TURBINE PRIORITY AND ITS EFFECTS ON PASSAGE OF STEELHEAD AT SNAKE RIVER DAMS

Part IV of final report for

MIGRATION OF ADULT CHINOOK SALMON AND STEELHEAD PAST DAMS AND THROUGH RESERVOIRS IN THE LOWER SNAKE RIVER AND INTO TRIBUTARIES

by


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Preface

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 salmon and steelhead.

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

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Abstract

Tests were conducted in 1993 and 1994 to evaluate the effect of turbine unit operation patterns on passage of steelhead at Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dams on the lower Snake River. Steelhead outfitted with radio transmitters were monitored to determine where they first approached the dams, entrances first used, and total time used to pass the dams while turbine operation was alternated from one end of the powerhouse to the other (turbine priority treatments). We found that median times for steelhead to first approach and to first enter into the fishways at the four dams were similar for all turbine priority treatments, and steelhead mostly used the same entrances to enter fishways regardless of turbine operation. We concluded that the turbine priority treatments tested had little, if any, influence on the time for steelhead to approach, enter, or pass through the fishways.
Introduction

Turbine priority tests were conducted in 1993 and 1994 to determine if fishway entrance use by steelhead *Oncorhynchus mykiss* was related to turbine unit operation. Moreover, if fish could be attracted to specific fishway entrances by turbine discharge, would they enter fishways where they first approached the dam, and was there an advantage to entering fishways at one end of the powerhouse or the other in terms of time required to pass dams after entering the fishways.

A priority of use schedule was set up for the turbines in each powerhouse at Snake River dams to alternate turbine operation daily from one end of the powerhouse to the other. Entrances of the fishways approached and entered by adult steelhead with transmitters was monitored and compared with unit operation in the powerhouse. During the summer and fall, flows in the Snake River are usually low enough to be passed through one to three turbines. At Snake River dams, when flows are low, water is normally passed through the turbines nearest the riverbank end of the powerhouse (southern end at Ice Harbor, Little Goose, and Lower Granite dams, and northern end at Lower Monumental Dam) to provide attraction flows for the main fishway entrances on the riverbank. If location of operating turbine units did not affect the success of passage by adult salmon and steelhead, then turbine use could be scheduled as needed to prevent overuse of some turbines.

Methods

Tests were conducted in 1993 and 1994 to determine if the passage of steelhead outfitted with radio transmitters was affected by turbines that were operated at the Snake River dams. In 1993, turbine operation was alternated daily between the north-priority (turbine 6, then 6 and 5, then 6, 5, and 4 if required at Ice Harbor, Little Goose, and Lower Granite dams; turbine 1, then 1 and 2, then 1, 2, and 3 if required at Lower Monumental Dam) and the south-priority (turbine 1, then 1 and 2, then 1, 2, and 3 at Ice Harbor, Little Goose, and Lower Granite dams; turbine 6, then 6 and 5, then 6, 5, and 4 if required at Lower Monumental Dam) from 7 July to 30 November. Test hours were 0400 - 2000 h. Turbine operation switched to the nighttime priority for juveniles (turbines 4-6 at Lower Granite, Little Goose, and Ice Harbor dams, as identified in Fish Passage Plan) at 2001 h and continued until 0359 h the next morning.

In 1994, at Lower Granite and Little Goose dams, turbine priorities were alternated between the regular south priority (turbine 1, then 1 and 2, then 1, 2, and 3 if required), an alternate south priority (turbine 2, then 2 and 3 if required) and the north priority (turbine 6, then 6 and 5, then 6, 5 and 4 if required). At Lower Monumental and Ice Harbor dams, there was a concurrent study to determine if spilling 1.1 kcfs from the spillbay adjacent to the south and north ladders, respectively, would attract more adult steelhead to those ladders. To avoid a potential interaction with the results of the spill study, turbine operation alternated between the north priority (turbine 1, then 1 and 2, then 1, 2 and 3 if required) and an alternate north priority (turbine 2, then
2 and 3) at Lower Monumental Dam. Turbine discharges were alternated between the two priorities for two consecutive days within 6 d blocks from 16 September to 30 November. The order of turbine priorities during each block was randomly selected. The turbine priority test at Ice Harbor Dam in 1994 was aborted because of many protracted turbine outages.

During the test period each year, we collected hourly average turbine discharge for each dam. Powerhouse operators were successful in keeping powerhouse operations within the schedule most of the time, with exceptions as noted.

We would expect to observe a preponderance of fishway entrance use (approaches and entries) near operating turbines if the discharge from operating turbines affects where adult steelhead first approach and enter fishways. To assess whether steelhead respond to shifting powerhouse operation we determined which entrance to the fishway fish first approached and first entered. We chose the first approach and first entrance to the fishway because most adult salmon and steelhead make repeated approaches to the fishway before entering, and often exit and re-enter the fishway at least once before passing the dam (Bjornn et al. 1994, 1995). The location and time required to first approach the dam seemed more related to tailrace conditions and turbine unit operation than subsequent events. From time and location of the first entrance to the fishway, we determined how soon after the first approach a fish first entered the fishway and whether they entered the fishway in the same area they first approached or if they searched for a different entrance. We used median time for fish to first enter the fishway and time to pass a dam after first entering the fishway to evaluate whether shifting entrance use in response to turbine use had a negative effect on time to pass a dam.

Data were collected as steelhead outfitted with radio transmitters passed within the range of antennas that were connected to the SRX and DSP/SRX receivers, as described in Part I of the final report. Records were compiled for each fish passing the dams to determine the date and time it entered the tailrace, and the date, time, and location it first approached and first entered the fishway and exited the top of the ladder. The fishway entrance first approached and first entered by each fish was matched with the turbine units operating at the time and categorized as to whether the fish had been exposed to one or more treatments (turbine priority treatments) in the tailrace before they approached or entered the fishway. For example, a fish that entered the tailrace at 1200 h, first approached the dam at 1300 h, and first entered the fishway at 1400 h was only exposed to one turbine priority. On the other hand, a fish that entered the tailrace at 1900 h, first approached the dam at 2200 h, and first entered the fishway the next morning at 0700 h was in the tailrace long enough to be exposed to more than one treatment (the turbine priority on the first day, the nighttime priority, and the turbine priority on the second day). A fish could enter the tailrace and first approach the dam during one treatment but not enter the fishway for several hours, potentially exposing the fish to more than one turbine priority condition in the tailrace before entering the fishway. In this example, the fish was in the tailrace during one treatment when it first approached the fishway, but was exposed to another discharge when it entered the
fishway. Our results include only those fish that first approached and first entered the fishway during one treatment. Time to pass the dam after first entering the fishway was calculated as the difference from when a fish first entered the fishway (and was assigned the existing turbine priority) to when it exited the top of the ladder.

To help put results from the 1993 and 1994 tests in perspective, receivers with underwater antennas were used to monitor entrance use at the Lower Granite Dam fishway by steelhead outfitted with radio transmitters in 1992. Daytime (0400 - 2000 h) turbine operations at Lower Granite Dam in 1992 was turbine 1, then 1 and 2, then 1, 2, and 3; whereas the nighttime priority was turbines 6, 5, or 4 in any order (2000 - 0400 h) (U.S. Army Corps of Engineers Fish Passage Plan). In 1992, 56% of the known first approaches (n = 343 fish) occurred between south-shore entrance-1 and orifice gate-4 (south priority) and 43% from orifice gate-7 to north powerhouse entrance-3 (north priority, Figure 38 in Bjornn et al. 1994). Almost 19% of the 343 fish approached the dam first at north powerhouse entrance -3, an indication that some of the steelhead traveled up the northern edge of the powerhouse discharge as they approached the dam. Seven fish first approached the dam at the north-shore entrance, an indication that most fish stayed within the powerhouse discharge and did not move up along the wall of the navigation lock where the only flow was from the north-shore entrance.

About 53% of the fish first entered the Lower Granite Dam fishway in 1992 between south-shore entrance-1 and orifice gate-4 and most of those were at south-shore entrance-2 (Figure 40 in Bjornn et al. 1994). Almost 30% of the fish first entered the fishway between orifice gate-7 and NPE-3, and 18% entered at the north-shore entrance.

