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Radio-Tracking Studies on Adult Chinook Salmon and Steelhead Trout at Lower Columbia River Hydroelectric Dams, 1971–77

Edited by
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RADIO-TRACKING STUDIES ON ADULT CHINOOK SALMON AND STEELHEAD TROUT AT LOWER COLUMBIA RIVER HYDROELECTRIC DAMS, 1971-77

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PREFACE

The introduction of radio tags for fisheries research on the Columbia River in 1971 by the National Marine Fisheries Service (NMFS), Seattle, Washington, opened up a specialized technique for investigating the behavior of adult salmonids at hydroelectric dams. This report presents the results of six studies on migration of adult chinook salmon, Oncorhynchus tshawytscha, and steelhead trout, Salmo gairdneri, in the lower Columbia River. The studies were conducted from 1971 to 1977 and concern safe passage of these fish over hydroelectric dams blocking the river.

Previous to the construction of Bonneville Dam in 1938, upstream migrating adult salmonids were detained only by natural obstacles such as Cascade Rapids and Celilo Falls. Since completion of Bonneville Dam, subsequent construction of three more dams has turned much of the lower Columbia River into a series of four consecutive lakes. They extend approximately 180 miles from Bonneville Dam to the confluence of the Snake River and inundate historical mainstream spawning grounds. To enable chinook salmon and steelhead trout to swim upstream to their remaining spawning grounds in the headwaters of the tributary streams, fish ladders were constructed at each of the dams. But even with fish ladders, dams cause delays, creating problems related to passage, upstream progress, and survival.

Management agencies need data on individual movement and swimming behavior of fish around dams, but the study of fish behavior in the turbulent waters just downstream from a major dam such as Bonneville has been, until recently, an impossible task. Ultrasonic tags, which have been used extensively to study fish behavior, are useless in these waters because the entrained air and turbulence caused by spilling water greatly attenuates the signal. For several years radio frequency tags had been used to track fish, though not over a range exceeding 0.25 mile and not in an area comparable to that below Bonneville Dam (Lonsdale and Baxter 1968). In 1970, we began development of an extended range radio frequency tag that would permit us to work in such an area. The outlook was promising because radio waves are not attenuated by turbulent or aerated water and fish can be tracked from shore allowing them to be followed up to the face of the dam.

In 1970, fishery biologists and electronic technicians of the Northwest and Alaska Fisheries Center, Seattle, Washington, completed the development of a radio tag for use on returning adult salmonids. While the concept of radio tags was not new, tags developed by NMFS technicians had a greater range than those that had been used before--over 1 mile as compared to 0.25 mile--and they could be used to track fish in turbulent areas comparable to those found around dams in the lower Columbia River. The radio tag provided the first opportunity for researchers to study migrating salmonids in these areas and to obtain data on fish behavior and movement not possible to achieve by conventional tagging methods.

The radio tagging studies were conducted from Bonneville Dam to John Day Dam on the lower part of the Columbia River. Of special concern was Bonneville Dam, about 145 miles from the ocean and the first obstruction encountered by returning adult salmon. Another area of interest was The Dalles Dam, the next dam upstream from Bonneville and 192 miles from the ocean, and in 1977 we continued our tracking upriver to John Day Dam (River Mile 216). Tagging and tracking techniques established in the first 2 years (Part 1 of this report) proved that radio frequency tags were workable and valuable tools for obtaining information on fish behavior that was unattainable by other means. Research was begun in 1971 at Bonneville Dam to test the tag, to establish tagging and tracking techniques, and to start building a data base on salmonid behavior. The study was continued in 1972, similar in design but including data from The Dalles Dam 30 miles upstream from Bonneville Dam. The success of this study led to more specific investigations during the ensuing years.

Research in 1973 (Part 2) was primarily an investigation of the effects of major changes in flow through the turbines caused by varying power demands ("peaking") on fall chinook salmon attempting to pass Bonneville Dam. Other research was also carried out.

Tracking studies in 1974 (Part 3) determined the effect of spillway deflectors on adult fish swimming in the spill area below the dam. The deflectors were installed because, at some dams, plunging water caused high concentrations of dissolved atmospheric gas potentially lethal to juvenile and adult migrants below the dam. This led to the design and placement of structures on the spillway that deflect the spilling water to a more horizontal flow, thereby reducing air entrainment and the amount of dissolved gas in the water. The effect on adult migrants of being swept back over the dam via the spillway (fallback) was also examined.

The 1975 investigations (Part 4) related to the behavior of chinook salmon and steelhead trout at both Bonneville and The Dalles Dams as well as travel rates and behavior through the 30 miles of reservoir between the two dams.

In 1976 (Part 5), studies at Bonneville Dam evaluated potential solutions to the problem of adult migrants falling back over the spillway and also examined fish behavior in relation to the effectiveness of the powerhouse fish collection system.

Research in 1977 (Part 6) focused on the problem of unexplained losses of adult migrants between dams. Radio tracking of adult chinook salmon was conducted that year to determine areas of loss between Bonneville and John Day Dams.

The results from these studies have produced behavioral data that only radio tracking could provide, giving new insight on managing the runs of adult chinook salmon and steelhead trout migrating past hydroelectric dams on the lower Columbia River. In addition, operators of the dams have been made more aware of the importance of providing and maintaining better and safer passage conditions for these fish. It is clear that information obtained from radio tags and from tracking the tagged fish has been of great value in the study of fish migration past dams on the Columbia River.

REFERENCE

LONSDALE, E. M., and G. T. BAXTER.
1968. Design and field tests of a radio-wave transmitter for fish tagging. Prog. Fish-Cult. 30:47-52.

Part 1. MIGRATION OF ADULT SPRING CHINOOK SALMON BELOW BONNEVILLE DAM IN 1971 AND BELOW BONNEVILLE AND THE DALLES DAMS IN 1972

By Gerald E. Monan and Kenneth L. Liscom

INTRODUCTION

The loss of adult salmon and steelhead trout at and between dams on the Columbia and Snake Rivers as indicated by fish counts at each dam is a major concern of fishery management agencies in the Northwest. These count discrepancies vary in magnitude from dam to dam and from year to year, but studies have shown the numbers of missing fish are significant (Fredd 1966; Merrell et al. 1971). Finding a means to pinpoint exactly where and how these discrepancies occur has been a goal of fisheries scientists for a number of years.

Weiss (1970) showed a loss of about 13% of the spring and summer chinook salmon runs at Bonneville Dam and about a 12% loss of spring and 24% of summer chinook salmon between Bonneville and The Dalles Dam. Up to this time, however, specific causative factors involved in these losses remain largely unknown. Studies of the behavior of individual fish within the problem area are offered as a means of partially explaining these losses.

The development in 1970 of a radio tag with expanded range capabilities at the Northwest and Alaska Fisheries Center in Seattle, Washington, provided a new tool for the study of salmon behavior. The objectives of this 2-year study were: 1) to test our recently developed radio-tracking equipment on salmon under field conditions and 2) to study the behavior of adult spring chinook salmon. Specifically, we wanted to study salmon behavior immediately below Bonneville Dam, to compare this behavior with that at The Dalles Dam, and to determine specific loss-related problem areas.

EXPERIMENTAL SITE AND EQUIPMENT

Site

During the first year of this study, the area under investigation was the Columbia River from just below Bradford Island to Bonneville Dam, a distance of about 1 mile. In 1972, the area of the Columbia River under investigation was expanded and split into three main sections: 1) the immediate vicinity of Bonneville Dam, 2) the area between Bonneville and The Dalles Dams, and 3) the immediate vicinity of The Dalles Dam.

The Bonneville Dam spillway is separated from the powerhouse by Bradford Island (Fig. 1) which effectively divides the river into two channels. The main source of flow for the north channel is the spillway and for the south channel is the powerhouse turbine discharges. Consequently, the flow characteristics in the study area are determined primarily by the operation of the dam. Fishway entrances are located on the north and south side of the spillway and across the face of the powerhouse. The fishways from the south side of the spillway and the north side of the powerhouse connect and form a single fishway over the dam.

The design of The Dalles Dam is rather unique in that the non overflow dam and powerhouse are built almost at a 90° angle to the spillway (Fig. 2). This creates a separate channel along the face of the powerhouse. Two fishways, "north" and "east," provide fish passage over the dam. The entrance to the north fishway is at the northern end of the

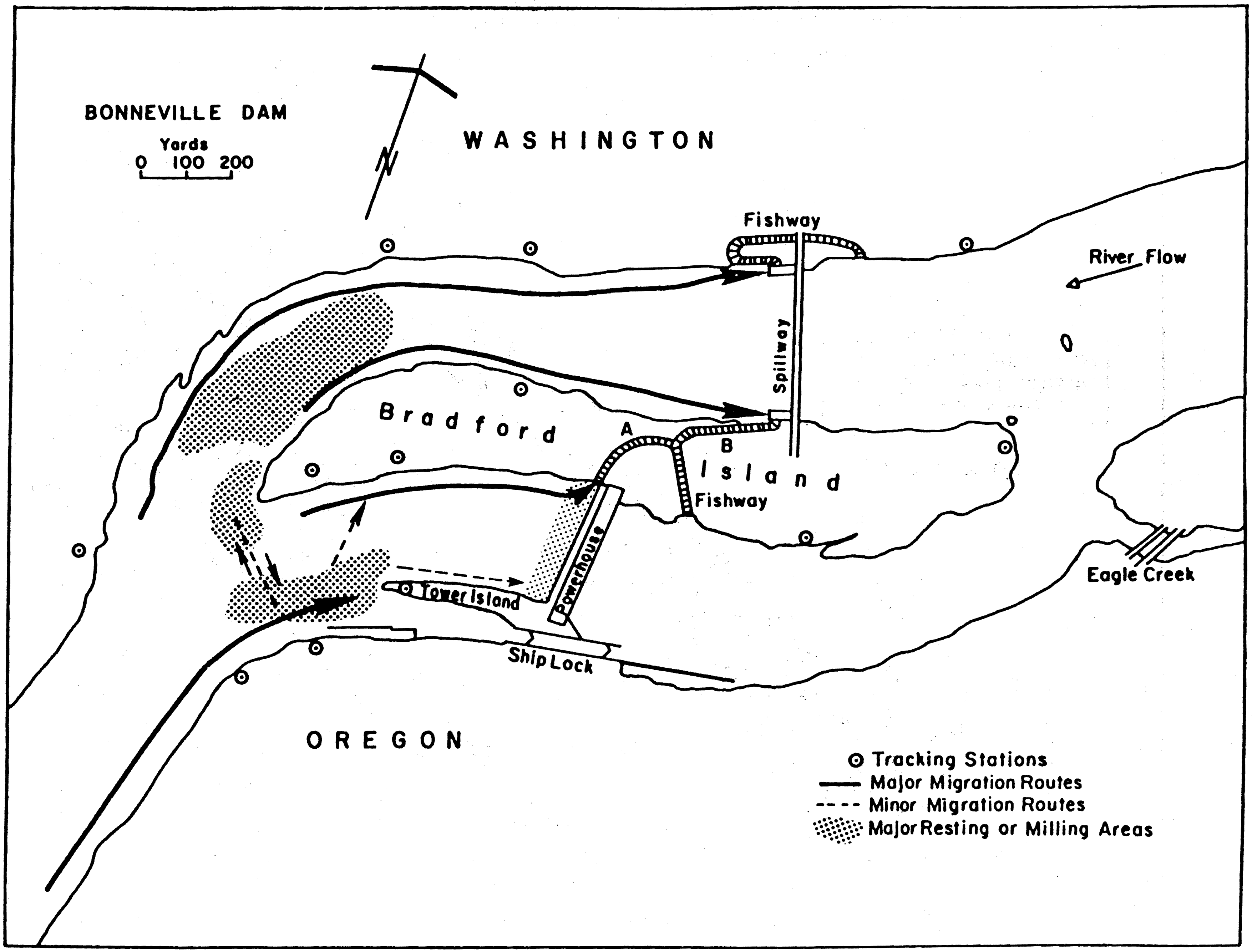


Figure 1.--The 1971-1972 Bonneville Dam study area showing fish tracking stations and the areas most used by spring chinook salmon below the dam for traveling, milling, and resting.

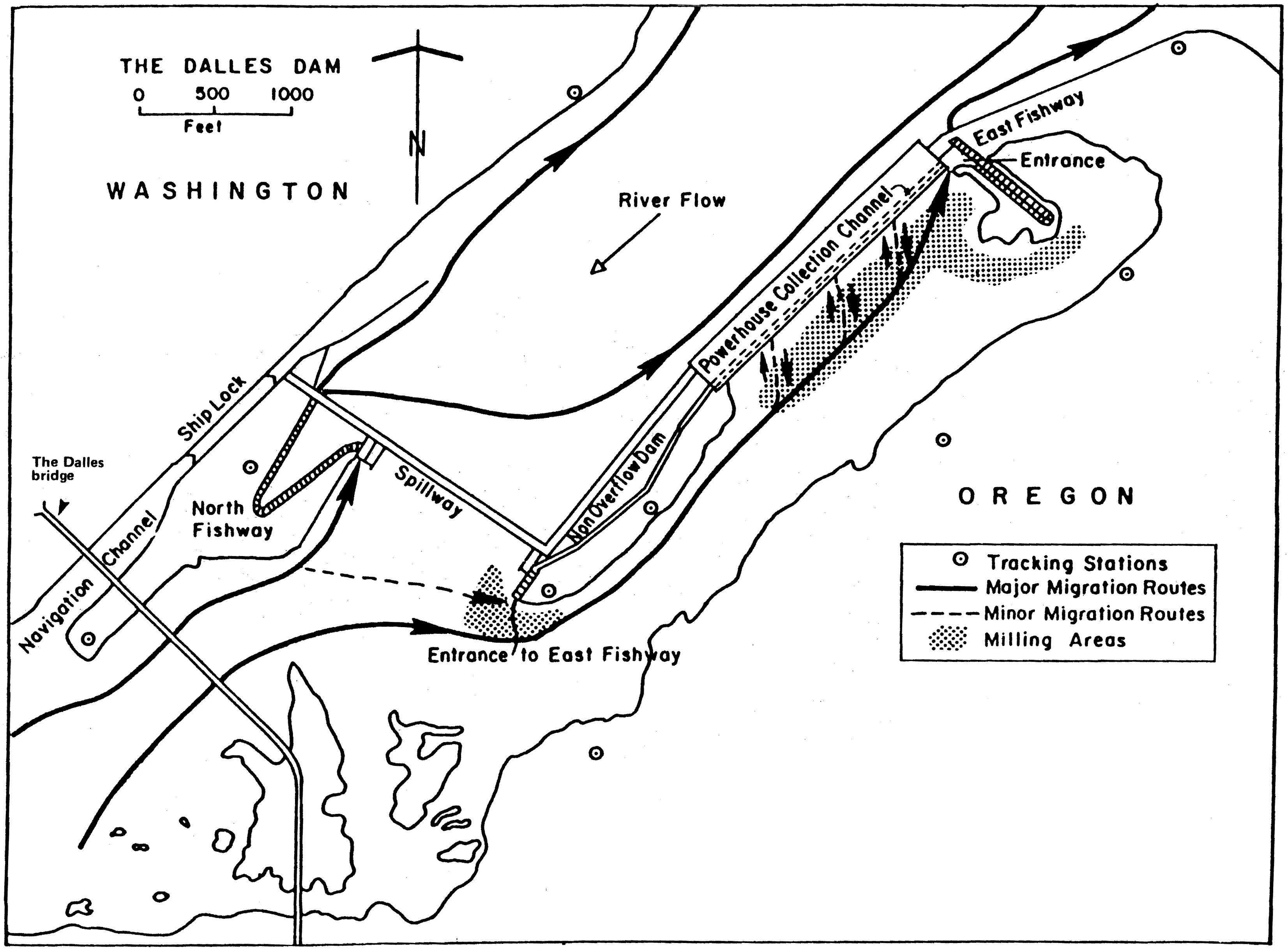


Figure 2.--Plan view of The Dalles Dam study area showing fish tracking stations and areas most used by spring chinook salmon for traveling and milling.

spillway. The east fishway has entrances at the eastern end of the powerhouse, along the face of the powerhouse, and at the southern end of the spillway. The entrances along the powerhouse are a series of orifices that allow the salmon to swim into an internal channel that flows in front of the powerhouse.

Radio Tag

The radio tag is a high frequency radio transmitter that operates on a carrier frequency of approximately 30 megahertz (MHz) (Figs. 3, 4). The transmitter is battery powered with a transmitting life of about 12-15 days. Transmitter and batteries are sealed in a plastic capsule 4 inches long by 0.75 inch in diameter. Tags weigh about 1 ounce in water and can be pulse-rate coded or frequency coded. To provide 10 separately identifiable tag codes, we used five frequencies (30.17, 30.19, 30.21, 30.23, and 30.25 MHz) and pulsed each frequency at two rates (1 pulse per second and 3 pulses per second).

Each tag has an antenna lead at each end. One lead is a stainless steel band 0.438 inch wide by 0.003 inch thick that encircles the posterior end of the tag. The other lead is a short piece of wire that comes out of the anterior end of the tag and terminates in a small barbed needle. The body of the fish serves as the tag's antenna. The steel band makes contact with the fish's stomach wall at one end and the barbed needle is inserted into the flesh of the fish's mouth at the other end.

In 1972, the antenna lead was modified with a 1-inch length of 1/8-inch diameter stainless steel tubing attached to the anterior antenna wire. To this extension, we attached a small plastic barb which was

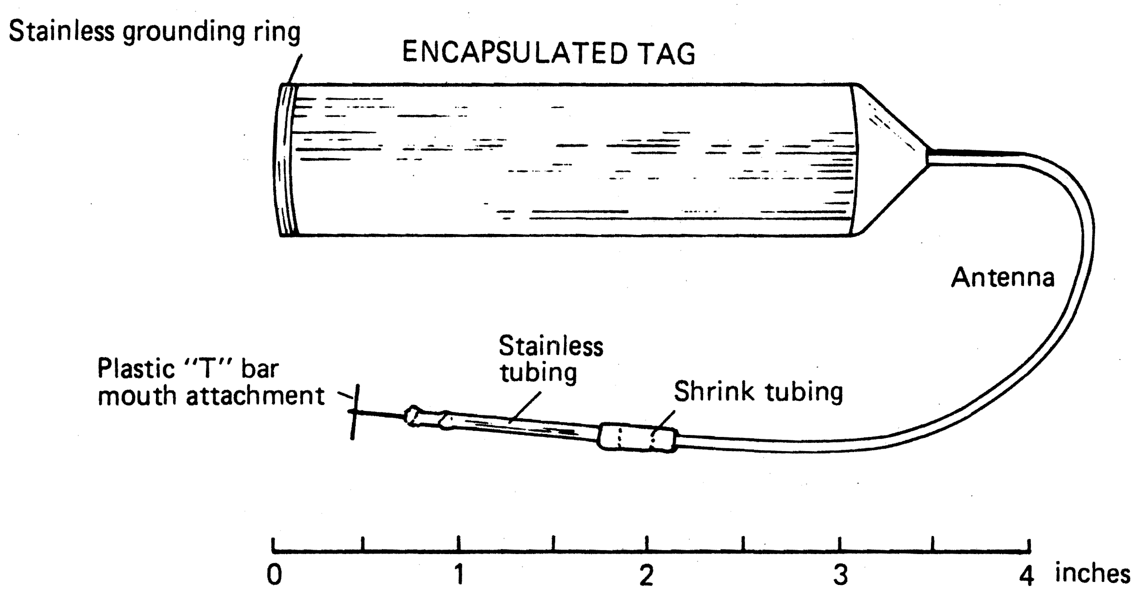
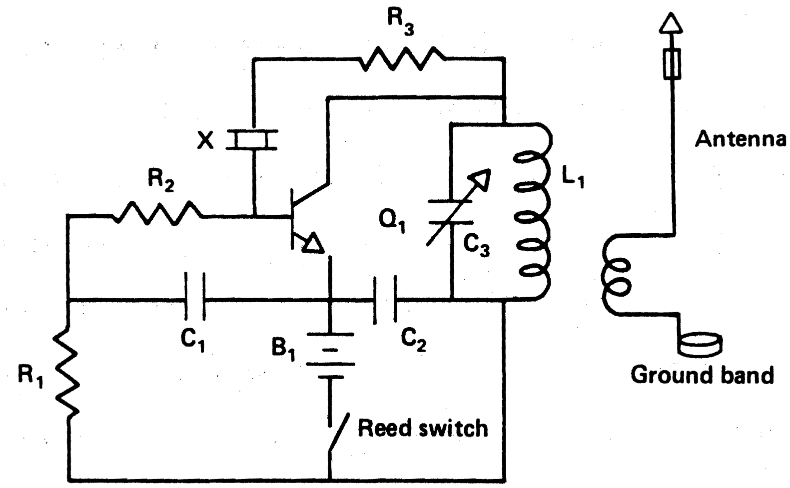


Figure 3.--View of encapsulated radio tag antenna attachment.

30 mhz RADIO FISH TAG



C_1	6.8 MFD fast pulse, 15 MFD slow pulse
C_2	0.01 MFD
C_3	Arch type 406, 15 to 115 pF
R_1	1 meg.
R_2	680 ohms
R_3	0 to 47 ohms
Q_1	2N2925
L_1	8 turns, No. 24 AWG 5/8 inch form 3 turns antenna link, No. 32 AWG
X	30 Mhz third overtone crystal
B_1	TR118T2, 11.2 V mercury battery

Figure 4.--Schematic of 1971 radio frequency tag.

inserted into the roof of the fish's mouth to prevent the fish from swallowing the antenna.

Direction Finder Receiver and Antenna

The direction finder (D.F.) receiver used by the trackers was a self-contained, battery-operated unit that received the radio signal from the antenna, amplified it, and converted it to an audible tone. The receiver has a capacity of 12 channels, but we used only the 5 channels matching the frequencies of our tags. A channel selector switch allowed the operator to select the tag frequencies desired. To eliminate as much extraneous noise as possible, each operator used earphones to listen to the signal. The receiver fit into a water repellent case fitted with a shoulder harness worn to position the receiver at the operator's chest. This left the tracker's hands free to take notes and rotate the antenna.

Our primary tracking antenna was a directional loop 18 inches in diameter. Each antenna contained a tuning stub and a variable capacitor. The antenna was matched to the receiver by adjusting the variable capacitor for resonance and the dimensions of the stub for the desired impedance. The 18-inch diameter loop was used for tracking except when the fish was very close to the tracker. Then, a similarly constructed antenna having only an 8-inch diameter loop and a correspondingly sharper null pattern was used.

Power for the receiver was provided by rechargeable nickel-cadmium batteries. One battery powered the unit for about 4 hours, so operators carried a spare battery with them for their 8-hour shift.

Fishway Monitoring Units

A simple receiver and antenna unit was also placed at each fishway counting station to alert the counters to the presence of a tagged fish. A standard 18-inch diameter loop antenna was mounted slightly in front of and above a white counting board, located underwater in the fishway, over which fish were identified and counted. The antenna was positioned to pick up tag signals as the fish approached and left the counting station. The receiver was a battery-powered broadband superhet VHF-FM monitor modified for our use. An audio alarm device was added to provide a beeping noise that could be heard by the fish counter when a radio-tagged fish approached the counting station. This system did not distinguish between tag frequencies, but it did indicate whether the tag had a fast or slow pulse rate. The gain on the receiver was set to activate the audio signal only when the fish was in the immediate vicinity of the counting board.

In addition to the aforementioned receiving equipment, in the second year of the study automatic recording monitors were located at the entrances and exits to the fishways at both dams to record the time and code of tagged fish entering or leaving the fishways. These monitors were sonic tag monitors converted to receive radio frequency tags. Their purpose was to provide backup data on passage of fish through the fishways.

EXPERIMENTAL PROCEDURES

Trapping and Tagging

Fish for tagging were diverted from the fishway on the north side of the Bonneville spillway dam into the Fisheries-Engineering Research

Laboratory. After fish entered the laboratory, they passed a viewing chamber where, by manipulation of gates, fish could be selected for tagging by diverting them into a trapping facility.

After passing the viewing chamber, fish diverted for tagging ascended a 20-foot Denil-type fishway into a short holding area. From the holding area they swam over a false weir and descended a slide into a tank containing an anesthetizing solution (MS-222).

As soon as a fish was anesthetized, it was lifted to a tagging rack. The fish was placed into the rack belly up and its lower jaw raised to fully open the mouth. The tagger then took the radio tag body out of an antiseptic solution of zephiran chloride, dipped the posterior end (that portion entering the fish initially) in glycerin, and inserted the tag into the stomach of the fish through the esophagus. The short antenna lead attached to the anterior end of the tag was allowed to extend into the mouth of the fish. The barbed needle was inserted, just under the skin, along the roof of the salmon's mouth. The fish was then turned over and a spaghetti tag was attached near the base of the dorsal fin (Rounsefell 1963). Control fish were handled in the same way except they received only the spaghetti tag. Spaghetti tags were color coded to identify fish from each release group. Tables 1 and 2 summarize the tagging data.

After tagging, the fish were placed in a fish hauling truck to recover from the anesthetic. During the recovery period (approximately 30 minutes), river water was pumped through the hauling tank. When a load of six or seven fish had recovered, the truck was driven to the river, where the fish were released. The 1971 release site was near Beacon Rock about 4

Table 1.--Summary of tagging data for spring chinook salmon used in the 1971 study.

		Controls			Test fish			
Release group	Date of release	Flag color	Flag number	Fish length (mm)	Flag color	Flag number	Radio tag code	Fish length (mm)
I	4/13	Orange	10141	927	White	1	LFA	737
"	"	"	10142	711	"	2	LSA	737
"	"	"	10143	787	"	3	JFA	673
"	"	"	10144	724	"	4	DSA	698
"	"	"	10145	762	"	5	FSA	775
"	"	"	10146	673	"	6	HSA	724
"	"	"	10147	686	"	7	FFA	838
"	"	"	10148	724	"	8	DFA	737
"	"	"	10149	978	"	9	HFA	838
"	"	"	10150	876	"	10	JSA	686
II	4/27	Yellow	1	737	Pink	1	JFB	800
"	"	"	6	648	"	2	HFB	914
"	"	"	2	952	"	3	FFB	749
"	"	"	7	724	"	4	FSB	762
"	"	"	4	724	"	5	LSB	1,092
"	"	"	9	622	"	6	JSB	724
"	"	"	8	914	"	7	LFB	724
"	"	"	3	762	"	8	DSB	927
"	"	"	5	762	"	9	DFB	787
"	"	"	10	902	"	10	HSB	1,003

Table 2.--Summary of tagging data for spring chinook salmon used in the 1972 study.

Control group	Test group	
Fish length (mm)	Tag code	Fish length (mm)
Group A - released at Beacon Rock on April 11		
870	1DS	710
670	2DF	820
680	1ES	940
910	1EF	640
735	1HS	860
745	1HF	760
780	2KF	705
690	1KS	650
790	1LF	690
650	1LS	725
Group B - released at Cascade Locks - Stevenson on April 25.		
900	1FS	730
730	2HS	730
740	1IS	730
720	1FF	880
900	2HF	740
670	1IF	730
880	1JS	900
750	2EF	770
730	1JF	920
720	1KF	780
Group C - released at Cascade Locks - Stevenson on May 9		
780	3DF	800
780	2ES	760
750	2FS	960
850	3HS	1,000
970	2JF	820
750	3EF	880
630	2LF	820
750	2DS	690
800	3HF	720
900	2LS	950

Table 2.--Continued.

Control group	Test group	
Fish length (mm)	Tag code	Fish length (mm)
Group D - released at Beacon Rock on May 18-19		
715	3ES	940
745	3FF	900
740	2IF	800
770	2IS	1,045
990	3JS	685
1,010	3JF	985
960	3LS	720
755	4HF	705
750	3LF	830
655	3KF	690

river miles below Bonneville Dam. In 1972, two release sites were used, one 4 miles below Bonneville Dam and the other 5 miles above it.

Tracking and Plotting

Once the radio-tagged fish were placed in the river, their whereabouts were monitored intermittently from the release site to the downstream boundary of the study area by periodically drifting the river and listening for tagged fish. In 1971, tracking within the study area was done on a 24-hour basis. Three crews operated each day: the first shift covered the period from 0600 to 1430 hours; the second shift, 1400 to 2030; and the third shift, 2000 to 0630. The first and second shifts had four-man crews, the third shift only two people. Each crew chief was responsible for deploying the crew to the tracking stations giving the best possible coverage of fish in the area. Tracking stations were established on the Washington and Oregon shores and on Bradford and Tower Islands (Fig. 1).

Each fish tracker had a standard complement of equipment: the D.F. receiver and directional antenna, a two-way walkie-talkie, a map of the area, a watch, and a notebook for recording data. The walkie-talkies allowed all trackers to keep in contact so their efforts could be constantly coordinated.

When a tagged fish came into the study area, its position was usually monitored by two or more trackers. By tuning to the frequency of the tag, rotating the loop antenna until a null point was reached, and then sighting along the geometric axis of the loop, the tracker could establish a bearing for the tagged fish. If a second tracker was doing the same thing simultaneously, the two bearings could be plotted and the location of the fish established by triangulation.

Initially, we attempted to use compasses to establish bearings, but compass deviation caused by proximity to the dam and other large structures created more problems than we could cope with. We solved the problem by obtaining a large, detailed aerial photograph of the area from the U.S. Army Corps of Engineers (CofE). The scale of the photo allowed us to easily distinguish landmarks throughout the area. Thereafter, the trackers recorded bearings of the fish by landmarks observed through the sight on their antenna when they obtained the null.

To establish location of the fish, bearing data were plotted on the aerial photograph. The tracking stations were marked on the photo and the photo covered with clear plastic. Grease pencil lines were drawn on the plastic from the appropriate tracking station to the landmark recorded in the notes. A similar line was drawn for the other tracker's reading and the point of intersection represented the fish's location. A time series of the plots made up the path taken by the fish.

The number of plots and the interval between plots depended upon how fast the fish was moving and the number of fish in the area. If two or more fish were in the area, we concentrated on the one that was the most active.

In 1972, tagged fish were monitored intermittently from the release point to the downstream boundary of the study areas at Bonneville and The Dalles Dams by crews equipped with mobile tracking gear traveling along the highway on either side of the river as well as by boats drifting the area periodically. Tracking near the dams was done on a 16-hour basis. Two crews operated each day; the first shift from 0600 to 1430 hours; the second shift, 1400 to 2230 hours. Specific tracking stations were established on the Washington and Oregon shores and on various islands in the Bonneville (Fig. 1) and The Dalles areas (Fig. 2). Each crew chief was responsible for deploying the crew to give the best possible coverage of fish in the total study area.

Fixed tracking stations were established in 1972, each with a fixed mount topped by a compass rose adapted for the insertion of the loop antenna base. The geometric axis or null point of the antenna corresponded to a pointer that rotated with the antenna over the compass rose. By tuning to the frequency of the tag, rotating the loop antenna until the null point was reached, and then noting the location of the pointer on the compass rose, the tracker could establish a bearing on the tagged fish. Simultaneously a second and occasionally a third tracker was doing the same thing from other stations, establishing the multiple bearings needed to plot the location of the fish by triangulation.

EVALUATION OF THE RADIO FREQUENCY SYSTEM AS A TRACKING TOOL

Equipment

Any complex electronic system, no matter now well tested in the laboratory, can be expected to show some deficiencies in its first rugged field test. The radio-frequency tracking system performed well for an initial application. Some problems were experienced with the system, but these were minor and most were remedied during the study.

The radio tag, after correction of an initial design fault, proved to be workable and reliable. In our first group of 10 tagged fish, 5 tags stopped transmitting on the first day. A resistor in the base circuit, too small to allow sufficient voltage to feed back to the oscillator, caused the tag to quit when the battery began to drain slightly after only a short period of operation. Only tags with the fast pulse rate were affected. Before the second group of fish were tagged, the fast-pulse tag circuit was modified and the problem did not reoccur.

Signal strength from the tag was more than adequate to obtain good range throughout the study area. Ranges of over 0.5 mile were average with our receiving equipment. Tags recovered later showed no evidence of leaking or deterioration of the capsules or antenna leads. Careful dissection of a tagged fish captured in 1972 in the adult separator trap at Little Goose Dam on the Snake River (about 250 miles upstream from Bonneville Dam) revealed that the radio tag was still in the stomach of the fish, and no abrasion or irritation was evident in the stomach wall or esophagus.

The receiving unit proved to be adequate for the study, although we had some problems resulting primarily from extensive use (loose connections, switch failures, crystal failures, etc.). Once the weak points of the receiver were known, slight modifications and preventive maintenance solved most of the problems.

The individual loop antennas had small variations among them that required calibration to maintain accurate bearings from the null. A smaller 8-inch diameter loop antenna did a reasonably good job at close range and was used at certain times, for example, when a specific pool location was needed on tagged fish as they ascended the fish ladder.

Anomalies of radio-wave transmission gave us some problems below high voltage power lines. Once we realized these readings could be misleading, it was usually easy to position the trackers to avoid these problem areas.

Reciprocal readings were another problem. A null could indicate a fish anywhere along the imaginary line corresponding to the null in front of the tracker or 180° away to the rear. With the trackers located on Washington or Oregon shores, this was a problem only when the fish approached along the shoreline very close to the tracker, reversed its course in front of the tracking station and moved away quickly in the direction from which it came. This occurred surprisingly often. Erroneous readings could also be obtained when tracking from Bradford Island with the river in front and back of the trackers. Once everyone became aware of the confusion that reciprocal bearings could cause, closer coordination among trackers via two-way radio helped alleviate the problem.

Anomalies of radio-wave transmission gave us problems at The Dalles Dam in 1972. Because of the physical design of the dam, we were continually bothered by reflected signals caused by the large expanse of the powerhouse running parallel to and within close proximity of the high, sheer rock bank on the Oregon shore. These problems were overcome in later studies by employing more trackers. Additional bearings helped sort out reflected signals from real signals.

The tag detectors located in the fishways at the counting station functioned very well. Occasionally random sources of electrical energy would cause the unit to emit a beep or two, but this signal was easily distinguished from the rhythm of the regularly pulsed tag.

The only items of equipment that performed unsatisfactorily in 1972 were the automatic monitors for detecting fish entry and exit from the fishways. These units were old and had been used extensively for sonar monitoring during several field seasons. Although considerable repairs were made on the units prior to installation, they had apparently reached a stage of deterioration that made it impossible to obtain the required information due to constant breakdowns. Reliable data from these units were definitely missed during the analysis of the study. New units were designed and constructed for later studies.

Effect on Fish Behavior

There appeared to be no major differences between the performance of radio-tagged fish and control fish. Timing and survival over Bonneville Dam in 1971 were similar. However, there appeared to be a greater tendency for fish tagged with radio tags to fall back over the dam. Fish counters recorded 14 radio-tagged fish from Group II crossing the counting boards even though we tagged only 10 (Table 3); 8 control tags were observed by the counters and one was caught below the dam. Because of the small number of fish tagged, firm evaluation of the effect of the radio tag on fish performance is difficult. Earlier laboratory test showed no visible difference between the fish behavior of radio-tagged and control fish.

Table 3.--Number of crossings observed passing upstream over the counting boards in the fishways at Bonneville Dam in 1971 (10 fish were tagged in each category).

Release group	Type of tag	
	Radio	Control
I	9[a]	10
II	14	8[a]

[a]One additional fish was caught by a fisherman below the dam.

BEHAVIOR OF TAGGED FISH IN THE STUDY AREAS

The 1971 Study

Twenty adult spring chinook salmon were tagged and tracked during two tracking periods in 1971--10 in Group I tagged 13 April and tracked from 13 to 23 April, and 10 in Group II tagged on 27 April and tracked from 27 April to 12 May. Complete or partial tracks were obtained from 14 of these fish. As noted previously, five tagged fish were not tracked during the first period because of tag failures. One fish from the second group apparently passed through the study area very quickly and was not heard by tracking personnel until it was in the ladder.

Elapsed time between release of fish at Beacon Rock and initial contact by trackers within the study area ranged from 18 to 91 hours and averaged 47 hours (Table 4). This duration includes the time fish needed to recover from handling and swim the 4 miles to the study area. Because we only tracked the fish within the study area in 1971, specific patterns of movement following release of the fish were confined solely to the immediate area below the dam.

Although fish within the study area exhibited a variety of individual behavior patterns, some generalized uniformity of behavior was noted. These general behavior patterns enlighten us on how fish respond below Bonneville Dam in relation to river discharge (Table 5).

Tracks indicate water flows influence fish behavior in several ways. When appreciably less water was coming over the spill than was being discharged from the turbines (about 140,000 ft^3/s), fish activity was concentrated in the powerhouse channel. When the two flows were about equal, the activities of the fish were equal in the two channels. When the

Table 4.--Elapsed times of radio-tagged spring chinook salmon from release at Beacon Rock to initial contact in the study area (approximately 4 miles) in relation to average river flows at time of migration in 1971 study.

Tag code[a]	Migration time (h)	Average river flow during migration (ft^3/s)
FFB	18	181,000
DFB	24	184,000
JFB	30	184,000
HSB	38	187,000
FSA	38	271,000
LSA	42	271,000
LSB	43	192,000
HFB	46	187,000
FSB	49	188,000
JSB	49	188,000
HSA	60	273,000
DSA	67	274,000
DSB	69	192,000
JSA	91	280,000
Average	47	218,000

[a]Tag LFB (group II) is excluded from this table because its signal was not heard until after the fishway.

Table 5.--Average flow conditions of the Columbia at Bonneville Dam during the 1971 study period.

Date	Spill	Powerhouse discharge	Total river flow
	-----------------1,000 ft^3/s	-----------------	
April 13	141	144	289
14	123	145	271
15	127	144	275
16	134	144	283
17	139	145	287
18	130	145	278
19	134	145	283
20	138	145	287
21	138	144	287
22	150	142	299
23	128	145	278
24	105	145	254
25	125	145	273
26	77	145	275
27	35	142	181
28	41	142	187
29	50	142	196
30	58	142	204
May 1	126	143	274
2	169	145	317
3	227	144	375
4	286	142	432
5	320	140	464
6	383	115	502
7	407	113	524
8	408	113	525
9	416	114	534
10	424	115	543
11	431	113	548
12	434	115	553
13	435	116	554
14	436	116	556
15	430	116	551
16	421	117	542
17	390	133	525
18	357	141	502
19	341	141	486
20	329	142	474
21	339	120	463
22	334	115	453
23	318	114	437
24	295	136	435
25	292	143	440
26	311	140	455
27	326	143	474
28	347	143	495
29	366	142	513
30	368	143	516
31	366	143	514

spill exceeded about 170,000 ft^3/s and turbines operated at full load, giving a total river flow of about 325,000 ft^3/s, tagged fish did not move much in either channel (Table 6).

Table 6.--Number of periods of sustained upstream fish movement in powerhouse and spillway channels during different spill conditions in 1971 study.

Spill condition		Number of periods of sustained movement: Powerhouse channel	Number of periods of sustained movement: Spillway channel
Low	35-110,000 ft^3/s	7	3
Med.	111,000-170,000 ft^3/s	5	6
High	170,000-246,000 ft^3/s	1	1

During periods of high flow, fish generally moved downstream out of the study area and established holding positions below islands or in protected waters below projections from the banks. The fish would occasionally venture out into faster water, but would usually return to their holding area. The area just downstream from Bradford Island and the waters downstream from islands near Beacon Rock were favored resting areas of the tagged fish. At the end of the usable battery life of the tags (approximately 15 days after release), five radio-tagged fish from our second group remained in the Beacon Rock area. All of these fish had been up in the study area at least once, but returned downstream during the period of high river discharge.

Cessation of movement upstream caused by high river flows was temporary. During the delay, fish were in waters heavily supersaturated with dissolved nitrogen. For example, samples of Columbia River water taken near Beacon Rock on 7 May were analyzed and found to have nitrogen saturation levels of 126.8 to 132.6%. Ebel[1/] reported levels of dissolved nitrogen saturation from 124.6 to 132.6% in the tailrace area of Bonneville Dam during the latter part of April and the early part of May. Beiningen and Ebel (1970) reported that high levels of dissolved nitrogen gas (in excess of 125% saturation) are detrimental to adult salmon when exposure is prolonged. Coutant and Genoway (1968) stated that abrupt differences between external and internal gas tensions (a condition which can cause gas bubble disease) may occur when fish move from deep river travel to the shallow conditions experienced at fish passage facilities at dams. Just how this prolonged exposure to high nitrogen supersaturation affected our fish as they continued upstream is a matter of conjecture. However, reports by fish counters indicated that practically all our tagged fish (Table 2) eventually crossed the counting boards; 62% of those crossing the boards went over the Bradford Island fishway and 38% over the Washington fishway. Two tagged fish, one from each release, were caught by fishermen below the dam. The last tagged fish reported by the fish counters (a control fish, Group II) crossed the counting board on 4 June--38 days after its release.

That high flows delay upstream passage is further substantiated by the difference between Groups I and II in the time elapsed from release to crossing. During the 15 days between their release and the time the river

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[1/] Wesley J. Ebel, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, 2725 Montlake Blvd. N.E., Seattle, WA 98112, pers. commun. 1971.

flow approached 325,000 ft^3/s, 79% of our first group of tagged fish crossed the dam. Group II, however, had only 5 days available before high flows began. In the first 15 days after release of the second group, only 47% of the fish had crossed the dam; over 50% of these fish crossed in the first 5 days.

High flows apparently also affect the frequency of fish fallback over the dam. We had no evidence of fallback among our first group of fish. However, on 5 May we tracked a fish from the second group that exited above the dam from the Bradford Island fishway and swam around the island to the spill area where it was swept over the dam. The fish quickly entered and ascended the B branch of the Bradford Island fishway, but then descended the A branch and exited from it. It then remained in a holding area just below the tip of Bradford Island. This fish eventually reascended (exact date unknown), and was subsequently caught above the dam by an Indian fishermen on 22 May. Observations by fish counters further confirmed a fallback problem within the second group of fish; four more radio-tagged fish were counted through the fishways than were tagged.

Behavior of tagged fish in the fishways is also of interest. Of the 10 fish we tracked into the fishways, five entered more than once and four entered once and stayed until they went over the counting boards. One fish's tag quit after it entered the fishway so its subsequent behavior was unknown. Two fish reached the counting stations after they were closed for the night. We observed three fish that spent time in both the Washington and Bradford Island fishways and three that swam through both the A and B branches of the Bradford Island fishway (two went in A and out B and one went in B and out A). The amount of time fish spent in the fishways ranged from 4 to 86 hours and averaged 63 hours. Time in the fishways represented

4 to 63% of the total time from release until the fish passed over the dam. Table 7 shows that fish tended to spend more time in the fishways as river flows increased.

Table 7.--Total time tagged fish spent in the fishways compared to the average river flow from time of release until time of entry into fishway in 1971 study.

