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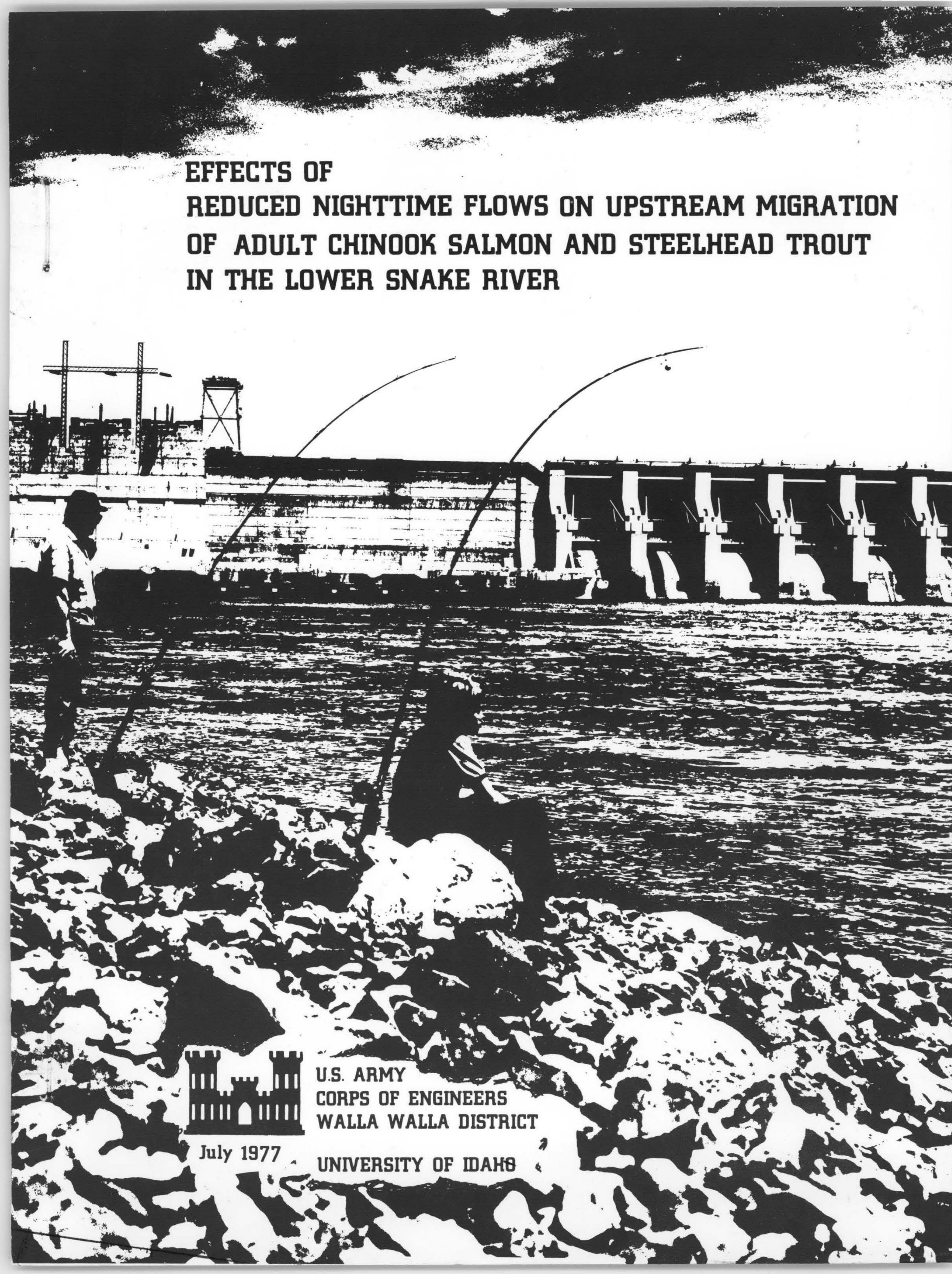

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EFFECTS OF REDUCED NIGHTTIME FLOWS ON UPSTREAM MIGRATION OF ADULT CHINOOK SALMON AND STEELHEAD TROUT IN THE LOWER SNAKE RIVER

by

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ABSTRACT

Storage of water at night and discharge through turbines at lower Snake River dams during the day would best meet demands for power production. However, fisheries managers were concerned that such flow regulations would interfere with upstream migration of anadromous salmonids. During 1975 and 1976, we assessed the effects of reduced nighttime flows on the upstream migration of adult chinook salmon and steelhead trout. During the summer and fall, reducing discharge from the dams to zero at night (2300-0700 hours) had no observable effect on migration of adult fish.

During the first phase of the study (July-October 1975), we used radio telemetry and mark-recapture techniques to evaluate chinook and steelhead movement patterns and travel rates during the periods of uncontrolled and reduced nighttime flows. Nighttime flows were provided for 8 hours each night on a 7-day rotating schedule of 0 and 10,000 cfs. Test fish were collected at Little Goose Dam, radio- or magnetic-tagged and transported to downriver release sites. Radio-tagged fish were monitored 24 hours each day to document movement patterns; radio- and magnetic-tagged fish recaptured at Little Goose Dam were used to determine travel rates.

We observed no differences in behavior or rates of travel of radio- or magnetic-tagged chinook or steelhead which could be attributed to nighttime flow regimes tested. Few tagged chinook successfully passed through the study area during test flow periods, but fish counts at the dams were not altered by the nighttime flows tested. Failure of tagged chinook to migrate successfully was probably a result of handling and downriver transportation stress.

Seventy-five percent of all steelhead tagged passed through the study area during flow tests. Transporting adult steelhead downriver had no observable effect on migration rate or success. Total movement and recapture of steelhead tagged and released during late October and early November decreased due to initiation of overwintering behavior associated with decreasing water temperature.

We studied steelhead overwintering behavior in Lower Monumental Reservoir from December, 1975 to March, 1976. We found that overwintering steelhead were relatively inactive and generally occupied the upstream two-thirds of the reservoir. Although we were unable to test effects of zero nighttime flows on overwintering steelhead, we observed no movement patterns which appeared related to discharge.

The second phase of the study was an evaluation of 1976 chinook and steelhead passage over lower Snake River dams (using fish counts). This passage was associated with nighttime flows of 0 and 20,000 cfs

on a 2 day alternating schedule. Using analysis of variance and Wilcoxon's signed-ranks test we found no significant differences (.05 level) in counts of chinook or steelhead between the two nighttime test flow conditions, thus substantiating our 1975 findings.

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INTRODUCTION

Demand for electricity in the Pacific Northwest has, and will continue to increase the need to supply hydroelectric power during peak demand periods. To accomplish this, power producers must store water during periods of low power demand and release it during periods of high power demand. This results in seasonal, weekly and daily fluctuation of power production referred to as peaking. In general, periods of high power demand and high discharge from hydroelectric dams are associated with daylight hours and weekdays, while low demand and low discharge is associated with nighttime and weekends.

During summer and fall, lower Snake River discharge ranges from 20,000 to 60,000 cfs, well below the flows needed to operate the six turbines at each dam at full efficiency (120,000 cfs). One way to increase water utilization efficiency for power production would be to release no water at night. Storage of water at night and discharge through the turbines during the day would best meet demands for electricity, but fisheries managers were concerned that such flow regulation would interfere with the upstream migration of adult salmon and steelhead.

This study was initiated in July 1975 by personnel of the Idaho Cooperative Fishery Research Unit after a request was made by the U.S. Army Corps of Engineers to the Idaho Water Resources Research Institute. The Corps of Engineers provided funds for the study.

The purpose of the study was to evaluate effects of reduced nighttime flows on upstream migration of adult chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Salmo gairdneri*) through lower Snake River reservoirs. We were specifically interested in determining whether a no-flow condition at night would effect behavior, travel rates and survival of upstream migrating salmon and steelhead and of overwintering steelhead in lower Snake River reservoirs.

Our study consisted of two phases. The first phase (July, 1975-March, 1976) utilized radio telemetry and mark-recapture techniques to evaluate response of chinook and steelhead to reduced nighttime flows and to study overwintering behavior of steelhead. The second phase (July - December, 1976) evaluated effects of test nighttime flows on fish passage as determined from fish counts at the dams.

STUDY AREA

We conducted this study in southeastern Washington on the lower Snake River, just upstream from its confluence with the Columbia River (Figure 1). Ice Harbor Dam, located 16.1 km (10 mi) upstream from the Columbia-Snake confluence, marked the lower end of our study area. From this point the study area continued upreservoir for 96.5 km (60 mi) including Lower Monumental Dam and Reservoir and terminating at Little Goose Dam (Figure 2).

The three dams within the study area (Ice Harbor, Lower Monumental and Little Goose), were constructed between 1956 and 1970 as multi-purpose projects for power generation, slack water navigation, irrigation and recreation. Flows through these projects are manipulated primarily to store water daily and weekly when demand for electricity is low and to release it for generation of electricity when demand is larger. Each dam is presently equipped with three generators, with a full complement of six generators to be in operation by 1978.

To allow passage of anadromous salmonids, lower Snake River dams are equipped with fish passage facilities. Ice Harbor and Lower Monumental dams have a ladder system on each shore. Little Goose Dam is laddered on only one side but has an attraction and tunnel system beneath the spillway to pass fish from the non-laddered side to the passage facility. Each ladder has a counting station where migrating adult salmonids are enumerated by species. These stations are monitored by trained personnel from April through October each year.

The study area contained two reservoirs (Ice Harbor and Lower Monumental pools), which range in depth from over 30.5 m (100 ft) in the lower areas of each pool to less than 6.0 m (20 ft) in the tail race of the dams; the average depths are 14.8 m (48.6 ft) and 17.4 m (57.2 ft) respectively. These reservoirs occupy a steep walled canyon and average approximately 600 m (666 yd) in width. Reservoir temperatures range from winter lows near 2 C (35.6 F) to summer highs of over 21 C (70 F). Falter and Funk (1973) and Falter et al. (1977) reported that lower Snake River reservoirs are essentially homothermal, varying no more than 2 C (3.6 F) from top to bottom. Peak river flow occurs in late spring to early summer usually in the 100,000-200,000 cfs range. During the remainder of the year flows usually range between 20,000 and 60,000 cfs. Extremes have ranged from 409,000 cfs (June, 1894) to 6,660 cfs (September, 1958) as measured at Clarkston, Washington (Anonymous, 1973). Flows and temperatures of the Snake River as recorded at Ice Harbor Dam in 1975 are presented in Figure 3.

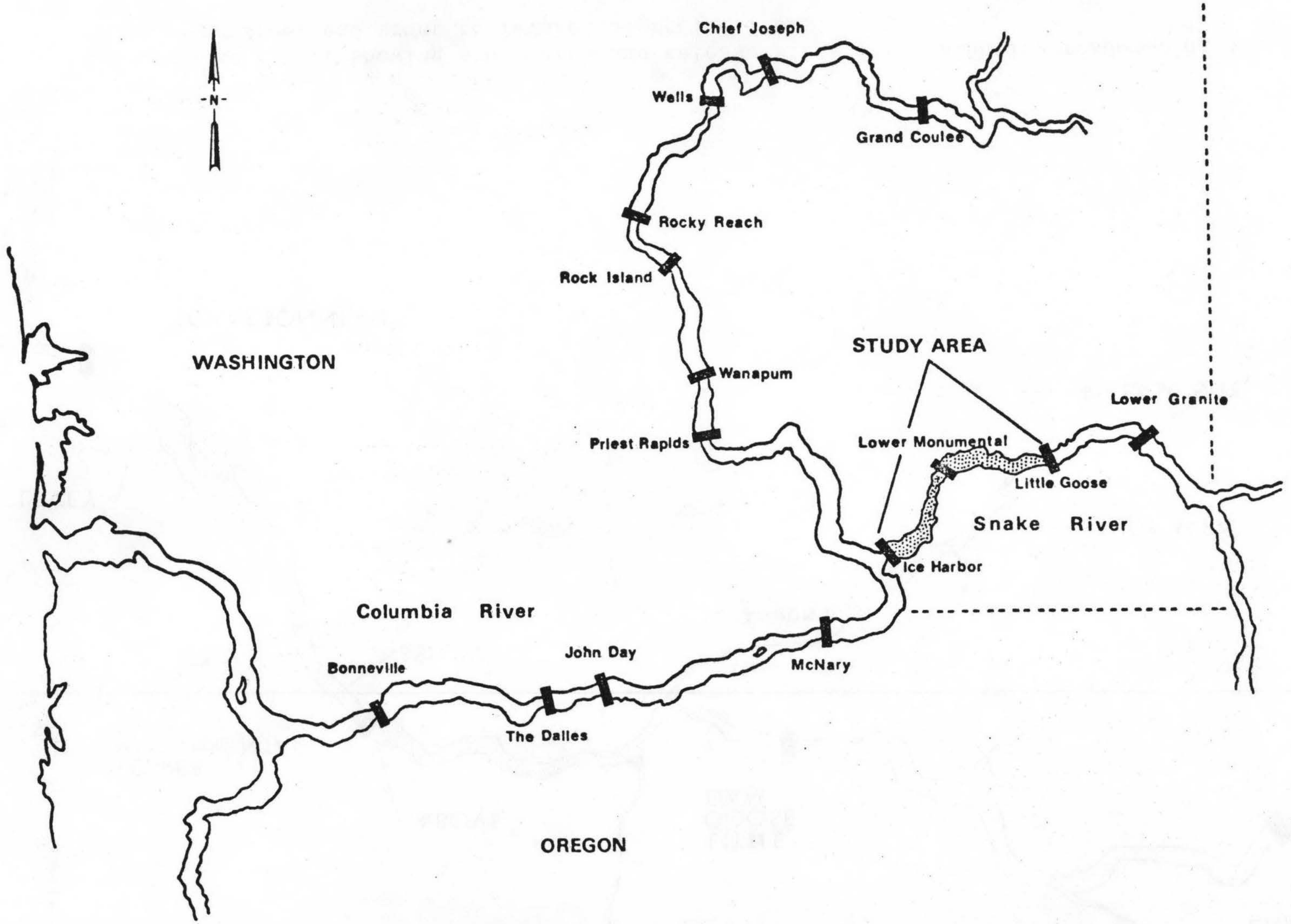

Figure 1. Location of nighttime flow study area in relation to Columbia and lower Snake River dams.

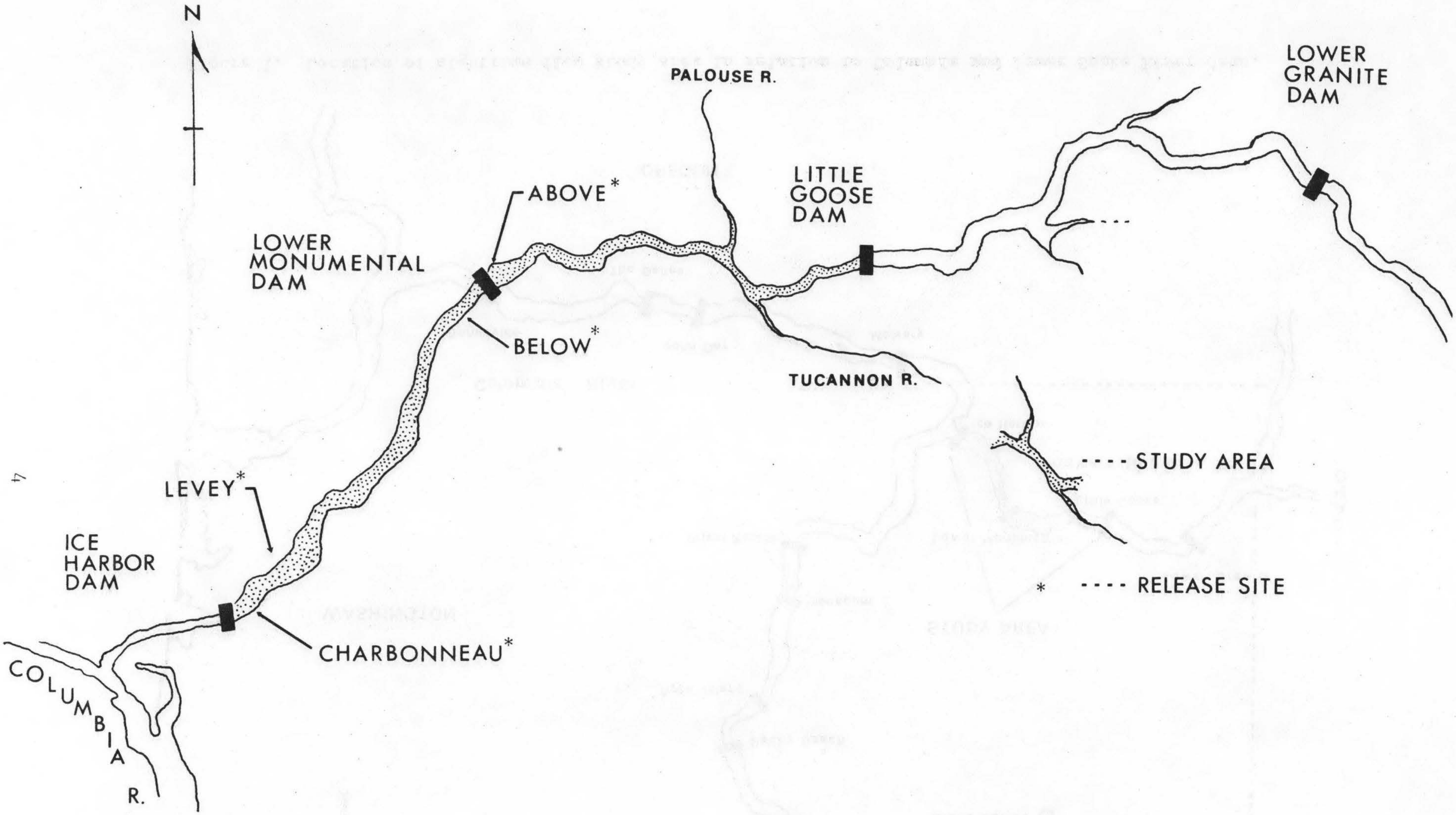

Figure 2. Lower Snake River, showing study area and release sites for evaluating response of adult chinook salmon and steelhead trout to reduced nighttime flows.

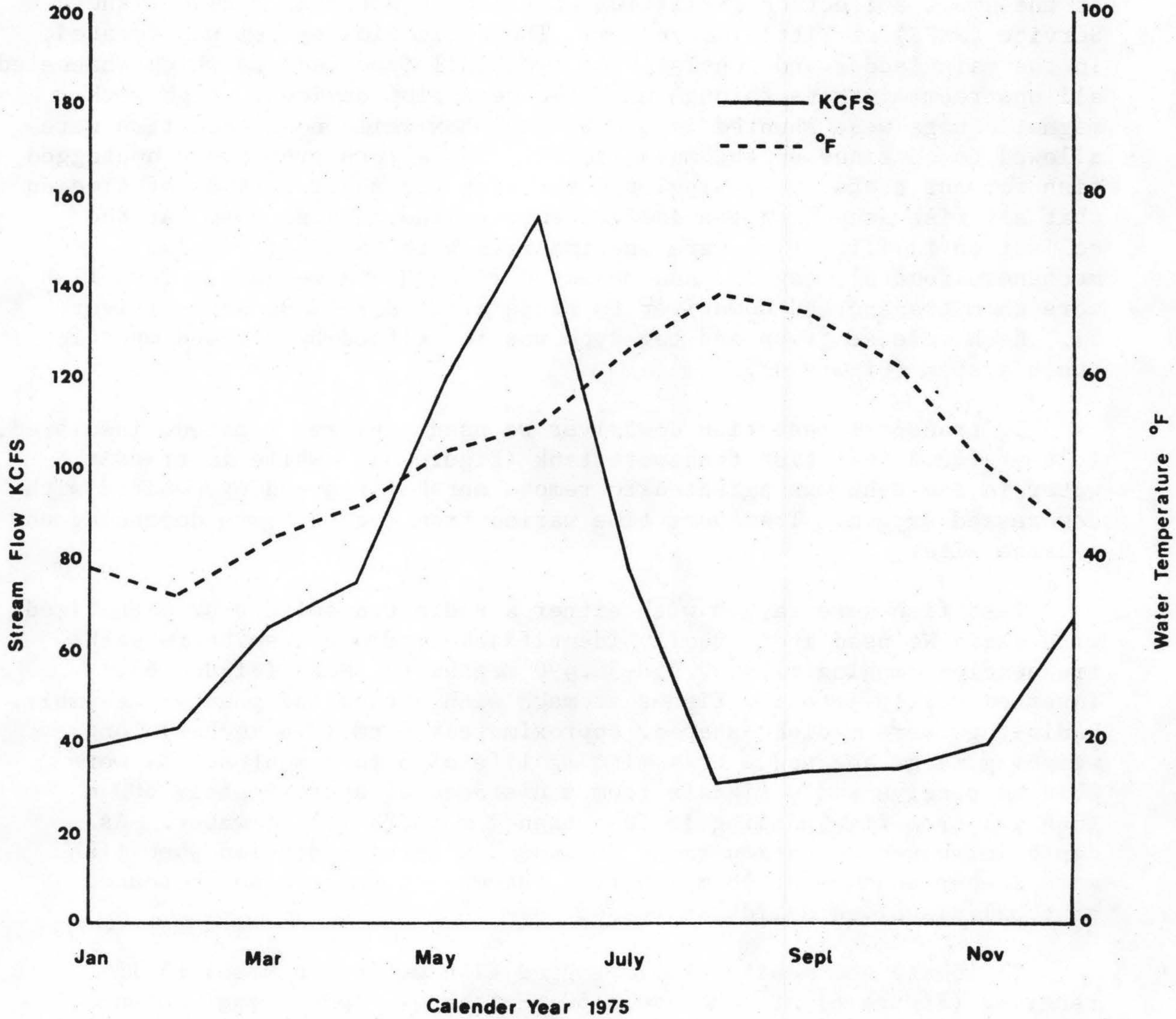

Figure 3. Mean monthly flow and temperature of the Snake River at Ice Harbor Dam, 1975.

PROCEDURES

During 1975 we used radiotelemetry and mark-recapture techniques to monitor behavior and migration rates of fish subjected to reduced nighttime flows. Adult chinook salmon and steelhead trout were collected at the adult collection facilities operated by National Marine Fishery Service (NMFS) at Little Goose Dam. The collection system was located in the main ladder and consisted of two Denil type ladders which channeled all upstream migrants through magnetic detection devices. Fish with magnetic tags were shunted into a holding box while nontagged fish were allowed to continue up the main ladder. To capture previously nontagged fish for our tests, we manipulated the trap for short periods of time so that all fish ascending the ladders entered the holding box. At the collection facility fish were anesthetized with MS 222 (tricaine methanesulfonate), tagged, and measured (length and weight). Test fish were then transported downriver to predetermined release sites (Figure 2). Each release group and tag type was identified by a coded opercle punch system (Figure 4).