First approaches to the southern half of the fishway (south-shore entrance-1 to orifice gate-4) by steelhead outfitted with radio transmitters in 1992 were spread equally at all entrances, but first entries to the fishway were concentrated at south-shore entrance-2 (Figures 38 and 40 in Bjornn et al. 1994). Along the northern end of the powerhouse, the proportions of fish first approaching the fishway was similar to those first entering at each of those entrances. Only 1% of the first approaches to the fishway were at the north-shore entrance yet 18% of the first entrances were at that site.

**Results**

**Ice Harbor Dam - 1993**

Openings to the fishway along the southern half of the powerhouse at Ice Harbor Dam (turbines 1, 2, and 3) are the south-shore entrance and orifice gates 1, 2, 4, and 6, whereas the entrances along the northern half of the powerhouse (turbines 4, 5, and 6) are orifice gates 8, 10, and 12 and north powerhouse-2 (Figure 1).

Turbine unit operations at Ice Harbor Dam were scheduled to alternate daily between north or south priorities between 0400 - 2000 h each day from 7 July to 30 November for a total of 2,352 h. Because
Figure 1. Fishway entrances and location of antennas used at Ice Harbor Dam during 1993 and 1994 steelhead migration seasons.
of outages at one or more turbines, only 1,766 h met the criteria we established for either south or north priority. At Ice Harbor Dam in 1993, turbine unit operations met the north- or south-priority criteria if all operating units were from the northern or southern half of the powerhouse, and if a majority of the flow was from either the northern or southern half of the powerhouse (turbine units 1, 3, and 5 operating, for example, would be classed as meeting south priority). Whenever an equal number of turbines was used on both halves of the powerhouse, the criteria were not met. Criteria for south-turbine priority was met 64% of the time and the north priority 36% of the time (Figure 2). Turbines 2 and 4 were out of service the entire season. With one turbine out of service in both halves of the powerhouse neither treatment (north or south priority) had three turbines available when needed. Whenever an additional turbine outage occurred the operator usually had to use at least one turbine from the other half of the powerhouse. There were many temporary outages at the two available turbines in the northern half of the powerhouse, including turbine 6 being off-line all of November. Thus, turbines in the southern half of the powerhouse were used on days scheduled for north priority and there were fewer hours of test conditions for north-priority treatments. North-turbine priority was achieved only three to four times between 7 July and 20 August. River flows were greater than 50 kcfs requiring more than three turbines on-line from the start of the test period up to 18 August, but only one turbine on the northern end of the powerhouse was available much of the time through mid-August requiring the operator to use two turbines on the southern half of the powerhouse. River discharge dropped below 40 kcfs on 21 August requiring only two turbines to pass the river flow, allowing dam operators to meet criteria for turbine priority treatments.

Ten fish that passed the dam between 7 July and 20 August were included in the analysis. Two fish first approached and entered the fishway during north-turbine priority and eight during south-turbine priority. We included these fish in the analysis because the time they took to first approach and enter the fishway was similar to those of fish during the remainder of the sampling season.

Of the 1,127 h during the south-turbine priority, 40% was with one turbine operating and 60% with two turbines operating (Figure 3). The north-turbine priority was achieved for 639 h, 54% of that time with one turbine operating, 46% with two.

Receivers and antennas were reliable throughout the study season with the exception of gaps at receivers monitoring fish entering the tailrace on 11 and 19 October and 6-8 November, the top of the south ladder from 15-20 October, and north powerhouse entrance-2 from 24-30 November (Figure 4 in Bjornn et al. 1995). These outages reduced the number of fish recorded entering the tailrace and exiting from the top of the ladder at the respective times, and thus reduced the number of fish included in parts of the analysis.

**Time to pass the dam.**—Total median passage time from the tailrace to top of the ladder (calculated by summing the median time to first enter the fishway and time to exit the ladder after first entering
Figure 2. Periods of time when north- and south-turbine priorities occurred from 7 July - 30 November between 0400 - 2000 h at Ice Harbor Dam in 1993. A continuous line represents turbine operation that met test criteria for either north- or south-turbine priority.
Figure 2 continued.
Figure 3. Time for steelhead to pass Ice Harbor Dam after first entering the fishway during north- or south-turbine priority tests throughout the study season, and when one or two turbines were operating in 1993.
the fishway) for the whole season for steelhead first entering the fishway during south-turbine priority (67 fish) was 15.9 h, 4 h less than for steelhead first entering the fishway during north-turbine priority (59 fish). When one turbine was operating, total median passage time for fish first entering the fishway during the south-turbine priority (20 fish) was 19.6 h versus 11.6 h for those (12 fish) first entering the fishway during north-turbine priority. When two turbines were operating, median passage time was 13.1 h for fish first entering the fishway during the south-turbine priority (47 fish) and 20.3 h for those first entering during the north-turbine priority (47 fish).

Time to pass from first entry to exit at the top of a ladder was 14.2 h median time for 67 steelhead that entered during south-turbine priority (Figure 3). Only one fish failed to pass the dam in 3 d or less after first entering the fishway. For 59 fish first entering the fishway during a north-turbine priority, the median time from first entry to exit from the top of the ladder was 18.3 h. Most of the 59 fish that first entered the fishway during a north-priority test passed the dam in less than 3 d, but one fish took 18.1 d to pass the dam. When one turbine was operating, median entry-to-exit times for 20 fish that passed during the south-turbine priority was 18.4 h, and 10 h for 12 fish that first entered during a north-turbine priority. With two turbines operating, median entry-to-exit times for 47 fish that first entered the fishway during a south-turbine priority was 11.7 h, and was 18.7 h for 47 fish that entered the fishway during a north-turbine priority.

First approaches to fishway.
Throughout the season, 134 steelhead were exposed to a single treatment in the tailrace before first approaching the fishway (Figure 4). Of those, 52% first approached the dam during a south-turbine priority and 48% during the north priority. Fish that entered the tailrace and were first recorded at the dam during the south-turbine priority had a median time to approach of 1.3 h, the same as for those first approaching the dam during a north-turbine priority. All fish approached the dam within 7 h of entering the tailrace. Similar times to approach an entrance were observed for steelhead with one or two turbines operating (Figure 4).

When one turbine was operating, there were 104 more hours (30%) of the south-turbine priority than north-turbine priority, but almost twice as many fish first approached the fishway during the south-turbine priority as compared to the north-turbine priority. When two turbines were operating, there were about 2.3 times more hours of south-turbine priority operation than north-turbine priority, but almost equal numbers of fish first approached the fishway during both treatments.

For 61 fish with known first approach locations during the south-turbine priority, 52% first approached the entrances to the fishway along the southern half of the powerhouse. Forty-one percent first approached the four openings to the fishway along the northern half of the powerhouse, and 7% approached the north-shore entrance first (Figure 5). During the north-turbine priority, 63% of 52 fish (excludes the 12 fish with unknown approach locations) approached the fishway first along the southern half of the powerhouse.
Figure 4. Time for steelhead to first approach the Ice Harbor fishway from passage into the tailrace during north- or south-turbine priority tests throughout the study season, and when one or two turbines were operating in 1993.
Figure 5. Ice Harbor fishway entrances first approached by steelhead during north- or south-turbine priority tests throughout the study season, and when one or two turbines were operating in 1993.
powerhouse, 37% along the northern half, and none at the north-shore entrance.

When one turbine was operating during the south-priority treatments, 76% of the 21 fish with known approach locations first approached the fishway along the south half of the powerhouse, 24% along the north half, and none at the north-shore entrance (Figure 5). During the north-priority, 64% first approached the fishway along the south half of the powerhouse, and 36% along the north half.

When two turbines were operating during south-turbine priority, 40% of fish first approached the fishway along the southern half of the powerhouse, 50% along the northern half, and 10% at the north-shore entrance (Figure 5). During north-priority operation, 63% first approached along the southern half of the powerhouse and 37% approached the northern half first.