Tag	Time in fishways (h)	Average river flow (ft^3/s)
HSB	4	247,000
DSA	59	267,000
FSA	66	275,000
LSB	71	192,000
FSB	71	278,000
LSA	86	274,000
HSA	86	280,000

Specific routes taken by the fish through the study area were variable; however, some similarities were apparent. The fish tended to move within 50 yards of shore. This was especially true when the fish headed toward the fishways. All approaches to the fishways in the spillway channel were along the shore. Four of the six fish that entered the A branch of the Bradford Island fishway entered the powerhouse collection system near the north side adjacent to Bradford Island. The other two entered the collection system near the south side of the powerhouse (Oregon shore). At one time or another fish were tracked in practically every part of the study area. Fish movement during hours of darkness was very limited. Areas that fish consistently chose for traveling, holding, or resting are shown in Fig. 1.

The 1972 Study

Forty adult spring chinook salmon were tagged with radio tags and tracked during four periods in 1972--10 in Group A, tagged on 11 April and released 4 miles below Bonneville Dam; 10 in Group B, tagged on 25 April and released 5 miles above Bonneville Dam; 10 in Group C, tagged on 9 May and released 5 miles above Bonneville Dam; and 10 in Group D tagged 18-19 May and released 4 miles below Bonneville Dam. Along with each group of radio-tagged fish, an equal number of fish were tagged with flag tags only to act as controls.

Complete or partial tracks were obtained from all 40 radio-tagged fish. Data from these tracks are most clearly understood if we examine them in relation to the three main sections of the river studied: 1) the area immediately below Bonneville Dam, 2) the river between Bonneville Dam and The Dalles Dam area, and 3) the area near The Dalles Dam.

Fish Behavior in the Bonneville Dam Study Area

Twenty radio-tagged fish from Groups A and D were released below Bonneville Dam and tracked in the Bonneville area. The general pattern of fish movement below the dam is shown in Figure 1. Subsequent details on movement upstream from Bonneville Dam are given in following sections of this report.

Group A--In Group A, all 10 radio-tagged fish and 6 of 10 controls were counted going over Bonneville Dam. Daily average river flows while the fish were in the area below the dam ranged from 176,000 to 338,000

ft^3/s and averaged 314,000 ft^3/s. Powerhouse discharges were relatively steady between 140,000 and 150,000 ft^3/s. There were no known fallbacks, nor were any fish caught below the dam. The apparent low number of controls observed passing upstream was probably a result of two factors[2/]: 1) the flag tags were difficult to see in the turbid water (observation of radio-tagged fish was aided by the audio-signal sounded by the electronic monitors which alerted the fish counters that a tagged fish was in the area) and 2) counting boards were left open during the 10-minute break period taken by counters each hour. If a control went over during this time, it could not be recorded; however, radio-tagged fish could be and were recorded during the break period.

Although behavior of fish below the dam was variable, a number of points were of interest. The amount of time fish from Group A spent in the area immediately below Bonneville Dam prior to crossing the counting boards ranged from 11 to 226 hours and averaged 101 hours. During this time, the fish spent from 4 to 57 hours (average 22 hours) in the fishways. Four fish entered the fishways more than once and six entered only once and continued their passage over the dam. One fish spent time in the Bradford Island fishway prior to crossing the dam via the Washington fishway. Eighty percent of the radio-tagged fish and 50% of the observed control fish crossed the dam via the Bradford Island fishway. Without exception, fish tracked into the fishways entered from along the bank rather than from across the spillway or powerhouse. Although fish were tracked throughout the area, only one swam close to the face of the powerhouse and none swam

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2/ These considerations apply to the recording of tagged fish throughout the experiment.

close to the spillway. Fish entered the Bradford Island fishway in equal numbers from both branches.

Group D--In this group, seven radio-tagged fish and eight controls were counted over Bonneville Dam during the study. One additional radio-tagged fish crossed the dam unobserved after the study and was later taken in the Indian fishery. Two controls were observed also crossing at a later date. Thus, in the final tally, 8 of 10 radio-tagged fish eventually crossed Bonneville Dam. The fate of the other two is unknown. Daily average river flows while fish were in the area ranged from 460,000 to 537,000 ft^3/s and averaged 484,000 ft^3/s. Powerhouse discharges were relatively steady at approximately 140,000 ft^3/s.

One fallback was observed among the radio-tagged fish and no radio-tagged fish were caught below the dam. The radio-tagged fish that fell back reascended the dam and was taken by a sport fisherman 69 days later near Little Goose Dam on the Snake River. At least two fallbacks must have occurred among the controls because 10 control fish were observed passing the dam and 2 were known to have been caught below the dam.

The time Group D fish spent in the area immediately below the dam prior to crossing ranged from 45 to 408 hours (2-17 days) and averaged 181 hours.

All 10 radio-tagged fish entered and spent some time in the fishways, even those that had not crossed by the termination of the study. Radio-tagged fish spent from 1 to 145 hours (average 64 hours) in the fishways. Four of the fish entered the fishways more than once and six entered once and stayed until they were counted over the board. Three fish spent time in both fishways. Seventy-five percent of the radio-tagged fish and 40% of the controls crossed the Bradford Island fishway. Without exception, fish tracked into the fishways entered from along the bank. All of the fish tracked into the Bradford Island fishway entered from the B or spillway branch. Fish were generally observed throughout the area, but no fish from Group D swam close to the face of the spillway or powerhouse.

Fish Behavior between Bonneville Dam and The Dalles Dam Study Areas

Twenty radio-tagged fish--10 in Group B and 10 in Group C--were released in the area 5 miles upstream from Bonneville Dam. In addition, 17 radio-tagged fish from Groups A and D crossed Bonneville Dam during the study and were available for tracking. The tracking effort immediately above Bonneville Dam was intensive and detailed tracks were obtained in this area. However, monitoring of fish behavior from River Mile 146 to 191 was intermittent. Most of the tracking in these 45 miles of river was done by traveling along the highways on either side of the river and listening for tagged fish. This system provided the approximate locations of tagged fish on a day-to-day basis, but it did not provide a detailed description of their migration route. Coverage of the area in this manner was fairly good, but fish in certain locations could be easily missed at any particular time. In addition to these routine tracks by car, we also conducted intensive searches throughout the whole area by boat to look for missing fish on specific occasions.

Group A--Ten radio-tagged fish from this group crossed Bonneville Dam from 14 to 26 April. The most noteworthy aspect of their behavior concerned their activities immediately after they exited from the fishways. Six of the seven fish tracked as they exited from the Bradford Island fishway traveled close to the shore of Bradford Island, went around the upstream tip, and then swam downstream to the spillway area before continuing upstream away from the dam. Four of these six fish completely crossed the forebay above the spillway and then went upstream out of the Bonneville area along the Washington shore. The other two fish swam halfway across the spillway area and then turned and swam upstream in the center channel. One fish exiting from Bradford Island fishway crossed to the Oregon shore immediately after coming out of the fishway. This fish continued upstream along the Oregon shore. Two fish were tracked coming out of the Washington fishway and both continued upstream along the Washington shore. The 10th fish in Group A exited from the Bradford Island fishway, but we did not get a track on it until it was well away from the dam.

Counter-currents that prevailed in the forebay during most spill conditions, including while Group A passed upstream, apparently contributed to the crossover of fish from the Bradford Island fishway. The dominant feature was a strong counter eddy that passed upstream around the tip of Bradford Island from the spillway side (Fig. 5). Fish apparently orient to this eddy and subsequently cross the forebay above the spillway. This eddy is not apparent at all flow levels. At high river flows, the water sweeps by the point without forming the eddy (Fig. 6).

None of the fish from Group A that swam above the spillway were swept back over the dam. Spill, however, was comparatively low during this

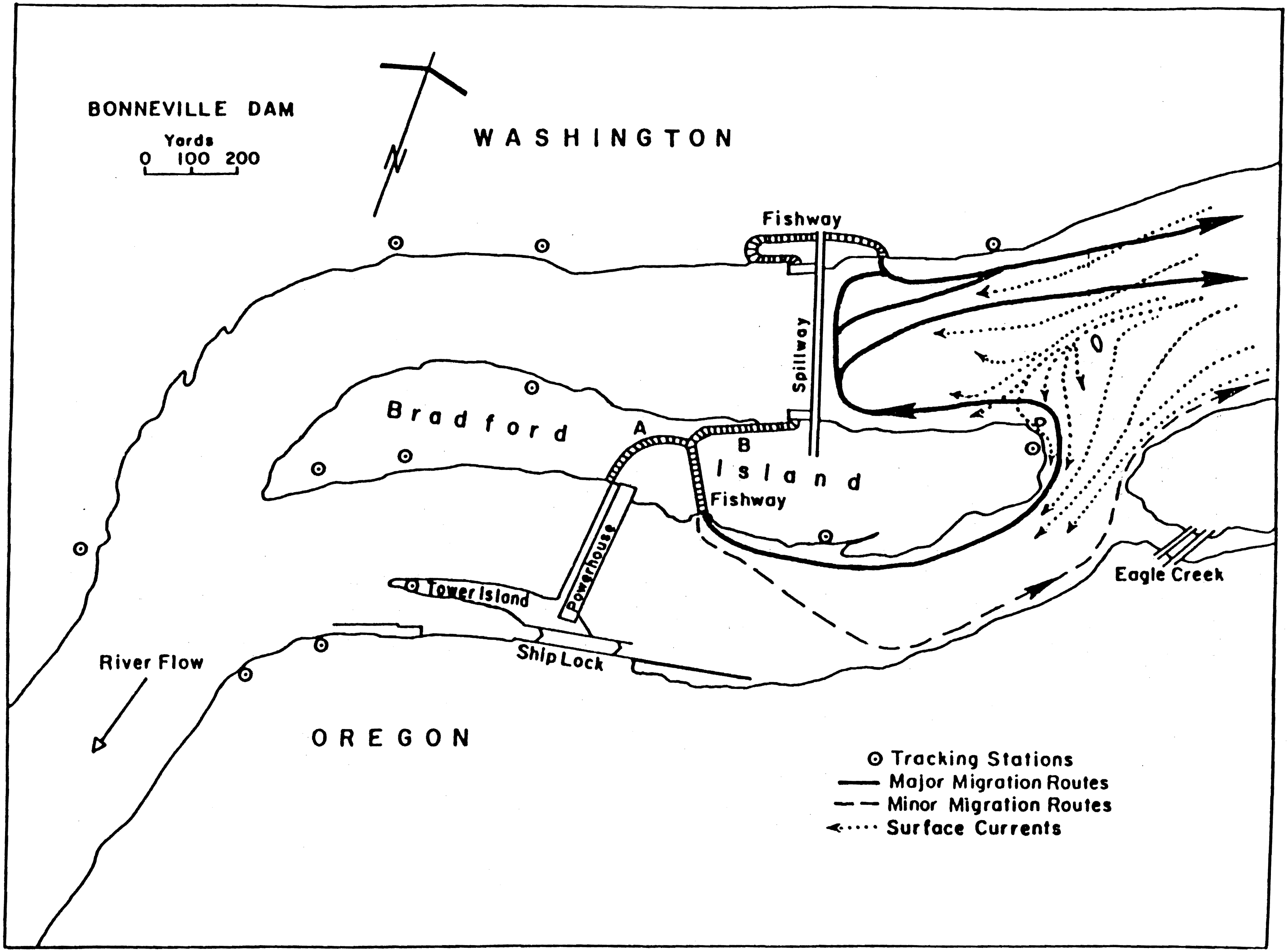

Figure 5.--The Bonneville Dam study area showing the pattern of surface current observed at the upstream end of Bradford Island during river flows of 248,000 ft^3/s. The general migration paths taken by spring chinook salmon after exiting the fishways in 1972 are also shown.

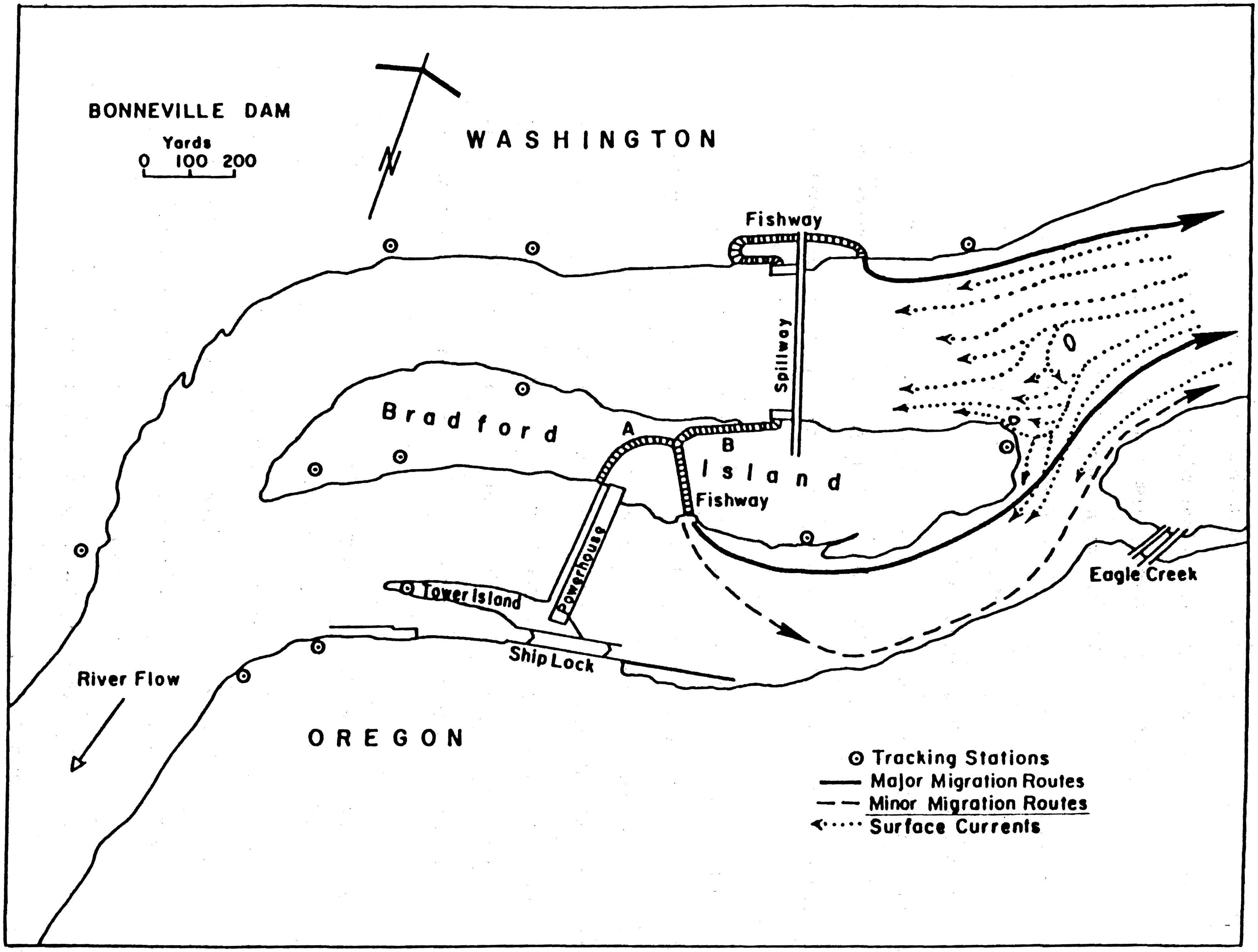

Figure 6.--The Bonneville Dam study area showing the pattern of surface currents observed at the upstream end of Bradford Island during river flows of 468,000 ft^3/s. The general migration paths taken by spring chinook salmon after exiting the fishways in 1972 are also shown.

period (31,000 to 172,000 ft^3/s) in relation to subsequent spills in May.

No specific holding areas were observed as the fish swam upstream to The Dalles Dam. River flows ranged from 178,000 to 310,000 ft^3/s, and travel time of the fish through the area averaged 51 hours. Seven of the fish were known to have reached The Dalles Dam area and one was known to have been taken in the Indian fishery. One fish was tracked to River Mile 151 where the tag could be heard until the battery finally ran down and the tag quit transmitting (10 days). The other fish was tracked to River Mile 148 and was never heard from again although specific searches were conducted throughout the area. Data on this group of fish are summarized in Table 8.

Group B--Ten radio-tagged fish were released approximately 5 miles upstream from Bonneville Dam on 25 April. No congregations of fish were noted, and nothing of particular interest was observed in the fish's journey through the area. Seven of the fish made it to The Dalles Dam area, two were tracked to the tributaries, and one was taken in the Indian fishery (see Table 9). River flows were moderate (178,000 to 256,000 ft^3/s, and the passage time of the fish through the area averaged 64 hours.

If we compare passage times through the area for Groups A and B, we can obtain an approximate assessment of delay due to tagging and handling. The time for Group A fish began when they crossed Bonneville Dam. These fish had already migrated 4 miles on their own and were considered fully recovered from handling. The time for Group B fish began as soon as they were released into the river. Group A fish took 51 hours to travel 47 miles (0.92 mi/h) while group B fish took 64 hours to travel 42 miles (0.65 mi/h). By adjusting travel time of Group B fish to account for the

Table 8.--Summary of 1972 tracking data on Group A fish from Bonneville Dam to The Dalles Dam area.

Group	Tag code	Date over Bonneville	Date entered The Dalles Dam study area	Elapsed time Bonneville to The Dalles (h)	River flow (1,000 ft^3/s)	Fate of fish
A	FF	4/14	4/17[a]	Unknown	-	Passed over The Dalles Dam
A	DF	4/17	4/19	50	299	Last heard at entrance to east fishway at The Dalles Dam
A	HF	4/17	4/19	51	299	Passed over The Dalles Dam
A	KF	4/19	4/21	48	265	Passed over the Dalles Dam
A	HS	4/20	4/21	30	256	Passed over The Dalles Dam
A	LF	4/20	-	-	-	Taken in Indian fishery between Bonneville and The Dalles Dam
A	LS	4/22	-	-	-	Tracked to River Mile 151. Tag was heard in same location for 10 days until battery quit - fish presumed dead or tag lost
A	ES	4/23	4/27	92	182	Passed over The Dalles Dam
A	DS	4/26	-	-	-	Tracked to River Mile 148 and never heard from again
A	KS	4/26	4/28	36	191	Passed over The Dalles Dam
Avg.	-	-	-	51	249	

[a]Exact time unknown.

Table 9.--Summary of 1972 tracking data on Group B fish from 5 miles above Bonneville Dam to The Dalles Dam area.

Group	Tag code	Date released above Bonneville	Date entered The Dalles study area	Elapsed time release point to The Dalles (h)	River flow (1,000 ft^3/s)	Fate of fish
B	IS	4/25	4/26	30	183	Passed over The Dalles Dam
B	HF	4/25	4/27	42	186	Reached The Dalles area but headed downstream and disappeared.
B	JS	4/25	4/27	54	186	Passed over The Dalles Dam
B	IF	4/25	4/28	67	188	" " "
B	EF	4/25	4/28	66	188	" " "
B	JF	4/25	4/28	67	188	" " "
B	HS	4/25	4/30	122	204	" " "
B	FS	4/25	-	-	-	Taken in Indian fishery near Lyle
B	FF	4/25	-	-	-	Fish tracked to mouth of Klickitat River on 5/5
B	KF	4/25	-	-	-	Fish tracked to mouth of Wind River on 4/26
Avg.	-	-	-	64	189	

additional distance traveled (5 miles) by Group A fish, we find that Group B took 20.7 hours longer to reach The Dalles Dam than did Group A ($64 + \frac{5.0}{0.65} - 51 = 20.7$). Therefore a delay of about 1 day may be considered due to handling and tagging.

Group C--A second group of 10 radio-tagged fish was released approximately 5 miles upstream from Bonneville Dam on 9 May. River flows were considerably higher (318,000 to 452,000 ft^3/s) during this period, and fish required from 120 to 196 hours to reach The Dalles area (Table 10.) Only three of 10 fish from this group arrived at The Dalles; three were known to have been taken in the Indian fishery, two were tracked into the Klickitat River, one was recovered at the Carson Hatchery, and one was tracked to River Mile 151 on 10 May, where the signal was lost and never regained despite searches conducted throughout the area.

As in the previous release above Bonneville Dam, no congregations of fish were noted.

One fish remained in the same location near a gill net for 6 days. During this time, we could detect little or no movement and the fish was thought to be dead. Finally, however, the fish began to move upstream and eventually crossed The Dalles Dam. The counter observing this fish reported that it had extensive injuries which had not been visible when it was tagged.

Group D--We have previously noted that 7 of 10 radio-tagged fish released below Bonneville Dam on 18-19 May continued passage upstream from Bonneville Dam after being counted out of the fishways between 24 May and 5 June. One additional radio-tagged fish crossed Bonneville Dam sometime later (exact date unknown) and was taken in the Indian fishery above Bonneville Dam.

Table 10.--Summary of 1972 tracking data on Group C fish from 5 miles above Bonneville Dam to The Dalles area.

Group	Tag code	Date released above Bonneville	Date entered The Dalles study area	Elapsed time release point to The Dalles (h)	River flow (1,000 ft^3/s)	Fate of fish
C	LF	5/9	5/14	120	343	Passed over The Dalles Dam
C	HF	5/9	5/16	173	358	Passed over The Dalles Dam[a]
C	FS	5/9	5/17	196	368	" " "
C	DF	5/9	-	-	-	Taken in Indian fishery near Drano Lake
C	ES	5/9	-	-	-	Taken in Indian fishery near Cook
C	EF	5/9	-	-	-	Taken in Indian fishery near Drano Lake
C	LS	5/9	-	-	-	Tag returned from Carson Hatchery
C	HS	5/9	-	-	-	Tag tracked into Klickitat River on 5/10
C	DS	5/9	-	-	-	Tag tracked into Klickitat River on 5/10
C	JF	5/9	-	-	-	Tag last heard at River Mile 151 on 5/10
Avg.	-	-	-	163	356	

[a]This fish remained in one location near an Indian gill net for 6 days. It was presumed dead, but then it started to move upstream, when it crossed The Dalles, the counter reported extensive injuries to the fish.

River flows were high during this period, averaging approximately 522,000 ft^3/s.

Behavior of fish in this group as they exited the Bradford Island fishway was different from that of Group A fish. Five fish were known to have exited from the Bradford Island fishway (six were counted but one of these was a fallback that reascended the ladder and consequently was counted twice). Three of the fish swam along the Bradford Island shore to the upstream end and passed directly on upriver. One of the fish swam along Bradford Island, around the point, and down along the north side of the Island to the spillway where it was swept over the dam. When this fish reascended the dam, it again exited from the Bradford Island fishway, but this time, instead of going around Bradford Island, it swam to the Oregon shore and then upriver. The fifth fish of the group exited the Bradford Island fishway and stayed in the middle of the channel until it crossed to the Oregon shore near Eagle Creek. Flows during this period were apparently sufficiently high to break up the counter eddy that prevailed around the tip of Bradford Island during the earlier period, when flows were considerably lower.

Routes followed by fish exiting from the Washington fishway were similar to those taken by fish in Group A. Only two fish were known to have entered the area from the Washington fishway and both continued upriver along the Washington shore.

No congregations of Group D fish were observed between Bonneville Dam and The Dalles Dam. Five of the eight fish passing Bonneville Dam reached The Dalles area, two were taken in the Indian fishery, and one was recovered at the Klickitat Hatchery. Data from this group of fish are summarized in Table 11.

Table 11.--Summary of 1972 tracking data on Group D fish from Bonneville Dam to The Dalles Dam area. River flows during the period 24 May through 7 June averaged 522,000 ft^3/s.

Group	Tag code	Date over Bonneville	Date entered The Dalles study area	Elapsed time Bonneville to The Dalles (h)	Fate of fish
D	FF	24 May	-	-	Taken in Indian fishery near Stevenson
D	LF	25 May	Unknown	-	Reported to have crossed The Dalles 2 June
D	KF	29 May	Unknown	-	Reported to have crossed The Dalles 2 June
D	JS	30 May	-	-	Tag was returned from Klickitat Hatchery
D	ES	31 May	Unknown	-	Reported to have crossed The Dalles 7 June
D	IS	1 June	-	-	Came out at Bradford Island fishway, swam around Bradford Island and fell back over the dam
D	IS	5 June[a]	Unknown	-	Do not know when it crossed The Dalles, but tag was recovered at Little Goose Dam on the Snake River
D	LS	28 May	Unknown	-	Reported over The Dalles on 6 June

Table 11.--Continued.

Group	Tag code	Date over Bonneville	Date entered The Dalles study area	Elapsed time Bonneville to The Dalles (h)	Fate of fish
D	IF	Unknown	-	-	Taken in Indian fishery near Stevenson
D	JF	-	-	-	Still below Bonneville Dam at end of study
D	HF	-	-	-	Still below Bonneville Dam at end of study

[a]This was this fish's second crossing of Bonneville Dam.

Fish Behavior in The Dalles Dam Study Area

The immediate area of The Dalles Dam was the uppermost segment of the river in which we tracked fish. As fish from all four groups approached The Dalles Dam, their behavior was monitored in detail by tracking crews in the study area. The general pattern of fish movement in the area is shown in Figure 2.

Group A--Seven out of 10 radio-tagged fish in this group reached The Dalles Dam area. Six of the seven were known to have gone on upstream past The Dalles Dam. The seventh fish was near or in the entrance to the east fishway at the end of a night shift, but when the next day's crew came on duty they could not locate the fish. Since we never heard the tag signal anywhere in the study area again, the fish conceivably went upstream over the dam. Daily average river flows during the time the fish were in the vicinity of the dam ranged from 174,000 to 283,000 ft^3/s and averaged 209,000 ft^3/s.

One control fish was known to have been caught prior to reaching The Dalles Dam area, and seven of the remaining nine controls subsequently passed upstream over The Dalles Dam.

Time spent by radio-tagged fish in the study area below The Dalles Dam and in ascending the fishways ranged from 4 to 69 hours and averaged 39 hours. Within this time, fish spent from 3 to 23 hours (average 7 hours) in the fishways. At Bonneville Dam, this same group of fish spent from 11 to 226 hours (average 101 hours) from the time they entered the study area below the dam until they had ascended the dam. During this period, they were in the fishways from 4 to 57 hours (average 22 hours).

All radio-tagged fish crossed The Dalles Dam via the east fishway as did six of seven controls. Every radio-tagged fish approaching The Dalles Dam entered the fishway once and continued its ascent over the dam. This direct movement of Group A through the fishway at The Dalles Dam is in contrast to movement at Bonneville Dam where four fish from this group backed out and then reentered the fishways prior to crossing the dam. If we examine the total of all groups, eight out of 20 radio-tagged fish that entered the fishways at Bonneville Dam backed out of the fishways, whereas only 2 out of 17 did so at The Dalles Dam.

Tracking this first group of fish in The Dalles area was made difficult by our lack of experience with signal reflection problems. However, we did observe several things of interest. Most of the fish approaching the dam passed under The Dalles Bridge near midchannel and showed little inclination to hold or mill below the dam. The only milling area of any consequence (and it was minimal) appeared to be at the corner of the spillway and nonoverflow section ("the corner").

Behavior of Group A fish in relation to the fishways at The Dalles Dam is noteworthy. One fish entered the east fishway via the entrance at the corner, whereas the rest appeared to enter the entrance at the east end of the powerhouse. In contrast to what we observed at Bonneville, the fish did appear to travel along The Dalles powerhouse collection system. Although it was difficult to determine for certain, it appeared that two fish from Group A made entries into the powerhouse collection system before entering the east fishway via the entrance at the east end of the powerhouse.

All fish observed exiting from the east fishway proceeded directly upstream without delay. The route taken upstream did not expose them to areas where fallback might be a problem.

Group B--Seven out of the 10 radio-tagged fish in this group reached The Dalles Dam area. Six of the seven were known to have gone on upstream past The Dalles Dam. The seventh fish entered the area at 0645 hours on 27 April, milled about at the south end of the spillway, was heard briefly near the east fishway, and then turned and swam downstream out of the area at 1152 hours. The fish was never recorded again even though specific searches were made. Daily average river flows while Group B fish were in this study area ranged from 189,000 to 268,000 ft^3/s and averaged 225,000 ft^3/s.

One control fish was known to have been caught prior to reaching The Dalles Dam area, and five out of the remaining nine subsequently passed upstream over the dam.

The amount of time spent by radio-tagged fish of Group B in the study area below The Dalles Dam and in the fishways ranged from 5 to 51 hours and averaged 36 hours. During this time they spent from 1 to 4 hours (average 3 hours) in the fishways. All of the fish tracked except one remained in the fishway originally entered and completed passage upstream over the counting board. The remaining fish entered the east fishway then exited back out, but later reentered the same fishway and subsequently passed over the counting board. Four of the radio-tagged fish and all five of the control fish crossed the dam via the east fishway. Two radio-tagged fish crossed via the north fishway.

Tracking of the B Group was somewhat less trying than for the A Group, but the problems with reflected signals continued. Nevertheless, we did obtain fairly good data from the B Group of fish. Approaches by these fish to the area were similar to those made by Group A fish. Some milling occurred at the corner of the dam and in the area around the east fishway. Several fish apparently entered and passed back out of the fishway collection system along the face of the powerhouse. Fish that entered the east fishway did so from the east end of the powerhouse. The exact point of entrance was impossible to pinpoint. One fish that entered the north fishway did so by swimming upstream along the north shore; the other fish swam across the base of the spillway (there was no spill at the time) from the south and entered the fishway. Both fish that exited from the upstream end of the north fishway crossed above the spillway (when there was no spill) and proceeded along the face of the powerhouse prior to going upriver near the Oregon shore. Fish tracked leaving the east fishway proceeded directly upriver away from the dam.

Group C--Three radio-tagged fish from this group reached The Dalles area, and all of these passed upstream over the dam. One control was known to have been caught prior to reaching The Dalles Dam area, and two of the remaining nine fish were counted going over The Dalles Dam. Daily average river flows during the time fish were in the vicinity of the dam ranged from 359,000 ft^3/s to 468,000 ft^3/s and averaged 417,000 ft^3/s.

Elapsed time spent by radio-tagged fish in the area prior to crossing the counting boards at the top of the fishways ranged from 9 to 46 hours and averaged 23 hours. During this time, they spent from 5 to 17 hours (average 11 hours) in the fishways. One fish remained for some time in the north fishway and then exited from the downstream end and eventually crossed the dam via the east fishway. As far as is known, the other two fish made only one entry into the fishways. Two of the radio-tagged fish crossed the dam via the north fishway, and one radio-tagged fish and both controls used the east fishway.

Good tracks were obtained below the dam on two of the three radio-tagged fish. Both fish entered the area along the Washington shore, moving closely along the shore and directly into the north fishway. One fish stayed in the fishway until it went over the counting board the next morning. The second fish left the downstream end of the fishway, dropped downstream 1,500 feet, and then crossed the river to the Oregon shore. The fish then crossed the powerhouse channel toward the powerhouse and entered the collection system near the west end of the powerhouse. To the best of our knowledge it entered the east fishway from the powerhouse collection system.

Fish exiting from the upstream end of the fishways passed quickly upstream. The two fish from the north fishway traveled up the Washington shore and the fish from the east ladder passed upriver near the Oregon shore.

Group D--No fish from this group was tracked into The Dalles Dam area by the time the experiment was terminated on 5 June. Of the 10 radio-tagged fish released below Bonneville Dam, five were eventually accounted for by counters at The Dalles Dam, two were taken in the Indian fishery above Bonneville Dam, and one entered the Klickitat River. Three control fish were known to have been caught below The Dalles Dam area, and three of the remaining seven were counted over The Dalles Dam. Average river flows during this period were high, near 500,000 ft^3/s.

DISCUSSION

Investigations in the spring of 1971 demonstrated that tracking of radio-tagged fish in turbulent areas below and between dams would be a feasible technique for aquiring detailed information on the movement of salmon in these areas. Despite the small number of fish tracked, useful information was obtained in this and the 1972 study on the behavior of individual fish from below Bonneville Dam to The Dalles Dam.

It appears fish passage problems concerning spring chinook are more likely a product of events at Bonneville Dam and the river area between Bonneville and The Dalles Dam than at The Dalles Dam. Fish not only mill about more below Bonneville, but they spend more time negotiating the fishways. The potential for fallbacks appears to be greater at Bonneville Dam than at The Dalles Dam. At Bonneville Dam, the likelihood of fallback appears to be tied to river flows and hydraulic conditions at the upstream end of Bradford Island. Because a majority of spring chinook salmon use the Bradford Island fishway, under certain conditions a high percentage of these fish are exposed to the spillway and the potential for fallback could be considerable. Whether these conditions will prevail in the future when river discharges are more fully regulated than at this time or in the past remains to be seen. In any event, the limited evidence at this time suggested that river dynamics upstream from the fishway exits could influence fallback. Further study of the fallback aspect was warranted in view of the potential effects of such occurrences on fishway counts and "unaccounted" losses of fish between dams, and so additional research was conducted in 1976 (see Part 5 in this Technical Memorandum).

Results of our work indicate that spring chinook salmon are able to survive falling back over Bonneville Dam and then reascend the fishways. In both 1971 and 1972, a radio-tagged spring chinook salmon was tracked as it fell back over the dam. In both cases, the fish reentered the fishway and successfully crossed over the dam a second time. Counts of control fish also give indication of survival and reascent of fallbacks. At least 2 of 20 controls reascended Bonneville Dam in 1972.

Specific and thorough searches were carried out throughout the entire area for missing fish. We feel that if the fish had still been in the area, we would have heard the signal from the tag; since we did not, we believe the fish probably left the area either by swimming up a tributary or through capture in the fishery.

Our limited tracking efforts in the river between the dams failed to pinpoint any specific problem areas related to unaccountable losses. We did, however, track a number of fish into tributaries and accounted for at least seven radio tags from the Indian fishery. A few tags were returned voluntarily from the fishermen and some voluntarily from the fish buyers and packing houses. Several others, however, were located by electronic surveillance of fish trucks and buyer's stations. These undoubtedly would have gone unnoticed had it not been for the diligence of the radio-trackers.

Circumstantial evidence does point to the possibility of gill-net dropout (the loss of fish due to gill-net injuries), which could be instrumental in spring chinook salmon mortalities in the Bonneville-Dalles Dam area. We tracked one fish to a gill-net site near River Mile 158 where it held up and remained relatively immobile for 6 days. This fish, however, did finally move on and crossed The Dalles Dam. Here the counter reported seeing extensive injuries on the fish. We also tracked another fish to a fishing site near River Mile 151, where it remained for many days until the tag's battery ran down. Both of these fish could have been dropouts. Although one eventually continued upstream, the extent of its injuries were such that it is possible the fish did not survive to spawn. The other conceivably was dead at the fishing site. Studies by Thompson and Hunter (1973) with sockeye salmon have shown that a high percentage of fish enmeshed in gill nets escape or drop out. They further show that about 40% of these dropouts die within 2 days and up to 80% die within 6 days of disentanglement. Many fish bore injuries and gill-net marks on them when they passed The Dalles Dam. The counting records for 1972 contain many comments concerning injured fish following commencement of net fishing below The Dalles Dam and very few, if any, such comments prior to that time.

Tracking indicates that if spring chinook salmon reach The Dalles area, they successfully pass upstream over the dam. Few fish milled or delayed below the dam, and after exit from the east ladder (the ladder used by the large majority of the tagged salmon), the fish used a direct and rapid route upriver which did not expose them to the spillway and potential fallback problems.

Table 12 summarizes the disposition of our 40 1972 radio-tagged fish. At the termination of the study, two fish remained below Bonneville Dam and an examination of subsequent fish counts does not indicate their crossing. Of the 38 tagged fish that either crossed or were released above Bonneville Dam, 21 (55%) crossed The Dalles Dam, 7 (18%) were known to have been captured in the Indian fishery, and 6 (16%) were tracked into tributaries.

Table 12.--Summary of the disposition of radio-tagged fish in the 1972 study.

Group	Number released	Release date	Release site	River flow range (1,000 ft^3/s)	Remained below Bonneville	Crossed Bonneville	Tracked to tributaries	Caught in Indian fishery[a]	Unaccounted loss between dams	Crossed The Dalles
A	10	4/11	Below Bonneville	174 - 365	0	10	0	1	2	7
B	10	4/25	Above Bonneville	178 - 268	-	-	2	1	1	6
C	10	5/9	Above Bonneville	317 - 452	-	-	3	3	1	3
D	10	5/18-19	Below Bonneville	468 - 560	2[b]	9[c]	1	2	0	5
TOTAL	40	-	-	-	2[b]	19[c]	6	7	4	21

[a]Between Bonneville and The Dalles Dam only.

[b]Two fish were below the dam when the study was terminated. The ultimate fate of these fish is unknown.

[c]Includes a fish that fell back over the dam and reascended; it was counted over the dam twice.

The fate 4 (11%) remained unknown. It is interesting to note that spring chinook salmon counts at The Dalles Dam for 1972 were 103,107 or 55% of the 186,140 spring chinook salmon counted over Bonneville Dam (Junge[3/]).

CONCLUSIONS

1. The use of radio-frequency fish tags for tracking fish is a workable and useful approach to studying fish behavior below and past dams.

2. Spring chinook salmon spend more time crossing over Bonneville Dam than they do The Dalles Dam.

3. A substantial percentage (95%) of spring chinook salmon that reach The Dalles Dam area successfully pass over the dam.

4. The unaccountable losses of spring chinook salmon between Bonneville and The Dalles Dams were less than 11% in this study. These losses are more likely associated with events at Bonneville Dam and in the river between Bonneville and The Dalles Dams than with those at The Dalles Dam.

5. High river discharge (300,000 ft^3/s and up) delays passage of spring chinook throughout the study area.

6. During high flow periods, fallback can contribute to inflated fish counts at Bonneville Dam. If the fish survive and recross (as they did in this study), they may be counted more than once.

7. During certain river flows (between 248,000 and 468,000 ft^3/s), fallback can be more of a problem for spring chinook salmon at Bonneville Dam than at The Dalles Dam.

[3/] Charles O. Junge, Fish Commission of Oregon, Clackamas, OR 97015, pers. commun.

8. Mortalities from gill-net dropouts are a possible causative factor in the unaccountable loss of spring chinook salmon.

9. Because of high saturation levels of dissolved nitrogen in the area below Bonneville Dam during the spring, extended exposure of spring chinook salmon in the restricted water depths of the fishways could lead to aggravation of the problem of gas bubble disease. Thought should be given to operation of the fishways to minimize the time fish spend in transit. For example, the time that counting station gates are closed should be kept to an absolute minimum. Perhaps a screen divider at the confluence of the A and B branches of the Bradford Island fishway would eliminate fallback from one branch to the other.

10. Further tracking studies should be designed to study behavior of other races and species of fish in the area and to provide additional data on the relationship between volume of flow (spill vs. turbines) and success of passage.

11. Further work to study fish behavior below dams should be scheduled when river flows can be controlled and specific conditions studied (see Part 2 in this Technical Memorandum).

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Part 2. EFFECTS OF POWER PEAKING ON PASSAGE OF FALL CHINOOK SALMON AT BONNEVILLE DAM IN 1973

By Gerald E. Monan and Kenneth L. Liscom

INTRODUCTION

Predicted changes in the pattern of electrical energy production in the Pacific Northwest may increase power peaking operations at mainstem dams on the Columbia and Snake Rivers. Thermal-electric plants are expected to take on more of the base load demands; but when demand for power is high, the large amounts of electricity produced at dams will result in high powerhouse discharges. To accommodate the additional production needs, new turbines are scheduled for construction at existing dams. When power demands are low, water will be stored for later use, thus lowering river flows. As power production at hydroelectric plants fluctuates more radically than in the past, so too will the magnitude of hourly and daily fluctuations in powerhouse discharges.

As water storage capacity and the number of turbines increase, river flows will be increasingly controlled by powerhouse discharges. The extent of this may be tempered by environmental considerations. One such consideration is the effect of manipulated flow on movement and survival of anadromous fish in the Columbia River system.

Fishery agencies are concerned that peaking operations could adversely affect the migration and survival of adult salmonids in the Columbia River Basin. Peaking may alter the production of salmonids by influencing the effectiveness of fish passage facilities at dams; the passage of fish between dams; or the effectiveness of commercial, Indian, and sport fisheries.

Determination of the overall effects of power peaking on production of salmonids involves a comprehensive program involving both adults and juveniles. The research reported upon here is part of such a program. To understand how adult salmon would react to increased peaking activities, we must learn more about fish behavior and how it relates to conditions in the river. This study was designed as a beginning to our search for information on the effects of peaking on adult salmonids. In addition, experiences gained in this initial endeavor may be expected to provide a framework for development of future research plans and requirements.

The primary aim of the study was to develop an understanding of the effect of power peaking operations on the behavior and survival of migrating adult fall chinook salmon. However, we had three overall objectives: (1) to determine the immediate effect of periodic reduction in flows through the Bonneville powerhouse on behavior and passage of migrating adult salmon, (2) to evaluate the fish passage efficiency of a newly-constructed portion of the Bradford Island fishway, and (3) to determine passage times for salmon between Bonneville Dam and the Cascade Locks.

EXPERIMENTAL SITE AND EQUIPMENT

At Bonneville Dam, the Columbia River is effectively divided into two channels by Bradford Island, which also separates the spillway from the powerhouse (See Part 1 and Fig. 1). Since all the water in the river must pass through the powerhouse or over the spillway, flow characteristics below the dam are determined largely by the dam's operation.

