WELLS DAM RADIO-TELEMETRY STUDY, 1992

by

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EXECUTIVE SUMMARY

In 1992, the National Marine Fisheries Service conducted a radio-telemetry study to determine migration rates and timing of adult sockeye salmon (*Oncorhynchus nerka*) between Rocky Reach Dam and Wells Dam in the mid-Columbia River and to the spawning grounds in British Columbia, Canada. Particular emphasis was placed on identifying fish passage problems and determining the extent of delay for fish at Wells Dam and at the mouth of the Okanogan River.

Ninety-six fish were collected and radio tagged at Rocky Reach Dam. Travel time between Rocky Reach Dam and Wells Dam was about 1.5 days. The overall median passage time at Wells Dam was 1 day with the majority of the delay occurring prior to fish-ladder entry. Tagged fish spent a median of 2 hours between arrival at the dam and first attempting fish-ladder entry. Once in the fish ladders, median time for fish passage was 5 hours. Median passage time through the right-bank fish ladder was 4 hours compared to 6 hours for the left-bank fish ladder. Fifty-six percent of the fish passed between 1100 and 1700 h, with the remainder divided equally between morning and evening hours. Fishway entrance efficiency was highest for the left-bank fish ladder. For each fish ladder, the end (downstream) entrance was selected more frequently than the side entrance.

A fallback rate of 13% was found during periods of spill. A correction factor of 0.853 to adjust inflated adult sockeye

salmon counts for fallback at Wells Dam was determined. No fallback was recorded during no-spill periods.

Sockeye salmon entry into the Okanogan River began when water temperatures dropped and river flow decreased. Most of the radio-tagged fish entered the river during early morning hours between 23 and 28 August. Median migration time for the 117 km reach from river entry to Zosel Dam was 4.6 days (about 25 km per day).

The median migration time from Wells Dam to Zosel Dam (150.6 km) was 36.4 days (4.2 km per day). A portion (15%) of the radio-tagged sockeye salmon were exposed to the fishery at Chief Joseph Dam. About half of these fish appeared to range between the tailrace at Chief Joseph Dam and the mouth of the Okanogan River until proceeding to the spawning grounds.

No appreciable delay prior to passage was found at Zosel Dam. Most fish passed over Zosel Dam during the early morning hours. Some fish may have passed Zosel Dam by swimming under spill gates.

Median residence time in Osoyoos Lake before entry into the spawning area was 28 days. Sharply decreasing water temperature and slightly increasing river flow appeared to trigger the migration from the lake to the spawning area on about 1 October.

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INTRODUCTION

In recent years, the number of sockeye salmon (*Oncorhynchus nerka*) counted at Rocky Reach Dam, River Kilometer (RKm) 762.2 [River Mile (RM) 473.7] on the mid-Columbia River (Fig. 1), have differed from counts at Wells Dam, RKm 829.4 (RM 515.5). In 1990, for example, the count at Rocky Reach Dam was 18% higher than the count at Wells Dam. Numerous factors could have contributed to the disparity: 1) there may have been direct mortality associated with Rocky Reach Dam passage or the Wells Dam fishway entrance, 2) high spring and summer flows may have caused delay and mortality, 3) spill may have caused increased fallback through the spillways which in turn resulted in inflated counts in the fishways, 4) counting techniques, species identification, and numbers of days or hourly counting periods may have differed between the dams, and 5) delay in the Wells Dam ladders (possibly due to trapping operations) may have led to rejection of the ladder and to subsequent mortalities.

Limited data exist concerning adult sockeye salmon migration timing and survival from Wells Dam to the spawning grounds. Major and Mighell (1966) concluded that the delay of sockeye salmon near the mouth of the Okanogan River was due to a thermal block or associated factors when water temperature was greater than 21.1°C.

As part of the enhancement plan for sockeye salmon stocks upstream from Wells Dam, Pratt et al. (1991) recommended a

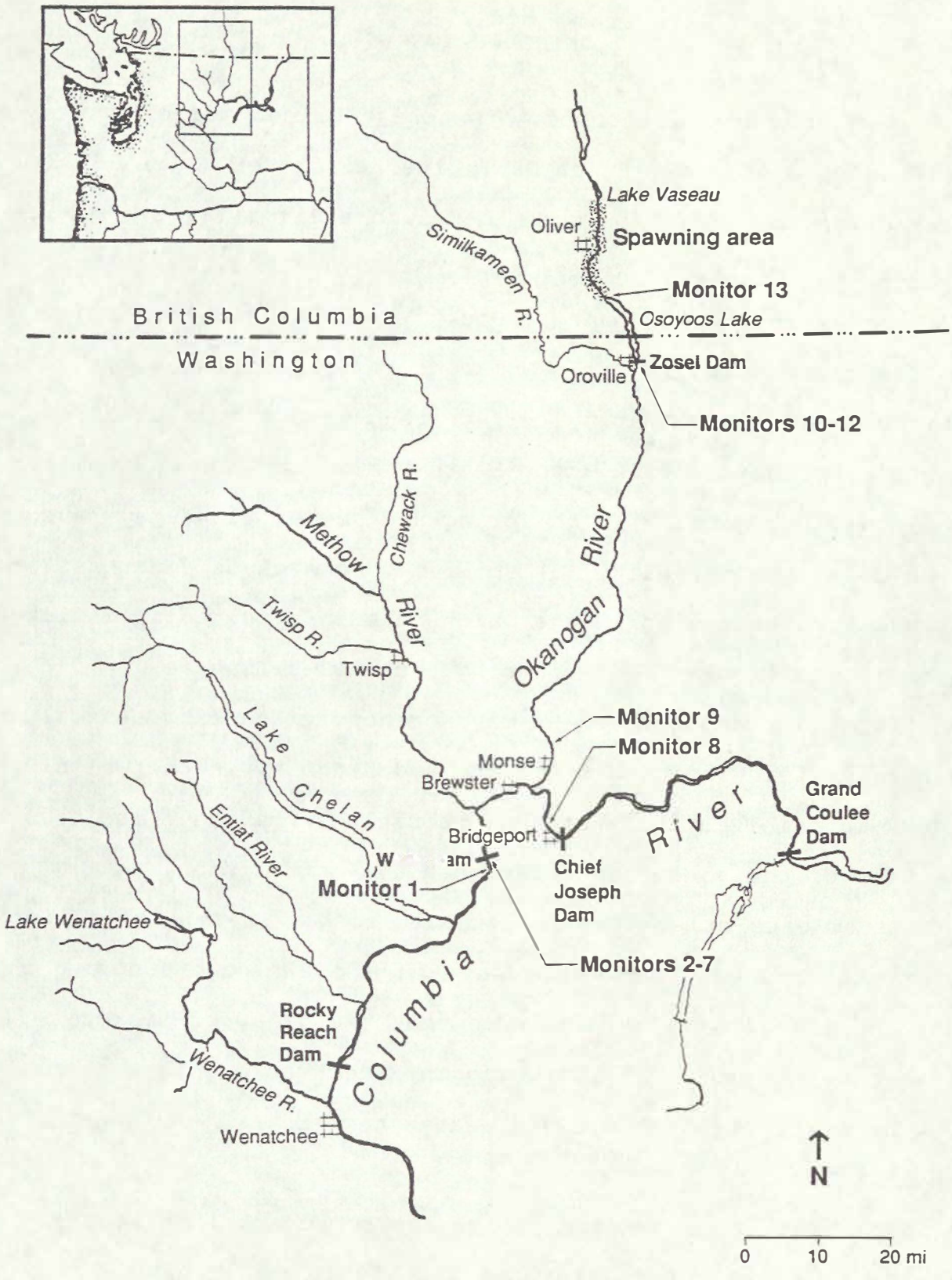

Figure 1.--Map of study area showing fixed-site monitor numbers and locations and spawning area (adapted from Major and Mighell 1966).

radio-tracking study to assess pre-spawning mortality and to assess spawning distribution. In late 1991, the National Marine Fisheries Service (NMFS), in cooperation with the Douglas County Public Utility District, conducted a radio-telemetry study of the sockeye salmon migration in the mid-Columbia River. The results of the 1992 research are presented in this report.

OBJECTIVES

The overall objective of the Wells Dam radio-telemetry study was to identify problem areas that might be associated with adult sockeye salmon passage between Rocky Reach Dam, Wells Dam, and the spawning grounds. Major goals were to collect information on 1) passage times at Wells Dam and at the mouth of the Okanogan River, 2) migrational behavior, and 3) run timing.

Specific goals for this study were covered by the following research tasks:

Task 1. Determine passage time at Wells Dam under existing spill, flow, and powerhouse operating conditions.

- **Task 1.1.** Determine the median time between at-dam arrival (entering dam tailrace) and fish-ladder entrance at Wells Dam.
- **Task 1.2.** Determine the median fish-ladder entrance to exit time at each Wells Dam fish ladder.

Task 2. Evaluate fish-ladder entrance efficiency at Wells Dam. Determine fish-ladder entrance preferences under various operating conditions.

- **Task 2.1.** Determine percentage of fish entries associated with each of the four fish-ladder entrance locations.

Task 2.2. Determine percentage of fish entries associated with successful fish-ladder passage.

Task 3. Determine the fall-back rate and routes under various conditions of spill, flow, and powerhouse operation.

Task 4. Determine percentage of the tagged population exposed to the fishery at Chief Joseph Dam.

Task 5. Determine spatial and temporal factors associated with sockeye salmon entry into the Okanogan River.

Task 5.1. Determine flows and temperatures.

Task 5.2. Determine dates and diel timing.

Task 5.3. Determine behavioral patterns of fish that approach Chief Joseph Dam before entering the Okanogan River.

Task 6. Determine overall timing and rate of migration of sockeye salmon from Wells Dam forebay to Zosel Dam.

Task 7. Determine rate of movement of sockeye salmon in the Okanogan River between river entry and Zosel Dam.

Task 8. Determine delay and passage time of sockeye salmon at Zosel Dam.

Task 9. Determine residence time of sockeye salmon in Osoyoos Lake before entering the spawning area.

Task 10. Determine river flow and temperature during the period sockeye salmon leave Osoyoos Lake for the spawning area.

MATERIALS AND METHODS

Study Duration

Field work began in June 1992 at Rocky Reach Dam and ended in mid-November with adult spawning.

Study Area

Sockeye salmon were trapped and radio tagged at Rocky Reach Dam, released about 5.3 km upstream, and tracked to spawning grounds in the Okanogan River system (Fig. 1). The study area included the Columbia River from Rocky Reach Dam to Chief Joseph Dam, RKm 877.1 (RM 545.1) and the Okanogan River to the spawning areas near Oliver, British Columbia, Canada, Okanagan River RKm 159.5 (RM 99.1).

Radio-Telemetry Tags

Radio-telemetry tags were sized for the smallest anticipated adult sockeye salmon. In 1990, the proportion of 3-year-old fish [mean fork-length (FL) = 37.9 cm] among the Okanogan River fish sampled at Wells Dam was 45% (Fryer and Schwartzberg 1991). Four- and 5-year-old fish were the only other age groups found in significant proportions--26% (mean FL = 50.1 cm) and 23% (mean FL = 57.2 cm), respectively. Stomach-implant tags were sized to fit fish as small as 35-cm FL.

Radio tags for the study were purchased from Lotek Engineering Inc.[1], of Newmarket, Ontario, Canada. Each tag was powered by one 3.5-V lithium battery with a life span of about 5 months. The transmitter and battery were sealed in a cylindrical plastic capsule 4.4-cm long x 1.4-cm diameter. Tags weighed about 10.7 g in air and had a 40-cm, 22-gauge flexible-whip antenna attached to one end. Each tag transmitted a unique identification code (20 per frequency) on one of five frequencies spaced 20 kHz apart (149.720 mHz to 149.800 mHz).

Radio-Tagging

Radio tagging of adult salmon involved three major procedures: trapping, tagging, and releasing. Fish were radio tagged on week days from 8 July to 4 August.

Trapping

The adult trap in the fish ladder at Rocky Reach Dam was used to collect fish. The trap was lowered over the weir orifices in the fish ladder. The trap floor in front of the right-side (facing downstream) orifice was covered with a sheet of white plastic to facilitate viewing fish from above water as they entered the trap. The left-side orifice was closed by a slide gate to prevent escape. The trap was raised as soon as the daily quota (four to six sockeye salmon) was collected (approximately 0.5 hour during most of the fish migration). Fish

[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

were then transferred from the trap to a tank located on a 3.05 X 6.1-m barge in the forebay via a 46.1-cm diameter pipe. Non-target fish were immediately removed from the collection tank and released into the forebay.

Tagging

Sockeye salmon ranging from 40- to 60-cm FL were radio tagged. For tagging, sockeye salmon were individually transferred by dipnet from the collection tank to an anesthetic tank containing a 50ppm MS-222 solution. After examination for marks, tags, or injuries, fish were weighed, measured, and had a scale sample removed. Each fish was then placed on its dorsal surface in a vinyl tagging cradle, and a radio tag was inserted through the mouth and into the stomach of the fish. During the entire tagging procedure (approximately 2 to 5 minutes), fish were continually moistened.

The age of the radio-tagged fish was determined later from the scale samples read by Columbia River Inter-Tribal Fish Commission (CRITFC) personnel.

Releasing

After tagging, fish were placed in a aluminum holding/transport tank enclosed within a boat-shaped hull (tote boat) for recovery and holding. Tagged fish were initially held overnight for post-tagging mortality and tag regurgitation observations. Later, once tagging and holding procedures were

determined acceptable, fish were tagged in the morning and released at the end of the workday (about 1500 h).

Tagged fish required no further direct handling prior to release. For the release, the tote boat was towed 5.3 km upstream from Rocky Reach Dam (to RKm 767.5), about 1 km upstream from Turtle Rock Island. The tank's interior was then reexamined for regurgitated tags. A 30-cm cap on the stern of the tote boat was removed, and fish were allowed to escape. The inside of the tank was then inspected a final time for tags. A 2.5-cm lip at the bottom prevented tags from sliding out.

Radio Tracking

Radio tracking began on 9 July when the first tagged fish was released. Tagged fish locations and instream progress were continuously recorded by fixed-site monitors (Figs. 1-3) and by mobile monitoring units that operated from auto, boat, or airplane.

Table 1 lists the location and numerical designation of the fixed-site radio-telemetry monitors. Initially, Monitor 8 was located on the left bank about 0.8 km below Chief Joseph Dam. However, the monitor was relocated downstream to the Colville Tribal Fish Hatchery (about 6.4-km downstream) after about 2 weeks due to intense radio interference, apparently from the power facilities near the dam.

Mobile tracking was used to monitor fish between fixed site monitors and to locate and recover stationary tags. On the spawning ground, tags were recovered by examining carcasses.

