (Figure 38 in Bjornn et al. 1994). In 1993 and 1994, powerhouse discharge priorities alternated between northern and southern ends of the powerhouses at each of the lower Snake River dams (see Part IV of the final report for results of turbine priority tests). There was lower use of entrances along the south half of the powerhouse and higher use of the northern entrances at Lower Granite Dam in 1993 and 1994, as
Figure 83. Number of first and total entries by chinook salmon into the Lower Granite Dam fishway entrances in spring and summer 1993. See Figure 64 for location of entrances.
Figure 84. Net number of first and total exits from each fishway entrance by chinook salmon at Lower Granite Dam in spring and summer 1993. See Figure 64 for location of entrances.
compared to entrance use in 1992. The distribution of approaches at other dams during 1993 and 1994 were similar to the distribution observed at Lower Granite Dam during 1992.

Steelhead approached the Lower Granite Dam fishway an average of 51 times in 1992, but only 17 and 18 times in 1993 and 1994, and from 14 to 20 times in 1993 and 1994 at the other Snake River dams. Seventeen percent of all the steelhead that approached the Lower Granite Dam fishway in 1992 did so 10 times or less (Bjornn et al. 1994; Figure 39), and the percentages increased to 57% and 49% in 1993 and 1994. At the other dams in 1993 and 1994, 53% to 62% approached the dam 10 times or less, with the exception of Ice Harbor Dam in 1993 (17%).

Fewer steelhead approached at spillway ladder entrances at Ice Harbor and Lower Monumental dams, or the NSEs at Little Goose and Lower Granite dams, as compared to approaches at the other entrances. Approaches to spillway ladder entrances at Ice Harbor and Lower Monumental dams were higher in 1994 than in 1993, perhaps because of the 1.1 kcfs from the spillbay adjacent to these entrances (2- of 4-d blocks, from 0500-2000 h, during fall 1994).

Median time for steelhead to first approach each of the fishways was 1.0 to 2.4 h at all dams in all years, except at Lower Granite Dam in 1992 where it was 3.4 h (Table 1). During the later years, median time to first enter fishways was 1.9 to 3.4 h at Ice Harbor, Lower Monumental, and Little Goose dams and 4.8 to 5.5 h at Lower Granite Dam. Median time to pass over the dams was 10 to 13.4 h each year at Ice Harbor, Lower Monumental, and Little Goose dams, except in 1993 when median passage time at Ice Harbor Dam was 19 h. At Lower Granite Dam, median time for steelhead with transmitters to pass over the dam was longer (27.1 to 31.7 h) because they were diverted into the adult trap (Table 1).

Steelhead used a more limited number of entrances to enter fishways than those they approached. Steelhead approached and entered all entrances, but most entries were at entrances on either end of the powerhouse and at the spillway ladder entrances at Ice Harbor and Lower Monumental dams. North-shore entrances at Little Goose and Lower Granite dams were not used to enter the fishways as much as the NSE at Ice Harbor Dam and SSE at Lower Monumental Dam. Fish made an average of two to four entries into fishways before passing the dams, except at Ice Harbor Dam in 1993 when fish made an average of six entries. In 1993 and 1994, 43% to 59% of the steelhead exited the fishway into the tailrace at least once, except at Ice Harbor Dam in 1993 when 71% did so. Only 36% of the steelhead exited the Lower Granite Dam fishway in 1992. The average number of exits by steelhead ranged from 1.9 to 4.9 times at the four dams in 1993 and 1994. The maximum number of exits recorded by a single fish at a dam was 63 at Ice Harbor Dam in 1993. That fish also exited nine times at Lower Monumental Dam and was then captured by an angler at Little Goose Dam. Another high-exit fish had 45 exits at Ice Harbor Dam then had 31, 15, and zero exits at Lower Monumental, Little Goose, and Lower Granite dams, and was last recorded in the Middle Fork of the Salmon River. Most steelhead exited from
the powerhouse collection channels back into the tailrace from entrances closest to the bottom of the ladder and entrances at the midriver end of the powerhouses. Some fish exited via the spillway ladder entrances at Ice Harbor and Lower Monumental dams and the NSEs at Little Goose and Lower Granite dams, but relatively few exited via the orifice-gate openings.