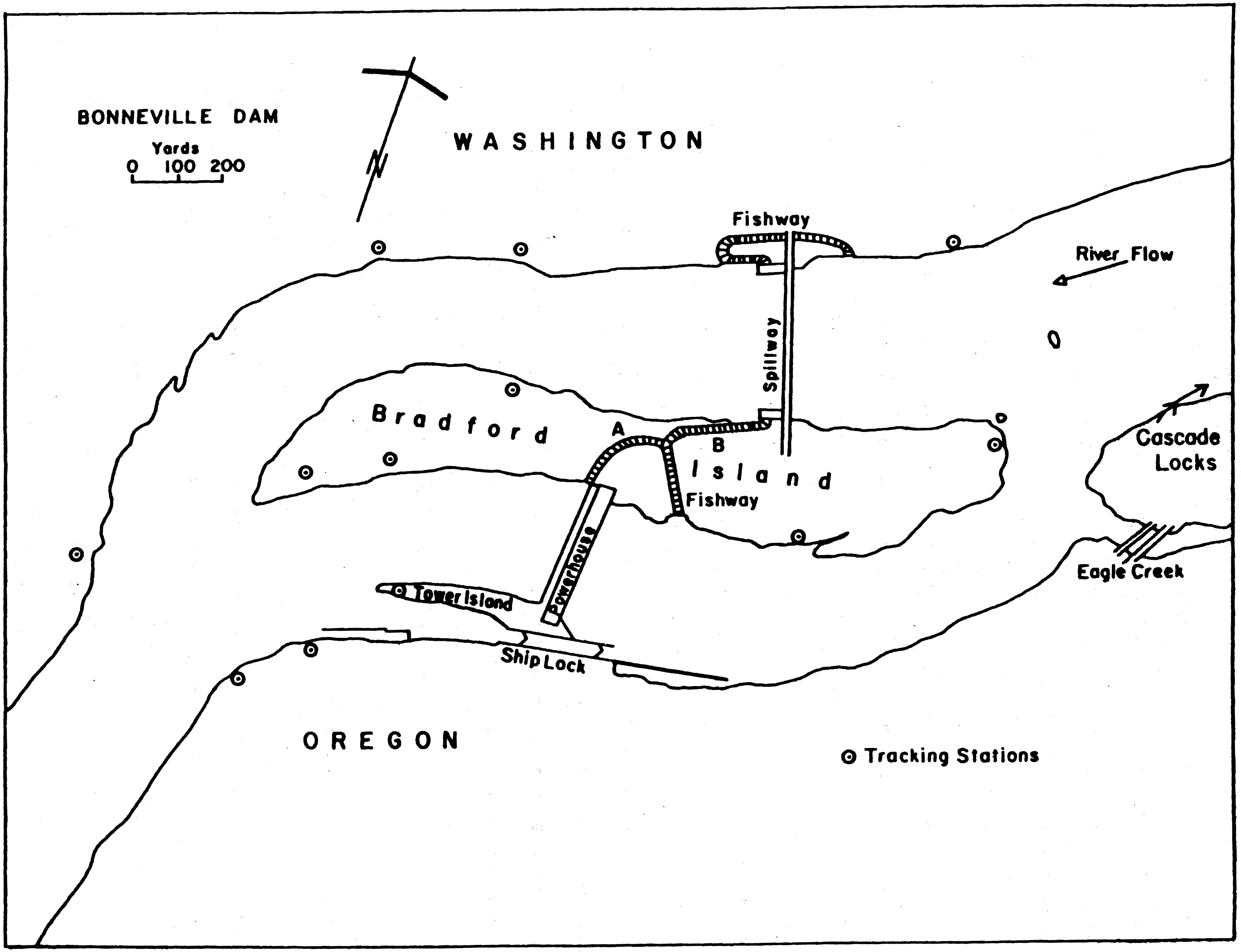


Figure 1.--The 1973 Bonneville Dam study area showing the fixed tracking stations.

Immediately above the dam, the north and south channels are each about 400 yards wide. Upstream from the tip of Bradford Island the channels soon join and narrow to a total width of about 500 yards. The river continues through this narrow gorge upstream for about 3 miles, then widens to approximately 1,300 yards near Cascade Locks.

Radio Tag

The radio tag is similar to the high frequency radio transmitter used previously, operating on a carrier frequency of approximately 30 megahertz (MHz). Changes in the circuitry improved frequency stability and tag reliability (Fig. 2). One pulse rate of two pulses per second was used for all tags.

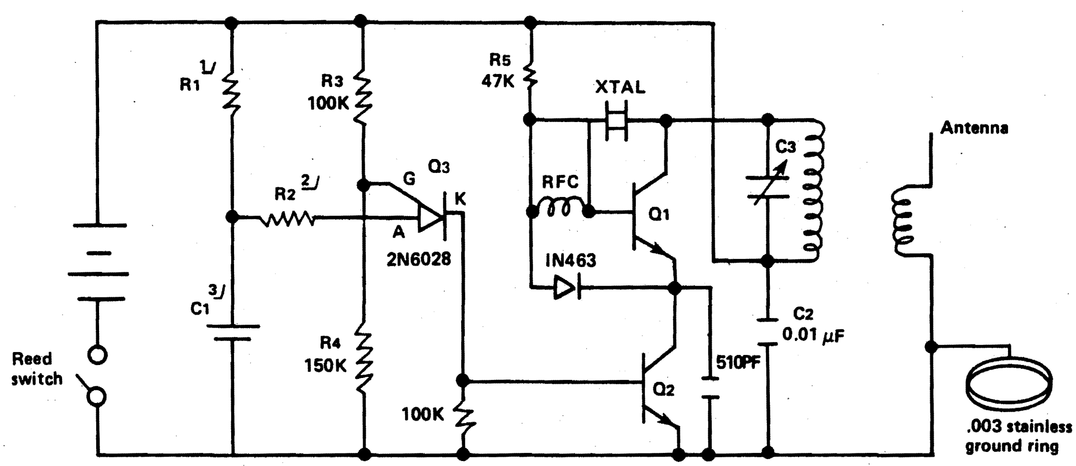
Direction Finder-Receiver and Antenna

The direction finder-receiver used in conjunction with the 18-inch diameter directional loop antenna was described in the previous study. A smaller 8-inch diameter loop with a correspondingly sharper null pattern was used for special tracking situations.

Fishway Monitoring Units

Movement of fish in the fishways was monitored by two different systems. One was the simple unit described in Part 1 that was used to alert fish counters to the presence of a tagged fish in a specific area. The other was a sophisticated telemetry unit that transmitted data on the movements of tagged fish in the fishways to a data collection center.

RADIO TAG-SPRING, 1973



Fast pulse = 600-30 1/ R_1 1.2 meg. 2/ R_2 15K 3/ C_1 0.56 MFD
Slow pulse = 1500-75 1/ R_1 1.8 meg. 2/ R_2 18K 3/ C_1 0.82 MFD

RFC = 75 turns, no. 40 wire on a 22 meg. 1/8 watt register
Q_1 = 2N2222 Q_2 = 2N2925 Q_3 = 2N6028

Figure 2.--Circuitry design for radio frequency fish tag used in 1973.

The simplest unit was placed at each fishway counting station to alert the counters to the presence of a tagged fish. This year, an additional audio signal receiver informed counters in the Bradford Island counting station when tagged fish left the fishway exit. An antenna for this unit was located slightly upstream from the exit of the Bradford Island fishway.

The telemetry units determined when specific tagged fish entered and started up the fishways. Each telemetry unit received signals from two antennas in the fishway, one located just inside the entrance and the other about 100 feet up the ladder. As the receiver unit picked up tag signals, it determined the tag frequency, converted the information to a tone code, and transmitted the appropriate code via radio transmitter to the receiver in the data collection center. The tone code was automatically decoded and a flashing light on a panel array indicated the tag frequency and location. By viewing the light panel and clock, observers determined the time each tagged fish moved into each specific fishway, and whether the fish was near the upstream or downstream antenna. By observing the sequence of events, it was easy to determine if the fish was moving up, holding in, or moving down the fishway.

EXPERIMENTAL PLAN

The original experimental plan called for tagging and tracking as many individually identifiable fall chinook salmon as possible between 20 August and 21 September 1973. Tagged fish were to be released into the river about 4 miles below the dam and their activities monitored as they approached the dam, crossed it, and swam through the reservoir to Cascade Locks. While tagged fish were in the vicinity of the dam, flows through the turbine units were to be manipulated to simulate power peaking operations.

However, during the period of our study, river flows in the Columbia River Basin were at an all-time low. Lack of normal snowpack the previous winter followed by an unusually dry spring and summer created an abnormal shortage of water. Production of sufficient electrical energy for consumers was a critical problem. Consequently, instead of manipulating flows for experimental purposes, we had to accept flows which allowed maximum production.

Meetings were held with all concerned parties to develop a plan for individual turbine discharge that would provide some experimental variables within the production schedule necessary for maximum power production. Two methods for reduction of powerhouse generation were selected:

1. The "feathered" method--flow from Turbines 1, 2, 10, 9, 3, 8, 4, 7, and 5 (in that order) would be decreased to about 2/3 to 1/2 of turbine capacity as required.

2. The "shutdown" method--Units 1 and 10 would be shut down as required. Further reduction, if required, would be accomplished by feathering the remaining units in the same order as Item 1 above.

The operating plan was to be carried out in accordance with the following schedule:

21-24 and 27-31 August and 4-7, 10-14, and 17-20 September--Control periods

25-26 August and 8-9 September-----------------------Shutdown periods

1-3 and 15-16 September-----------------------------Feathered periods

The control periods were all on weekdays, and the test periods were on weekends.

In addition to peaking studies, we evaluated fish passage through a newly constructed section of the Bradford Island fishway. The new section (from the counting station to the exit) was a vertical-slot type rather than a conventional overflow-weir type (Fig. 3). We planned to determine if there was any undue delay of migration in the new section by comparing the time fish took to negotiate it with the time through the fishway downstream from the counting station.

As fish left the dam, their progress upriver to Cascade Locks was to be monitored to determine passage times through this area. Detailed tracking was not intended, but rather a validation of progress up the river.

EXPERIMENTAL PROCEDURES

Trapping and Tagging

Fish to be used in the study were trapped and tagged in the same manner as described in Part 1.

Due to the similarity in behavior observed in 1971 and 1972 between radio-tagged, control, and nontagged chinook salmon passing over Bonneville Dam, the decision was made to discontinue using control fish during this and future studies. Thus, half as many fish would be handled. Close observation would still be kept on observable behavior of tagged and nontagged fish.

After tagging, the fish were placed in a fish hauling truck, driven to the Beacon Rock release point about 4 miles below the river, and released

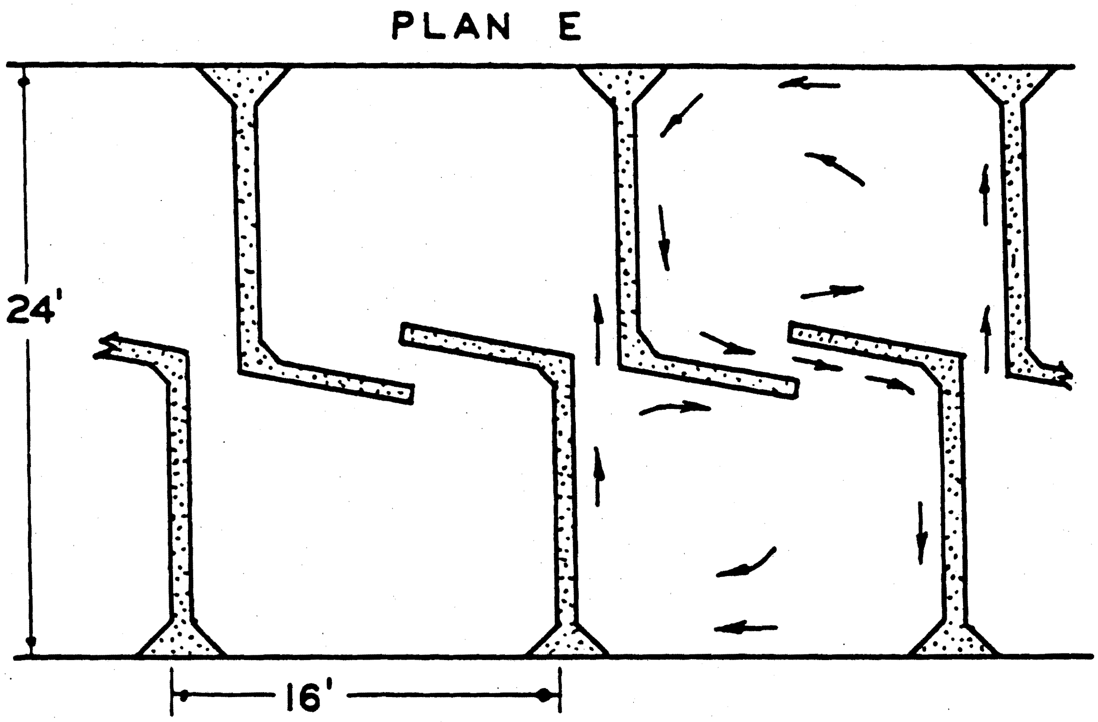


Figure 3.--Plan view of the slot-type fish ladder installed in the regulating section of the Bradford Island fishway at Bonneville Dam. Arrows indicate currents 1 ft below the surface at maximum flow. (From U.S. Army Corps of Engineers drawings.)

into the river. We released nine separately identifiable tagged fish on 20 August 1973. From then on during the study, whenever a tagged fish was tracked over the dam and upstream out of the study area, we tagged and released another fish with the same tag code. Thus, we attempted to keep nine separately identifiable tagged fish in the study area at all times. A total of 52 fall chinook salmon were tagged and released. Table 1 summarizes the tagging and release data.

Tracking and Plotting

Once the radio-tagged fish were placed in the river, their whereabouts were monitored intermittently from the release point until they reached the study area below Bonneville Dam. Trackers equipped with mobile tracking gear traveled along the highways on either side of the river periodically listening for tagged fish, and were able to alert staff at the dam when tagged fish were expected to enter the study area.

Tracking near the dam was done on a 24-hour basis with three crews made up of trackers and plotters. Fixed tracking stations were established on the north and south shores and on Bradford and Tower Islands (Fig. 1). Trackers were deployed to give the best possible coverage of fish in the study area.

Under the tracking system used during this study, all tracking was under the direction of the plotter located in the control center. When a tagged fish entered the study area, the plotter determined which trackers could best monitor the fish's location and called via two-way radio for bearings on specific fish from specific trackers.

Trackers determined bearings from their tracking stations to the tagged fish. Each tracker's station was equipped with a fixed mount and

Table 1.--Summary of tagging data for the peaking study on fall chinook salmon at Bonneville Dam in 1973.

Date released at Beacon Rock		Flag color	Radio tag code	Fish length (mm)
August	20	Pink-yellow	1D	950
	20	Pink-yellow	1E	890
	20	Pink-yellow	1F	950
	20	Pink-yellow	1G	900
	20	Pink-yellow	1H	890
	20	Pink-yellow	1I	950
	20	Pink-yellow	1J	850
	20	Pink-yellow	1K	1000
	20	Pink-yellow	1L	790
	22	Blue-white	2J	860
	22	Blue-white	2L	935
	25	Orange-yellow	3J	860
	25	Blue-white	2K	850
	26	Blue-white	2E	960
	27	Blue-white	2D	930
	29	Orange-yellow	3E	960
	29	Blue-white	2F	840
	29	Blue-white	2I	760
	29	Red-white	4J	890
	29	Orange-yellow	3K	970
September	02	Orange-yellow	5J	840
	02	Red-white	4K	870
	03	Red-white	4E	830
	04	Orange-yellow	3I	960
	04	Orange-yellow	3L	820
	05	Orange-yellow	3D	700
	05	Orange-yellow	3F	760
	05	Orange-blue	5K	840
	06	Red-white	5E	840
	06	Blue-white	2H	910
	06	Red-white	4I	760
	07	Blue-white	2G	830
	07	Red-orange	6K	840
	07	Red-white	4L	820
	09	Red-white	4D	910
	09	Red-white	4E	880
	10	Orange-blue	6E	870
	10	Orange-yellow	3H	930
	11	Orange-blue	5D	860
	11	Orange-blue	5F	760
	11	Orange-yellow	3G	820
	11	Orange-blue	5I	820
	12	Red-white	4H	640

Table 1.--continued.

Date released at Beacon Rock	Flag color	Radio tag code	Fish length (mm)
September 12	Green-white	7K	920
13	Red-orange	7E	830
13	Red-orange	6I	860
15	Red-orange	6D	820
15	Green-white	7I	890
16	Blue-yellow	8K	730
16	Orange-blue	5L	860
17	Green-white	7D	750
17	Red-orange	6F	830

compass rose for the loop antenna. The antenna was coupled into the mount so the geometric axis or null point of the antenna corresponded to a pointer that rotated with the antenna over the compass rose. The tracker established a bearing to the tagged fish by tuning to the frequency of the tag, rotating the antenna until the null point was determined, and then noting the location of the pointer on the compass rose. Simultaneously, a second and perhaps a third tracker did the same thing, and the bearings were radioed to the plotter.

Locations of the fish were plotted immediately by triangulation on charts made from an aerial photograph showing the position of the tracking stations and corresponding compass roses. A time-sequence series of these plots provided details on the path taken by the fish. The number of plots and the interval between plots indicated how fast each fish was moving and the number of fish in the area.

Because the bearings were so closely coordinated, anomalies of radio-wave transmission were immediately apparent with this plotting system. When these occurred, the plotter immediately called for additional bearings from other tracking stations.

EFFECTS OF PEAKING ON FISH PASSAGE

Because power production was the major consideration for turbine regulation at Bonneville Dam during this study, flow conditions created below the dam were rather unstable, and without the pronounced differences in flows that would have been desirable for the study. During this study period, the daily average river flow at Bonneville Dam ranged from 78,900 to 139,600 ft^3/s and averaged 108,000 ft^3/s. Except for the standard fishway attraction water, there was no spill during the study. Table 2 shows the low and high daily powerhouse discharges during test and control periods, and the averages of these values. Table 3 shows the hourly average flows through each turbine during the days with the lowest and highest average daily discharges during test and control periods.

Fish behavior in the area was variable, but no dramatic or immediate changes in behavior were observed that could be directly correlated with changes in flow patterns. Fish movements throughout the area were plotted over each hour and related to the prevailing turbine operation; no specific correlations were found. Fish were found in all portions of the study area below the dam. Migration routes below the dam were less well defined than previously observed with spring chinook salmon (see Part I). Figure 4 shows the general migration routes and milling areas below the dam.

No specific patterns of movement were apparent, however the total amount of fish activity (cumulative time spent by all tagged fish) within portions of the study area was affected by the modified peaking operations. By dividing the study area into subdivisions (powerhouse approach channel, powerhouse collection system at the base of the powerhouse, Bradford Island fishway, spill approach channel, and Washington fishway), computing the total amount of time fish were active within each subdivision each day, and comparing test periods with control periods, we can see changes in the amount of fish activity in each subdivision. During test periods when flow through the turbines was reduced, the amount of activity increased for tagged fish in certain portions of the study area. Tagged fish spent 56 to 64% more time in the powerhouse approach channel during test periods than they did during control periods (Table 4). Fish also spent more time in

Table 2.--Range of daily average powerhouse discharges during peaking study at Bonneville Dam 1973.

Period	Daily average powerhouse discharge (ft^3/s)		
	Low	High	Average
Control	84,000	133,200	108,700
Test (shutdown)	72,400	101,100	83,900
Test (feathered)	81,500	91,300	88,600

Table 3.--Hourly average flows through each turbine for the days with the lowest and highest average daily discharges during control and test periods (flows are given in 1,000 ft^3/s). (Bonneville Dam 21 August - 20 September 1973).

Period	Time	Turbines 1	2	3	4	5	6	7	8	9	10	Hourly total
Control-low flow	0100-0800	6.9	6.9	7.7	7.4	8.2	0	8.2	8.2	9.0	8.2	70.7
	0900-1100	7.7	7.7	7.2	8.9	12.5	12.0	12.5	6.9	8.9	8.9	93.2
	1200-2400	8.5	8.5	6.7	6.7	11.8	11.8	11.8	6.9	10.0	10.0	92.7
Control-high flow	0100-0800	10.0	10.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	132.0
	0900	9.9	9.9	9.9	14.2	9.9	14.2	14.2	9.9	9.9	13.7	115.7
	1000	9.9	9.4	13.9	13.9	13.7	14.2	13.9	13.9	13.9	13.7	130.4
	1100	9.9	9.6	14.2	14.2	14.2	14.5	14.2	14.2	9.9	9.9	124.8
	1200	8.1	9.3	9.0	9.0	8.8	9.0	9.0	9.0	10.2	7.9	89.3
	1300-1700	10.9	11.2	14.3	14.3	14.3	14.3	10.3	10.3	14.5	10.9	125.3
	1800-2400	10.5	10.5	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	133.8
Test (shutdown) low flow	0100-0600	6.4	8.5	8.5	0	8.2	0	7.8	7.8	9.0	9.0	65.2
	0700	6.1	8.7	3.3	3.3	8.1	6.7	7.7	7.5	9.3	7.3	68.0
	0800	0	8.9	9.1	11.9	9.1	8.7	9.3	9.3	11.5	0	77.8
	0900-1100	0	9.6	11.2	12.9	12.9	12.9	12.9	11.0	12.9	0	96.3
	1200-1700	0	9.5	6.5	12.3	6.8	8.0	6.8	6.5	12.3	0	68.7
	1800-2400	0	9.6	7.4	12.3	7.4	0	7.4	7.4	12.3	0	63.8
Test (shutdown) high flow	0100	10.5	10.7	13.2	12.2	13.4	12.7	12.7	12.4	13.2	13.4	124.4
	0200	0.9	10.2	12.0	13.2	13.4	13.2	13.4	12.0	13.4	7.7	109.4
	0300-0800	0	10.2	7.0	7.0	7.2	12.8	7.0	7.0	13.2	7.0	78.4
	0900-1200	0	10.0	10.6	10.4	10.6	11.5	10.2	10.4	13.0	7.0	93.7
	1300-1600	8.3	10.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	126.8
	1700-2200	0	10.0	8.1	9.0	10.0	10.0	10.0	9.0	13.0	10.5	89.7
	2300-2400	0	10.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	115.8
Test (feathered) low flow	0100-1400	6.7	8.4	8.7	11.3	0	0	11.3	8.8	10.0	8.8	74.0
	1500-2400	7.4	9.5	11.2	12.5	0	0	12.5	12.0	11.4	9.5	86.0
Test (feathered) high flow	0100-0700	7.2	7.2	8.5	9.0	9.0	0	9.1	8.9	10.1	10.1	79.1
	0800	7.1	7.3	9.9	9.9	10.7	7.1	8.0	8.0	10.3	10.0	88.3
	0900-1800	6.8	6.8	6.8	9.5	13.0	13.0	13.0	10.0	10.0	10.0	98.9
	1900-2100	6.9	6.9	7.1	9.6	10.3	9.8	9.8	9.8	9.8	9.8	89.8
	2200-2400	7.0	7.0	7.0	12.9	12.9	12.9	12.9	9.4	9.4	9.4	100.8

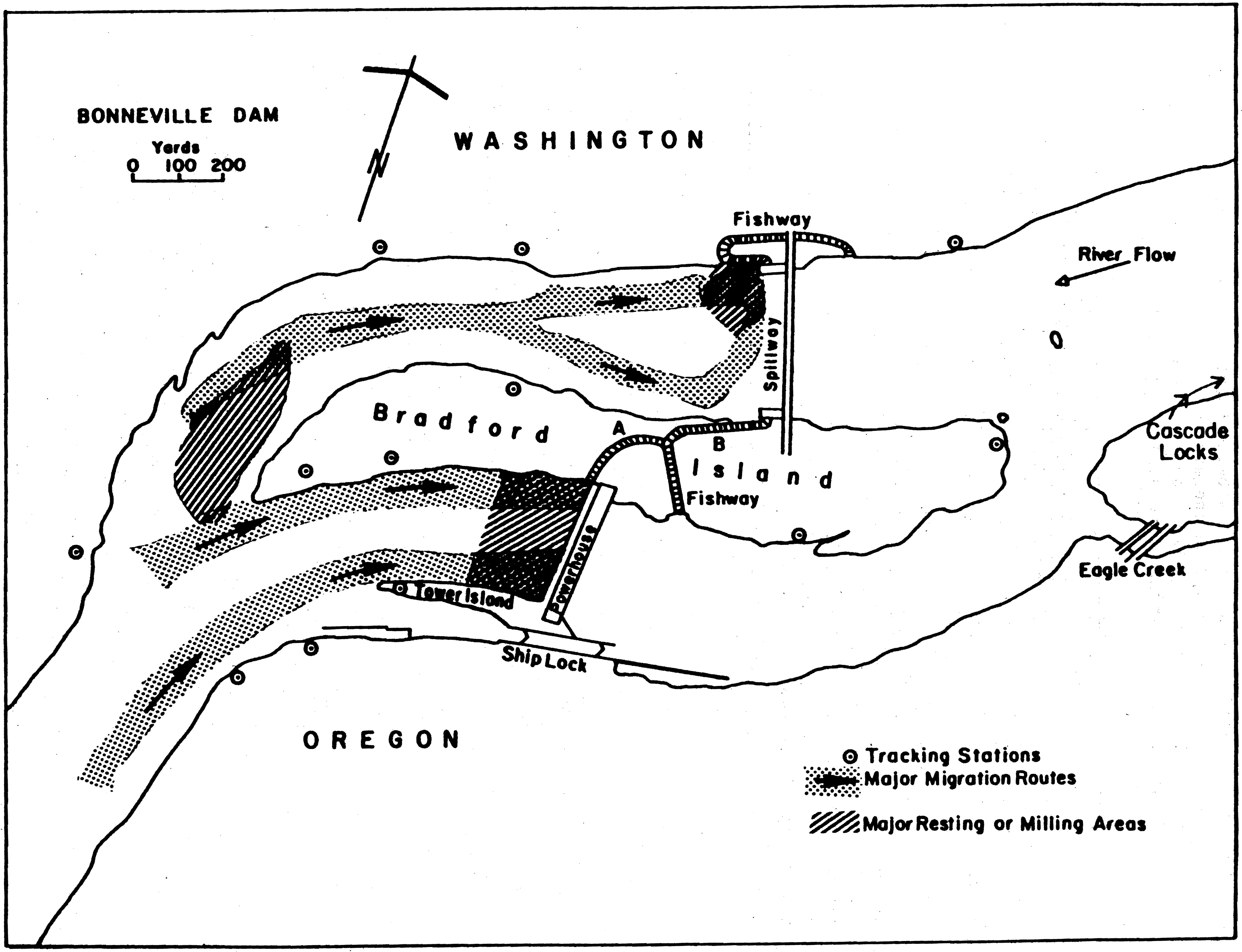


Figure 4.--Areas below Bonneville Dam most used by fall chinook salmon for traveling, milling, and resting.

Table 4.--Fish activity index in areas below Bonneville Dam during test periods in 1973 (based on the average number of hours tagged fish spent in each area per day, and expressed in percent increase or decrease of the average time spent during control days).

Area	Change from average control days (%)	
	Feathered test	Shutdown test
Spillway channel	-19	-23
Washington fishway	-59	-49
Powerhouse channel	+64	+56
Collection system	+21	+14
Bradford Island fishway	+73	+ 9

the powerhouse collection system and the Bradford Island fishway and less time in the spillway channel during the test periods. Fish had a greater tendency to approach the dam via the powerhouse approach channel when the flow was reduced through the turbines; consequently, during test periods tagged fish spent more time in areas associated with the powerhouse channel and less time in areas associated with the spillway channel.

Along with the increase in fish activity in the powerhouse channel during test periods, there was an increase in passage of tagged fish over the dam. Of the 31 tracking days during the study, 22 were control days, 5 feathered condition test days, and 4 shutdown condition test days. Table 5 shows the actual data on tagged fish tracked past the dam and the theoretical data based on 22 tracking days for each condition. This extrapolation of data is possible because we maintained a relatively constant population of nine tagged fish below the dam each day by releasing a new tagged fish into the study area each time a fish crossed the dam. Fish passage during both test conditions appeared better than that during the control condition. The feathered test condition resulted in a marked improvement in fish passage through the A branch of the Bradford Island fishway.

A substantial percentage, 45 of the 52 tagged fish released below the dam, subsequently crossed over. Of the remaining seven, four were caught below the dam by fishermen and three were still below the dam at the termination of the experiment. Of the 45 that crossed the dam, the elapsed time from release until crossing ranged from 1 to 16 days and averaged 4 days. These times include the 24-hour period we believe an average tagged fish needs to recover from handling and marking.

Table 5.--Data on radio-tagged fall chinook salmon crossing over Bonneville Dam in 1973 study.

Experimental condition	No. of days condition existed	Actual no. of tagged fish observed passing dam[a]			Theoretical no. of tagged fish passing dam[b]		
		Wash. and Bradford Island B fishway[c]	Bradford Island A fishway	Navigation lock	Wash. and Bradford Island B fishway[c]	Bradford Island A fishway	Navigation lock
Control	22	13	12	2	13	12	2
Shutdown test	4	3	3	0	16	16	0
Feathered	5	3	8	0	13	35	0

[a]One additional tagged fish was known to have crossed the dam, however, its actual crossing was not observed.

[b]Numbers of fish have been adjusted to simulate an equal number of tracking days (22) for each experimental condition.

[c]Data from the Washington fishway and the Bradford Island B fishway are combined because they both have their entrances in the spillway channel.

FISH BEHAVIOR FROM BONNEVILLE DAM TO CASCADE LOCKS

After tagged fish left the fishways and entered the forebay, their activities were monitored until they reached Cascade Locks. Because of manpower limitations, we were unable to closely track all of the tagged fish. We did, however, get good tracks on most of the fish while they were in the vicinity of the dam and monitored their rate of progress upriver to Cascade Locks (Fig. 5).

Upon leaving the Bradford Island fishway, approximately 70% of the tagged fish followed the shoreline of Bradford Island around into the eddy and to the spillway area. The majority of these fish swam across the face of the spillway (which was not spilling during this study) and proceeded upstream along the Washington shoreline. Several fish from the Bradford Island fishway swam close enough to the exit of the Washington fishway to activate the tagged-fish detector at that counting station.

The few fish that did not swim around Bradford Island to the spillway swam up the channel past Bradford Island, and proceeded upstream. An exception to this pattern, which is discussed later, involved several fish that spent the night resting in the vicinity of the dam before they went on upstream.

The majority of the tagged fish leaving the Washington shore fishway proceeded directly upstream. About 30% of the fish traveled back toward the spillway after exit from the fishway before turning and going upstream.

Five of the 13 tagged fish that exited the fishways in the late afternoon-evening period spent the night near the dam--four from the

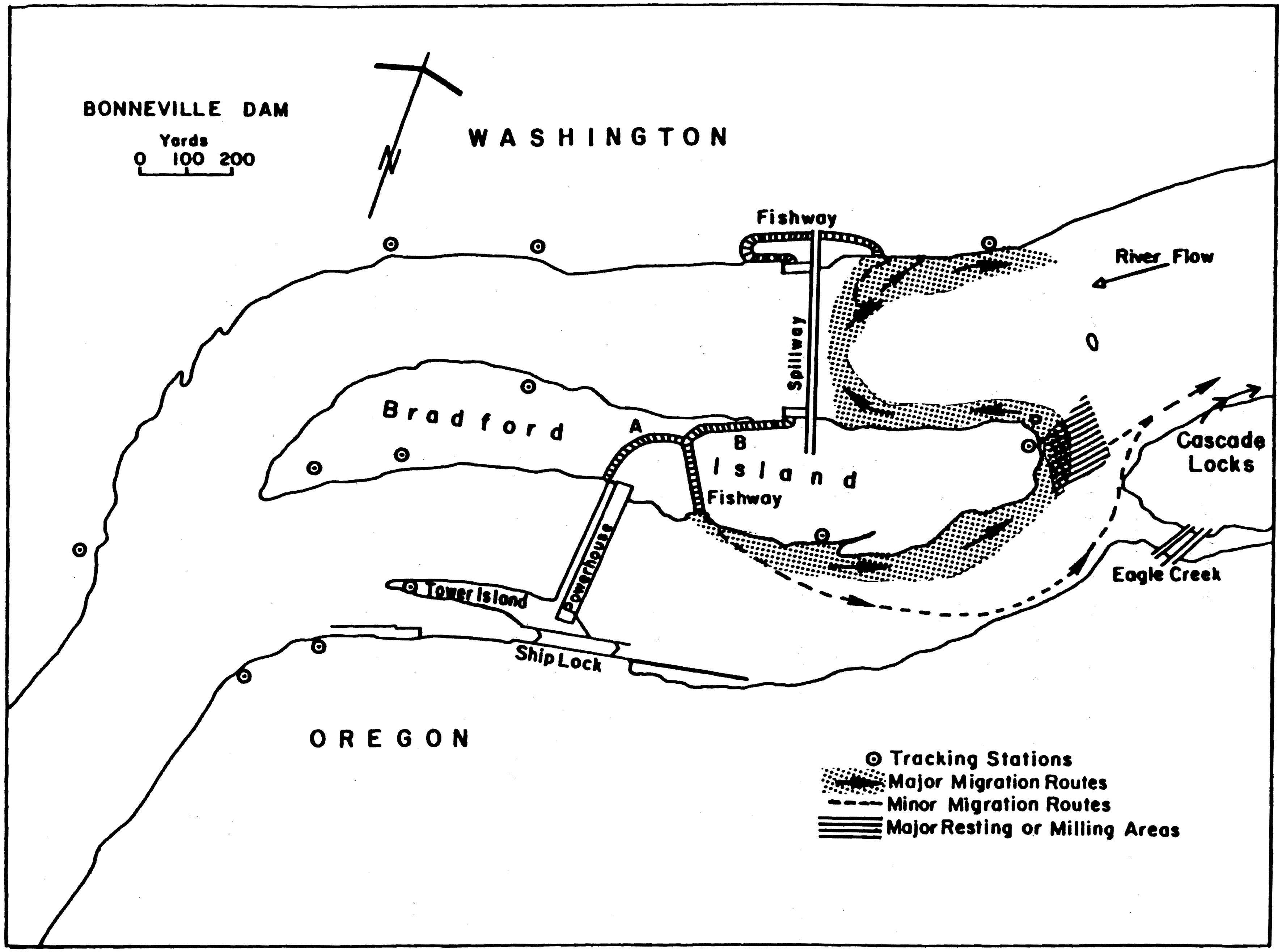


Figure 5.--Areas above Bonneville Dam most used by fall chinook salmon for traveling, milling, and resting after exiting the fishways.

Bradford Island fishway and one from the Washington fishway. Four of the fish remained in approximately the same location, an area just upstream from the tip of Bradford Island. The fifth fish remained just outside the exit from the Bradford Island fishway. All of these fish moved about very little during the night, but started upstream again as dawn approached.

The rate of movement for all fish once they left the vicinity of the dam and proceeded upstream was fairly consistent and rapid. If we exclude the five fish that spent the night near the dam, the average time for tagged fish to reach Cascade Locks was 105 minutes from the time they exited the fishways. Fish from the Bradford Island fishway averaged 113 minutes to reach Cascade Locks, while fish from the Washington fishway averaged 89 minutes. Fish that spent the night near the dam averaged 83 minutes to reach Cascade Locks once they began to move on upstream.

Once fish left the vicinity of the dam, plotting of their positions was discontinued. However, based on the strength of the signal received and their rate of progress upriver, we believe the fish moved upstream rather directly and generally traveled closer to the Washington shore than the Oregon shore. Table 6 summarizes fish movement from release to Cascade Locks.

FISH PASSAGE TIME THROUGH A VERTICAL SLOT FISHWAY

A comparison of times taken by tagged fish to negotiate the various fishways was used to determine the fish-passage effectiveness of the newly constructed vertical slot portion of the Bradford Island fishway. Monitors indicated the time tagged fish entered the fishways, passed the counting stations which separated the two types of fishways, and exited into the

Table 6.--Summary of data on fall chinook salmon tagged with radio tags, released at Beacon Rock, and tracked in the vicinity of Bonneville Dam in 1973.

Tag code	Elapsed time, release to crossing dam (h)	Route over the dam (fishway etc.)	Period fish crossed dam			Elapsed time in upper Bradford Island fishway (min)	Elapsed time, fishway exit to Cascade Locks (min)	Remarks
				Weekend				
			Weekday	Shutdown	Feathered			
12L	22	WASH	*			N/A	?	
6J	26	WASH	*			N/A	70	
1F	287	BRAD "A"[a]			*	17	98	
13D	138	WASH		*		N/A	87	
5H	290	BRAD "A"			*	---	?	
13E	120	BRAD "A"		*		13	94	
13K	92	BRAD "A"	*			9	88	
7I	75	?	*			---	?	
7G	N/A	N/A	N/A	N/A		N/A	N/A	Caught below dam
10J	54	LOCK	*			N/A	?	
9L	283	BRAD "A"			*	10	70	
4K	101	WASH	*			N/A	54	
7J	69	WASH	*			N/A	?	
7E	49	WASH	*			N/A	88	
8D	195	BRAD "A"	*			11	82	
4E	98	WASH			*	N/A	59	
2J	80	WASH			*	N/A	96	
4I	122	BRAD "A"			*	11	92	
3K	69	BRAD "A"			*	17	102	
11K	55	BRAD "A"	*			8	106	
14J	391	BRAD "A"	*			9	780	
3E	54	WASH	*			N/A	108	
11L	23	WASH	*			N/A	128	
3I	24	BRAD "A"	*			4	167	
6D	80	WASH		*		N/A	699	
11F	81	BRAD "A"		*		16	145	
12K	19	BRAD "A"	*			14	128	
2E	77	BRAD "A"		*		20	130	
9H	77	WASH		*		N/A	109	

Table 6.--Continued.

Tag code	Elapsed time, release to crossing dam (h)	Route over the dam (fishway etc.)	Period fish crossed dam: Weekday	Weekend: Shutdown	Weekend: Feathered	Elapsed time in upper Bradford Island fishway (min)	Elapsed time, fishway exit to Cascade Locks (min)	Remarks
9I	102	WASH	*			N/A	95	
10G	83	BRAD "A"	*			10	739	
8K	95	BRAD "A"	*			18	83	
3L	169	BRAD "A"			*	---	---	
10D	29	BRAD "A"	*			25	137	
13F	27	BRAD "A"	*			50	724	
1E	62	LOCK	*			N/A	156	
7H	26	WASH	*			N/A	84	
11D	77	BRAD "A"	*			20	116	
10F	77	BRAD "A"			*	19	91	
5G	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Remained below dam at term. of study
2I	33	BRAD "A"	*			18	922	
10H	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Caught below dam
6K	80	BRAD "A"			*	12	165	
5E	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Caught below dam
11I	35	WASH	*			N/A	105	
12F	152	WASH	*			N/A	85	
4D	28	BRAD "B"[b]			*	13	125	
8I	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Caught below dam
5K	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Remained below dam at term. of study
14L	96	WASH	*			N/A	72	
3D	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Remained below dam at term. of study
8F	30	BRAD "B"	*			8	145	

[a]The north side of the powerhouse branch of the fishway is designated "A."

[b]The south side of the spillway branch of the fishway is designated "B."

river above the dam. The 23 tagged fish timed through the Bradford Island fishway averaged 15 minutes through the 193-foot long vertical slot section and 220 minutes through the 1,032-foot long overfall weir section. In the 1,312-foot long Washington weir type fishway, 15 tagged fish averaged 290 minutes traveling from entrance to exit. Passage times for tagged fish through the new section of the Bradford Island fishway indicated the fish accepted the new conditions and passed through with little delay.

Passage times through both the Bradford Island and Washington fishways may have been increased slightly by abnormal conditions. The activities of construction crews working adjacent to the Bradford Island fishway were known to delay some fish, and fish-tagging activities in the Fisheries-Engineering Research Laboratory may have caused some delay for fish in the Washington fishway.

SUMMARY AND CONCLUSIONS

Production of electrical energy in the future within the Pacific Northwest will involve more peaking operations at mainstem dams on the Columbia and Snake Rivers. Fishery agencies are concerned that peaking operations could adversely affect the migration and survival of adult salmonids.

To provide initial data on the effects of peaking on adult salmonids, we tagged adult fall chinook salmon with radio tags, released them below Bonneville Dam, and studied their behavior in relation to varying powerhouse discharges (weekend vs. weekday). The study took place from 21 August to 20 September 1973, and 52 fall chinook salmon were tagged and tracked. Of the fish tagged, 45 crossed the dam and went on upstream, 4 were caught by fishermen below the dam, and 3 remained below the dam at the termination of the study.

Because of the critical electrical energy shortage brought on by the record low river flows, power production commitments did not allow sufficient control over turbine flows to adequately study the effects of peaking on salmon behavior in the immediate vicinity of Bonneville Dam. We were, however, able to obtain useful data on behavior of fall chinook salmon during the low flow conditions that prevailed. Table 6 summarizes pertinent data regarding adult chinook salmon passage past the dam during test (weekend) and control (weekday) periods, the effectiveness of the new vertical slot section of fishway at the upper end of the Bradford Island fishway, and the time taken by fall chinook salmon to migrate from Bonneville Dam upstream to Cascade Locks.

The main conclusions we reached are as follows:

1. Within the flow conditions available, slight reductions in flow through the turbines attracted more fish into the powerhouse approach channel.

2. Of the two methods used to reduce powerhouse discharge, feathering the turbines achieved a more dramatic increase in fish passage than shutoff of the end turbines.

3. The newly constructed vertical slot section of the Bradford Island fishway effectively passes fall chinook salmon.

4. During low river flow conditions, fall chinook salmon, on leaving the immediate vicinity of the dam, proceed upstream to Cascade Locks with little milling or delay.

5. Further work to study fish behavior below dams in relation to power peaking must be scheduled when power production schedules are more flexible. Specific turbine conditions must be created and maintained for a sufficient length of time to permit meaningful assessments of the effect of various discharges on movement and survival of upstream migrants.

ACKNOWLEDGMENTS

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The helpful and cooperative attitudes of all personnel of the U.S. Army Corps of Engineers at Bonneville Dam were greatly appreciated.

Part 3. EFFECT OF SPILLWAY DEFLECTORS AND FALLBACK ON ADULT CHINOOK SALMON AND STEELHEAD TROUT AT BONNEVILLE DAM IN 1974

By Gerald E. Monan and Kenneth L. Liscom

INTRODUCTION

Large volumes of water plunging over spillways at dams in the Columbia and Snake Rivers cause high concentrations of dissolved gases in these rivers. Supersaturation of dissolved gases associated with plunging water at the dams causes substantial losses of migrating salmon (Ebel 1971).

Major modifications of spillways at dams in the Columbia and Snake Rivers were proposed as part of an overall program to reduce the concentrations of gas. To decrease the force of the plunging water, spillway flow deflectors were added to the spillbays (segments of the spill section, each with a spillgate for water flow control) (Fig. 1). The deflectors decrease the angle at which the spilling water strikes the river. Prior to installation of spillway deflectors at all dams, fisheries agencies and the U.S. Army Corps of Engineers (CofE) wished to make certain that hydraulic conditions created by the modifications did not adversely affect survival and passage of fish at the CofE projects.

Initial studies were conducted at Lower Monumental Dam, where two of the eight spillbays had deflectors installed. While adult chinook salmon sometimes used the potentially dangerous area immediately below the modified spillbays, there was no evidence that fish were injured or their passage impaired (Monan and Liscom 1974). Based on this finding with adults and on similar findings with juveniles (Long and Ossiander 1974),

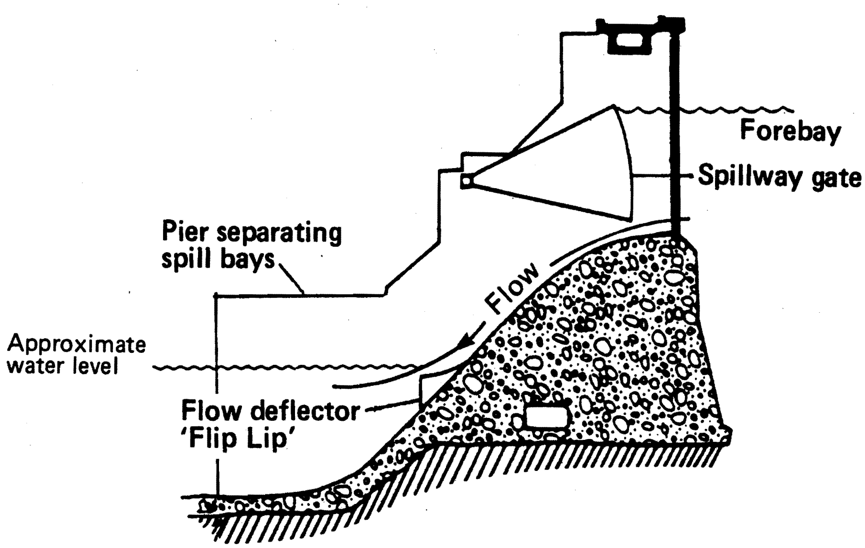

Figure 1.--Cross section of a spillway bay with a typical flow deflector installation.

fishery agencies recommended that additional spillbays be modified at major dams in the Columbia River Basin.

