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Ecological Research Series

# Pollution Effects on Adult Steelhead Migration in the Snake River

Office of Research and Development
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# POLLUTION EFFECTS ON ADULT STEELHEAD MIGRATION

# IN THE SNAKE RIVER

by

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ABSTRACT

A three-year field study was conducted from 1969-1971 to assess the relationship of Kraft mill effluent and pre-impoundment limnological conditions to adult steelhead trout (Salmo gairdneri Richardson) behavior in the Snake River near Lewiston, Idaho. Steelhead were tagged with an ultrasonic transmitter and followed through a 25 km section of the proposed Lower Granite Reservoir. Limnological parameters were measured in the Clearwater and Snake Rivers and then compared with fish behavior. Mixing patterns of the Clearwater River with the Snake River were also assessed.

Mean water quality changes in the Snake River as a result of pollution inputs in the Lewiston area are very subtle. In terms of toxic effects from chemical loading, the Snake River water quality is not greatly altered except in the immediate area of pollution input; we did not observe steelhead avoidance of these localized problem areas.

No significant correlation could be made between any chemical water quality parameter and steelhead behavior. However, as the temperature dropped below 15 C fish movement slowed, fish generally stopped moving at night, and resting periods increased in length and number. Steelhead generally showed a preference to move in water with off-bottom current velocities of 0.2 to 0.5 m/sec and showed a definite pattern of crossover and resting points in the river.

This report was submitted in fulfillment of Project Number 18050 DMB under the sponsorship of the Environmental Protection Agency. Work was completed as of December, 1971.

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ACKNOWLEDGMENTS

The authors wish to thank Drs. Don Chapman and Ted Bjornn of the Idaho Cooperative Fishery Unit for their counsel throughout this study.

Mr. Wes Ebel, National Marine Fisheries Service, and his supporting staff permitted the use of their adult fish migrant trapping facilities at Ice Harbor Dam.

We thank Dr. Richard Wallace, fishery scientist at the University of Idaho, for his help and advice on steelhead behavior in 1969 and 1970.

The support of the Office of Research and Monitoring, Environmental Protection Agency, especially the help provided by Project Officers Drs. Gerry Bouck and Gary Chapman is sincerely appreciated.

## SECTION I

## CONCLUSIONS

1. The Snake River shows only slight deterioration of water quality from the pollution load it receives in the Lewiston area.

2. Mixing of the Snake and Clearwater River flows is inversely related to flow volume.

3. We were unable to relate steelhead behavior to pollution inputs in the Lewiston area under free-flowing conditions.

4. River temperature is positively correlated with steelhead travel rates.

5. Wide variations in steelhead behavior were noted from fish to fish and from year to year.

6. Above confluence steelhead behavior is not significantly different than below confluence behavior.

## SECTION II

## RECOMMENDATIONS

Water quality parameters should be measured after Lower Granite Dam is closed to show effects of localized pollution problem areas which might result from poor dispersion of wastes in the reservoir.

Adult steelhead migration behavior through the reservoir after its completion in 1975 should be studied for comparison to the altered post-impoundment limnology of the "run-of-river" reservoir.

Lay-over and over-wintering areas for steelhead should be described to determine whether Dworshak release temperature and flow can affect steelhead behavior in the upper areas of Lower Granite pool.

## SECTION III

## INTRODUCTION

This report summarizes the three-year pre-impoundment phase of a proposed two-part study relating adult summer steelhead migrational behavior to water quality changes associated with the impoundment of Lower Granite Dam on the lower Snake River, Idaho-Washington. Lower Granite Dam is a low-head dam at river kilometer (RK) 172 currently under construction and scheduled for completion in 1975. It will convert a free-flowing stretch of the Snake River that now receives urban sewage and Kraft pulping mill wastes to an impoundment.

The chief objective of the two-part study is to assess migrational behavior of adult summer steelhead before and after limnological conditions in the lower Snake River are altered by filling of Lower Granite Reservoir. The study situation offers an opportunity to observe organism response to changing environmental conditions in an uncontrolled field situation. We then propose to relate pre- and post-impoundment behavior with pre- and post-limnology of the lower Snake River study section. This comparison will help describe the impact of Lower Granite Dam on the Snake and Clearwater River steelhead runs. In the first study phase, reported here, we described steelhead travel paths, migration rates, and other general characteristics of upstream movement during peak migration times in 1969, 1970, and 1971.

### STUDY AREA

The Snake River flows north out of Hell's Canyon for 160 km, then turns west at RK 224 to join the Columbia River in southeastern Washington (Figure 1). The two largest tributaries of the lower Snake are the Salmon and the Clearwater Rivers at RK 290 and RK 225, respectively. Asotin Creek at RK 233 and Alpowa Creek at RK 211 also flow into the Snake River in the study area.