Chain-link fishway fences were installed at Little Goose and Lower Granite dams in fishways prior to the 1991 migration season to deter fish from leaving the fishway via NPE-1 and NPE-2 while traveling upstream past these sites. We did not monitor fishway entrance use of steelhead successfully in 1991, but did monitor their movements successfully in 1992 at Lower Granite Dam. Despite the fishway fence at Lower Granite Dam, we found that many steelhead exited the fishway via NPE-1 and NPE-2 in 1992, the first year we used SXR/DSP receivers to monitor movements in the fishway. More than half of the steelhead entered the transition pool at the bottom of the ladder turned around and swam back downstream in the collection channel. If they traveled as far as the NPEs and were on the tailrace side of the collection channel, they could be guided by the fence to the NPEs, the opposite effect of

Table 1. Median times (h) for steelhead and chinook salmon to first approach dams, first enter into fishways, and exit from the top of fish ladders from 1991-1994. (Number of fish in parenthesis.) Passage times at Lower Granite Dam are for fish diverted into the adult trap in the fish ladder. Undiverted fish probably had passage times similar to those at the other dams.

<table>
<thead>
<tr>
<th></th>
<th>Ice Harbor</th>
<th>Lower Monumental</th>
<th>Little Goose</th>
<th>Lower Granite</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Median time to first approach dam (h):</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SH-1992</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>3.4 (221)</td>
</tr>
<tr>
<td>SH-1993</td>
<td>1.7 (268)</td>
<td>2.2 (200)</td>
<td>1.0 (194)</td>
<td>1.2 (144)</td>
</tr>
<tr>
<td>SH-1994</td>
<td>1.2 (231)</td>
<td>1.7 (224)</td>
<td>1.0 (218)</td>
<td>2.4 (175)</td>
</tr>
<tr>
<td>CK-1993</td>
<td>1.2 (152)</td>
<td>1.9 (277)</td>
<td>0.7 (296)</td>
<td>0.7 (281)</td>
</tr>
</tbody>
</table>

| **Median time to first entry (h):** |            |                  |              |               |
| SH-1992              | -----      | -----            | -----        | 5.5 (182)     |
| SH-1993              | 2.2 (305)  | 3.4 (176)        | 1.7 (187)    | 4.8 (147)     |
| SH-1994              | 1.9 (238)  | 2.4 (209)        | 2.2 (216)    | 4.8 (171)     |
| CK-1993              | 2.6 (149)  | 4.6 (271)        | 3.9 (273)    | 1.9 (269)     |

| **Median time to exit ladder (h):** |            |                  |              |               |
| SH-1991              | 48.0 (117) | 19.2 (230)       | 12.0 (114)   | 26.4 (119)    |
| SH-1992              | 62.4 (104) | 19.2 (301)       | 14.4 (304)   | 27.1 (191)    |
| SH-1993              | 19.0 (276) | 13.4 (186)       | 12.0 (182)   | 31.7 (136)    |
| SH-1994              | 12.0 (224) | 12.0 (197)       | 10.6 (213)   | 28.8 (169)    |
| CK-1991              | 129.6 (195)| 16.8 (193)       | 19.2 (212)   | 38.4 (213)    |
| CK-1992              | 28.8 (440) | 9.6 (429)        | 4.8 (436)    | 31.2 (350)    |
| CK-1993              | 20.6 (163) | 18.0 (281)       | 14.4 (288)   | 27.6 (265)    |
that intended by installation of the fences. For 1993, the fence was removed from the Lower Granite Dam fishway and left in place at Little Goose Dam. First and total exits were similar at the NPEs at both dams in 1993 with the most exits at NPE-2, NPE-1, and NPE-3 in declining order (Figures 50 and 71). For 1994, the fishway fence at Little Goose Dam was modified so that there was less chance for fish to be guided out of NPE-1 or NPE-2 by the fence. Exits at the Lower Granite Dam NPEs in 1994 were similar to those in 1993, but at Little Goose Dam first and total exits were reduced at NPE-1 and NPE-2 and slightly increased at NPE-3 and the NSE (see Part VI of final report for results of the fishway fence study).