To transport test fish downriver we used a pickup mounted, insulated, 1.14 m^3 (40.2 ft^3) fish transport tank (Figure 5). While in transit, water in the tank was agitated to remove metabolites and oxygenated with compressed oxygen. Transport time varied from 1 to 2 hours depending on release site.

Test fish were tagged with either a radio transmitter or magnetized wire tag. We used individually identifiable radio transmitters with frequencies ranging from 50.250-50.490 megahertz (MHz) (Figure 6), inserted orally into the fishes stomach with a tube and plunger assembly. Radio-tags were padlock-shaped, approximately 6 cm (2.4 inches) long, weighing 14 gm and had a transmitting life of 6 to 7 months. We were able to receive radio signals from a distance of approximately 600 m (666 yd) from fish holding in less than 1 m (3.28 ft) of water. As depth increased reception range decreased with no reception when fish were deeper than about 18 m (60 ft). Reception range also decreased as total dissolved solids increased.

To locate and monitor radio-tagged fish we used a Model LA-12 receiver (Figure 6) attached to a 50 MHz, three element yagi antenna, mounted on a boat or pickup truck (Figures 7 and 8). In areas inaccessible to either boat or truck we used a handheld loop antenna (Figure 8). Both tags and receiver were manufactured by AVM Instrument Company, Champaign, Illinois.

We magnetic-tagged test fish by placing a fine, 2-3 mm length of magnetic wire (NMFS nose tag wire) under the skin below the insertion of the dorsal fin (Figure 9) and by orally inserting a magnetized 0.95 cm (3/8 inch) stainless steel ball bearing into the stomach. The ball bearing served as a backup tag in case of wire tag loss. After the chinook migration portion of the study, we replaced the ball bearing

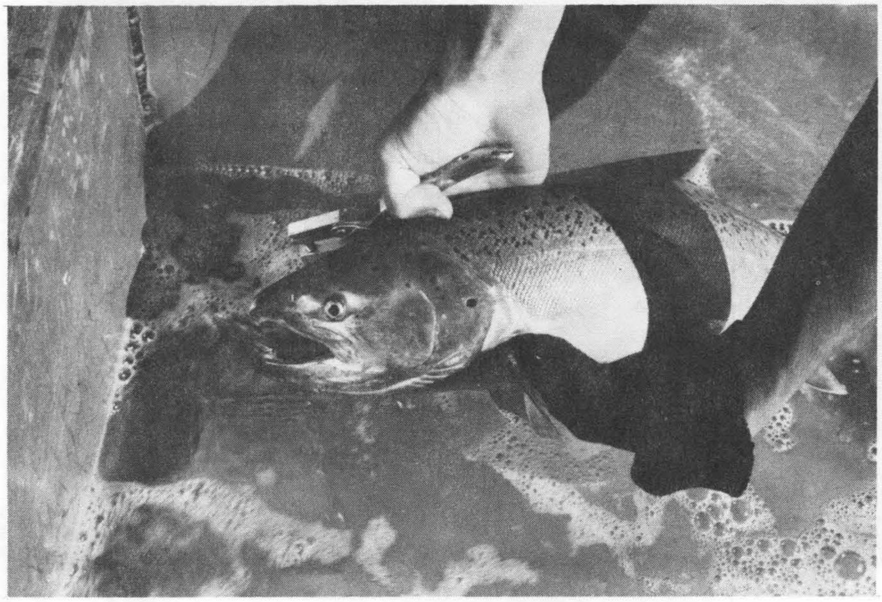

Figure 4. Chinook salmon with opercle punch used to identify release group and tag type upon recapture.

Figure 5. Pickup-mounted tank used to transport test fish downreservoir to release sites.

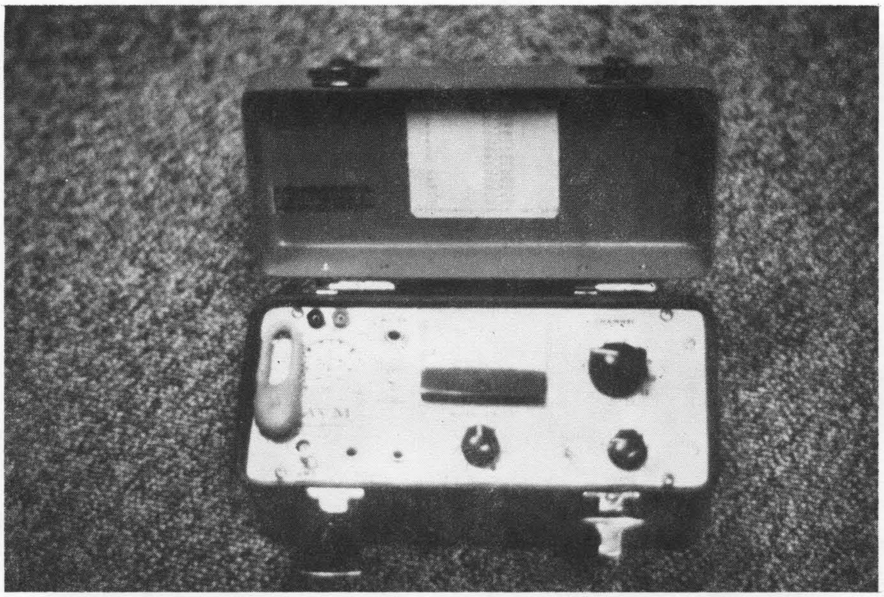

Figure 6. AVM receiver (Model LA-12) and radio transmitter.

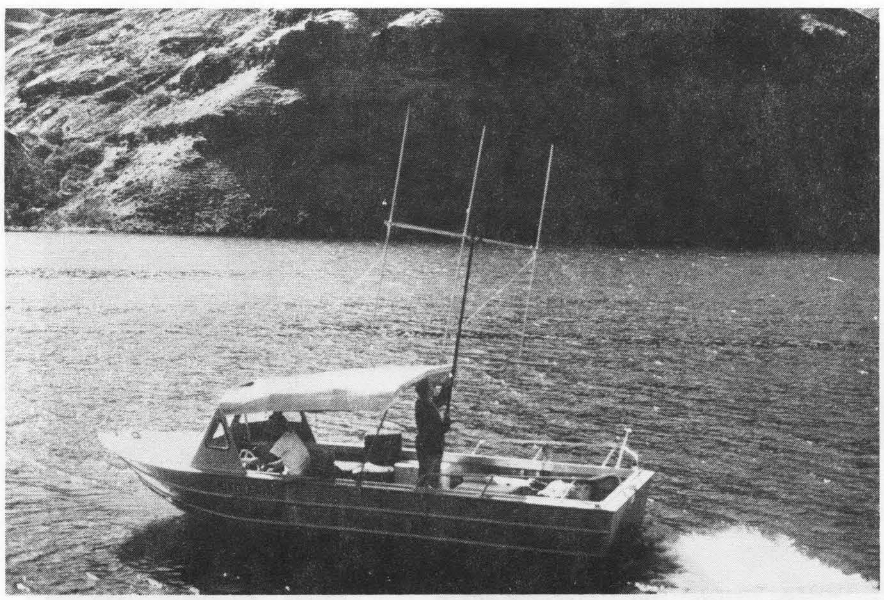

Figure 7. Boat mounted yagi antenna for reservoir tracking of adult chinook salmon and steelhead trout.

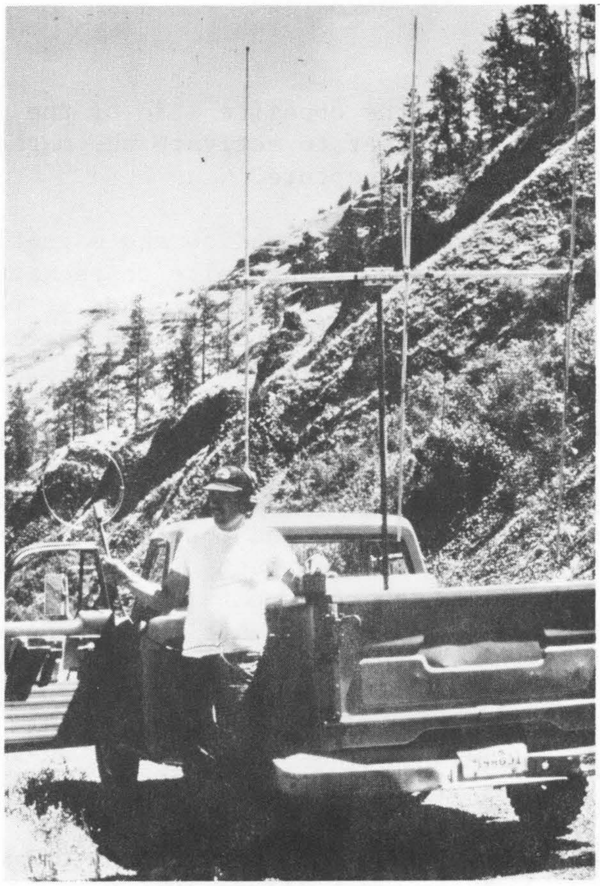

Figure 8. Pickup-mounted yagi and handheld loop antennas used for monitoring movements and location of adult chinook salmon and steelhead trout.

Figure 9. Insertion of magnetic wire tag into adult chinook salmon.

with a second wire tag inserted on the opposite side of the fish. Both radio and magnetic tags were sufficient to activate the magnetic detectors at Little Goose Dam, allowing recapture.

We calculated rate of travel for both radio- and magnetic-tagged fish by determining elapsed time from release site to recapture at Little Goose Dam. Release time and site was determined at recapture from our opercle punch code. Radio-tagged chinook and steelhead were monitored on a 24 hour a day basis to determine movement and behavior patterns. Radio tracking was conducted primarily from boats using three 8 hour shifts of usually one man each. During a shift the tracker would locate known fish and scan for others while covering as much reservoir as possible. The next tracker would continue where the previous one left off. The time, position (river mile and position in reservoir), and any pertinent observations were logged each time a fish was located. NMFS personnel recorded opercle punch code, date and time of return of all recaptured chinook and steelhead in conjunction with operating the collection facilities at Little Goose Dam.

Adult Chinook Salmon Tests

In 1975 we evaluated the response of adult chinook salmon to three nighttime flow conditions: uncontrolled, 10,000 and 0 cfs. With the exception of the uncontrolled period, which lasted 17 days, nighttime flows of 10,000 cfs and 0 cfs were alternated on a 7 day schedule (Table 1). Test flows were provided at Lower Monumental and Little Goose dams between 2300 and 0700 hours. Daytime flows were unaltered from normal operation.

Three release sites were used in evaluating effects of reduced nighttime flows on chinook migration (Figure 2). The Charbonneau release site was chosen so we could gather movement and behavioral information from the entire length of the study area. Because tagged fish did not pass through the study area within a test period, the Charbonneau release site was later augmented with two additional sites. One site was located directly above Lower Monumental Dam and the other approximately 0.8 km (0.5 mi) below the dam (Figure 2).

At the beginning of each flow period we released four radio-tagged and 2 to 25 magnetic-tagged adult chinook depending upon availability (Table 1). In addition to releasing additional radio-tagged chinook each period, we continued to monitor radio-tagged chinook from previous releases until they left the study area or were lost. During flow period III (0 cfs, July 31-August 6) no radio-tagged chinook were released due to tag supply problems and during period V (0 cfs, August 14-20) we were able to magnetic-tag and release only two adult chinook due to the declining fish run.

All chinook were collected at the Little Goose trap and transported downriver by truck. We were unable to collect any chinook in the lower end of the study area to use as a control for testing effects of transportation on summer chinook.

Controlled nighttime flows provided by the Army Corps of Engineers were, in most cases, very similiar to those requested. In general, requested nighttime flows of 10,000 cfs ranged between 11,000 and 15,000 cfs, while 0 cfs nighttime test flows averaged less than 200 cfs over the entire 8 hour period. Any flow that did occur during the 0 cfs test flows was generally confined to the first or last hour of that nights test. During all tests the fish ladder systems discharged approximately 200 cfs.

Table 1. Controlled flow schedule and number of test fish released for evaluating effects of reduced nighttime flows on upstream migration of adult chinook salmon, 1975.

Flow period		Number released		Nighttime flow (cfs) (2300-0700 hours)
		radio	magn.	
I.	July 7-23	8	25	Uncontrolled[a/]
II.	July 24-30	4	20	10,000
III.	July 31-August 6	0	25	0
IV.	August 7-13	4	22	10,000
V.	August 14-20	4	2	0

a/ Nighttime flows during the uncontrolled period ranged from 63.0 to 12.8 kcfs (average flow 2300-0700 hrs).

Adult Steelhead Trout Tests

To assess effects of reduced nighttime flows on the upstream migration of adult steelhead trout, we radio- and magnetic-tagged steelhead during September, October and November, 1975. Nighttime flows were controlled in the same manner described earlier (Table 2).

We released 8 radio- and 25 magnetic-tagged steelhead at the Charbonneau release site (Figure 2) at the beginning of each test period. During periods II (10,000 cfs, September 22-28) and VII (0 cfs, October 27-November 2) we released no radio-tagged steelhead, but we continued to monitor fish remaining in the study area from previous releases. During each of the last five flow periods we also released 10 magnetic-tagged steelhead at the release site above Lower Monumental Dam (Figure 2).

To test effects of our downriver transportation, adult steelhead trout were collected in a Merwin trap operated by NMFS at Levey (Figure 2). Previously non-tagged steelhead caught in the trap were opercle punched, magnetic-tagged by NMFS personnel and released at the collection site. Rate of travel and recapture percentage of non-transported steelhead were compared with transported steelhead. Fish were collected in the Merwin trap and released during periods I, II, III and IV.

Table 2. Controlled flow schedule and number of test fish released for evaluating effects of reduced nighttime flows on upstream migration of adult steelhead trout, 1975.

Flow period		Number released		Nighttime flow (cfs)
		radio	magn.	(2300-0700 hours)
I	September 8-21	8	30	20,000
II	September 22-28	0	50	10,000
III	September 29-October 5	8	49	0
IV	October 6-12	8	35	10,000
V	October 13-19	8	43	0
VI	October 20-26	8	35	10,000 a/
VII	October 27-November 2	0	35	0 b/
VIII	November 3-9	8	35	Uncontrolled

a/ Modified 10,000-controlled between 2400 to 0600 hours.

b/ Modified 0-controlled between 2400 to 0600 hours.

Overwintering Steelhead Trout

Effects of 0 and 10,000 cfs nighttime flows on overwintering of steelhead trout in lower Snake River reservoirs were not assessed because of the inability of the Army Corps of Engineers to provide requested test flows. However, to gain information on steelhead overwintering locations and behavior within the reservoirs we radio-tagged 10 adult steelhead and monitored their general movement patterns from December, 1975 to March, 1976. In addition, we monitored movements of radio-tagged steelhead remaining in the study area from earlier steelhead movement studies.

Test fish were collected at Little Goose Dam, tagged, opercle punched and transported downriver to the release site just above Lower Monumental Dam (Figure 10). For this portion of the study we reduced the study area to Lower Monumental Pool only.

The collection system at Little Goose Dam was closed to continuous operation from November 25, 1975 through March 1, 1976, except for two brief periods when we were collecting test fish. During the period of closure, fish were allowed to cross the dam without detection. Since we did not monitor overwintering fish on a 24 hour basis and detection facilities were not in operation, we were unable to determine if, or when, a test fish left the study area by crossing Little Goose Dam. In addition, we could not assume that fish we could not locate had left the study area, since we had difficulty receiving radio signals from fish occupying water depths greater than 18 m (60 ft).

We monitored radio-tagged steelhead movements within the study area (Figure 10) on a weekly basis during December, 1975 and January, 1976 and thereafter only periodically through mid-March, 1976. Tracking was conducted during daylight hours from boat or pickup truck. We recorded time, location, and placement in reservoir (which shore) each time a radio-tagged steelhead was located.

Dam Count Analysis

Based on our findings in 1975, we restructured the experimental design for 1976. To further evaluate effects of reduced nighttime flow on the migration of adult chinook salmon and steelhead trout, nighttime flow was controlled at Ice Harbor, Lower Monumental and Little Goose dams during summer and early fall 1976. Nighttime flows were controlled on a 2 day rotating schedule of 20,000 cfs or 0 cfs between 2300 to 0700 hours. Lower Monumental and Little Goose dams had the same sequence of nighttime test flows while Ice Harbor was on the alternate sequence (Table 3).

During 1976 we did not use any tagged and transported chinook or steelhead since we wanted to avoid using handled fish. Instead, daily fish passage counts were statistically analyzed using analysis of variance with a randomized complete block design and Wilcoxon's signed-ranks test to evaluate effects of the 0 cfs and 20,000 cfs nighttime flows on chinook and steelhead passage. Dam counts the day following each nighttime test flow were used in analyzing the response of the migrating population to the test flow condition.

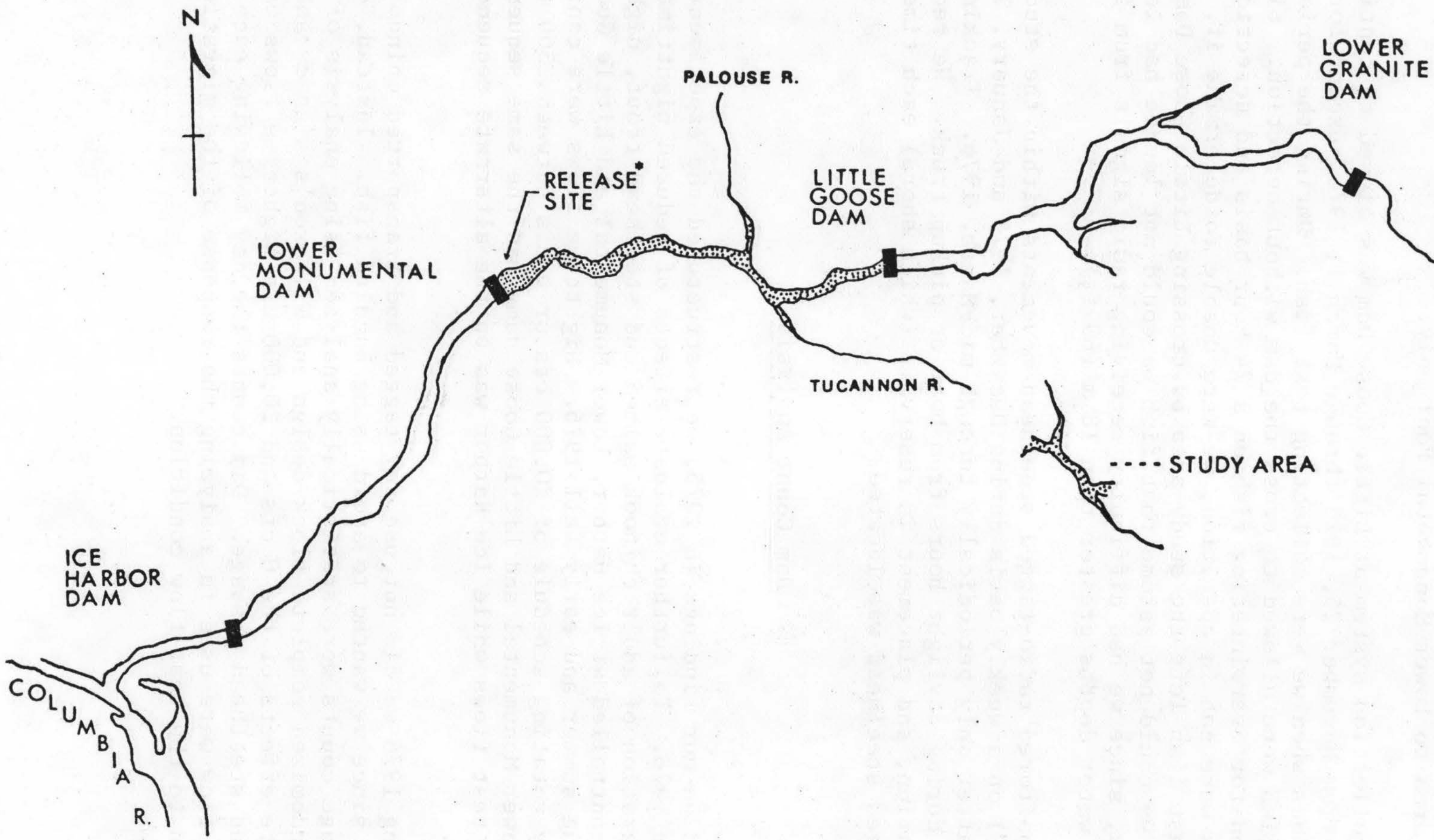

Figure 10. Lower Snake River, showing study area and release site for overwintering steelhead study.

Table 3. Sequence of controlled nighttime flow tests, 1976.

Date	Ice Harbor	Lower Monumental	Little Goose
July 21, 22	0 cfs	20,000	20,000
23, 25	20,000	0	0
25, 26	0	20,000	20,000
27, 28	20,000	0	0
29, 30	0	20,000	20,000
31, 1	20,000	0	0
Aug. 2, 3	0	20,000	20,000
4, 5	20,000	0	0
6, 7	0	20,000	20,000
8, 9	20,000	0	0
10, 11	0	20,000	20,000
12, 13	20,000	0	0
14, 15	0	20,000	20,000
16, 17 a/	20,000	0	0
18, 19	0	20,000	20,000
20, 21	20,000	0	0
22, 23	0	20,000	20,000
24, 25	20,000	0	0
26, 27	0	20,000	20,000
28, 29	20,000	0	0
30, 31	0	20,000	20,000
Sept. 1, 2	20,000	0	0
3, 4	0	20,000	20,000
5, 6	20,000	0	0
7, 8	0	20,000	20,000
9, 10	20,000	0	0
11, 12	0	20,000	20,000
b/			
20, 21	0	20,000	
22, 23	20,000	0	
24, 25	0	20,000	
26, 27	20,000	0	
28, 29	0	20,000	
30, 1	20,000	0	
Oct. 2, 3	0	20,000	
4, 5	20,000		

a/ Scheduled nighttime flow controls not provided.

b/ Nighttime flow controls were not provided from September 13-19 at all dams. Test flows were resumed at Ice Harbor and Lower Monumental dams on September 20.

RESULTS

Adult Chinook Salmon Movements, 1975

Radio-Tagged Chinook

We did not observe any differences in behavior or rates of travel for radio-tagged adult chinook salmon which could be related to reduced nighttime flows tested. More of the radio-tagged adult chinook released during flow period I (uncontrolled, July 7-23) moved upstream and crossed dams than those released during subsequent controlled flow periods (Figure 11), but not because of differences in nighttime flows. Of the eight radio-tagged chinook we released during this period, seven reached Lower Monumental Dam and three of these crossed the dam. During flow periods II, IV, and V (Table 1), 50% or more of each release group did not reach the immediate upstream dam from their release site. Appendix A contains diagrammatic maps of the movements of all individual radio-tagged adult chinook salmon for all release groups.