First entry into fishway.- Throughout the season, 126 steelhead were exposed to only one treatment in the tailrace before first entry into the fishway (Figure 6). Of those, 53% first entered the fishway during south-turbine priority and 47% during north-turbine priority. Median time for fish to first enter the fishway after passage into tailrace during the south-turbine priority was 1.7 h, 6 min longer than those first entering during the north-turbine priority. Fish took 18 and 24 min to first enter the fishway after they first approached during north- and south-turbine priorities.

When one turbine was operating, almost twice as many fish first entered the fishway during the south-turbine priority compared to the north-turbine priority (Figure 6). Median time for fish to first enter the fishway during a south-priority test was 1.2 h, 24 min faster than those entering during the north-priority test, however, there were only 12 fish that first entered the fishway during north priority. Fish first entering the fishway during south-turbine priority when two turbines were operating took 1.4 h, 12 min less than those entering during a north priority.

As with first approaches to the fishway by steelhead, more fish first entered the fishway along the southern end of the powerhouse, and especially at the south-shore entrance (Figure 7). Of the 67 fish that first entered the fishway during the south-turbine priority, 64% first entered the fishway along the southern half of the powerhouse, 30% along the northern half of the powerhouse, and 6% first entered at the north-shore entrance. About 69% of the 59 fish first entering the fishway during a north-turbine priority did so along the southern half of the powerhouse, 25% along the northern half, and 5% at the north-shore entrance.

When one turbine was operating, most of the 20 fish (85%) that first entered the fishway during a south-priority test did so along the southern half of the powerhouse and the remaining 15% entered along the northern half (Figure 7). During north-turbine priority, 5 of 12 fish first entered the fishway at the southern half of the powerhouse and the rest entered along the northern half. When two turbines were operating during south-turbine priority, 55% of the 47 fish first entered along the southern half of the powerhouse, 36% along the northern half, and 9% entered the north-shore entrance. During north priority, 77% of 47 fish first
Figure 6. Time for steelhead to first enter the Ice Harbor fishway during north- or south-turbine priority tests throughout the study season, and when one or two turbines were operating in 1993.
Figure 7. Ice Harbor fishway entrances first entered by steelhead during north- or south-turbine priority tests throughout the study season, and when one or two turbines were operating in 1993.
entered along the southern half of the powerhouse, 17% along the northern half, and 6% at the north-shore entrance.

**Lower Monumental Dam - 1993**

Openings to the fishway along the southern half of the powerhouse at Lower Monumental Dam (turbines 4, 5, and 6) are south powerhouse entrances 1 and 2, and orifice gates 9 and 7 (Figure 8). Orifice gates 5, 3, and 1 and the north-shore entrance are open along the northern half of the powerhouse (turbines 1, 2, and 3).

Turbine unit operations at Lower Monumental Dam were scheduled to alternate daily between north- and south-priority treatments between 0400 - 2000 h each day from 7 July to 30 November. At Lower Monumental Dam, turbine operations met the criteria for north or south priority during 2,052 h of the available 2,352 h (Figure 9). South-turbine priority was in effect 64% of the time and north-turbine priority 36%. The large time for south priority was primarily the result of turbine 3, on the northern half of the powerhouse being out-of-service the entire season. Only turbines 1 and 2 were available for north-priority tests and turbines 4, 5, and 6 for south-priority tests. When river flows were sufficient to require three turbines, the north-priority criteria could be maintained with two turbines on the northern half of the powerhouse and one turbine on the southern half, however, when the flow required four turbines, the discharge was split into equal discharge from both ends of the powerhouse and the data were not used. Additional disruptions occurred when the remaining turbines in the northern half of the powerhouse were temporarily out-of-service. Powerhouse discharge was split between the northern and southern halves when river flow required two turbines and one of the remaining two north turbines was temporarily out-of-service. Turbine 2 was off-line for annual maintenance from 1 September to 13 October. Powerhouse discharge fluctuated between 15 and 52 kcfs through September and October, and with only one turbine available in the northern end of the powerhouse, south-turbine priority was operating a majority of the time. Turbine priorities alternated as scheduled from 11 October to 29 November because river flows dropped below 40 kcfs and turbine two was back on-line starting 13 October.

Of the 1,317 h during the south-turbine priority, 37% was with one turbine operating, 39% with two turbines, and 24% with three turbines (Figure 10). The north-turbine priority was tested for 735 h, 57% of the time was with one turbine operating and 43% with two turbines operating.

Receivers and antennas were reliable throughout the study season with the exception of gaps at receivers monitoring the tailrace from 27 September to 3 October, the top of the north ladder from 15-20 October, and orifice gates-3 and -5 from 22-30 November (Figure 4 in Bjornn et al. 1995). These outages reduced the number of fish recorded while entering the tailrace and exiting from the top of the ladder at the respective times, and thus reduced the number of fish included in parts of the analysis.

**Time to pass the dam**.- Total median passage time from the tailrace to the top
Figure 8. Fishway entrances and location of antennae used at Lower Monumental Dam during 1993 and 1994 steelhead migration seasons.
Figure 9. Periods of time when north- and south-turbine priorities occurred from 7 July - 30 November between 0400 - 2000 h at Lower Monumental Dam in 1993. A continuous line represents turbine use that met test criteria for either north- or south-turbine priority.
Figure 10. Time for steelhead to pass Lower Monumental Dam after first entering the fishway during the north- or south-turbine priority rest throughout the entire season, and when one, two or three turbines were operating in 1993.
of the ladder for steelhead first entering the fishway during a north-turbine priority (52 fish) was 9.2 h, 1.7 h less than those first entering the fishway during the south-turbine priority. When one turbine was operating, 24 fish first entering the fishway during north-turbine priority had a median time to pass the dam of 8.4 h, whereas those fish (n = 13) first entering the fishway during south-turbine priority did so in 9.4 h. When two turbines were operating, the median passage time was 10.2 h for fish (n = 15) first entering the fishway during the north-turbine priority and 22.1 h for those (n = 16) first entering during the south-turbine priority. Throughout the season, 52 steelhead that first entered the fishway during a south-turbine priority had a median passage time of 9.1 h from first entry into the fishway to exit from the top of the ladder (Figure 10). Forty-nine of 52 fish passed the dam in 3 d or less after first entering the fishway. Median time for 29 fish first entering the fishway during the north-turbine priority was 7.2 h to exit the top of the ladder after first entering. Most of the 29 fish that first entered the fishway during the north-turbine priority passed the dam in less than 3 d, but one fish took 57.5 d to pass the dam.

**First approaches to fishway.**
Throughout the season, 96 steelhead were exposed to a single treatment in the tailrace before first approaching the fishway (Figure 11). Of those, 66% first approached the dam during a south-turbine priority and 34% during north-turbine priority. Fish that entered the tailrace and first approached the powerhouse during south-turbine priority took 18 min longer (median) than fish that first approached during a north-turbine priority. Most fish approached the fishway within 6 h of entering the tailrace, although one fish took almost 11 h. Fish first approaching the fishway during the south-priority took 12 to 24 min longer than those first approaching during the north-turbine priority when one or two turbines were operating.

Of the 60 fish with known locations of first approach during a south-turbine priority, 52% first approached the entrances to the fishway along the southern half of the powerhouse (Figure 12). Forty-one percent first approached the four openings to the fishway along the north half of the powerhouse, and 6% were at the south-shore entrance. During north-turbine priority, 39% of 31 fish first approached the fishway (excludes two fish with unknown approach locations) along the southern half of the powerhouse, 58% along the northern half of the powerhouse, and 3% at the south-shore entrance.

When one turbine was operating during south-turbine priority, 52% of the 25 fish with known first approach locations did so along the southern half of the powerhouse, 40% along the northern half, and less than 1% were at the south-shore entrance (Figure 12). During north-turbine priority, 37% first approached the fishway along the southern half of the powerhouse, and 63% along the northern half.