Bonneville Dam was one of the dams scheduled for modification. The impact of modifications to Bonneville Dam is particularly important because it is the first dam encountered by adult salmon and steelhead trout during their upstream migration, and more fish pass it than any other project in the Columbia River Basin. Consequently, spillway deflectors on only 4 bays out of 18 were authorized and completed by the spring of 1974. Further work was held in abeyance until it was determined that fish were not adversely affected by the installation of deflectors.

Because radio-tracking studies of salmon have proven to be effective in studying behavior of free-swimming fish, radio-tracking was chosen to study the effects the modifications had on adult salmon and steelhead trout. The primary objectives of the study were to determine whether adult salmon and steelhead trout frequent the potentially dangerous areas below the modified spillbays, and if so, whether the fish are injured or killed by hydraulic conditions immediately below the deflectors. A secondary objective was to determine fish behavior in relation to fallback.

EXPERIMENTAL SITE AND EQUIPMENT

Site

At Bonneville Dam, the spillway is separated from the powerhouse by Bradford Island, effectively dividing the river into two channels (Fig. 2). The overall length of the spillway is 1,450 feet and it contains 18 spillbays each 50 feet wide. Spillbays 13, 14, 15, and 18 were modified with spillway deflectors. Since very little water is spilled over bay 18, we were concerned primarily with the flows over bays 13, 14, and 15.

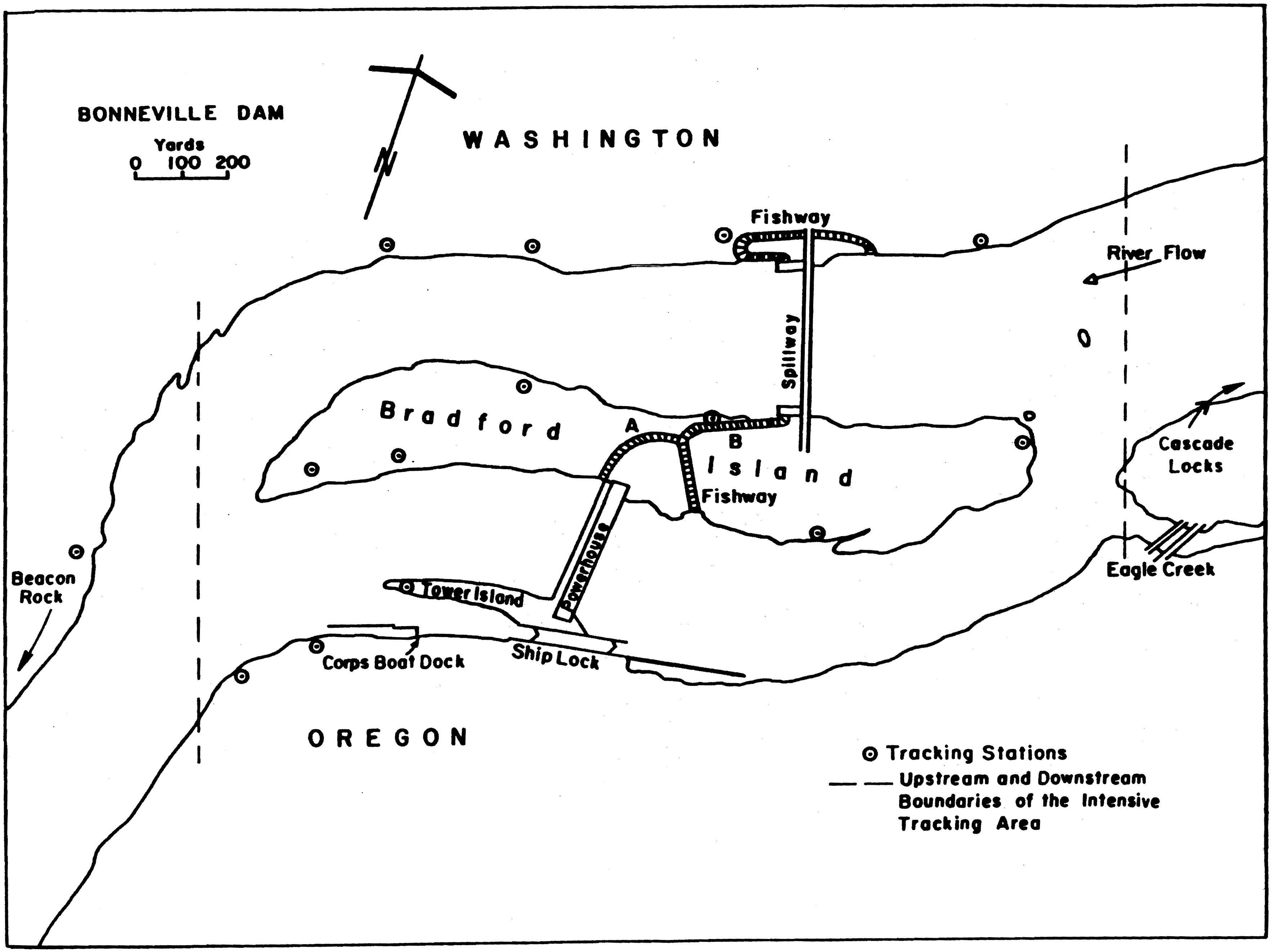

Figure 2.--The 1974 Bonneville Dam study area showing the fish tracking stations and the boundaries of the intensive tracking area.

Fishway entrances are located on the north and south ends of the spillway and across the face of the powerhouse. Fishways from the south side of the spillway ("B" branch) and north side of the powerhouse ("A" branch) connect and form a common fishway over the dam.

The exit from the Washington fishway is on the Washington shore approximately 387 feet upstream from the spillway. The exit from the Bradford Island fishway is on the south side of Bradford Island approximately 465 feet upstream from the powerhouse. Immediately above the dam, the river is divided by Bradford Island into two channels, each about 400 yards wide. Upstream from the tip of Bradford Island the forebay soon narrows to a total width of about 500 yards. This narrow gorge continues upstream for about 3 miles, then increases in width to approximately 1,300 yards near Cascade Locks.

Equipment

The radio tag (with a single pulse rate), direction finder-receiver, antennas, and fishway monitoring units were all as described in the previous studies.

EXPERIMENTAL PLAN

The original plan called for tagging and tracking as many individually identifiable spring chinook salmon as possible between 1 April and 10 May 1974. As the study progressed, it was decided to tag and track additional fish between 29 May and 21 June 1974. For the purpose of the report, chinook salmon tagged and tracked during the extended portion of the study are considered to be summer run fish. All tagged fish were released into the river approximately 4 miles downstream from the dam and then tracked as they approached the dam, crossed over, and swam through the reservoir to Cascade Locks.

From 1 to 15 April, we had planned to control the spill from the dam (as much as river flows would permit) so as to create conditions that would maximize attraction of radio-tagged fish into the areas below the modified spillbays. For the remainder of the study, we would accept whatever spill patterns were deemed appropriate by the state fisheries agencies and the CofE. However, because river flows were substantial (271,000 to 317,000 ft^3/s) even during the first 15 days of April, it was difficult to set up controlled spill patterns.

During the extended portion of the study, we planned to continue the study of chinook salmon activity in relation to the modified spillbays and in addition obtain tracks of fish exiting the fishways during high river flows (400,000 to 500,000 ft^3/s). We also planned to tag a small number of steelhead trout (in approximately a 4:1 chinook:steelhead ratio) to determine if they would accept and retain the radio tags. If they did, we planned to monitor their activities in relation to both the spillway deflectors and the fallback problem.

Ancillary to the main study, we planned to obtain data in two areas of interest. To learn if there was excessive delay through the new vertical slot portion of the Washington shore fishway, we planned to time the fish from counting station to exit and compare that time with times through the conventional portion of the fishway and through the Bradford Island fishway (modified to a vertical slot fishway in 1973). We also proposed to monitor both the downstream entrance and the side entrance to the "B" branch of the Bradford Island fishway to obtain an idea of their relative use.

EXPERIMENTAL PROCEDURES

Trapping and Tagging

Fish to be used in the study were trapped and tagged in the same manner as described in Part I.

Initially, we released nine separately identifiable tagged fish on 2 April 1974. From then on during the study, whenever a tagged fish was tracked over the dam and upstream out of the study area, we tagged and released another fish with the same radio-tag code. Thus, we attempted to keep nine separately identifiable tagged fish in the study area at all times. A total of 63 chinook salmon and 7 steelhead trout were tagged and released at Beacon Rock Park about 4 miles below the dam. Table 1 summarizes the tagging and release data.

Tracking and Plotting

As in previous years, the tagged fish were monitored intermittently from the release point until they reached the intensive tracking area adjacent to Bonneville Dam. Trackers equipped with mobile tracking gear traveled along the highways on either side of the river periodically and listened for tagged fish to alert staff at the dam when to expect the fish to enter the study area.

Once inside the study area, the tagged fish were tracked and their positions plotted by the same method used during the 1973 study (see Part 2). Small wooden shelters were added at each tracking station this year, however, to protect personnel from the weather.

Table 1.-- Summary of tagging data for chinook salmon and steelhead trout used in the 1974 study at Bonneville Dam.

Date released	Species	Flag color	Radio tag code	Fish length (mm)
April 2	Chinook	Orange/green	30D	830
2	Chinook	Orange/green	20E	920
2	Chinook	Orange/green	27F	920
2	Chinook	Orange/green	23G	830
2	Chinook	Orange/green	27H	970
2	Chinook	Orange/green	28I	940
2	Chinook	Orange/green	21J	740
2	Chinook	Orange/green	26K	870
2	Chinook	Orange/green	22L	800
8	Chinook	Blue/white	38E	840
11	Chinook	Blue/white	24D	840
11	Chinook	Blue/white	31L	890
15	Chinook	Pink/orange	22E	820
15	Chinook	Blue/white	32F	840
17	Chinook	Blue/white	29K	720
17	Chinook	Pink/orange	25L	840
20	Chinook	Pink/orange	34D	820
20	Chinook	Blue/white	25G	750
20	Chinook	Blue/white	20H	780
20	Chinook	Blue/white	30J	860
23	Chinook	Green/blue	25D	890
23	Chinook	Pink/orange	20G	880
24	Chinook	Pink/orange	29J	900
24	Chinook	Pink/orange	24K	880
25	Chinook	Green/blue	30G	880
25	Chinook	Pink/orange	22H	960
27	Chinook	Blue/white	22I	800
27	Chinook	Green/blue	28L	870
30	Chinook	White/orange	22D	900
30	Chinook	White/orange	32G	860
May 2	Chinook	Green/blue	33E	920
2	Chinook	Pink/orange	24I	760
2	Chinook	Green/blue	24J	890
3	Chinook	White/orange	32J	880
5	Chinook	Blue/yellow	26D	720
5	Chinook	Green/blue	29H	750
5	Chinook	Green/blue	22K	740
5	Chinook	White/orange	20L	740
7	Chinook	White/orange	26E	890
7	Chinook	Blue/yellow	22G	780
7	Chinook	Green/blue	26I	760
7	Chinook	Blue/yellow	26J	870
31	Steelhead	Pink/white	31D	770
31	Chinook	Blue/yellow	27E	860
31	Chinook	Pink/orange	21F	680
31	Steelhead	Pink/white	28G	740
31	Chinook	White/orange	23H	810

Table 1.--Continued.

Date released	Species	Flag color	Radio tag code	Fish length (mm)
May 31	Steelhead	White/orange	25I	720
31	Chinook	Pink/white	20J	760
31	Chinook	White/orange	23K	820
31	Chinook	Blue/yellow	7L	790
June 3	Chinook	Green/blue	35H	700
5	Steelhead	Blue/orange	27D	700
5	Chinook	Pink/white	21H	730
5	Chinook	Blue/orange	22J	870
5	Chinook	Blue/yellow	21K	750
7	Chinook	Green/blue	30F	980
7	Chinook	Pink/green	8J	830
8	Chinook	Pink/white	21E	750
8	Chinook	Blue/orange	2G	980
9	Chinook	Pink/white	29L	790
10	Steelhead	Pink/white	33K	650
12	Chinook	Blue/orange	27L	820
13	Chinook	Blue/orange	34E	920
13	Steelhead	Pink/green	24G	700
14	Chinook	White/yellow	13J	730
14	Chinook	Blue/orange	36K	760
18	Steelhead	Pink/green	24E	800
18	Chinook	White/orange	28F	860
18	Chinook	Pink/green	23L	870

EFFECT OF SPILLWAY DEFLECTORS ON FISH

Chinook Salmon

Spring chinook salmon were tracked between 3 April and 9 May. Total river flows ranged from 268,000 to 422,400 ft^3/s and averaged 334,900 ft^3/s. Spill ranged from 120,000 to 282,000 ft^3/s and averaged 187,200 ft^3/s. The pattern of spill varied throughout the study, but essentially Bays 13, 14, and 15 (bays with spillway deflectors) were operated as a unit. Spill through each of the bays ranged from 6,331 to 19,279 ft^3/s and averaged approximately 10,400 ft^3/s.

Of the 42 spring chinook salmon tagged and released at Beacon Rock, 37 were tracked in the vicinity of the dam, 26 were tracked in the spill channel, and 20 were tracked close to or in the area just below the spillway. Only six tagged fish swam into the high velocity area below Bays 13, 14, or 15.

None of the six fish exposed to the flows immediately below the spillway deflectors showed any signs of abnormal behavior before or after their entrance into the area. Subsequent observations of these fish at the fishway counting stations revealed that one of the six exposed fish had a slight scrape on the left side of the base of the caudal fin; the other five had no visible injuries. An occasional scrape was also noticed on other tagged fish which had not been exposed to the direct spill from Bays 13, 14, or 15. None of the injuries appeared serious.

Nothing was noted in the behavior of the fish after their exposure to the flows from the deflectors that indicated they suffered any debilitating consequences. The time it took them to migrate from the dam to Cascade

Locks was comparable to the time taken by the balance of the spring chinook salmon tracked. Two of the six fish were recaptured later. One was recovered at the Klickitat Hatchery (Washington Department of Fisheries), and the other was recovered in the adult separator at Little Goose Dam on the Snake River (Ebel 1974).

Summer chinook salmon were tracked between 31 May and 21 June. Total river flows ranged from 352,400 to 565,800 ft^3/s and averaged 431,300 ft^3/s. Spill ranged from 219,200 to 428,700 ft^3/s and averaged 297,500 ft^3/s. The pattern of spill was variable, but essentially Bays 13 and 15 spilled the same volumes and Bay 14 the same or slightly less. Spill through each of these bays ranged from 6,382 to 25,544 ft^3/s and averaged approximately 13,300 ft^3/s.

Of the 21 summer chinook salmon tagged and released at Beacon Rock, 20 were tracked in the vicinity of the dam, 18 in the spill channel, and 12 close to or in the area just below the spillway. Only eight swam into the high velocity area below Bays 13, 14, or 15. None of the eight fish exposed to the flows immediately below the spillway deflectors showed any signs of abnormal behavior before or after their entrance into the spill area. Subsequent observations of these fish at the fishway counting stations revealed that one of the eight exposed fish had a hemorrhaged left eye; the other seven had no visible injuries. No other tagged fish were observed with hemorrhaged eyes, but an occasional slight scrape was observed.

Again, nothing was noted in the behavior of the fish after exposure to flows from the deflectors that indicated they suffered any debilitating consequences, and migration time from the dam to Cascade Locks was comparable to the time taken by the balance of the summer chinook salmon tracked. None of the eight tagged fish were recaptured later.

Steelhead Trout

Steelhead trout were tracked during the same time period and river conditions as summer chinook salmon. Of the seven steelhead trout tagged and released at Beacon Rock, five were tracked in the vicinity of the dam, four in the spill channel, and two near the spillway. No tagged steelhead were tracked into the area immediately below Bays 13, 14, or 15.

FALLBACK OF FISH OVER THE DAM

Chinook Salmon

An alarming number of tagged fish exiting the fishways into the forebay at Bonneville Dam continued their migration along a route that led to their falling back over the dam (Fig. 3). Most fish involved were from the Bradford Island fishway and were swept over the spillway. However, two fish fell back through the powerhouse, and one returned to the area below the dam via the navigation locks.

Rate and Consequences of Fallback

During the tracking period for spring chinook salmon, 35 tagged fish made an initial ascent of the fishways and eight (23%) of these fell back over the dam. The rate of fallback was not equal for fish exiting the Washington and Bradford Island fishways. Only one of the eight fish (12%) initially ascending the Washington fishway fell back, whereas out of the 27 fish ascending the Bradford Island fishway, 7 (26%) fell back. Seven of the eight total fallbacks fell over the spillway; one fish from the Bradford Island fishway returned through the navigation locks.

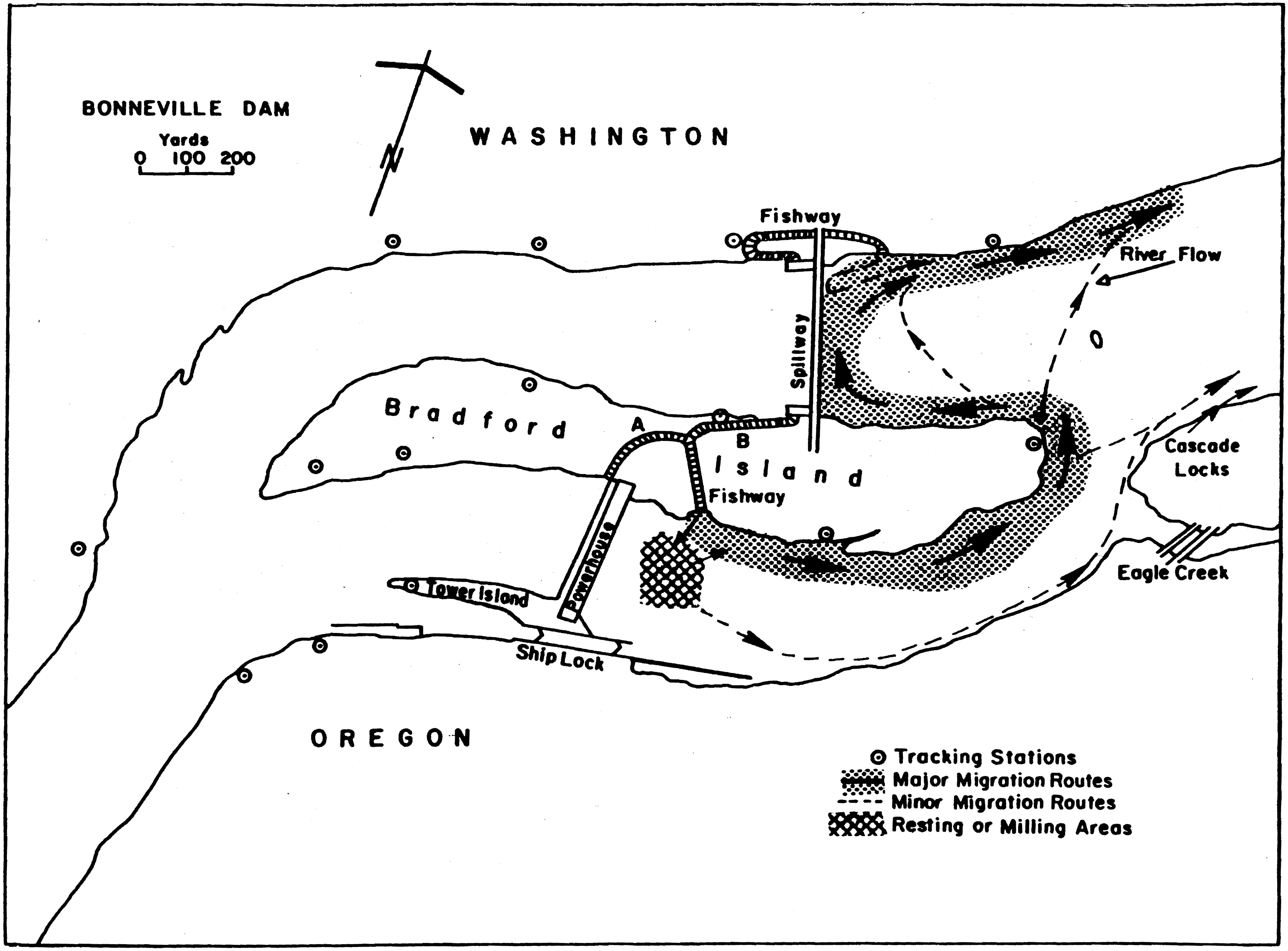

Figure 3.--The study area at Bonneville Dam showing the areas most used in 1974 by tagged spring and summer chinook salmon for traveling, milling, and resting after exiting the fishways.

Fallback of spring chinook salmon did not necessarily represent a loss to the run. All of the radio-tagged spring chinook salmon that fell back over the dam survived the experience, reascended the fishways, and were counted over the dam again. None of the reascending tagged salmon fell back a second time and none showed any evidence of injury. The recovery rate at Little Goose Dam for fish that fell back over Bonneville Dam and reascended was as high or higher than the recovery rate for nonfallbacks.

Radio-tagged salmon reascending the dam did not necessarily use the same fishway they used in their initial ascent (Table 2). Of the eight tagged fish that fell back, seven initially ascended via the Bradford Island fishway and one via the Washington fishway. However, when these fish reascended, five used the Washington fishway and only three used the Bradford Island fishway.

Tracking below the dam indicated that most of the fallbacks did not leave the spill channel after they fell back. Most of them reascended the Washington fishway, and one of the three reascents in the Bradford Island fishway entered the "B" branch which has its entrance in the spillway channel. Fallbacks did not spend a great deal of time below the dam before entering the fishways and recrossing the dam (Table 2). Of the eight fallbacks, one traveled downstream out of the immediate area and took almost 17 days to recross the dam; the others averaged only 26 hours until they recrossed.

Fallback and reascent of spring chinook salmon inflate the fish count at Bonneville Dam. Data on fallback and reascent of radio-tagged spring chinook salmon can be used to estimate the magnitude of this inflation. If we relate the number of crossings of radio-tagged fish at each fishway to

Table 2.--Spillways used by fallbacks of spring chinook salmon during their initial ascent and subsequent reascent of Bonneville Dam in 1974. Time from fallback to the second crossing of the dam is also indicated.

Tag code	Fishway used in initial ascent	Where fall back occurred	Fishway used in reascent	Time from fallback to reascent (h)
23G	Brad. Isl. "A"[a]	Spillway	Wash. shore	407
27G	Brad. Isl. "A"	Spillway	Wash. shore	11
24D	Brad. Isl. "A"	Spillway	Brad. Isl. "A"	35
21J	Brad. Isl. "A"	Spillway	Brad. Isl. "A"	16
22H	Brad. Isl. "A"	Locks	Wash. shore	37
22D	Brad. Isl. "B"[b]	Spillway	Wash. shore	24
32G	Brad. Isl. "A"	Spillway	Brad. Isl. "B"	45
24I	Wash. shore	Spillway	Wash. shore	14

[a]The north side of the powerhouse branch of the fishway is designated "A".

[b]The south side of the spillway branch of the fishway is designated "B".

the actual number of radio-tagged fish, we arrive at a correction factor to apply to the fishway counts. The fishway count of adult spring chinook salmon was estimated to be inflated by about 20% or over 25,000 fish (Table 3).

Eighteen radio-tagged summer chinook salmon made an initial ascent of the fishways, and subsequently seven (39%) of these fell back over the dam. No fish from the Washington fishway fell back, but the rate for the Bradford Island fishway was 58% (7/12). Five fish fell back through the spill, and two passed through the powerhouse.

All fallbacks that passed over the spillway reascended the dam as did one of the fish passing through the powerhouse. The other fish passing through the powerhouse was tracked to a spot near the CofE boat dock on the Oregon shore where it remained without changing position until the end of the project and was presumed dead. None of the fish that reascended the fishways showed any visible signs of injury, and none fell back a second time.

Summer chinook salmon, like spring chinook salmon did not necessarily use the same fishway to reascend the dam that they had used in their initial ascent (Table 4). All of the tagged fish that fell back initially ascended the Bradford Island fishway, but two used the Washington fishway for their reascent.

Tracking below the dam indicated most fallbacks of tagged summer chinook salmon stayed in the channel they fell back into. The surviving fallback through the powerhouse reascended the dam via the "A" branch of the Bradford Island fishway, and all fallbacks through the spill either reascended the Washington fishway or the "B" branch of the Bradford Island fishway. Fallbacks of summer chinook salmon took longer on the average to

Table 3.--Inflation of the spring chinook count at Bonneville Dam as determined by the application of a correction factor based on fallback and reascent of radio-tagged salmon in 1974.

Item	Fishway: Washington (no.)	Fishway: Bradford Isl. (no.)	Total (no.)
Total radio-tagged fish counted (X)	13	30	43
Net radio-tagged fish actually crossing (Y)	8	27	35
Correction factor (Y/X)	0.62	0.90	--
Adult spring chinook salmon count	45,845	78,223	124,068
Corrected count	28,423	70,400	98,823
Overcount (Inflation)	17,422	7,823	25,245

Table 4.--Spillways used by fallbacks of summer chinook salmon for their initial ascent and subsequent reascent of Bonneville Dam in 1974. Time from fallback to the second crossing of the dam is also indicated.

Tag Code	Fishway used in initial ascent	Where fallback occurred	Fishway used in reascent	Time from fallback to reascent (h)
27E	Brad. Isl. "B"[a]	Powerhouse	--	--
21F	Brad. Isl. "B"	Powerhouse	Brad. Isl. "A"	3
35H	Brad. Isl. "A"[b]	Spillway	Brad. Isl. "B"	3
7L	Brad. Isl. "B"	Spillway	Wash. shore	117
36K	Brad. Isl. "A"	Spillway	Brad. Isl. "B"	235
21H	Brad. Isl. "B"	Spillway	Wash. shore	445
8J	Brad. Isl. "B"	Spillway	Brad. Isl. "B"	19

[a]The south side of the spillway branch of the fishway is desginated "B".

[b]The north side of the powerhouse branch of the fishway is designated "A".

recross the dam than did fallbacks of spring chinook salmon (Table 4). One of the fallbacks traveled downstream out of the immediate area and took almost 19 days to recross the dam; whereas the others averaged 75 hours until recrossing.

Fallback of summer chinook salmon also caused inflation of the fish count at Bonneville Dam. If we use the data on fallback and reascents for summer chinook salmon in the same way we did for spring chinook salmon, we can arrive at a correction factor to apply to the fishway counts. Table 5 shows that the fishway count of adult summer chinook salmon was estimated to be inflated by approximately 25%, or almost 10,000 fish.

Cause of Fallback

The chance of fallback for a fish might be affected by conditions both below and above the dam.

To determine why certain fish fell back over the dam and others did not, we examined the following factors concerning the fish and their behavior before they crossed the dam:

1. Fish length and color (bright, medium bright, or medium).
2. River flow from time of release until last entry into the fishway.
*3. Migration path through the area.
*4. Elapsed time from release until crossing.
*5. Time spent in powerhouse channel.
*6. Time spent in spill channel.
*7. Time spent near fishway entrances.
8. Number of entries into fishways.
9. Time spent in fishway while crossing dam.

Table 5.--Inflation of the summer chinook count at Bonneville Dam as determined by the application of a correction factor based on fallback and reascent of radio-tagged salmon in 1974.

Item	Fishway: Washington (no.)	Fishway: Bradford Isl. (no.)	Total (no.)
Total radio-tagged fish counted (X)	8	16	24
Net radio-tagged fish actually crossing (Y)	6	12	18
Correction factor (Y/X)	0.75	0.75	--
Adult summer chinook salmon count	16,345	22,685	39,030
Corrected count	12,259	17,014	29,273
Overcount (inflation)	4,086	5,671	9,757

Five of the items reflected a slight difference between fallbacks and nonfallbacks and are marked with an asterisk; however, none could be isolated as a major factor causing fallback. Table 6 shows that fish that eventually fell back generally moved through the area below the dam quickest and followed a more direct route into the fishways.

The following above-dam variables were also examined:

*1. Fishway used by the fish.

2. Time of day the fish entered the forebay.

*3. Migration route.

*4. Hydraulic conditions from the time fish exited the fishway until fallback occurred or the fish was safely away from the dam.

a. Total river flow.

b. Pattern and volume of spill.

c. Volume of flow through the powerhouse.

d. Ratio of powerhouse flow to spillway flows.

e. Forebay water levels (maximum flucuations vary from dam to dam and are dependent on power production and other various operational procedures for water control).

We obtained complete tracks on 48 radio-tagged spring and summer chinook salmon as they exited the fishways and entered the forebay for the first time. We tracked these fish until they either fell back over the dam or were safely on their way upriver. The tracks were examined in relation to the four variables above, and within the conditions of this study, only those items marked with an asterisk could be correlated to whether a fish fell back or not.

Table 6.--Behavioral differences between chinook salmon that subsequently fell back over Bonneville Dam and those that did not during the 1974 study.

Item	Migration path through area	Avg. time release to crossing dam (h/fish)	Avg. time in powerhouse channel (h/fish)	Avg. time in spill channel (h/fish)	Avg. time near fishway entrances (h/fish)
Eventual fallbacks	Most direct	122	5.4	12.1	0.3
Non-fallbacks	Least direct	127	12.7	16.0	2.7

The factor contributing the most to fallback was whether the fish entered the forebay from the Bradford Island or Washington fishway. Fish initially using the Bradford Island fishway were almost five times more likely to fall back. Figure 4 shows the disposition of the tagged fish at each point of choice after they entered the forebay. After exiting the Bradford Island fishway, 76% of the fish tended to proceed upriver along Bradford Island. (A similar percentage of radio-tagged fall chinook exiting the Bradford Island fishway in 1973 followed the same path (see Part 2). The remaining 24% either crossed over to the Oregon shore or traveled in the middle portion of the powerhouse channel. Of the fish traveling along Bradford Island, 68% swam around the upstream end and downriver toward the spillway. The remaining 32% swam past the end of the island and safely upriver. Total river flow, powerhouse flow, spillway flow and pattern, ratio of spill to powerhouse flow, and forebay levels in the two channels were examined from the time fish exited the fishway until they rounded or swam on past the end of the island, but the only correlation found was the amount of spill to fallback.

Fifty-eight percent of the fish that swam around the tip of the island and back toward the spill were swept back over the dam. Spill ranged from 141,000 to 323,000 ft^3/s and averaged 207,000 ft^3/s while these fish were in the area. High volumes of spill tended to produce a high percentage of fallbacks. At spills below 200,000 ft^3/s, the fallback rate for these fish was 40%; at flows greater than 200,000 ft^3/s, the rate was 63%. Fish predominantly fell back through the south end of the spillway--through Bays 15, 16, and 17. Fish that did not fall back generally crossed the spillway channel and swam upriver along the Washington shore.

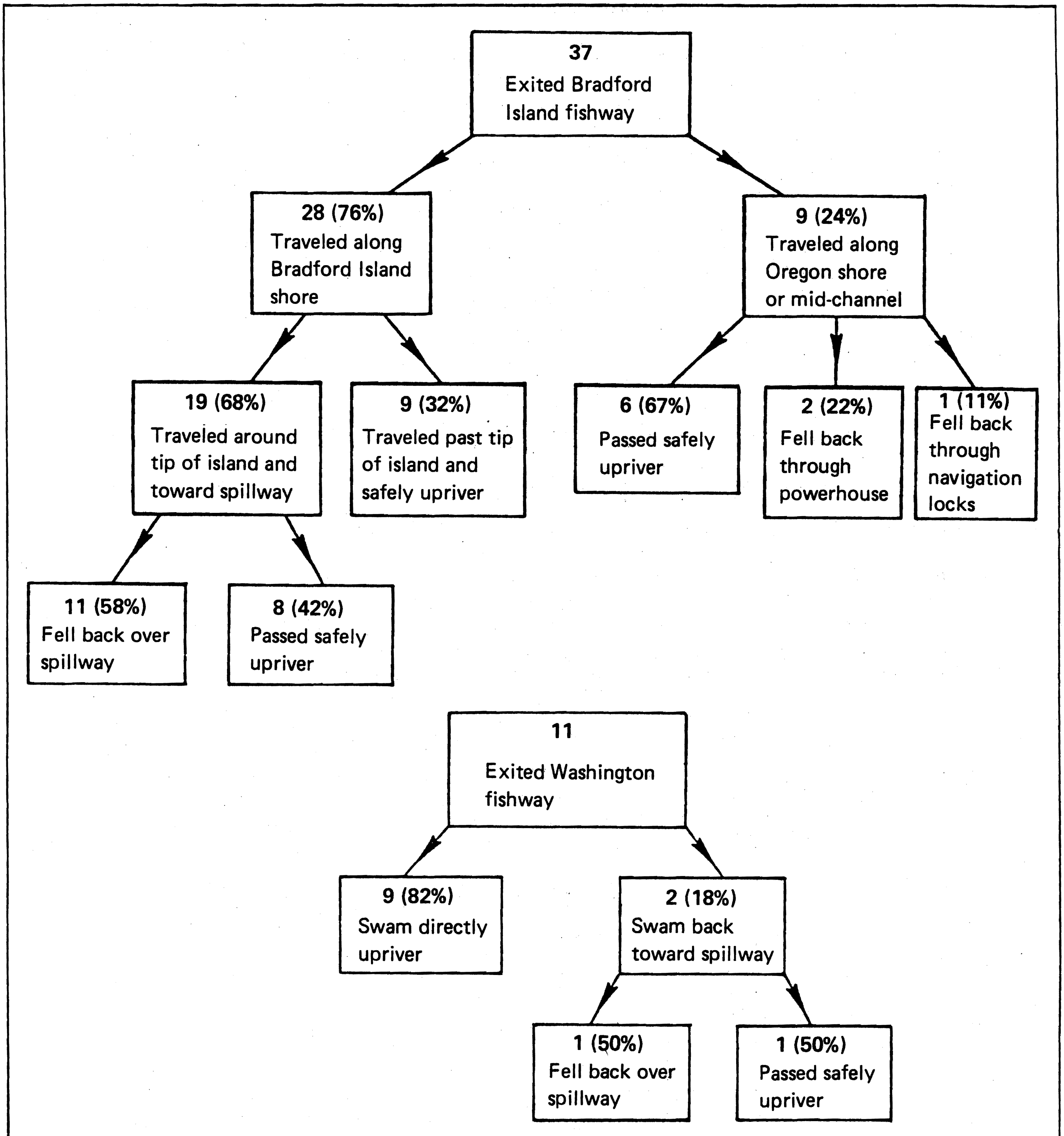

Figure 4.--Disposition of tracked chinook salmon after they left the Bonneville Dam fishladders (shown in percent) making a choice at each decision point.

Fish that exited the Bradford Island fishway, but did not travel along Bradford Island (24% of the total) were also subject to fallback. Most of these fish passed safely upstream (67%), while two fish (22%) went downstream through the turbines and one (11%) went downstream through the navigation locks. No definite patterns of movement were observed, and fallback appeared to be a consequence of random wandering.

Disposition of radio-tagged fish initially exiting the Washington fishway is also shown in Figure 4. Most of these fish (nine, or 82%) swam directly upstream, primarily near the Washington shore. Spring chinook salmon tracked in 1973 behaved similarly (see Part 2). The remaining two (18%) swam toward the spillway, and one of these was swept back over the spillway. The other fish avoided falling back and swam upstream safely away from the dam. The single fallback among fish from the Washington fishway occurred about midway across the spillway. No factor could be isolated to indicate why the one fish from the Washington fishway fell back.

Steelhead Trout

Very little meaningful data are available regarding the fallback problem in steelhead trout because of the small number of tagged fish involved. Only seven steelhead trout were tagged during the 31 May to 18 June tagging period, and three of these were caught by fishermen before they crossed the dam. Of the four remaining, three made their initial ascents of the dam via the Washington fishway. Of these, two went safely upstream along the Washington shore, and the third traveled downstream toward the spillway and fell back through bay 3 or 4. It reascended the

Bradford Island fishway, exited, traveled around Bradford Island, and fell back through bay 16 or 17. After surviving the second fallback, the fish was caught by a fisherman below the dam.

The one fish that initially ascended the Bradford Island fishway followed a route around Bradford Island and along the spillway and fell back through bay 4 or 5. To the best of our knowledge, it did not reascend the dam. The fish traveled to an area about 4 miles downstream, where it milled about for several days and then disappeared. It was not heard from again.

GENERAL OBSERVATIONS

Below the Dam

Of the 42 spring chinook salmon tagged with radio tags, only seven were not observed ascending the dam during the initial study period. Of these seven, one was caught by a fisherman below the dam, one was in the powerhouse collection system when tracking terminated on 9 May and was later recovered at Little Goose Dam, four were tagged late in the study and had not yet moved into the study area (one of these was also subsequently recovered at Little Goose Dam), and one either died or regurgitated its tag at the junction of the "A" and "B" branches of the Bradford Island fishway. This last fish entered the "A" branch entrance and ascended to the junction of the "B" branch on 22 April; signals from its tag could still be heard in the same location when tracking stopped on 9 May.

Of the 21 summer chinook salmon tagged with radio-tags, only three did not ascend the dam by the termination of the study. Of these fish, one was in the Washington fishway (this fish was later caught by a fisherman below the dam); one was tracked into the Washington fishway on 12 June when the tag signal abruptly stopped, and the fish was neither heard nor seen after that time; and the third was released on 12 June and never heard in the study area.

Although the behavior of tagged fish below the dam was variable, a number of points are of interest. The amount of time spring chinook salmon spent from first entry into the study area until they crossed the dam ranged from 3 to 540 hours and averaged 60 hours. Times for summer chinook salmon ranged from 3 to 128 hours and averaged 47 hours. Both groups averaged less time than the averages (101 and 181 hours) for the two groups of spring chinook salmon tracked at Bonneville Dam in 1972 (see Part 1). River flows were only slightly different for the 2 years. The average total flow below Bonneville Dam during this year's tracking was 334,900 ft^3/s for spring chinook salmon and 431,300 ft^3/s for summer chinook salmon. In 1972, flows during the two tracking periods for spring chinook salmon averaged 314,000 and 484,000 ft^3/s.

Although spring and summer chinook salmon traveled throughout the area immediately below the dam, they had fairly well-defined migration routes (Fig. 5). The routes were very similar to those followed by spring chinook salmon tracked in 1972. There was, however, more activity near the powerhouse this year than in 1972, and more crossing of the spill channel 200 to 300 yards below the spillway.

Not enough steelhead trout were tracked for meaningful migration routes to be established. However, we did establish that steelhead would retain the tag and not regurgitate it as we had feared.

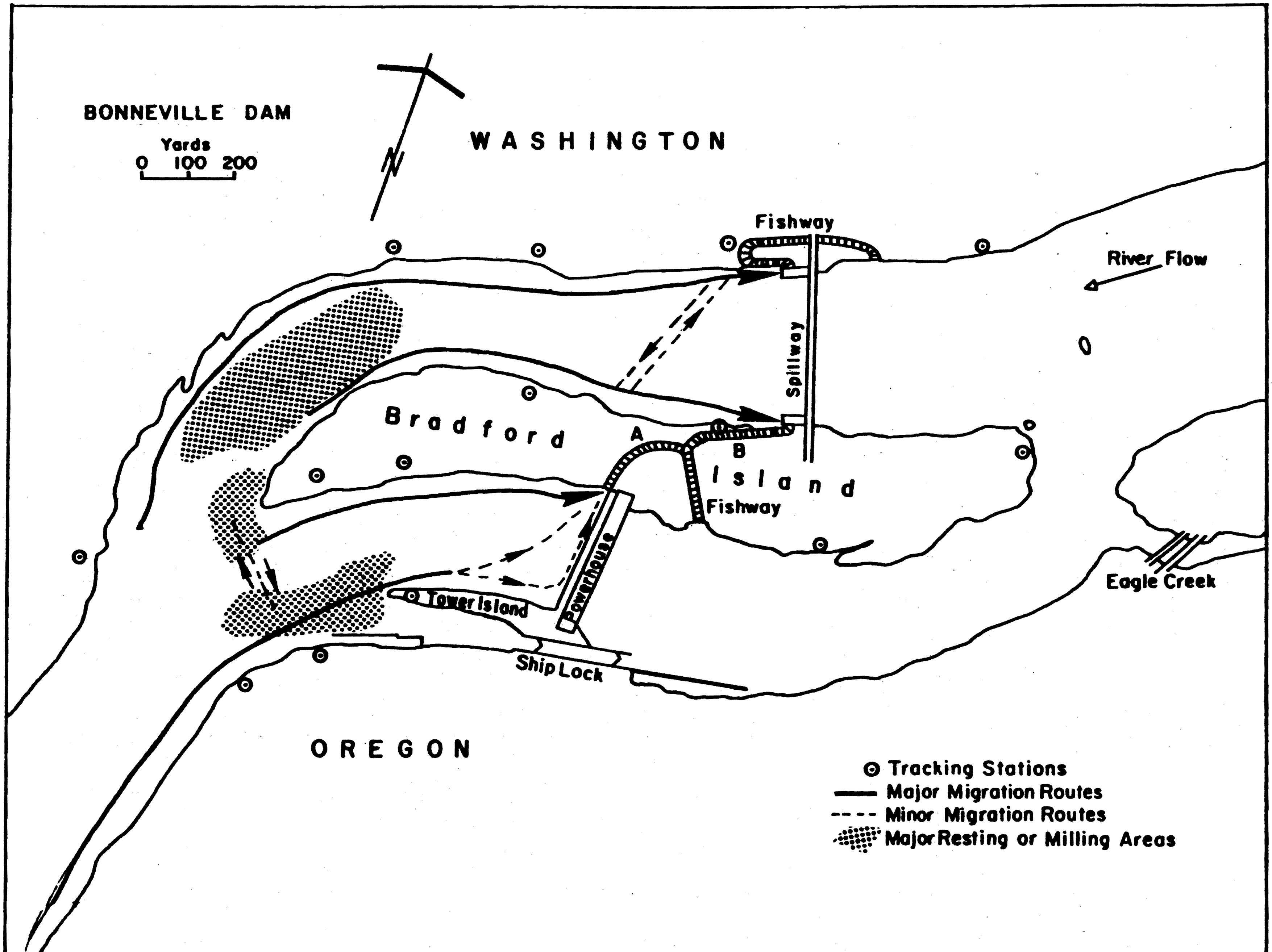

Figure 5.--The 1974 Bonneville Dam study area showing the areas most used by 1974 spring and summer chinook salmon below the dam for traveling, milling, and resting.

Fishway Data

The activities of tagged salmon in and near the fishways were carefully monitored to provide data on fishway effectiveness. Sufficient tracks were obtained on both spring and summer chinook salmon to provide useful data. Unfortunately, steelhead data were again too limited to use.