Width of the Snake River in the study area ranged from 140 to 260 m (200 m average). Stream depth was 2.0 to 8.5 m (4.0 m average) during the study period. Mean minimum flows in the study area approximated 570 $m^3$/sec, occurring near September 1 (U.S. Geological Survey 1970). Mean maximum flows approximated 5700 $m^3$/sec around June 1. Hydropower peaking at Hell's Canyon and Brownlee Dams on the middle Snake River (RK 397 and RK 459) cause daily flow fluctuations of up to 150 $m^3$/sec during summer months.

Widely spaced rapids separate long pools of moderate velocity and greater depth in the study area. Rubble 8 to 20 cm in diameter dominates the substrate, and many sandbars are formed in the study area by annual high water.


Figure 1. Lower Snake River, Idaho-Washington.

The Lower Granite pool will extend from Lower Granite Dam upstream 59 km on the Snake and 8 km on the Clearwater River. Elevation of the study section ranges from 206 meters to 216 meters above mean sea level with a gradient of 0.60 m/km.

Downstream from the Clearwater River, the Snake River will by 1975, be a contiguous series of low-head impoundments formed by Ice Harbor Dam (RK 16), Lower Monumental Dam (RK 68), Little Goose Dam (RK 113), and the incomplete Lower Granite Dam (RK 174). Asotin Dam is currently an authorized but unfunded low-head project at RK 235.

The Snake River flows into the Lower Granite pool area a turbulent, geologically youthful stream. Chemically, however, it shows the intensive changes it has sustained in south Idaho from irrigation, food processing, urban, and cattle feedlot discharges. The three upstream impoundments at RK 397, RK 439, and RK 459 (Hell's Canyon, Oxbow, and Brownlee) slightly improve the chemical quality of the Snake River flowing out of south Idaho before reaching the Lewiston area. Snake River flows and temperatures for the three pre-impoundment study years (1969, 1970, and 1971) show control by these existing upstream storage projects (Figures 2 and 3). The Clearwater River was unregulated for the study years, except for the small Washington Water Power Dam at Clearwater RK 11 and Dworshak Dam on the North Fork of the Clearwater River. Gates at Dworshak Dam were closed on September 27, 1971, causing abrupt flow decreases in the Clearwater.

Several significant waste water flows enter this area (Figure 4):

1. The cities of Lewiston-Clarkston with a combined population of 33,000 contribute 10 x $10^3$ $m^3$/day of primary treated sewage, and 2.5 x $10^3$ $m^3$/day of secondary treated sewage (Miller 1972). All sewage will be receiving secondary treatment by Lower Granite pool filling in 1975. Asotin, south of Lewiston-Clarkston, contributes an additional small amount of primary treated sewage.

2. Potlatch Forests, Incorporated, of Lewiston operates a Kraft process pulping operation which discharges 121.1 x $10^3$ $m^3$/day of primary treated wastes into the Snake River immediately above the Clearwater River confluence. These wastes contain 40.9 x $10^3$ kg/day 5-day BOD, 142.4 x $10^3$ kg/day COD, 25.4 x $10^3$ kg/day $SO_4$, and 45.4 kg/day Na. Potlatch Forests plans to initiate secondary treatment with an aerated lagoon by 1975. Because it will still contain high COD and dissolved materials, the effluent will contribute to the physical and chemical changes when Lower Granite Dam impounds the free-flowing stream. Increased algal and bacterial growth, as well as slightly increased temperatures and reduced dissolved oxygen in the backwater areas, are expected after the river slows (U.S. Public Health Service 1964; Falter and Funk 1973).