When two turbines were operating during south-turbine priority, 57% of fish first approached the fishway along the southern half of the powerhouse, 33% along the northern half, and 10% at the south-shore entrance (Figure 12). No fish
Figure 11. Time for steelhead to first approach the Lower Monumental fishway after passage into the tailrace during north- or south-turbine priority tests throughout the study season, and when one, two, or three turbines were operating in 1993.
Figure 12. Lower Monumental fishway entrances first approached by steelhead during north- or south-turbine priority tests throughout the study season, and when one, two, or three turbines were operating in 1993.
first approached the north-shore entrance during either treatment.

**First entry into fishway.** - Throughout the season, 81 steelhead were exposed to only one treatment in the tailrace before first entry into the fishway (Figure 13). Of those, 64% first entered the fishway during a south-turbine priority and 36% during north-turbine priority. Median time for fish first entering the fishway during the north-turbine priority was 2.0 h after passing into tailrace area, 48 min faster than those first entering during a south-turbine priority, and 18 min after first approaching the fishway. Fish had median time of 36 min to enter the fishway after first approaching during south-turbine priority.

When one turbine was operating, twice as many fish first entered the fishway during the south-turbine priority as compared to the north-turbine priority despite a similar amount of time for each treatment (Figure 13). The median time for fish to first enter the fishway during a south priority was 1.9 h, 6 min longer than those entering during a north priority.

When two turbines were operating, median time to enter for fish first entering the fishway during a south-turbine priority was 2.5 h, 18 min longer than those entering during a north-turbine priority (Figure 13). Fish that first entered the fishway during the south-turbine priority when three turbine units were operating, did so in a median of 3.5 h which was 1 h longer than those first entering the fishway during a south priority when two turbines were operating, and 2 h longer than when one turbine was operating.

Although first approaches to the fishway by steelhead reflected the corresponding turbine priority (Figure 12), first entries to the fishway were concentrated at the south powerhouse entrances and the south-shore entrance during both turbine priorities (Figure 14). Of 47 fish (excluding five fish with unknown entrance locations) that first entered the fishway during south-turbine priority, 47% first entered along the southern half of the powerhouse, 23% along the northern half, and 30% at the south-shore entrance. Approximately 56% of the 25 fish approaching the fishway during north-turbine priority did so along the southern half of the powerhouse, 24% along the northern half, and 20% at the south-shore entrance.

When one turbine was operating, one-half of the 20 fish that first entered the fishway during the south priority did so along the southern half of the powerhouse, 30% along the northern half, and 20% at the south-shore entrance (Figure 14). During the north-turbine priority, seven of the 13 fish first entered the fishway at the southern half of the powerhouse, and two fish first entered at both the northern half of the powerhouse and the south-shore entrance.

When two turbines were operating, six of the 14 fish with known fishway entrances first entered along the southern half of the powerhouse, two along the northern half of the powerhouse, and six at the south-shore entrance (Figure 14). During the north-turbine priority, seven of 14 fish first entered along the southern half of the powerhouse, four along the northern half, and three at the south-shore entrance.
Figure 13. Time for steelhead to first enter the Lower Monumental fishway after passage into the tailrace during north- or south-turbine priority tests throughout the study season, and when one, two, or three turbines were operating in 1993.
Figure 14. Lower Monumental fishway entrances first entered by steelhead during north- or south-turbine priority tests throughout the study season, and when one, two, or three turbines were operating in 1993.
When three turbine units were operating during the south-turbine priority, six of the 13 fish first entered along the southern half of the powerhouse, three along the northern half, and four at the south-shore entrance (Figure 14).

**Lower Monumental Dam -1994**

In 1994, turbine priority tests were conducted from 16 September to 30 November, the period of time steelhead were trapped at Ice Harbor Dam and released at Hood Park downstream from the dam. Flows in the river during the test period were low and only required the operation of one or two turbines. The tests in 1994 were to assess fish passage with normal priority (turbine 1, then 1 and 2, then 1, 2, and 3), the north priority as in 1993, and an alternate north priority (turbine 2, then 2 and 3) to determine if passage was affected by not using turbine 1.

Turbine operations at the powerhouse were alternated on a 2 to 4 d schedule between north and alternate north priorities (turbine 2, then 3 if necessary) of turbine use between 0400 - 2000 h each day (Figure 15). Of the 1,199 h when criteria for the test were met, north-turbine priority was in effect 54% of the time and alternate north-turbine priority 46%. Of the 645 h of north-turbine priority, 81% was with one turbine operating, 18.9% with two turbines on-line, and 0.1% with three turbines (Figure 16). Alternate north-turbine priority was in effect for 554 h, 57% with one turbine operating and 43% with two turbines operating.

Receivers and antennas were reliable throughout the study season with the exception of gaps at receivers monitoring the north-shore entrance and orifice gate-1 from 22 October to 2 November, the top of the north ladder from 25 October to 2 November, and orifice gates-3 and -5 from 28-30 November. These outages reduced the number of fish recorded as they first approached and entered the north-shore entrance and orifice gate-1, and those exiting the top of the ladder, and thus reduced the number of fish included in parts of the analysis. The outage at orifice gates-3 and -5 occurred when few fish were passing the dam.

**Time to pass the dam.-** Throughout the season, steelhead that first entered the fishway during a north-turbine priority had a median time of 9.0 h to pass the dam after first passing the tailrace receiver, 0.1 h less than those first entering the fishway during alternate north-turbine priority. Most of the steelhead passed the dam when one turbine was operating during both priorities.

Time to pass the dam after first entering the fishway was the same (median of 7.2 h) for 62 steelhead that first entered the fishway during north-turbine priority and 47 fish during alternate north-turbine priority (Figure 16). The median time to exit the top of the ladder after first entering the fishway when one turbine was operating was the same as for the whole season because only one turbine was used during most of the test period. Most fish passed the dam in less than 3 d but a few took up to 5.3 d.

**First approaches to fishway.-** Throughout the season, 120 steelhead were exposed to only one treatment in the tailrace before first approaching the
Figure 15. Periods of time when north- and alternate north-priorities occurred from 16 September - 30 November between 0400 - 2000 h at Lower Monumental Dam in 1994. A continuous line represents powerhouse discharge that met test criteria for either north- or south-turbine priority.
Figure 16. Time for steelhead to pass Lower Monumental Dam after first entering the fishway during north- or alternate north-turbine priority tests throughout the study season, and when one, two, or three turbines were operating in 1994.
fishway (Figure 17). Of those, 57% first approached the fishway during north-turbine priority and 43% during alternate north-turbine priority. Median time for fish to first approach the fishway after entering the tailrace was 1.3 to 1.5 h during both treatments regardless of whether one, two, or three turbines were operating. Most fish first approached the fishway within 2 h of entering the tailrace, although a few took up to 6 h.

Where fish first approached the fishway was not affected by north- and alternate north-turbine priorities. During north-turbine priority, 27% of 64 fish with known locations first approached the dam along the southern half of the powerhouse, about 56% were along the northern half, and 17% at the south-shore entrance (Figure 18). During alternate north-turbine priority, 28% of 51 fish first approached the fishway (excludes one fish with an unknown approach location) along the southern half of the powerhouse, 53% along the northern half, and 19% were at the south-shore entrance.

Where fish first approached the fishway when one turbine was operating was virtually the same as that for the whole season because only one turbine was used during 82% of the test period. When one turbine was operating during north priority, 23% of 53 fish with known locations first approached the fishway along the southern half of the powerhouse, 58% along the northern half, and 19% at the south-shore entrance (Figure 18). During alternate north-turbine priority, 29% first approached the fishway along the southern half of the powerhouse, 54% along the northern half, and 17% at the south-shore entrance.

*First entry into fishway.* - Throughout the season, 109 steelhead were exposed to a single treatment in the tailrace before first entry into the fishway (Figure 19). Of those, 57% first entered the fishway during north-turbine priority and 43% during alternate north-turbine priority. The median time for fish to first enter the fishway during north-turbine priority was 1.8 h, 6 min faster than the median for fish first entering the fishway during alternate north-turbine priority.

Median time to first enter the fishway when one turbine was operating was virtually the same as that observed for the whole season. Median time for fish to first enter the fishway during north-turbine priority was 1.8 h, 6 min faster than those entering during alternate north-turbine priority (Figure 19). When two turbines were operating, median time to first entry was 2.1 h both priorities, 12 to 18 min longer than the time to first enter the fishway when only one turbine unit was operating.