Spring Chinook Salmon

Spring chinook salmon averaged 8.5 hours in the fishway used to ascend the dam. Passage through the Bradford Island fishway was generally faster than through the Washington fishway--6.1 and 19.6 hours, respectively. However, tagging activities by the National Marine Fisheries Service and the Oregon Fish Commission in the Washington fishway probably delayed passage. Passage times for fish through the new vertical slot portions of both the Bradford Island and the Washington fishways were good: 21 and 28 minutes, respectively.

Tagged fish did not always stay in a fishway once they entered it, nor did they necessarily cross the dam via the first fishway they entered. While 55% entered a fishway and stayed in it until they crossed the dam, 17% used only one fishway, but made more than one entry into it; 22% entered two different fishways; and 6% made entries into all three fishway entrances. The average time spent by fish near the fishway entrance varied from entrance to entrance. Salmon making their initial crossing of the dam averaged 0.9 hour near the Bradford Island "A" entrance, 2.3 hours near the Washington entrance, and 3.2 hours near the Bradford Island "B" entrance.

The percentages of tagged adult spring chinook salmon using the two fishways at Bonneville Dam compared favorably with the percentages of untagged adults using the fishways (CofE fish counts). The Washington fishway was used by 30% of the tagged and 37% of the untagged spring chinook salmon. The Bradford Island fishway was used by 70% of the tagged and 63% of the untagged spring chinook salmon.

Tracking of tagged salmon provided considerable information about the utilization of the various entrances to the Bradford Island fishway. This fishway can be entered from the "A" or "B" branch. Tagged spring chinook salmon utilizing the Bradford Island fishway primarily entered from the "A" entrance (72%). At the "B" entrance, we attempted to use our monitor equipment to distinguish between those fish coming in the downstream facing entrance and those coming in the side entrance (45° to the spill flow and approximately 20 feet up the fishladder from the downstream facing entrance). It was very difficult to accurately make this distinction; but to the best of our knowledge, the split was about 50% each.

Summer Chinook Salmon

Summer chinook salmon were more likely to use only one fishway and spend less time in it. They averaged 4.9 hours in the fishway as they crossed the dam. Passage times through the Bradford Island fishway again averaged less than in the Washington fishway--4.6 and 5.5 hours, respectively. Passage times through the vertical slot portions of the two fishways were the same as for spring chinook salmon, i.e., 21 minutes for the Bradford Island fishway and 28 minutes for the Washington fishway. However, summer chinook salmon did not always stay in a fishway once they entered it, nor did they necessarily cross the dam via the first fishway they entered. In fact, 63% entered only one fishway and remained in it until crossing; 16% used only one fishway, but made more than one entry into it; 16% entered two different fishways; and 5% made entries into all three fishway entrances.

The use of fishways by radio-tagged summer chinook salmon compared favorably to the choice of fishways by untagged fish in CofE fish counts. The Washington fishway was used by 36% of the tagged and 42% of the untagged fish. The Bradford Island fishway was used by 64% of the radio-tagged fish and 58% of the untagged fish.

Radio-tagged summer chinook salmon entering the Bradford Island fishway primarily entered from the "B" entrance (59%). Again, we attempted to determine the number of tagged fish entering the "B" entrance from the side gate compared with the number entering the downstream gate. Our best estimate is that 70% of these fish used the side gate.

Recoveries of Tagged Fish

A total of 54 radio-tagged spring and summer chinook salmon were known to have migrated safely away from Bonneville Dam, and tags from 18 of these were subsequently recovered (Table 7). Of the 37 tagged spring chinook salmon continuing upstream, 14% were captured in the Indian fishery in the Bonneville Dam reservoir, 8% were recovered from tributaries to the Bonneville Dam reservoir, and 19% were recovered in the adult separator at Little Goose Dam. Of the 17 summer chinook salmon migrating on upriver, all of the recoveries (18%) were from Little Goose Dam.

Migration Rates Upriver

The progress of radio-tagged salmon upriver was closely monitored from the time they left the immediate vicinity of Bonneville Dam until they

Table 7.--Recoveries of radio-tagged chinook salmon above Bonneville Dam in 1974.

Seasonal race	Number known to have passed Bonneville Dam	Number of recoveries				
		Indian fishery Bonneville Dam Forebay	Wind River	Klickitat River	Little Goose Dam	Total
Spring	37	5	1	2	7	15
Summer	17	0	0	0	3	3
Total	54	5	1	2	10	18

reached Cascade Locks about 2-1/2 miles upstream. Times taken by spring chinook salmon ranged from 55 to 357 minutes and averaged 108 minutes. Times for summer chinook salmon ranged from 45 to 150 minutes and averaged 74 minutes. Once salmon left the immediate vicinity of the dam and began swimming upriver, their average rate of travel was approximately 1.5 mi/h for the section of river from Bonneville Dam to Cascade Locks.

Recoveries of radio-tagged salmon at Little Goose Dam provided a means of establishing a rate of travel for a long journey that included passage over five dams. Times taken by seven spring chinook salmon to travel the 253 miles ranged from 312 to 824 hours and averaged 441 hours (about 18 days). The three summer chinook salmon took from 713 to 818 hours and averaged 766 hours (about 32 days). Overall, once salmon left the immediate vicinity of Bonneville Dam and began swimming upriver, their average rate of travel, including the time to negotiate five dams and find their way into the fishways at Little Goose Dam, was approximately 0.5 mi/h.

CONCLUSIONS

1. Spring and summer chinook salmon and steelhead trout swim very close to or into the discharge from spillbays with deflectors installed.

2. Spring and summer chinook salmon swimming of their own volition into the area immediately below a spillway discharging water over a spillway deflector do not suffer debilitating injuries when discharges through the bays are in the range of 6,200 to 25,500 ft^3/s.

3. Insufficient data were obtained for steelhead trout to indicate if debilitating injuries might or might not occur from flows immediately below a spillway deflector.

4. Fallback of salmon and steelhead trout during periods of spill is a substantial problem at Bonneville Dam.

5. Fish exiting the Bradford Island fishway into the forebay have the highest potential for falling back over the dam.

6. Fallback is primarily a consequence of fish following (for reasons unknown) a migration route from the exit of the Bradford Island fishway around Bradford Island to the vicinity of the spillway.

7. Fish in the vicinity of the spillway are more likely to fall back as spill volume increases.

8. Fallback does not result in a substantial mortality at Bonneville Dam, but it does delay the adult salmon in their upstream migration, and it contributes to greatly inflated fish counts.

9. The newly constructed vertical slot sections of the Bradford Island and Washington fishways effectively pass spring and summer chinook salmon and steelhead trout.

10. The side gate entrance to the "B" branch of the Bradford Island fishway is an important entry for spring and summer chinook salmon utilizing the "B" branch.

11. Steelhead trout can be tagged and tracked with internal-radio tags.

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1974. Radio-tracking of spring chinook salmon to determine effect of spillway deflectors on passage at Lower Monumental Dam, 1973. Unpubl. manuscr., 20 p. Northwest and Alaska Fisheries Center, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112. (Prepared for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, under Delivery Order DACW57-73-F-0534.)

Part 4. BEHAVIOR STUDIES OF SUMMER CHINOOK SALMON AND STEELHEAD TROUT AT AND BETWEEN BONNEVILLE AND THE DALLES DAMS IN 1975

By Gerald E. Monan and Kenneth L. Liscom

INTRODUCTION

A multiplicity of concerns about adult fish passage at and between Bonneville and The Dalles Dams exists for agencies interested in the welfare of salmon and steelhead trout in the Columbia River Basin. Power-peaking, flow control, fallback, unaccountable losses, tributary turnoff, spillway deflector flows, intermittent spill, and fishway efficiency are some of the important concerns affecting the adult migrations of anadromous fish in this area.

To understand the impact of these factors requires extensive and sophisticated research. Not all of the ramifications of the problems can be studied with one technique or in a single experiment. However, through the use of radio-tracking, much information can be gained during a single tracking season. The disadvantage of radio-tracking is the inherent limitation on the number of fish that can be tracked in a season. However, the tracks themselves are actual case histories of each fish's behavior and, when the data are combined, show useful relationships between fish behavior and the areas of concern. Increased significance can be attached to such apparent relationships by examining a problem during more than one season.

The radio-tracking study carried out at and between Bonneville and The Dalles Dams during the summer of 1975 was a multipurpose study designed to obtain initial data on specific problems and to provide additional data on problems studied previously. The primary goal of this study was to determine the effect of power peaking at The Dalles Dam on the behavior and survival of summer chinook salmon. A secondary goal was to obtain information concerning losses between dams, tributary turnoff, fallback, and the hazards associated with spillway flows.

Specifically, there were six main objectives: 1) determine the effect of periodic reduction in flow through The Dalles Dam powerhouse on behavior and passage of adult salmonids; 2) determine if a fallback problem exists at The Dalles Dam; 3) ascertain if flow conditions associated with the sudden transition from a nonspill condition to a spill condition at a dam cause injuries to adult salmonids in the area; 4) determine if flow conditions associated with the recently installed full complement of spillway deflectors at Bonneville Dam caused debilitating injuries to adult salmonids; 5) monitor the migration of salmon and steelhead trout between Bonneville and The Dalles Dams to determine areas of delay, mortality, and specific tributary turnoff; and 6) test a newly developed radio-telemetry pressure tag for the acquisition of data on the swimming depths of migrating adult salmonids.

EXPERIMENTAL SITE AND EQUIPMENT

The section of the Columbia River under investigation extended from about 5 miles below Bonneville Dam to about 1 mile above The Dalles Dam. Bonneville Dam is about 145 miles from the ocean and is the first dam encountered by adult salmonids in the river. The Dalles Dam is the next dam upriver and is about 192 miles from the ocean. There are five major tributaries between the dams (the Wind, Little White Salmon, White Salmon, Hood, and Klickitat Rivers).

At Bonneville Dam, the spillway is separated from the powerhouse by Bradford Island (Fig. 1) which effectively divides the river into two channels. The primary source of water in the north channel is the spillway, and the 10 main turbine discharges provide most of the water for the south channel. The spillway contains 18 spillbays each about 50 feet wide. Twelve of the bays have been modified with spillway deflectors. Fishway entrances are located on the north and south ends of the spillway and across the face of the powerhouse. The fishways from the south side of the spillway ("B" branch) and from the powerhouse ("A" branch) connect and form a single fishway over the dam. The exit from the north or Washington fishway is on the Washington shore approximately 387 feet upstream from the spillway. The exit from Bradford Island fishway is on the south side of Bradford Island approximately 465 feet upstream from the powerhouse.

Immediately above the dam, the forebay is divided by Bradford Island into two channels each about 400 yards wide. Upstream from the tip of Bradford Island, the forebay soon narrows to a total width of about 500 yards. This narrow gorge continues upstream for approximately 3 miles, then increases in width to about 1,300 yards near Cascade Locks. For the next 43 miles the river varies in width from about 300 to 2,000 yards and averages about 1,000 yards until it reaches The Dalles Dam.

At The Dalles Dam, the nonoverflow dam and powerhouse are built at almost a 90° angle to the river and the spillway (Fig. 2). The front of the powerhouse faces the southern shore of the river and creates a separate channel along the face of the powerhouse with most of the water provided by

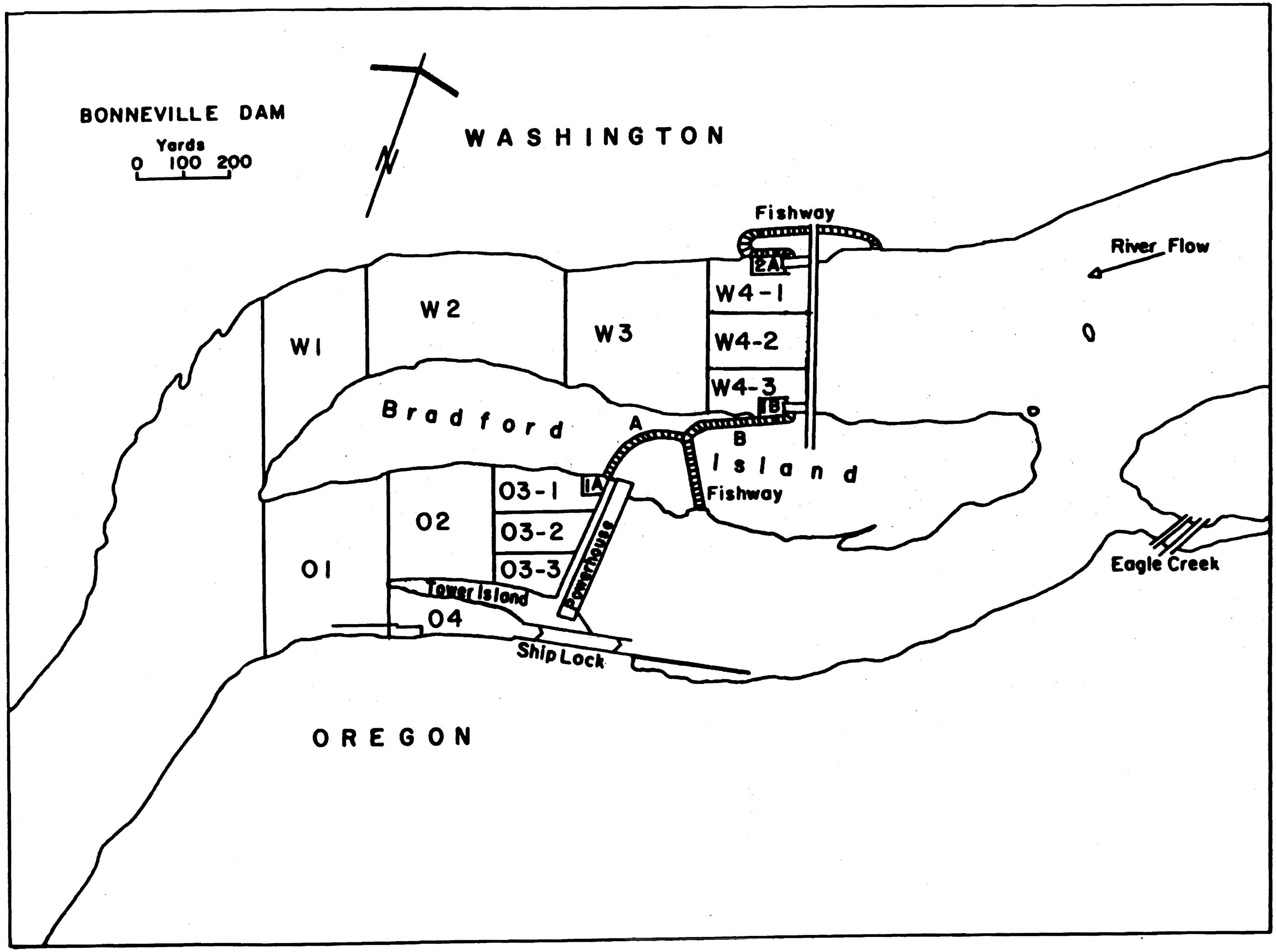

Figure 1.--The Bonneville Dam study area, showing subdivisions.

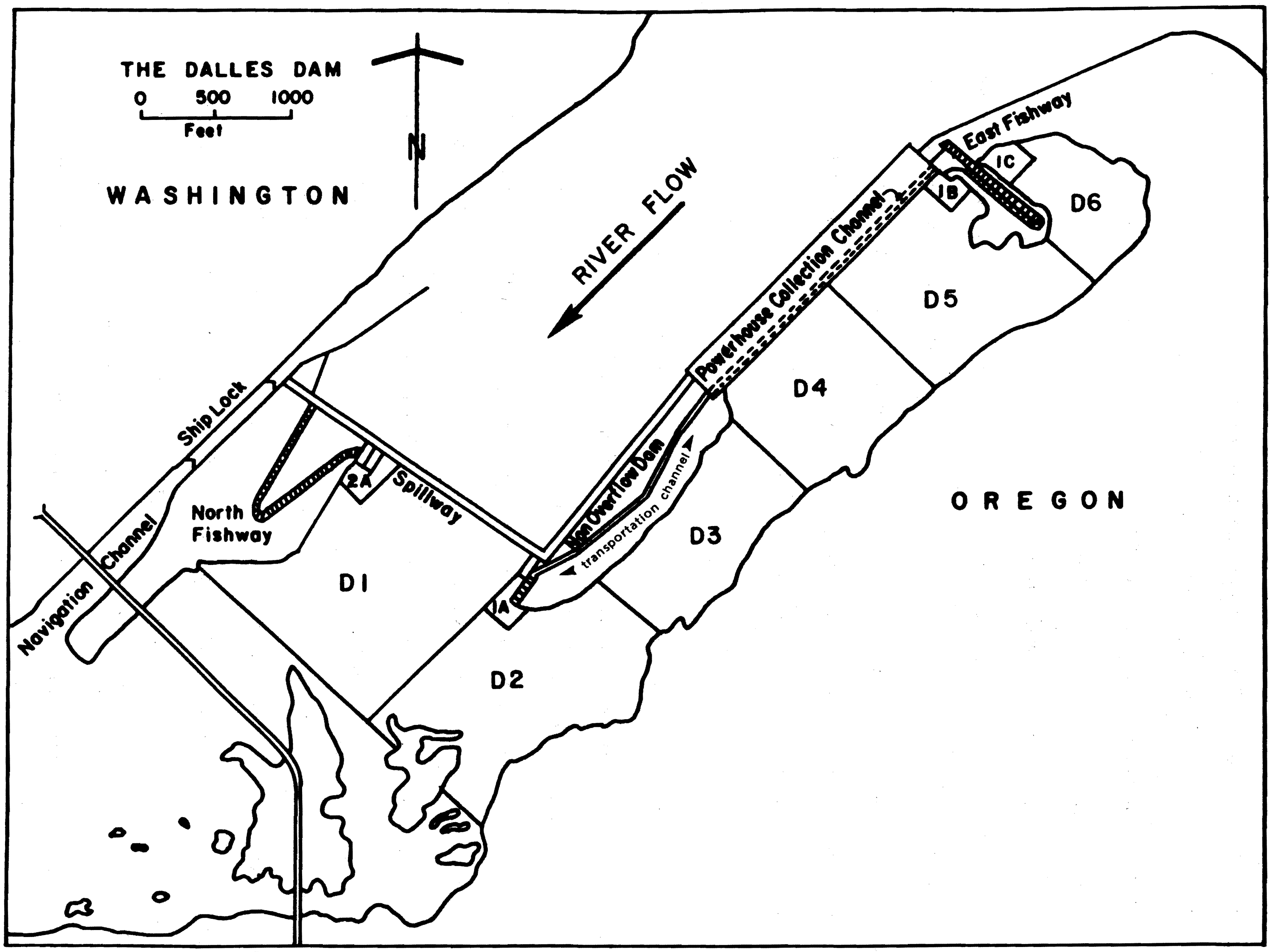

Figure 2.--The Dalles Dam study area, showing subdivisions.

the discharge of 22 turbines. None of the 23 spillbays have spillway deflectors installed. The entrance to the north fishway is at the northern end of the spillway. The east fishway has entrances at the eastern end of the powerhouse, along the face of the powerhouse, and at the southern end of the spillway. The entrance at the southern end of the spillway connects to a transportation channel that takes fish all the way across the powerhouse area to the east fishway. The exits to both fishways are right at the upstream side of the dam; the north fishway exit is between the navigation lock and the spillway (about 450 feet north of the north end of the spillway), and the east fishway exit is at the west end of the closure dam about 225 feet east of the powerhouse.

Radio Tags

The basic radio beacon tag is the same as previously used, with a carrier frequency of approximately 30 megahertz (MHz).

The pressure tag that we introduced in this study to measure depth is also a small battery operated radio transmitter operating on a carrier frequency of approximately 30 MHz. The tag has a battery life of about 6-1/2 days, and the transmitter and batteries are sealed in a plastic capsule 4-1/4 inches long by 1 inch in diameter, which is slightly larger than the regular radio tag being used. The pressure sensitive transducer is mounted on the nose of the capsule. Tags weigh less than 1 ounce in water and are carried in the stomach of the fish, in the same way as the beacon tag. The tag transmits 30.21 MHz pulses that are 30 milliseconds long. The pulse interval or period varies with pressure. This pulse was modulated with 1-millisecond pulses that varied in interval or period according to the internal temperature of the tag. The period for pressure and temperature data was set to vary over a range of 0 to 60 feet and from 45° to 70° F. It was necessary to monitor the internal temperature of the tag because the pressure data output of the tag varied with temperature, hence temperature data were necessary to convert the pulse data to depth.

Direction Finder-Receiver and Antenna

The direction finder-receiver used by the trackers is the self-contained, battery-operated unit employed during previous studies in conjunction with the 18- and 8-inch diameter directional loop antennas.

Search Receiver

To facilitate monitoring pressure- and radio-tagged fish between Bonneville and The Dalles Dams, a new receiver was designed and built by our technicians. The unit, designated as our "search receiver," continuously monitored all nine tag frequencies and worked in conjunction with an omnidirectional whip antenna. When these units were installed in an automobile, they allowed the operator to drive along the river and continuously monitor the area for all radio-tagged fish. When a tag or tags came within range, a beeping sound was heard and an indicator light on a panel indicated which tag code or codes were being received. If directional data to the tagged fish were needed, the operator switched a conventional tracking unit to the appropriate channel and rotated the loop antenna to establish the direction the signal was coming from. The new receivers were extremely reliable and the system was very effective in providing adequate coverage of the study area.

Pressure Tag Receiver

To receive data from our pressure tag, a more sophisticated receiving system was needed. Basically, the system developed consisted of four main components: 1) a quarter-wave whip antenna, 2) a broad band receiver (the search receiver described above), 3) a phase-lock loop demodulator and pulse conditioner, and 4) an electronic digital counter.

In operation, the signal from the pressure tag was intercepted by the antenna and fed into the search receiver. From the search receiver, the second intermediate frequency was transferred to the monitor and served as input to the demodulator and pulse conditioning (DPC) unit. The demodulator extracted the pressure and temperature data which were then fed into a pulse length discriminator that cleaned up the signal by rejecting the sharp electronic noise bursts commonly found around hydro-electric dams. This circuit was followed by a variable duration, one-shot multivibrator used to blank out temperature data pulses to facilitate measuring the pressure data. The output of the DPC unit was fed into a digital counter operated in the period average mode. A switch in the DPC unit enabled the operator to read out data on temperature or pressure. Each pressure tag had been previously calibrated so that by consulting the appropriate graph, the specific readings obtained on the electronic counter could be converted to depth in feet and temperature in degrees Fahrenheit. Depth information was accurate to within plus or minus 6 inches or less and temperature information to plus or minus 1/2° F.

Fishway Monitoring Units

Movement of fish in the fishways was monitored by two different systems. One was the simple unit used to alert fish counters to the presence of a tagged fish in a specific area. The other was the sophisticated telemetry unit that transmitted data on the movements of tagged fish in the fishway to the data collection center. Both systems were described in previous sections of this report.

GENERAL EXPERIMENTAL PLAN

Plans called for tagging and tracking as many individually indentifiable summer chinook salmon as possible between 28 June and 4 August 1975. In addition, a small number of steelhead trout were to be tagged and tracked. Most of the radio-tagged fish were to be released into the river about 4 miles downstream from Bonneville Dam. However, a few fish were to be released between Bonneville and The Dalles Dams to provide fish sooner for tracking at the Dalles Dam. Otherwise, the crew would have had to wait for fish from the first group released below Bonneville Dam to negotiate the dam and then swim all the way to The Dalles Dam. Intensive tracking was to take place near the dams, and the progress and disposition of the fish in the river between the two dams were to be monitored. While fish were being tracked, specific controlled peaking operations were to be carried out at The Dalles Dam.

Several meetings were held with concerned fishery agencies and the U.S. Army Corps of Engineers (CofE) personnel in an effort to establish peaking conditions that would be tested. Various experimental designs were proposed, but, despite excellent cooperation by all parties, it was in reality weather conditions, physical limitations at the dams, and critical power production demands that dictated the conditions that were available for testing. The final compromise plan called for normal operations during the week and a 30% reduction in flow through the powerhouse at The Dalles Dam on weekends.

Special procedures were established for the studies involving the sudden transition from a nonspill condition to a spill condition. When the tracking crew tracked a radio-tagged fish up to the base of a closed spillway, the tracking crew could request and receive immediate spill from selected gates.

Data on swimming depths of migrating salmon were to be obtained by releasing fish tagged with the new pressure tags and then continuously monitoring their activities from their point of release below Bonneville Dam until they moved upriver and crossed The Dalles Dam.

EXPERIMENTAL PROCEDURES

Trapping and Tagging

Fish to be used in this study were trapped and tagged in the same manner described in Part 1, except that some fish received pressure tags instead of the conventional radio tags.

Initially, we released five separately identifiable tagged chinook salmon on 28 June 1975 at Beacon Rock, Washington, and four more separately identifiable tagged chinook salmon on 29 June near Lyle, Washington, about 35 miles upstream from the Bonneville Dam. From then on during the study, whenever a tagged fish was tracked over The Dalles Dam and upstream out of the immediate area, we tagged and released another fish with the same radio-tag code. Thus, we attempted to keep nine separately identifiable tagged fish in the study area (Beacon Rock to just upstream from The Dalles

Dam) at all times. A total of 41 chinook salmon and 4 steelhead trout were tagged and released at Beacon Rock Park about 4 miles below the dam. Six additional tagged chinook salmon were released above Bonneville Dam--five near Lyle and one near the Cascade Locks, Oregon, less than 3 miles above the dam. Table 1 summarizes the tagging and release data.

Tracking and Plotting

Once the conventionally radio-tagged fish were released into the river, their activities were monitored intermittently from the release point until they reached the intensive tracking zones adjacent to Bonneville and The Dalles Dams. Below Bonneville Dam, trackers equipped with mobile tracking gear traveled along the highways on either side of the river periodically and listened for tagged fish to alert staff at the dam when tagged fish would be expected to enter the tracking area.

The section between the two dams was monitored on a routine schedule. During each day and swing shift, two mobile trackers traveled by auto from Bonneville Dam to The Dalles Dam and back to Bonneville Dam. The two mobile trackers worked as a team--one traveling the roads along the Washington shore and the other along the Oregon shore. They maintained radio contact with each other to coordinate their activities and assure as complete coverage of the area as possible. As the trackers located a tagged fish between the two dams, they recorded the fish's approximate location and their time of contact. This system did not provide full coverage for each fish as it migrated upstream, but it did allow for a general picture of the rate of progress upriver. It also provided information on the fate of tagged fish between the dams (for example, tributary turnoff or capture by fishermen).

Table 1.--Summary of tagging data, for chinook salmon and steelhead trout used in the 1975 study at and between Bonneville and The Dalles Dams.

Date of release	Release point	Species	Flag color	Radio tag code	Fish length (mm)
June 28	Beacon Rock	Chinook	Red-white	14D	850
28	Beacon Rock	Chinook	Red-white	23F	800
28	Beacon Rock	Chinook	Red-white	1H	810
28	Beacon Rock	Chinook	Red-white	23J	940
28	Beacon Rock	Chinook	Red-white	26L	720
29	Lyle, Wash.	Chinook	Red-white	25E	940
29	Lyle, Wash.	Chinook	Red-white	27G	840
29	Lyle, Wash.	Chinook	Red-white	31K	710
29	Lyle, Wash.	Chinook	Red-white	33I	860
July 1	Beacon Rock	Chinook	Green-blue	23I	960
2	Beacon Rock	Chinook	Green-blue	32D	890
2	Beacon Rock	Chinook	Green-blue	30E	930
2	Beacon Rock	Chinook	Green-blue	9K	910
2	Beacon Rock	Chinook	Green-blue	32L	1010
4	Beacon Rock	Chinook	Green-blue	8H	880
6	Beacon Rock	Chinook	Yellow-red	10I	790
7	Beacon Rock	Chinook	Yellow-red	5D	860
8	Beacon Rock	Chinook	Yellow-red	23E	860
8	Beacon Rock	Chinook	Green-blue	31G	840
8	Beacon Rock	Chinook	Green-blue	31F	840
8	Beacon Rock	Chinook	Yellow-red	6L	890
9	Beacon Rock	Chinook	Orange-green	27I	850
10	Beacon Rock	Chinook	Yellow-red	20K	940
11	Beacon Rock	Steelhead	Green-blue	34J	721
11	Beacon Rock	Steelhead	Orange-green	34K	787
13	Beacon Rock	Chinook	Orange-green	23D	812
13	Beacon Rock	Steelhead	Orange-green	33E	711
15	Beacon Rock	Chinook	Yellow-green	12I	1030
15	Beacon Rock	Chinook	Orange-white	5H[a]	952
16	Beacon Rock	Chinook	Orange-green	21L	965
16	Beacon Rock	Chinook	Yellow-red	36G	965
16	Beacon Rock	Chinook	Yellow-green	43D	825
18	Beacon Rock	Chinook	Orange-green	12H	927
19	Beacon Rock	Chinook	Yellow-red	11J	889
20	Beacon Rock	Chinook	Yellow-red	29F	787
20	Beacon Rock	Chinook	Yellow-green	30L	901
21	Beacon Rock	Chinook	Yellow-red	21G	939
22	Beacon Rock	Chinook	Red-orange	43I	749
22	Beacon Rock	Steelhead	Yellow-green	11E	810
22	Beacon Rock	Chinook	Yellow-green	32K	960
22	Beacon Rock	Chinook	Yellow-green	3H[a]	930
23	Beacon Rock	Chinook	Red-orange	35D	760
23	Beacon Rock	Chinook	Red-orange	8L	860

Table 1.--Continued.

Date of release	Release point	Species	Flag color	Radio tag code	Fish length (mm)
July 24	Beacon Rock	Chinook	Orange-green	33G	890
25	Beacon Rock	Chinook	Orange-green	27J	890
27	Beacon Rock	Chinook	Orange-green	42F	660
28	Beacon Rock	Chinook	Red-blue	21I	760
29	Beacon Rock	Chinook	Red-orange	6E	920
29	Beacon Rock	Chinook	Red-orange	99H[a]	950
30	Cascade Locks	Chinook	Yellow-green	98G	960
31	Beacon Rock	Chinook	Red-orange	25K	710

[a]Pressure sensitive tag.

Tracking of the conventionally radio-tagged fish near the dams was done primarily from fixed tracking stations located throughout the area (Figs. 3 and 4). Near The Dalles Dam, tracking was on a 24-hour basis with three crews made up of trackers and plotters. At Bonneville Dam, sufficient coverage was obtained with only a day- and a swing-shift crew, providing continuous tracking from 0600 to 2230 hours each day.

Plotting of the fish followed the same procedures described in earlier studies, using triangulation to determine location and an aerial photograph for charting their routes.

Tracking procedures for fish carrying a pressure tag were more complex. When the fish were near the dams, regular tracking crews tracked the fish in the same manner as fish tagged with conventional radio tags. This provided good records of the exact patterns of movement of the fish throughout the area near the dams. In addition, a tracking crew operating in a specially outfitted van-type truck followed the tagged fish and recorded the pressure and temperature data. The two-man crew in the truck was rotated each shift, as we kept the pressure-tagged fish under continuous surveillance from the time of its release until it left the study area. When a fish was not in the immediate vicinity of the dam, its location was recorded only as an approximation; but accurate depth of travel information was continuously recorded for the entire migration of the fish through the study area.

POWER PEAKING AND FISH PASSAGE

The effects of power peaking on the behavior of migrating adult salmonids in the vicinity of The Dalles Dam proved very difficult to study.

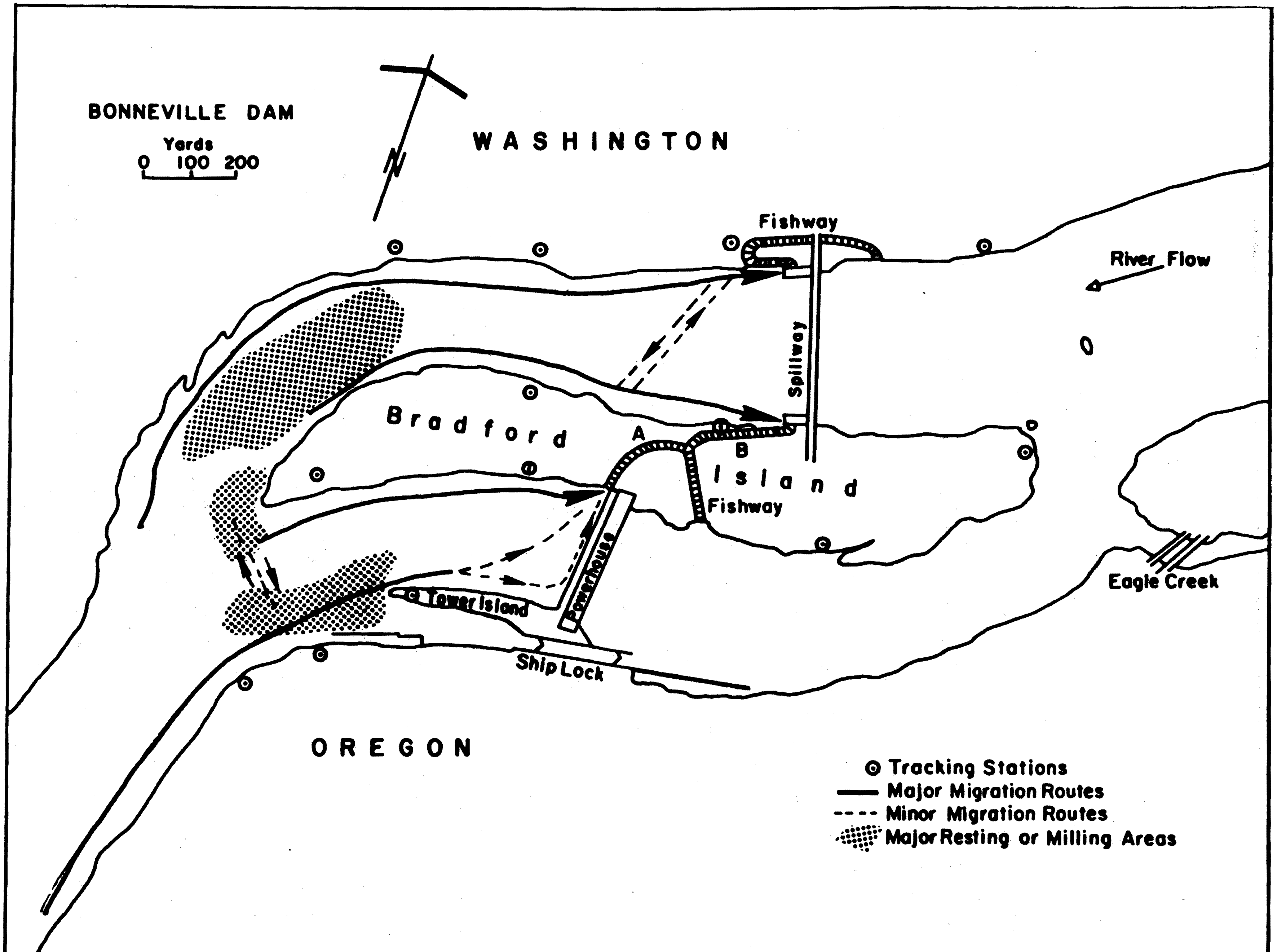

Figure 3.--The Bonneville Dam study area showing the areas below the dam most used by summer chinook salmon and steelhead trout in 1975 for traveling, milling, and resting.

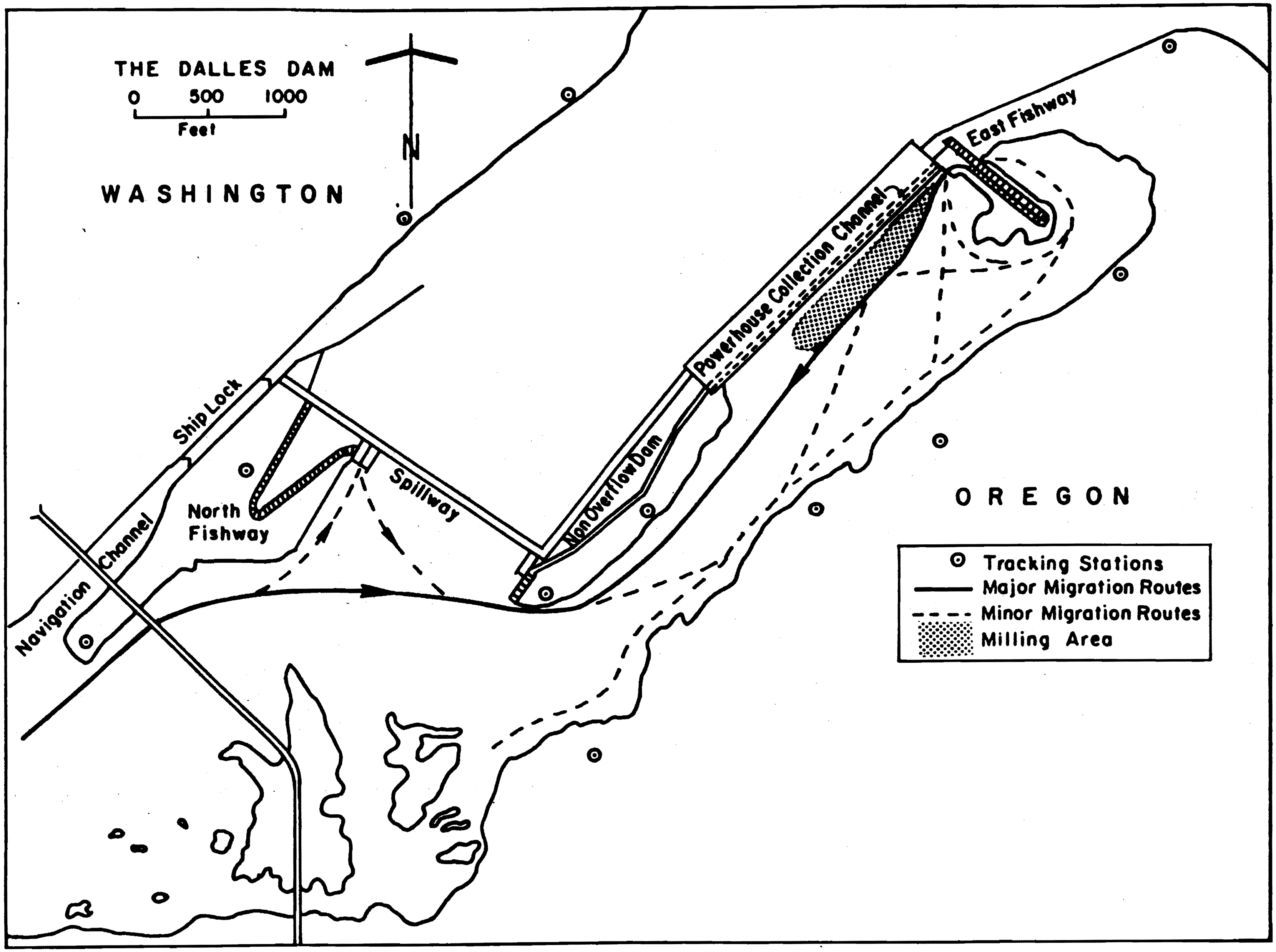

Figure 4.--The Dalles Dam study area showing the area below the dam most used by summer chinook salmon and steelhead trout in 1975 for traveling, milling, and resting.

We learned that in spite of the good intentions of all personnel concerned, it is difficult and perhaps impossible for experimental purposes to obtain strict control over the operation of a large hydroelectric plant like The Dalles Dam. Our compromise experimental design called for a 30% reduction in flow through the powerhouse on weekends during the study; but because of weather conditions and the necessity to supply power, even this experimental design was difficult to achieve on a regular basis.

During the period of study at The Dalles Dam, there were five weekends available: 4-5, 12-13, 19-20, and 26-27 July and 2-3 August. The desired reductions in flow were possible during only one of these weekends (4-5 July); partial reductions were available during the other four weekends. We had a total of 8 days that met or approximated the desired flow reductions: 4, 5, 6, 12, 13, 20, and 27 July and 3 August. The low, high, and average turbine discharges for each day of the study are shown in Table 2.

We carefully examined the tracks obtained for all tagged fish and compared behavior during reduced flows (test conditions) with behavior during normal flows (control conditions). Comparisons were made of individual fish as well as of groups of fish that were in the area during similar powerhouse discharges.

Fish behavior in the area was variable; no dramatic or immediate changes in behavior were observed that could be directly correlated with changes in turbine discharges. In fact, there was no evidence to indicate that the reductions in flow had any significant effect on fish passage in the section under study. By sectioning the study area into subdivisions (Fig. 2) and dividing the time each tagged fish spent in each subdivision

Table 2.--The low, high, and daily average turbine discharges at The Dalles Dam during the 1975 tracking program (based on hourly averages and given in 1000 f^3/s).

Date		Low	High	Average
June	28	137.0	212.3	155.6
	29	132.3	143.6	135.7
	30	117.5	251.7	175.8
July	1	126.1	266.3	205.4
	2	121.1	276.2	202.3
	3	130.6	310.4	224.0
	4	142.1	193.6	167.7
	5	135.6	192.3	159.6
	6	129.0	197.2	158.5
	7	134.1	297.1	228.7
	8	156.6	304.1	240.7
	9	164.1	345.5	243.5
	10	157.2	297.0	239.2
	11	175.9	277.3	219.0
	12	131.2	234.5	182.8
	13	130.9	210.3	161.8
	14	150.6	281.0	224.8
	15	128.9	263.5	222.5
	16	105.4	252.4	192.0
	17	129.9	282.7	208.7
	18	82.8	281.5	201.4
	19	52.2	313.4	184.2
	20	110.4	204.7	154.0
	21	86.6	266.2	197.9
	22	84.8	293.1	193.0
	23	45.7	212.0	143.3
	24	59.9	233.8	165.5
	25	75.8	237.3	175.7
	26	49.7	205.6	125.2
	27	60.8	138.9	101.3
	28	53.7	215.8	133.9
	29	54.0	171.9	119.3
	30	59.4	205.6	135.1
	31	50.9	224.6	140.2
August	1	69.0	273.6	152.7
	2	79.8	232.9	165.4
	3	92.1	170.0	121.2
	4	83.2	211.3	139.4

by the total time the fish spent in the entire study area during either the test or control conditions, we arrived at the percentage of time a fish spent in each subdivision. Table 3 shows these percentages for both the test and control conditions. Generally, fish behaved very similarly in this respect during both test and control periods. Based on the number of test and control days that tagged salmon were in the test area below the dam and the number of tagged fish crossing the dam on these days, the rate of passage was similar for test and control days--about one tagged fish per day over the dam.

Careful examination of the behavior of tagged fish that were in the tailrace when significant increases or decreases in turbine discharges were being made revealed no consistent behavior pattern. Individual variation among fish, changes in other factors such as time of day, and the small numbers of test fish available made it probable that only very dramatic effects would be detected.