Uncontrolled Flow Period: During flow period I (uncontrolled, July 7-23) we released eight radio-tagged adult chinook salmon in two releases of four fish each (July 7 and July 15), at the Charbonneau release site. Radio contact with two of these fish was lost soon after release. One of these two chinook was never relocated and was not recaptured. The second fish was recaptured at Little Goose Dam on July 12, 5 days after its release at Charbonneau. This fish had a travel rate for the 95 km (59 mi) from Charbonneau to Little Goose Dam of 20.4 km/day (12.7 mi/day) (Table 4). Included in this rate is crossing Lower Monumental Dam and recapture at Little Goose Dam.

The remaining six fish traveled the 49.2 km (30.6 mi) from Charbonneau to the base of Lower Monumental Dam at an average rate of 31.1 km/day (19.3 mi/day) with a range of 11.1 to 59.1 km/day (6.9 to 36.7 mi/day) (Table 4). These six chinook remained in the vicinity of the base of Lower Monumental Dam for periods ranging from less than 1 day to a maximum of 10 days before radio contact was lost or the fish moved over the dam. Since there are no collection facilities at Lower Monumental Dam and our opercle punches were not visible to the fish counters, we were not always able to document the precise time when a fish crossed the dam or at times if a fish crossed at all.

We successfully monitored the movements of three of the eight radio-tagged chinook (37.5%) released during the uncontrolled flow period through the Ice Harbor pool, over Lower Monumental Dam and up to Little Goose Dam. These fish traveled the 95 km (59 mi) from release at Charbonneau to recapture at Little Goose Dam at rates ranging from 8.4 to 20.4 km/day (5.2 to 12.7 mi/day) (Table 4). These rates of travel include crossing Lower Monumental Dam and recapture at Little Goose Dam for all but one fish. This fish reached Little Goose but was not recaptured and was lost soon after its arrival at Little Goose Dam.

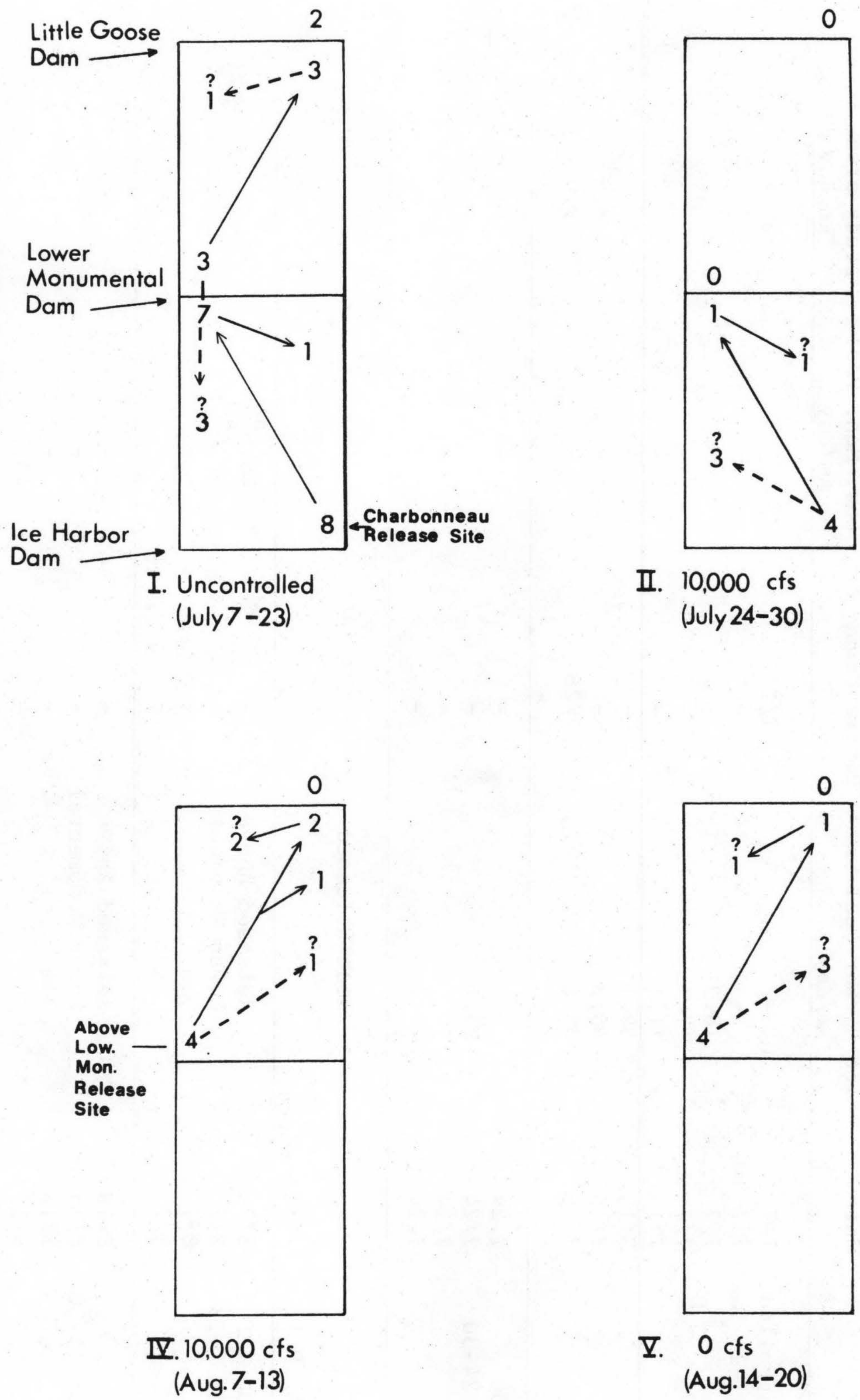

Figure 11. Diagrammatic representation of study area showing number of radio-tagged chinook released, release site, number crossing Lower Monumental Dam, and recaptures at Little Goose Dam by flow period.

Table 4. Travel rate and recapture of radio-tagged adult chinook salmon by flow period, 1975.

Flow period	Release date	Travel rate Ice Harbor Pool km/day	Date recaptured Little Goose	Travel rate Low. Mon. Pool km/day	Travel rate study area km/day
I. Uncontrolled	7/7	-	7/12	-	20.4
July 7-23	7/7	-	-	-	
	7/7	18.3	-	-	
	7/7	17.1	-	-	
	7/15	11.1	-	-	
	7/15	59.1	-	-	
	7/15	45.2	-	-	8.4[a/]
	7/15	35.6	7/26	-	9.0
II. 10,000	7/24		-	-	-
July 24-30	7/24	35.6	-	-	-
	7/24		-	-	-
	7/24		-	-	-
III. 0 July 31-August 6		None Released			
IV. 10,000	8/7	Released Above	-	48.6[a/]	-
August 7-13	8/7	Lower Monumental	-	35.6[a/]	-
	8/7	Dam	-	-	-
	8/7		-	-	-
V. 0	8/15	Released Above	-	-	-
August 14-20	8/15	Lower Monumental	-	-	-
	8/15	Dam	-	-	-
	8/15		-	49.7	-

a/ Rate of travel does not include recapture at Little Goose.

Controlled Flow Periods: At the beginning of controlled flow periods II (10,000 cfs, July 24-30), IV (10,000 cfs, August 7-13) and V (0 cfs, August 14-20) we released four radio-tagged adult chinook salmon. Test fish for period II were released at Charbonneau while radio-tagged fish for periods IV and V were released at the above Lower Monumental Dam release site (Figures 2 and 11). We were unable to release any radio-tagged chinook during flow period III (0 cfs, July 31-August 6) because of tag supply problems, however, we did continue to monitor previously released fish which were still in the study area.

Only one of four chinook released during flow period II reached Lower Monumental Dam and this fish did not cross the dam. This fish traveled from Charbonneau to Lower Monumental Dam at a rate of 35.6 km/day (22.1 mi/day) (Table 4).

During periods IV (10,000 cfs, August 7-13) and V (0 cfs, August 14-20) all eight radio-tagged chinook were released above Lower Monumental Dam (Figure 2, Table 4). Three (37.5%) of these eight radio-tagged chinook reached Little Goose Dam, traveling at rates ranging from 35.6 to 49.7 km/day (22.1-30.9 mi/day) with an average of 44.6 km/day (27.7 mi/day); none of these chinook crossed Little Goose Dam.

Observations from all releases revealed two basic movement patterns within the study area. The first, in Ice Harbor Pool, consisted of steady movement upreservoir to Lower Monumental Dam followed by a period of delay ranging from less than 1 day to a maximum of 18 days. Movement below the dam was seemingly random in the tail race with fish often moving in and out of the fish ladder entrances. Limited downreservoir movement of 1.6 to 3.2 km (1-2 mi) was also observed.

Of the 12 radio-tagged chinook released during 1975 at Charbonneau, 10 were known to have left the release area within 24 hours. Of the 12, eight were known to have reached Lower Monumental Dam; six of these delayed at the dam for at least 3 days, and five of these may not have crossed the dam (Figure 11).

The second movement pattern was observed in Lower Monumental Pool. As in Ice Harbor Pool, radio-tagged chinook movement was steady, although more rapid (Table 4) up to Little Goose Dam. Upon reaching the dam area, fish sought the ladder entrances for less than 1 day and were either recaptured at the NMFS collection facility (2 of 6) or moved back downreservoir (4 of 6) and were lost (Figure 11 and Appendix A). This pattern was displayed by all chinook reaching Little Goose Dam whether released from Charbonneau or upstream from Lower Monumental Dam.

Radio-tagged chinook moved primarily during daylight starting at or near dawn and ceasing shortly after dusk. However, we monitored four radio-tagged chinook which moved up- or downreservoir more than 1.6 km (1 mi) at night. In addition there was considerable "random" movement of radio-tagged chinook in the tail race area of Lower Monumental Dam at night, but not associated with fish crossing the dam. We observed most nighttime movement during the uncontrolled flow period. During this period, we were able to maintain the closest surveillance on test fish because most of the fish were holding in the tail race of Lower Monumental Dam for considerable periods of time (1 to 18 days). During the later flow periods when the fish were widely distributed, we had more difficulty maintaining radio contact with individual fish for extended periods.

We monitored movements of radio-tagged chinook at time of flow change (2300 and 0700 hours) and observed no correlation. Since movement was often initiated at dawn, test fish were usually already moving when the 0700 hour flow initiation occurred and usually had stopped moving before the 2300 hour flow reduction.

Magnetic-Tagged Chinook

We recaptured the largest number of magnetic-tagged adult chinook salmon at Little Goose Dam from the groups released during flow period I (uncontrolled, July 7-23), with few to no recaptures of fish released during subsequent controlled flow periods (Table 5).

During the uncontrolled flow period we released 25 magnetic-tagged adult chinook salmon at Charbonneau (Figure 2). Twenty-two (88%) were later recaptured at Little Goose Dam, with 15 of these recaptured during the uncontrolled flow period, six during period II and one during period III (Table 6).

Only four of the 69 magnetic-tagged chinook released during the controlled flow periods were recaptured at Little Goose Dam (Table 5). Three of these returned to the Little Goose trap during the same period as released (Table 6).

During flow period II (10,000 cfs, July 24-30), we started releasing some magnetic-tagged chinook just below Lower Monumental Dam (Figure 2). We made this change because fish released at Charbonneau were not traveling the entire study area within one test period (7 days). During periods III (0 cfs, July 31-August 6), IV (10,000 cfs, August 7-13) and V (0 cfs, August 14-20), we released all fish at the above and below Lower Monumental Dam release sites. We hoped to be able to determine the delay effect of Lower Monumental Dam by this release system, but because few chinook were recaptured during the control flow periods we were unsuccessful.

Table 5. Comparison of rates of travel and recapture of magnetic-tagged adult chinook salmon during uncontrolled, 10,000 cfs and 0 cfs nighttime flow regimes, 1975.

Flow period	Number released	Date released	Release site	Number recaptured	Percent recaptured	Rate of travel (km/day) Range	Rate of travel (km/day) Mean
I. Uncontrolled July 7-July 23	25	7/7, 7/9	Charbonneau	22	88	4.0-26.4	11.8
II. 10,000 cfs July 24-July 30	4	7/24	Charbonneau	2	50	9.3-20.0	14.6
	16	7/27	Below Lower Monumental	1	6	31.4	31.4
III. 0 cfs July 31-Aug 6	12	7/31	Below Lower Monumental	1	8	13.8	13.8
	13	8/1	Above Lower Monumental	0	0	-	-
IV. 10,000 cfs Aug 7-Aug 13	9	8/8, 8/9	Below Lower Monumental	0	0	-	-
	13	8/7, 8/8	Above Lower Monumental	0	0	-	-
V. 0 cfs Aug 14-Aug 20	2	8/14, 8/15	Above Lower Monumental	0	0	-	-
Totals	94			26	27.6	4.0-31.4	12.0

Table 6. Radio- and magnetic-tagged adult chinook salmon recaptured at Little Goose Dam by flow period and release site, 1975.

		Period of recapture						
Flow period and number released	Release site	July 7-23 Uncontrolled	July 24-30 10,000 cfs	July 31-Aug 6 0 cfs	Aug 7-13 10,000 cfs	Aug 14-20 0 cfs	Number recaptured	Percentage of total
I. Uncontrolled								
4 radio 7/7	Charbonneau	1	-	-	-	-	1	25.0
4 radio 7/15	"	1	-	-	-	-	1	25.0
25 magnetic	"	15	6	1	-	-	22	88.0
II. 10,000 cfs								
4 radio	Charbonneau		-	-	-	-	0	0
4 magnetic	"		2	-	-	-	2	50.0
16 magnetic	Below Lower Monumental Dam		-	1	-	-	1	6.5
III. 0 cfs								
12 magnetic	Below Lower Monumental Dam			1	-	-	1	8.0
13 magnetic	Above Lower Monumental Dam			-	-	-	0	0
IV. 10,000 cfs								
4 radio	Above Lower Monumental Dam				-	-	0	0
13 magnetic	Above Lower Monumental Dam				-	-	0	0
4 magnetic	Below Lower Monumental Dam				-	-	0	0
V. 0 cfs								
4 radio	Above Lower Monumental Dam					-	0	0
2 magnetic	Above Lower Monumental Dam					-	0	0

Adult Steelhead Trout Movement, 1975

Radio-Tagged Steelhead

We did not observe any differences in behavior patterns or rates of travel for radio-tagged adult steelhead trout which could be attributed to the reduced nighttime flow regimes tested. Travel rates and recapture percentages for fish released during the first five flow periods were similar but decreased during the last period (Tables 7 and 8).

Radio-tagged steelhead monitored during all test flows from early September to late October (periods I-V) showed little difference in rate of travel or recapture percentage. Mean rates of travel for these periods ranged from 9.6 to 12.6 km/day (6.0 to 7.8 mi/day) for the 95 km (59 mi) from release at Charbonneau to recapture at Little Goose Dam (Table 7). Recapture percentages for these same periods ranged from 62.5% to 87.5% with a mean of 75%.

Since Lower Monumental Dam had no fish collection facilities, we were not always able to determine the exact time fish crossed that dam and were unable to establish average rates of travel within individual reservoirs. We did determine rate of travel for some radio-tagged steelhead through Ice Harbor pool. Of the 48 radio-tagged steelhead released, we monitored 11 as they first approached Lower Monumental Dam. Travel rates for these fish ranged from 2.96 to 38.4 km/day (1.8 to 23.8 mi/day) with an average of 20.9 km/day (13.0 mi/day) (Table 7).

Fewer radio-tagged steelhead released during flow periods VI (10,000 cfs, Oct. 20-26) and VIII (uncontrolled, Nov. 3-9) were recaptured at Little Goose Dam than previously released fish. Recapture percentages dropped to 25% and 12.5% for periods VI and VIII, respectively (Table 7). Those fish which were recaptured had a faster rate of travel through the entire study area than earlier fish. During periods VI and VIII radio-tagged steelhead traveled the 95 km (59 mi) from release at Charbonneau to recapture at Little Goose Dam at rates of 20.8 and 20.7 km/day (13.0 and 12.9 mi/day), respectively.

We observed different fish movement patterns in the tail races of Lower Monumental versus Little Goose Dam but no differences within the pools themselves. Radio-tagged steelhead moved rapidly from Charbonneau up to and over Lower Monumental Dam. Of the 48 radio-tagged steelhead released, 37 (77.1%) reached Lower Monumental Dam and 36 (75.0%) crossed the dam with little delay or downreservoir movement (Table 7). Radio-tagged fish generally moved over Lower Monumental Dam in less than 24 hours after reaching the dam. Radio-tagged steelhead moved rapidly through Lower Monumental pool to the base of Little Goose Dam. Of the 36 radio-tagged steelhead known to have crossed Lower Monumental Dam, 32 (88.9%) reached Little Goose Dam and 27 (75%) were recaptured as they moved up the ladder. Of the 32 which reached Little Goose Dam, 20 either delayed more than 24 hours and/or moved back downriver for more

Table 7. Travel rate and recapture of radio-tagged adult steelhead trout by flow period, 1975.

Flow and test period	Release date	Number released	Number reaching Lower Monumental	Rate of travel to Lower Monumental Dam km/day: Mean	Rate of travel to Lower Monumental Dam km/day: Range	Number crossing Lower Monumental	Number reaching Little Goose	Recaptures: Number	Recaptures: Percent	Rate of Travel to Little Goose km/day: Mean	Rate of Travel to Little Goose km/day: Range	Rate of Travel over Little Goose km/day: Mean	Rate of Travel over Little Goose km/day: Range
I 20,000 cfs Sept. 8-21	9/10	8	8	20.0	12.91-21.89	8	8	7	87.5	11.86	11.39-12.31	10.07	8.08-16.14
II 10,000 cfs Sept. 22-28		0											
III 0 cfs Sept. 29-Oct. 5	9/29	8	6	22.2	21.25-23.18	6	6	6	75.0	15.69	9.49-24.34	9.59	3.68-20.06
IV 10,000 cfs Oct. 6-12	10/7	8	7	2.91[a]		7	7	5	62.5	20.92	13.81-25.18	12.58	8.93-20.06
V 0 cfs Oct. 13-19	10/13	8	8	29.31	21.25-38.34	8	8	6	75.0	19.58	5.98-29.94	10.83	4.17-23.49
VI 10,000 cfs Oct. 20-26	10/21	8	6	18.89		6	4	2	25.0	15.30	12.15-19.90	20.84	7.38-34.27
VII 0 cfs Oct. 27-Nov. 2		0											
VIII Uncontrolled	11/13	8	2	15.69		1	1	1	12.5			20.72	
TOTALS		48	37	20.92	2.91-38.34	36	32	27	56.2	16.67		14.11	

a/ When range is not given, only one fish was monitored as it approached the dam.

(1 km = 0.621 miles)

Table 8. Comparison of rates of travel and recapture of magnetic-tagged adult steelhead trout during 20,000 cfs, 10,000 cfs, 0 cfs and uncontrolled nighttime flow regimes, 1975.

	Flow period	Number released	Date released	Release site	Number recaptured	Percentage recaptured	Rate of travel (km/day)	
							Range	Mean
I.	20,000 cfs	25	9/8, 9/9	Charbonneau	19	76	2.09-20.76	9.72
	Sept 8-Sept 21	5	9/11, 9/16	Levey	5	100	3.54-18.50	11.84
II.	10,000 cfs	25	9/23	Charbonneau	20	80	3.01-20.43	11.62
	Sept 22-Sept 28	25	9/22, 9/25	Levey	16	64	2.90-30.41	13.48
III.	0 cfs	25	9/29	Charbonneau	18	72	4.02-19.63	11.04
	Sept 20-Oct 5	10	9/29	Above Lo. Mo.[a/]	9	90	2.41-25.42	13.53
		14	10/1	Levey	8	57	7.24-24.14	13.74
IV.	10,000 cfs	25	10/6	Charbonneau	18	72	3.22-25.90	15.22
	Oct 6-Oct 12	10	10/7	Above Lo. Mo.	6	60	4.18-16.89	9.94
V.	0 cfs	25	10/13	Charbonneau	20	80	4.02-45.70	17.55
	Oct 13-Oct19	10	10/13	Above Lo. Mo.	9	90	4.02-20.76	8.25
		8	10/14	Levey	5	62	4.34-23.01	11.10
VI.	10,000 cfs	25	10/20	Charbonneau	17	68	5.31-34.11	14.06
	Oct 20-Oct 26	10	10/21	Above Lo. Mo.	9	90	5.15-38.13	19.74
VII.	0 cfs	25	10/27	Charbonneau	16	64	4.67-25.58	14.03
	Oct 27-Nov 2	10	10/28	Above Lo. Mo.	6	60	4.70-14.80	7.85
VIII.	Uncontrolled	25	11/3	Charbonneau	6	24	6.76-24.62	11.86
	Nov 3-Nov 9	10	11/4	Above Lo. Mo.	2	20	4.02-11.74	7.88
	Totals	312			209	67	2.09-45.70	12.36

a/ Above Lower Monumental Dam

than 8 km (5 mi). Delay at Little Goose Dam was also evident when comparing rates of travel up to Little Goose Dam with rates including recapture. Rates of travel up to Little Goose Dam averaged 16.7 km/day (10.4 mi/day) while rates including recapture averaged 14.1 km/day (8.8 mi/day) (Table 7). Seventeen (85%) of the fish which delayed or back-tracked did reapproach and cross Little Goose Dam. Time spent at the dam or backtracking ranged from 1 to 14 days ($\bar{X}$ = 6.2 days) and was characterized by random movement in or near the fish ladder entrances, sometimes interrupted by downriver movement of up to 32.8 km (20 mi) (Appendix B).

We found radio-tagged steelhead moving at all hours of the day, but most movement occurred during daylight hours. Of all radio-tagged steelhead released, we observed 7 (15%) which moved 1.6 km (1 mi) or more at night. While we commonly observed short distance nighttime movement of radio-tagged steelhead in and near the tail race of both dams, we observed only one attempted dam crossing during darkness. During period V (0 cfs, October 13-19), one radio-tagged steelhead entered and ascended the Lower Monumental north shore ladder during the hours 0100 to 0600.

Changes in movement patterns were often associated with sunrise or sunset. A radio-tagged steelhead which had stopped or which had been moving downstream during the night would often start moving upstream with daylight. Since the controlled nighttime flows ended at 0700 hours, we were unable to determine whether changes in movement patterns were brought about by daylight or the increased flows. We observed no trends in behavior that could be directly attributed to the periods of flow change (2300 hours and 0700 hours).