Although first approaches all by steelhead occurred at fishway entrances, most approached at the northern end of the powerhouse (Figure 18). First entrances to the fishway, however, were concentrated along the southern end of the powerhouse (Figure 20). Of the 57 fish that first entered the fishway (excluding the five fish with unknown entrance locations) during north-turbine priority, 49% first entered along the southern half of the powerhouse, about 32% first entered along the northern half, and 19% at the south-shore entrance. Forty-six percent of 43 fish that first entered the fishway during alternate north-turbine priority entered along the southern half of the powerhouse, 21%
Figure 17. Time for steelhead to first approach the Lower Monumental fishway from passage into the tailrace during north- or alternate north-turbine priority tests throughout the study season, and when one, two, or three turbines were operating in 1994.
Figure 18. Lower Monumental fishway entrances first approached by steelhead during north- or alternate north-turbine priority tests throughout the study season, and when one, two, or three turbines were operating in 1994.
Figure 19. Time for steelhead to first enter the Lower Monumental fishway during north- or alternate north-turbine priority tests throughout the study season, and when one, two, or three turbines were operating in 1994.
Figure 20. Lower Monumental fishway entrances first entered by steelhead during north- or south-priority tests throughout the study season, and when one, two, or three turbines were operating in 1994.
along the northern half, and 33% at the south-shore entrance. The distribution of first entries to the fishway when one turbine was operating was virtually the same as that during the whole season.

**Little Goose Dam - 1993**

Openings to the fishway along the southern half of the powerhouse (turbines 1, 2, and 3) were south-shore entrance-1, and orifice gates-1, -4 and -6, whereas orifice gate-10 and north powerhouse entrances-1, -2 and -3 were open along the northern half of the powerhouse (Figure 21). The north powerhouse entrances were rotated between either -1 and -3 open, or -2 and -3 open, concurrent with the turbine priority test.

Unit operations were scheduled to alternate daily between north or south priorities of turbine use between 0400 - 2000 h each day from 7 July to 30 November. A total of 1,819 h met the criteria for north- or south-turbine priority (Figure 22). South-turbine priority was in effect 68% of the time and north priority 32%. The preponderance of time with south-turbine priority was primarily due to turbine 6 being out-of-service from July to November, turbine 4 off-line from 6 August to 9 September and turbine 5 out-of-service from 4 October to 30 November. Turbine priorities occurred as scheduled from 10 September to 4 October because river flows dropped below 40 kcfs and turbine 4 was back on-line on 10 September. However, turbine 5 went off-line on 5 October and river flows increased to more than 50 kcfs until 20 October, forcing the operators to use the three southern turbines. River flows decreased to 15 to 20 kcfs by 20 October and a few hours of north-turbine priority were achieved by 30 November.

Of the 1,233 h during the south-turbine priority, 36% was with one turbine operating, 63% with two turbines, and less than 1% with three turbines operating (Figure 23). North-turbine priority was tested for 586 h, 57% of the time was with one turbine, 32% with two turbines, and 1% with three turbines operating.

Receivers and antennas were reliable throughout the study season with the exception of gaps at receivers monitoring fish entering the tailrace from 24-26 August and 29 August to 3 September, orifice gates-6 and -10 on 20 September, the south-shore entrance and orifice gates-1 and -4 from 11-30 November, orifice gates-6 and -10 from 25-30 November, and the north powerhouse entrances from 17-30 November (Figure 4 in Bjornn et al. 1995). While those outages reduced the number of fish recorded when entering the tailrace and those first approaching and first entering the fishway at the respective sites, the outages occurred when relatively few fish were passing the dam.
Figure 21. Fishway entrances and location of antennae used at Little Goose Dam during 1993 and 1994 steelhead migration seasons.
Figure 22. Periods of time when north- or south-turbine priorities occurred from 7 July - 30 November between 0400 - 2000 h at Little Goose Dam in 1993. A continuous line represents turbine operation that met test criteria for either north- or south-turbine priority.
Figure 22 continued.
Figure 23. Time for steelhead to pass Little Goose Dam after first entering the fishway during north- or south-turbine priority tests throughout the season, and when one or two turbines were operating in 1993.
**Time to pass the dam.**- Total median passage time from the tailrace to the top of the ladder for steelhead first entering the fishway during a south-turbine priority (56 fish) was 6.0 h, 6.2 h less than for those fish (n = 19) first entering the fishway during north-turbine priority. When one turbine was operating, 12 fish first entered the fishway during south-turbine priority and passed the dam in a median time of 4.4 h, whereas those first entering the fishway during north-turbine priority (14 fish) did so in 13.0 h. When two turbines were operating, median time to pass the dam was 6.2 h for fish first entering the fishway during south-turbine priority and 7.2 h for those first entering during north-turbine priority.

Median passage time from first entry into fishway to passage over the dam for 56 steelhead that entered during south-turbine priority was 5 h (Figure 23). Fifty-three of 56 fish passed the dam in less than 3 d. Nineteen fish first entering the fishway during a north-turbine priority had a median time of 11 h to exit the top of the ladder. Most of the 19 fish that first entered the fishway during a north-turbine priority passed the dam in less than 1.5 d, but one fish took 8.1 d to pass the dam.

**First approaches to fishway.**- Throughout the season, 89 steelhead were exposed to a single treatment in the tailrace before first approaching the fishway (Figure 24). Of those, 74% first approached the fishway during the south-turbine priority and 26% during the north-turbine priority. Median time to first approach the fishway during a south-turbine priority was 36 min after passage into tailrace, 12 min faster than fish that first approached the dam during a north-turbine priority. All fish approached the dam within 3 h of entering the tailrace.

Of 62 fish with known locations that first approached the dam during a south-turbine priority, 42% first approached entrances along the southern half of the powerhouse, 40% first approached the four openings to the fishway along the northern half of the powerhouse, and 18% at the north-shore entrance (Figure 25). Of 22 fish (excludes one fish with an unknown approach location) first approaching the fishway during a north-turbine priority, 27% did so along the southern half of the powerhouse, 55% along the northern half, and 18% at the north-shore entrance.

When one turbine was operating during south-turbine priority, nine of 18 fish with known locations first approached the fishway along the southern half of the powerhouse, 33% along the northern half, and 17% at the north-shore entrance (Figure 25). During north-turbine priority, 19% first approached the fishway along the southern half of the powerhouse, 62% along the northern half, and 19% at the north-shore entrance.

When two turbines were operating during south-turbine priority, 39% of the fish first approached the south-shore entrance and orifice gate-1 or -6, 43% first approached along the northern half of the powerhouse, and 18% at the north-shore entrance (Figure 25). No fish exposed to one treatment in the tailrace approached first at orifice gate-4.

**First entry into fishway.**- Throughout the season, 75 steelhead were exposed to
Figure 24. Time for steelhead to first approach the Little goose fishway after passage into the tailrace during north- or south-turbine priority tests throughout the study season, and when one or two turbines were operating in 1993.
Figure 25. Little Goose fishway entrances first approached by steelhead during north- and south-priority tests throughout the study season, and when one or two turbines were operating in 1993.
a single treatment in the tailrace before first entry into the fishway (Figure 26). Of those, 75% first entered the fishway during a south-turbine priority and 25% during the north-turbine priority. Fish that first entered the fishway during a south-turbine priority had a median time of 1.0 h to enter the fishway after passage into the tailrace area, which was 12 min faster than fish first entering the fishway during a north-turbine priority. During both priority treatments, median time to enter the fishway after first approach was about 12 min.

When one turbine was operating, about the same number of fish first entered the fishway during both treatments, despite 125 h more of the south priority than the north priority (Figure 26). Median time to first enter the fishway during the south-turbine priority was 0.8 h after passage into the tailrace, 18 min faster than those first entering during the north priority. When two units were operating, median entry time during both priority treatments was 1.1 h.