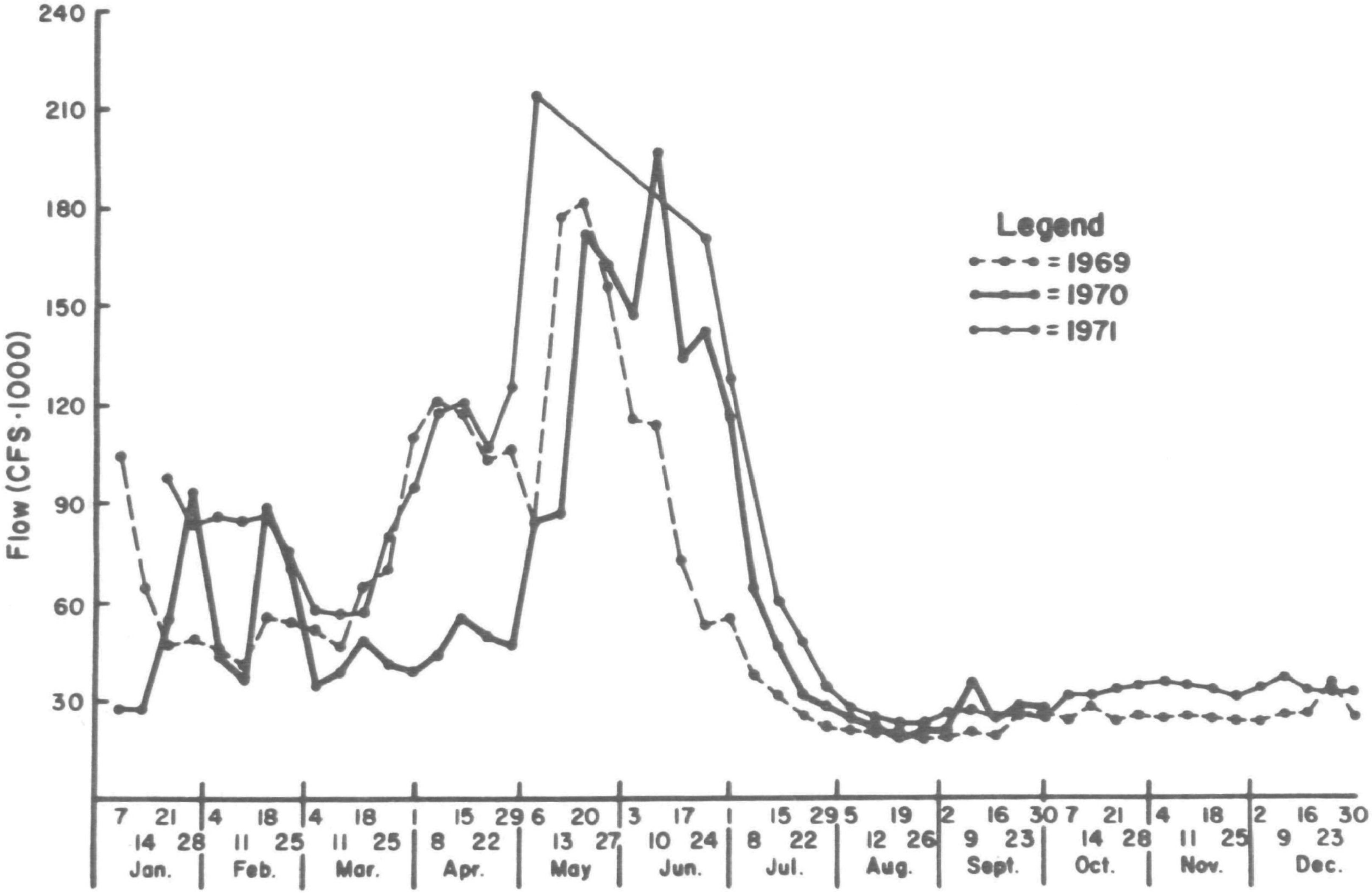


Figure 2. Snake River flow volume below the Snake - Clearwater confluence, 1969-71.