It has become clear during this study that to isolate the effects of peaking from the myriad of other variables affecting adult passage requires a complex and regimented experimental design. As a result of problems associated with this year's work and work done at Bonneville Dam in 1973 (see Part 2) new techniques will have to be developed before specific differences caused by peaking can be detected and analysed at a large hydroelectric dam. Thus, the ability to study the effect of peaking on adult salmonids at this time in the Columbia River is questionable.

Table 3.--The percentage of their total time in the area that tagged fish spent in each subdivision[a] below The Dalles Dam during normal operating periods (control) and during the test periods (reduced powerhouse discharges).

Condition	Area (percentage of time in each)									
	2A	1A	1B	1C	D1	D2	D3	D4	D5	D6
Control	1	1	9	1	21	23	8	11	21	4
Test	1	1	9	1	27	23	8	11	17	2

[a]Subdivisions are illustrated in Figure 2.

EFFECT OF SPILLWAY DEFLECTORS ON SALMONIDS AT BONNEVILLE DAM

The total complement of spillway deflectors planned for Bonneville Dam had been installed by the beginning of this study. Of the 18 spillbays at the dam, all except bays 1, 2, 3, 16, and 17 were modified by the addition of spillway deflectors. Four bays (13, 14, 15, and 18) were modified prior to our study in 1974 (see Part 3) and the remainder were modified in late 1974 and early 1975.

Daily average river flows during the tracking period (28 June - 3 August) ranged from 109,100 to 311,700 ft^3/s and averaged 211,900 ft^3/s. Daily average spill ranged from 2,400 to 163,200 ft^3/s and averaged 70,551 ft^3/s.

We planned to track as many fish as possible in the area of the spillway to determine whether the conditions created below the spillway deflectors during various flow volumes adversely affected adult migrants. Not all radio-tagged fish released below Bonneville Dam were tracked into the areas in question below the spillway. Of the 41 summer chinook salmon, 38 were tracked within the vicinity of the dam; 12 of these entered and were tracked into the high velocity section below spillbays discharging water over a deflector. All four radio-tagged steelhead trout were tracked within the vicinity of the dam, but only one entered a relevant high velocity area.

None of the 13 fish exposed to the flows below the spillway deflectors gave any indication of abnormal behavior before or after their entry into the critical zone. Subsequent observations of these fish as they passed the counting stations revealed no evidence of injuries. In fact, nothing about the condition or behavior of the fish after their exposure to flows from the deflectors indicated they suffered any debilitating consequences. All of the exposed chinook salmon migrated safely to The Dalles Dam, and their travel times were comparable to the times taken by the balance of the chinook salmon tracked. All but one of the salmon tracked into critical areas were tracked over The Dalles Dam, and the one that was not was in the east fishway at The Dalles Dam when the study was terminated. The one steelhead exposed to the flows below the deflectors was reported to have been in excellent condition when it was caught by a sport fisherman in the Wind River. Two of the 12 salmon were subsequently observed approximately 250 miles upstream at the adult separator at Little Goose Dam on the Snake River.

Three previous studies--one at Lower Monumental Dam, one at Bonneville Dam, and one at Lower Granite Dam--also indicated that flows from spillway deflectors do not cause debilitating injuries to migrating adult salmonids (Monan and Liscom 1974 and Liscom and Monan 1976).

EFFECT OF SPILL COMMENCEMENT ON FISH

During the tracking period at The Dalles Dam, there were seven occasions when we were able to observe how the sudden transition from a nonspill condition to a spill condition affected radio-tagged salmon swimming immediately below the spillway. A test of this situation required a tagged fish to approach the face of the spillway while the spillway was closed and then remain there long enough for the control room to be notified and the spill to be started. In each test, the gate immediately above the fish as well as the two adjacent gates were opened 1 foot simultaneously and as quickly as possible, allowing about 1500 ft^3/s of water from each gate to plunge down on the fish.

The first test took place on 19 July when fish 36G swam up to and remained below spillgate 22. The appropriate gates were opened at 2105 hours and remained open until 2115 hours. The fish's immediate reaction was to move downstream at an angle out of the flow and into the powerhouse channel. The fish held in that area for 15 minutes and then swam downstream leaving the area at 2310 hours. The fish returned the next morning, entering the east fishway, and was observed passing the counting station at 1808 hours. Visual examination of the fish as it passed the counting station revealed no observable injuries.

The second test took place on 20 July when fish 12I swam up to and remained below gate 19. The gates were opened at 0505 hours and remained open until 0520 hours. The fish immediately moved downstream approximately 900 feet and angled to the north out of the flow. It then held its position for about 7 minutes before continuing downstream out of the tracking area. Thirty minutes later the fish moved back into the tracking area and up to the spillway. Subsequent tracking within the vicinity of the dam revealed no evidence of abnormal behavior, and careful observation of the fish as it passed the counting station in the north fishway at 1313 hours on 21 July revealed no sign of injuries.

The third test took place on 23 July when fish 12H swam up to and remained below gate 19. The gates were opened at 0745 hours and remained open until 0755 hours. The fish immediately moved downstream about 450 feet and angled to the south out of the flow and then turned and swam upstream into the powerhouse channel. Again, no abnormal behavior was observed as the fish was tracked. The fish appeared to be in good condition as it was observed passing the counting station in the east fishway at 1829 hours on 23 July.

Four additional tests were run with four additional fish. The results from these tests were similar to the case histories already described. One fish had not crossed over the dam by the time the study was terminated on 4 August. It was in the east fishway near the counting station, and there had been nothing abnormal about its behavior and no reason to suspect it was injured.

The reactions of all seven fish tested were similar in that they immediately moved downstream as the spill began. They all seemed to resume their normal migration pattern with a minimum of delay and none appeared to suffer any debilitating injuries.

SWIMMING DEPTHS OF ADULT SALMON VIA RADIO TELEMETRY

This year's tracking program provided the first opportunity to field test our recently developed pressure sensing radio tags and related receiving equipment and at the same time acquire new information about the swimming depths of adult salmon as they approach and cross over major dams. Three chinook salmon were tagged with pressure sensing tags and released below Bonneville Dam. Two of the tags were of the same design. The third, which contained a different style transducer, failed to function satisfactorily and no useful depth data were obtained from it. (Laboratory tests had indicated there might be a problem, but we felt a field test was justified.) Excellent data were obtained from the other two tagged fish.

Our system for tracking the pressure-tagged fish and receiving the telemetered pressure and temperature information proved to be workable. The effective range for the pressure tag was about 70% of that of a conventional beacon tag. As long as the trackers were within range and had a good signal from the tag, the pressure information was excellent. Difficulties were encountered when the trackers were at the edge of the range and the signal was poor. If the signal was weak, the depth readings were intermittent and inaccurate. The range was adequate for tracking in the immediate vicinity of the dams where the tracking vehicle could cross the river to stay on the same side as the fish. When the tagged fish was swimming in the river between the dams, some data were lost when the fish moved from one side of the river to the other and the tracking vehicle was unable to follow. Nevertheless, good records of the depth of travel for the two fish were obtained both in the vicinity of the dams and in the river between.

With data available from merely two fish, only general conclusions regarding the swimming depths of adult salmon as they migrate upstream are appropriate. Generally, the fish swam at 3 to 12 feet of depth with occasional excursions closer to the surface and as deep as 48 feet. Both fish tended to swim at shallower and more uniform depths between 2300 and 0400 hours each night. Figures 5, 6, 7, 8, 9, and 10 show the average hourly swimming depths plotted against time of day and river mile. The depths of travel during the times spent in the areas immediately below Bonneville and The Dalles Dams are shown in Figures 5, 6, 7, and 8. Depths of travel through a representative section of the river between the two dams (River mile 147 to 175) are illustrated in Figures 9 and 10.

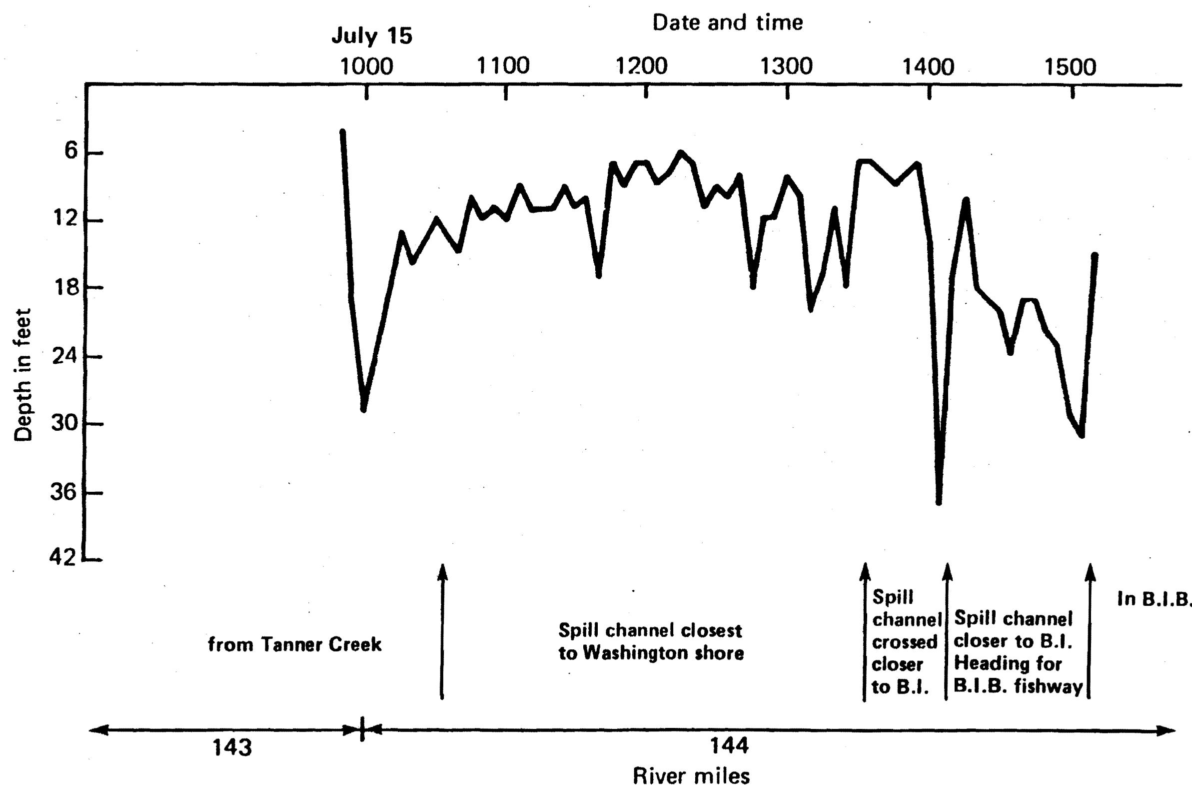

Figure 5.--Depth of travel for a free swimming chinook salmon (5H) in relation to date and time, river mile, and selected points of interest below Bonneville Dam (BI refers to Bradford Island).

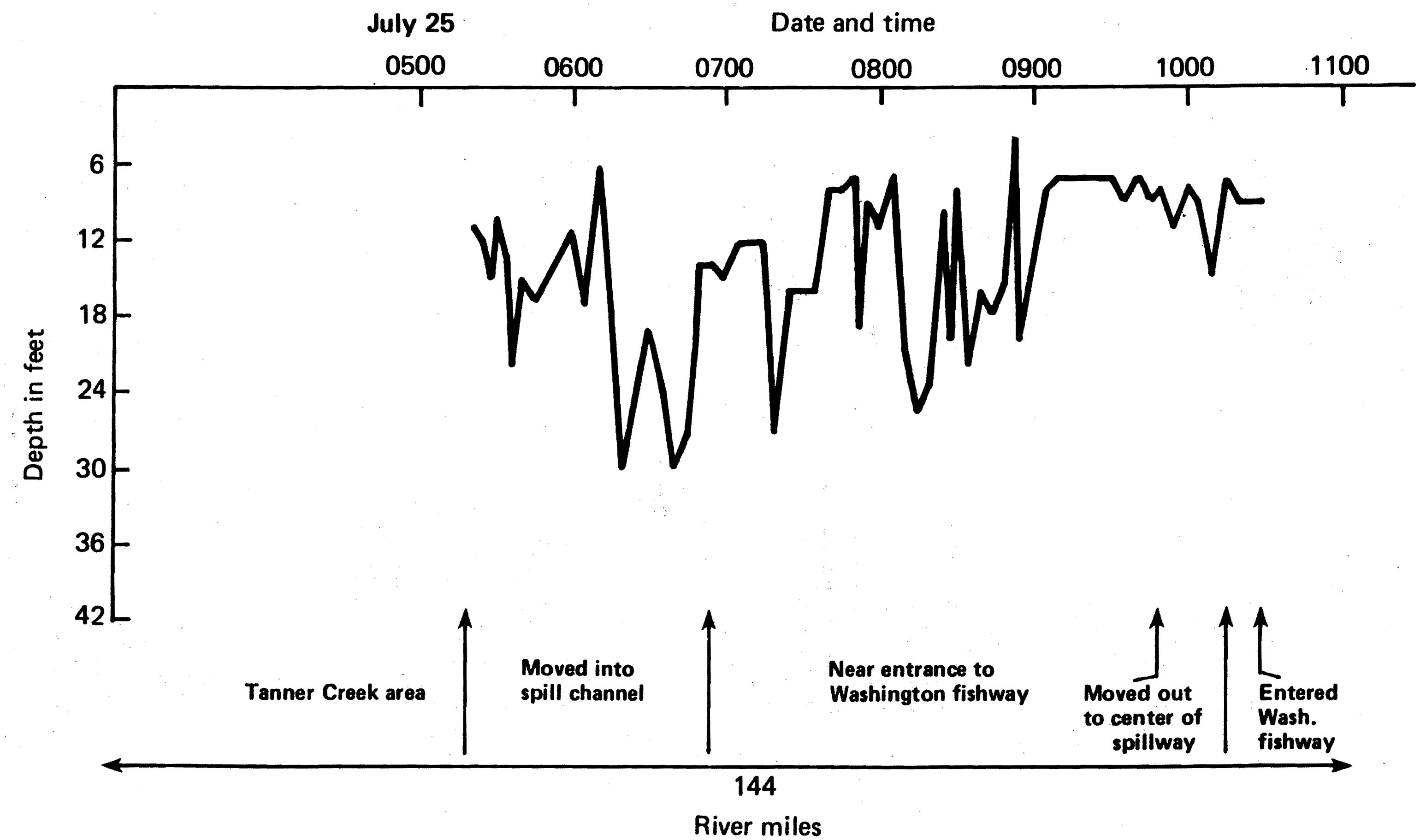

Figure 6.--Depth of travel for a free swimming chinook salmon (3H) in relation to date and time, river mile, and selected points of interest below Bonneville Dam.

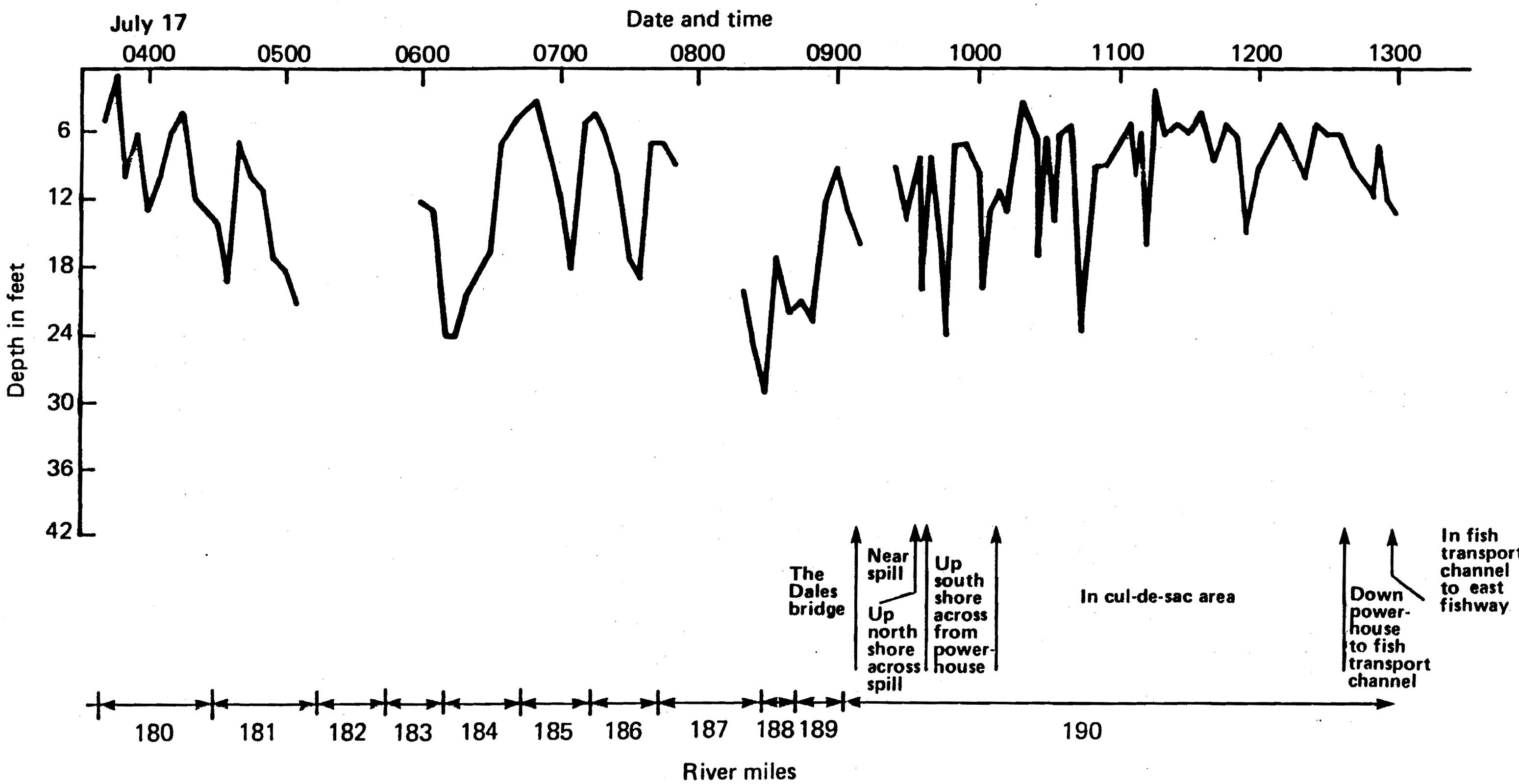

Figure 7.--Depth of travel for a free swimming chinook salmon (5H) in relation to date and time, river mile, and selected points of interest below The Dalles Dam.

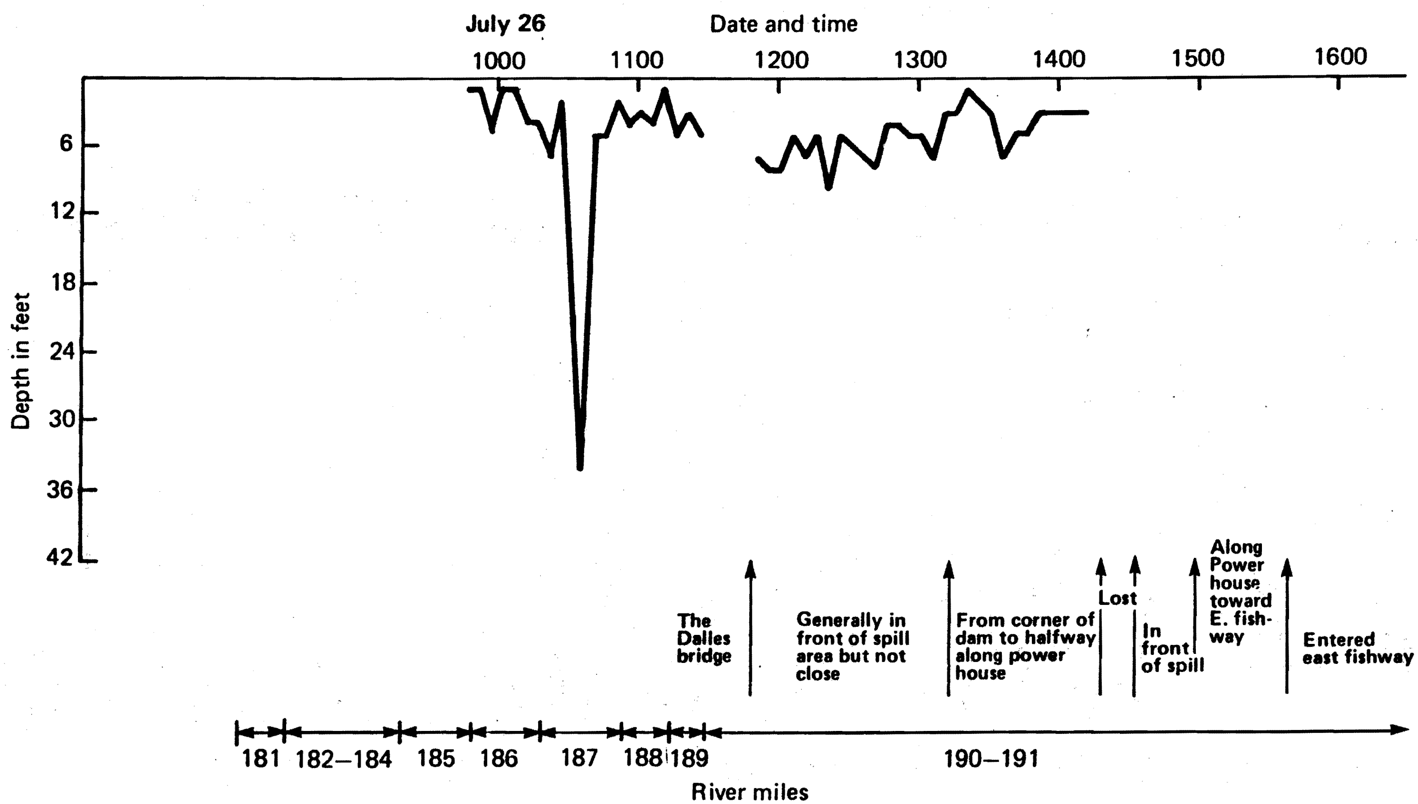

Figure 8.--Depth of travel for a free swimming chinook salmon (3H) in relation to date and time, river mile, and selected points of interest below The Dalles Dam.

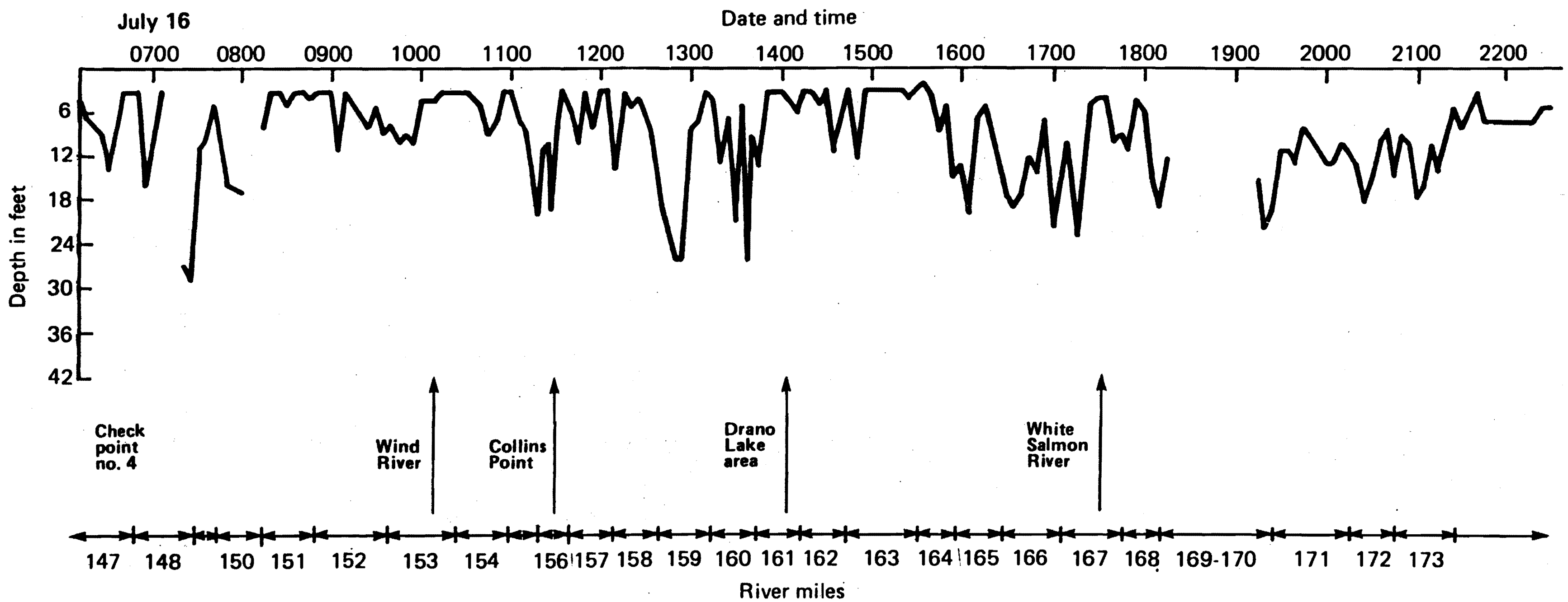

Figure 9.--Depth of travel for a free swimming chinook salmon (5H) in relation to date and time, river mile, and selected points of interest in a section of river between Bonneville and The Dalles Dams.

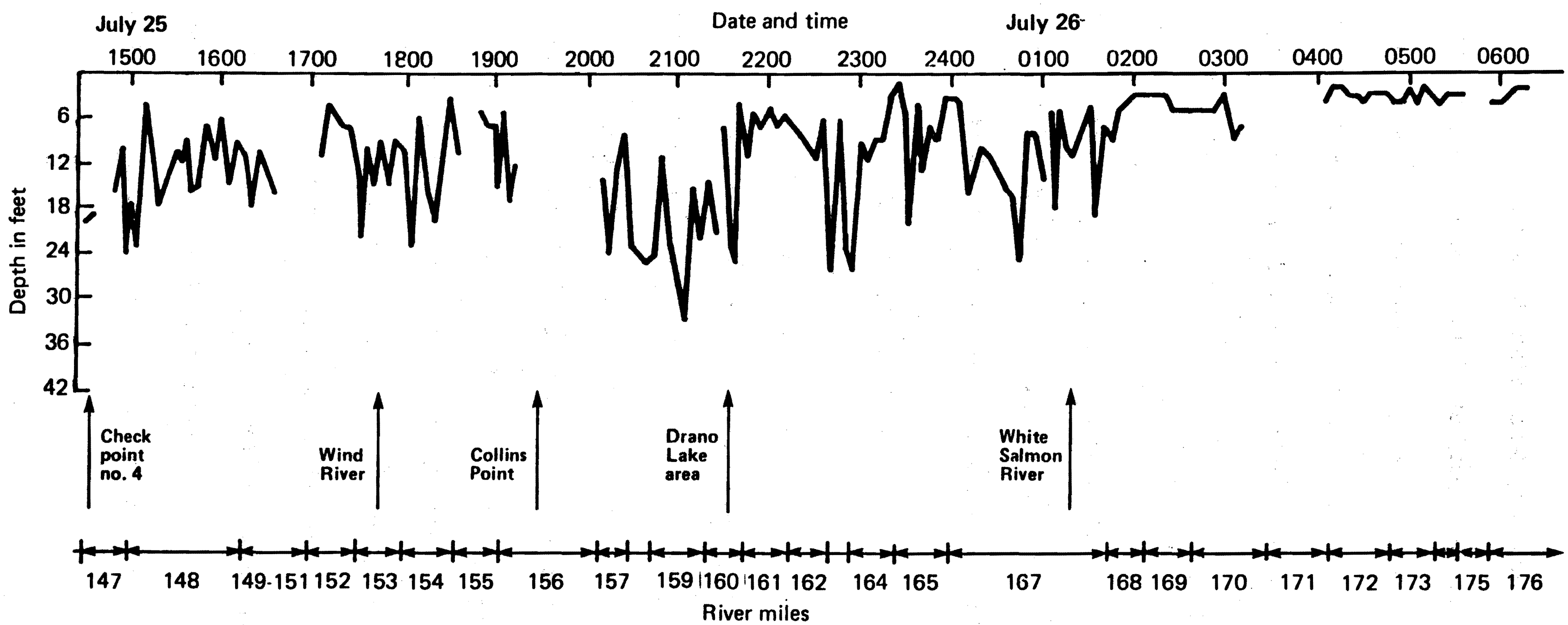

Figure 10.--Depth of travel for a free swimming chinook salmon (3H) in relation to date and time, river mile, and selected points of interest in a section of river between Bonneville and The Dalles Dam.

Figures 9 and 10 show that both fish spent a considerable amount of time swimming at depths of less than 6 feet. If this behavior were to occur frequently during periods of high concentrations of dissolved atmospheric gases in the river, it would provide hydrostatic compensation of less than 18% of saturation. Levels of supersaturation in excess of 135% are known to occur in the river and prolonged exposure of adult salmonids at depths of less than 6 feet could result in stress from gas bubble disease.

For an initial field test of complex equipment, the results obtained were very gratifying. We are confident that the tags and techniques developed will be extremely useful in future studies.

GENERAL OBSERVATIONS

Bonneville Dam Area

Of the 41 chinook salmon tagged with radio tags and released below Bonneville Dam, only four were not observed ascending the dam during the study period. Of the four, one was never found after its release on 28 June; one was tracked to Tanner Creek below the dam on 7 July and then lost until it was observed passing over The Dalles Dam on 18 July; one evidently passed the Bonneville area on 17 July during the time trackers were not on duty (2230 hours to 0600 hours), as it was heard by the day crew on 18 July a few miles upstream from the dam; and one was released on 28 July and had not crossed the dam by the time tracking in the Bonneville locale was terminated on 3 August. (This fish was subsequently observed going upstream at the Bradford Island counting station on 18 August.)

All four radio-tagged steelhead released below Bonneville Dam were tracked and observed as they passed upstream through the fishways at the dam.

This year, as in past studies, the behavior of the fish below the dam was variable. Time spent by tagged fish from their first entry into the study area until they crossed the dam ranged from 4 to 124 hours and averaged 37 hours for summer chinook salmon; it ranged from 16 to 81 hours and averaged 38 hours for steelhead trout. The average time chinook salmon spent below the dam in 1975 was less than the average of 47 hours spent by summer chinook salmon tracked during 1974 (see Part 3 of this report), when river flows were higher. River flows during this year's study averaged 211,900 ft^3/s, while in 1974 they averaged 431,300 ft^3/s.

Both the steelhead trout and the chinook salmon traveled throughout the area immediately below the dam, although fairly well-defined migration routes were observed (Fig. 3). These general routes were essentially the same as we observed in our previous tracking study of summer chinook salmon.

To compare fish passage conditions in the two main channels (powerhouse and spillway) below Bonneville Dam, we calculated the probability of a successful crossing by a tagged chinook salmon based on the number of entries made by fish into certain zones. For example, an entry into one of the main channels was defined as a fish swimming upstream and entering either area WI (spillway channel) or OI (powerhouse channel) (Fig. 1). The probability that a chinook salmon that entered a specified channel would remain in the channel and cross the dam was calculated by dividing the total number of crossings via fishways in the channel by the total number of entries into the channel. This system was also used to provide probabilities for crossings based on entries into areas we designated as being within the direct influence of flows from the fishway entrances (Areas 2A, 1B, and 1A in Figure 1) and also on entries into the fishways themselves.

The results of the probability calculations are summarized in Table 4. By comparing the powerhouse channel with the spillway channel, it can be seen that fish entering the spillway channel were about twice as likely to cross the dam as those entering the powerhouse channel. Furthermore, fish in the areas under the influence of flows from the Washington fishway or the "B" branch of the Bradford Island fishway were more likely to pass over the dam than those fish near the "A" branch of the Bradford Island fishway. (The slightly lower probability indicated for the Washington fishway was probably due to fish trapping and tagging activities taking place in the Washington fishway.) However, once the fish were inside the fishway, the chances of passage were similar.

We also monitored the time tagged fish spent in areas 2A, 1B, and 1A and found the average times spent by tagged fish in front of the Washington fishway and the "B" branch of the Bradford Island fishway were similar (37 and 30 minutes, respectively). This was about one-half of the average time (61 minutes) spent by tagged fish outside the entrance to the "A" branch of the Bradford Island fishway.

Summer chinook salmon averaged 3.7 hours in the fishway they used to ascend and cross the dam. Passage through the Bradford Island fishway was generally faster than through the Washington fishway; 3.3 and 4.2 hours,

Table 4.--Probabilities of tagged summer chinook salmon crossing Bonneville Dam based upon entries into specific locations.

Area	Number of entries into area	Number of dam crossings resulting	Probability of crossing dam
Spill channel	72	23	0.32
Powerhouse channel	76	12	0.16
Washington fishway area	45	14	0.31
Bradford Island "B" fishway area	26	9	0.35
Bradford Island "A" fishway area	64	12	0.19
Washington fishway	27	14	0.52
Bradford Island "B" fishway	13	9	0.69
Bradford Island "A" fishway	20	12	0.60

respectively. However, tagging activities in the Washington fishway probably delayed passage. Passage times were slightly less this year than in 1974 when summer chinook salmon averaged 4.6 hours ascending the Bradford Island fishway and 5.5 hours while ascending the Washington fishway.

The use of fishways by radio-tagged summer chinook salmon compared favorably to the choice of fishways by untagged fish (CofE fish counts); i.e., there was no significant difference between tagged and untagged fish. The Washington fishway was used by 62% of the tagged and 60% of the untagged fish. The Bradford Island fishway was used by 38% of the tagged and 40% of the untagged fish.

The four steelhead tagged and tracked all used the Bradford Island fishway and averaged 6.0 hours ascending and crossing the dam.

The behavior of the chinook salmon immediately above the dam was similar to that observed in previous tracking studies at Bonneville Dam. After exiting the Bradford Island fishway, about 70% of the tagged salmon swam upstream along Bradford Island, and most of these continued around the island to the spillway area. The other 30% either crossed over to the Oregon shore and moved on upstream or traveled upstream in midchannel. Of the tagged salmon exiting the Washington fishway 73% traveled upstream away from the dam. The other 27% swam toward the spillway before falling back or proceeding upstream.

Only five of the radio-tagged salmon fell back over the dam, all via the spillway. Undoubtedly, this small number of fish falling back is attributable to the small amount of water spilled during the tracking period. Spill ranged from 2,400 to 159,000 ft^3/s and averaged 67,961 ft^3/s. The percentages of fish that followed routes that took them near the spillway was comparable to previous years, so the opportunity for fallback existed. More tagged fish from the Washington fishway fell back than did fish from the Bradford Island fishway--three fish and two fish, respectively. However, the total number of fallback was so small, no real significance can be attached to this development.

All four of the radio-tagged steelhead trout exited the Bradford Island fishway and followed the shoreline of the island around to the spillway section. None were swept back over the dam.

Four of the five salmon that fell back survived the experience and reascended the dam with no visible signs of injury. One fish failed to survive falling back over the spillway. Tracking of this fish as it fell back indicated that it must have been stunned or badly injured because it simply drifted downstream with the current and showed no signs of actively swimming. We periodically monitored the tag signal as it remained in one location about 5 miles downstream from the dam. We subsequently recovered the tag 7 days later when the fish was found lodged in the brush on the shore. The remains were too badly decomposed to determine the cause of death. This fish was the first radio-tagged fish to be killed while falling back over a spillway, although one was severely injured at Lower Granite Dam during the spring of 1975 (Liscom and Monan 1976).

Between Bonneville and The Dalles Dam

Once fish left the immediate vicinity of Bonneville Dam and continued their migration upstream, the rate of travel was fairly steady. The travel time from dam to dam ranged from 20 to 53 hours and averaged 30 hours.

Other than individual variation between fish, the factor most affecting the rate of travel was time of day; fish generally slowed down during the hours of darkness.

The biggest zones of delay within the total study area were the dams. On the average, tagged fish spent about 40 hours negotiating the mile of river encompassing each dam, whereas they only took about 30 hours to travel the approximately 45 miles between the dams.

No problem areas were located between the dams. Only four trackable salmon failed to reach The Dalles Dam area. Two tagged salmon were caught by fishermen, one near Cascade Locks, Oregon, and the other near Lyle, Washington. One of the remaining two was tracked as far as River Mile 164 (near Hood River) and was progressing upstream in a normal manner, emitting a strong signal, when the swing shift crew terminated the day's track. The next morning, the day crew was unable to locate the fish. Searches were made throughout the region including the tributaries, but the signal from the tagged fish was never heard again. The other "lost" fish was the fish tagged with the faulty pressure tag. This fish was tracked as far as River Mile 167 when the tag signal faded and was never heard again. The signal had been getting progressively weaker and was difficult to track.

Only one of the four tagged steelhead trout made it to The Dalles Dam. The other three were tracked well up into tributaries; two into the Klickitat River and one into the Wind River. The fish in the Wind River and one of the fish in the Klickitat River were caught later by fishermen and the tags were recovered. The one steelhead that reached The Dalles area crossed the dam and subsequently was caught by a fisherman in the Deschutes River.

The Dalles Dam Area

Of the 38 tagged chinook salmon known to have reached The Dalles Dam, all but three crossed the dam and went upstream. The remaining three were tracked into the vicinity of the dam, and there is nothing in their behavior pattern to indicate any specific reason for their failing to cross the dam. Fish 23J entered the study area on 6 July and was tracked in the area until 0600 hours on 7 July when the signal from the fish was lost in the powerhouse channel near the west end of the powerhouse. During the time the fish was tracked, it made entries into both the north and east fishways. Trackers continued to search for the fish in the vicinity but failed to locate it. Fish 98G arrived at The Dalles Dam on 31 July and was tracked throughout the area with no indication of any problems. On 3 August, the fish was in the east fishway when it turned around, left the fishway via the transportation channel (Fig. 2), continued downstream, and left the tracking area at 1145 hours. The fish had not returned to The Dalles Dam by the end of the study on 4 August. Fish 27J entered The Dalles Dam area on 1 August and made repeated trips back and forth in front of the powerhouse. When tracking was terminated on 4 August, the fish was in the east fishway.

The one steelhead that reached The Dalles Dam entered the tracking zone on 14 July. It was tracked throughout the area and made many trips back and forth in front of the powerhouse. The last plot on the fish was in the east fishway on the morning of 16 July. The tag signal was lost during the shift change (0600 to 0630 hours), but the fish must have crossed the dam during this period and moved quickly upriver as it was caught by a fisherman near the mouth of the Deschutes River later on the same day.

Movement of radio-tagged fish below the dam was extensive. Fish usually approached the dam via the north half of the river and generally moved over to the tailrace at the base of the ladder and up into the vicinity of the east fishway (Fig. 4). Activity was greatest around the tailrace (area of turbine outflow) as most fish spent considerable time milling or using the area as a pathway to and from the east fishway. It was not unusual for a fish to make several trips through the tailrace before entering the fishway for the final time and crossing the dam. Fish stayed on the move most of the time with very little holding in any specific location below the dam.

Fish frequently entered the east fishway only to swim back out the entrance after a period of time. There are four entrances to the east fishway: the south spill-transportation channel entrance, the powerhouse collection system, the east entrance, and the cul-de-sac entrance. All entrances were just as readily used as exits. In fact, almost every conceivable combination of entering and exiting occurred. This is in direct contrast to our experience with spring chinook salmon in 1972, when 15 of 17 fish tracked into the fishways remained there and crossed the dam (see Part 1). Using a system of probabilities similar to those calculated for the fishways at Bonneville Dam, we arrived at a probability of 0.06 that a fish entering the east fishway would remain in and cross the dam.

Entrance-exit activities in the north fishway were similar, but not as extensive. We calculated a probability of 0.19 that a fish entering the north fishway would remain in and cross the dam.

The time tagged fish spent from their initial approach to the dam until they made their final entry into a fishway to cross the dam ranged from 1 to 125 hours and averaged 35 hours. While this time does not appear excessive, it could have been reduced very substantially if a higher percentage of fish had remained in the fishways and crossed the dam on their first entry.

The final choice of fishways by the tagged chinook salmon compared favorably to the choice by untagged adult chinook salmon (CofE fish counts) for the same period. The east fishway was used by 80% of the tagged and 82% of the untagged chinook salmon. The north fishway was used by 20% of the tagged and 18% of the untagged chinook salmon.

Activities of the tagged fish were monitored from the time they approached a fishway entrance until they crossed the counting station and entered the forebay. The salmon averaged 5.5 hours in the fishway during their ascent and crossing of the dam. Passage through the north fishway was generally faster than through the east fishway--4.9 hours as compared to 5.7 hours. In our 1972 tracking study, spring chinook salmon averaged about 6 hours in the fishways on their final ascent. The times for final ascent in the two studies are comparable, but the total time this year's fish spent in the fishways, including entries that did not result in passage, was considerably higher. The two main areas of rejection and delay in the east fishway were near the base of the fishway just inside the entrance and near the top of the fishway in the control section. The average amounts of time a tagged fish spent near the fishway entrances were similar for areas 2A, 1A, and 1C, about 23 to 33 minutes. However, the average time for area 1B was 121 minutes.

The behavior of tagged fish immediately above the dam was similar to that observed in the 1972 tracking study. The fish generally moved quickly and fairly directly upstream and did not follow routes that would lead to fallback problems (Fig. 11).

CONCLUSIONS

1. Power peaking, as simulated by an approximate 30% reduction of flow through the powerhouse at The Dalles Dam, did not cause significant changes in fish passage conditions for adult salmonids at the dam.

2. Adult chinook salmon and steelhead trout swim into or near the discharges from the spillway deflectors at Bonneville Dam.

3. Adult salmonids swimming of their own volition into the area below a spillway discharging water over a spillway deflector are not likely to be seriously injured by the hydraulic conditions they encounter.

4. Passage conditions for salmonids, during the period of this study, were generally good at and below Bonneville and The Dalles Dams. However, both dams represent a point of delay in the upstream migration of summer chinook salmon and steelhead trout.

5. Once salmonids entered the fishways at Bonneville dam, the effectiveness of the various fishways for passing salmonids were about equal. However, conditions near the entrance to the "A" branch of the Bradford Island fishway were not as effective in enticing fish to enter the fishway as were conditions associated with the other fishway entrances.