Magnetic-Tagged Steelhead

As with radio-tagged steelhead, magnetic-tagged test fish showed no trends in rate of travel or recapture percentage that could be attributed to reduced nighttime test flows. The percentage of magnetic-tagged steelhead recaptured and their rates of travel were similar to those of radio-tagged fish. Mean rates of travel for all test flows ranged from 7.9 to 19.7 km/day with an overall mean of 12.4 km/day (4.9 to 12.3 mi/day, $\bar{X}$ = 7.7) (Table 8). Fish recaptured ranged from 100% to a low of 20% of those released and as with radio-tagged steelhead, a smaller percentage of fish released during the last two flow periods were recaptured (Table 8).

During the steelhead migration portion of the study, we released a total of 312 magnetic-tagged adult steelhead: 200 at Charbonneau, 52 at Levey, and 60 above Lower Monumental Dam. Fish released at Charbonneau and upstream from Lower Monumental Dam were transported downriver from Little Goose Dam while fish released at Levey were collected, magnetic-tagged and returned to the reservior at Levey (Figure 2).

Transporting adult steelhead back downriver during September and October did not adversely affect rates of travel or percentage recaptured (Table 8; Figure 12). Mean travel rate of both transported steelhead released at Charbonneau and nontransported steelhead released at Levey was 12.5 km/day (7.8 mi/day) for the same time periods. Seventy-seven percent of the transported steelhead were recaptured at Little Goose Dam compared to 71% return from nontransported releases.

About 50% of all radio- and magnetic-tagged steelhead were recaptured within two weeks after release. This held true until late October when tagged steelhead apparently started overwintering (Table 9). The remaining recaptures were collected throughout the 1975 study period and into the spring of 1976.

After the collection facilities at Little Goose Dam were reopened in March 1976, 19 of our tagged steelhead were recaptured. All but one of these spring recaptures had been released in the last three flow periods of 1975 (Table 9). These data support the hypothesis that reduced recaptures from late October-early November releases were a result of fish ceasing their migration to overwinter and not test flow conditions.

Overwintering Steelhead Trout

The Army Corps of Engineers was unable to supply needed flows to test effects of reduced nighttime discharge on overwintering. However, we did gather data on general movement and behavior patterns of steelhead overwintering in lower Snake River reservoirs.

We monitored 10 radio-tagged adult steelhead released upstream from Lower Monumental Dam on December 11 and 12, 1975 and 10 radio-tagged steelhead remaining in the study area from our previous tests.

The basic movement patterns of overwintering fish we monitored were:

1) slow movement upreservoir with frequent and prolonged stops,
2) limited downreservoir movements,
3) lateral and vertical movement of fish holding in a particular area, and
4) a tendency to occupy the upstream two-thirds of the reservoir.

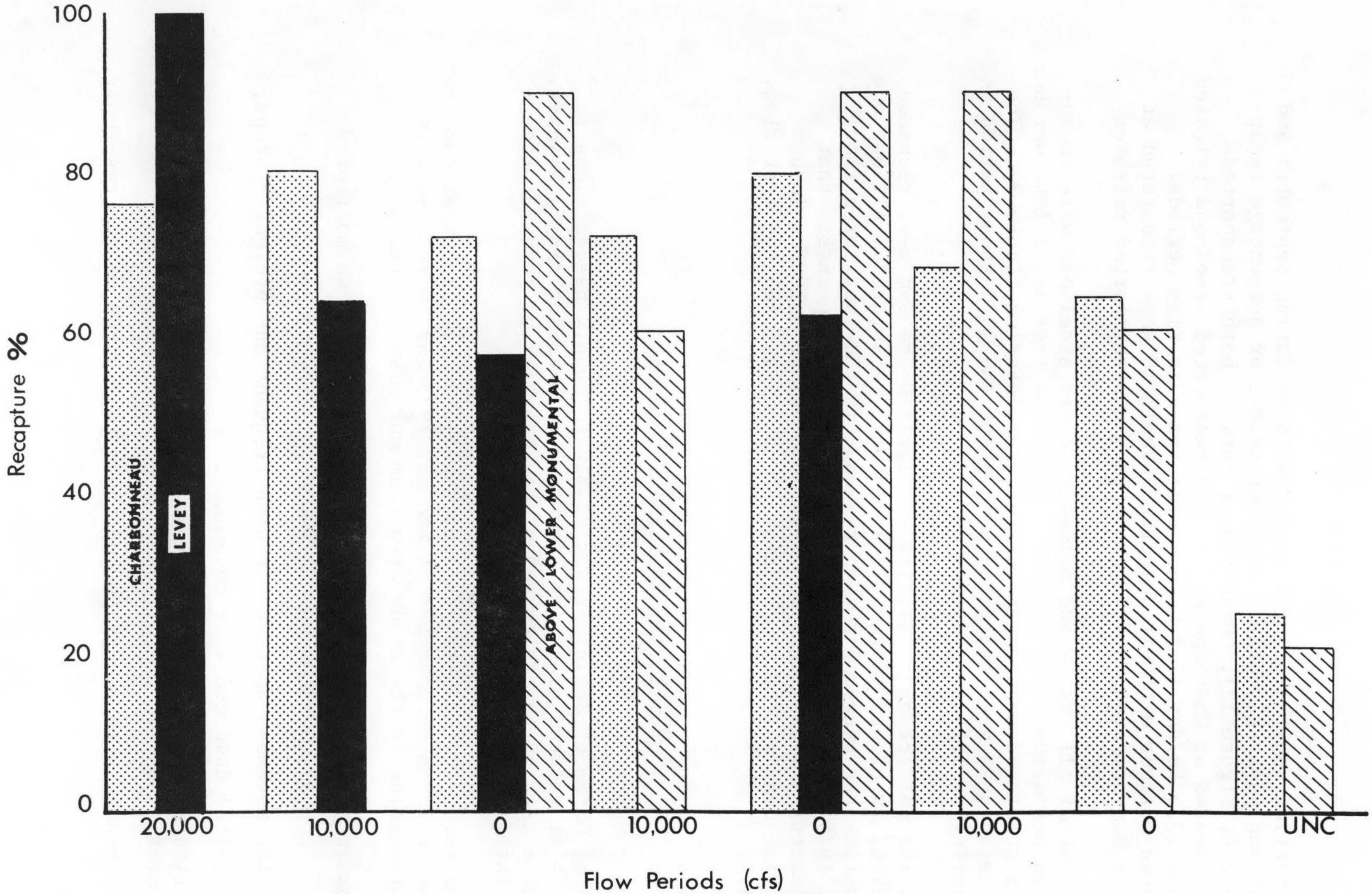

Figure 12. Comparison of recapture percentages of transported and nontransported magnetic-tagged steelhead, 1975. Charbonneau and above Lower Monumental releases were transported downreservoir while Levey releases were not transported.

Table 9. Radio- and magnetic-tagged adult steelhead trout recaptured at Little Goose Dam by flow period and release site, fall 1975 and spring, 1976.

			Period of Recapture											
			Fall 1975							Spring 1976				
Test period, no. released, tag type	Release site		9/8-9/22 20,000	9/23-9/29 10,000	9/30-10/13 0	10/7-10/13 10,000	10/14-10/20 0	10/21-10/27 10,000	10/28-11/3 0	11/14-11/17 Uncontrolled		3/18-4/8	Total No.	%
I. 20,000 cfs														
8 Radio	Charb.[a]		7										7	87.5
20 Mag.	Charb.	4	10	1	1		1	2					19	76.0
5 Mag.	Levey		2	2			1			1[b]			5	100
II. 10,000 cfs														
25 Mag.	Charb.			7	9	2		1	1				20	80.0
25 Mag.	Levey			8	2	2	3	1					16	64.0
III. 0 cfs														
8 Radio	Charb.				1	3	1	1					6	75.0
25 Mag.	Charb.				5	9	1	3					18	72.0
14 Mag.	Levey				2	5	1						8	57.0
10 Mag.	Above Lower Monumental				6	2	1						9	90.0
IV. 10,000 cfs														
8 Radio	Charb.					1	4						5	62.5
25 Mag.	Charb.					9	6	2		1			18	72.0
10 Mag.	Above Lower Monumental					4	2						6	60.0
V. 0 cfs														
8 Radio	Charb.						1	3	1	1			6	75.0
25 Mag.	Charb.						12	5	1	2		1	21	84.0
8 Mag.	Levey						1	2	1	1			5	62.5
10 Mag.	Above Lower Monumental						3	6					9	90.0
VI. 10,000 cfs														
8 Radio	Charb.							1	1			4	6	75.0
25 Mag.	Charb.							6	9	2			17	68.0
10 Mag.	Above Lower Monumental							7	2			1	10	100
VII. 0 cfs														
25 Mag.	Charb.								9	4	3	3	19	75.0
10 Mag	Above Lower Monumental								2	3	1		6	60.0
VIII. Uncontrolled														
8 Radio	Charb.									1		2	3	38.0
25 Mag.	Charb.									1	5	6	12	48.0
10 Mag.	Above Lower Monumental									1	1	1	3	30.0

[a] Charbonneau release site.

[b] Recaptured twice (Sept. 25; Nov. 2, 1975)

During the winter study period upreservoir movements of radio-tagged steelhead were usually less than 1.0 km/day (0.6 mi/day), although we monitored some fish moving as much as 32 km (20 mi) in one week. Prolonged stops were common with some fish staying in or near the same location for several days. While in an area, radio-tagged steelhead displayed some lateral movement across the reservoir and, judging by relative radio signal strength, also moved up and down in the water column. The more frequent observation of fish in the upstream two-thirds of the reservoir could be biased as we had difficulty receiving radio signals from fish deeper than 18 m (60 ft). The lower end of Lower Monumental pool has depths exceeding 30.5 m (100 ft).

Only two of the 10 steelhead radio-tagged and released to study overwintering behavior were known to have reached Little Goose Dam. One other test fish was located approximately 2.4 km (1.5 mi) below Little Goose but was not observed at the dam. The two fish which reached Little Goose Dam remained in the vicinity of the dam for 1 to 5 days and either moved back downreservoir and were not relocated or moved over the dam without detection. Since we did not maintain constant surveillance during our overwintering studies, we were unable to determine the time test fish first reached Little Goose Dam. Movement patterns of overwintering test fish are shown in Appendix C.

The NMFS adult collection facilities were not in operation from November 25, 1975 through March 1, 1976, except for two brief periods during the time we were collecting fish for tagging and transportation. Therefore, we were unable to determine if, or when, a test fish left the study area by crossing Little Goose Dam during that period. We could not assume unlocated fish had left the study area, because the fish may have been in water too deep for radio reception.

When the collection facilities were reopened in the spring of 1976, most test fish recaptured were from 1975 October and November releases. Only one radio-tagged steelhead released during the overwintering objective was recaptured in the spring. This fish was one of the two we monitored at Little Goose Dam. However, it is probable that some radio- and magnetic-tagged steelhead overwintering below Little Goose crossed the dam during the period when the collection facilities were not in operation (November 25, 1975-March 1, 1976). We know from past dam counts that few steelhead pass over dams during the winter period.

Dam Count Analysis

Using analysis of variance and Wilcoxon's signed-ranks test of counts of chinook and steelhead crossing Snake River Dams, we found no significant difference between numbers crossing with nighttime flows of 0 versus 20,000 cfs during the period July 21-October 5, 1976 (Table 10). We analyzed fish counts from Ice Harbor, Lower Monumental and Little Goose dams. We applied a randomized complete block design in our analysis of variance, defining a block as one consecutive set of 0 and 20,000 cfs nighttime flow periods (i.e. 2 days 0 cfs and 2 days 20,000 cfs); each of the three dams were tested independently. By analyzing our data in this manner we were able to test for differences within blocks with nearly homogenous conditions (position in run, river temperature, etc). Any significant differences in the numbers of chinook and steelhead crossing lower Snake River Dams within a block would indicate an effect from our test flow conditions.

Results of analyzing variance showed no relationship between test nighttime flows and salmonid passage when comparisons were made within blocks for each dam (Table 10). As expected, however, the numbers of fish passing between blocks were significantly different for both chinook and steelhead at Ice Harbor, Lower Monumental and Little Goose dams. These differences were caused by changes in number of fish moving upriver as the runs progressed and were not a function of our test flow conditions.

We were unable to conduct similar analyses on 1975 dam count data because controlled flow tests were 7 days duration as opposed to 2 days in 1976. Similar analysis of 1975 data would have necessitated 14 day blocks, causing natural flucations in the run to appear as effects of test nighttime flows.

Because our data did not meet some of the assumptions of analysis of variance, we also analyzed dam counts using the non-parametric, analagous Wilcoxon's signed-ranks test. Identical comparisons were made and in each case we found no statistical difference (.05 level) between chinook and steelhead passage and test nighttime flows of 0 and 20,000 cfs.

Table 10. Least squares analysis of variance for test nighttime flow and fish passage at Ice Harbor, Lower Monumental and Little Goose dams for chinook salmon and steelhead trout, 1976.

Ice Harbor Dam

Chinook Salmon

Source	D.F.	Mean Squares	F
Between blocks	16	1312.590	23.54**
Within blocks	1	14.769	< 1
Between x within	16	55.765	0.831
Error	34	67.088	
Total	68		

Steelhead Trout

Source	D.F.	Mean Squares	F
Between blocks	16	53657.284	23.23**
Within blocks	1	535.391	< 1
Between x within	16	2310.052	1.047
Error	34	2207.137	
Total	68		

Table 10. (Continued)

Lower Monumental Dam

Chinook Salmon

Sources	D.F.	Mean Squares	F
Between blocks	15	2488.028	35.32**
Within blocks	1	43.537	< 1
Between x within	15	70.450	0.816
Error	32	86.364	
Total	64		

Steelhead Trout

Sources	D.F.	Mean Squares	F
Between blocks	15	65082.255	22.78**
Within blocks	1	100.423	< 1
Between x within	15	2856.582	2.010
Error	32	1421.266	
Total	64		

Table 10. (Continued)

Little Goose Dam

Chinook Salmon

Source	D.F.	Mean Squares	F
Between blocks	12	1207.207	4.57*
Within blocks	1	410.700	1.56
Between x within	12	263.986	2.233
Error	26	118.231	
Total	52		

Steelhead Trout

Source	D.F.	Mean Squares	F
Between blocks	12	17898.823	2.31
Within blocks	1	793.102	< 1
Between x within	12	7755.147	1.270
Error	26	6106.737	
Total	52		

DISCUSSION

By utilizing radio-telemetry and mark-recapture techniques and by statistically analyzing dam counts, we conclude that reduced nighttime flows tested had no effects on upriver migration of adult chinook salmon and steelhead trout. Although we were unable to test effects of reduced nighttime flows on overwintering of steelhead in lower Snake River reservoirs, our observations on behavior of overwintering steelhead gave no indication that reduced nighttime flows would have a detrimental effect.

In evaluating effects of reduced nighttime flows on adult chinook salmon migration we found that most radio- and magnetic-tagged chinook which successfully passed through the study area were released during the uncontrolled flow period (July 7-23, 1975) (Tables 4 and 5). These data should not be interpreted to mean that reduced nighttime flows caused fish passage problems at the dams or within the reservoirs.

To determine if the untagged population of summer chinook reacted similarily to our 1975 test flows, we examined fish counts from Ice Harbor, Lower Monumental, Little Goose and Lower Granite dams for the period July through August, 1975. If reduced nighttime flows caused poor passage of chinook during flow tests, we would expect reduced passage at Little Goose and Lower Monumental dams (nighttime flows controlled) compared to passage at Lower Granite and Ice Harbor dams (nighttime flows not controlled). After comparing chinook passage for each nighttime test period at each dam, we could not find any indication that reduced nighttime flows had affected the untagged fish (Figure 13).

The timing of our tests in relation to the chinook run and the 7 day duration of test flows in 1975 made statistical comparisons between test periods inappropriate. However, in 1976 nighttime test flows were of 2 day duration and statistical comparisons were possible. Using analysis of variance and Wilcoxon's signed-ranks test we analyzed dam counts from Ice Harbor, Lower Monumental and Little Goose dams. Findings of these analyses supported our 1975 observations that nighttime flows had no detectable adverse effect on the migrating fish.

Since untagged summer chinook in both 1975 and 1976 showed no adverse response to reduced nighttime flows, we believe that failure of radio- and magnetic-tagged fish to successfully pass through the study area in 1975 was not a result of test flows but rather a result of handling and transportation stress. When nighttime flows were reduced during 1975 physical conditions included reduction in total discharge, no spill at the dams and reservoir water temperatures ranging from 20.0 to 21.1 C (68-70 F) (Figure 14). During the 1975 uncontrolled flow period, when radio- and magnetic-tagged chinook passed through the study area more successfully, reservoir water temperatures ranged from 15.6 to 18.9 C (60-66 F) (Figure 14) and high flows were passing the dams. In addition, chinook used in the uncontrolled flow tests were taken from

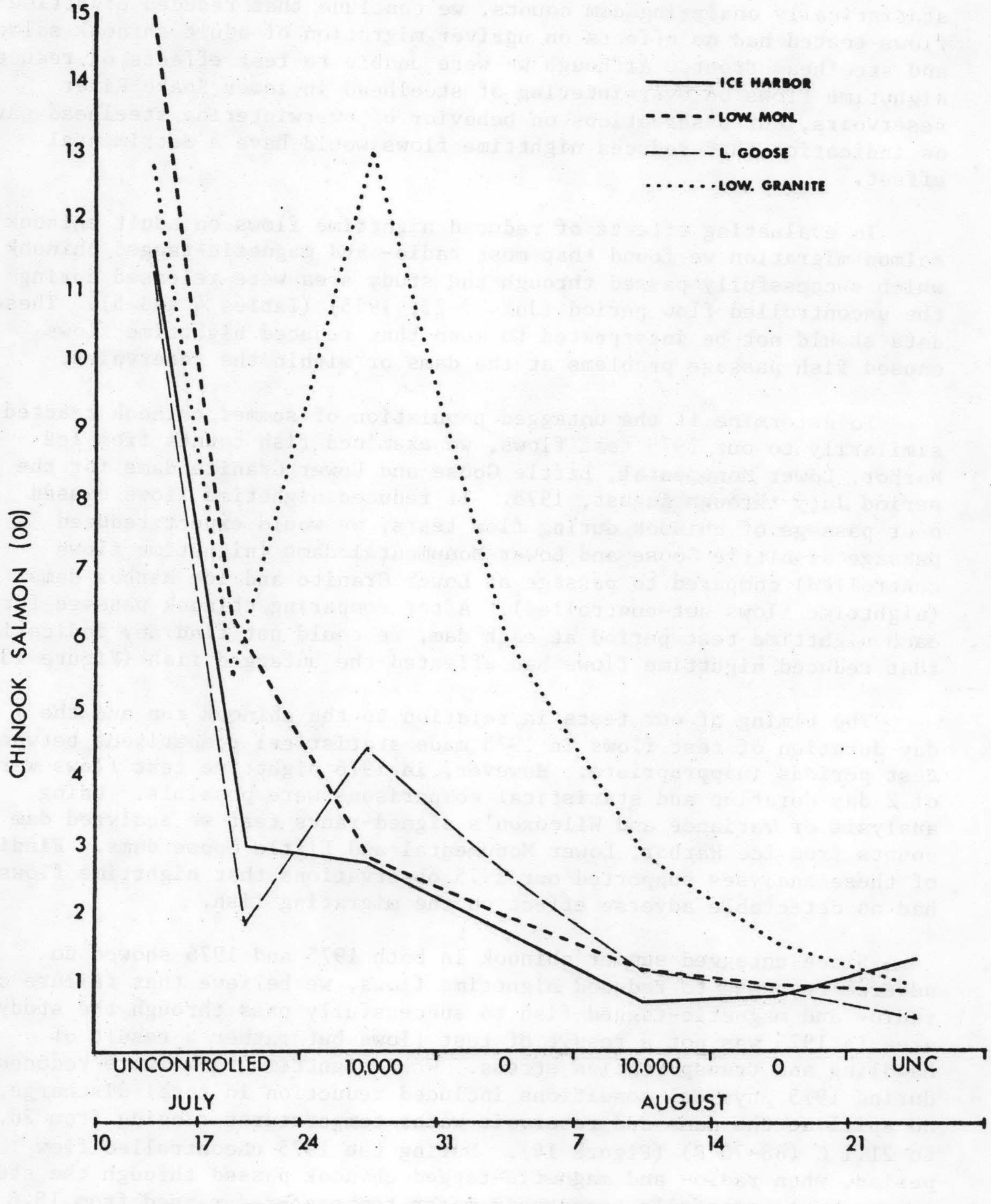

Figure 13. Comparison of chinook salmon passage over lower Snake River dams during reduced nighttime flow tests, 1975.

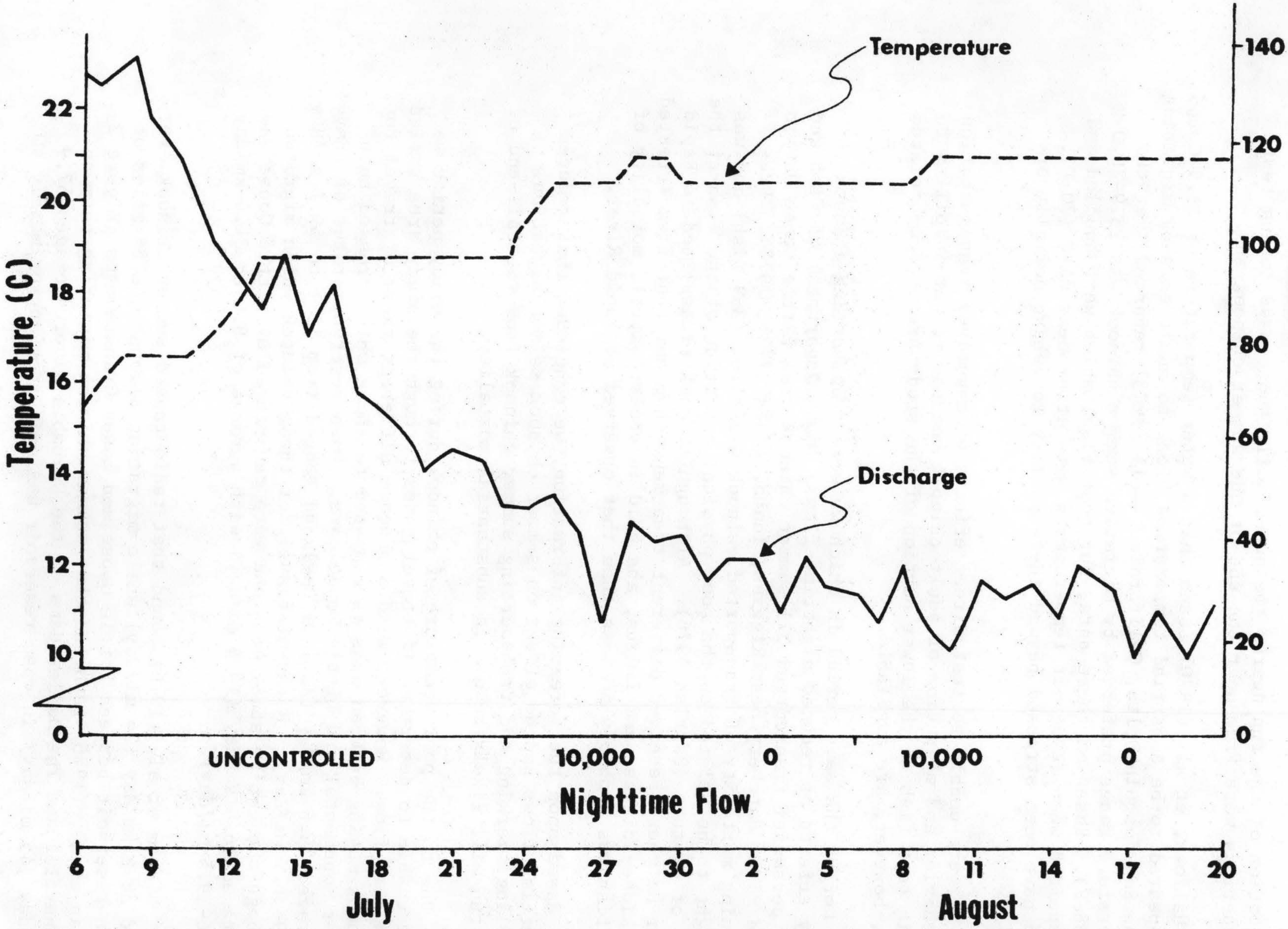

Figure 14. Temperature and mean daily flow at Little Goose Dam during tests on effects of reduced nighttime flows on chinook salmon migration, July and August, 1975.

the portion of the run nearer the peak, while those used during test flow periods were from near the end of the summer chinook run.