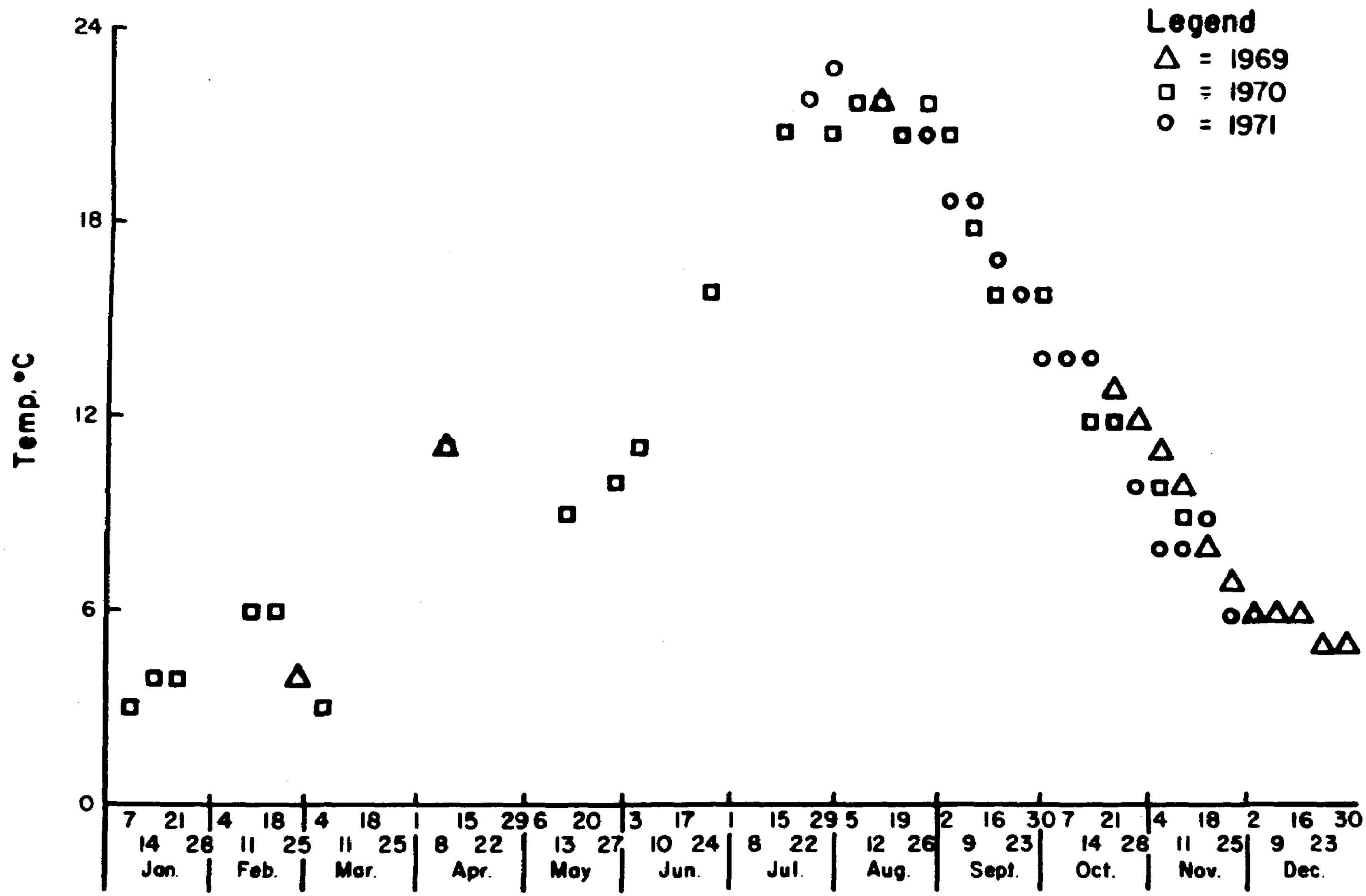


Figure 3. Snake River temperatures below the Snake-Clearwater confluence, 1969-71.

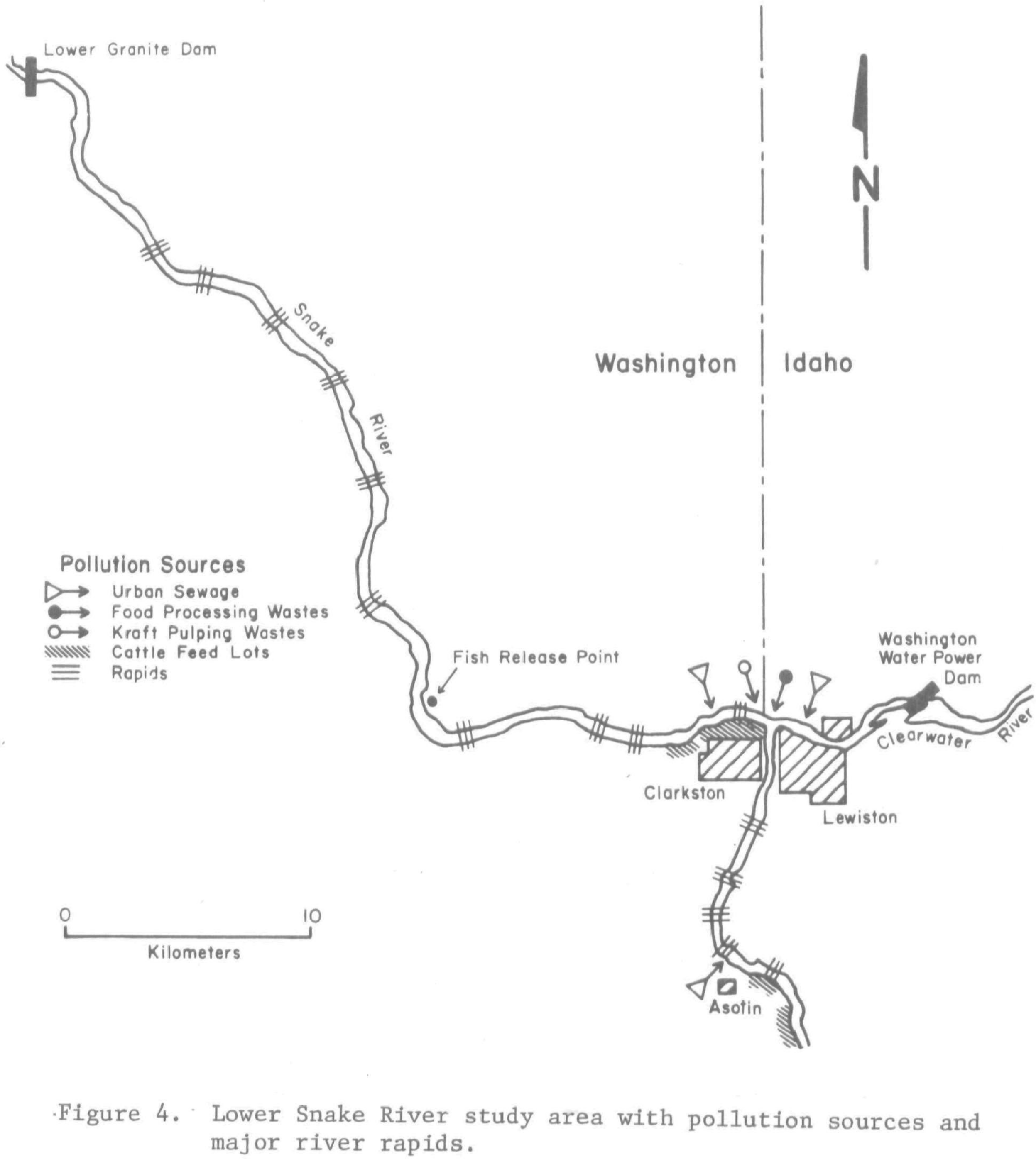


Figure 4. Lower Snake River study area with pollution sources and major river rapids.