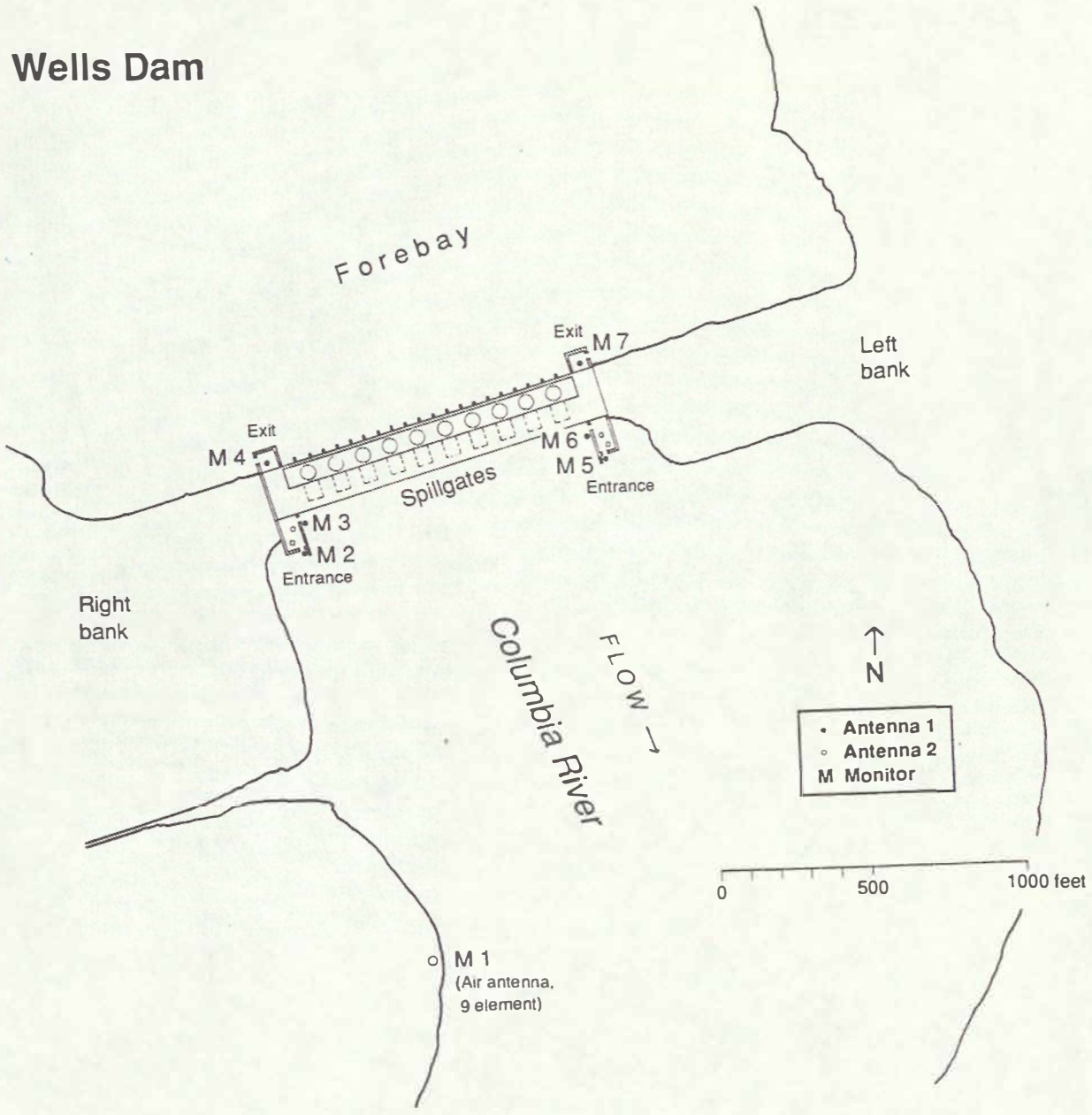

Figure 2.--Fixed-site monitor numbers and locations at Wells Dam.

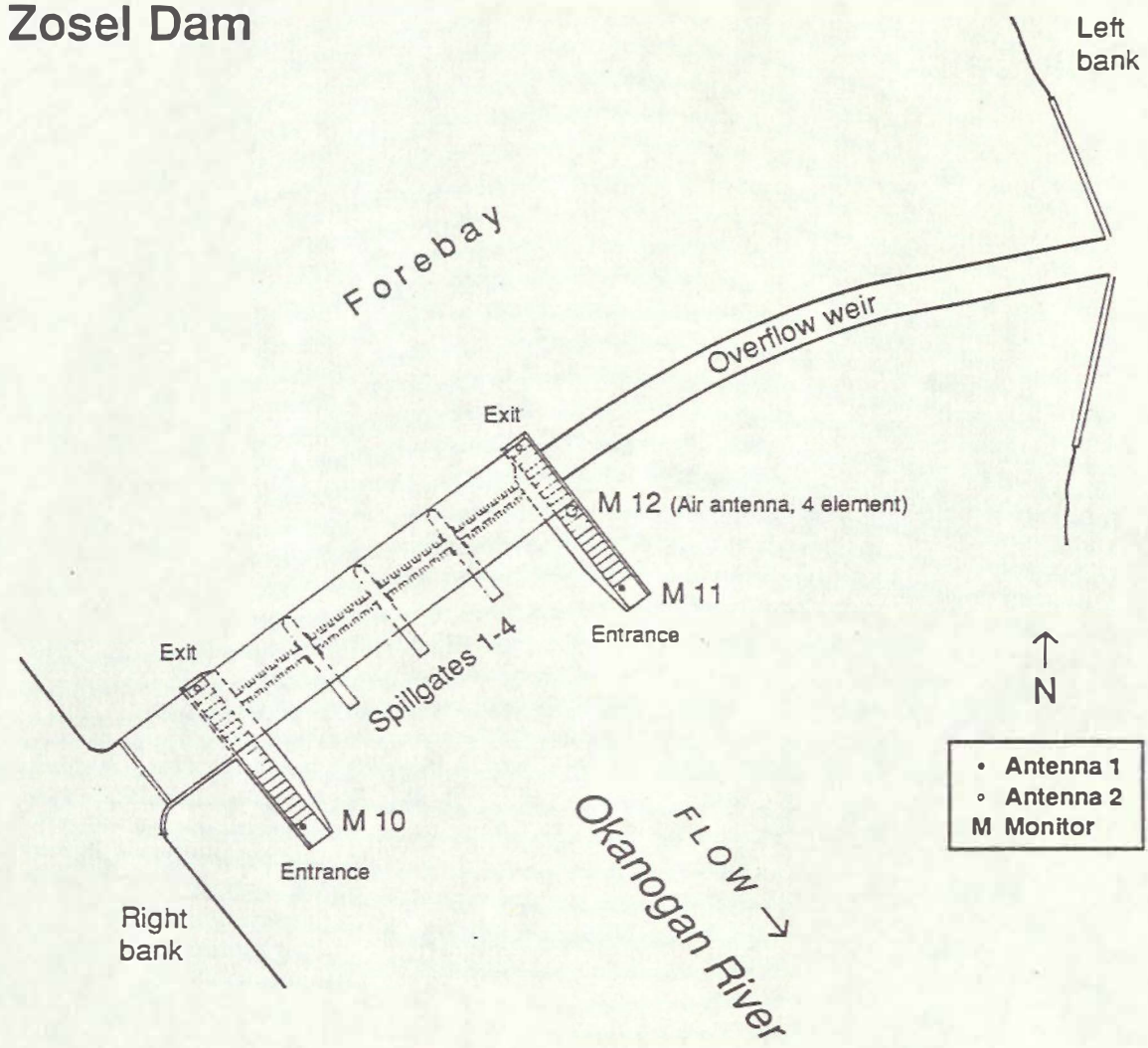

Figure 3.--Fixed-site monitor numbers and locations at Zosel Dam.

Table 1.--Fixed monitor sites, mid-Columbia and Okanogan Rivers system.

Monitor Number	Monitor Location	River	River Mile	River Kilometer	Antennae Number	Antennae Type
1	Wells Dam (tailrace)	Columbia	515.0	829.0	1	9-element Yagi (air)
2	Wells Dam (right-bank fish ladder-end entry)	Columbia	517.0	832.0	1 2	Underwater coax cable (outside) Underwater coax cable (inside)
3	Wells Dam (right-bank fish ladder-side entry)	Columbia	517.0	832.0	1 2	Underwater coax cable (outside) Underwater coax cable (inside)
4	Wells Dam (right-bank fish ladder-exit)	Columbia	517.0	832.0	1	Underwater coax cable
5	Wells Dam (left-bank fish ladder-end entry)	Columbia	517.0	832.0	1 2	Underwater coax cable (outside) Underwater coax cable (inside)
6	Wells Dam (left-bank fish ladder-side entry)	Columbia	517.0	832.0	1 2	Underwater coax cable (outside) Underwater coax cable (inside)
7	Wells Dam (left-bank fish ladder-exit)	Columbia	517.0	832.0	1	Underwater coax cable
8	Colville Tribe Fish Hatchery	Columbia	542.0	872.1	1	9-element Yagi (air)
9	Monse (Gebber's pump house)	Okanogan	6.0	9.7	1 2	4-element Yagi (air-downstream) 4-element Yagi (air-upstream)
10	Zosel Dam (right-bank fish ladder)	Okanogan	77.4	124.5	1 2	Underwater coax cable (entrance) Underwater coax cable (exit)
11	Zosel Dam (left-bank fish ladder)	Okanogan	77.4	124.5	1 2	Underwater coax cable (entrance) Underwater coax cable (exit)
12	Zosel Dam (mid-dam)	Okanogan	77.4	124.5	1	4-element Yagi (air)
13	Lake Osoyoos (0.5 mi above lake)	Okanogan	90.8	146.1	1	9-element Yagi (air)

Radio-Telemetry Monitoring Equipment and Data Collection

All fixed site monitors utilized Lotek Model SRX-400 telemetry receivers for signal detection and data processing and storage. At Zosel Dam, receivers with underwater antennae incorporated Lotek DSP-500 receiver/co-processors for simultaneous scanning of all antennas and frequencies (Fig. 3). The DSP-500 detected the signal from a transmitter (tag) and passed information concerning frequency, verification, and data storage to the SRX-400 receiver.

Four types of antennae were used for signal detection: underwater, multiple element Yagi, hand-held 3-element folding Yagi, and H antennas.

Underwater antennae consisted of coaxial cable, with about 2.5 cm of the shielding stripped from the distal end, suspended outside and within fish-ladder entrances and exits to detect the presence and passage of tagged fish within about 4.6-6.1 m. Yagi multiple element antennae were used as air antennae at fixed sites to monitor fish in a general area. Hand-held or staff-mounted three-element folding Yagi antennae were used for tracking by boat or auto. Two wing-strut-mounted H-pattern antennae were used on a high-winged aircraft for aerial tracking.

Fixed-site telemetry data were downloaded to lap-top computers at least once per week. When personnel were available, mobile surveillance was also conducted at least once per week. Aerial surveillance of the mid-Columbia River and major tributaries was conducted on 2 days.

River flow, water temperature, spill, and turbine operation data were obtained from appropriate water management and power producing agencies. Water temperature at the mouth of the Okanogan River was monitored when mobile tracking.

Fish behavior between arrival and ladder entry at Wells Dam was monitored by observing activity near and inside the fish-ladder collection system. Entrance preference was evaluated by the total number of tag-activity periods on each antenna. Tag-activity periods were also used to determine the effects of adult trap operation and spill on entrance preference.

The adult fish collection trap in the left-bank fish ladder was operated periodically by Washington Department of Fisheries, Wells Hatchery. The trap was operated 8 hours per day (0700-1500 h) on Monday, Wednesday, and Friday from 6 July through 3 August.

Working tags were located by radio signal. Non-working tags were found primarily by examining carcasses. To encourage the return of recovered radio tags and information, a $20 reward was offered.

Entrance efficiency was determined from the number of entrance attempts at each fish ladder relative to the number of successful passages.

Residence time in Osoyoos Lake before entering the spawning grounds was determined from the last time tagged fish were recorded upstream from Zosel Dam to the first time they were registered at Monitor 13 at the north end of the lake.

RESULTS AND DISCUSSION

We originally planned to radio tag a representative cross-section of the sockeye salmon population passing Rocky Reach Dam. The receipt and installation schedule of electronic monitoring gear at Wells Dam was based on adult arrival timing in 1990 and 1991. However, in 1992, adult fish arrived about 2 weeks earlier than expected. By 8 July, about 10,000 fish, representing 24% of the 1992 sockeye salmon run, had passed Rocky Reach Dam. The end of the sockeye salmon passage at Bonneville Dam also occurred much earlier than expected, requiring acceleration and completion of radio tagging about 3 weeks ahead of schedule. Appendix Table 1 lists and summarizes the fates of individual tagged fish. A detailed tag life history for each radio-tagged fish is presented in Appendix Table 2.

Sockeye salmon collected and tagged at Rocky Reach Dam ranged in length and weight from 46-60 cm (mean = 50.5 cm) and 0.64-2.0 kg (mean = 1.1 kg), respectively. The percentages of 4- and 5-year old fish were 95% and 5%, respectively. Ninety-six radio-tagged adult sockeye salmon were released upstream from Rocky Reach Dam, and 89 were subsequently recorded in the Wells Dam tailrace with 83 (86%) successfully passing the dam (Table 2). Monitors installed in the fish-ladder exits recorded 71 tagged fish passing over Wells Dam. An additional 12 fish passed Wells Dam without being recorded by the fish-ladder monitors. Seven fish were detected upstream from Wells Dam by mobile tracking, and the remainder by fixed-site monitors.

Table 2.--Activity summary at Wells Dam of 96 radio-tagged sockeye salmon released above Rocky Reach Dam.

Tagged fish recorded exiting Wells Dam	71
Tagged fish recorded by mobile tracking upstream from Wells Dam (but not recorded as exiting Wells Dam)	7
Tagged fish recorded at fixed-site monitors upstream from Wells Dam (but not recorded as exiting Wells Dam)	3
Tags within recovered fish on spawning grounds (but not recorded as exiting Wells Dam)	2
Tagged fish trapped in left-bank ladder at Wells Dam and transported to Methow Hatchery	2
Tagged fish recorded in Wells Dam tailrace (but not seen again)	8
Tagged fish never recorded after release	3
	96

Immediate regurgitation of radio tags was not a factor. During the tagging/releasing effort, one regurgitated tag was found in the tote boat.

Tables 2 and 3 summarize activity and locations, respectively, of recovered fish or radio tags. Thirty-four (35%) of the original 96 tags were recovered. Twenty-six tags, 11 of which were no longer transmitting a signal, were recovered on the spawning grounds. The average maximum life span of the 11 failed tags was less than 101 days (Table 4), well short of the desired 5-month life span. Non-recovered tags may have experienced similar battery failure.

Five tags were recovered on the river bank, well away from the river's edge, suggesting fish or tags were intentionally removed from the river.

Results for the specific research elements were:

Task 1. Determine passage time at Wells Dam under existing spill, flow, and powerhouse operating conditions.

Seventy-nine radio-tagged fish (82.3%) were detected by Monitor 1, downstream from Wells Dam (Figs. 1-2). Elapsed time from release to the monitor ranged from <1 to 10 days with a median of 1.5 days (Fig. 4 and Table 5). Seventy-one radio-tagged sockeye salmon passed over Wells Dam according to the exit monitors. However, tags in six of those fish failed to register on Monitor 1, and tags in two fish failed to register on the entrance monitors. Overall passage time for 63 tagged fish, from the first downstream monitor (Monitor 1) record to the last

Table 3.--Recovered radio tags from sockeye salmon. Abbreviations: CO - Columbia River, SI - Similkameen River, OK - Okanogan River.

Location	River	RM	RKM	Tags Recovered Active	Failed
Colville Tribal Hatchery	CO	542	872	1	
Wells Dam[1]	CO	517	832	2	
Oroville, Washington	SI	3	5	1	
Below Zosel Dam	OK	47-77	76-124	4	
Spawning grounds (British Columbia)	OK	99-104	159-167	15	11
				23	11

[1] Fish were trapped at Wells Dam and transported to Methow Hatchery, Winthrop, Washington for brood stock.

Table 4.-- Longevity of failed radio tags. Abbreviations: CO - Columbia River, OK - Okanogan River.

Tag	Release date	Last active record River-RKm	Last active record Date	Recovery date	Maximum possible duration (days)
2134	14 Jul	OK - 0	27 Jul	20 Oct	98
2242	11 Jul	CO - 858	18 Aug	28 Oct	109
2247[1]	20 Jul	CO - 762	20 Jul	29 Oct	101
2328	16 Jul	CO - 872	24 Jul	21 Oct	97
2330	23 Jul	OK - 166	15 Oct	15 Oct	84
2436	17 Jul	OK - 0	03 Aug	28 Oct	103
2437	13 Jul	OK - 10	28 Aug	28 Oct	107
2447[1]	14 Jul	CO - 762	14 Jul	29 Oct	107
2534	10 Jul	OK - 10	25 Aug	26 Oct	108
2535	27 Jul	OK - 146	13 Sep	28 Oct	103
2550	17 Jul	OK - 0	31 Jul	21 Oct	96
					___
				Average duration	101 days

[1] Never recorded after release until recovery of tag.