Of 52 fish that first entered the fishway throughout the season (56 fish minus the four fish with unknown entrance locations) during a south-turbine priority, 56% first entered the fishway along the southern half of the powerhouse (Figure 27). About 42% first entered the four openings to the fishway along the northern half of the powerhouse, and one fish first entered at the north-shore entrance. During north-turbine priority, 53% of the 19 fish first entered the fishway along the southern half of the powerhouse, and 47% along the northern half.

When one turbine was operating, 64% of the fish first entered the fishway along the southern half of the powerhouse (7 of 11 during south priority; 9 of 14 during north) and 36% along the northern half (4 of 11 during south priority; 5 of 14 during north) during both priorities (Figure 27). When two turbines were operating, during south-turbine priority, 54% of the 41 fish first entered the fishway along the southern half of the powerhouse, 44% along the northern half, and one fish entered at the north-shore entrance.

**Little Goose Dam - 1994**

Turbine operation at the Little Goose powerhouse alternated between south-, alternate south (turbine 2, then 3 if required) and north priorities from 0400 - 2000 h each day from 16 September to 30 November. Criteria for all of the priorities was met for a total of 1,095 h (Figure 28). South-turbine priority occurred 36% of the time, alternate south priority 33%, and north priority 31%.

Of the 395 h when south-turbine priority occurred, 81% was with one turbine operating and 19% with two turbines (Figure 29). All 366 h of alternate south priority was with one turbine operating. North-turbine priority was provided for 334 h, 87% of the time with one turbine operating and 13% with two turbines.

Receivers and antennas were reliable throughout the study season with the exception of gaps at the receivers monitoring orifice gates-1 and -4 from 27 September to 5 October and 18-30 November, and the north-shore entrance from 23-28 November (Figure 4 in Bjornn 1995). These outages reduced the number of fish recorded when first approaching and entering the fishway at
Figure 26. Time for steelhead to first enter the Little Goose fishway after passage into the tailrace during north- or south-turbine priority tests throughout the study season, and when one or two turbines were operating in 1993.
Figure 27. Little Goose fishway entrances first entered by steelhead during north- or south-turbine priority tests throughout the study season, and when one or two turbines were operating in 1993.
Figure 28. Periods of time when north-, south-, and alternate south-turbine priority tests occurred from 16 September - 30 November between 0400 - 2000 h at Little Goose Dam in 1994. A continuous line represents powerhouse discharge that met criteria for either north-, south-, or alternate south-turbine priority.
the respective sites, however, there were few fish passing the dam at those times.

**Time to pass the dam.** For the test period, steelhead that first entered the fishway during south-turbine priority had a median time of 5.9 h to pass the dam after first passing the tailrace receiver, 0.8 h less than fish first entering the fishway during north-turbine priority, and 2.7 h faster than during alternate south-turbine priority. During most of the test period only one turbine was used during all three turbine priorities, thus, the time to pass the dam for the full test period was the same as for when one turbine was operating.

Median time to pass the dam after first entry into the fishway for 46 steelhead that first entered the fishway during south-turbine priority was 4.8 h, versus 7.2 h for 25 fish that first entered during alternate south-turbine priority, and 4.8 h for 34 fish that first entered during north-turbine priority (Figure 29). Most fish passed the dam in 0.5 d or less after first entering the fishway but a few took up to 28.3 d.

**First approaches to fishway.** For the full test period, 140 steelhead were exposed to a single treatment in the tailrace before first approaching the fishway (Figure 30). Of those, 40% first approached the fishway during south-turbine priority, 26% during alternate south-turbine priority, and 34% during north-turbine priority. Median time to first approach the fishway after entering the tailrace was 56 min during alternate south- and north-turbine priorities, and 48 min during south-turbine priority. Most fish first approached the dam within 2 h of entering the tailrace, and all fish had done so after 9 h. Median time to first approach the dam when one turbine was operating was the same as that for the entire season during each treatment because only one turbine was used for most of the test period at Little Goose Dam.

Of 52 fish with known locations that first approached the dam during south-turbine priority, 52% first approached the fishway along the southern half of the powerhouse, 37% along the northern half, and 11% at the north-shore entrance (Figure 31). During alternate south-turbine priority, 56% of 27 fish with known locations first approached the four openings to the fishway along the southern half of the powerhouse, 37% along the northern half, and 7% at the north-shore entrance. Forty-five percent of 44 fish (excludes four fish with unknown approach locations) approached the fishway during north-turbine priority along the southern half of the powerhouse, 41% along the northern half, and 14% at the north-shore entrance.

Where steelhead first approached the fishway during the three treatments when one turbine was operating was similar to that during the whole season because river flows required only one turbine to be operating for most of the test period. Where fish first approached the fishway during south- and alternate south-turbine priorities was similar in that about half were along the southern half of the powerhouse, 37% along the northern half, and the remainder at the north-shore entrance (Figure 31). During north-turbine priority, 46% of the fish first approached along the southern half of the powerhouse, 42% along the northern half, and 12% at the north-shore entrance.
Figure 29. Time for steelhead to pass Little Goose Dam after first entering the fishway during north-, south-, or alternatesouth-turbine priority tests throughout the study season, and when one or two turbines were operating in 1994.
Figure 30. Time for steelhead to first approach the Little Goose fishway during north-, south-, or alternate south-turbine priority tests throughout the study season, and when one or two turbines were operating in 1994.
Figure 31. Little Goose fishway entrances first approached by steelhead during north-, south-, or alternate south-turbine priority throughout the study season, and when one or two turbines were operating in 1994.
First entry into fishway.- During the test period, 104 steelhead were exposed to a single treatment in the tailrace before first entry into the fishway (Figure 32). Of those, 44% first entered the fishway during south-turbine priority, 24% during alternate south-turbine priority, and 32% during north-turbine priority. Fish that first entered the fishway during south-turbine priority had median times of 1.1 h, about 6 min after they first approached the fishway. Fish entering the fishway during alternate south-turbine priority had a median time of 1.4 h, 30 min after first approaching the fishway, and fish entering the fishway during north-turbine priority had a median time of 1.9 h, 1.0 h after first approaching the dam. All fish entered the fishway within 10 h of entering the tailrace. Time for a fish to first enter the fishway during the three treatments when one turbine was operating was similar to results for the full test period because one turbine was used most of the time.

Although steelhead approached virtually all entrances to the fishway (Figure 31), first entries were concentrated at south-shore entrance-1. Of 46 fish that first entered the fishway during the south-turbine priority, 57% were along the southern half of the powerhouse, and 43% were along the northern half (Figure 33). Approximately 56% of 25 fish that first entered the fishway during alternate south-turbine priority did so along the southern half of the powerhouse and 44% entered along the northern half. During north-turbine priority, 64% first entered the fishway along the southern half of the powerhouse, and 36% were along the northern half. No fish first entered the fishway at the north shore entrance.

Openings to the fishway along the southern half of the powerhouse at Lower Granite Dam (turbines 1, 2, and 3) are south-shore entrances-1 and -2, and orifice gates-1 and -4, whereas orifice gates-7 and -10 and north powerhouse entrances-1, -2 and -3 are open along the northern half of the powerhouse (turbines 4, 5, and 6) (Figure 34). The north powerhouse entrances were rotated between either -1 and -3 open, or -2 and -3 open concurrent with the turbine priority test.