Hallock, et al. (1970) found that a water temperature of 18.9 C (66 F) appeared to be a partial temperature block to adult chinook migrating in the San Joaquin Delta, California. Bell (1973) reported that the temperature range preferred by migrating summer chinook was 13.9-20.0 C (57-68 F). Based on these data, our test fish, which were handled and transported when reservoir temperatures were at or near 21 C (70 F), could have been stressed beyond their ability to behave normally or survive.

We were unable to test direct effects of downriver transportation on behavior and migration of adult chinook because of our inability to obtain test fish in the lower portion of the study area. Some related data, however, are available.

During the same period in which we were transporting chinook to study effects of reduced nighttime flows, Idaho Department of Fish and Game personnel transported 571 summer chinook from Little Goose Dam to Rapid River Hatchery near Riggins, Idaho, (July 17-21, 1975). Pre-spawning mortality of transported chinook was 64.6% (369 fish) and was thought to be related to the poor physical condition of the fish at the time of capture (Parrish 1976). Although chinook transported to Rapid River Hatchery received different treatment than our test fish (treated for kidney disease and fungus, and held in cooler water), mortality of our fish was probably no less than that observed at Rapid River.

Based upon the foregoing information, we concluded that reduced nighttime flows had no effect on summer chinook salmon migration. Handling, marking and transporting summer chinook from the tail-end of the run will likely result in substantial mortality.

Due to the poor recapture of chinook during the study period we were unable to determine if travel rates through the study area varied with test flow. However, we did observe different rates of travel for chinook moving between dams as compared to those which crossed both Lower Monumental and Little Goose dams. Open reservoir rates of travel averaged 35.6 km/day (22.1 mi/day) and ranged from 11.1 to 59.1 km/day (6.9-36.7 mi/day). Rates of travel for those chinook which migrated through the entire study area and were recaptured at Little Goose Dam averaged 16.8 km/day (10.4 mi/day) with a range of 9.0 to 31.4 km/day (5.6-19.5 mi/day).

Liscom et al. (1976) found that radio-tagged summer chinook averaged 38.6 km/day (24 mi/day) while migrating through the 36 miles of open reservoir between Little Goose and Lower Granite dams (Figure 2). Monan et al. (1976) reported that summer chinook migrating between Bonneville and The Dalles dams on the Columbia River averaged 57.9 km/day (45 mi/day) in open reservoir while it took approximately 40 hours to negotiate the 1.6 km (1 mi) containing each dam. Rates of travel of chinook salmon we observed in 1975 for open reservoir migration were comparable to those of Liscom et al. (1976) while Monan et al. (1976) reported a faster rate for chinook in the lower Columbia River. Delay caused by dams is apparent in the differences between the rates of travel with and without dam passage.

We were unable to document any movement or behavior pattern that could be correlated to either controlled nighttime flows or to the actual periods of flow change (i.e., daytime peaking to nighttime controlled flows). Monan et al. (1976) reported similar results in that "no dramatic or immediate changes in behavior were observed that could be directly correlated with changes in turbine flow." They also found no evidence to indicate that reductions in flow had any significant effect on chinook passage at The Dalles Dam.

By the end of 1978 or early 1979, lower Snake River dams are scheduled to double their power generation capacity as the full complement of six generators are installed at each dam. At the present time, full scale peaking operations without spilling are confined to time periods when river flow is below approximately 60,000 cfs. With the new generators in operation, this capacity will be doubled and full scale peaking flows will be possible at an earlier date. It has been reported that a portion of the between-dam losses of Columbia and Snake river chinook stocks can be attributed to peaking (Anonomous 1975; Junge 1966, 1971). Junge (1971) found that flows from peaking operations, when in excess of 100,000 cfs, caused increased delay and were associated with poor salmonid passage at Priest Rapids Dam citing turbulance below the power house as the main factor causing poor passage. At dams such as Little Goose and Lower Granite this turbulance could obstruct the major entrances to fish passage facilities. While we have shown that reduced nighttime flows do not adversely affect migrating chinook salmon, large daytime flows associated with a full scale peaking operation (including zero nighttime flows) could cause delay. Further study into the effects of full-scale peaking operations, especially the high flow portion, may be warranted.

The behavior or rate of travel of radio- or magnetic-tagged adult steelhead trout was not affected by the reduced nighttime flows we tested. Rate of travel and recapture percentages were similar during flow periods I-V (September 8 - October 19, 1975) which included uncontrolled, 0 cfs and 10,000 cfs test nighttime flows (Tables 7 and 8). During periods VI - VIII (October 20 - November 9, 1975) total movement of radio-tagged steelhead slowed and recaptures of both radio- and magnetic-tagged steelhead decreased. Results obtained from test flows during September and October 1975 suggested that reduced movement and recaptures in late October and early November were not a result of reduced nighttime flow tests but rather a probable response to decreasing reservoir temperatures and initiation of overwintering behavior. Water temperatures during September and early October ranged from 20.6 C down to 15.5 C (69-60 F) while during later test periods temperatures dropped as low as 10 C (50 F). Falter et al. (1974) reported that steelhead movement was positively correlated with water temperatures in lower Snake River reservoirs and that steelhead migration rates were less than 1.6 km/day (1 mi/day) in the 0-11 C (32-51.8 F) temperature range. Recaptures during the spring of 1976 were predominately steelhead released during these latter three periods (Table 9). These data provide additional evidence supporting the hypothesis that reduced recaptures of radio- and magnetic-tagged steelhead in late October and early November was a result of initiation of overwintering behavior rather than a response to test flow conditions.

Our tests on effects of downriver transportation showed that transported steelhead performed equally as well as non-transported fish in terms of rate of travel (Table 8) and recapture percentage (Figure 12). Transportation, therefore, appears to have much less of an affect on steelhead than on chinook. Possible explanations for this are (1) more favorable enviornmental conditions during the period in which steelhead were migrating (reduced temperature) and (2) the fact that the steelhead were 6 months away from spawning while chinook would spawn by fall.

Individual steelhead travel rates were variable but the range of rates between test periods was similar for all flow tests. Overall average rate of travel was 12.8 km/day (7.9 mi/day) with mean rates ranging from 7.8 to 20.8 km/day (4.9-12.9 mi/day) including passage of Lower Monumental Dam and recapture at Little Goose Dam. Falter et al. (1974) reported mean travel rates ranging from 0.5 km/day to 15.3 km/day (0.3 to 9.5 mi/day).

Our data indicate that Little Goose Dam delayed steelhead migration more than did Lower Monumental Dam. Radio-tagged steelhead usually passed Lower Monumental Dam in less than 1 day while 62% of those reaching Little Goose delayed for more than 24 hours. In addition, differences between rates of travel up to Little Goose and travel rates including recapture at Little Goose indicated the dam caused some delay in steelhead migration. There were considerable construction activities at the dam during our study.

To determine if the general population of migrating steelhead was responding similarly to our tagged fish during test flows, we evaluated 1975 steelhead fish count data from Ice Harbor, Lower Monumental, Little Goose and Lower Granite dams for the period September 8 through November 2. No trends in adult steelhead passage which could be related to 10,000 or 0 cfs test nighttime flow conditions were observed (Figure 15). We also evaluated 1976 chinook and steelhead counts made during the 20,000 and 0 cfs nighttime flow tests at Ice Harbor, Lower Monumental and Little Goose dams. Evaluation of these counts showed that

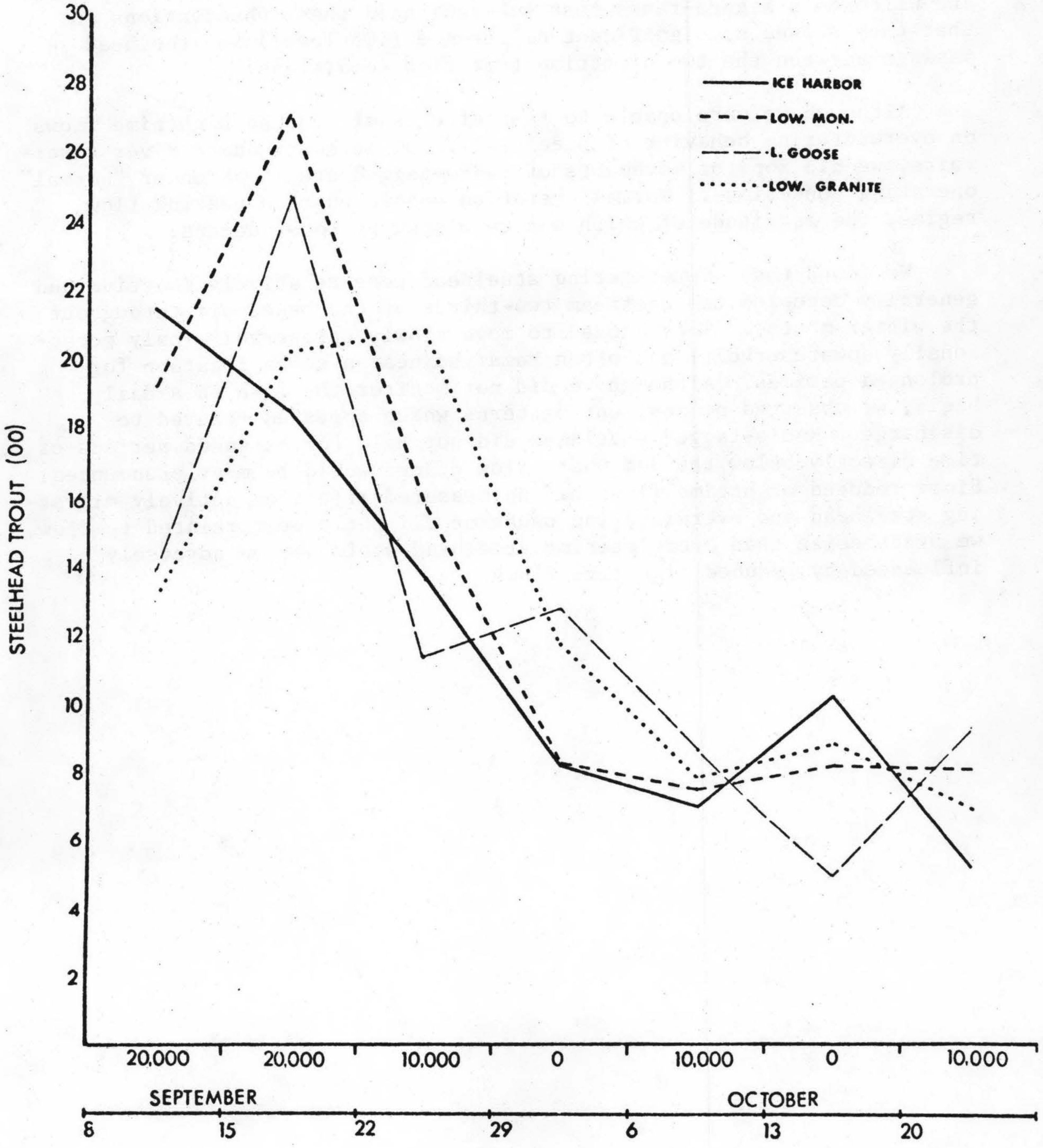

Figure 15. Comparison of weekly steelhead trout passage over lower Snake River dams during reduced nighttime flow tests, 1975.

daily numbers of chinook and steelhead passing lower Snake River dams were extremely variable and fluctuations in number could not be related to test nighttime flow conditions (Figures 16-19). Analysis of variance and Wilcoxon's signed-ranks test substanitated these observations in that they showed no significant difference (.05 level) in steelhead passage between the two nighttime test flow conditions.

Although we were unable to test effects of reduced nighttime flows on overwintering behavior of steelhead trout in lower Snake River reservoirs, we did monitor movements of radio-tagged steelhead under "normal" operating conditions. Normal operation consisted of a peaking flow regime, the magnitude of which was regulated by power demand.

We found that overwintering steelhead were relatively inactive and generally occupied the upstream two-thirds of the reservoir throughout the winter months. They tended to move slowly upreservoir (only occasionally downreservoir) and often remained near a given location for prolonged periods. Although we did not monitor the fish on a daily basis, we observed no movement patterns which appeared related to discharge. Radio-tagged steelhead did not hold for extended periods of time directly below the dam where flow change would be most pronounced. Since reduced nighttime flows had no measured effect on actively migrating steelhead and overwintering behavior did not appear related to flow, we hypothesize that overwintering steelhead would not be adversely influenced by reduced nighttime flows.

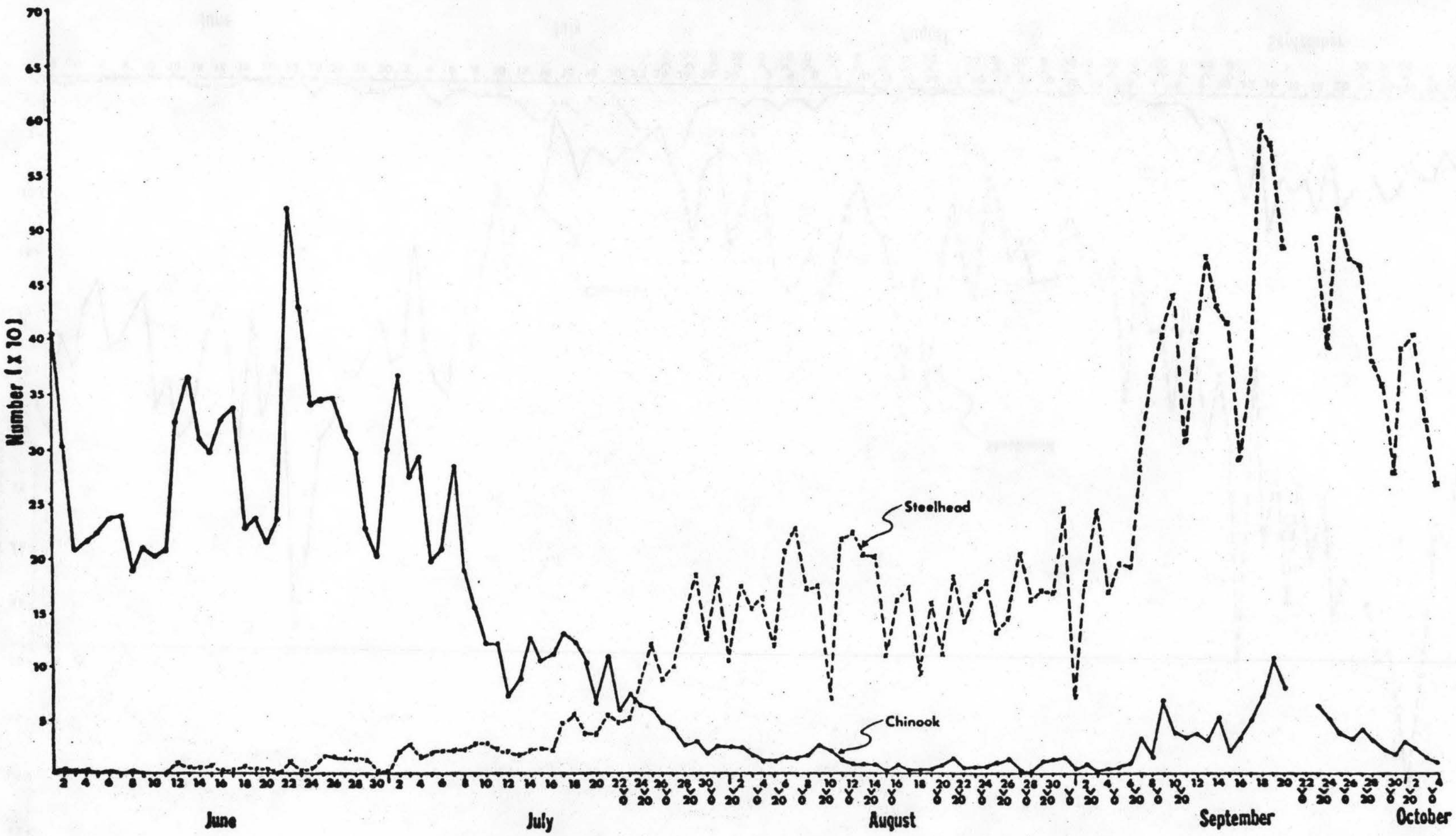

Figure 16. Daily chinook and steelhead passage over Ice Harbor Dam before and during 1976 reduced nighttime flow tests of 0 and 20,000 cfs.

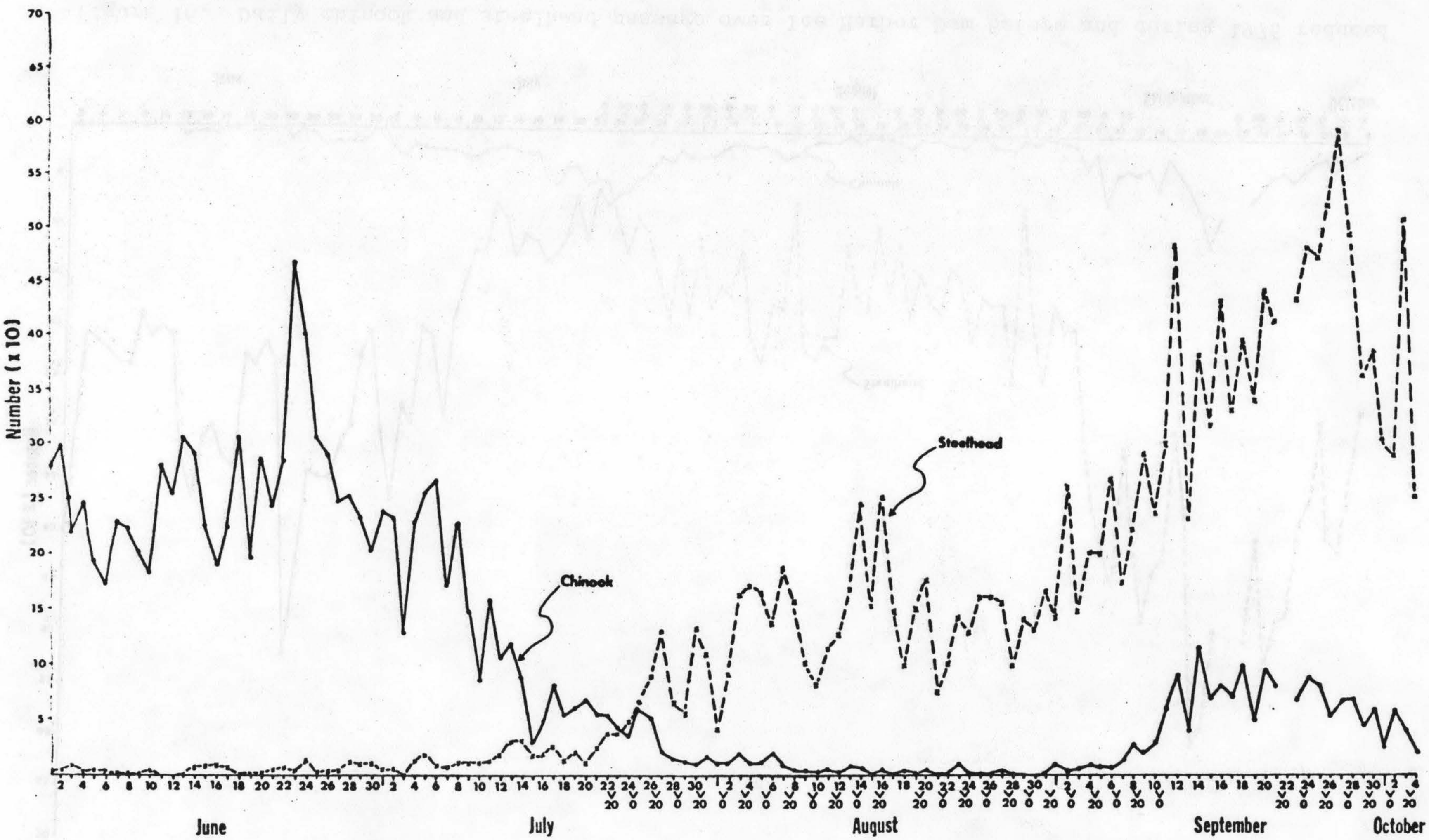

Figure 17. Daily chinook and steelhead passage over Lower Monumental Dam before and during 1976 reduced nighttime flow tests of 0 and 20,000 cfs.