Kraft pulping effluent adversely affects fish and other aquatic life (Stammer 1958; Whitney and Spindler 1959; Webb 1958; and Williams 1969). The reduced velocities and turbulence in the reservoir area can compound these detrimental effects by allowing concentrations of effluent to remain undispersed, thus concentrating waste assimilation into a smaller area (U.S. Public Health Service 1964).

3. Runoff from cattle feedlots and winter cattle feeding operations above Lewiston near the Snake River contributes significant amounts of nitrogen loading (Miller 1972).

Steelhead trout (Salmo gairdneri Richardson) in the Snake River are a major fish resource with 60,000 to 100,000 adult steelhead annually migrating through the Lower Granite pool area to upstream spawning areas in Idaho and Oregon. The run peaks in September-early October at a time of minimal water quality (Oregon Fish Commission 1967). Upstream migrating fish are confronted with lowest flows, highest concentrations of pollutants, lowest oxygen concentrations, and highest temperatures of the year. Chinook salmon runs through the area have averaged 77,000 . . . 36,000 spring chinook, 24,000 summer chinook, and 17,000 fall chinook (U.S. Corps of Engineers 1970). Summer steelhead runs stand to be affected most from a deterioration of water quality because of their timing.

SECTION IV

EXPERIMENTAL DESIGN

The fundamental working hypothesis as posed in the initial proposal in 1967 was: (1) "Lower Granite Dam has no effect upon the migrational behavior of adult steelhead trout." Hypothesis (1) can only be tested in the post-impoundment phase by study of steelhead behavior through the slack water of Lower Granite Reservoir.

Comparison with pre-impoundment behavior (the control phase) should delineate impoundment effects upon steelhead migration. Because of the addition of dams in the Snake and Clearwater systems, and changes in amounts and treatments of industrial and sewage effluents into the pool area since 1967, there is really no true "control" to this pre-post impoundment comparison. The best available "control" or approximation to it, is the Lower Granite pool area before impoundment.

We will reject $H_1$ after impoundment if:

1. Steelhead travel time through the study area increases or decreases.

2. General migration pathways significantly change.

3. General pathways after impoundment are not significantly different, but avoidance reactions or temporary stoppages occur at specific points due to factors such as:

    a. low dissolved oxygen

    b. high Kraft mill effluent

    c. high or low pH

    d. thermal layering

    e. presence of hydrogen sulfide

    f. high ammonia levels

    g. reverse flows at the Snake-Clearwater confluence

4. Timing of the steelhead run changes, i.e. the peak of the run shifts forward or backward in time.

If we reject $H_1$ for one or more of the above reasons, then the altered steelhead behavior is a result of impoundment or altered water quality, or a combination of both. We will compare migration patterns as detailed in Figure 5.