6. As in past studies, adult salmonids exiting the fishways into the forebay at Bonneville Dam followed migration routes which took them near

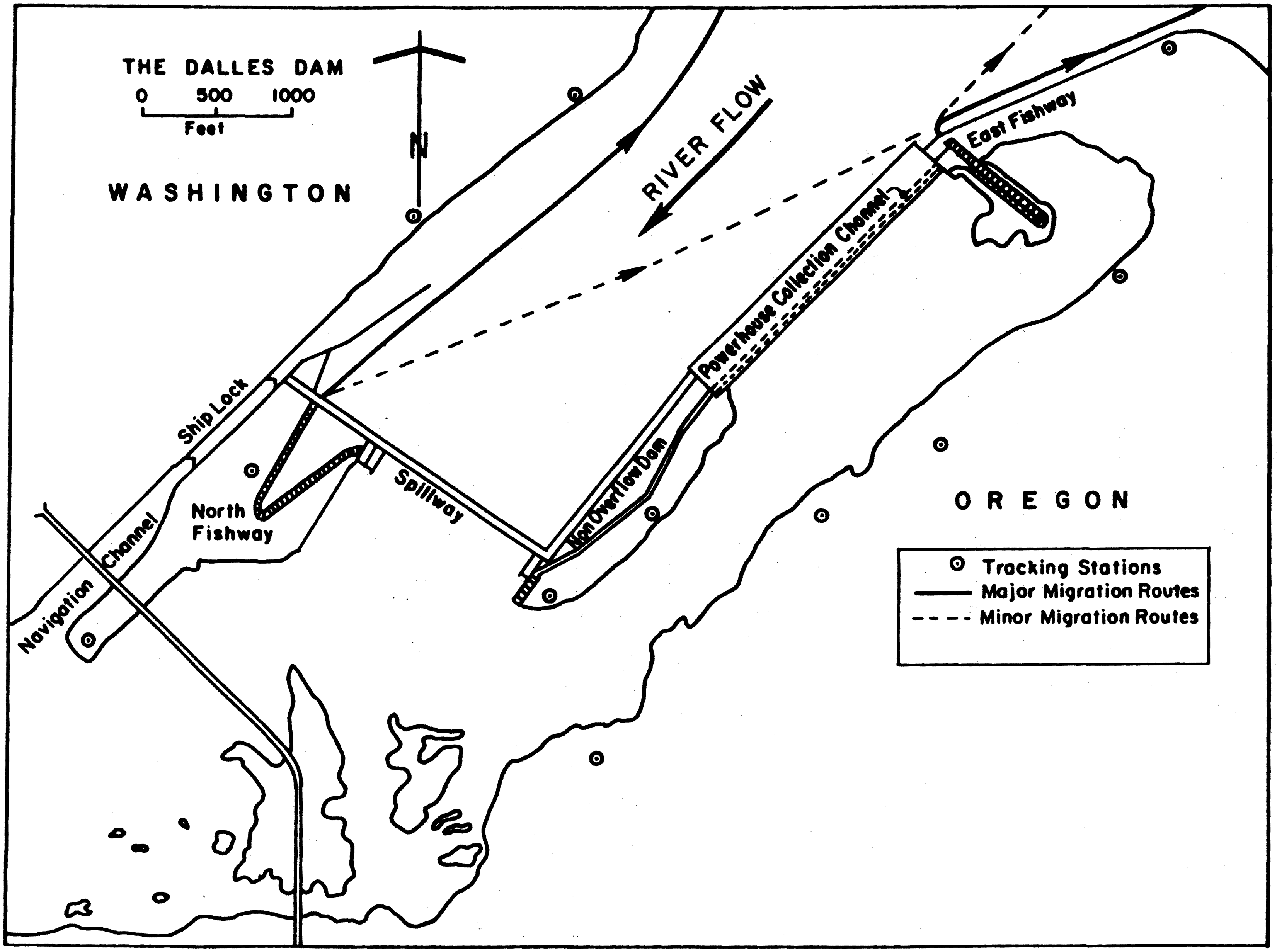

Figure 11.--The Dalles Dam study area showing the general migration paths taken by summer chinook salmon after exiting the fishways into the forebay.

the spillway where they were subject to being swept back over the dam. However, fallback was reduced during this study due to the small quanity of spill.

7. Fish passage conditions between Bonneville and The Dalles Dam were favorable during the study.

8. Fish passage at The Dalles Dam was delayed for many fish that made repeated entries, exits, and reentries of the fishways before remaining in a fishway and crossing the dam. This apparent reluctance to accept the fishway was more of a problem in the east fishway than the north fishway.

9. Because fish exiting the fishways into the forebay at The Dalles Dam move rather quickly upstream and away from the dam, fallback problems are minimal.

10. The sudden transition from a nonspill condition to spill condition at The Dalles Dam is not likely to cause debilitating injuries to adult salmonids in the immediate area below the spillway.

11. Swimming depths of free-swimming adult salmonids may be effectively monitored through the use of pressure sensitive radio tags and related receiving equipment developed by personnel of the National Marine Fisheries Service.

ACKNOWLEDGMENTS

The following staff members of the National Marine Fisheries Service, Northwest and Alaska Fisheries Center, Seattle, Washington participated directly in the study; Charles J. Bartlett, Gordon F. Esterberg, Donald L. Thorne, and Charles D. Volz. Lowell C. Stuehrenberg assisted with the analysis of the data.

The help and cooperation of all personnel of the U.S. Army Corps of Engineers, especially those at Bonneville and The Dalles Dams, were greatly appreciated. We are particularly appreciative of the efforts of Richard Duncan and his staff in assisting us at The Dalles Dam.

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Part 5. EVALUATION OF POTENTIAL SOLUTIONS TO THE FALLBACK PROBLEM AND EXAMINATION OF FISH BEHAVIOR IN RELATION TO THE POWERHOUSE COLLECTION SYSTEM FOR SPRING CHINOOK SALMON AT BONNEVILLE DAM, 1976

By Kenneth L. Liscom, Gerald E. Monan, and
Lowell C. Stuehrenberg

INTRODUCTION

Two areas of immediate concern have developed in relation to adult fish passage at Bonneville Dam (Fig. 1) on the Columbia River. One is the problem of fish falling back over the spillway after they ascend the dam (Part 3 of this report and Junge and Carnegie 1976). The other involves the apparent inefficiency of the powerhouse collection system (Junge and Carnegie 1976).

Our previous radio tracking studies have shown that as fish enter the forebay from the Bradford Island fishway, many orient to the Bradford Island shore--swimming to and around the upstream end of the island and down to the spillway. Most of these fish swim across the channel in front of the spillway to the Washington shore and continue upstream. However, during periods of spill many fall back over the spillway.

Fallback has three deleterious effects: 1) direct mortality of salmon at time of fallback, 2) indirect mortality due to added delay for reentry and reascension of fishways, and 3) inflated fish counts which hamper management of the runs.

A committee, made up of representatives of the U.S. Army Corps of Engineers (CofE), Oregon Department of Fish and Wildlife (ODFW), and National Marine Fisheries Service (NMFS), was formed to develop a means to break up the pattern of fish swimming around Bradford Island to the spillway. Many things were considered, but because of time restrictions for construction, the only practical device suitable for installation during the 1976 spring chinook salmon run was a deflector net extending about 150 feet out into the channel from just upstream of the fishway.

Radio-tracking studies of chinook salmon at Bonneville Dam during the spring of 1976 were primarily designed to study the reaction of tagged fish to the deflector net and to obtain information on specific areas of fallback.

In addition, tracking information obtained on radio-tagged fish in the powerhouse channel below the dam supplemented data obtained by the CofE in their electronic tunnel studies. Recent decreases in the numbers of chinook salmon using the "A" branch of the Bradford Island fishway were thought to be a result of a decrease in the efficiency of the fish collection system located across the downstream face of the powerhouse. To study this problem under various flow conditions, personnel from the CofE installed electronic fish counting tunnels in the orifices of the collection system to provide information on the number of entries and exits made by fish at the orifices. Radio tracking studies were carried out in conjunction with the tunnel studies to provide information on the effect of flow conditions on fish approaching the powerhouse.

The study had five specific objectives: 1) evaluate the effectiveness of the deflector net in reducing fallback and monitor the reactions of fish to the net, 2) determine if fish released into the forebay at different distances across the powerhouse channel fell back at different rates from those exiting the Bradford Island fishway, 3) determine which specific spillbays radio-tagged fish fell back through, 4) determine swimming depth of tagged fish as they swam around the deflector net and Bradford Island, and 5) monitor radio-tagged fish as they approached the powerhouse fish collection system.

EXPERIMENTAL SITE AND EQUIPMENT

As Bonneville Dam is the first dam on the Columbia River encountered by returning adult salmonids, fish counts taken there are instrumental in managing the runs. At the dam, the spillway is separated from the powerhouse by Bradford Island (Fig. 1), creating two channels. Fishway entrances are located at the north and south ends of the spillway, and a fish collection system runs across the face of the powerhouse with a fishway entrance at the north end. The south spill ("B") branch and the powerhouse ("A") branch connect to form a single fishway over the dam. The exit to the north fishway is on the Washington shore approximately 387 feet upstream from the spillway. The Bradford Island fishway exit is on the south side of the island about 465 feet upstream from the powerhouse.

Radio Tags

The conventional radio tag was used during this study. The batteries powered the transmitter for about 12 days. Pressure tags were also used during this study, and their battery life was approximately 6-1/2 days. As described in the 1975 study (Part 4), the pressure tag capsule is somewhat larger than the conventional tag: 4-1/4 inches long by 1-inch in diameter with the pressure transducer mounted on the forward end. This tag weighs approximately one ounce in water and is carried in the stomach of the fish, like the conventional tag. The tag transmits 30.21 megahertz (MHz) pulses

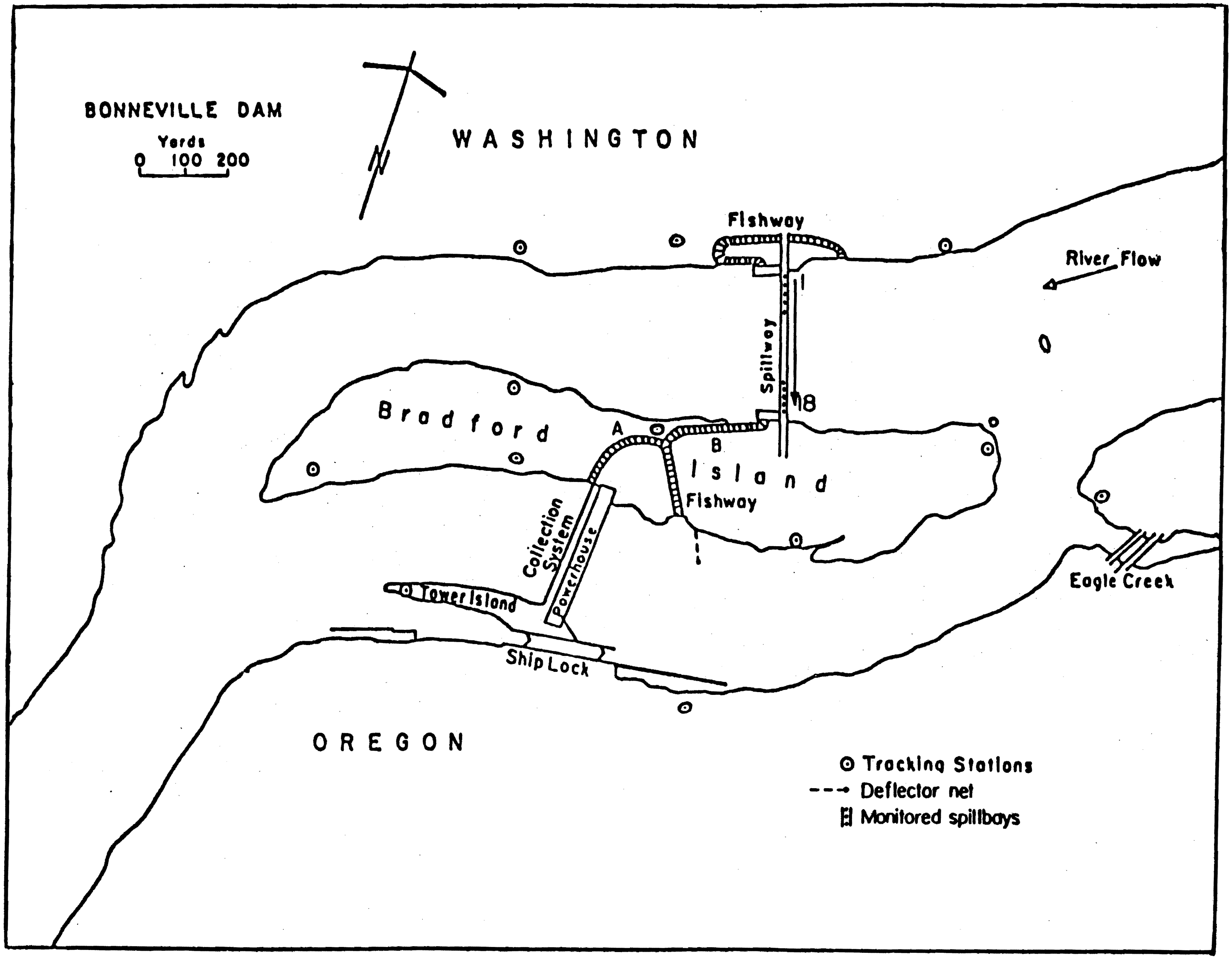

Figure 1.--The Bonneville study area and location of the deflector net.

30 milliseconds long. The pulse interval or period varies with pressure (depth), and the period for pressure was set to vary over a range of from 0 to 60 feet.

Direction Finder-Receiver and Antennas

The direction finder-receiver used by trackers was a self-contained battery-operated unit which received the radio signal from the antenna, amplified it, and converted it to an audible tone. The operator could monitor any one of the nine frequencies at any time. To eliminate as much extraneous noise as possible, each operator used earphones to listen to the signal.

Two types of directional antennas were used for tracking: the loop antenna used in previous years and a two-element vertically polarized directional beam antenna (Adcock)[1/]. The loop antennas were mounted on vehicles to be used as mobile units. The larger Adcock antennas were used at the fixed tracking stations. The horizontal boom of the Adcock is 6 feet 4 inches long. The two vertical elements are 15 feet 9-3/4 inches long and are attached to the boom at their centers. The antennas were mounted on 16-foot masts making the height of the upper tip of the elements about 24 feet from the ground. Guy lines stabilized the mast, and trackers could easily turn the unit by hand while tracking tagged fish.

Pressure Tag Receiver

Pressure tag signals require a sophisticated receiving system consisting of five main components: 1) a quarter-wave whip antenna, 2) a

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1/ Reference to trade names does not imply endoresement by the National Marine Fisheries Service, NOAA.

broad band receiver, 3) a phase-lock loop demodulator with pulse conditioner, 4) an electronic digital counter, and 5) a clamp-bar direct-current strip-chart recorder.

The strip-chart recorder was used for the first time and enabled us to keep a permanent and continuous record of the fish's swimming depth. Signals from the tag were recorded on pressure sensitive paper as a measurement of the pulse interval. Each pressure tag was calibrated just before being inserted into the fish, and the appropriate graphs were used to convert the pulse interval to depth. Depth information was accurate to within plus or minus 6 inches.

Fishway Monitoring Units

Movement of fish in the fishways was monitored by two different systems. One was the usual, simple unit to alert fish counters to the presence of a tagged fish in a specific area. The other was a sophisticated telemetry unit that transmitted data on the movements of tagged fish in the fishways to the data collection center.

The simple alert system was a battery-powered receiver placed in the counting house and a standard 18-inch diameter loop antenna positioned over the fishway pool just below the counting house. This system did not distinguish between specific tag codes. The gain controls on the receivers were set so they would give an audible beeping sound when fish were in the immediate vicinity of the counting station.

The telemetry units first used in 1974 monitored the fishway entrances and determined when specific tagged fish entered the fishway. In 1976, two underwater antennas were suspended from floats--one just inside the entrance and the other about 100 feet upstream. (Previously, loop antennas had been suspended over the water suface). The underwater antenna was developed by our electronic technicians for use in fishways and other areas where reduced range is desirable. The unit is a dipole antenna resonant underwater at 30.21 MHz. Its range is less than that of a loop antenna, so it provides more accurate data on fish movement into the fishways.

As tag signals came into the receiver unit (located adjacent to the fishway), it determined the tag frequency, converted the information to a tone code, and transmitted the appropriate code via radio transmitter to the receiver in the data control center. The tone code was automatically translated and a flashing light on a panel array indicated the frequency and location of the tag. By viewing the light panel and clock, observers determined the time each tagged fish moved into each fishway, and whether the fish was near the upstream or downstream antenna. By noting the sequence of events, the observers could determine if the fish was moving upstream, holding, or moving down the fishway.

Spillway Gate Monitoring Units

Fallback was monitored at the spillway section of the dam by underwater antennas, counting house-type receivers, and strip chart recorders. The antennas were weighted and lowered to a depth of about 20 feet on the upstream side of the spillway in the grooves for concrete stops-logs which hold back water for spillgate maintenance. Two antennas per spillbay were used, one antenna in the north slot and one in the south slot. The antennas were positioned in the gate slots to minimize damage by swirling logs and other debris that collect above the spillway gates and that move in the substantial water currents and velocities that occur during water spill. A receiver was attached to the safety railing above each gate being monitored and relayed tag signals received by the antennas to one of the multichannel strip chart recorders. One recorder was housed at the north end of the spillway and one at the south end. When a fish fell back, the appropriate pen in the recorder indicated on the chart paper which gate the fish fell through. The moving chart was calibrated so the time an event occurred could be determined. Identifying the proper tag code was done by cross-checking with central control room charts.

GENERAL EXPERIMENTAL PLAN

Plans called for tagging and tracking as many individually identifiable spring chinook salmon as possible between 23 April and 27 May 1976. Fish were released at various locations below and above Bonneville Dam. Tracking was most intense above the dam in the channel around Bradford Island and at the spillway. Fish continuing around Bradford Island and swimming toward the spillway were carefully monitored, and special efforts were made to ascertain the exact spillway gate where any fallback occurred.

Radio-tagged fish were tracked below the dam prior to their entry into the fishways. Special emphasis was placed on tracking fish as they approached the powerhouse collection system. Because of manpower restraints, tracking below the dam was done only when there were no radio-tagged fish in the forebay.

Data on swimming depths of migrating chinook salmon were obtained by releasing pressure-tagged fish, which were monitored continuously from the point of release until they left the Bonneville Dam study area.

EXPERIMENTAL PROCEDURES

Trapping and Tagging

Chinook salmon for tagging were diverted from the fishway on the north side of the Bonneville spillway into a trapping facility in the Fisheries-Engineering Research Laboratory. Fish were routed up the 20-foot Denil type fishway to a short holding area from which they swam over a false weir and down a slide into a tank of water containing anesthetic (MS-222). Chinook salmon under 660 mm were considered too small to safely carry the tag, but the rest were tagged as they came. Tagging procedures for both the conventional radio tag and the pressure sensitive tag, as described in previous years' studies, were the same.

After tagging, fish were placed in a fish hauling truck, driven to a release point, and released into the Columbia River either directly or after being held in a live box. Our initial releases for this study were made into the river below Bonneville Dam at the entrance to Hamilton Slough on the Washington shore about 0.9 mile downstream from the powerhouse. Later downstream releases were made at Dodson, Oregon, approximately 4 miles below the dam. Releases above the dam were made from the ODFW recovery pen located immediately upstream from the deflector device, from a live box midway across the powerhouse channel, and from the fish lock at the south end of the powerhouse. To expose more fish to the deflector net, tagged fish were also released into the Bradford Island "A" branch fishway just below the intersection with the "B" branch. Table 1 shows the number of fish released at each location.

A total of 67 spring chinook salmon were tagged and released in the vicinity of the dam, and we attempted to have at least nine separately

Table 1.--Release sites and number of radio-tagged fish released.

Location	Number of fish
Hamilton Slough (Washington side)	21
Dodson, Oregon	7
Bradford Island "A" branch	12
Recovery pen	14
Fish lock	9
Midchannel	4
Total	67

identifiable tagged fish in the study area at all times. On occasion, a duplicate code was released when one or more tag codes were downstream and out of the tracking area. These duplicate releases were always made at upstream locations. Releases below the dam were not made until a fish with a particular code left the study area above the dam and continued upstream. The data on fish tagged and released are detailed in Table 2.

Tracking and Plotting

Fish tagged with conventional radio tags and released into the river below Bonneville Dam were monitored intermittently from the release point until they entered the study area adjacent to the dam. Trackers equipped with mobile tracking gear traveled along the highways on either side of the river periodically and listened for signals to alert staff at the dam when tagged fish were approaching the tracking area.

Tracking fish near the dam was done from 0600 to 2230 hours each day primarily from fixed tracking stations located throughout the area (Fig. 1). Because we did not have sufficient trackers to cover the total area at any one time and the fallback problem was of primary interest, tracking above the dam was given top priority. When a tagged fish entered a fishway, all trackers were alerted to be ready to be transported to the upstream stations. When the fish reached the section in the fishway where the tag activated the receiver in the counting house, trackers were immediately transported to designated stations above the dam. Tracking below the dam was discontinued except for mobile units and a permanent station on Bradford Island just below the spill section of the dam which verified fallbacks and tracked fish near the fishway entrances. Primary surveillance continued above the dam until all tagged fish left the forebay

Table 2.--Tagging data for chinook salmon used in the 1976 study at Bonneville Dam.

Date released	Location	Flag color	Radio tag code	Fish length (mm)
April 23	Hamilton Slough	Blue/orange	D6A	720
23	Hamilton Slough	Blue/orange	E6B	980
23	Hamilton Slough	Blue/orange	F6A	950
23	Hamilton Slough	Blue/orange	L6C	690
23	Hamilton Slough	Blue/orange	K6A	800
23	Hamilton Slough	Blue/orange	H6D	830
23	Hamilton Slough	Blue/orange	J6D	760
23	Hamilton Slough	Blue/orange	G6E	730
23	Hamilton Slough	Blue/orange	I6E	880
26	Hamilton Slough	Pink/white	D6B	760
26	Pen	Pink/white	H6G	680
26	Pen	Yellow/green	H6K	680
27	"A" branch[a]	Pink/white	F6I	820
28	"A" branch[a]	Pink/white	E6S	720
28	Hamilton Slough	White/blue	D6C	810
30	Hamilton Slough	Pink/white	I6N	730
30	Hamilton Slough	Pink/white	G6G	750
May 1	Pen	White/blue	I6G	850
1	Hamilton Slough	Pink/white	L6L	750
2	Pen	Pink/white	K6I	730
2	Hamilton Slough	Pink/white	J6O	850
2	Hamilton Slough	White/blue	G6M	670
3	Hamilton Slough	White/blue	K6L	850
4	Hamilton Slough	White/blue	E6J	670
4	"A" branch[a]	White/blue	L6G	830
5	"A" branch[a]	Orange/green	L6B	860
5	"A" branch[a]	White/blue	J6A	730
6	Fish lock	Orange/green	D6G	970
7	"A" branch[a]	White/blue	HD17	800
7	Fish lock	Pink/orange	D6D	670
9	Hamilton Slough	Green/white	D6F	720
9	Pen	Orange/green	E6E	660
10	Hamilton Slough	Orange/green	I6L	880
10	"A" branch[a]	Orange/green	K6H	880
10	Fish lock	Pink/orange	L6J	690
12	Pen	Green/white	L6H	710
12	Dodson	Orange/green	G6F	740
14	Dodson	Pink/orange	E6A	870
14	Fish lock	Pink/orange	K6G	940
15	Pen	Green/white	F6G	760
15	Pen	Yellow/pink	D6E	700
16	"A" branch[a]	Orange/green	HD13	770
16	Fish lock	Yellow/pink	J6M	720
16	Dodson	Orange/white	K6E	760

Table 2.--Continued.

Date released		Location	Flag color	Radio tag code	Fish length (mm)
May	17	Pen	Orange/white	F6H	900
	18	Dodson	White/blue	F6D	830
	18	Hamilton Slough	Green/white	K6B	920
	19	"A" branch[a]	Pink/orange	J6K	980
	19	Fish lock	Pink/orange	I6H	710
	20	Pen	Yellow/pink	L6I	850
	21	Fish lock	Green/white	E6G	900
	21	"A" branch[a]	Green/white	I6A	740
	21	Dodson	Orange/green	J6B	840
	22	"A" branch[a]	Pink/orange	H14	920
	22	Fish lock	Orange/green	F6J	840
	22	Pen	Yellow/pink	E6C	660
	22	Mid-channel	Yellow/pink	K6J	940
	22	Dodson	Pink/orange	G6D	770
	23	Dodson	Yellow/pink	I6B	820
	24	"A" branch[a]	Green/white	H15	800
	24	Mid-channel	Pink/blue	K6F	900
	25	Mid-channel	Blue/yellow	K6C	770
	26	Mid-channel	Yellow/pink	G6H	780
	26	Fish lock	Orange/white	J6H	830
	26	Pen	Pink/orange	F6B	950
	27	Pen	Blue/yellow	J6G	770
	27	Pen	Orange/white	G6J	810

[a]This release site was in the Bradford Island "A" branch fishladder approximately 100 feet below intersection with the "B" branch.

area, either by swimming upstream or by falling back. Trackers were then re-deployed to resume tracking below the dam in the appropriate areas. Tracking stations above the dam were always manned previous to releases in the forebay resulting in some days when little or no tracking was done below the dam.

Plotting the routes followed by both the conventionally-tagged fish and the pressure-tagged fish followed the same procedures that were used in earlier studies described in this report.

DEFLECTOR NET AND FISH BEHAVIOR

The seine net used to deflect migrating adult salmon away from the Bradford Island shore was installed approximately 200 feet upstream from the Bradford Island fishway exit (Fig. 2). The 150-foot long net was made of 3-inch stretched mesh and extended from the shore into the forebay at a slight angle upstream. It created a 150-foot long barrier from the surface to the river bottom. Water depth was 18 feet deep at the outer end of the net when the forebay water level gauge indicated 74 feet (above sea level). Piling driven offshore held the outer end of the net in place. Installation of the deflector net was done by the CofE for the ODFW.

The net appeared at best only marginally effective in discouraging fish from following the shoreline of Bradford Island around to the spillway. A total of 14 radio-tagged chinook salmon were exposed to the deflector net, and tracking showed that two fish (15%) may have been deflected by the net. Past tracking studies, however, have shown a natural tendency for about 28% of the fish to cross to the Oregon shore without the net, so it is debatable whether these two fish were deflected or crossed over on their own.

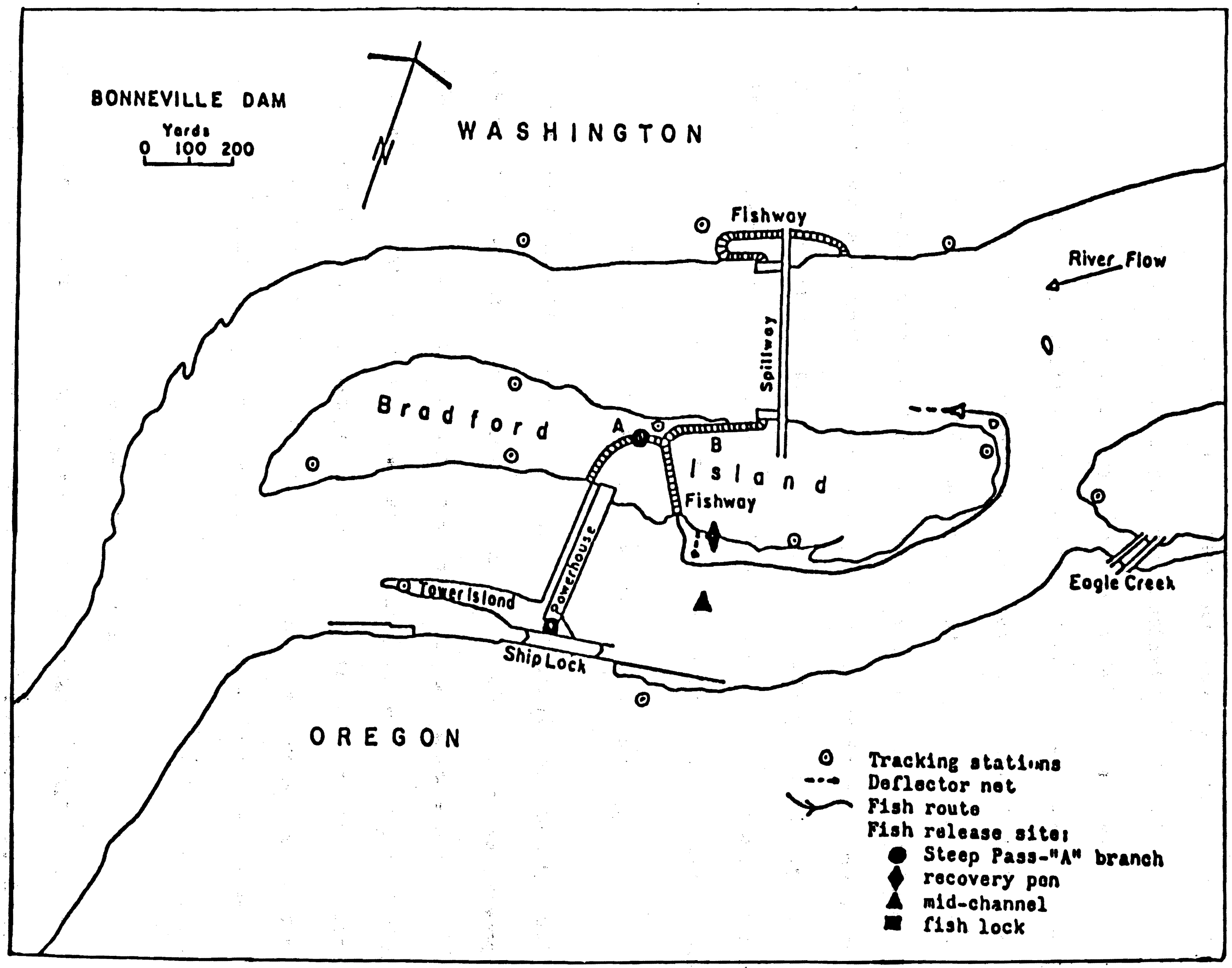

Figure 2.--The Bonneville study area showing the relative position of the deflector net and release sites above the dam. Also shown is the general route tagged fish took to swim around the net, along Bradford Island, to the spill.

There was no indication that fish were delayed by or fought the net. Tracks showed fish approaching the net, then moving away, but repeated movement into the net was not seen. Milling below the net was not extensive nor was there a tendency for tagged fish to drop back toward the powerhouse. Generally, fish moved along the net, around the end, then swam upstream to intercept the Bradford Island shore (Fig. 2). The result was that most fish followed the same route as observed in previous years--along the shore, around the tip of the island, and back to the spillway.

Swimming depth was recorded for one chinook salmon carrying a pressure tag as it swam around the deflector net (Fig. 3). Average swimming depth was 4.1 feet with a range from zero feet (surface) to about 10 feet. Figure 4 shows the entire recording of the fish's depth as it swam from the Bradford Island exit until it fell back over the spillway.

BEHAVIOR OF FISH RELEASED IN POWERHOUSE CHANNEL

The behavior of tagged fish released at three different locations in the powerhouse channel above the dam was monitored (Fig. 2). One release site was in the ODFW recovery pen just upstream from the deflector net. These releases were made to increase the number of potential fallbacks for the study of fallback location. A second release site was off the tip of the net in midchannel to simulate a longer net and the third was in the fish lock at the south end of the powerhouse to test displacement of fish to the Oregon shore.

Recovery Pen Releases

Of the 14 fish released from the recovery pen, 10 were tracked beyond the tip of the island during the study and 9 (90%) swam around the tip and

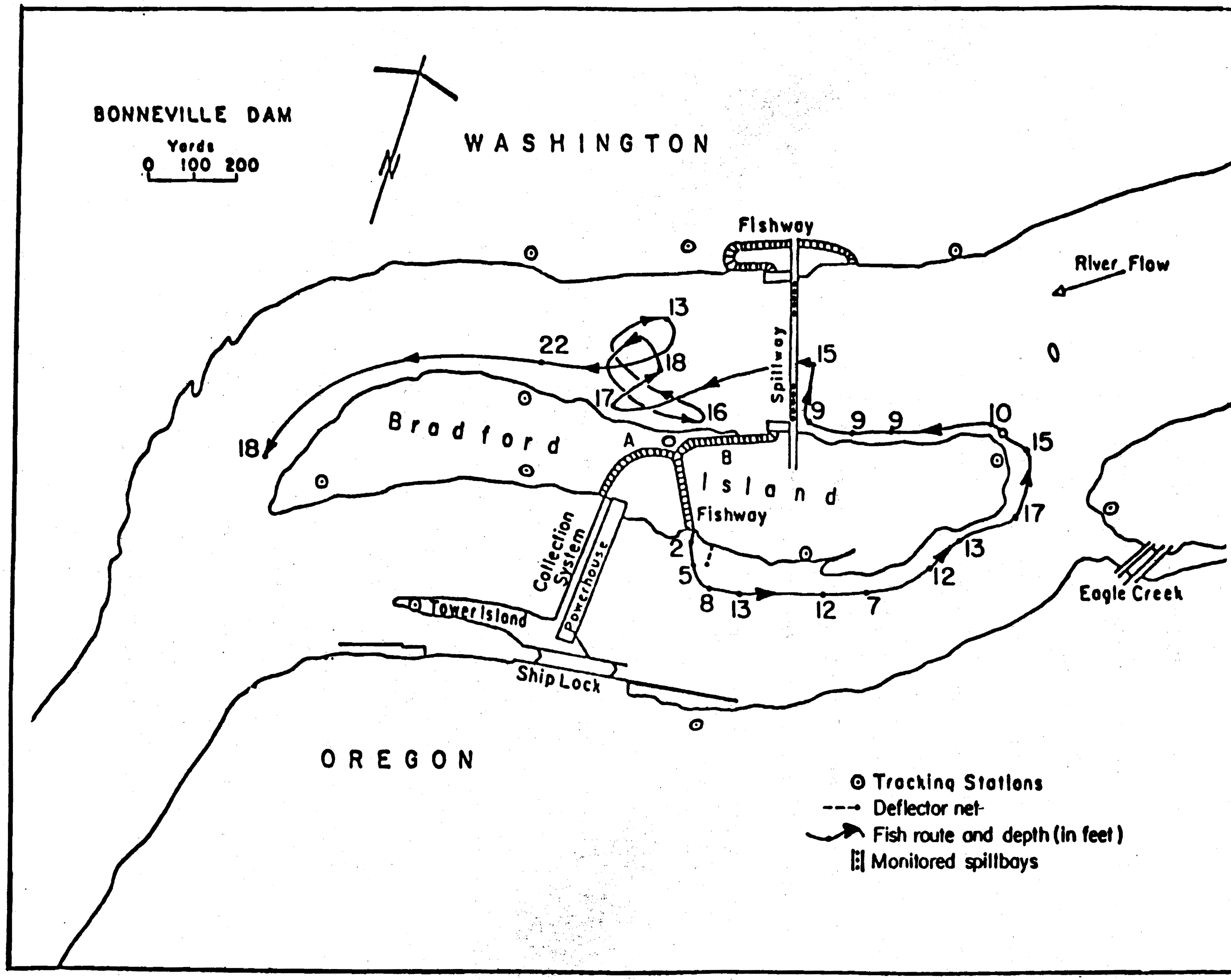

Figure 3.--Route taken by adult chinook salmon carrying a pressure-sensitive radio tag showing representative depths (in feet) at approximate locations. Monitored spillbays are indicated.

back to the spill. Four of these fell back. A single fish crossed to the Oregon shore above the mouth of Eagle Creek and went upstream. Most tagged fish released in the pen milled about before moving on.

Midchannel Releases

Data from forebay releases in midchannel above the powerhouse showed three out of four tagged fish swimming upstream without apparent orientation to Bradford Island. The other fish swam around the tip of the island to the spill but did not fall back.

Fish Lock Releases

Nine radio-tagged chinook salmon were released into the fish lock. The tag signal from one fish was lost before it exited the lock. The other eight fish were all tracked leaving the lock and went on upstream without going near the spillway. In fact, only one fish swam close to the tip of Bradford Island. The others went upstream close to the Oregon shore or near midchannel. None of these fish swam immediately in front of the powerhouse or made a move to go into the navigation lock when the upstream gates were open or to swim near the gates while they were closed.

FALLBACK THROUGH THE SPILLWAY

Each radio-tagged fish that swam into the spill area was closely observed for fallback so that the specific spillbay could be determined. Recording monitors were placed in bays 2, 3, 4, 5, and 6 at the north end of the spillway and in bays 13, 14, 15, 16, and 17 at the south end (Fig. 3). We found that fallback occurred across the entire spillway

(Table 3) with no definite pattern other than that fish from the Bradford Island fishway tended to fall back through spillbays at the south end of the spillway, and fish from the Washington fishway tended to fall back through spillbays at the north end of the spillway.

A higher rate of fallback (24%[2/]) was observed for fish exiting the Washington fishway than for those exiting the Bradford Island fishway (18%[2/]). Our previous studies indicated that fish from the Bradford Island fishway were more prone to fall back. Nothing was observed to explain the change. Total fallback was 19%[2/] for all 64 fish tracked above the dam. More multiple fallbacks occurred than have been observed before; one fish fell back three times and another fell back twice.

An excellent depth record of a fallback was obtained when a chinook salmon carrying a pressure-sensitive tag was carried over the spillway (Fig. 4). The track shows the fish approach the spill area, swim in close to the dam, then begin swimming across the spillway. The depth of travel increased to 27 feet (approximate depth of the bottom of the spillway gate at that time) and then the chart indicated zero feet (surface). The time and location correlated well with fixed tracking station plots of the tagged fish being taken at the time.

FISH BEHAVIOR BELOW BONNEVILLE DAM

A total of 28 chinook salmon were radio-tagged and released below Bonneville Dam. A high proportion of tagged fish (17, or 77%) ascended the

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2/ Includes multiple counts for fish which fell beck more than once.

Table 3.--Distribution of fallback through the spillway at Bonneville Dam during the 1976 study.

Fishway exited	Spillbays[a] 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Unk[b]	Total
Washington	1	1			1		1							1				5
Bradford Island					1			1		1		1			1	1	1	7
Total	1	1			2		1	1		1		1		1	1	1	1	12

[a]Bay 8, 9, and 11 fallback determined from active tracking.

[b]Specific spillbay unknown but at the south end.

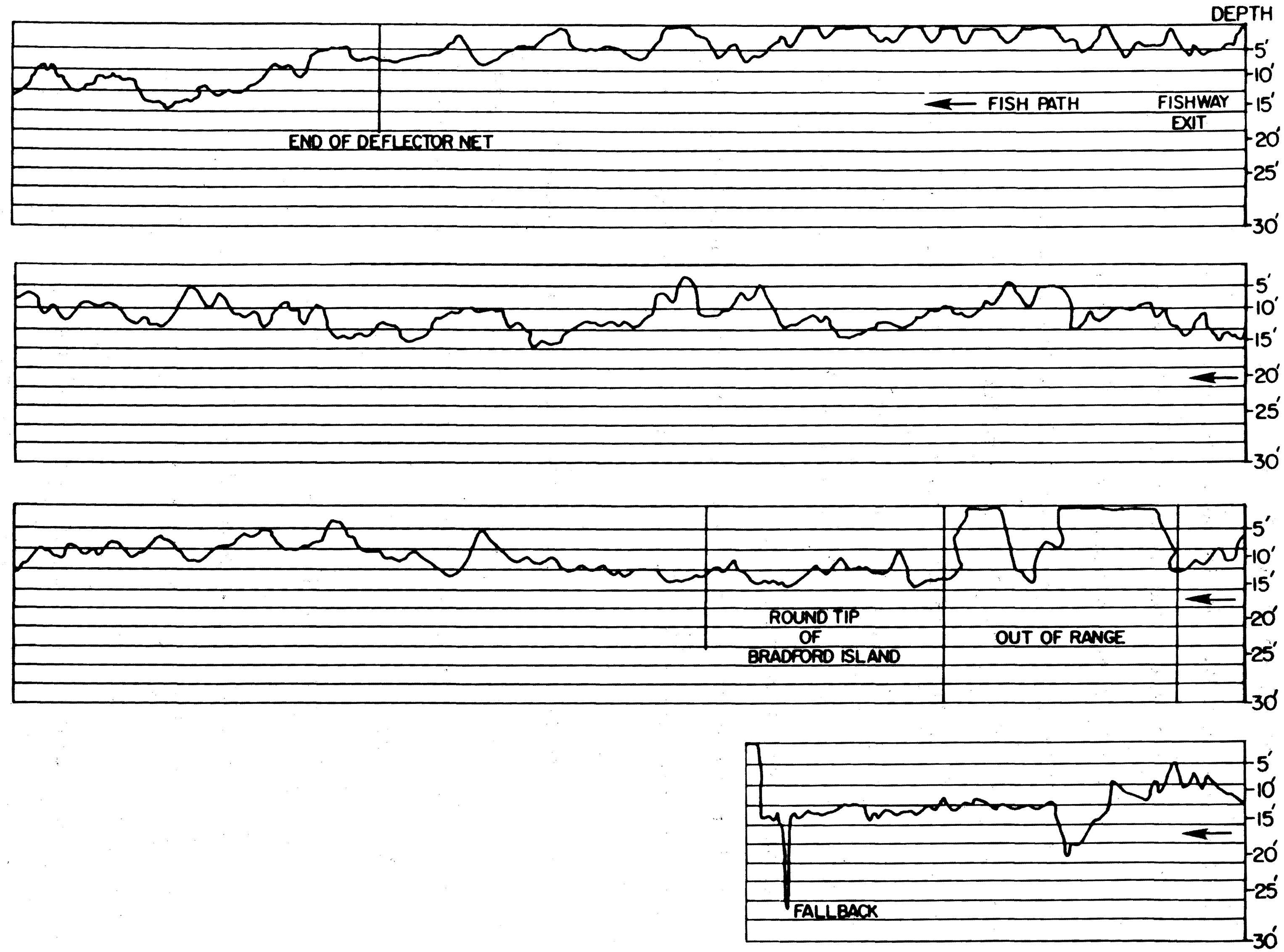

Figure 4.--Record of the swimming depth for a chinook salmon carrying a pressure-sensitive telemetry tag. The period from the time the fish exited the Bradford Island fishway until it fell back over the dam is shown. The figure reads from right to left.

Washington shore fishway, while only 53% of the regular run used that fishway during the same period. It is believed that the release site at Hamilton Slough may have been the reason for the higher north shore passage, but fish released at Dodson also used the Washington shore fishway to a greater degree--five out of seven fish. Even though many fish used the Washington fishway to cross the dam, a good number of fish spent part of their time in the powerhouse channel while below the dam. Of the 21 fish released at Hamilton Slough, 10 (48%) spent some time below the powerhouse. Five fish entered the "A" branch fishway and two of these stayed in and crossed over the dam.

Of the fish released at Dodson, five of the seven fish entered the powerhouse channel; one entered the "A" branch fishway and continued up to cross the dam.

Limited tracking below the powerhouse indicated the fish behaved much the same as in previous years. Because of insufficient data, it was impossible to correlate data from fish tracks obtained this year with data from the CofE tunnel studies.

RECOVERIES OF TAGGED FISH

Recoveries of tagged fish were widespread, with tags from 21 fish (31% of the fish tagged) subsequently recovered (Table 4). The Snake River system accounted for 50% of the recoveries.

One interesting recovery was made in Catherine Creek, a tributary to the Grande Ronde River, roughly 462 miles from Bonneville Dam. The tag came from a fallback that had reascended the dam, reached the spawning

Table 4.--Recoveries of radio-tagged chinook salmon released in the vicinity of Bonneville Dam, 1976.