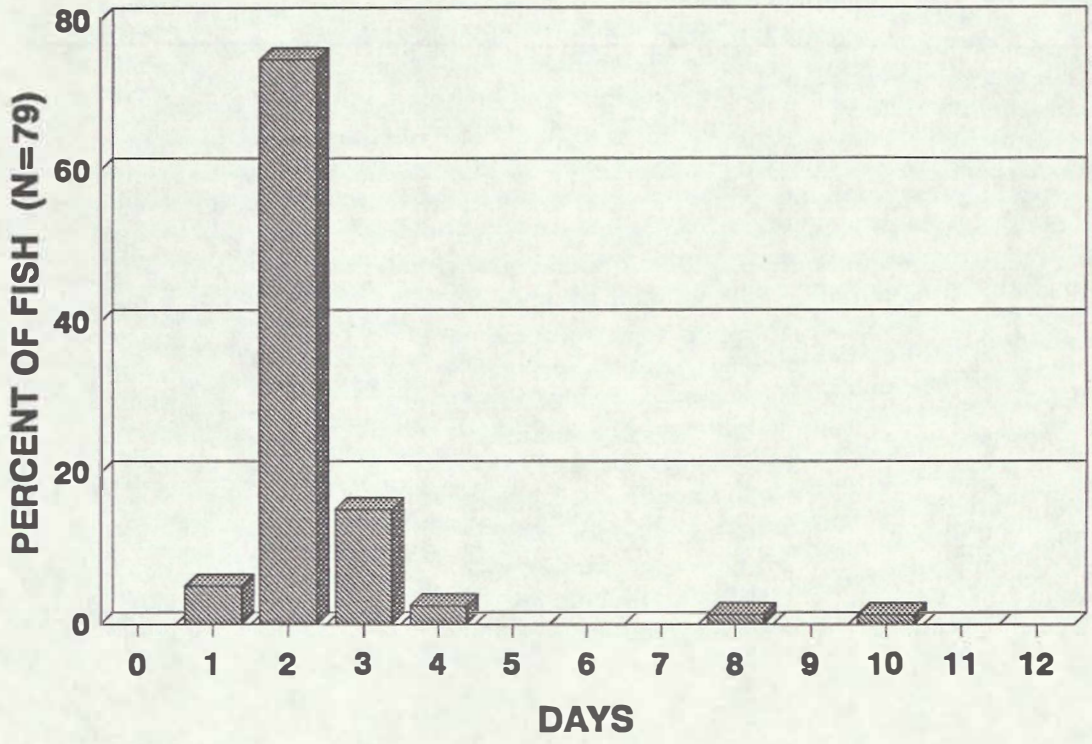

Figure 4.--Travel times of radio-tagged sockeye salmon from release above Rocky Reach Dam to Monitor 1 at Wells Dam tailrace.

Table 5.--Passage time (days) of radio-tagged sockeye salmon (with complete passage records) released 5.3 kilometers upstream from Rocky Reach Dam and monitored at Wells Dam.

	Release to Wells Dam	Monitor 1 to first ladder record	Ladder Passage			Overall passage at Wells Dam
			Overall	Right	Left	
n	79	79	69	24	45	63
Min	0.7	<0.1	0.1	0.1	0.1	0.3
Max	9.6	0.7	11.4	2.7	11.4	18.5
Median	1.5	0.1	0.2	0.2	0.3	1.3

ladder-exit monitor record, ranged from <1 to 19 days, with a median of 1.3 days (Fig. 5 and Table 5).

Due to migration rates and the time required for the monitors to scan through the five frequencies, tags were not recorded at all of the monitors.

Task 1.1. Determine the median time between at-dam arrival (entering dam tailrace) and fish-ladder entrance at Wells Dam.

Seventy-nine radio-tagged fish were detected by Monitor 1 prior to being recorded at the fish-ladder entrances (Monitors 2, 3, 5, or 6). Elapsed time between arriving at Wells Dam and the initial record at one of the four fish-ladder entrances ranged from <1 to 17 hours, with a median of 2 hours (Fig. 6). However, many of the tagged fish did not proceed up the fish ladder following the initial encounter with a ladder entrance. Time from first record at the dam (by either Monitor 1 or one of the four fish-ladder entrance monitors) until last record at the ladder entrance (duration in tailrace) for 69 tagged fish ranged from <1 to 16 days, with a median of 1 day (Fig. 7).

Task 1.2. Determine the median fish-ladder entrance to exit time at each Wells Dam fish ladder.

Passage time through the fish ladders ranged from a minimum of 2 hours to a maximum of 273 hours, with a median time of 5 hours, for the 69 fish detected at both ladder entrance and exit monitors. Median passage time through the right-bank ladder for 24 fish was 4 hours, with a range of 2 to 64 hours. Median

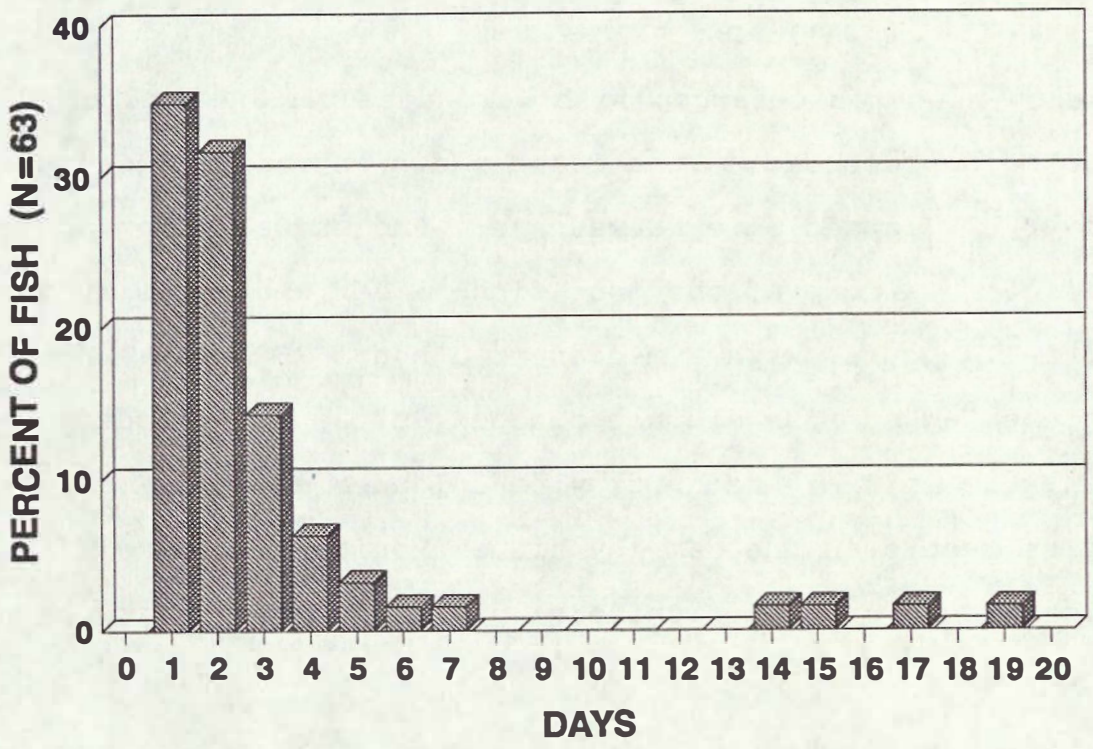

Figure 5.--Overall ladder passage times of radio-tagged sockeye salmon at Wells Dam.

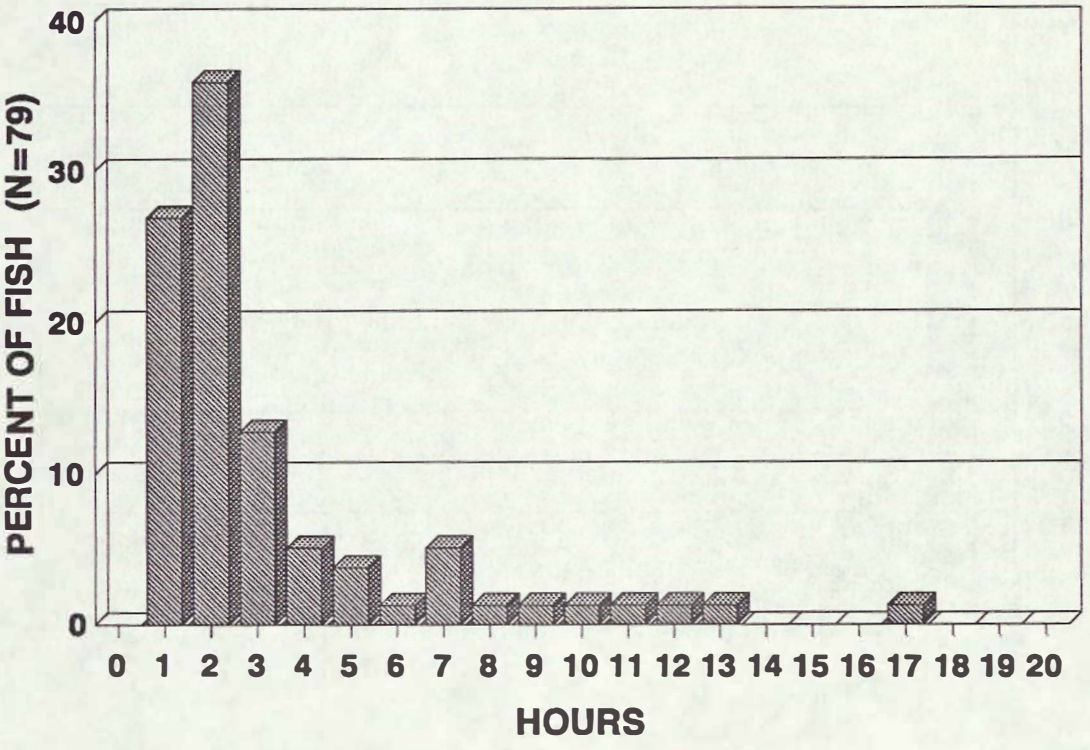

Figure 6.--Elapsed times of radio-tagged sockeye salmon between arriving at Wells Dam and the initial record at a fish-ladder entrance.

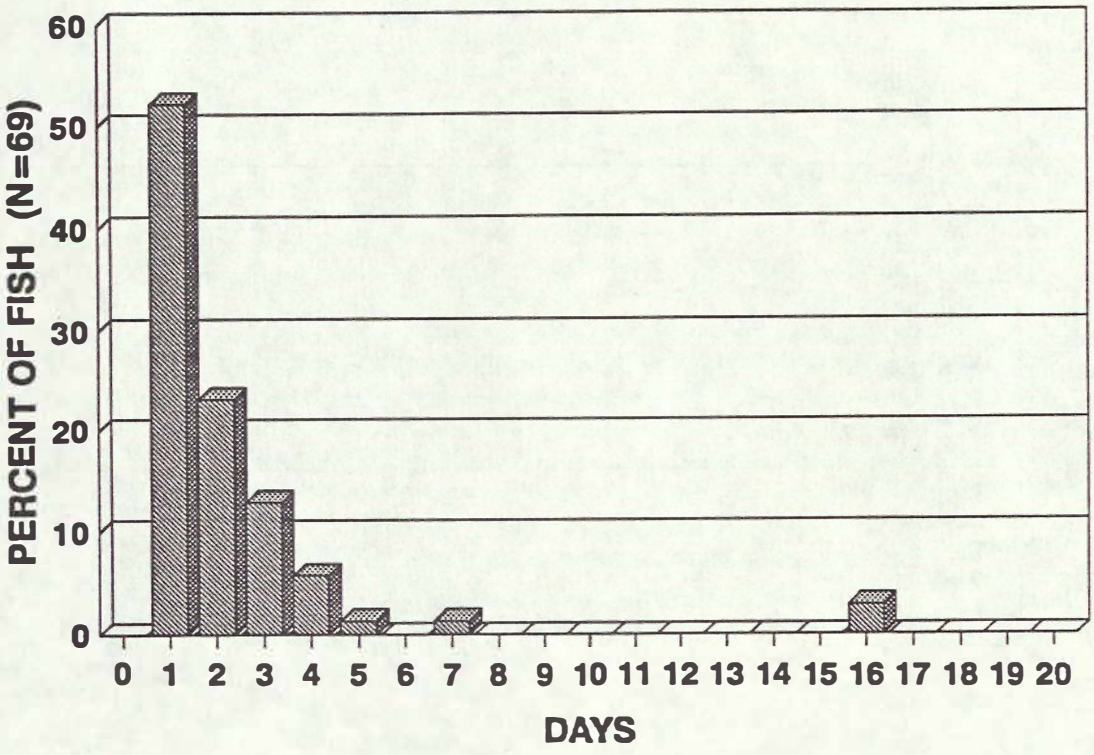

Figure 7.--Delay time in the tailrace before passage radio-tagged sockeye salmon at Wells Dam.

passage time in the left-bank ladder for 45 fish was 6 hours, with a range of 3 hours to a maximum of 273 hours (Fig. 8).

Monitoring of the 71 sockeye salmon recorded as exiting one of the two fish ladders at Wells Dam indicated that 40 (56%) of the tagged fish exited between 1100 and 1700 h, 17 (24%) exited between 0000 and 1030 h, and 14 (20%) exited between 1700 and 2329 h (Fig. 9).

Task 2. Evaluate fish-ladder entrance efficiency at Wells Dam. Determine fish-ladder entrance preferences under various operating conditions.

Task 2.1. Determine percentage of fish entries associated with each of the four fish-ladder entrance locations.

Operation of the adult trapping facility significantly ($x^2 = 5.84$; $P = 0.0156$) increased, but not substantially, left-bank entrance activity. During trapping periods, 63.9% of entrance activity was at the left fish ladder as opposed to 59.8% during non-trapping periods. For the total run, activity at the left and right entrance areas was 61.6 to 38.4%, respectively.

Fish activity increased at the left-bank entrance during trapping periods perhaps indicating indecisiveness regarding passage. However, overall passage was not affected.

At the right-bank fish ladder, the downstream entrance had 796 outside antenna records and 369 inside antenna records. The side entrance had 201 outside antenna records and 58 inside antenna records. At the left-bank fish ladder, the downstream

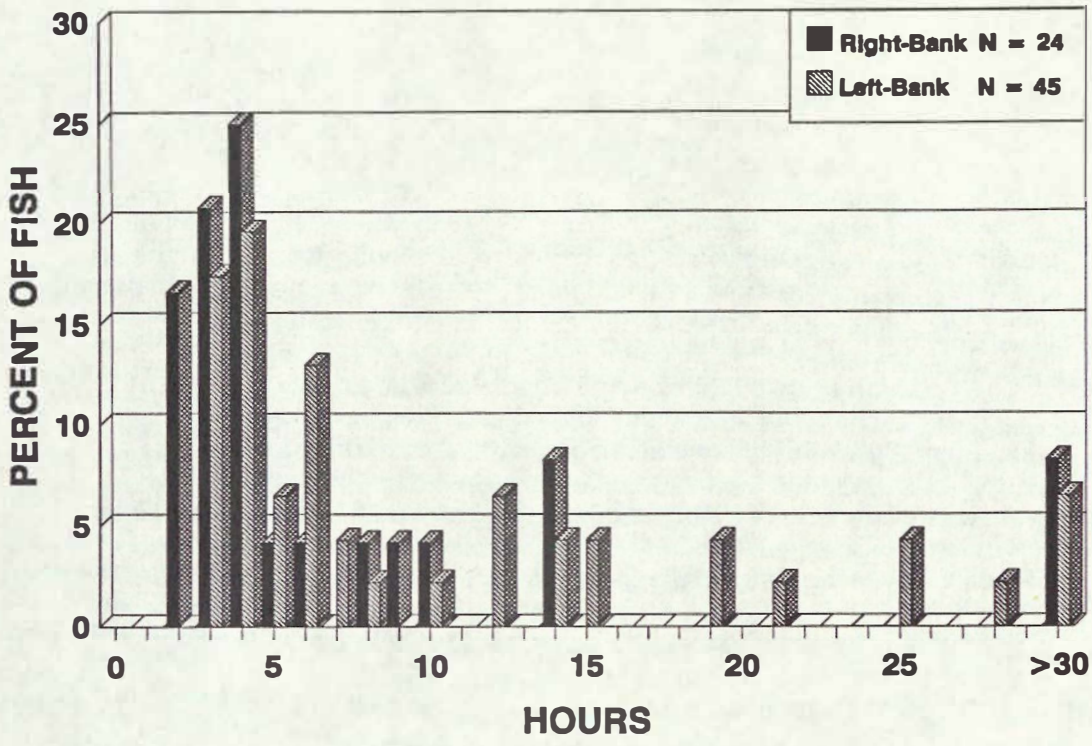

Figure 8.--Ladder-passage times of radio-tagged sockeye salmon at Wells Dam.