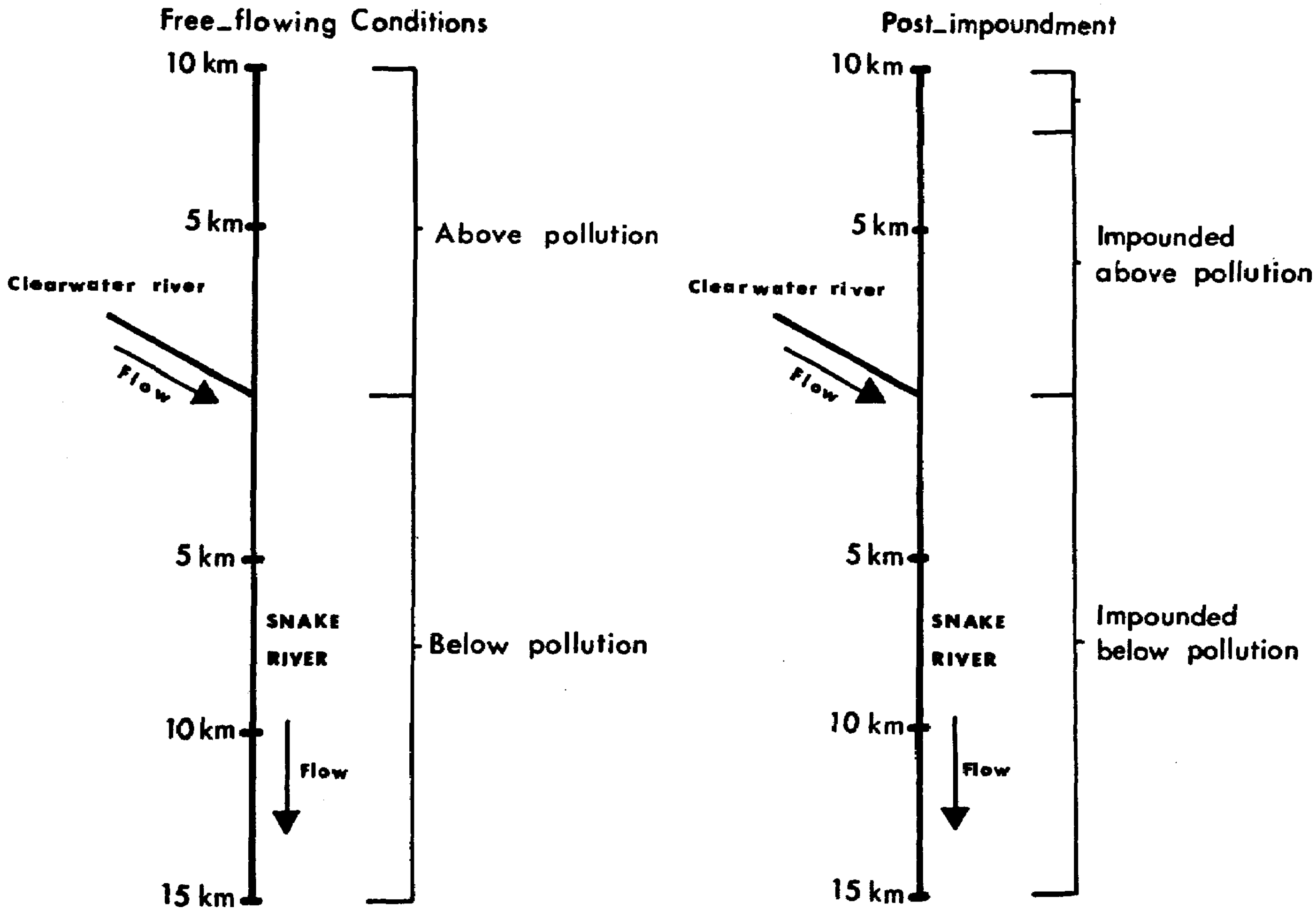


Figure 5. Schematic breakdown of free-flowing vs post-impoundment steelhead and water quality comparisons in the Lower Granite pool area.

## SECTION V

## METHODS

### MIXING PATTERNS

Pre-impoundment mixing patterns of the Snake and Clearwater Rivers downstream from their confluence were established to compare with migration patterns of adult steelhead. Samples at three points across the river could not adequately describe mixing patterns of these two large river flows in sufficient detail for comparison with steelhead movements. We selected the parameters of temperature and total dissolved solids to define mixing patterns of the Snake and Clearwater Rivers below their confluence for two reasons: (1) The two streams' temperature regimens are usually out of phase, hence degree of mixing should be apparent, and (2) Total dissolved solids levels of the two streams are always dissimilar, with no overlap throughout the year.

Cross-sectional profiles of temperature and total dissolved solids were constructed from vertical profiles taken at intervals across the Snake River at four points . . . 0.2 km, 2.4 km, 6.1 km, and 10.6 km below the Snake-Clearwater confluence in 1970 and early 1971. We used a digital thermistor (Digetec, United Systems, Inc.) with an instrument accuracy of ± 0.15 C. Total dissolved solids were measured with a conductivity meter (Hach Chemical Company) and remote 12 m lead. Vertical temperature and total dissolved solids profiles were taken at 18 m intervals across the stream. At each point, the boat was held steady in the river current by two 30 kg anchors.

We plotted the temperature and TDS series as cross-sectional profile maps from which we assessed general longitudinal and seasonal trends in mixing of the Snake River, Clearwater River, and Kraft effluent.

To obtain indices of mixing for seasonal comparison at sampling stations, computerized least-squares analyses of variance were run on selected temperature and TDS profiles which represented seasonal changes in mixing at each station. The least-squares analysis of variance separated variation in temperature and TDS within the profile into: (1) a component which resulted from changes in temperature and TDS with depth; and (2) a component caused by changes in temperature and TDS across the width of the stream. The F-values and mean squares for each station and seasonal pattern served as indices of mixing for seasonal comparison.

Duncan's Multiple Range Test was used to test for significant differences between mean temperatures and between mean TDS of adjacent width locations in cross-sectional profiles. These tests disclosed the locations and widths of mixing interfaces for each station and season.

We determined vertical profiles of current velocities with a cable-suspended Ott current meter, Model C-31 (Epic, Inc.) operated from a double-anchored boat. Velocities were calculated over the range of river flows encountered from July-December.