Turbine unit operations at Lower Granite Dam were scheduled to alternate daily between north- and south-priority discharges between 0400 - 2000 h each day from 7 July to 30 November. Criteria for north- and south-priority discharges were met most of the time (2,206 h) at Lower Granite Dam (Figure 35). South-turbine priority occurred 51% of the time and north-turbine priority 49%. North-turbine priority was not achieved as scheduled between 15 July and 6 August because turbine 6 was being repaired from 1-19 July and turbine 5 went off-line for annual maintenance from 19-29 July. Powerhouse discharges ranged between 55 and 70 kcf.s through July up to 7 August when flows dropped below 50 kcf.s and the operators were able to meet the test schedule. Four fish were included in the analysis that passed the dam between 15 July and 6 August. One fish first approached and entered the fishway during the north-turbine priority and three others during the south-turbine priority. We included the four fish in the analysis because the time they took to first approach and enter the fishway did not differ significantly from that of fish during the remainder of the sampling season.
Figure 32. Time for steelhead to first enter the Little Goose fishway during north-, south-, or alternate south-turbine priority tests throughout the study season, and when one or two turbines were operating in 1994.
Figure 33. Little Goose fishway entrances first entered by steelhead during north-, south-, or alternate south-turbine priority tests throughout the study season, and when one or two turbines were operating in 1994.
Figure 34. Fishway entrances and location of antennae used at Lower Granite Dam during 1993 and 1994 steelhead migration seasons.
Figure 35. Periods of time when north- or south-turbine priorities occurred from 7 July - 30 November between 0400 - 2000 h at Lower Granite Dam in 1993. A continuous line represents turbine operation that met test criteria for either north- or south-turbine priority.
Figure 35 continued.
Of the 1,128 h during south-turbine priority, 30% was with one turbine operating, 44% with two turbines running, and 26% with three (Figure 36). North-turbine priority was tested for 1,078 h, 40% of the time was with one turbine, 58% with two turbines, and 2% with three turbines.

Receivers and antennas were reliable throughout the study season with the exception of gaps at receivers monitoring the north-shore entrances from 17-20 July, orifice gates-1 and -4 from 3 to 9 September, and at orifice gates-7 and -10 from 23-30 November (Figure 4 in Bjornn et al. 1995). While these outages reduced the number of steelhead recorded as they first approached and first entered the fishway at those sites, the gaps occurred when relatively few fish were passing the dam.

**Time to pass the dam.**—Total median passage time from the tailrace to the top of the ladder for the whole season for steelhead first entering the fishway during a south-turbine priority (33 fish) was 26.6 h, 7.1 h less than those first entering the fishway during north-turbine priority (16 fish). When one turbine was operating, fish first entering the fishway during the south-turbine priority had a median time to pass the dam of 29.0 h, whereas those first entering the fishway during the north-turbine priority did so in 31.2 h. When two turbines were operating, median passage time was 27.4 h to pass the dam for fish first entering the fishway during south-turbine priority and 34.7 h for those first entering during north-turbine priority.

Median time to pass over the dam for 33 steelhead after first entering the fishway during south-turbine priority was 1.0 d (Figure 36). Most of the 33 fish passed the dam in 4 d or less after first entering the fishway but one fish took 22.2 d to pass the dam. Sixteen fish first entering the fishway during north-turbine priority had a median time of 1.3 d to exit the top of the ladder. All fish that first entered the fishway during the north-turbine priority passed the dam in less than 4 d. The National Marine Fisheries Service trap was operating during the study period and was a probable source of delay for fish.

**First approaches to fishway.**—Throughout the season, 68 steelhead were exposed to a single treatment in the tailrace before first approaching the fishway (Figure 37). Of those, 60% first approached the fishway during the south-turbine priority, and 40% during the north-turbine priority. Median time for both groups of fish from entry into the tailrace to first approach at the dam was 1.2 h, and all fish approached the dam within 4 h of entering the tailrace.

Of the 41 fish that first approached the fishway during a south-turbine priority, 39% first approached along the southern half of the powerhouse (Figure 38). Sixty-one percent of the fish first approached the four entrances to the fishway along the northern half of the powerhouse. During the north-turbine priority, 27% of 26 fish (excludes one fish with an unknown approach location) first approached the fishway along the southern half of the powerhouse, and 73% were along the northern half. No fish approached the fishway first at the
Figure 36. Time for steelhead to pass Lower Granite Dam after first entering the fishway during north- or south-turbine priority tests throughout the study season, and when one, two, or three turbines were operating in 1993.
Figure 37. Time for steelhead to first approach the Lower Granite fishway during north- or south-turbine priority tests throughout the study season, and when one, two, or three turbines were operating in 1993.
Figure 38. Lower Granite fishway entrances first approached by steelhead during north- or south-turbine priority tests throughout the study season, and when one, two, or three turbines were operating in 1993.
north-shore entrance during either treatment.

When one and three turbines were operating, fish first approached the fishway along the southern half of the powerhouse during both treatments (Figure 38). When two turbines were operating during south priority, 53% of fish first approached south-shore entrance-1 and orifice gate-1, and the remainder approached the fishway along the northern half of the powerhouse. During north-turbine priority, 35% of the fish approached fishway entrances first along the southern half of the powerhouse, and 65% along the northern half.

First entry into fishway.- Throughout the season, 49 steelhead were exposed to a single treatment in the tailrace before first entry into the fishway (Figure 39). Of those, 67% first entered the fishway during south-turbine priority and 33% during north-turbine priority. Both groups of fish had median times of about 2.5 h to first entry into the fishway after entering the tailrace, and about 1.3 h after first approaching the dam (Figure 37).

When one turbine was operating, the median time to first enter the fishway was about 2.5 h during both treatments and about 1.0 h longer when two turbines were operating. All fish entered the fishway within 10 h of entering the tailrace.

First entrance use.- Steelhead first approached virtually all of the available fishway entrances, but they first entered the fishway primarily at south-shore entrance-2 and north powerhouse entrance-2 (Figure 40). The 33 fish that first entered the fishway during south-turbine priority, 48.5% first entered the fishway along the southern and northern halves of the powerhouse equally. One fish first entered the fishway at the north-shore entrance. During north-turbine priority, 38% of the 15 fish (excludes one fish with an unknown entrance location) first entered the fishway along the southern half of the powerhouse, and 62% were along the northern half of the powerhouse. No fish entered the fishway for the first time at orifice gates-7 or -10, and orifice gate-4 was the site of first entry for one fish.

When one turbine was operating, 6 of 14 steelhead first entered the fishway along the northern half of the powerhouse during south-turbine priority (Figure 40). During north-priority, two of four fish first entered the fishway at both the northern and southern halves of the powerhouse. When two turbines were operating, during south-turbine priority, 8 of 13 fish first entered the fishway at south-shore entrances-1, -2 or orifice gate-1, 4 of 13 fish first entered the fishway along the northern half of the powerhouse, and one fish first entered at the north-shore entrance. During north-turbine priority, 4 of 11 fish (excluding one fish with an unknown entrance location) first entered the fishway along the southern half of the powerhouse and the remaining seven along the northern half.

Lower Granite Dam - 1994

Powerhouse turbine usage alternated between south-, alternate south- (turbine two, then three if required) and north-turbine priorities between 0400 - 2000 h each day from 16 September to 30 November for a total of 1,186 h (Figure 41). South-turbine priority was provided
Figure 39. Time for steelhead to first enter the Lower Granite fishway during north- or south-turbine priority tests throughout the study season, and when one, two, or three turbines were operating in 1993.
Figure 40. Lower Granite fishway entrances first entered by steelhead during north- or south-turbine priority tests throughout the study season, and when one, two, or three turbines were operating in 1993.
Figure 41. Periods of time when north-, south-, or alternate south-turbine priority tests occurred from 16 September - 30 November between 0400 - 2000 h at Lower Granite Dam in 1994. A continuous line represents turbine operation that met test criteria for either north-, south-, or alternate south-turbine priority.
37% of the time, alternate south priority 34%, and north priority 29%.

Of the 441 h of south-turbine priority, 87% was with one turbine operating and 13% with two turbines (Figure 42). Alternate south priority was provided for 407 h with one turbine operating and 78% of time and with two turbines 22%. North-turbine priority was tested 338 h, with one turbine 90% of the time, and two turbines 10%.

Receivers and antennas were reliable throughout the study season with the exception of the receiver monitoring the south-shore entrance-1 and -2 which did not perform properly all season (Figure 4, Bjornn et al. 1995). This outage reduced the number of fish recorded when first approaching and entering the fishway at these sites, and thus reduced the number of fish included in parts of the analysis. The receiver monitoring orifice gate-7 and -10 was out of service from 10-15 November but few fish were passing the dam at this time of the year.

**Time to pass dam.**- Median time for steelhead to pass over the dam after entering the tailrace during south-turbine priority was 17.0 h, 4.1 h less than for those first entering the fishway during north-turbine priority, and 13.7 h faster than for those first entering during alternate south-turbine priority. During most of the test period only one turbine was used.