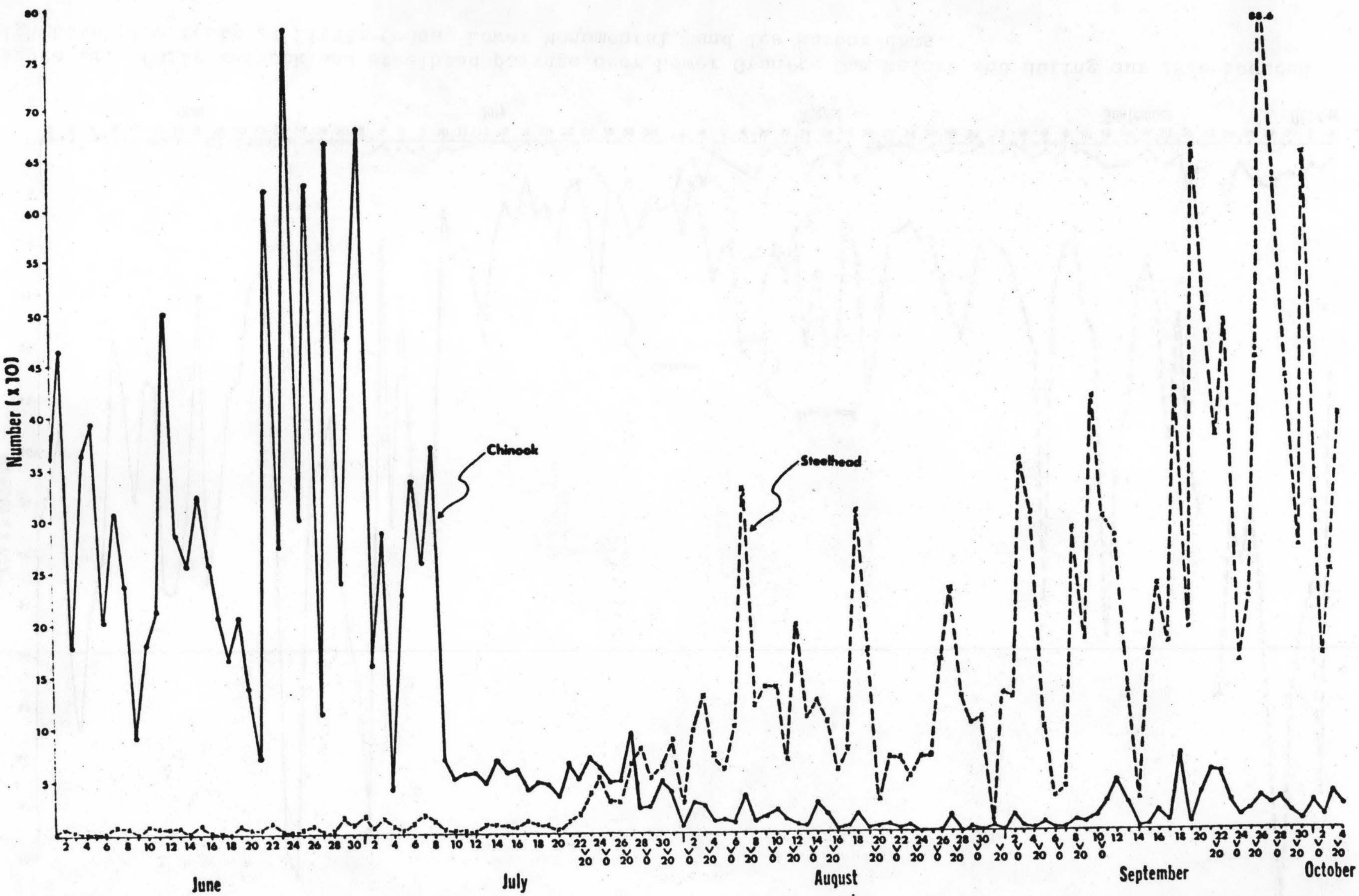

Figure 18. Daily chinook and steelhead passage over Little Goose Dam before and during 1976 reduced nighttime flow tests of 0 and 20,000 cfs.

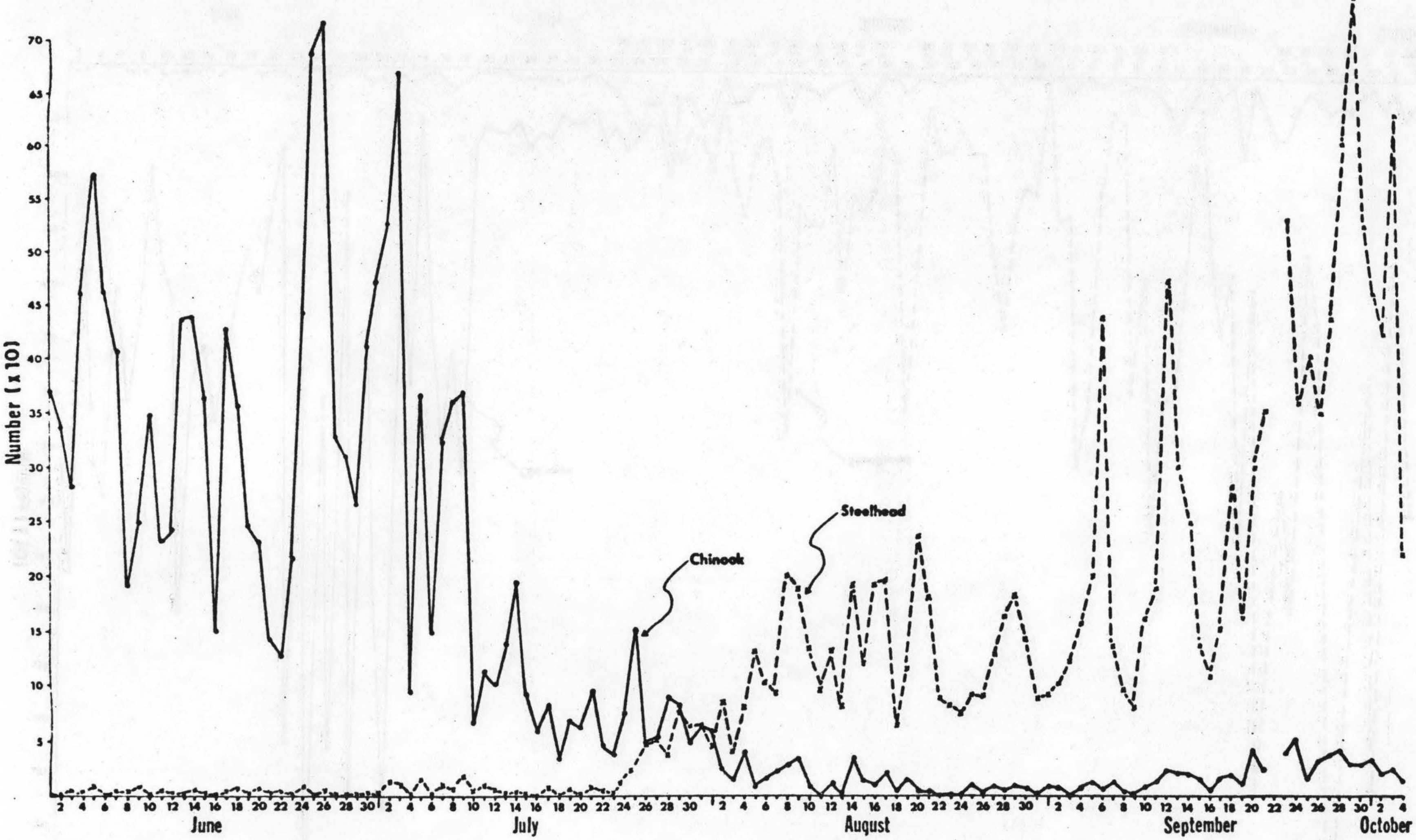

Figure 19. Daily chinook and steelhead passage over Lower Granite Dam before and during our 1976 reduced nighttime flow tests at Little Goose, Lower Monumental, and Ice Harbor dams.

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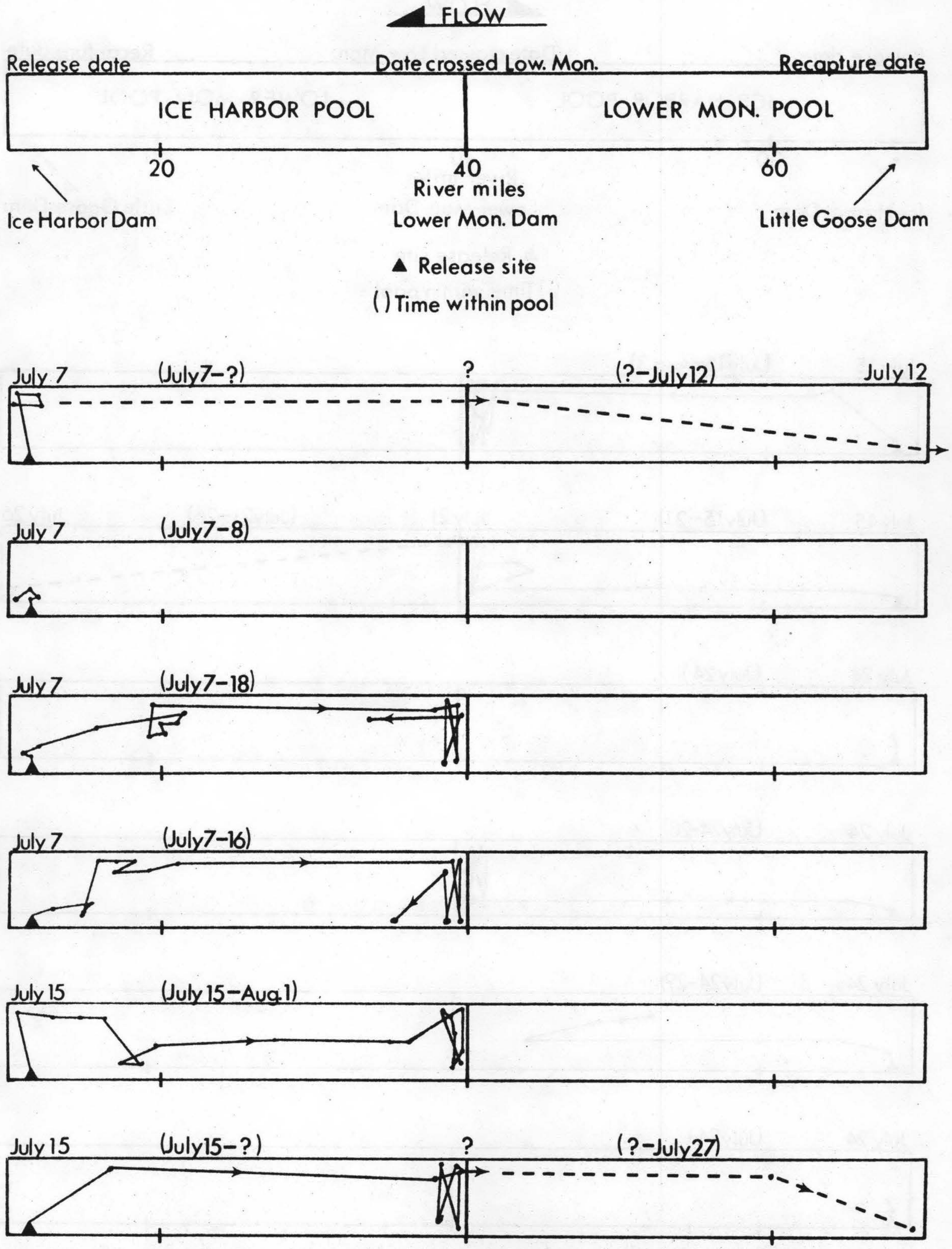
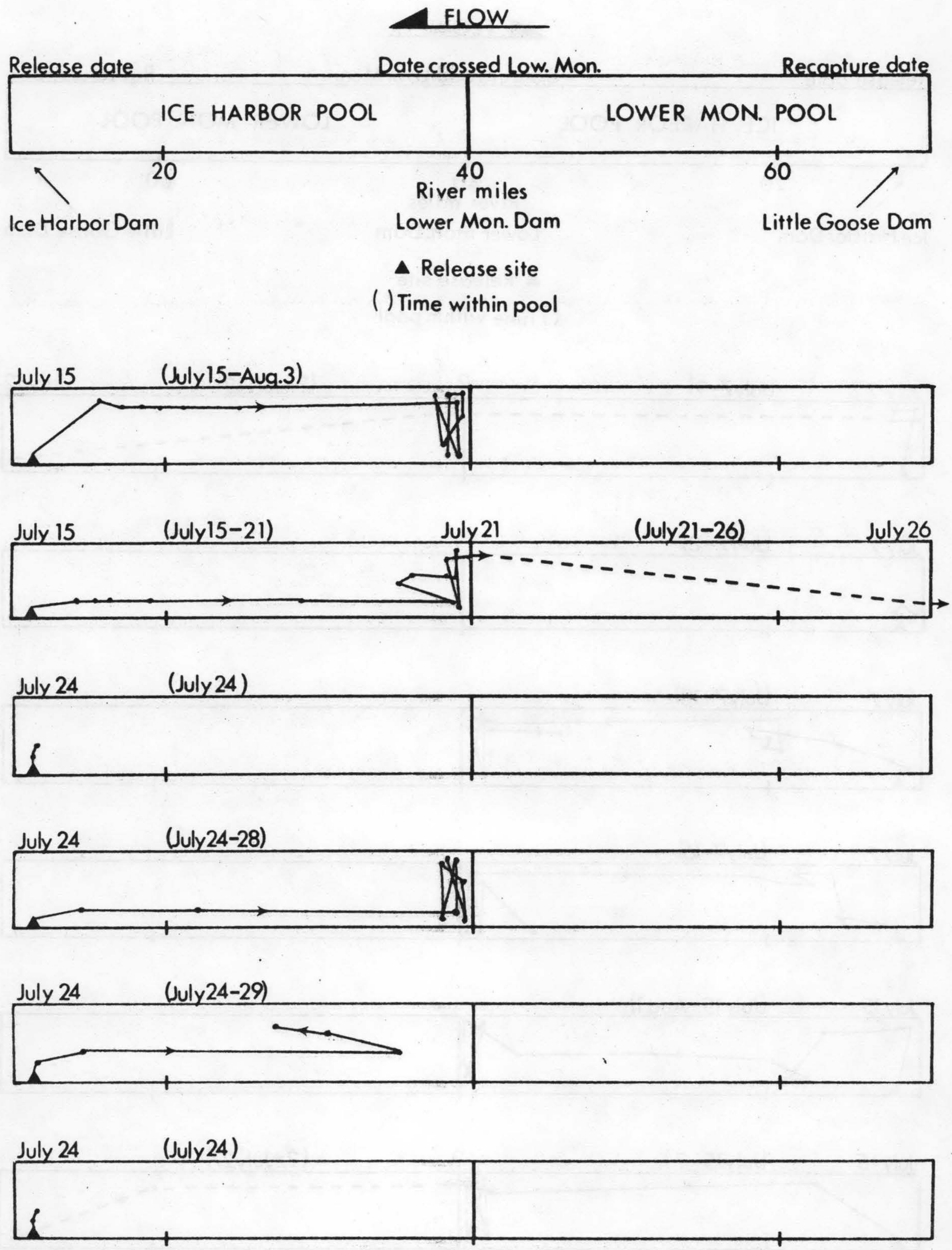
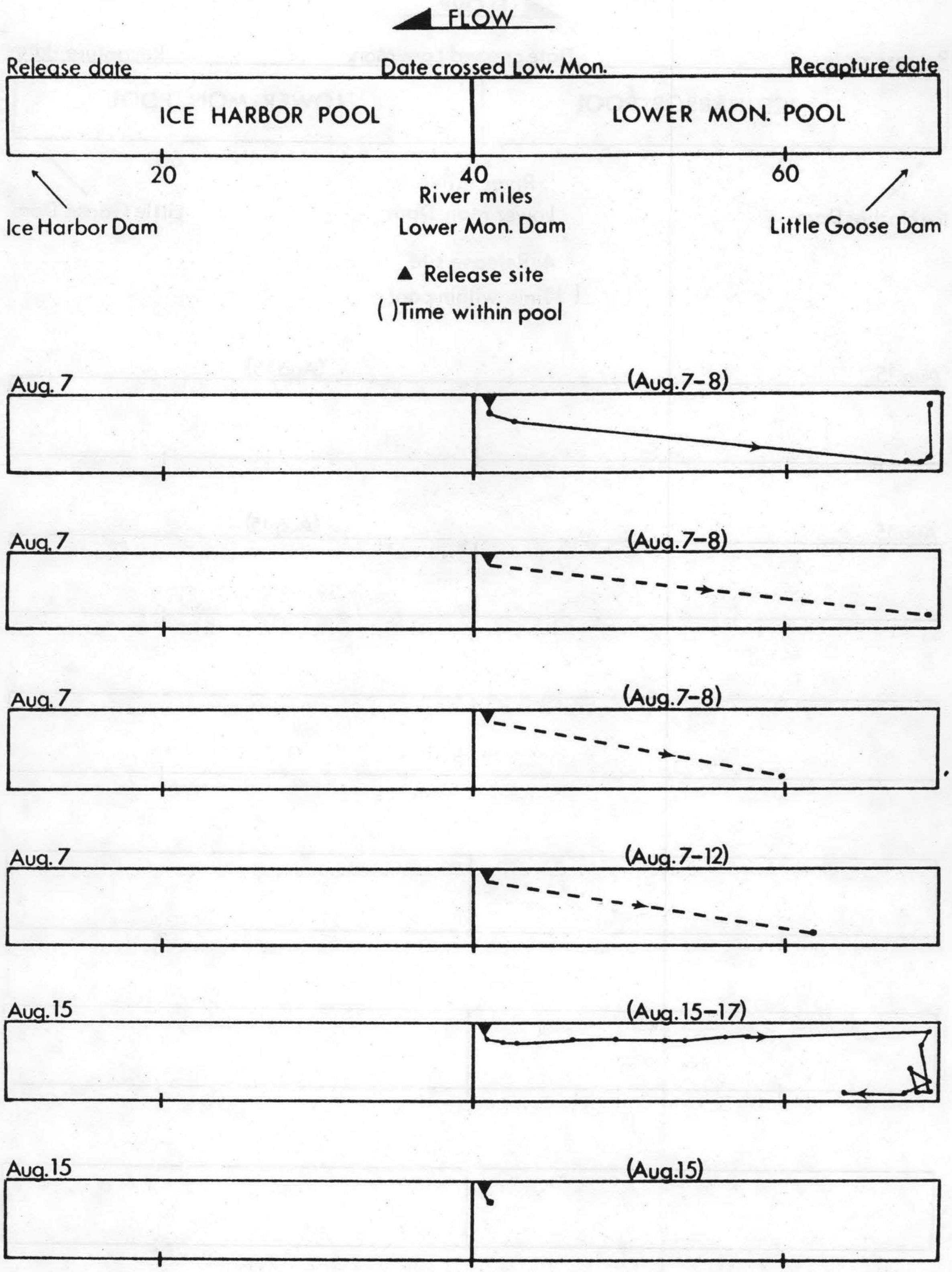
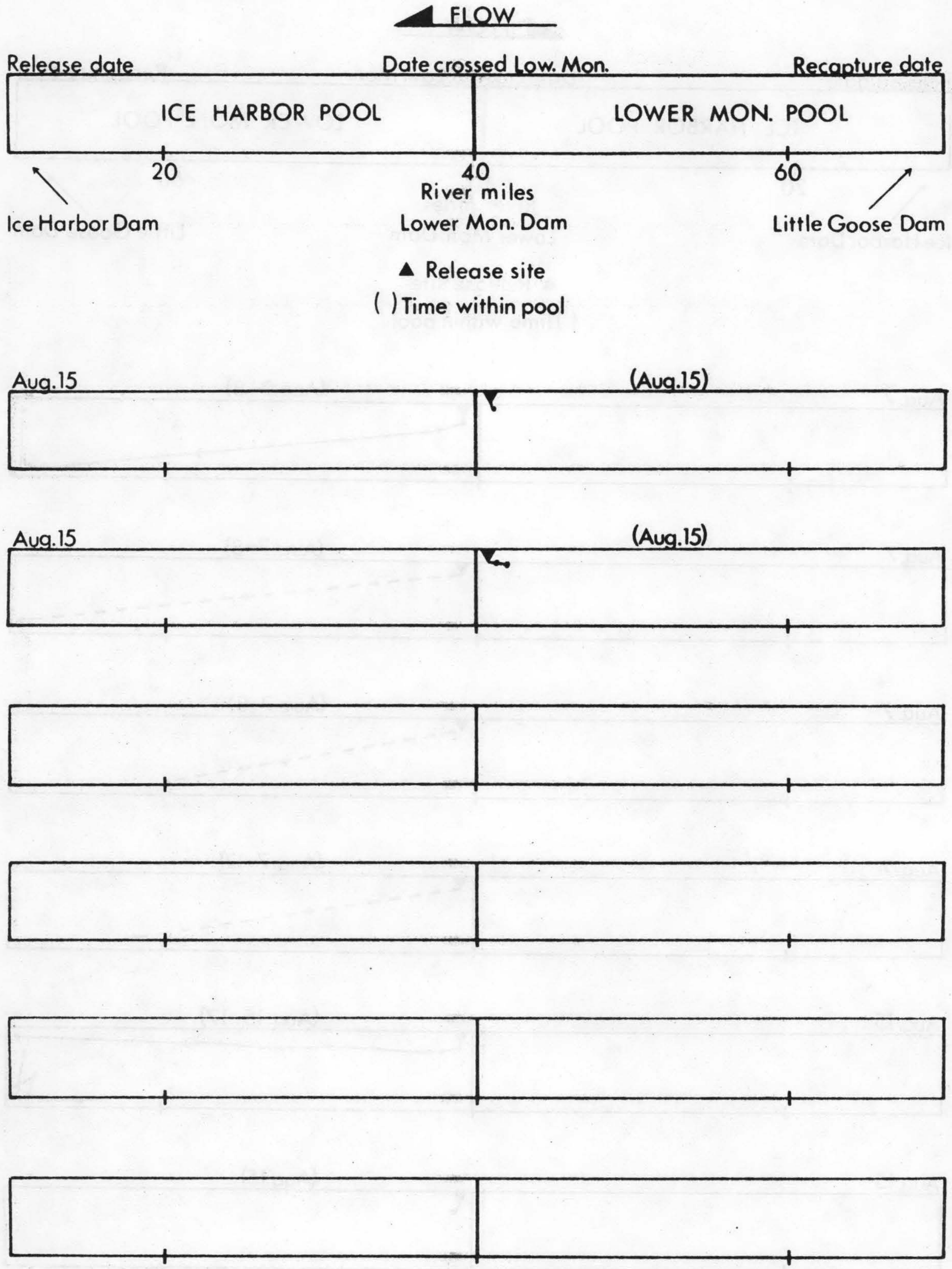
Appendix A

Diagrammatic sketch of radio-tagged chinook salmon movements within study area. Points represent actual locations and solid lines connect points of location within 24 hours of one another. Broken lines connect points of location more than 24 hours apart.