WATER QUALITY

Chemical aspects of the Snake and Clearwater Rivers were analysed according to APHA (1965) and EPA (1969). Total hardness, ammonia, and tannins were analysed by the Hach technique (Hach Chemical Company) and the Pearl-Benson Index as standardized in the pulp and paper industry (Barnes et al. 1963). The Pearl-Benson or nitroso technique was developed for detection of sulfite waste liquors, but it also indicates the presence of lignin sulfonate compounds in Kraft liquors. Total volatile solids of the water were determined gravimetrically by ashing three to six replicated samples.

We conducted water sampling intermittently from July through December of 1969, September through November of 1970, and July through November of 1971. Sampling was restricted to peak months of adult summer steelhead migration in the study area. A grass fire on July 27, 1970, at our field tracking facility destroyed much of our water sampling and analysis equipment, thus setting back water analysis until September of that year. We established stations on the two rivers in order to physically and chemically measure incoming river flows into the study area, mixing patterns of water quality parameters at various distances below the Snake-Clearwater confluence, and in the total Snake flow leaving the study area after complete mixing.

FISH TRACKING

Test steelhead were picked up in all three track years from the National Marine Fishery Service trapping facilities at Ice Harbor Dam (RK 16). We netted fish from the top of the fish ladder, anesthetized them with MS-222 (Tricaine methanesulfonate), and carried them in canvas bags to a waiting tank truck on top of the dam. They were then trucked upstream to the Snake River release point 15 km downstream from the Snake-Clearwater confluence. Ice, recirculation, and compressed oxygen were used to maintain the fish during the three to four hour transport. A maximum of six fish were hauled per trip in the 750 liter tank.

On arrival at the release point, we again anesthetized the fish prior to removal from the tank, measured total length, and inserted an ultrasonic transmitter into the fish stomachs via a tube and plunger assembly.

These sonic tags were the standard sonic transmitters SR69 and SR69A manufactured by Smith-Root, Inc., Seattle. The two types of tags used were cylindrical, 6.4 cm and 8.9 cm long, 1.4 and 1.9 cm in diameter, and 9 and 42 g respectively. Transmission life was approximately 20 days for the smaller tag and approximately 45 days for the larger tag at 70 KHz (± 1.5 KHz). The smaller tags were used early in the season when we could expect fish to pass through the study area within 15 days; the large tags were used later in the season when the fish were tracked up to six weeks. Different pulse rates were used so that more than one fish could be tracked at a time. Ultrasonic signals were picked up in the water by a hand-held directional hydrophone (Smith-Root, Inc.). The hydrophone supplied input to a battery-powered TA-60 Sonic Receiver (Smith-Root, Inc.) for conversion to an audible pulse.

We held tagged fish in 1m x 1m x 2m nylon mesh live boxes in water 1-1.5 m deep 12 to 48 hours before release into the Snake River. No discernible differences in fish behavior or movement were observed between different holding times. Fish were released as men and equipment became available to track fish. Early in the tracking program, two boats each with two men tracked a single fish; with increased tracking proficiency one man in a single boat could take a lateral bearing on a fish, then rapidly move behind the fish and take another bearing for an effective triangulation of position. Since most fish were 15-25 m from shore, estimated distances from shore were checked by throwing a weighted, marked line to shore. We logged a fish's position in relation to permanent shoreline markers (power poles, trees, houses, rock points, and artificial markers erected in the absence of other permanent natural markers).

In the first track year, we attempted to triangulate fish positions at chemical stations by pairs of portable hydrophones situated on shore a known distance apart, and zeroed on a compass bearing. This proved too time-consuming for use on fast moving fish and no more accurate than position fixes by boat. In subsequent years, all position fixing was done from boats.

Early in the track seasons (or at any other times if a fish moved continuously) we tracked the fish day and night. During times of little movement of fish, we checked fish locations only periodically throughout the day. We followed fish paths with particular care near our water quality stations and near the Snake-Clearwater confluence.

Night tracking was conducted just as day tracking but with the use of hand-held airplane landing lights to locate shoreline markers. Care was taken to keep the light from flashing over a fish's position.

During tracks, we maintained continuous records of wind velocity, barometric pressure, cloud cover, and maximum-minimum air temperature. River flow volumes were obtained from USGS records.

## SECTION VI

## RESULTS

Temperature patterns of the two streams were similar from year to year throughout the study. Midsummer Clearwater River temperatures exceeded Snake River temperatures before temperature equalization in late August. Maximal annual Snake River temperatures ($\approx$25 C) coincided with minimal annual Snake River flows ($\approx$18,000 cfs) in late August. The Clearwater River cooled more rapidly in September than the Snake and remained at lower temperatures through winter.

Snake and Clearwater River flows decreased to annual lows in late August then increased moderately through December (Figure 2). The Clearwater River contributed its greatest percentage to the combined flow in late November.

Total dissolved solids (TDS) in the Snake River were substantially higher than TDS in the Clearwater River throughout the study (Figures A-7a to A-7c). TDS in both streams attained an annual high in November, probably due to surface flushing of accumulated debris after extended periods of little rainfall.