Recovery location	Number of tag recoveries
Lower Granite Dam	2
Little Goose Dam	7
Little White Salmon Hatchery	4
Carson National Fish Hatchery	1
Sunnyside Dam (Yakima River)	1
Klickitat River	2
South prong of Catherine Creek	1
Columbia River (Bonneville forebay)	2
Longview, Washington	1
Total	21

grounds, spawned successfully, and died with the radio tag in its stomach and the flag tag still attached to its back.

GENERAL OBSERVATIONS

Of 67 chinook salmon tagged with radio tags, 19 had not been tracked upstream away from the dam by the end of the study: signals quit on three tags soon after release, nine fish were still below the dam (four out of the study area and five near the dam), four fish were still above the dam in the powerhouse channel, one fish remained in the "A" branch fishway, and two had shed their tags[3/]. We learned later that 8 of the 19 fish subsequently swam on upstream, and all but 3 of the 9 tagged fish that were below the dam at the end of the study are known to have crossed the dam.

Individual fish spent varying amounts of time below the dam before crossing and continuing their migration upstream; however, average times appeared to be similar to previous years. Dodson released fish, once they reached the study area, spent an average of 56 hours below the dam before crossing. This compared with the 60 hours average time spent by spring chinook salmon in 1974. The fish released at Hamilton Slough averaged 95 hours in the study area below the dam. This longer time is probably due to the proximity of the release site to the study area and the time needed for the fish to reorient after tagging and handling.

The average time spent by fish in traveling from the release site to the exit of a fishway compares closely to other years. Fish released at

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[3/] The shed tags were lost at the release site in the Bradford Island ladder. Modifications were made in our fish handling procedures at that site and no further instances of tags being shed were experienced.

Dodson spent an average of 4 days, 4 hours, and 18 minutes, while Hamilton Slough releases averaged 4 days, 3 hours, and 36 minutes. By comparison, spring chinook salmon in 1974 (see Part 3) spent an average of 4 days, 21 hours, and 36 minutes from time of release at Beacon Rock until they exited a fishway.

There were nine fallbacks from original crossings, and seven of these fish were known to have reascended the dam--one three times and another twice. Of the known reascents, four used the Bradford Island "B" branch fishway, two the Washington fishway, and one crossed without being tracked. One of the remaining two fallbacks was last located near Skamania Landing and the other approximately one-half mile below the spillway along the Washington shore.

It is of interest to note that four of the seven reascending fallback fish were subsequently recovered. The fish that fell back three times was recaptured in the adult separator at Lower Granite Dam and was reported in good condition. An Indian dip net at the Sunnyside Irrigation Diversion Dam caught the fish that fell back twice. Another fallback was subsequently reported as a dead spawned out female chinook salmon found in Catherine Creek. The fourth fish was recovered at the Little White Salmon Hatchery during spawning operations.

CONCLUSIONS

1. The deflector net, as installed, was not effective in changing the swimming pattern of migrating adult chinook salmon so as to reduce their exposure to the spillway and possible fallback over the spillway.

2. The net did not cause fish to delay or drop back to the powerhouse.

3. Releasing fish on or deflecting fish to the Oregon shore shows good potential for influencing migrating fish to swim directly upstream in midchannel or nearer the Oregon shore with less danger of fallback.

4. Fallback takes place over the width of the spillway and is not localized to any particular section.

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Part 6. LOSSES OF SPRING CHINOOK SALMON AND STEELHEAD TROUT BETWEEN BONNEVILLE AND JOHN DAY DAMS, 1977

By Kenneth L. Liscom, Lowell C. Stuehrenberg, and Gerald E. Monan

INTRODUCTION

Significant losses of adult salmonids between dams on the lower Columbia River have been occurring for several years (Junge and Carnegie 1976). In 1975, for example, only 50% of the 104,104 spring chinook salmon counted over Bonneville Dam were subsequently counted over The Dalles Dam, and only 78% of these fish were later counted over John Day Dam. The same year, 85,400 adult steelhead trout were counted over Bonneville Dam and only 67% of these fish were counted over The Dalles Dam. Of those counted over The Dalles Dam, only 57% of these were counted over John Day Dam. Some of these fish count discrepancies can be explained through estimates of gill-net catches, tributary turnoff, and overcount caused by fallback, However, losses occur over and above the estimates from known causes.

Many factors, singly or in combination, may be responsible for the differences in count. For example, unreported catch; underestimation of tributary turnoff; inflated counts at dams; and mortality due to stress from passing dams (Oregon Department of Fish and Wildlife 1977), gas bubble disease, or delay between dams are all potential contributors to the problem. These varied factors make the unaccountable loss problem difficult to solve.

This study was requested by the directors of Pacific Northwest state fishery agencies at their annual meeting in 1975. Its purpose was to investigate in depth the unaccountable loss problem in spring chinook salmon and to conduct a pilot study on losses of steelhead trout. The radio-tracking study conducted during the spring of 1977 had the following objectives: 1) to determine specific areas of the Columbia River between Bonneville and John Day Dams within which losses of adult spring chinook salmon occur, 2) to monitor major tributaries within the study area to update tributary turnoff estimates for spring chinook salmon, and 3) to determine the feasibility of radio tracking steelhead trout.

EXPERIMENTAL SITE AND EQUIPMENT

The study area encompassed the Columbia River from Bonneville Dam to John Day Dam, a distance of about 71 river miles (Fig. 1). Bonneville Dam, the first dam to be encountered by upstream migrating salmonids, is about 145 miles from the Pacific Ocean. Upstream from Bonneville Dam, approximately 47 miles, is The Dalles Dam, and 24 miles farther upstream is John Day Dam.

The pool behind Bonneville Dam "absorbs" a number of fish before they reach The Dalles Dam through a gill-net fishery; a sports fishery; and turnoff into five important tributaries--the Wind, Little White Salmon, White Salmon, Hood, and Klickitat Rivers.

Between The Dalles and John Day Dams there is an extensive gill-net fishery, a sports fishery, and one important tributary (the Deschutes River).

To localize problem zones, we divided the study area into five sections (Fig. 1): 1) Bonneville Dam, river mile 145 to river mile 161; 2) river mile 161 to 177; 3) river mile 177 to The Dalles Dam, river mile 192; 4) The Dalles Dam to river mile 209; and 5) river mile 209 to John Day Dam, river mile 216.

Radio Tag

The conventional radio tag is the small battery-powered radio transmitter operating on a carrier frequency of approximately 30 megahertz (MHz) used in the previous studies. The pulse rate and duration were adjusted to obtain a tag life of about 60 days. There were nine frequencies available for identifiable codes and two separate pulse rates, 1 pulse per 1.5 seconds and 1 pulse per second, enabling us to release 18 separately identifiable codes into the river at one time.

Tracking Receivers

Tracking receivers were of two types, a search receiver and a direction finder. Both units were carried in each vehicle used for tag surveillance.

The search receiver was in operation as the vehicle traveled along the road, constantly searching for radio-tag signals. When the vehicle approached the vicinity of a tag, the signal received by the antenna was amplified and converted to an audible tone by the search receiver while at the same time a flashing light indicated which frequency was being received. The operator then switched to the direction finder receiver to locate the position of the fish.

Once the direction finder receiver was in operation (amplifying the tag signal and producing an audible tone), the operator could listen to any one of the nine frequencies at any time, locate the position of any fish in the vicinity, and record it. An improved receiver was used in this study. This receiver is capable of filtering out more extraneous noise than other equipment we have used and has better fine tuning for more precise direction finding.

Monitors

Monitors were employed at the border of each study section, at fishway exits, and at the counting stations.

The monitors at the section borders in the main stem Columbia River recorded tagged fish movement at each check point. The monitors consisted of an upstream and downstream antenna, a search receiver, a microprocessor, and a printer. The two antennas allowed us to detect upstream and downstream movement, while the search receiver separated the tag signals into the correct frequency channels. The microprocessor controlled the sampling period, stored the data, and controlled the printout of those data.

Monitor operation began with the microprocessor sequentially checking each of the nine frequencies. On each frequency channel pulses were counted for 4.5 seconds on the downstream antenna and 4.5 seconds on the upstream antenna. The count was determined by the pulse rates of tags present during the sampling period; for example, one slow tag resulted in two counts, one fast tag in three counts, and one fast and one slow tag in five counts. The count received was stored in the microprocessor until all nine frequencies had been checked. The data were then compared to the previous scan. When a change in count number indicated a change in fish status, the unit printed the month, day, hour, minute, channel number, pulse rate number, site location, and antenna.

River section monitors were powered by two wet-cell car batteries. At remote sites the batteries were changed daily. Where AC power was available, trickle chargers eliminated the need for battery changes.

Fishway exit monitors were modified telemetry units as used in previous radio-tracking studies. These monitors were modified to print, on chart recorders, the pulse rate and frequency of each radio-tagged fish exiting the fishway. Passage time was determined from time marks on the tape. This was especially important information for the 16 hours of each day when no tracking personnel were on duty to record the information. When no tags were in the area, the tape advanced once every 6 minutes, and a time mark was imprinted. When a tagged fish swam into the vicinity of a monitor, the signal triggered the monitoring unit to mark each pulse and a corresponding time mark on the tape until the fish went out of receiving range. Tapes were read each morning before tracking crews began their surveillance to determine which tagged fish, if any, had crossed a dam during the absence of the trackers. Pulse rate was determined by noting the distance between pulse marks, and each frequency appeared on a different line on the chart.

Counting station monitors were battery-powered alert receivers placed in the counting house with an antenna located in the fishway pool just below the counting window or board. When a radio-tagged fish came within range of the antenna, an audible "beep" alerted the counter that a radio-tagged fish was about to pass.

Antennas

Four types of antennas were used to pick up tag signals for the various receiving equipment: whips, vertically polarized beams, underwater dipole-types, and directional loops.

Omnidirectional whip antennas, similar to those used for CB communication equipment, were used with the search receivers. In addition to search receivers, mobile units carried directional tracking receivers and 18" diameter directional loop antennas which could be rotated to locate a tagged fish.

Vertically polarized, three-element beam antennas tuned for maximum forward gain at 30.21 MHz were used with the monitors on the main river study sections. Two antennas were used at each monitor site and were mounted on 24-foot steel towers approximately 150 feet apart and parallel to the river. One antenna was beamed 45° downstream and one 45° upstream.

Fishway exit monitors and the counting station alert receivers received radio-tag signals from an underwater dipole-type antenna. These antennas were resonant underwater at 30.21 MHz and had a tighter range than the other antennas used.

GENERAL EXPERIMENTAL PLAN

The general experimental plan was to tag and track as many spring chinook salmon and steelhead trout as possible from 17 April through 10 June. Although chinook salmon studies were the prime objective, steelhead trout comprised approximately 25% of the total number of fish tagged. All fish were tagged at and released below Bonneville Dam. Electronic surveillance was the principal method of monitoring the progress of radio-tagged fish as they swam through the study area. Manned mobile tracking units followed fish at the dams, within the prescribed river sections, and into the tributaries. Unmanned monitors located at the boundary of each study section (Fig. 1) indicated passage through those areas and helped to localize fish losses.

EXPERIMENTAL PROCEDURES

Trapping and Tagging

The fish to be used in the study were trapped and tagged in the same manner as described in earlier studies.

Radio-tracking check points locations from Bonneville Dam to John Day Dam for unaccountable loss study SPRING, 1977

Check Station	Location	
1	Cook	R. mile 161
2	Memaloose Is.	R. mile 177
3	The Dalles Dam	R. mile 192
4	Biggs	R. mile 209
5	John Day Dam	R. mile 216

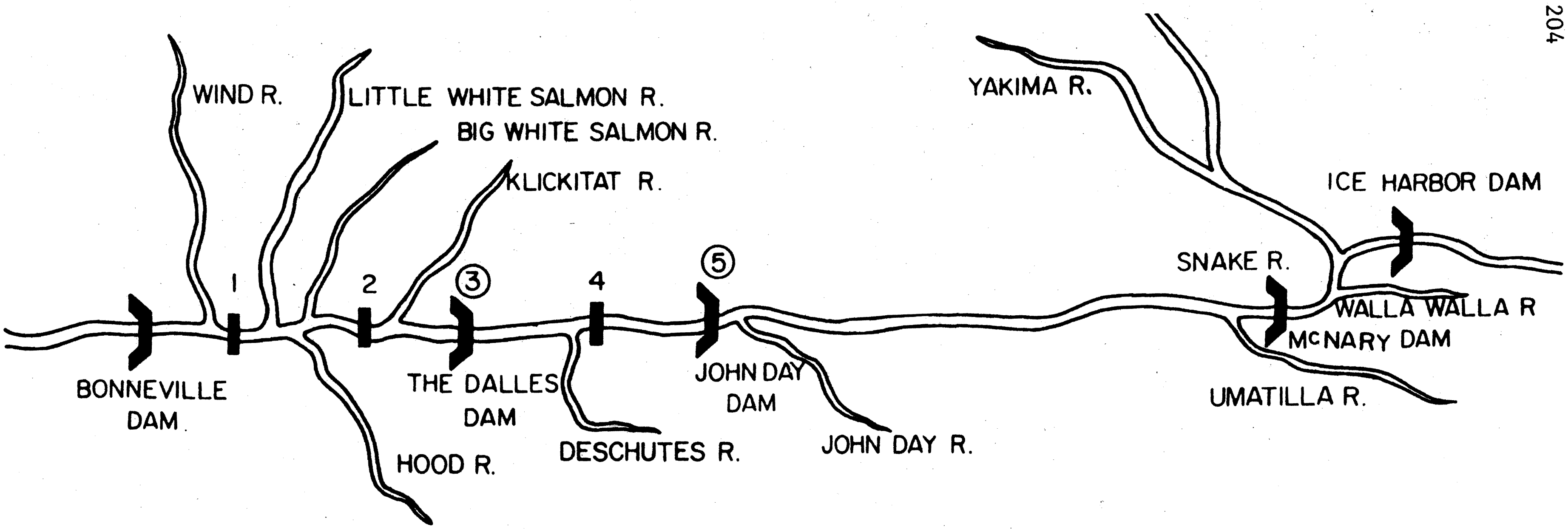

Figure 1.--The radio-tracking study area showing tributaries and river section boundaries.

After tagging, fish were released directly from the fish hauling truck into the Columbia River. Our first releases were made at Dodson, Oregon, approximately 4 miles below the dam. Most releases, however, were made at Skamania Landing about 6 miles downriver on the Washington side. An alternate release site at Hamilton Slough (on the Washington side of the river about 0.9 mile downstream from the powerhouse) was used when the river flow was so low fish could not be released safely at Skamania Landing or Dodson.

A total of 92 chinook salmon and 42 steelhead trout were tagged and released below Bonneville Dam, and we attempted to have at least 18 separately identifiable tagged fish in the first 9 miles of the study area at all times. New releases were not made until a fish with a particular code had crossed Bonneville Dam and had progressed upriver about 9 miles (to the vicinity of Wind River). Data on fish tagged and released are shown in Table 1.

Surveillance of Tagged Fish

As each fish was tagged, a data punch card was created. The card was kept current with information gathered by manned mobile tracking units and unmanned electronic monitoring devices. Radio-tagged fish were monitored intermittently until they reached Bonneville Dam. Once the tagged fish were in the immediate vicinity of a dam, their behavior was monitored as closely as possible. Special attention was given to fish exiting the Bradford Island fishway at Bonneville Dam to observe their movement near Bradford Island. Mobile units monitored the whereabouts of the fish from 0700 to 1600 hours every day throughout the time they were in the study area.

Table 1.--Tagging data for chinook salmon and steelhead trout used in the 1977 unaccountable loss study between Bonneville and John Day Dams.

Date released	Location	Flag color	Radio tag code	Fish length (cm)	Fish weight (kg)	Fish condition[a]	Species
April 17	Skamania Landing	Blue-orange	F7BS	80	6.5	1	Chinook
17	Skamania Landing	Blue-orange	H7AF	71	4.5	1	Chinook
17	Skamania Landing	Blue-orange	D7KS	71	5.0	1	Chinook
17	Skamania Landing	Blue-orange	D7BF	78	5.7	1	Chinook
17	Skamania Landing	Blue-orange	K7MF	83	8.0	1	Chinook
17	Skamania Landing	Blue-orange	L7JS	89	8.6	1	Chinook
17	Skamania Landing	Blue-orange	I7NF	78	5.4	1	Chinook
17	Skamania Landing	Blue-orange	E7AS	72	4.5	1	Chinook
April 17	Dodson	Blue-orange	I7LS	70	4.2	1	Chinook
17	Dodson	Blue-orange	H7IS	72	5.4	2	Chinook
17	Dodson	Blue-orange	F7DF	71	4.5	1	Chinook
17	Dodson	Blue-orange	G7MS	78	5.9	1	Chinook
17	Dodson	Blue-orange	G7KF	67	3.6	1	Chinook
17	Dodson	Blue-orange	E7IF	78	5.2	1	Chinook
17	Dodson	Blue-orange	J7MS	72	5.0	1	Chinook
17	Dodson	Blue-orange	K7LS	71	4.8	1	Chinook
17	Dodson	Blue-orange	J7IF	100	15.0	1	Chinook
April 18	Dodson	Blue-orange	L7HF	79	6.1	1	Chinook
20	Skamania Landing	Pink-white	J7GS	74	5.4	1	Chinook
20	Skamania Landing	Pink-white	G7GS	72	4.5	1	Chinook
20	Skamania Landing	Pink-orange	F7KS	83	7.4	1	Chinook
20	Skamania Landing	Orange-green	G7MF	76	5.9	1	Chinook
21	Dodson	White-blue	D7BS	71	4.8	1	Chinook
21	Dodson	Green-white	E7CS	75	5.7	1	Chinook
21	Dodson	Pink-blue	H7CS	72	4.7	1	Chinook
21	Dodson	Blue-yellow	E7NF	84	8.2	1	Chinook
21	Dodson	Pink-green	F7KF	77	6.5	1	Chinook
22	Skamania Landing	Green-blue	K7FS	76	6.1	1	Chinook
22	Skamania Landing	Yellow-orange	K7AF	73	5.2	1	Chinook
22	Skamania Landing	White-yellow	I7KF	72	4.8	1	Chinook
23	Skamania Landing	Yellow-green	L7IS	66	4.2	1	Chinook
23	Skamania Landing	Green-white	H7FF	72	5.2	1	Chinook
25	Skamania Landing	Pink-white	E7ES	85	7.8	1	Chinook
25	Skamania Landing	Pink-orange	G7KS	90	8.6	1	Chinook
25	Skamania Landing	Green-white	I7CS	75	5.8	1	Chinook
25	Skamania Landing	Pink-blue	J7IS	78	5.9	1	Chinook
25	Skamania Landing	Yellow-green	H7MF	89	9.4	1	Chinook
26	Skamania Landing	Orange-green	F7FS	72	4.7	1	Chinook
26	Skamania Landing	Pink-green	G7DF	66	4.0	1	Chinook
26	Skamania Landing	White-yellow	K7NS	73	5.3	1	Chinook
27	Skamania Landing	Pink-blue	D7FF	70	4.3	1	Chinook
27	Skamania Landing	Blue-yellow	H7ES	77	5.2	1	Chinook
27	Skamania Landing	Green-blue	K7NF	69	4.1	2	Chinook

Table 1.--Continued.

Date released		Location	Flag color	Radio tag code	Fish length (cm)	Fish weight (kg)	Fish condition[a]	Species
April	27	Skamania Landing	Yellow-orange	L7KS	88	10.2	1	Chinook
	28	Skamania Landing	Pink-white	I7BF	77	6.1	1	Chinook
	28	Skamania Landing	Pink-orange	J7HS	70	3.9	1	Steelhead
	28	Skamania Landing	Green-white	F7LF	76	5.2	2	Chinook
	28	Skamania Landing	Green-blue	J7FF	75	5.0	1	Chinook
	29	Skamania Landing	Pink-green	E7AF	75	6.0	1	Chinook
	29	Skamania Landing	White-blue	H7KS	76	6.2	1	Chinook
	29	Skamania Landing	Blue-yellow	L7MF	71	5.3	2	Chinook
	30	Skamania Landing	Orange-green	D7JS	79	6.4	2	Chinook
	30	Skamania Landing	White-yellow	E7KS	80	7.0	1	Chinook
	30	Skamania Landing	Green-white	G7BS	72	5.0	1	Chinook
	30	Skamania Landing	Yellow-orange	K7KS	75	5.0	1	Chinook
	30	Skamania Landing	Pink-orange	K7HF	67	5.1	1	Chinook
	30	Skamania Landing	Green-blue	I7MS	71	5.4	2	Chinook
May	2	Skamania Landing	White-blue	F7LS	67	4.7	1	Chinook
	2	Skamania Landing	Pink-white	G7LF	70	4.4	1	Chinook
	2	Skamania Landing	Pink-green	H7JF	72	5.9	1	Chinook
	3	Skamania Landing	Pink-blue	G7CS	68	3.8	1	Steelhead
	3	Skamania Landing	Yellow-orange	H7NS	66	3.2	1	Steelhead
	4	Skamania Landing	White-blue	E7GF	82	7.0	1	Chinook
	4	Skamania Landing	Blue-yellow	I7IF	68	4.4	1	Chinook
	4	Skamania Landing	Green-white	L7ZS	68	3.6	1	Steelhead
	5	Skamania Landing	Yellow-green	D7KF	75	6.0	1	Chinook
	6	Skamania Landing	Pink-white	F7GS	76	6.1	1	Chinook
	6	Skamania Landing	Pink-green	J7JS	67	3.9	2	Chinook
	7	Skamania Landing	White-blue	F7EF	74	5.7	1	Chinook
	7	Skamania Landing	Green-white	G7AF	80	6.1	1	Chinook
	7	Skamania Landing	Blue-yellow	H7GF	71	3.9	1	Steelhead
	7	Skamania Landing	Yellow-orange	I7JS	71	3.6	1	Steelhead
	8	Skamania Landing	Pink-orange	D7CS	75	4.8	2	Steelhead
	8	Skamania Landing	Orange-green	E7BF	67	3.4	1	Steelhead
	8	Skamania Landing	Green-blue	I7DF	75	5.4	2	Chinook
	8	Skamania Landing	Pink-white	L7NS	80	5.3	1	Steelhead
	9	Hamilton Slough	Pink-orange	H7GS	89	10.0	1	Chinook
	9	Hamilton Slough	Green-white	K7HS	72	5.0	2	Chinook
	9	Hamilton Slough	White-yellow	K7FF	75	4.7	1	Steelhead
	9	Hamilton Slough	Yellow-green	L7XF	72	5.3	1	Chinook
	13	Hamilton Slough	Yellow-green	F7CF	63	3.8	2	Chinook
	13	Hamilton Slough	Green-white	F7AS	72	5.1	1	Chinook
	13	Hamilton Slough	Pink-green	J7EF	68	4.3	2	Chinook
	13	Hamilton Slough	White-blue	J7LS	75	5.7	1	Chinook
	13	Hamilton Slough	Pink-blue	E7NS	72	3.7	1	Steelhead
	15	Hamilton Slough	Green-white	H7AS	71	5.2	1	Chinook
	16	Hamilton Slough	Pink-white	D7CF	68	3.6	1	Steelhead

Table 1.--Continued

Date released		Location	Flag color	Radio tag code	Fish length (cm)	Fish weight (kg)	Fish condition[a]	Species
May	16	Hamilton Slough	Pink-orange	E7MF	68	3.6	1	Steelhead
	16	Hamilton Slough	Orange-green	H7DF	69	3.5	1	Steelhead
	16	Hamilton Slough	Pink-blue	I7MF	69	3.5	1	Steelhead
	16	Hamilton Slough	Blue-yellow	K7CS	69	3.8	1	Steelhead
	16	Hamilton Slough	Green-blue	L7YF	68	3.4	1	Steelhead
	17	Hamilton Slough	White-blue	G7FF	74	4.4	1	Steelhead
	17	Hamilton Slough	Yellow-green	G7ES	69	3.6	1	Steelhead
	17	Hamilton Slough	Pink-green	I7ES	66	3.2	1	Steelhead
	17	Hamilton Slough	Green-blue	L7CS	76	6.1	1	Chinook
	18	Skamania Landing	Orange-green	H7JS	77	6.4	1	Chinook
	19	Skamania Landing	Green-white	J7FS	71	5.1	1	Chinook
	19	Skamania Landing	Pink-green	L7MS	77	7.0	1	Chinook
	20	Skamania Landing	White-blue	J7CF	68	3.7	1	Chinook
	21	Skamania Landing	Pink-blue	F7ES	79	5.1	1	Steelhead
	21	Skamania Landing	White-blue	I7AS	72	4.8	1	Chinook
	22	Skamania Landing	Orange-green	I7FF	68	3.2	1	Steelhead
	22	Skamania Landing	Pink-green	K7ES	69	4.7	1	Chinook
	23	Skamania Landing	Pink-white	H7HS	71	3.3	1	Steelhead
	23	Skamania Landing	Pink-orange	G7JF	69	4.0	2	Steelhead
	23	Skamania Landing	Pink-blue	H7KF	75	4.2	1	Steelhead
	24	Skamania Landing	White-yellow	L7FS	70	4.2	1	Steelhead
	24	Skamania Landing	White-blue	E7LS	68	3.6	1	Steelhead
	24	Skamania Landing	Yellow-orange	J7BF	68	3.6	1	Steelhead
	24	Skamania Landing	Blue-yellow	J7BS	71	4.1	1	Steelhead
	25	Skamania Landing	Orange-green	F7HF	72	3.6	1	Steelhead
	25	Skamania Landing	Pink-blue	K7GS	73	3.8	1	Steelhead
	27	Skamania Landing	Green-white	D7AF	70	5.0	1	Chinook
	27	Skamania Landing	Blue-yellow	G7LS	66	4.5	1	Chinook
	27	Skamania Landing	Green-blue	G7BF	67	3.6	1	Steelhead
	27	Skamania Landing	Yellow-green	I7FS	78	6.4	1	Chinook
	29	Skamania Landing	Pink-green	H7MS	68	4.1	1	Chinook
	29	Skamania Landing	White-blue	H7NF	71	5.2	1	Chinook
	29	Skamania Landing	Yellow-orange	I7HF	71	3.4	1	Steelhead
	30	Skamania Landing	Pink-white	D7HS	68	4.1	1	Chinook
	30	Skamania Landing	Blue-yellow	F7JF	75	4.8	1	Steelhead
	30	Skamania Landing	Orange-green	K7JF	74	6.1	1	Chinook
	30	Skamania Landing	Pink-blue	L7DF	67	3.6	1	Steelhead
	31	Skamania Landing	Pink-orange	K7DS	71	5.1	1	Chinook
	31	Skamania Landing	Yellow-green	E7DS	72	4.9	1	Steelhead
	31	Skamania Landing	Pink-green	F7CS	70	4.1	1	Steelhead
June	1	Skamania Landing	Pink-green	G7IS	72	4.1	1	Steelhead
	1	Skamania Landing	White-blue	L7LS	73	4.5	1	Steelhead
	2	Skamania Landing	Blue-yellow	I7HS	69	3.4	1	Steelhead

Table 1.--Continued.

Date released	Location	Flag color	Radio tag code	Fish length (cm)	Fish weight (kg)	Fish condition[a]	Species
June 2	Skamania Landing	White-yellow	H7DS	75	4.8	1	Steelhead
3	Skamania Landing	White-blue	D7EF	71	5.3	1	Chinook
3	Skamania Landing	Pink-white	F7NF	71	5.9	1	Steelhead
3	Skamania Landing	Green-white	L7KF	71	5.0	1	Chinook

[a]Condition code (based on visual examination): 1 = Fish in good to excellent condition.
2 = Fish in fair to bad condition - scars, wounds, dark, etc.

Between the dams, mobile units traveled the highways beside the main-stem Columbia River recording on maps the day-by-day location and progress of individual fish. These mobile units worked in a clockwise pattern within their assigned area. One mobile unit began monitoring tags each morning at Bonneville Dam, traveled upriver along the Washington shore until it reached The Dalles Dam, and returned to Bonneville Dam on the Oregon side. At the same time, another mobile unit left The Dalles Dam, traveling down the Oregon shore to Bonneville Dam and then back to The Dalles Dam on the Washington side. This same procedure was used to monitor the river between The Dalles and John Day Dams.

Each mobile unit carried data forms and plotting maps of the section to be surveyed. Personnel recorded the position, time, and date of each tag located. A record was kept for each round trip regardless of whether signals from a tag had been heard before or not. Data collected were turned in at the end of the shift and each mobile driver, in addition to using the tracking maps, wrote out a daily summary of the search results and observations. These data were relayed daily to a central location at Bonneville Dam where the position of each fish was plotted on a master chart of the study area.

A separate mobile unit monitored the five tributaries between Bonneville and The Dalles Dams. The Deschutes River was covered by mobile units during their surveillance runs between The Dalles and John Day Dams.

OBSERVATIONS OF RADIO-TAGGED CHINOOK SALMON AND STEELHEAD TROUT

Our chief objective was to observe the disposition and behavior of spring chinook salmon and steelhead trout moving through the study area and to look for changes in behavior which could be contributing to unaccountable losses.

Chinook Salmon

Disposition of Tagged Fish Between Dams

Of the 92 chinook salmon released carrying radio tags, 90 crossed over Bonneville Dam. The two fish not ascending the fishways by the end of the study had been released shortly before the last day of tagging and were still between the point of release and the dam. Tagged chinook salmon that ascended Bonneville, The Dalles, and John Day Dams did so proportionally to untagged chinook salmon (Table 2).

Table 3 summarizes the disposition of radio-tagged chinook salmon within the study area at the end of the study. Between Bonneville and The Dalles Dam, the gill-net fishery had taken 14% of the tagged fish, tributary turnoff accounted for 7%, 2% had fallen back over Bonneville Dam, and 3% were still actively swimming in the main stem between the dams. The remaining 73% had crossed The Dalles Dam. Of the 66 radio-tagged chinook salmon that had crossed The Dalles Dam, 3% had gone into the Deschutes River, 3% had been taken in gill nets, 2% were still actively swimming in the main stem between the dams, and 92% had crossed John Day Dam.

Travel Time

Radio-tagged chinook salmon migration rates were steady at about 1.0 mi/h through the unobstructed sections of the Columbia River, but delay was noted in the vicinity of dams--at Bonneville Dam an average of 48 hours; The Dalles Dam, 15 hours; and John Day Dam, 45 hours. Additional

Table 2.--Comparing the proportion of radio-tagged to untagged spring chinook salmon using the Washington shore and Oregon shore fishways at Bonneville, The Dalles, and John Day Dams in 1977[a].

Dam	Washington fishway		Oregon fishway	
	Tagged (%)	Untagged (%)	Tagged (%)	Untagged (%)
Bonneville	10	12	89	88
The Dalles	5	7	95	93
John Day	34	32	66	68

[a]One radio-tagged chinook salmon was known to have passed over Bonneville Dam by way of the navigation lock.

Table 3.--Disposition of radio-tagged spring chinook salmon within the study area in 1977. (Ninety-two fish were tagged and released below Bonneville Dam.)

Fish location	Number of fish	
Never crossed Bonneville Dam[a]	2	--
Crossed Bonneville Dam	90	--
Ascended tributaries:		
Wind River		4
Little White Salmon River		2
Indian Fishery		13
Fallbacks[b]		2
Between Bonneville and The Dalles Dams[a]		3
Crossed The Dalles Dam	66	--
Ascended the Deschutes River		2
Indian Fishery		2
Between The Dalles and John Day Dams[a]		1
Crossed John Day Dam	61	--

[a]Still active and being tracked when study was terminated.

[b]Neither fish reascended the dam--one went through turbines and was killed, and the other was still active below Bonneville Dam.

delay at the dams was noted in 11 fish that had incurred severe injuries prior to tagging. At Bonneville Dam, injured fish spent an average of 57 hours; The Dalles Dam, 38 hours; and at John Day Dam, 83 hours. While the average travel rate for injured fish of 0.88 mi/h between dams was not statistically slower than the overall average, a significant delay could result if the slower rate coupled with the increased delay at dams continued as they progressed upstream.

Ten of the injured fish crossed John Day Dam. The eleventh injured fish reached John Day Dam where it remained for 18 days. This fish was subsequently captured in a steep-pass fishway 40 miles up the Deschutes River.

Overshoot

Every tagged chinook salmon tracked into a tributary had swum beyond the tributary by at least 5 miles before returning to enter. The average "overshoot" was 12 miles, and fish took from 6 to 38 days after initially approaching their tributary stream to enter it. Some fish were observed entering more than one tributary, although none entered its final stream more than once. One tagged chinook salmon ascended The Dalles Dam fishway to the counting board, descended the fishway, exited, swam downstream, and entered the Wind River 27 days after crossing Bonneville Dam. A second fish spent 38 days off Drano Lake (at the mouth of the Little White Salmon River) before entering that system.

Behavior of two tagged chinook salmon that crossed Bonneville Dam, swam a considerable distance upstream, and then returned to the dam indicated an overshoot. Both fish had been fin clipped before our study--one, tag code GAF-right pelvic and the other, tag code IAS-adipose. Extensive inquiry produced no clue as to the origin of these two fish. The fish carrying tag code GAF was radio-tagged 7 May; crossed the dam 8 May; reached River Mile 156 (just upstream from the Wind River) on 9 May; and returned to Bonneville Dam, just upstream of the powerhouse intake, on 10 May. It swam about near the powerhouse until 7 June (a period of 28 days). During this time it was visually observed on one occasion. On 7 June, spillway gates in bays 4, 5, 15, and 16 were opened at 0845 hours and each was spilling 22,000 ft^3/s. At 0930 hours spill at each gate dropped to about 10,000 ft^3/s. Between 0900 and 1000 hours, the fish swam upstream, out of the powerhouse channel, around Bradford Island, and fell back over the spillway through bay 15 or 16. The fish held for some time by a large rock next to Bradford Island before swimming on downstream and remaining there through termination of tracking. The salmon carrying tag code IAS was radio-tagged 21 May; crossed Bonneville Dam 22 May; reached river mile 177 (the Little White Salmon River) on 23 May; and was back at the dam, just upstream from the powerhouse, 24 May. The signal from IAS abruptly stopped on 27 May. Given the fish's location when the signal stopped, the fish probably fell through a turbine.

Steelhead Trout

Disposition of Tagged Fish Between Dams

There were 42 steelhead trout tagged and released below Bonneville Dam between 28 April and 8 June. Thirty of these fish crossed Bonneville Dam during the study, and tag returns showed the subsequent passage of five more, giving a total of 35. As with the chinook salmon, passage of radio-tagged steelhead trout through the fishways at Bonneville and The Dalles Dams was proportional to untagged fish (Table 4). At John Day Dam relative passage through the fishways did not appear to be as proportional with steelhead trout as it was with chinook salmon, but this was probably because of the small numbers of steelhead trout involved. Of the seven tagged fish remaining below Bonneville Dam at the study's end, one had been caught by a sport fisherman, three had at least approached the dam before their signals were lost, one was being monitored about 2 miles below Skamania Landing, and two were being monitored in the vicinity of Bonneville Dam.

Table 5 shows the final disposition of radio-tagged steelhead trout within the study area. Between Bonneville and The Dalles Dams, tributaries had accounted for 34% of the tagged steelhead trout, while 3% had been taken by gill nets and 3% were still actively swimming in the river. The other 60% had crossed The Dalles Dam.

Of the 21 tagged steelhead trout that had crossed The Dalles Dam when the study ended, 5% had gone into the Deschutes River, 14% were still actively swimming in the main stem between the dams, and 81% had crossed John Day Dam.

Travel Time

Steelhead trout took slightly longer to negotiate the Columbia River between dams than did chinook salmon--not necessarily swimming more slowly, but tending to wander more. The upstream movement for steelhead trout between Bonneville and John Day Dams averaged 0.8 mi/h. This movement rate

Table 4.--Comparing the proportion of radio-tagged to untagged steelhead trout using the Washington shore and Oregon shore fishways at Bonneville, The Dalles, and John Day Dams in 1977.

Dam	Washington fishway		Oregon fishway	
	Tagged (%)	Untagged (%)	Tagged (%)	Untagged (%)
Bonneville	25	28	75	72
The Dalles	22	16	78	84
John Day	47	29	53	71

Table 5.--Disposition of radio-tagged steelhead trout within the study area in 1977 (forty-two fish were tagged and released below Bonneville Dam).

Fish location	Number of fish	
Never crossed Bonneville	7[a]	--
Crossed Bonneville Dam	35	--
Ascended tributaries:		
Wind River		3
Hood River		4
Klickitat River		5
Indian fishery		1
Between Bonneville and The Dalles Dams		1[b]
Crossed The Dalles Dam	21	--
Ascended the Deschutes River		1
Between The Dalles and John Day Dams		3[b]
Crossed John Day Dam	17	--

[a]One caught below by sport fisherman; three actively being tracked when study terminated; and three tracked in area, but went downstream and did not return prior to end of study.

[b]Still active and being tracked when the study was terminated.

excludes time fish spent in the proximity of the dams. Tagged steelhead trout spent, on the average, 59 hours in the vicinity of Bonneville Dam, 19 hours near The Dalles Dam, and 63 hours near John Day Dam.

Only three fish were tagged that had incurred severe injuries prior to tagging. One of these fish had been monitored below Bonneville Dam for 27 days when the study ended, but it was caught by a sport fisherman in the Klickitat River on 21 July. The other two fish showed no aberrant behavior while being tracked.

Overshoot

Steelhead trout also "overshot" the tributary they eventually entered to stay. A total of 10 fish were tracked into tributaries; seven strayed beyond their eventual destination, and three proceeded directly into the tributary of their choice. The average distance steelhead trout overshot their intended tributary was 15 miles, and it took them from 3 to 23 days to return and enter. In one instance, a steelhead swam 25 miles beyond the Wind River before returning and ascending that stream. No steelhead trout returned to Bonneville Dam after leaving the immediate vicinity.

RECOVERIES OF TAGGED CHINOOK SALMON AND STEELHEAD TROUT

Tags were returned from fish caught in several areas along the Columbia, Snake, and Salmon Rivers. Of the 69 tags returned, 27 (39%) were from fish taken between Bonneville and John Day Dams. Tags returned represented 57% of the chinook salmon and 40% of the steelhead trout tagged. Table 6 summarizes the tag return data. It is interesting to note that almost all steelhead trout recoveries above the study area were in the Ringold Springs area above Pasco, Washington.

Table 6.--Summary of tag recoveries from radio-tagged chinook salmon and steelhead trout in 1977.

Location of recovery	Chinook salmon	Steelhead trout
Indian fishery:		
Between Bonneville Dam and The Dalles Dam	11	--
Klickitat River	--	1
Sport fishery:		
Columbia River below Bonneville Dam	--	1
Wind River	1	2
Hood River	--	1
Klickitat River	--	2
Deschutes River	2	1
Yakima River	1	--
Columbia River at Ringold	--	7
Icicle Creek	1	--
Camas Creek (middle fork Salmon River)	1	--
Columbia River at Vantage, Washington	--	1
Hatcheries:		
Carson	3	--
Little White	2	--
Ringold	--	1
Rapid River (Idaho)	1	--
Little Goose Dam:		
Adult trap	28	--
Unknown[a]	1	--
Total	52	17

[a]Returned from an area upstream from the study area, but specific location not known.

DISCUSSION

Observations in the past showed unaccountable losses of spring chinook salmon to be related to river flow: low flow correlated to small loss, and high flow to large loss (Part 1 of this report and Junge and Carnegie 1976). Results of this year's study further substantiated this relationship. In 1977, the flows in the Columbia River were very low, and the unaccountable loss of adult spring chinook was very small. At Bonneville Dam, the average daily total flow during the study period (17 April through 10 June 1977) was 136,000 ft^3/s and the average daily spill was 6,000 ft^3/s. There was no spill on 34 of the 55 days involved. In contrast, flows during the same period in 1976 (which was not an unusual year) averaged 325,000 ft^3/s daily total flow and 191,000 ft^3/s daily total spill. The Oregon Department of Fish and Wildlife estimated the unaccountable loss of adult spring chinook salmon between Bonneville and The Dalles Dams for 1977 at 7%[1/]; losses in 1976 were estimated at 22%. With all radio tags that passed Bonneville Dam accounted for during the study, we found an actual loss among tagged fish of only about 2% due to the two chinook salmon that fell back over Bonneville Dam.

To date, there have been no precise methods found for indexing tributary turnoff along the lower Columbia River. Numbers of fish returning to a given stream vary from year to year while estimates tend to remain relatively constant. Based on the 1977 study, we believe that radio tracking can be used effectively for indexing tributary turnoff for any given year provided the number of fish tagged is sufficient. It appears

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1/ Frank Young, Oregon Department of Fish and Wildlife, 17330 S. E. Evelyn, Clackamas, OR 97015, pers. commun. 1977.

that the 92 chinook salmon we tagged in 1977 do not represent a large enough sample, but the results show promise. The number of spring chinook salmon arriving at Little Goose Dam on the Snake River is very similar to what would be calculated to arrive based on data from radio-tagged fish. The count at Little Goose Dam was 39,555 fish, and the calculated number based on the number of radio-tagged fish that arrived at Little Goose Dam was 38,970[2/]; an error of only 1.5%.

Similar calculations at lower river tributaries (based on hatchery returns), where the number of fish involved was much smaller, do not work out as well. However, due to recent improvements in our radio tag that make many more codes available, we will be able to tag much larger numbers of fish during any given period in the future. If we concentrate on defining tributary turnoff using tags and techniques that are now available, we should be able to provide a reasonable index of tributary turnoff in the future.

All steelhead trout passing over Bonneville Dam were tracked and accounted for throughout the tracking area and no real problems were encountered during the study. This indicates that an extensive steelhead trout study is feasible. There were behavioral differences between chinook salmon and steelhead trout but not enough to require changes in tracking equipment or techniques.

Evidence of tagged chinook salmon and steelhead trout swimming beyond the tributary they eventually ascended indicates that this behavior could

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2/ $$\frac{(\text{Total Bonneville count}) \times (\text{Radio-tagged count at Little Goose Dam})}{(\text{Total radio-tagged})} = \frac{(119{,}000)\ (30)}{(92)} = 38{,}970$$

be prevalent among returning salmonids as they seek a stream in which to spawn. This "overshoot" may explain the occurrence of some fallback when fish unnecessarily cross a dam. This behavior may also explain instances where tagged fish released below a dam apparently do not ascend the dam at all but remain downstream or even leave the area.

Based on the effectiveness of this year's study and the current availability of tags with a significantly greater number of codes, a definitive study of the problem of unaccountable losses seems practical. Our methods of surveillance enabled us to keep track of every fish within the study area, and the methods should provide equally good results during higher river flows. Data were obtained that can be used to compare with information gathered in future studies. Behavioral changes will be more easily detected during a high flow year now that a baseline has been established during low flows. For the best possible results, the study should be planned, funded, and preparations completed ahead of time; then put into effect only in a year when forecasts indicate there will be an above-average runoff.

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