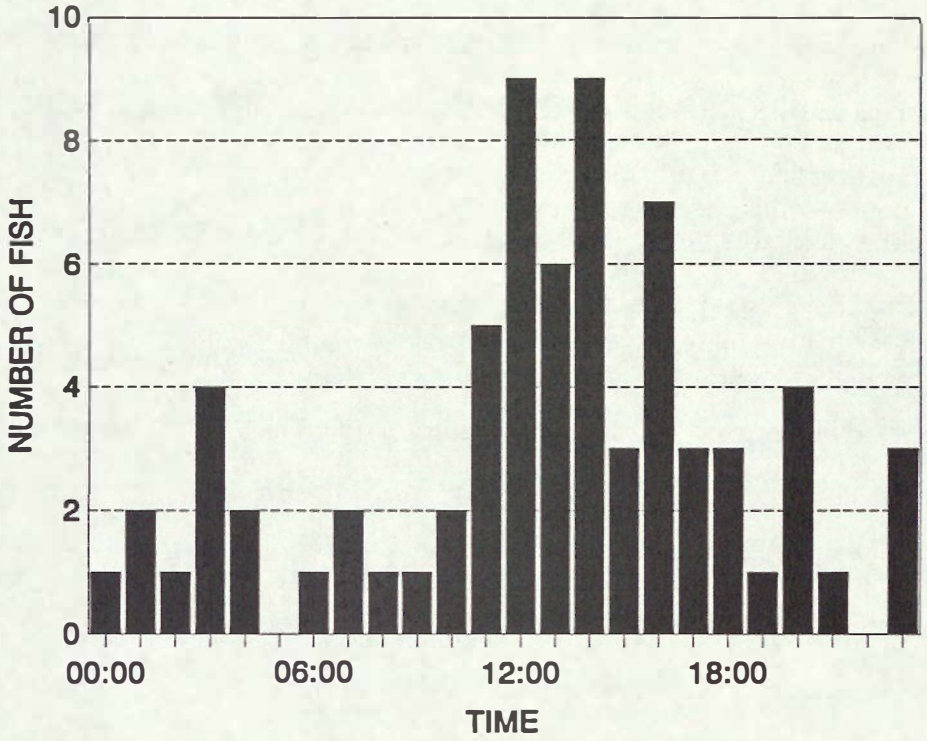

Figure 9.--Ladder-exit timing for radio-tagged sockeye salmon passing Wells Dam.

entrance had 735 outside antenna records and 1,132 inside antenna records, while the side entrance had 367 outside antenna records and 17 inside antenna records.

Task 2.2. Determine percentage of fish entries associated with successful ladder passage.

The left-bank fish ladder provided the highest passage (Fig. 10). Of the 69 radio-tagged sockeye salmon successfully passing over the fish ladders, 45 (65%) passed over the left-bank ladder and 24 (35%) passed over the right-bank ladder.

In both the right- and left-bank fish ladders, the end entrances provided much better passage than the side entrances. Thirty-one tagged fish (69%) passing over the left-bank fish ladder selected the end entrance, and 16 (67%) of those passing over the right-bank fish ladder preferred the end entrance.

Entrance efficiency was 24.5 and 41.5 entrance attempts at the left- and right-bank fish ladders, respectively for each tagged-fish passage recorded.

Task 3. Determine the fall-back rate and routes under various conditions of spill, flow, and powerhouse operation.

Spill occurred at Wells Dam during 1-27 July. Spill rate ranged from 4.1 to 7.6% of the flow (66 to 114 kcfs). Of 69 radio-tagged sockeye salmon, 52 (75%) passed during periods of spill and 17 (25%) passed during non-spill periods.

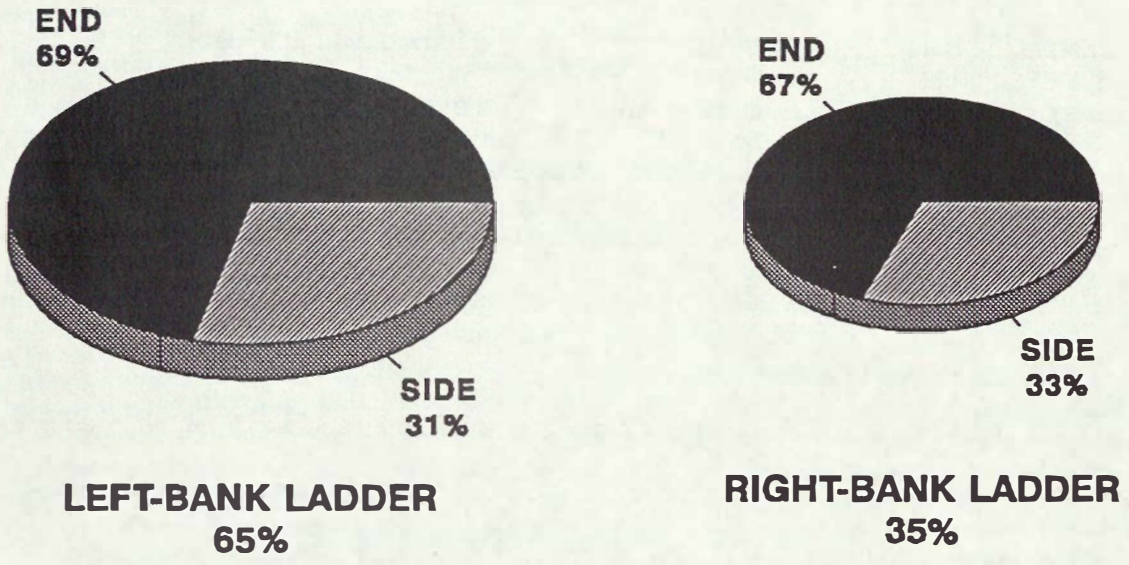

Figure 10.--Entrance selection by ladder by radio-tagged sockeye salmon at Wells Dam.

A "fallback" was defined as any fish passing the exit of a fish ladder that was subsequently found downstream in the tailrace. Nine (13%) of the 69 fish that passed Wells Dam fell back once (Fig. 11). Two of the nine fish fell back twice resulting in a total of 11 fallback occurrences. All of the fallbacks occurred during periods of spill.

One of the nine fish that fell back disappeared downstream. One fish fell back and reascended the fish ladder, but disappeared upstream from the dam. Five fish fell back, but subsequently passed the dam and entered the Okanogan River. Two fish fell back twice, before continuing upstream. One of these entered the Okanogan River and the other was recorded in the Chief Joseph Dam tailrace.

A total of 19 passes were made by the nine fish that fell back at Wells Dam, with eight fish continuing upstream after final passage. Therefore, the 52 radio-tagged sockeye salmon would have been counted as 63 fish passing the dam.

Fallback of adult sockeye salmon at Wells Dam during periods of spill appeared to inflate fish-ladder counts. The 1992 sockeye salmon passage at Wells Dam was 41,951 (U. S. Army Corps of Engineers 1992) with 35,303 (84%) passing during spill conditions, and 6,648 (16%) passing during non-spill conditions.

A correction factor to account for fallback at Wells Dam in 1992 was calculated by dividing 52 (number of radio-tagged sockeye salmon passing during spill conditions) by 63 (number of passes made by radio-tagged sockeye salmon during spill

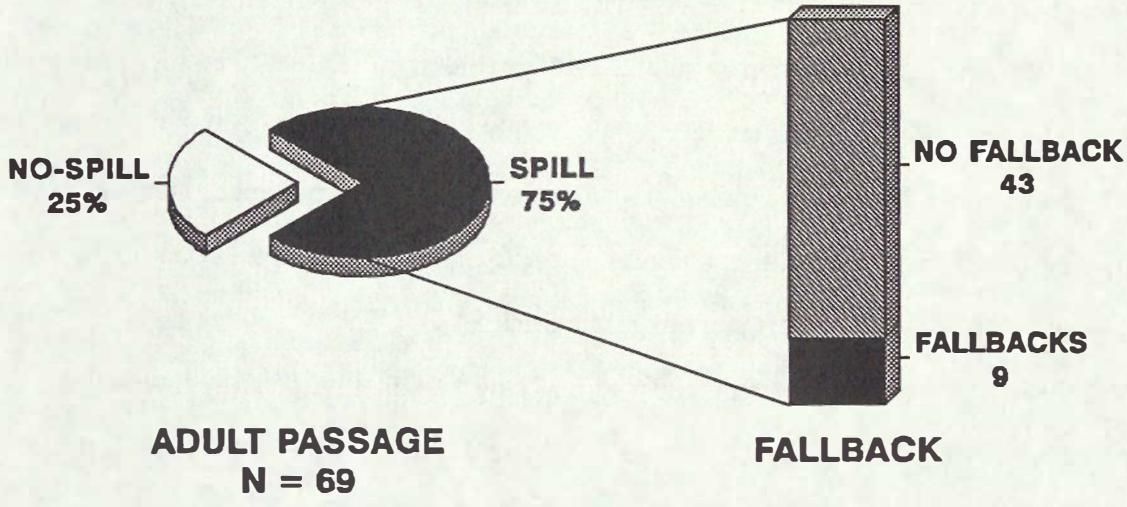

Figure 11.--Fallback rates of radio-tagged sockeye salmon during periods of spill at Wells Dam.

conditions). This factor, multiplied by 35,303 (fish count during spill), provided a corrected fish count of 29,139 fish (during spill). By adding the 6,648 (fish count during non-spill) the total adjusted run of sockeye salmon over Wells Dam in 1992 would be 35,787 fish. Dividing the total adjusted run (35,787 fish) by the total count (41,951 fish) provides a correction factor of 0.853 for the 1992 sockeye salmon count at Wells Dam.

This total adjusted run estimate was greater than Hansen's (1993) 1992 spawning population estimate of 22,587 fish. However, the comparison estimate of 34,679 fish (based on the "Factor 5" method) is relatively close. Differences in the estimates may be due to small sample size of radio-tagged fish, pre-spawning mortality, harvest, tributary escapement, etc.

In 1992, there was virtually no spill during the sockeye salmon run over Rocky Reach Dam. Therefore, fallback due to spill was non-existent. The fish-ladder count of sockeye salmon was 41,800 fish (U. S. Army Corps of Engineers 1992), 151 fish less than the count at Wells Dam, 61 km upstream. However, the adjusted count (to correct for fallback due to spill) at Wells Dam was 35,787 fish (6,013 less fish than the fish-ladder count at Rocky Reach Dam).

Based upon Bonneville Dam fallback data, increased spill rates would increase the rate of fallback (Liscom et al. 1985). Spilling at Wells Dam in July 1992 was not due to excess river flow, but was done to bypass juvenile salmonids downstream (Rick

Klinge, Douglas Co. PUD, personal communication 1994). Since 1992 was a low-flow year, migration years with high flows will have higher magnitudes of spill, potentially higher fallback rates, and inflated ladder counts. Further studies during years with mid- and high-flow conditions would provide data to develop a model for the correction of annual fish counts over Wells Dam.

Task 4. Determine the percentage of the tagged population exposed to the fishery at Chief Joseph Dam.

A portion of the sockeye salmon run may have been exposed to the fishery at Chief Joseph Dam. Fish entered the area, but radio interference prevented recordings of valid tag codes. Prior to relocating the monitor, only one tag (Tag 2328) was recorded, but never detected again. It was later recovered (non-working) on the spawning grounds. After relocation, 12 radio-tagged sockeye salmon were recorded. Of the 12 fish, 6 were subsequently recorded as entering the spawning area, and 6 were never recorded again. One additional radio tag (never recorded on Monitor 8) from a fish collected from the tailrace at Chief Joseph Dam was turned in for reward. This fish was among those recorded as successfully passing Wells Dam and was the only radio-tagged fish verified as harvested by the fishery.

In summary, 14 fish (15% of the tagged population) were potentially exposed to the fishery at Chief Joseph Dam tailrace.

Task 5. Determine spatial and temporal factors associated with sockeye salmon entry into the Okanogan River.

Task 5.1. Determine flows and temperatures.

Flows recorded at Tonasket (RKm 91.4) by the U.S. Geological Survey indicated a marked flow reduction of about 400 cfs beginning about 18 August and a substantial decrease in water temperature beginning on 22-24 August (Table 6). The migration up the Okanogan River coincided with the decreasing river flow and temperature (Fig. 12).

Major and Mighell (1966) determined that while high water temperature (above 21.1°C) in the Okanogan River was a major cause of delay for entry of sockeye salmon from the Columbia River, decreasing temperatures allow the migration to resume. Water temperature in rivers may be decreased by cool weather or through a mixing process (as at a confluence) by the addition of cooler water or reduction of warmer water. This mixing process at the confluence with the Similkameen River appears to have been instrumental in decreasing temperature in the lower Okanogan River.

Changes in flow proportions from the Similkameen and upper Okanogan Rivers appeared to directly affect water temperature in the lower Okanogan River. Prior to 17 August, 59% of the lower Okanogan River flow came from the Similkameen River. On 18 August flow over Zosel Dam was reduced by about 400 cfs resulting in an 84% contribution of Similkameen water to the lower Okanogan River flow through 25 August.

By 24 August, the temperature of the lower Okanogan River had been lowered substantially. Dennis Burton, Oroville-Tonasket Irrigation District, reported that mean daily water temperature

Table 6.--River flow and water temperature associated with radio-tagged sockeye salmon entry into the Okanogan River.