Median time to pass the dam after first entry into the fishway for 24 steelhead that first entered the fishway during south-turbine priority was 15.5 h (Figure 42). Thirty fish that first entered the fishway during alternate south-priority had a median time of 29.1 h (1.2 d) to then pass the dam, and 21 fish entering during north-turbine priority had a time of 19.7 h. Most of the fish passed the dam in 3 d or less after first entering the fishway but a few took up to 4.8 d. The National Marine Fisheries Service trap was operating during the study period and was a probable source of delay for fish in the ladder.

**First approaches to fishway.**- Over the whole season, 107 steelhead were exposed to a single treatment in the tailrace before their first approach to the fishway (Figure 43). Of those, 30% first approached the fishway during south-turbine priority, 37% during alternate south-turbine priority, and 33% during north-turbine priority. Fish that first approached the fishway during south-turbine priority had a median time of 1.1 h, 6 min faster than those first approaching the dam during alternate south-priority. Fish first approaching the fishway during north-turbine priority did so the fastest, in a median time of 48 min. All fish approached the dam within 4 h of entering the tailrace. Median time to first approach the fishway during the three treatments when one turbine was operating was similar to that for the whole season.

Of the 30 fish with known locations that first approached the fishway during south-turbine priority, 43% first approached the fishway along the southern half of the powerhouse, 50% along the northern half, and 7% at the north-shore entrance (Figure 44). During alternate south-turbine priority, 55% of 38 fish first approached the fishway along the southern half of the powerhouse, and the
Figure 42. Time for steelhead to pass Lower Granite Dam after first entering the fishway during north-, south-, or alternate south-turbine priority tests throughout the study season, and when one or two turbines were operating in 1994.
Figure 43. Time for steelhead to first approach the Lower Granite fishway during north-, south-, or alternate south-turbine priority tests throughout the study season, and when one or two turbines were operating in 1994.
Figure 44. Lower Granite fishway entrances first approached by steelhead during north-, south-, or alternate south-turbine priority tests throughout the study season, and when one or two turbines were operating in 1994.
Forty-one percent of 34 fish first approaching the fishway during north-turbine priority (excludes one fish with an unknown approach location) did so along the southern half of the powerhouse, 53% were along the northern half, and 6% at the north-shore entrance.

**First entry into fishway.** Over the whole season, 75 steelhead were exposed to a single treatment in the tailrace before first entering the fishway (Figure 45). Of those, 32% first entered the fishway during south-turbine priority, 40% during alternate south-priority, and 28% during north-turbine priority. All three groups of fish had a median time of about 1.5 h to first enter the fishway. Median time to first enter the fishway after first approaching the fishway was 24 min for steelhead entering during south-turbine priority and 36 min for fish entering during alternate south- and north-turbine priorities. All fish entered the fishway within 10 h of entering the tailrace.

Of 24 steelhead that first entered the fishway during south-turbine priority (excludes the one fish with an unknown entrance location), 57% did so along the southern half of the powerhouse, and 43% were along the northern half (Figure 46). Forty-seven percent of 30 fish entering the fishway during alternate south-turbine priority did so along the southern half of the powerhouse, and 53% along the northern half. During north-turbine priority, 37% of 21 fish first entered the fishway along the southern half of the powerhouse, and 63% along the north side. No fish first entered the fishway at the north-shore entrance during the three turbine priorities.

A majority of fish first entered the fishway along the south side of the powerhouse during the south- and alternate south-turbine priorities (61% and 53%, respectively), with the remainder along the northern half (Figure 46). During north-turbine priority, 41% of the fish entered the fishway first along the southern half of the powerhouse, and 59% entered along the northern half.

**Discussion**

Times for steelhead outfitted with transmitters to enter the fishways (1.0 - 2.6 h)—the most critical variable in this test in our view—were not consistently in favor of any turbine priority used at the four lower Snake River dams. Differences in median (0.0 - 0.8 h) and mean (0.01 - 0.8 h) times to enter fishways were small and not statistically significant, except in 1993 at Lower Monumental Dam where mean time for fish to first enter during south priority was longer (3.0 h) than during north priority (2.2 h). Steelhead used the same entrances to enter the fishways regardless of the turbine priority at the time of entry, probably because of the dimensions, locations, and discharges through the entrances. Differences in entry times between dams were at least partly due to differences in distances between tailrace receiver sites and the dams (0.5 - 2.7 km downstream).

Median times to first approach the fishways by steelhead at all four dams after passing the tailrace receivers were similar for all turbine priorities tested at the dams (Table 1). Differences in the times to approach between dams were largely due to the distances between tailrace receiver sites and the dams. Median
Figure 45. Time for steelhead to first enter the Lower Granite fishway during north-, south-, or alternate south-turbine priority tests throughout the study season, and when one or two turbines were operating in 1994.
Figure 46. Lower Granite fishway entrances first entered by steelhead during north-, south-, or alternate south-turbine priority tests throughout the study season, and when one or two turbines were operating in 1994.
Table 1. Median hours for steelhead outfitted with radio transmitters to first approach a dam after first passing tailrace receiver, median hours to first enter fishway, and total median time to pass over dam (tailrace receiver to top of the ladder) during north-, south-, alternate north-, and alternate south-turbine priority tests at the four Snake River dams in 1993 and 1994. Values in parentheses are number of steelhead used in calculating median times.

<table>
<thead>
<tr>
<th>Time to:</th>
<th>Ice Harbor Dam 1993</th>
<th>Lower Monumental Dam 1993</th>
<th>Little Goose Dam 1993</th>
<th>Lower Granite Dam 1993</th>
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<tr>
<td>First approach (h)</td>
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<td></td>
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<td>North</td>
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<td>1.7 (33)</td>
<td>1.7 (68)</td>
<td>0.8 (23)</td>
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<tr>
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<td>1.4 (52)</td>
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</tr>
<tr>
<td>Alt. north</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First entry (h)</td>
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<td></td>
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<td></td>
</tr>
<tr>
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<td>2.0 (29)</td>
<td>1.8 (52)</td>
<td>1.2 (19)</td>
</tr>
<tr>
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<td>1.8 (52)</td>
<td>1.0 (56)</td>
<td>1.1 (46)</td>
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<tr>
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</tr>
<tr>
<td>Alt. north</td>
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<tr>
<td>Pass over dam (h)</td>
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<tr>
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<tr>
<td>Alt. north</td>
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</tbody>
</table>

Times to enter the fishways after first approaches ranged from 0.3 to 1.4 h. Discharges during their trips back into the tailrace.

Median times for steelhead to pass over the dams after passing the tailrace receiver sites ranged from 5.9 to 33.7 h during the various turbine priorities tested in 1993 and 1994 (Table 1). Most of the time to pass over the dams was after first entry into the fishways (4.8 - 31.2 h).

Once inside the fishway, it would seem that turbine operation should not affect the time a fish takes to pass over a dam, but a significant number of fish exited the fishway, some several times, and these fish could be influenced by powerhouse discharges during their trips back into the tailrace.

The highest passage times were consistently at Lower Granite Dam where fish with transmitters were diverted into the adult trap and delayed in their passage over the dam. At Ice Harbor Dam in 1993, times for steelhead to enter the fishways were similar to those at other dams, but times to pass over the dams were about twice those at Lower Monumental and Little Goose dams. The longer times in the fishway at Ice Harbor Dam were probably caused by use of the trap at the top of the Ice Harbor south-shore ladder to
collect steelhead for the zero flow at night study.

Steelhead made slightly more approaches to fishway entrances along the northern half of the powerhouse (12% - 16%) when powerhouse discharges were shifted from south to north priority (opposite ends at Lower Monumental Dam), but steelhead used mostly the same entrances to enter the fishways regardless of turbine priority. Steelhead approached many entrances, some repeatedly, before entering the fishways. Entrances used by steelhead to enter the fishways were, in our view, more likely related to dimensions, locations, and discharges at the entrances than to turbine unit priority.
References