Most fishway entrances had more entries than exits throughout the study. The SSEs at Ice Harbor, Little Goose, and Lower Granite (SSE-2) dams, and the SSL at Lower Monumental Dam had the highest net entrance use (entries minus exits) each year. North-powerhouse entrances at Little Goose Dam had a minimum of 55 more entries than exits in 1994 (with modified fence), and there were 27 to 43 more entries than exits at Lower Granite Dam in 1994 (no fence). Spillway ladder entrances at Ice Harbor and Lower Monumental dams had 50 to 75 more entries by steelhead than exits both in 1993 and 1994, but 75 and 10 more fish exited than entered the NSEs at Little Goose and Lower Granite dams. The NPEs at Ice Harbor Dam and SPEs at Lower Monumental Dam had more steelhead exiting than entering. Both entrances faced into the tailrace and, unlike those at Little Goose and Lower Granite dams, were the last available entrances to the collection channel for fish traveling downstream. Neither collection channel at Ice Harbor or Lower Monumental dams had an open entrance facing into the spillway stilling basin, as existed at Little Goose and Lower Granite dams. Orifice gates at each dam generally received 15 to 30 more entries than exits.

**Chinook salmon 1993.** - Summary information on fishway entrance use and passage by chinook salmon in 1993 is presented in this report so that passage information for both chinook salmon and steelhead would be readily available for comparison. Detailed analyses of chinook salmon passage through fishways was reported in Bjornn et al. (1995). Chinook salmon approached, entered, and exited fishways at lower Snake River dams via all available entrances; but like steelhead, chinook entered and exited mostly at the largest entrances at both ends of the powerhouse collection channels and at entrances on the spillway side of the dams. There was comparatively little use of spillway ladder entrances and orifice-gates by chinook salmon.

Median times for chinook salmon to approach the fishway entrances were similar to those for steelhead (0.7 to 1.9 h, Table 1). Median times to enter the fishway were higher for chinook salmon than for steelhead at the three lower dams, and were about the same at Lower Granite Dam (27.6 h). Passage times at Lower Granite Dam included time when fish were diverted into the adult trap in the fish ladder. Undiverted fish probably had passage times similar to those at the other dams. Median passage times for chinook salmon from the tailrace to passage out of the top of the ladders at the three lower dams were higher than for steelhead, perhaps because of high flows and spills in 1993 (Table 1).
Chinook salmon approached Ice Harbor and Little Goose fishways an average of 30 to 35 times (medians 16 and 17), and approached fishways at Lower Monumental and Lower Granite dams an average 52 and 58 times (medians 25 and 39) in 1993. Chinook salmon first approached the fishways most often at shoreline and midriver ends of powerhouses, but many first approaches occurred at orifice gates. At Ice Harbor Dam, OG-2 had a high frequency of first approaches; at Lower Monumental Dam the highest frequencies were at OG-1 and OG-3; and at Lower Granite Dam OG-10 had a high frequency of first approaches. When total approaches to the fishway were considered, including approaches after fish exited into the tailrace, all entrances had a high frequency of approach, an indication of the lateral movements of salmon in the tailraces.

First and subsequent entries by chinook salmon were predominately at the larger shoreline and powerhouse entrances. At Ice Harbor Dam, the SSE and NPEs had the most total entries, followed closely by the NSE. At Lower Monumental Dam, SSE and SPE were most used, followed by the NSE. The SSE was most used at Little Goose Dam, although the NSE and NPEs were also used frequently. At Lower Granite Dam, SSE and NPE were most used to enter the fishway.

Most chinook salmon exited from the powerhouse collection channels at entrances near the shorelines and the large entrances at the midriver end of the powerhouse. The average number of exits by salmon ranged from 2.3 to 4.0 times at the four dams in 1993, about the same exit rate as steelhead. At Ice Harbor Dam, most exits occurred at the NPE and secondly at SSE. At Lower Monumental Dam, most exits were at the SSE, SPE, and NSE. Most exits at Little Goose and Lower Granite dams were at the SSE, but NPEs were also used frequently to exit the fishways.

The most effective entrances (highest entrance/exit ratio) varied among dams, but were usually the shoreline entrances. The NSE and OG-1 were most efficient, and the NPE was least effective at Ice Harbor Dam (more exits than entries). At Lower Monumental Dam, SSE, NSE, and OG-9 were most effective, while SPE-2 was least effective. At Little Goose Dam, SSE and NSE were most effective, and NPEs were least effective. The SSE-2, OG-1, and NPE-2 were the most effective entrances at Lower Granite Dam, and both SSE-1 and NPE-1 had more exits than entries.
References