Date	Number of fish	Water temperature (°C)	River flow (cfs)
04 Aug		23.9	
06 Aug		20.9	
09 Aug	1		868
10 Aug	1		910
11 Aug		19.4	961
18 Aug		22.7	950
19 Aug		20.3	651
22 Aug	1		506
23 Aug	10		520
24 Aug	4	15.9	540
25 Aug	3		515
27 Aug		18.2	511
28 Aug	2		668
30 Aug		17.8	
	—		
	22		

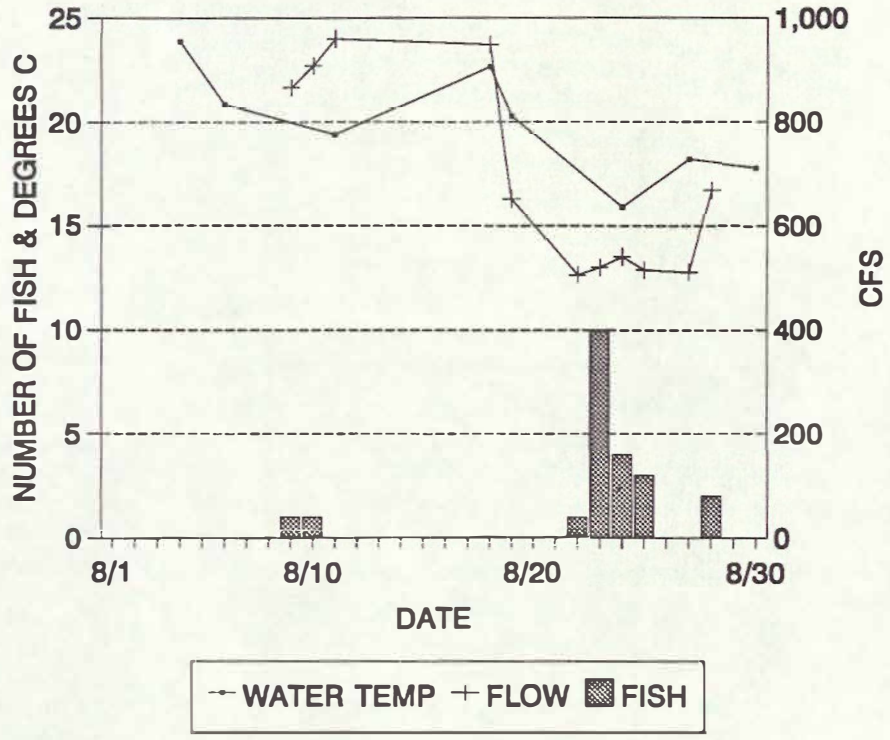

Figure 12.--Flow and water temperature during entry into the Okanogan River by radio-tagged sockeye salmon.

recorded downstream of Zosel Dam prior to 20 August was about 23.9° C, but decreased to 18.1° C by 24 August. However, water temperature in the Similkameen River was 21.8° C on 18 August, but decreased to 13.5° C by 24 August, apparently due to cool weather at the headwaters. The differences in water temperature in the two rivers and change in flow contribution resulted in the lower water temperatures of 22.7 and 15.9° C on 18 and 24 August, respectively, as measured at Ellisforde (RKm 102.5) 16.8 RKm downstream of the confluence.

Hansen (1993) also linked water flows and water temperatures at the mouth of the Similkameen River. Between 1-14 July when air temperatures would have been much higher, he found that the Similkameen River flowed cooler and apparently lowered the temperature of the Okanogan River at the confluence by as much as 2.9° C.

Task 5.2. Determine dates and diel timing.

Twenty-four radio-tagged sockeye salmon were recorded as they migrated past fixed-site Monitor 9 at Monse (Table 7). The first record was on 9 August at 1854 h, and the last record was on 28 August at 1823 h. Only three tagged fish, each on separate days, passed between 9 and 22 August. Ten fish (42%) passed on 23 August. The remaining 11 tagged fish entered the Okanogan River between 24 and 28 August.

Most movement was during the early morning hours (Fig. 13). Eleven (46%) of the 24 fish passed between 0400 and 0830 h. Six fish (25%) passed between 1600 and 2230 h.

Table 7.--Dates and diel timing of radio-tagged sockeye salmon entering the Okanogan River.

Entry date	Number of fish	Tag	Time recorded at Monitor 9
09 Aug	1	2541	1854
10 Aug	1	2444	1611
22 Aug	1	2546	1717
23 Aug	10	2349	0148
23 Aug		2229	0409
23 Aug		2237	0419
23 Aug		2250	0450
23 Aug		2342	0453
23 Aug		2335	0506
23 Aug		2346	0543
23 Aug		2143	0546
23 Aug		2243	0651
23 Aug		2439	0821
24 Aug	3	2536	0649
24 Aug		2145	1014
24 Aug		2442	2359
25 Aug	3	2430	0645
25 Aug		2138	1136
25 Aug		2339	2103
28 Aug	5	2429	1801
28 Aug		2531	1806
28 Aug		2437	1820
28 Aug		2534	1820
28 Aug		2435	1823
	24		

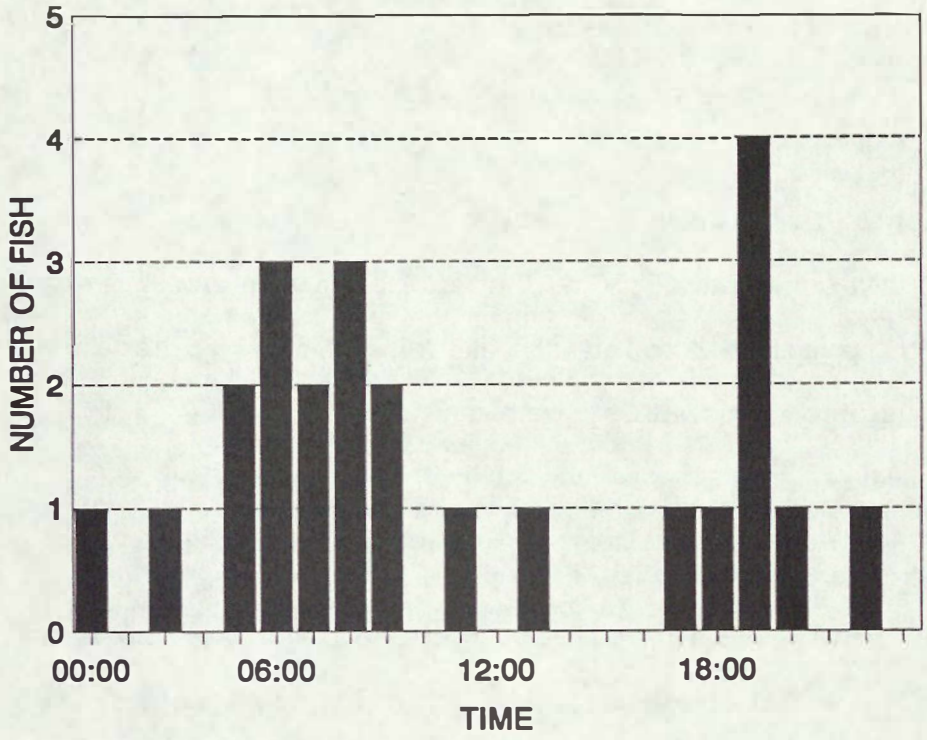

Figure 13.--Diel timing of radio-tagged sockeye salmon entering the Okanogan River.

Task 5.3. Determine behavioral patterns of fish that approach Chief Joseph Dam before entering the Okanogan River.

Three of the 14 radio-tagged fish detected near Chief Joseph Dam were monitored at the mouth of the Okanogan River by mobile tracking. Two of the three were recorded again on Monitor 9 (RKm 3.7), but only one was tracked further to RKm 69 in the Okanogan River. The tag was never recovered. The third fish was detected by mobile tracking at the mouth of the Methow River but was never seen again.

Three other fish were subsequently recovered on the spawning grounds. Two of those fish had been detected earlier by mobile tracking and remained around the mouth of the Okanogan River until the upstream migration began.

Task 6. Determine overall timing and rate of migration of sockeye salmon from Wells Dam forebay to Zosel Dam.

Twenty-six radio-tagged fish recorded as exiting a Wells Dam fish ladder were later detected at Zosel Dam. These fish took from 18.4 days to 83 days with a median of 36.4 days to migrate over the 150.6 km at a rate of 4.2 km per day (Fig. 14).

TASK 7. Determine rate of movement of sockeye salmon in the Okanogan River between river entry and Zosel Dam.

Sixteen fish entered the Okanogan River over a 4-day period (22-25 August) and arrived at Zosel Dam between 26 August and 4 October. These fish migrated upstream at a median rate of about 25 km per day, with a range of 1.7 to 41.8 days (median of

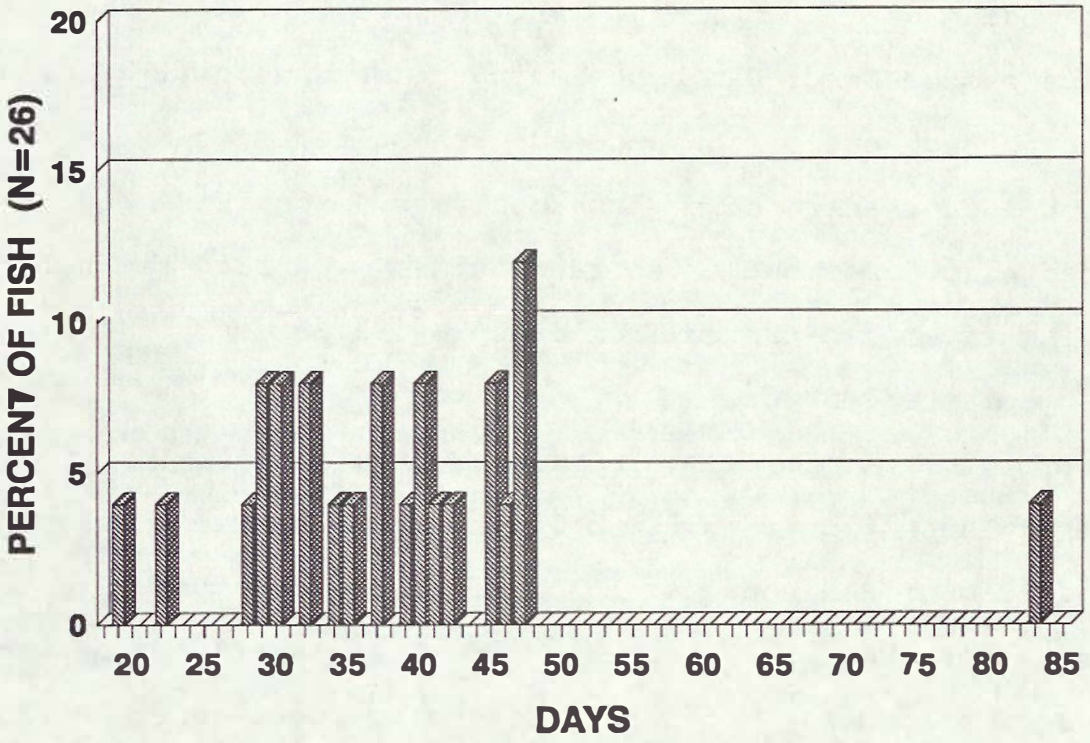

Figure 14.--Travel times of radio-tagged sockeye salmon from Wells Dam forebay to Zosel Dam.

4.6 days) to cover the 117 km distance from Monse (Monitor 9) to Zosel Dam (Fig. 15).

Task 8. Determine delay and passage time of sockeye salmon at Zosel Dam.

Twenty-nine radio-tagged sockeye salmon were detected when passing upstream from Zosel Dam. After arriving at Zosel Dam, overall time to pass ranged from 1 hour to a maximum of 240 hours with a median of 3 hours (Fig. 16). However, nine of these fish may have passed Zosel Dam by swimming under the spill gates or passing through one of the ladders without registering on either the fish-ladder entrance or exit monitors. Four fish had recorded exit times but no entrance times. Passage times for the remaining five fish ranged from 1 hour to a maximum of 111 hours with a median of 3 hours.

Twenty fish entered one of the two fish ladders (Monitors 10 and 11). These fish remained below the dam from less than 1 hour to a maximum of 235 hours with a median of 1 hour before entering a fish ladder (Fig. 17). Passage times were different between the two fish ladders. Of the 17 fish with known entrance and exit records, the nine left-bank fish ladder entries took from 2 to 28 minutes before exiting (median = 14 minutes). The remaining eight fish that entered the right-bank fish ladder took from 5 to 50 minutes (median = 18.5 minutes) before exiting (Fig. 18).

Of the 21 radio-tagged sockeye salmon with known exit records, 11 (52%) exited between 0100 and 0700 h, 2 (10%) exited between 0701 and 1400 h, and 8 (38%) exited between 1401 and 0100 h (Fig. 19).

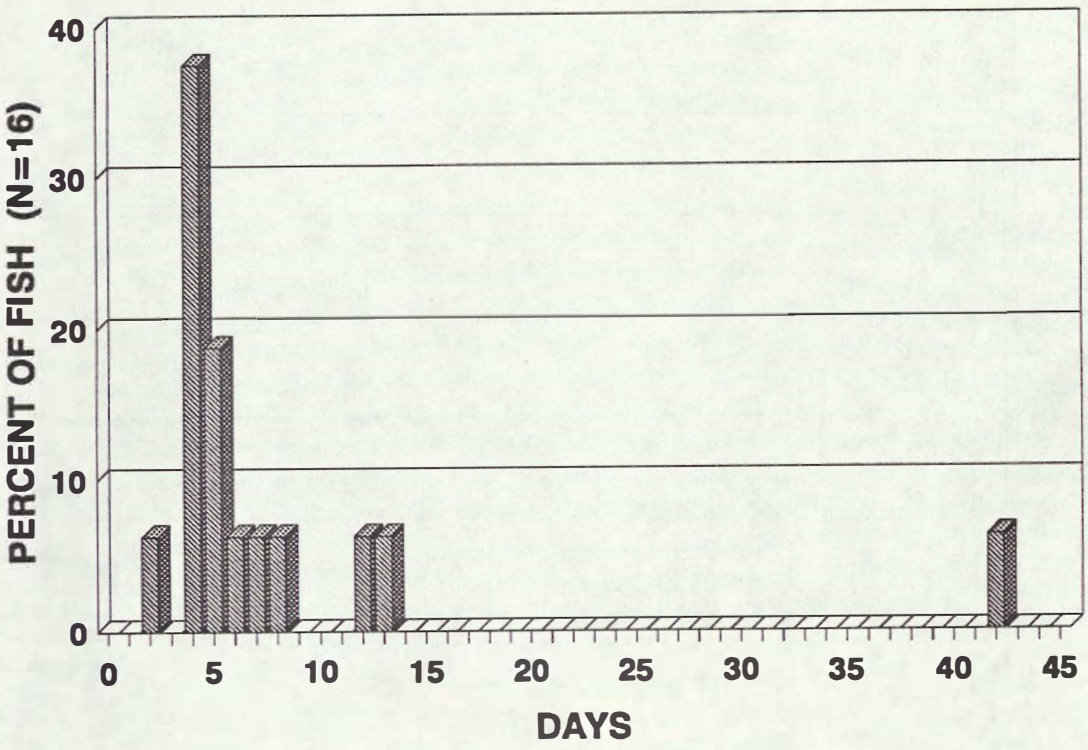

Figure 15.--Travel times of radio-tagged sockeye salmon from Okanogan River entry to Zosel Dam.

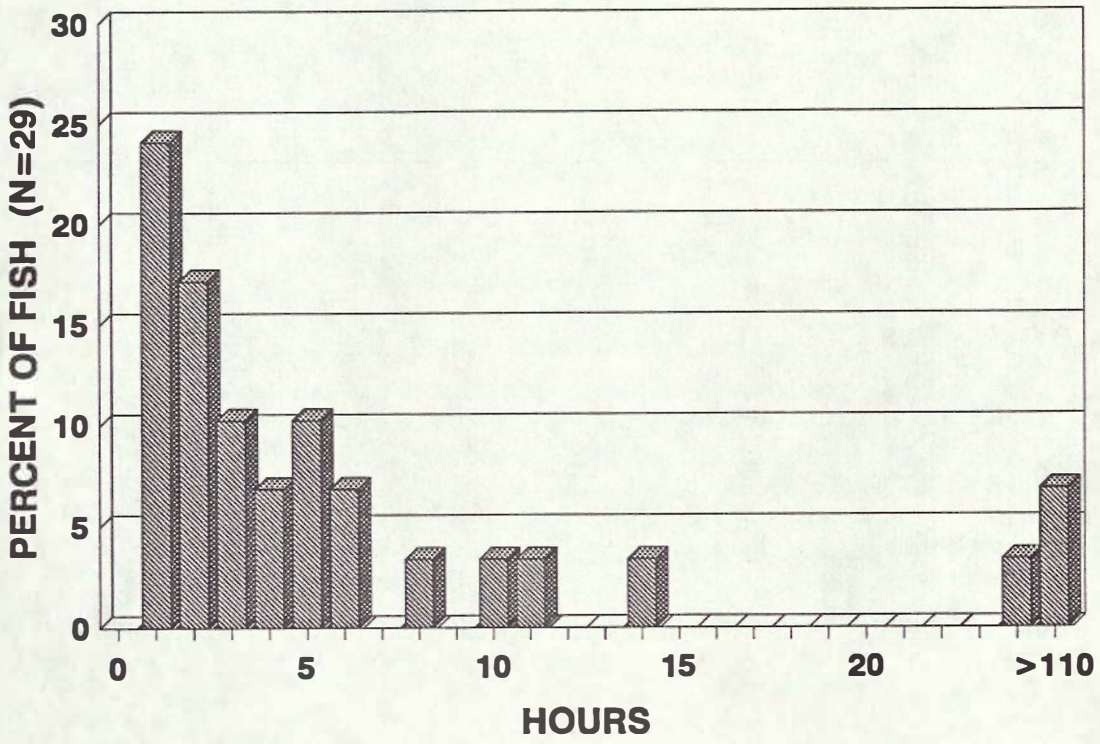

Figure 16.--Overall passage times of radio-tagged sockeye salmon at Zosel Dam.