FLOW
Release date
Date crossed Low. Mon.
Recapture date
ICE HARBOR POOL
LOWER MON. POOL
20
40
60
River miles
Ice Harbor Dam
Lower Mon. Dam
Little Goose Dam
▲ Release site
( ) Time within pool
July 7
(July7–?)
?
(?–July12)
July 12
July 7
(July7–8)
July 7
(July7–18)
July 7
(July7–16)
July 15
(July 15–Aug.1)
July 15
(July15–?)
?
(?–July27)

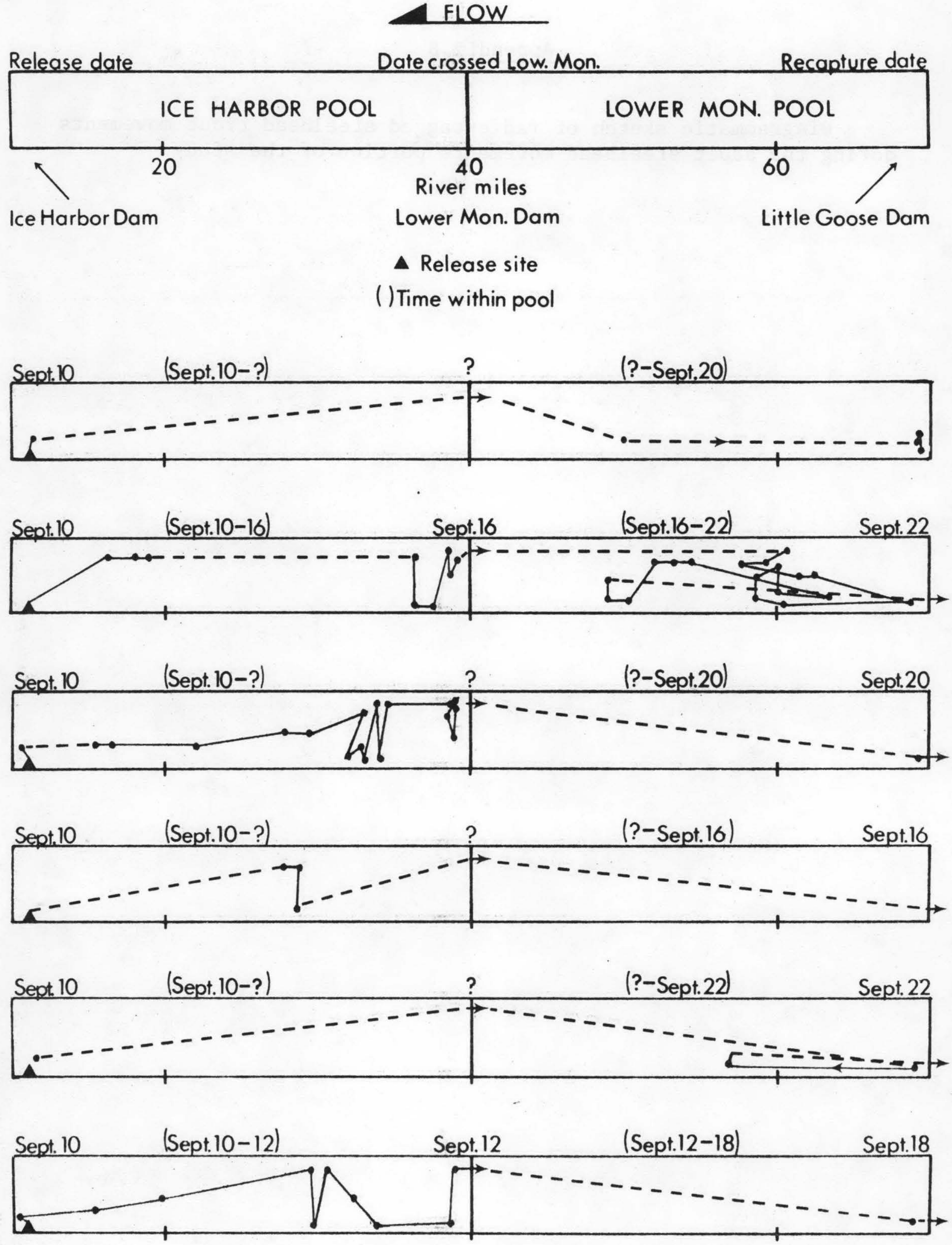

FLOW
Release date
Date crossed Low. Mon.
Recapture date
ICE HARBOR POOL
LOWER MON. POOL
20
40
60
River miles
Ice Harbor Dam
Lower Mon. Dam
Little Goose Dam
▲ Release site
( ) Time within pool
July 15
(July15–Aug.3)
July 15
(July15–21)
July 21
(July21–26)
July 26
July 24
(July 24)
July 24
(July24-28)
July 24
(July24-29)
July 24
(July24)


FLOW
Release date
Date crossed Low. Mon.
Recapture date
ICE HARBOR POOL
LOWER MON. POOL
20
40
60
River miles
Ice Harbor Dam
Lower Mon. Dam
Little Goose Dam
▲ Release site
( )Time within pool
Aug. 7
(Aug.7–8)
Aug. 7
(Aug.7–8)
Aug. 7
(Aug.7–8)
Aug. 7
(Aug.7–12)
Aug.15
(Aug.15–17)
Aug.15
(Aug.15)


FLOW
Release date
Date crossed Low. Mon.
Recapture date
ICE HARBOR POOL
LOWER MON. POOL
20
40
60
River miles
Ice Harbor Dam
Lower Mon. Dam
Little Goose Dam
▲ Release site
( ) Time within pool
Aug.15
(Aug.15)
Aug.15
(Aug.15)

Appendix B

Diagrammatic sketch of radio-tagged steelhead trout movements during the adult steelhead movements portion of the study.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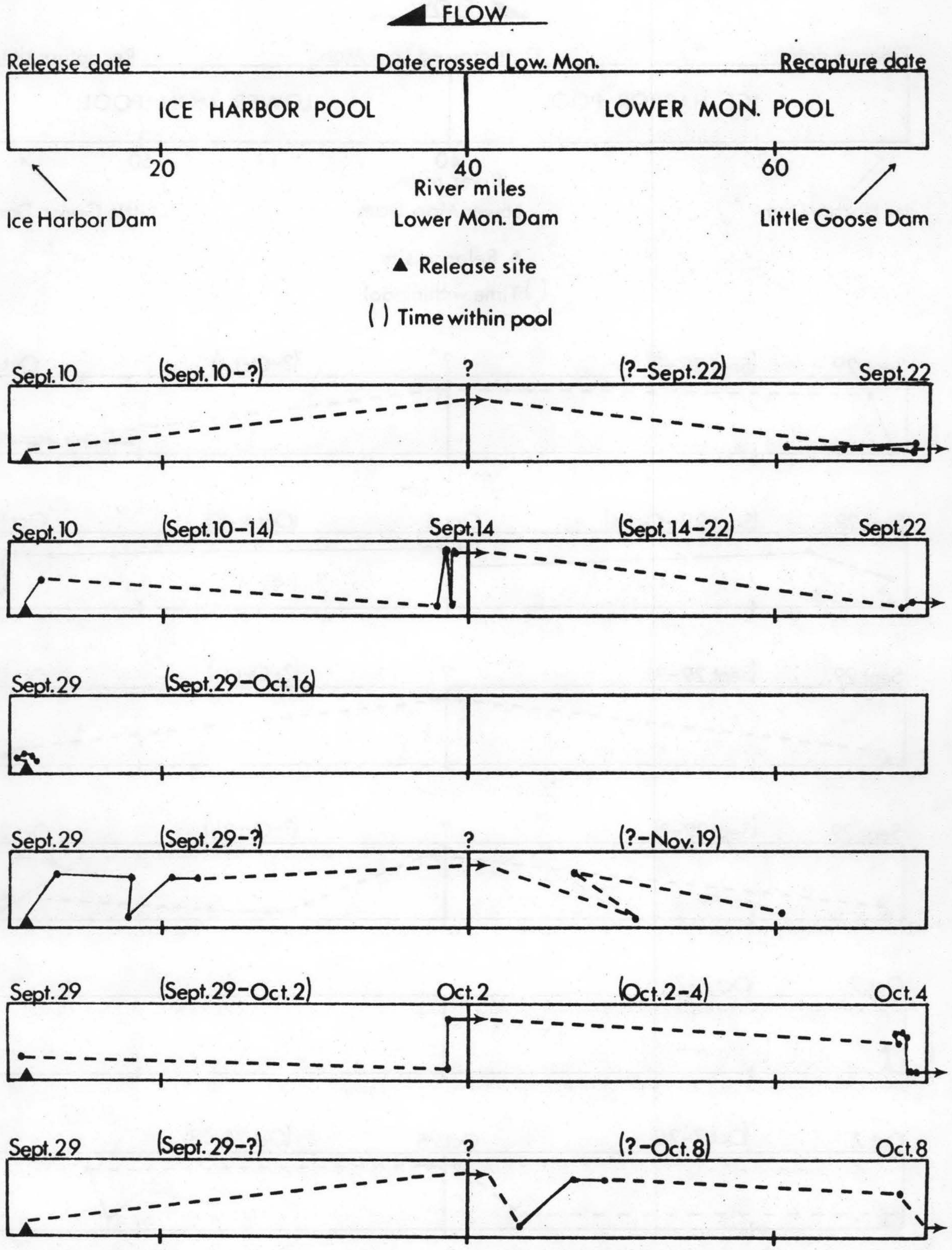
Release date
Date crossed Low. Mon.
Recapture date
ICE HARBOR POOL
LOWER MON. POOL
20
40
60
River miles
Ice Harbor Dam
Lower Mon. Dam
Little Goose Dam
▲ Release site
( ) Time within pool
Sept. 10
(Sept. 10-?)
?
(?-Sept. 20)
Sept. 10
(Sept. 10-16)
Sept. 16
(Sept. 16-22)
Sept. 22
Sept. 10
(Sept. 10-?)
?
(?-Sept. 20)
Sept. 20
Sept. 10
(Sept. 10-?)
?
(?-Sept. 16)
Sept. 16
Sept. 10
(Sept. 10-?)
?
(?-Sept. 22)
Sept. 22
Sept. 10
(Sept. 10-12)
Sept. 12
(Sept. 12-18)
Sept. 18


FLOW
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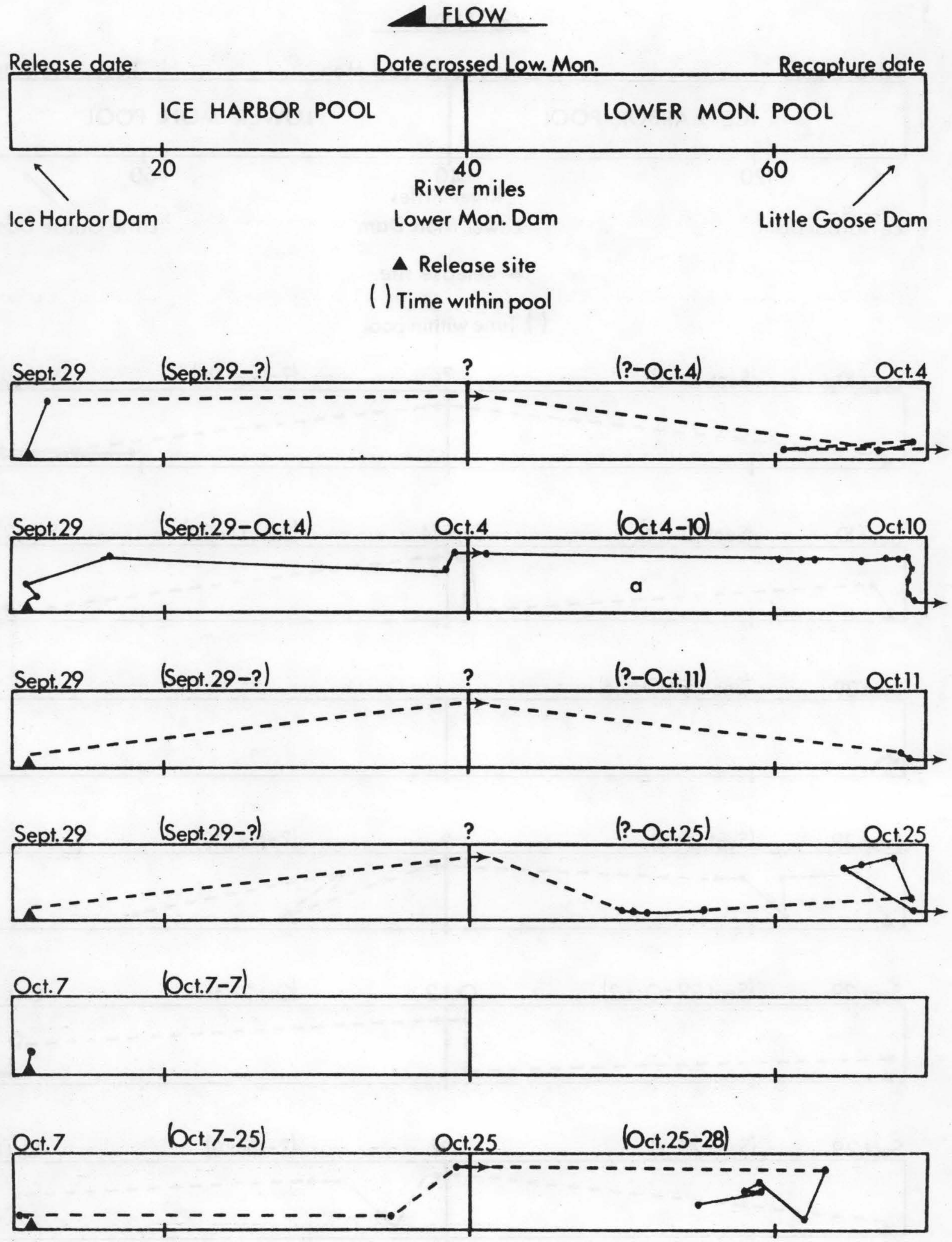
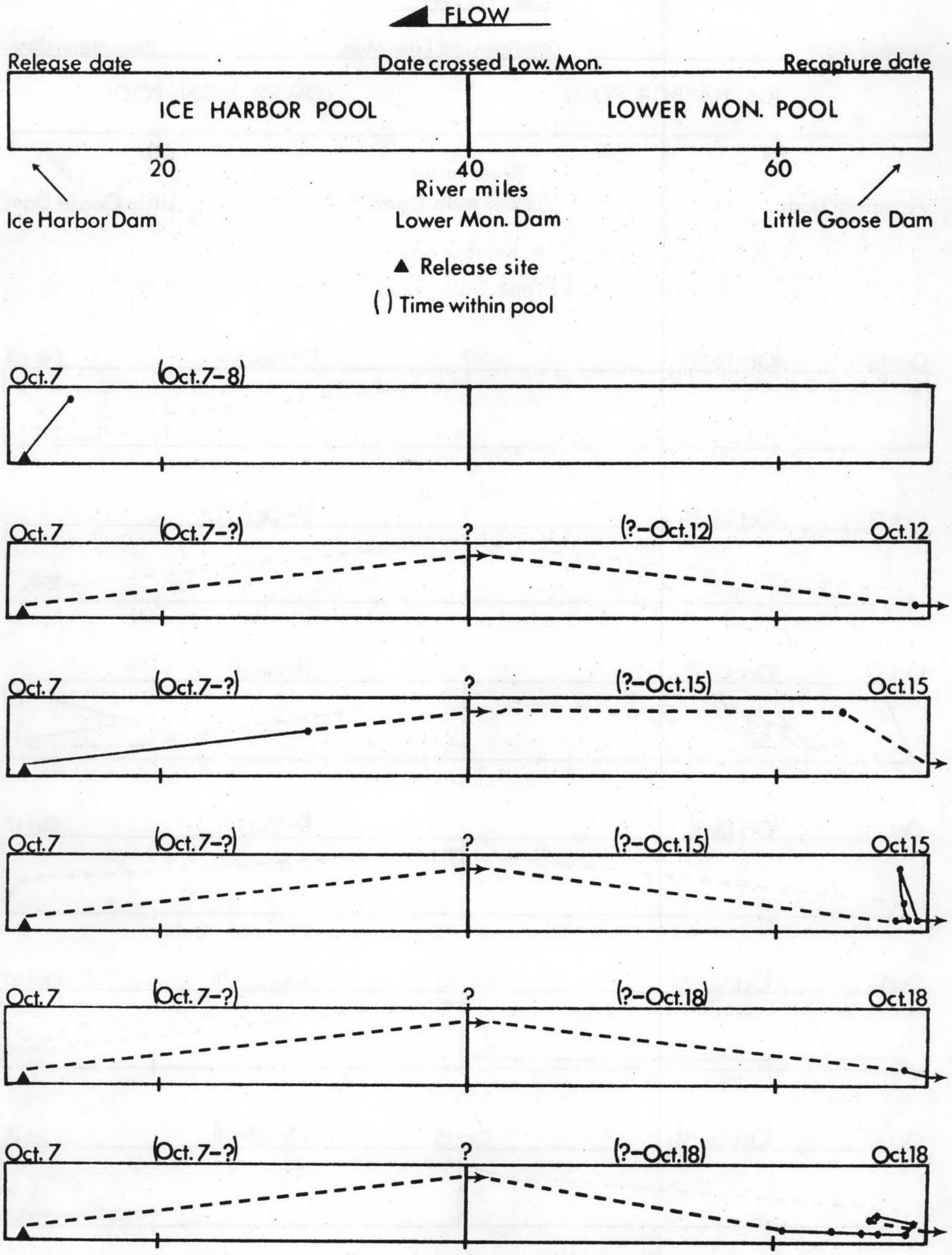
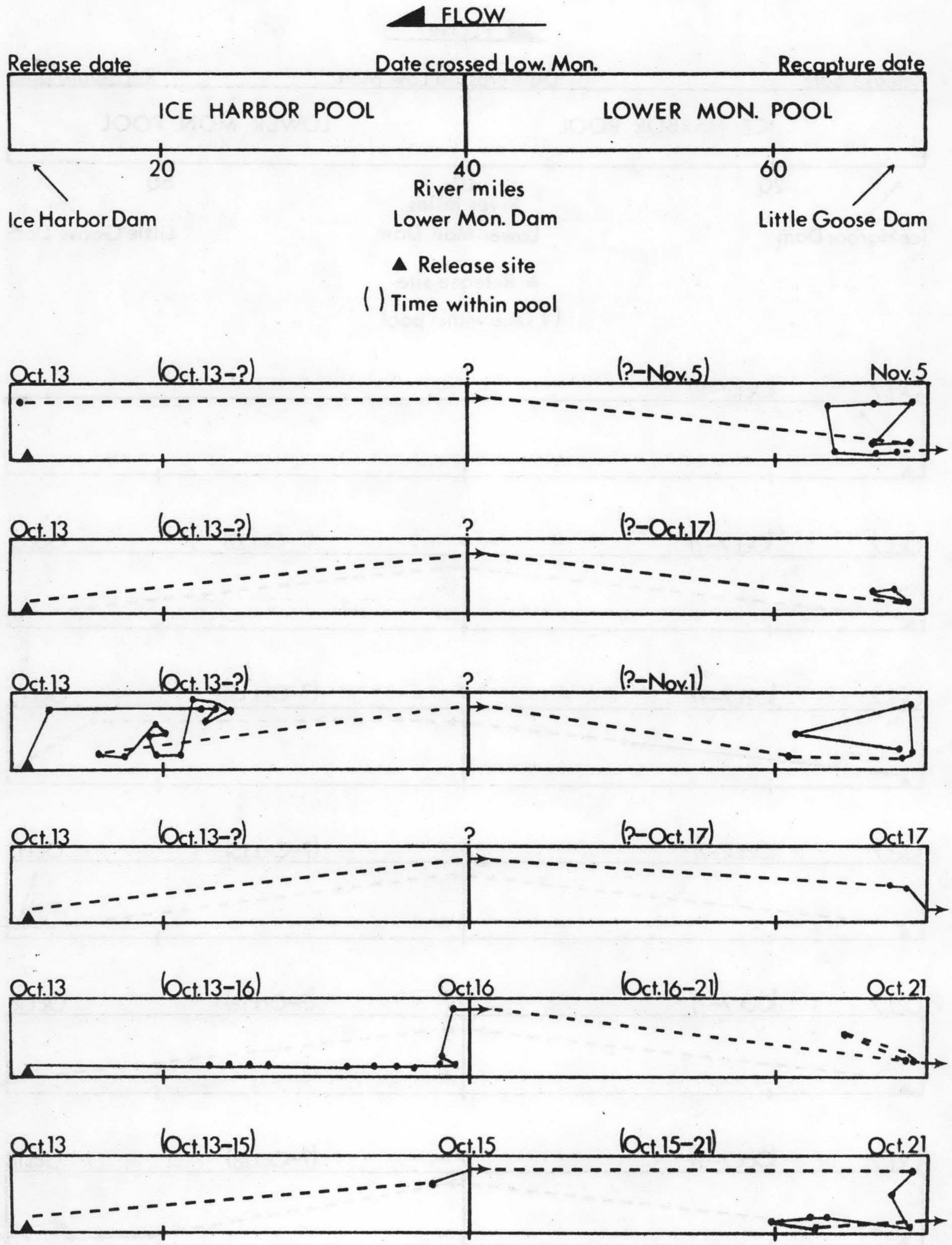
Date crossed Low. Mon.
Recapture date
ICE HARBOR POOL
LOWER MON. POOL
20
40
60
River miles
Ice Harbor Dam
Lower Mon. Dam
Little Goose Dam
▲ Release site
( ) Time within pool
Sept. 10
(Sept. 10-?)
?
(?-Sept. 22)
Sept. 22
Sept. 10
(Sept. 10-14)
Sept. 14
(Sept. 14-22)
Sept. 22
Sept. 29
(Sept. 29-Oct. 16)
Sept. 29
(Sept. 29-?)
?
(?-Nov. 19)
Sept. 29
(Sept. 29-Oct. 2)
Oct. 2
(Oct. 2-4)
Oct. 4
Sept. 29
(Sept. 29-?)
?
(?-Oct. 8)
Oct. 8


FLOW
Release date
Date crossed Low. Mon.
Recapture date
ICE HARBOR POOL
LOWER MON. POOL
20
40
60
River miles
Ice Harbor Dam
Lower Mon. Dam
Little Goose Dam
▲ Release site
( ) Time within pool
Sept. 29
(Sept. 29–?)
?
(?–Oct. 4)
Oct. 4
Sept. 29
(Sept. 29–Oct. 4)
Oct. 4
(Oct. 4–10)
Oct. 10
a
Sept. 29
(Sept. 29–?)
?
(?–Oct. 11)
Oct. 11
Sept. 29
(Sept. 29–?)
?
(?–Oct. 25)
Oct. 25
Oct. 7
(Oct. 7–7)
Oct. 7
(Oct. 7–25)
Oct. 25
(Oct. 25–28)


FLOW
Release date
Date crossed Low. Mon.
Recapture date
ICE HARBOR POOL
LOWER MON. POOL
20
40
60
River miles
Ice Harbor Dam
Lower Mon. Dam
Little Goose Dam
▲ Release site
( ) Time within pool
Oct.7
(Oct.7–8)
Oct.7
(Oct.7–?)
?
(?–Oct.12)
Oct.12
Oct.7
(Oct.7–?)
?
(?–Oct.15)
Oct.15
Oct.7
(Oct.7–?)
?
(?–Oct.15)
Oct.15
Oct.7
(Oct.7–?)
?
(?–Oct.18)
Oct.18
Oct.7
(Oct.7–?)
?
(?–Oct.18)
Oct.18