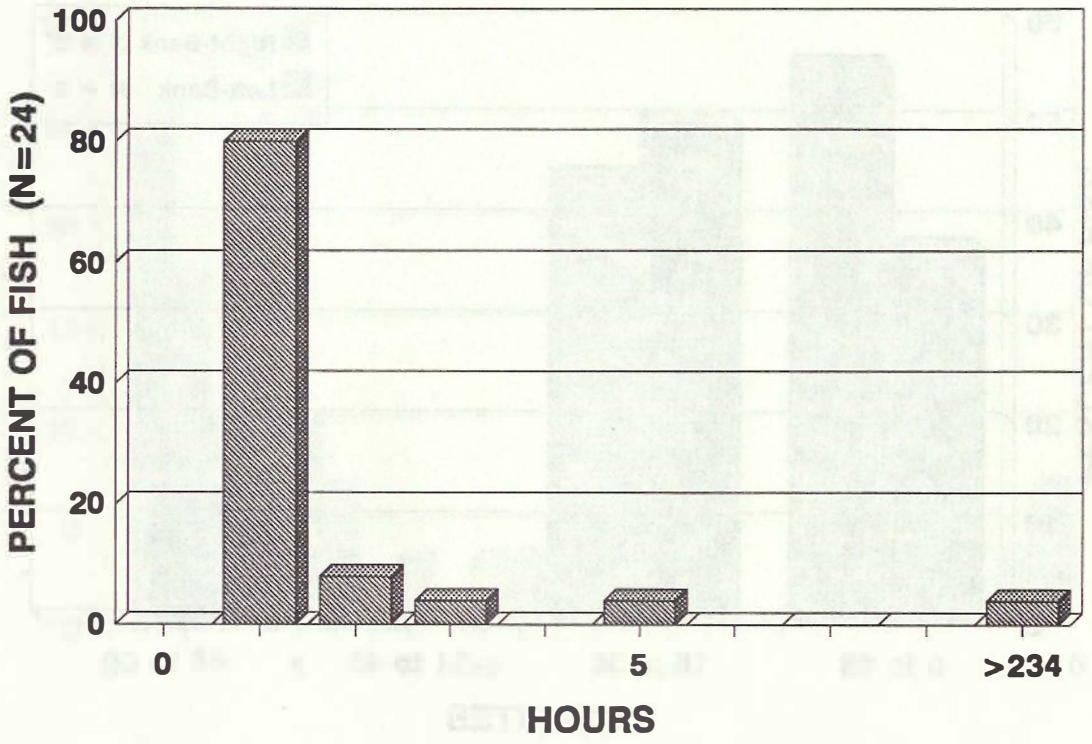

Figure 17.--Elapsed times of radio-tagged sockeye salmon in the tailrace before ladder entry at Zosel Dam.

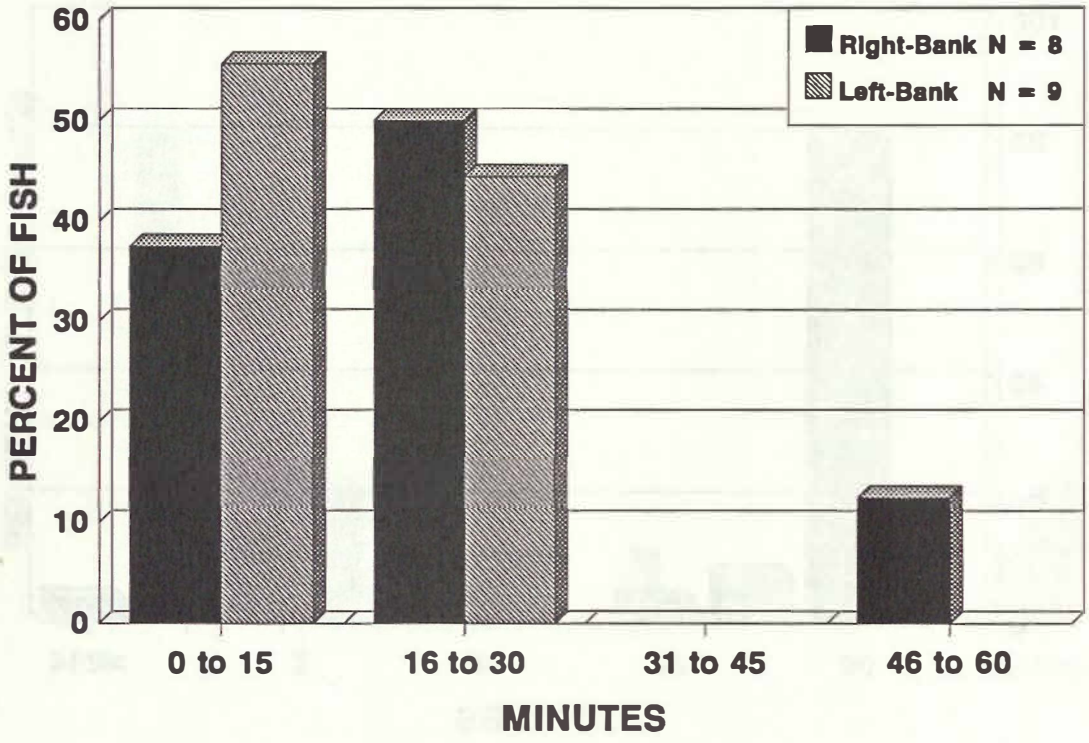

Figure 18.--Ladder-passage times of radio-tagged sockeye salmon at Zosel Dam.

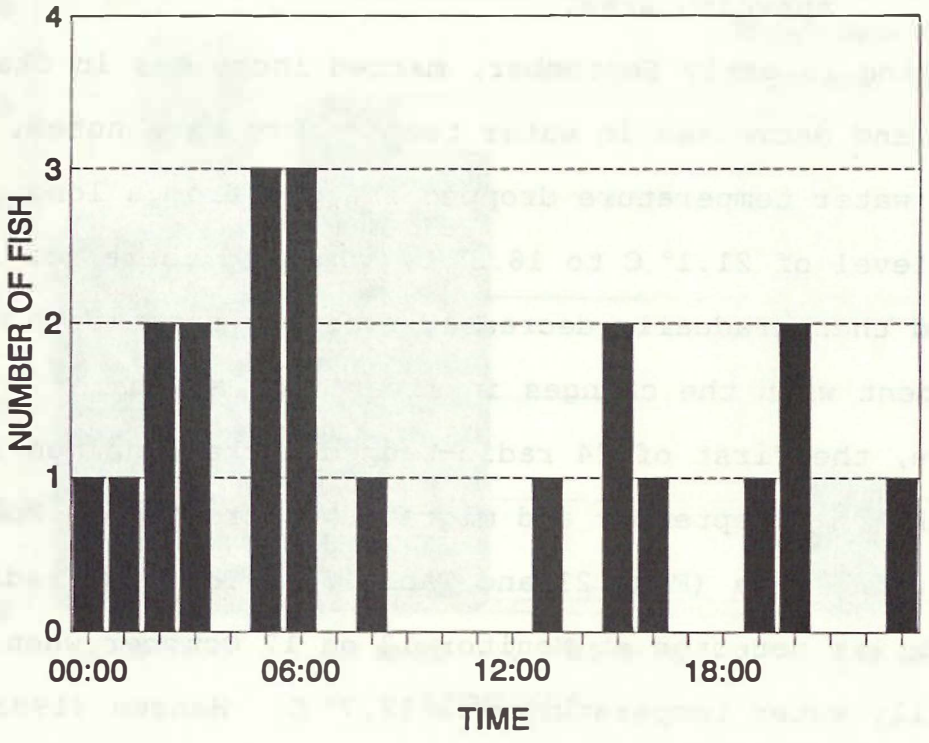

Figure 19.--Exit time from fish ladders of radio-tagged sockeye salmon passing Zosel Dam.

Task 9. Determine residence time of sockeye salmon in Osoyoos Lake before entering the spawning area.

Residence time for 22 tagged fish ranged from 16 hours to 46 days with a median of 28 days (Fig. 20). No fish were detected while they were in the lake, possibly as a result of holding in deeper waters.

Task 10. Determine river flow and temperature during the period sockeye salmon leave Osoyoos Lake for the spawning area.

Beginning in early September, marked increases in Okanogan River flow and decreases in water temperature were noted. On 5 September, water temperature dropped sharply from a long sustained level of 21.1° C to 18.3° C, remained there for about 1 week, and then gradually decreased over the next month.

Coincident with the changes in river flow and water temperature, the first of 24 radio-tagged sockeye salmon left Osoyoos Lake on 5 September and migrated upstream past Monitor 13 to the spawning area (Fig. 21 and Table 8). The last radio-tagged fish was detected at Monitor 13 on 17 October when the average daily water temperature was 12.7° C. Hansen (1993) also observed similar relationships among water temperature, river flow, and spawning activity. He noted slightly warmer temperatures in water when it passed from Vaseau Lake through Mcintyre Dam and that the water cooled as it proceeded south to Lake Osoyoos. However, when the weather cooled (or possibly when flows increased from releases) the water actually warmed by the time it reached the mouth at Lake Osoyoos. Hansen concluded that water temperature appeared to influence sockeye salmon movement and spawning activity.

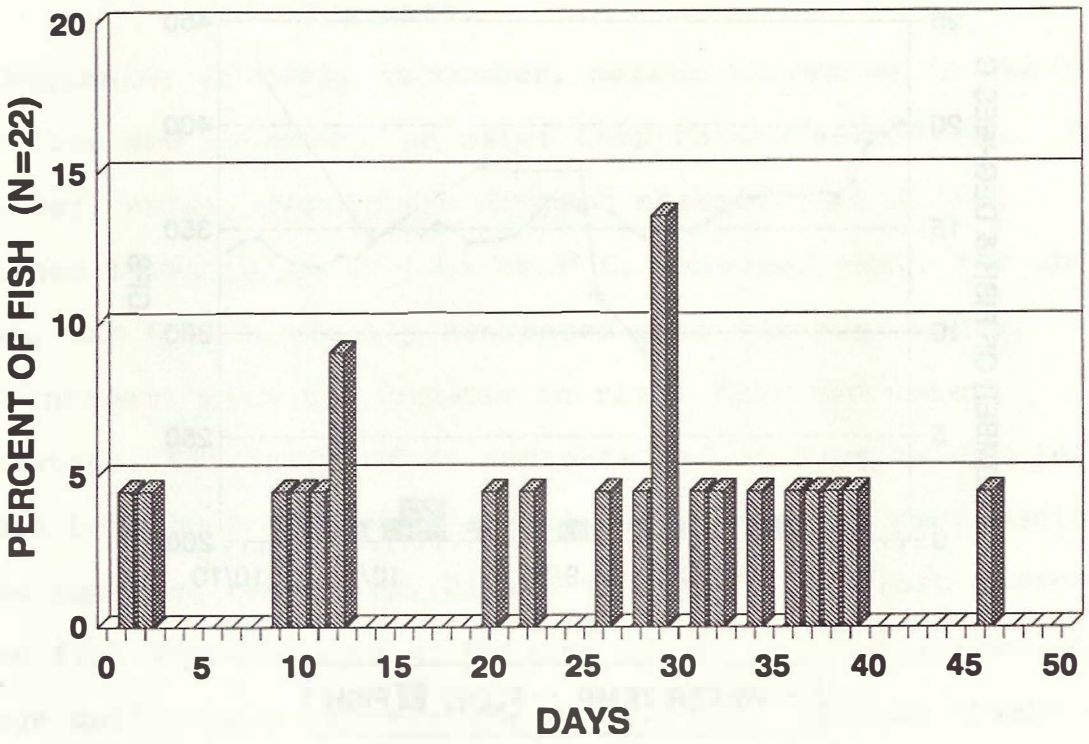

Figure 20.--Residence time for radio-tagged sockeye salmon in Osoyoos Lake before exiting to the spawning grounds.

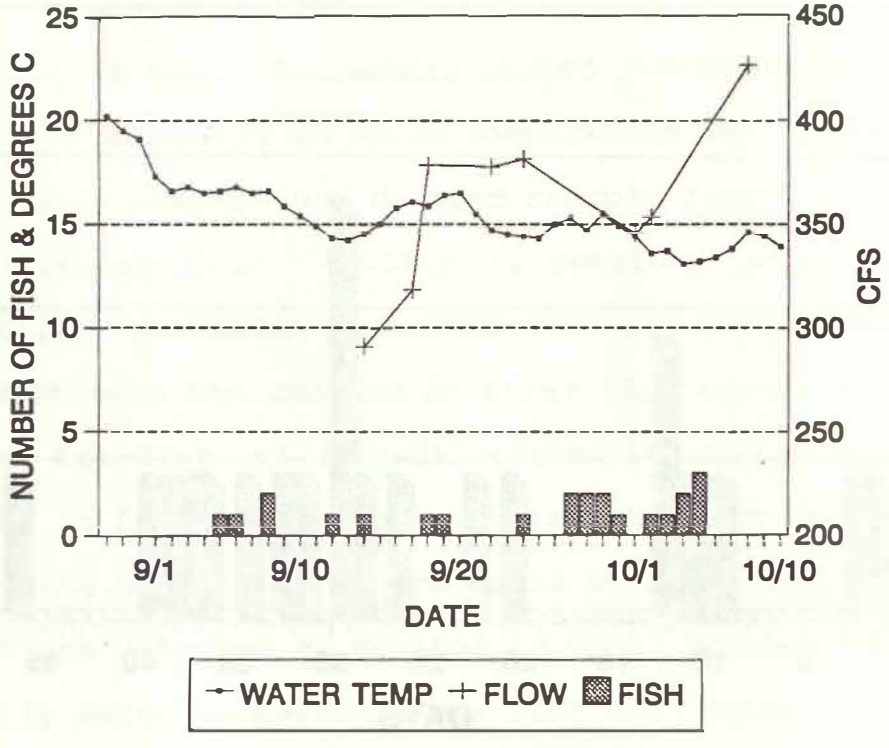

Figure 21.--Flow and water temperature during exit from Osoyoos Lake by radio-tagged sockeye salmon.

Table 8.--River flow and water temperature associated with radio-tagged sockeye salmon leaving Osoyoos Lake for the spawning area.

Date	Number of fish	Water temperature (°C)	River flow (cfs)
29 Aug		20.2	
30 Aug		19.5	
31 Aug		19.1	
01 Sep		17.3	
02 Sep		16.6	
03 Sep		16.6	
04 Sep		15.7	
05 Sep	1	16.6	
06 Sep	1	16.8	
07 Sep		16.5	
08 Sep	2	16.6	
09 Sep		15.9	
10 Sep		15.4	
11 Sep		14.9	
12 Sep	1	14.3	
13 Sep		14.2	
14 Sep	1	14.5	291.1
15 Sep		15.0	
16 Sep		15.8	
17 Sep		16.1	318.3
18 Sep	1	15.9	378.2
19 Sep	1	16.4	
20 Sep		16.5	
21 Sep		15.5	
22 Sep		14.7	377.7
23 Sep		14.5	
24 Sep	1	14.4	381.2
25 Sep		14.3	
26 Sep		15.0	
27 Sep	2	15.3	
28 Sep	2	14.7	
29 Sep	2	15.5	
30 Sep	1	14.9	
01 Oct		14.4	345.4
02 Oct	1	13.6	353.6
03 Oct	1	13.7	
04 Oct	2	13.1	
05 Oct	3	13.2	
06 Oct		13.4	
07 Oct		13.8	
08 Oct		14.6	426.7
09 Oct		14.4	
10 Oct		13.9	
11 Oct		13.2	
12 Oct		12.9	
13 Oct		12.7	
14 Oct		13.0	
15 Oct		13.3	
16 Oct		13.3	
17 Oct	1	12.7	
	24		

Seventy-one percent of the fish migrated from the lake between 2000 and 0200 h (Fig. 22 and Table 9). The inlet to the lake flows over a wide shallow delta which may influence preference of the fish for nocturnal passage.

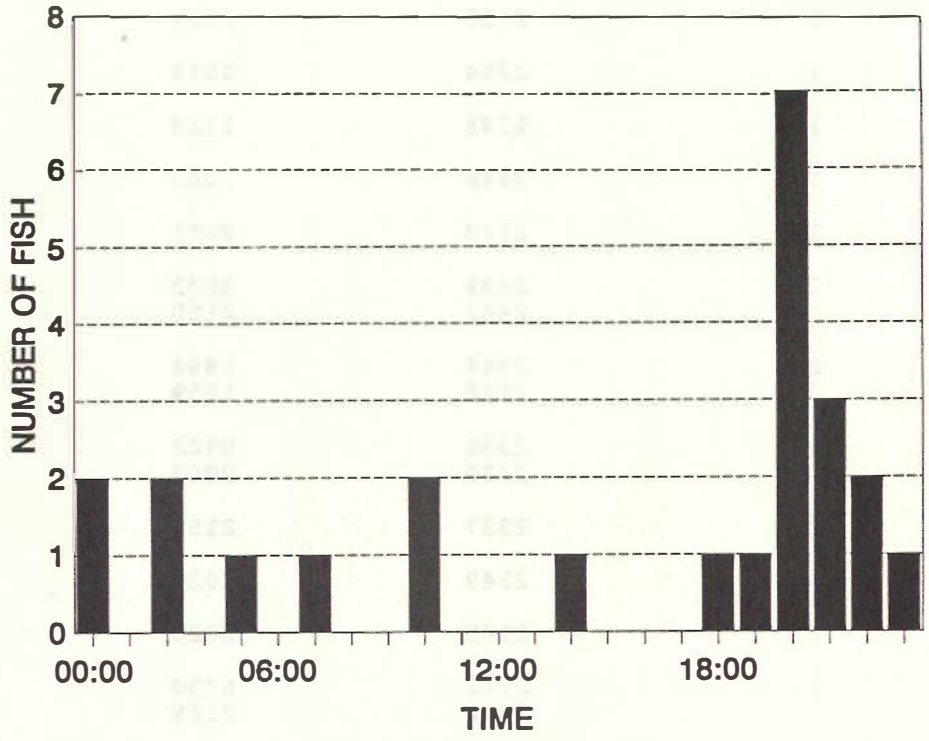

Figure 22.--Diel timing for radio-tagged sockeye salmon leaving Osoyoos Lake for the spawning grounds.

Table 9.--Dates and diel timing of radio-tagged sockeye salmon leaving Osoyoos Lake for the spawning area.

Exit date	Number of fish	Tag	Time recorded at Monitor 13
05 Sep	1	2250	0513
06 Sep	1	2342	2222
08 Sep	2	2336	2008
08 Sep		2430	2133
12 Sep	1	2535	2357
14 Sep	1	2344	1018
18 Sep	1	2348	1128
19 Sep	1	2148	0053
24 Sep	1	2143	0151
27 Sep	2	2439	2003
27 Sep		2442	2150
28 Sep	2	2544	1944
28 Sep		2542	1959
29 Sep	2	2335	0702
29 Sep		2339	2007
30 Sep	1	2337	2156
02 Oct	1	2349	2028
03 Oct	1	2145	2020
04 Oct	2	2243	0430
04 Oct		2546	2125
05 Oct	3	2536	0400
05 Oct		2350	1802
05 Oct		2346	2255
17 Oct	1	2445	2359
	24		

SUMMARY

Radio-tagged sockeye salmon migrated upstream from Rocky Reach Dam to Wells Dam (67.4 km) in about 37 hours. Upon arriving at Wells Dam, median passage time was about 30 hours.

Summaries by task were:

Task 1.1. The median time between at-dam arrival (entering dam tailrace) and initial record at a fish-ladder entrance at Wells Dam was 2 hours. However, the median time from first record at the dam (by either Monitor 1 or one of the four fish-ladder entrance monitors) until last record at a fish-ladder entrance was 1 day.

Task 1.2. The median fish-ladder entrance to exit time for both fish ladders combined was 5 hours. Median passage time through the right-bank fish ladder was 4 hours. Median passage time in the left-bank fish ladder was 6 hours.

Fifty-six percent of the fish exited between 1100 and 1700 h, 24% exited between 0000 and 1030 h, and 20% exited between 1700 and 2329 h.

Task 2.1. The left-bank fish ladder had a higher entrance activity and a much higher entrance efficiency than the right-bank fish ladder. Operation of the adult trapping facility significantly increased left-bank entrance activity. During trapping periods, 63.9% of entrance activity was at the left-bank fish ladder. For the total run, radio-tagged fish activity at the left-bank entrance area was 61.6%.

Task 2.2. Fish preferred the left-bank fish ladder at Wells Dam. The end entrances provided better passage than the side entrances in both the right- and left-bank fish ladders.

Task 3. Fallback of adult sockeye salmon occurred during periods of spill at Wells Dam. Fallback and its relationship to varying spill conditions at Wells Dam may be related to operational scenarios as well as to spill volumes.

Task 4. Fifteen percent of the radio-tagged fish were potentially exposed to the fishery at Chief Joseph Dam tailrace.

Task 5.1. The major migration of sockeye salmon into the Okanogan River coincided with a marked reduction in river flow (from about 950 to 510 cfs) beginning about 19 August and a decrease in water temperature (20.3 to 15.9°C) beginning on 22-24 August.

Task 5.2. Radio-tagged sockeye salmon entered the Okanogan River from 9 to 28 August, with approximately 80% of the migration occurring between 23 and 28 August. Forty-six percent entered the Okanogan River between 0400 and 0830 h, and 25% between 1600 and 2230 h. Most movement, therefore, was during the early morning hours.

Task 5.3. About half of the radio-tagged sockeye salmon that approached Chief Joseph Dam were subsequently recorded at or slightly upstream from the mouth of the Okanogan River or on the spawning grounds in Canada.

Task 6. Radio-tagged sockeye salmon that exited Wells Dam fish ladders between 13 July and 8 August arrived at Zosel Dam

between 21 August and 4 October. Median migration time from Wells Dam to Zosel Dam was 36.4 days at a rate of 4.2 km per day.

Task 7. Radio-tagged sockeye salmon required a median of 4.6 days to travel the 117 km distance between Okanogan River entry and Zosel Dam.

Task 8. After arriving at Zosel Dam, the overall median passage time past the dam was 3 hours. Median time before fish-ladder entry was less than 1 hour. About 52% of the fish exited between 0100 and 0700 h, and 38% exited between 1401 and 0100 h. Passage time differed between the two fish ladders. Median passage time for radio-tagged-fish entering the left-bank fish ladder was 14 minutes, while median passage time for the right-bank fish ladder was 18.5 minutes.

Some fish apparently passed Zosel Dam by swimming under the spill gates or managed to pass through one of the fish ladders without being recorded on either the entrance or exit monitors.

Task 9. Residence time for radio-tagged sockeye salmon in Osoyoos Lake before entering the spawning grounds ranged from 16 hours to 46 days with a median of 28 days.

Task 10. A marked change in daily Okanogan River flow and temperature was noted during the period sockeye salmon began to leave Osoyoos Lake for the spawning area. Flow increased about 40 cfs, and water temperature decreased from a long sustained level of near 21.1° C to about 18.3° C, remained there for about 1 week, and then gradually decreased to 10° C over the next

month. The last radio-tagged fish was detected at Monitor 13 on 17 October when the average daily water temperature was 12.7° C. Seventy-one percent of the radio-tagged sockeye salmon passed from the lake between 2000 and 0200 h.

RECOMMENDATIONS

1. We recommend, in the event of water shortage or restrictions in normal fish-ladder operations at Wells Dam, that the end entrances be selected for use over the side entrances; in more severe circumstances, we recommend that the left-bank fish ladder be operated in lieu of the right-bank fish ladder.

2. Fallback appears to directly contribute to inflated passage counts at Wells Dam. A correction factor of 0.853 should be applied to total numbers of sockeye salmon counted over Wells Dam in 1992 for a more accurate escapement estimate. Further radio-tracking studies focusing on fallback and its effects during varying spill conditions at all mid-Columbia River dams should be conducted.

3. We determined that 15% of the radio-tagged sockeye salmon were exposed to the "snag" fishery in the Chief Joseph Dam tailrace. Accurate harvest records for that fishery should be implemented.

4. Results from radio-tagged sockeye salmon indicated that delay was minimal at Zosel Dam and that most fish passed during night-time periods when their movement could not be observed. No structural changes to fish-passage facilities at Zosel Dam appear to be warranted. However, a concerted effort to determine extent of spawning, carcass counts, and harvest should be conducted for the area downstream of Zosel Dam and in the Similkameen River to account for missing fish and determine extent of spawning.

5. Increased flow, decreasing water temperature, and darkness coincided with the period most radio-tagged sockeye salmon left Osoyoos Lake for the spawning area. Manipulation of flow and water together by water management agencies may enhance sockeye salmon spawning and prevent de-watering of redds.

6. A thermal block generally occurs each summer at the mouth of the Okanogan River delaying the sockeye salmon migration until water temperature decreases to less than 21.1°C. Proportionate flows from the Similkameen River (cooler) and surface water passing over Zosel Dam from Lake Osoyoos (warmer) appear to directly affect water temperatures in the lower Okanogan River. Water regulation operations and their effect on water temperatures and flows in the Okanogan River system should be reviewed.

ACKNOWLEDGMENTS

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REFERENCES

Fryer, J. K., and M. Schwartzberg. 1991. Identification of Columbia Basin sockeye salmon stocks based on scale pattern analyses, 1990. Columbia River Inter-Tribal Fish Commission Tech. Rep. 91-2, 40 p. (Available from Columbia River Inter-Tribal Fish Commission, 975 S. E. Sandy, Suite #202, Portland, OR, 97214).

Hansen, J. 1993. Upper Okanogan River sockeye salmon spawning ground survey - 1992. Colville Confederated Tribes, Fish and Wildlife Department, Nespelem, Washington. Report for the Douglas County Public Utility District, 79 p. (Available from Colville Confederated Tribes, Fish and Wildlife Dept., Box 150, Nespelem, WA 99155).

Liscom, K. L., G. E. Monan, L. C. Stuehrenberg, and P. J. Wilder. 1985. Radio-tracking studies on adult chinook salmon and steelhead trout at lower Columbia River hydroelectric dams, 1971-77. NOAA Tech. Memo. NMFS F/NWC-81, 225 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd E., Seattle, WA 98112-2097.)

Major, R. L., and J. L. Mighell. 1966. Influence of Rocky Reach Dam and the temperature of the Okanogan River on the upstream migration of sockeye salmon. Fish. Bull. 66(1): 131-147.

Pratt, K. L., D. W. Chapman, and M. Hill. 1991. Potential to enhance sockeye salmon upstream from Wells Dam. Report to Douglas County Public Utility District, 87 p. (Available from Don Chapman Consultants, 3180 Airport Way, Boise, ID 83705.)

U. S. Army Corps of Engineers. 1992. Monthly fish passage summary reports. (Available from U.S. Army Corps of Engineers, Portland District, Portland, OR 97014.)

APPENDIX

Appendix Table 1.--Characteristics and fate of radio-tagged sockeye salmon.

Tag	Length (cm)	Weight (g)	Age	Last record		
				River	RKm	Fate
2128	52.1	1362.0	1.2	Columbia	832.4	Recorded
2130	48.5	998.8	1.2	Okanogan	3.2	Recorded
2131	55.5	1589.0	1.3	Columbia	763.1	Recorded
2134	50.8	1135.0	1.2	Okanogan	165.0	Recovered
2135	54.0	1362.0	1.2	Okanogan	0.0	Recorded
2137	50.8	1135.0	1.2	Okanogan	167.4	Recorded
2138	43.5	635.6	1.2	Okanogan	69.2	Recorded
2139	48.3	908.0	1.2	Columbia	858.1	Recorded
2141	50.8	1180.4	1.2	Columbia	832.4	Recorded
2142	50.5	1135.0	1.2	Columbia	872.6	Harvest
2143	51.9	1362.0	1.2	Okanogan	161.0	Recovered
2144	54.0	1498.2	1.2	Columbia	832.4	Recorded
2145	51.5	1271.2	1.2	Okanogan	164.2	Recovered
2146	46.0	771.8	1.2	Columbia	832.4	Recorded
2147	52.2	1225.8	1.2	Columbia	763.1	Recorded
2148	50.8	1362.0	1.2	Okanogan	161.0	Recovered
2149	54.0	1362.0	1.3	Columbia	872.6	Recorded
2150	53.3	1135.0	1.2	Columbia	832.4	Recorded
2229	49.5	1135.0	1.2	Okanogan	124.6	Recorded
2231	53.8	1180.4	1.2	Okanogan	4.8	Recorded
2234	52.2	1316.6	1.2	Okanogan	0.0	Recorded
2235	54.6	1816.0	1.2	Columbia	832.4	Recorded
2236	48.0	998.8	1.2	Okanogan	124.6	Recorded
2237	50.0	998.8	1.2	Okanogan	124.6	Recorded
2238	50.8	1135.0	1.2	Columbia	872.6	Recorded
2240	51.0	862.6	1.2	Methow	51.5	Hatchery
2241	47.2	953.4	1.2	Columbia	832.4	Recorded
2242	50.8	1135.0	1.2	Okanogan	162.6	Recovered
2243	45.7	908.0	1.2	Okanogan	161.0	Recorded
2244	56.2	1725.2	1.3	Columbia	829.2	Recorded
2245	52.0	1271.2	1.2	Okanogan	162.6	Recovered
2246	60.0	1997.6	1.3	Columbia	872.6	Recorded
2247	50.5	1044.2	1.2	Okanogan	159.4	Recovered
2249[1]	51.5	1135.0	1.2	Columbia	832.4	Recorded
2250	51.4	1135.0	1.2	Okanogan	161.0	Recovered
2328	50.5	1135.0	1.2	Okanogan	162.6	Recovered
2329	53.0	1271.2	1.2	Columbia	858.1	Recorded
2330	50.7	1180.4	1.2	Okanogan	165.8	Recovered
2331	48.2	1135.0	1.2	Columbia	832.4	Recorded
2334	60.0	1997.6	1.3	Columbia	829.2	Recorded
2335	52.3	1362.0	1.2	Okanogan	162.6	Recovered
2336	58.0	1725.2	1.3	Okanogan	165.8	Recorded
2337	49.2	953.4	1.2	Okanogan	146.2	Recorded

Appendix Table 1.--continued.