FLOW
Release date
Date crossed Low. Mon.
Recapture date
ICE HARBOR POOL
LOWER MON. POOL
20
40
60
River miles
Ice Harbor Dam
Lower Mon. Dam
Little Goose Dam
▲ Release site
( ) Time within pool
Oct. 13
(Oct. 13–?)
?
(?–Nov. 5)
Nov. 5
Oct. 13
(Oct. 13–?)
?
(?–Oct. 17)
Oct. 13
(Oct. 13–?)
?
(?–Nov. 1)
Oct. 13
(Oct. 13–?)
?
(?–Oct. 17)
Oct. 17
Oct. 13
(Oct. 13–16)
Oct. 16
(Oct. 16–21)
Oct. 21
Oct. 13
(Oct. 13–15)
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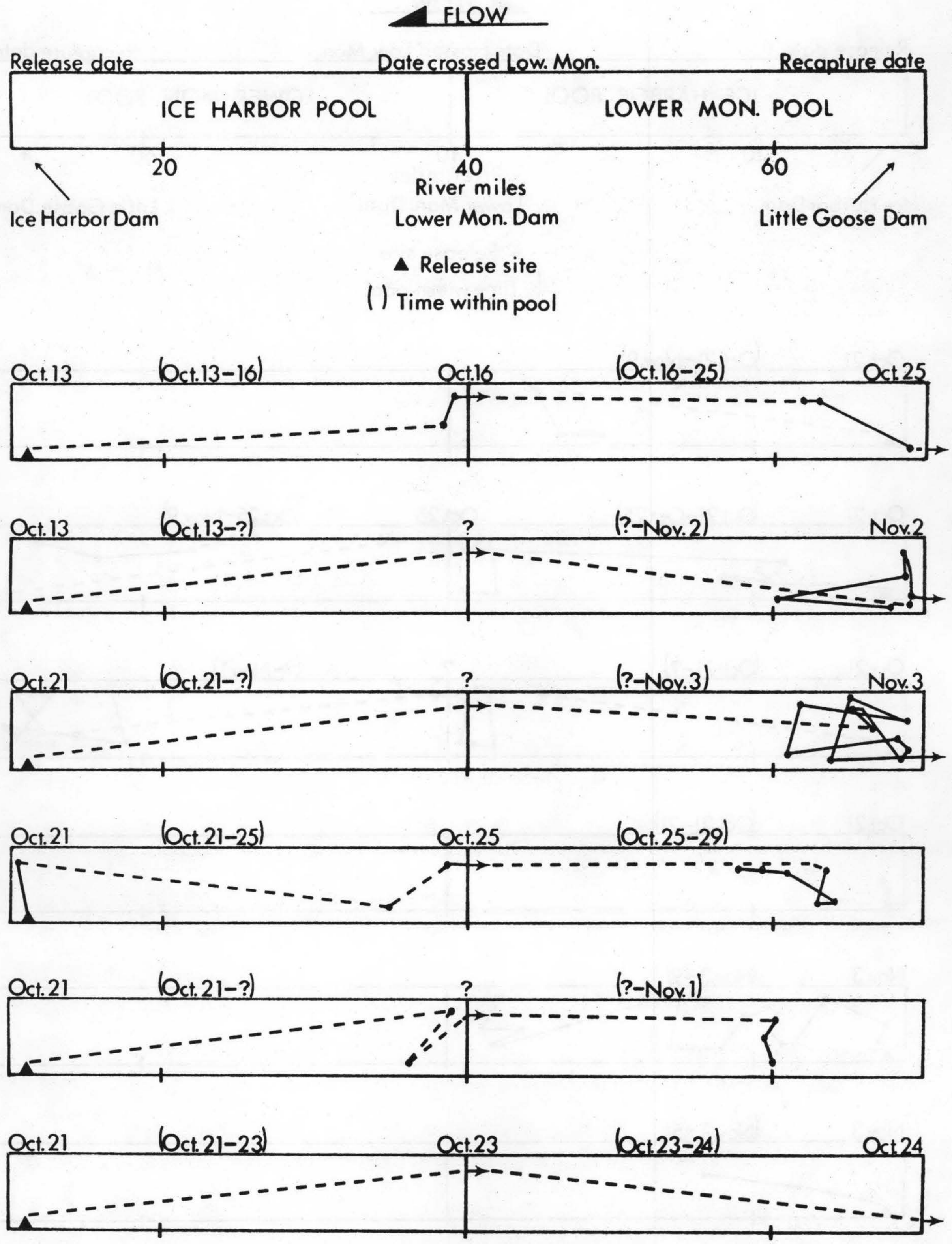
(Oct. 15–21)
Oct. 21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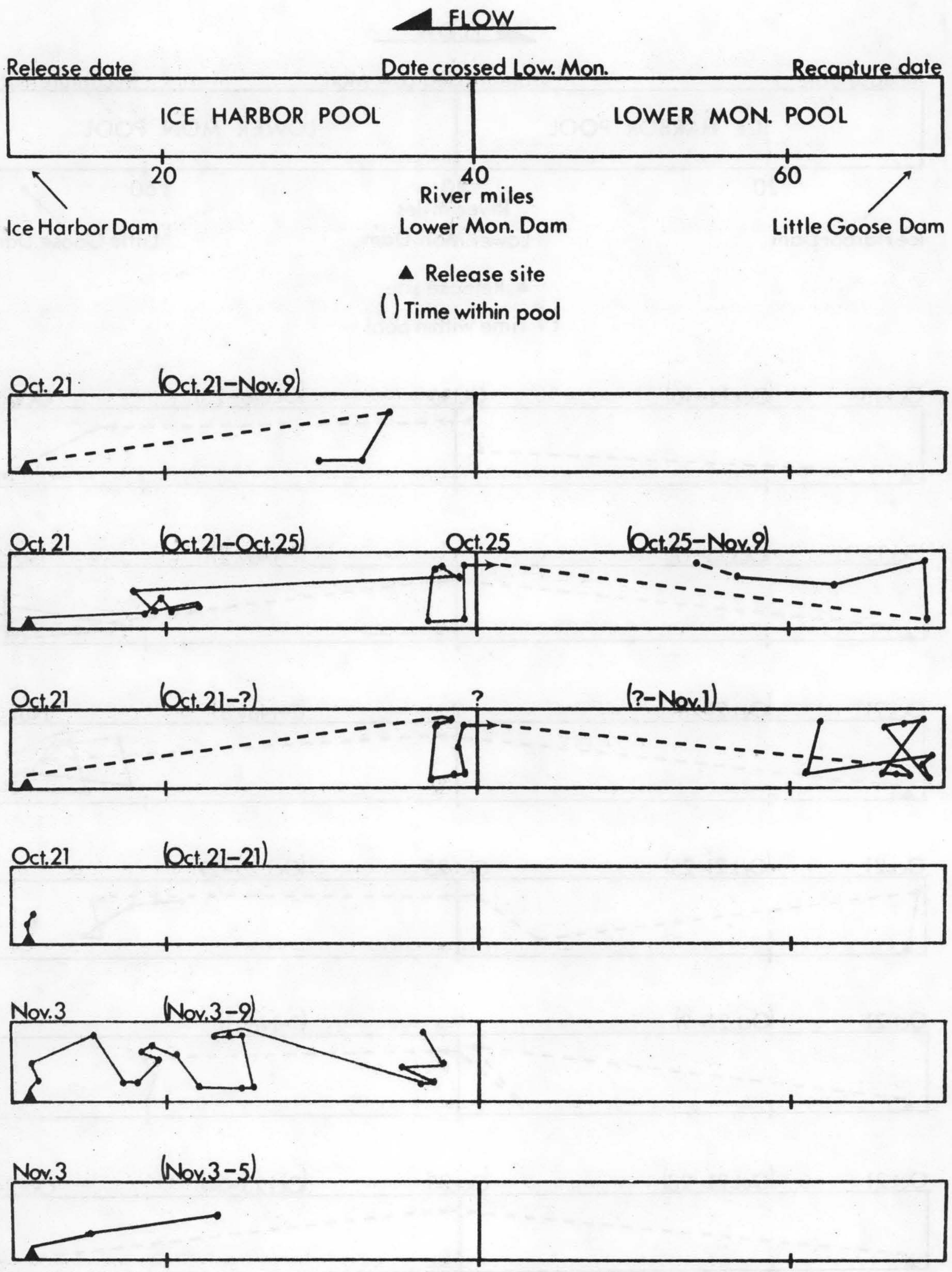
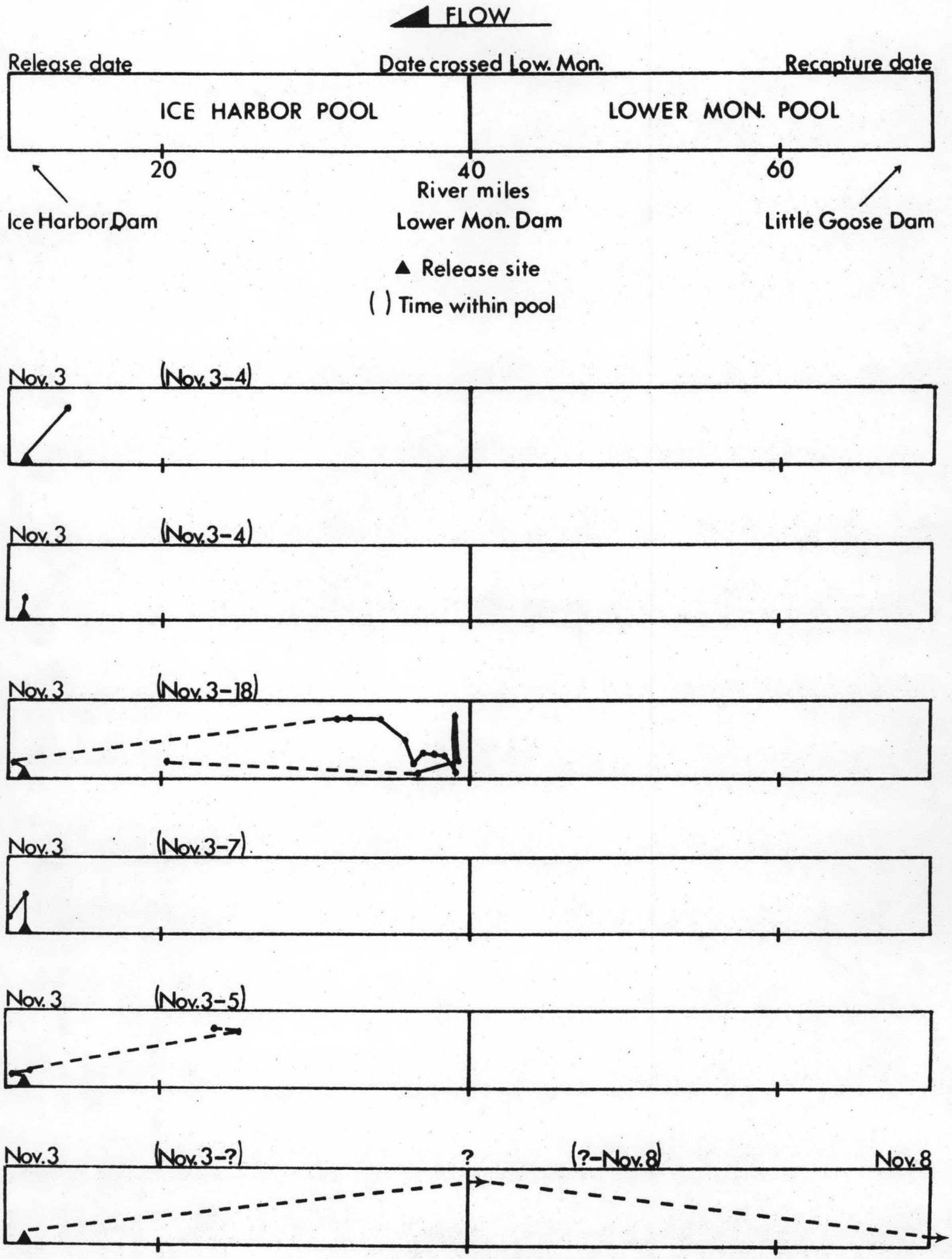
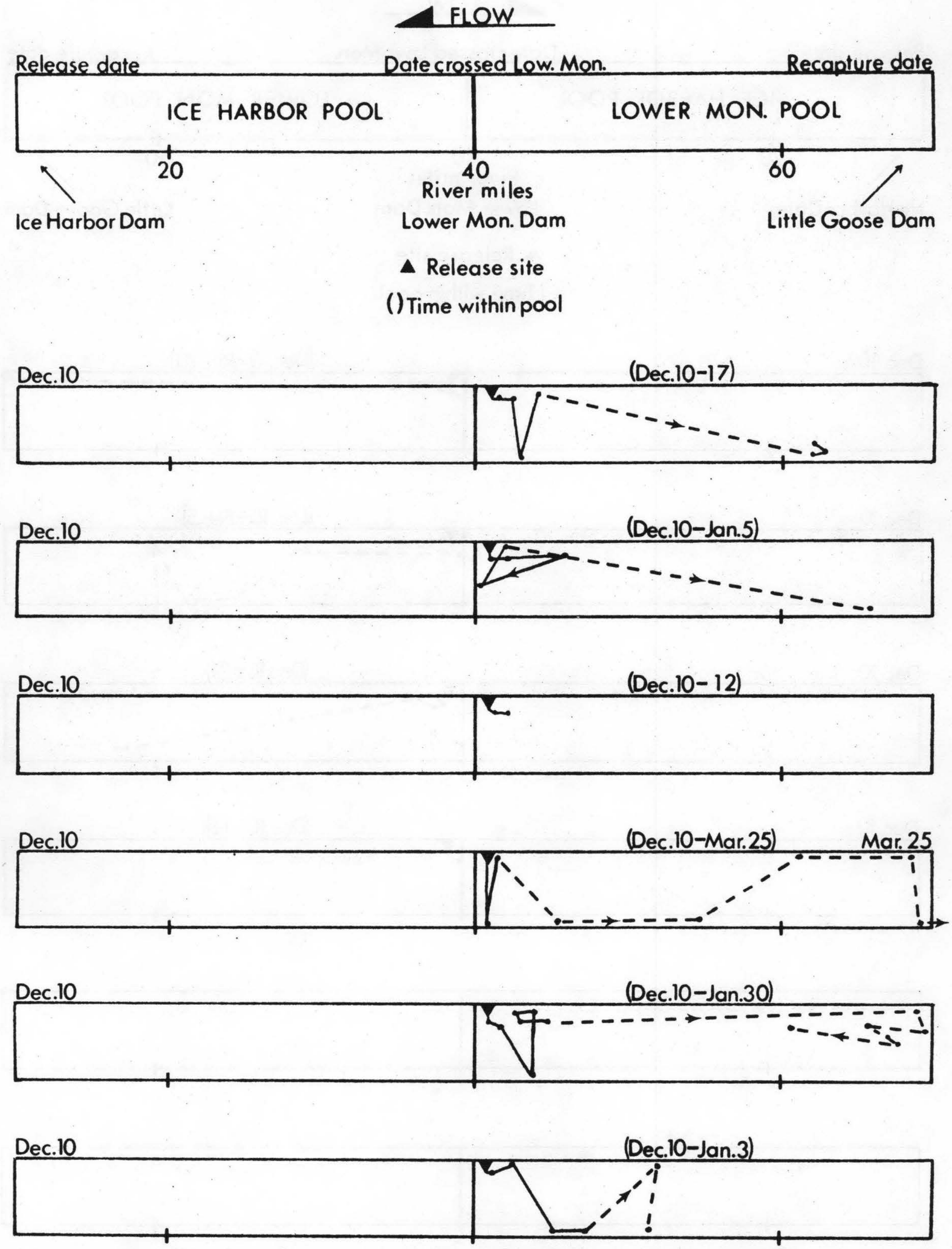
Release date
Date crossed Low. Mon.
Recapture date
ICE HARBOR POOL
LOWER MON. POOL
20
40
60
River miles
Ice Harbor Dam
Lower Mon. Dam
Little Goose Dam
▲ Release site
( ) Time within pool
Oct.13
(Oct.13–16)
Oct.16
(Oct.16–25)
Oct.25
Oct.13
(Oct.13–?)
?
(?–Nov.2)
Nov.2
Oct.21
(Oct.21–?)
?
(?–Nov.3)
Nov.3
Oct.21
(Oct.21–25)
Oct.25
(Oct.25–29)
Oct.21
(Oct.21–?)
?
(?–Nov.1)
Oct.21
(Oct.21–23)
Oct.23
(Oct.23–24)
Oct.24

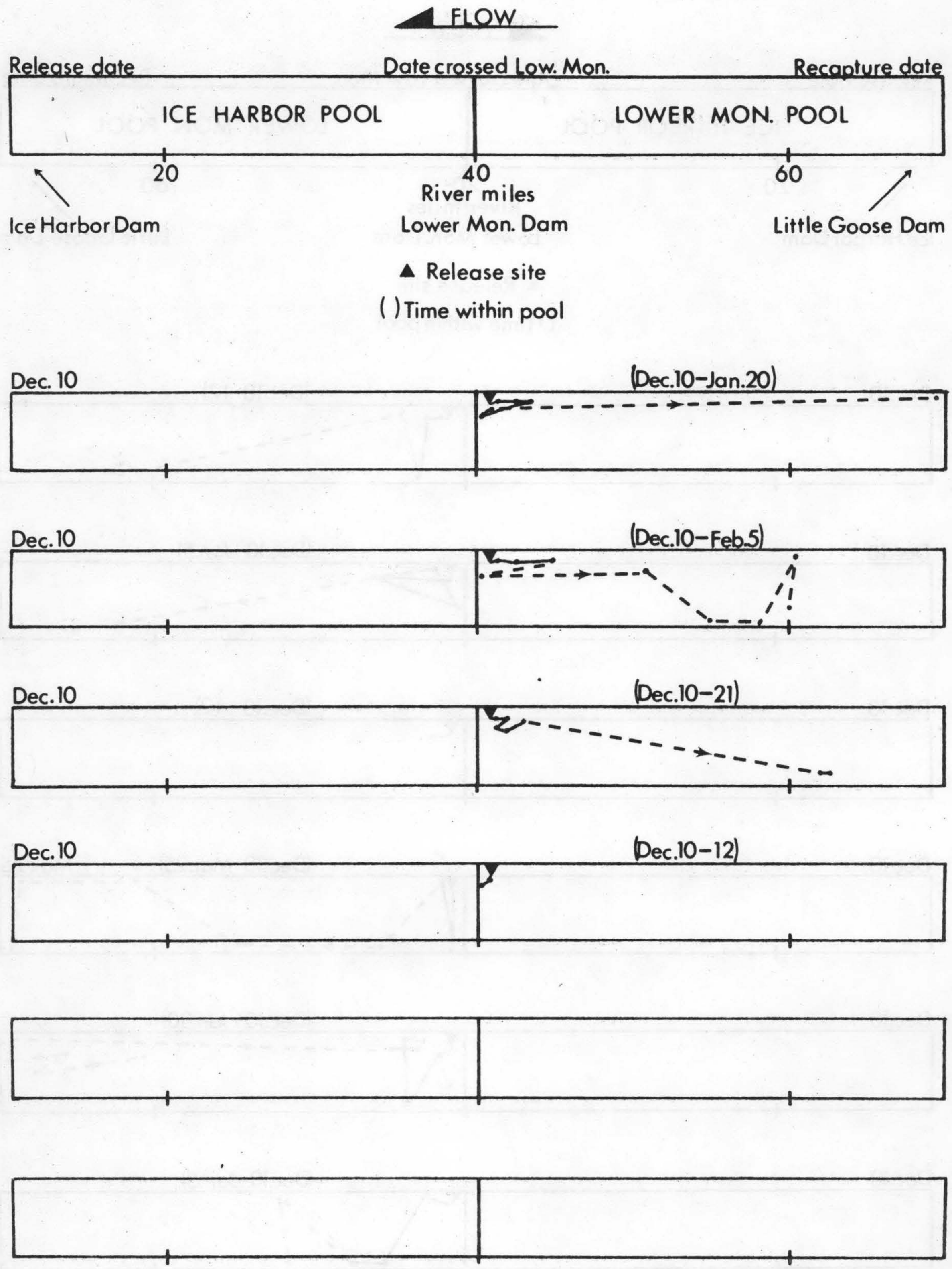

FLOW
Release date
Date crossed Low. Mon.
Recapture date
ICE HARBOR POOL
LOWER MON. POOL
20
40
60
River miles
Ice Harbor Dam
Lower Mon. Dam
Little Goose Dam
▲ Release site
( ) Time within pool
Oct. 21
(Oct. 21–Nov. 9)
Oct. 21
(Oct. 21–Oct. 25)
Oct. 25
(Oct. 25–Nov. 9)
Oct. 21
(Oct. 21–?)
?
(?–Nov. 1)
Oct. 21
(Oct. 21–21)
Nov. 3
(Nov. 3–9)
Nov. 3
(Nov. 3–5)


FLOW
Release date
Date crossed Low. Mon.
Recapture date
ICE HARBOR POOL
LOWER MON. POOL
20
40
60
River miles
Ice Harbor Dam
Lower Mon. Dam
Little Goose Dam
▲ Release site
( ) Time within pool
Nov. 3
(Nov. 3–4)
Nov. 3
(Nov. 3–4)
Nov. 3
(Nov. 3–18)
Nov. 3
(Nov. 3–7)
Nov. 3
(Nov. 3–5)
Nov. 3
(Nov. 3–?)
?
(?–Nov. 8)
Nov. 8

Appendix C

Diagrammatic sketch of radio-tagged sheelhead trout movements during the overwintering study.


FLOW
Release date
Date crossed Low. Mon.
Recapture date
ICE HARBOR POOL
LOWER MON. POOL
20
40
60
River miles
Ice Harbor Dam
Lower Mon. Dam
Little Goose Dam
▲ Release site
() Time within pool
Dec.10
(Dec.10-17)
Dec.10
(Dec.10-Jan.5)
Dec.10
(Dec.10- 12)
Dec.10
(Dec.10-Mar.25)
Mar. 25
Dec.10
(Dec.10-Jan.30)
Dec.10
(Dec.10-Jan.3)


FLOW
Release date
Date crossed Low. Mon.
Recapture date
ICE HARBOR POOL
LOWER MON. POOL
20
40
60
River miles
Ice Harbor Dam
Lower Mon. Dam
Little Goose Dam
▲ Release site
( ) Time within pool
Dec. 10
(Dec.10–Jan.20)
Dec. 10
(Dec.10–Feb.5)
Dec. 10
(Dec.10–21)
Dec. 10
(Dec.10–12)