Tag	Length (cm)	Weight (g)	Age	Last record		
				River	RKm	Fate
2338	50.5	1089.6	1.2	Okanogan	124.6	Recovered
2339	50.5	1044.2	1.2	Okanogan	163.4	Recovered
2340	50.5	1089.6	1.2	Okanogan	124.6	Recorded
2341	52.1	1362.0	1.2	Okanogan	2.4	Recorded
2342	53.0	1225.8	1.2	Okanogan	165.8	Recorded
2343	47.0	908.0	1.2	Okanogan	0.0	Recorded
2344	51.4	1225.8	1.2	Okanogan	146.2	Recorded
2345	52.4	1271.2	1.2	Okanogan	0.0	Recorded
2346	48.3	908.0	1.2	Okanogan	163.9	Recovered
2348	53.3	1589.0	1.2	Okanogan	162.6	Recovered
2349	48.3	998.8	1.2	Okanogan	164.2	Recorded
2350	53.0	1452.8	1.2	Okanogan	162.6	Recorded
2423[1]	54.1	1543.6	1.2	Columbia	829.2	Recorded
2429	49.7	1044.2	1.2	Okanogan	9.7	Recorded
2430	47.1	998.8	1.2	Okanogan	161.0	Recovered
2431	47.5	908.0	1.2	Okanogan	124.6	Recorded
2434	48.2	908.0	2.2	Columbia	875.8	Recorded
2435	49.5	1135.0	1.2	Okanogan	9.7	Recorded
2436	49.0	1044.2	1.2	Okanogan	162.6	Recovered
2437	49.5	1135.0	1.2	Okanogan	162.6	Recovered
2438	49.5	1135.0	1.2	Columbia	832.4	Recorded
2439	52.4	1271.2	1.2	Okanogan	162.6	Recovered
2441	48.3	1135.0	1.2	Columbia	859.7	Recorded
2442	48.9	998.8	1.2	Okanogan	167.4	Recovered
2443	48.0	998.8	1.2	Okanogan	2.3	Recorded
2444	51.5	1089.6	1.2	Smilkameen	4.8	Recovered
2445	48.7	908.0	1.2	Okanogan	146.2	Recorded
2446	52.0	1271.2	1.2	Okanogan	124.6	Recorded
2447	48.2	1135.0	1.2	Okanogan	162.6	Recovered
2448	45.0	771.8	1.2	Okanogan	124.6	Recorded
2449	42.4	726.4	2.1	Okanogan	3.2	Recorded
2450	49.5	953.4	1.2	Okanogan	3.2	Recorded
2528	50.0	953.4	1.2	Columbia	83.2	Recorded
2529	50.8	908.0	1.2	Okanogan	90.2	Recovered
2530	50.8	1044.2	1.2	Columbia	829.2	Recorded
2531	49.0	998.8	1.2	Okanogan	75.7	Recovered
2534[2]	47.0	908.0	nd	Okanogan	164.2	Recovered
2535	49.3	908.0	1.2	Okanogan	164.2	Recovered
2536	48.5	908.0	1.2	Okanogan	162.6	Recovered
2537	46.0	817.2	1.2	Okanogan	3.2	Recorded
2538	50.8	1362.0	1.2	Columbia	829.2	Recorded
2539	48.2	1135.0	1.2	Columbia	763.1	Recorded
2540	48.8	953.4	1.2	Methow	51.5	Hatchery
2541[3]	52.0	1225.8	1.2	Columbia	763.1	Regurg.
2541	46.8	862.6	2.2	Okanogan	123.3	Recovered
2542	46.4	908.0	1.2	Okanogan	162.6	Recorded

Appendix Table 1.--continued.

Tag	Length (cm)	Weight (g)	Age	Last record		
				River	RKm	Fate
2543	53.4	1225.8	1.2	Columbia	829.2	Recorded
2544	50.2	1135.0	1.2	Okanogan	162.6	Recorded
2545	50.8	1135.0	1.2	Okanogan	124.6	Recorded
2546	52.5	1407.4	1.2	Okanogan	164.2	Recovered
2547	46.4	817.2	1.2	Okanogan	159.4	Recovered
2548	49.0	998.8	1.2	Columbia	872.6	Recorded
2549	51.0	1089.6	1.2	Columbia	872.6	Recorded
2550	52.0	1225.8	1.2	Okanogan	162.6	Recovered

[1] Possible age 2.2 Wenatchee River sockeye salmon.
[2] Age not determined.
[3] Tag regurgitated in holding tank prior to release, therefore reused.

Appendix Table 2.--Histories of individual radio tags, mid-Columbia River radio-telemetry study, 1992.

Tag	Release		Arrive Wells Dam		Exit Wells Dam		Monitor	M 8		M 9	Arrive Zosel Dam		Exit Zosel Dam		Ladder	Arrive M 13		Exit M 13	
	Date	Time	Date	Time	Date	Time		First	Last	Date	Date	Time	Date	Time		Date	Time	Date	Time
2148	09 Jul	1025	10 Jul	0947	14 Jul	1135	7				28 Aug	0043	28 Aug	0611	11	19 Sep	0053	19 Sep	1932
2235	09 Jul	1025	11 Jul	1237															
2343	09 Jul	1025	11 Jul	1146	30 Jul	0056	4												
2438	09 Jul	1025	12 Jul	0416	15 Jul	1632	7												
2128	10 Jul	0850	11 Jul	1537	12 Jul	1451	7												
2137	10 Jul	0850	11 Jul	0712	14 Jul	1443	7				30 Aug	0035	30 Aug	0522	12				
2238	10 Jul	0850	11 Jul	0419	12 Jul	1627	4	27 Aug	27 Aug										
2346	10 Jul	0850	11 Jul	1045	13 Jul	0343	4			23 Aug	04 Oct	0112	04 Oct	1536	10	05 Oct	2254	05 Oct	2340
2441	10 Jul	0850	12 Jul	0454	18 Jul	1406	4												
2534	10 Jul	0850	11 Jul	0653	13 Jul	1552	7			25 Aug									
2139	11 Jul	0755	12 Jul	1914	15 Jul	2022	7												
2242	11 Jul	0755	11 Jul	1531	13 Jul	1714	7												
2348	11 Jul	0755	12 Jul	0805	13 Jul	1115	7				30 Aug	0114	30 Aug	0541	11	18 Sep	1127	18 Sep	2000
2435	11 Jul	0755	14 Jul	0357	18 Jul	1114	7			28 Aug									
2529	11 Jul	0755	12 Jul	0725	13 Jul	1000	7												
2229	13 Jul	1515	15 Jul	0823	16 Jul	1349	7			23 Aug	26 Aug	1508	26 Aug	1649	11				
2341	13 Jul	1515	14 Jul	2238	17 Jul	1252	7												
2437	13 Jul	1515	15 Jul	1653	17 Jul	0431	4			28 Aug									
2545	13 Jul	1515	15 Jul	0229	15 Jul	1641	4				29 Aug	0327	29 Aug	0608	10				
2134	14 Jul	1010	15 Jul	1925	17 Jul	1227	7												
2150	14 Jul	1010	15 Jul	0738	16 Jul	0949	4												
2243	14 Jul	1010	16 Jul	0848	17 Jul	1517	7			23 Aug	26 Aug	1732	26 Aug	1913	11	04 Oct	0429	04 Oct	1024
2331	14 Jul	1010	15 Jul	2126	16 Jul	2129	4												
2447	14 Jul	1010																	
2539	14 Jul	1010																	
2135	15 Jul	1535	17 Jul	1539	18 Jul	1206	7												
2249	15 Jul	1535	04 Aug	1311															
2342	15 Jul	1535	16 Jul	1830	18 Jul	1033	7			23 Aug	26 Aug	1616	26 Aug	2045	11	06 Sep	2222	06 Sep	2234
2443	15 Jul	1535	25 Jul	0519	26 Jul	1624	4												
2444	15 Jul	1535	17 Jul	0236	17 Jul	1441	7			10 Aug									
2528	15 Jul	1535	17 Jul	0700	18 Jul	0404	7												
2146	16 Jul	1335	18 Jul	0722	19 Jul	1109	7												
2240	16 Jul	1335	17 Jul	1824															
2350	16 Jul	1335	17 Jul	1430	19 Jul	1733	7	06 Aug	06 Aug							05 Oct	1801	05 Oct	1824
2431	16 Jul	1335	18 Jul	0430	18 Jul	1608	7												
2537	16 Jul	1335	18 Jul	0415	19 Jul	2326	7												
2130	16 Jul	1545	17 Jul	2338	18 Jul	2309	7												
2234	16 Jul	1545	17 Jul	1639	18 Jul	1307	7												
2328	16 Jul	1545						10 Aug	05 Sep										
2442	16 Jul	1545	18 Jul	0336	18 Jul	1740	7			24 Aug	01 Sep	2246	02 Sep	0039	12	27 Sep	2150	27 Sep	0700
2548	16 Jul	1545	18 Jul	0203	03 Aug	2009	4	05 Aug	11 Aug										
2142	17 Jul	1140	18 Jul	2356	24 Jul	1616	7												
2245	17 Jul	1140	18 Jul	1548	19 Jul	1119	4												
2329	17 Jul	1140																	
2436	17 Jul	1140	19 Jul	0704	21 Jul	1439	4												
2550	17 Jul	1140	18 Jul	1942	19 Jul	1341	7												
2144	17 Jul	1530	19 Jul	0142	19 Jul	1209	7												
2236	17 Jul	1530	19 Jul	0630	19 Jul	2000	4			23 Aug	04 Sep	0210	04 Sep	0518	12				
2339	17 Jul	1530	20 Jul	0415	22 Jul	0220	4			25 Aug	27 Aug	1444	01 Sep	0519	12	29 Sep	2006	29 Sep	2017
2446	17 Jul	1530	18 Jul	1927	19 Jul	1356	7												
2131	20 Jul	1530																	
2247	20 Jul	1530	22 Jul	0228															
2334	20 Jul	1530	22 Jul	0828															
2450	20 Jul	1530	23 Jul	0813	25 Jul	0434	7												

Appendix Table 2.--Continued.

Tag	Release		Arrive Wells Dam		Exit Wells Dam		Monitor	M 8		M 9	Arrive Zosel Dam		Exit Zosel Dam		Monitor	Arrive M 13		Exit M 13	
	Date	Time	Date	Time	Date	Time		First	Last	Date	Date	Time	Date	Time		Date	Time	Date	Time
2540	20 Jul	1530	22 Jul	0203															
2143	21 Jul	1520	22 Jul	2104	25 Jul	1903	7			23 Aug	26 Aug	1742	26 Aug	2019	11	24 Sep	0151	24 Sep	0154
2231	21 Jul	1520	23 Jul	0553	23 Jul	1221	4												
2338	21 Jul	1520	23 Jul	0145	25 Jul	0430	7				23 Aug	1026	10 Sep	1334	12				
2434	21 Jul	1520	23 Jul	1654				29 Jul	04 Aug										
2541	21 Jul	1520	23 Jul	0856	24 Jul	0853	7			09 Aug									
2547	21 Jul	1520	23 Jul	0837	24 Jul	1232	7				28 Aug	0159	28 Aug	0326	11				
2141	22 Jul	1515	23 Jul	2204															
2250	22 Jul	1515	24 Jul	0646	26 Jul	1200	4			23 Aug	04 Sep	0207	04 Sep	1346	10	05 Sep	0513	27 Oct	1945
2344	22 Jul	1515														14 Sep	1018	14 Sep	1018
2429	22 Jul	1515	26 Jul	1051						28 Aug									
2536	22 Jul	1515	25 Jul	0453	29 Jul	1434	4			24 Aug	06 Sep	0334	07 Sep	0239	11	05 Oct	0400	05 Oct	0437
2241	23 Jul	1515	25 Jul	0228	25 Jul	1324	7												
2330	23 Jul	1515	25 Jul	1320	26 Jul	2044	4												
2538	23 Jul	1515	25 Jul	0501	25 Jul	1640	7												
2546	23 Jul	1515	25 Jul	0016						22 Aug	28 Aug	0431	28 Aug	0534	10	04 Oct	2124	04 Oct	2143
2244	24 Jul	1520	26 Jul	0523															
2335	24 Jul	1520	25 Jul	2049						23 Aug	26 Aug	1654	26 Aug	1757	10	29 Sep	0702	29 Sep	1355
2430	24 Jul	1520	26 Jul	0306	27 Jul	1647	4	29 Jul	29 Jul	25 Aug	30 Aug	0506	30 Aug	1337	10	08 Sep	2133	09 Sep	2036
2542	24 Jul	1520	26 Jul	0524	26 Jul	1426	7				31 Aug	2252	31 Aug	2350	10	28 Sep	1958	28 Sep	2119
2544	24 Jul	1520	26 Jul	0434							20 Sep	0052	20 Sep	0534	10	28 Sep	1944	28 Sep	1947
2345	27 Jul	1520	28 Jul	2206	30 Jul	0100	7												
2349	27 Jul	1520	29 Jul	0128	29 Jul	1333	4	01 Aug	01 Aug	23 Aug	27 Aug	1354	27 Aug	1456	11	02 Oct	2028	02 Oct	2036
2439	27 Jul	1520	28 Jul	2202						23 Aug	26 Aug	2346	27 Aug	0037	11	27 Sep	2003	29 Sep	2131
2531	27 Jul	1520	29 Jul	0046	29 Jul	1832	4			25 Aug									
2535	27 Jul	1520	29 Jul	0542	01 Aug	0301	4	15 Aug	15 Aug		02 Sep	0053	02 Sep	0426	12	12 Sep	2357	13 Sep	0206
2336	28 Jul	1520	30 Jul	0300	30 Jul	2329	7				28 Aug	0257	28 Aug	0814	10	08 Sep	2008	08 Sep	2015
2340	28 Jul	1520	30 Jul	0136	30 Jul	1101	7	01 Aug	01 Aug		26 Aug	1625	26 Aug	1733	12				
2543	28 Jul	1520	30 Jul	1742															
2530	28 Jul	1520	31 Jul	1625															
2138	31 Jul	1530	03 Aug	0434	17 Aug	1420	4			25 Aug									
2145	31 Jul	1230	02 Aug	0246	02 Aug	1424	4			24 Aug	29 Aug	0217	29 Aug	0424	11	03 Oct	2019	03 Oct	2030
2147	31 Jul	1230																	
2149	31 Jul	1530	02 Aug	1759	05 Aug	0309	7	06 Aug	19 Aug										
2337	31 Jul	1230	01 Aug	2131	02 Aug	1846	7				21 Aug	0338	31 Aug	0318	10	30 Sep	2155	04 Oct	1926
2423	31 Jul	1230	08 Aug	0906															
2445	31 Jul	1530	02 Aug	0639	03 Aug	1521	7				02 Sep	0050	02 Sep	0158	12	17 Oct	2358	18 Oct	0011
2448	31 Jul	1530	02 Aug	1118															
2449	31 Jul	1230	02 Aug	1729	06 Aug	0100	7												
2237	04 Aug	1415	06 Aug	0653	08 Aug	0708	4	18 Aug	18 Aug		30 Aug	0318	30 Aug	1344	11				
2246	04 Aug	1415	05 Aug	1734	09 Aug	0729	4	10 Aug	05 Sep										
2549	04 Aug	1415	06 Aug	0328	08 Aug	1221	7	11 Aug	12 Aug										

Monitor Numbers: (M = monitor, see Figure 1.)
Monitor 4 Right-bank fish ladder at Wells Dam
Monitor 7 Left-bank fish ladder at Wells Dam
Monitor 8 Colville Tribal Fish Hatchery
Monitor 9 Monse pumping station (Okanogan River entry)
Monitor 10 Right-bank fish ladder at Zosel Dam
Monitor 11 Left-bank fish ladder at Zosel Dam
Monitor 12 Air antenna at Zosel Dam
Monitor 13 Okanogan River above Lake Osoyoos