### MIXING PATTERNS

#### 0.2 Km Below the Snake-Clearwater Confluence

At 0.2 km below the confluence, mixing took place at a swirling interface of the Snake and Clearwater flows (Figures 6 and 7). The location of the interface in the stream width depended on the magnitude and proportion of the Snake and Clearwater River flows. An increase in the proportion of Snake River water to the total flow forced the interface toward the north or Clearwater side.

The mixing interface, as indicated by temperature, occupied a 55 m portion of the stream cross-section in early August but narrowed to a width of 40 m and moved closer to the north shore in November and January (Figure 6). Kraft effluent was always contained between the two river flows at this station. In early August, Kraft effluent was a vertical column of warmer water at 55 m and in November it was a warm surface flow between 55 m and 75 m. Kraft effluent appeared as a vertical column of water of high TDS at 110 m across the channel in the late August profile (Figure 7) but was undetectable at any other time or at any of the downstream profiles.

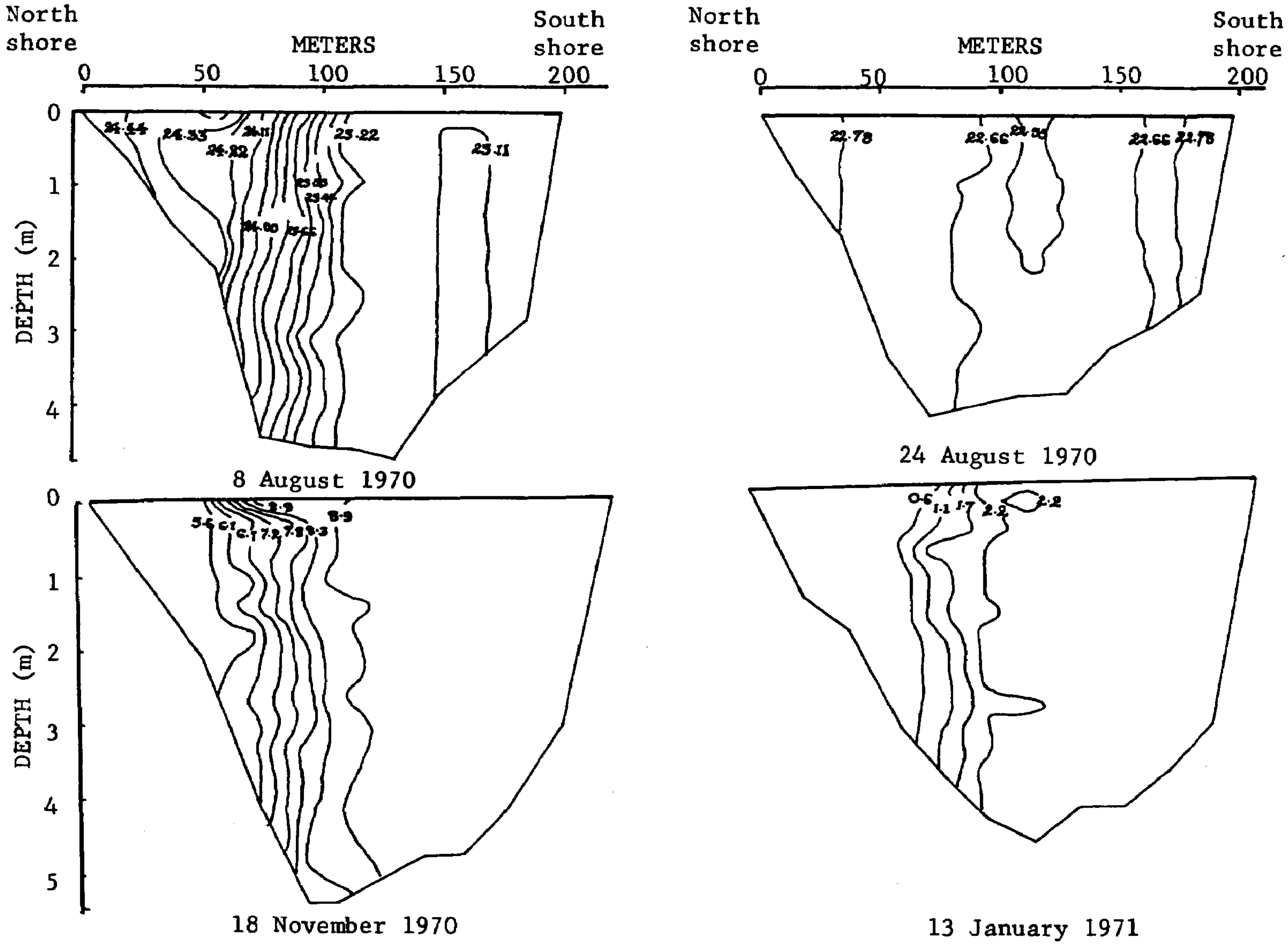


Figure 6. Temperature (C) profiles 0.2 km downstream from the Snake-Clearwater confluence.

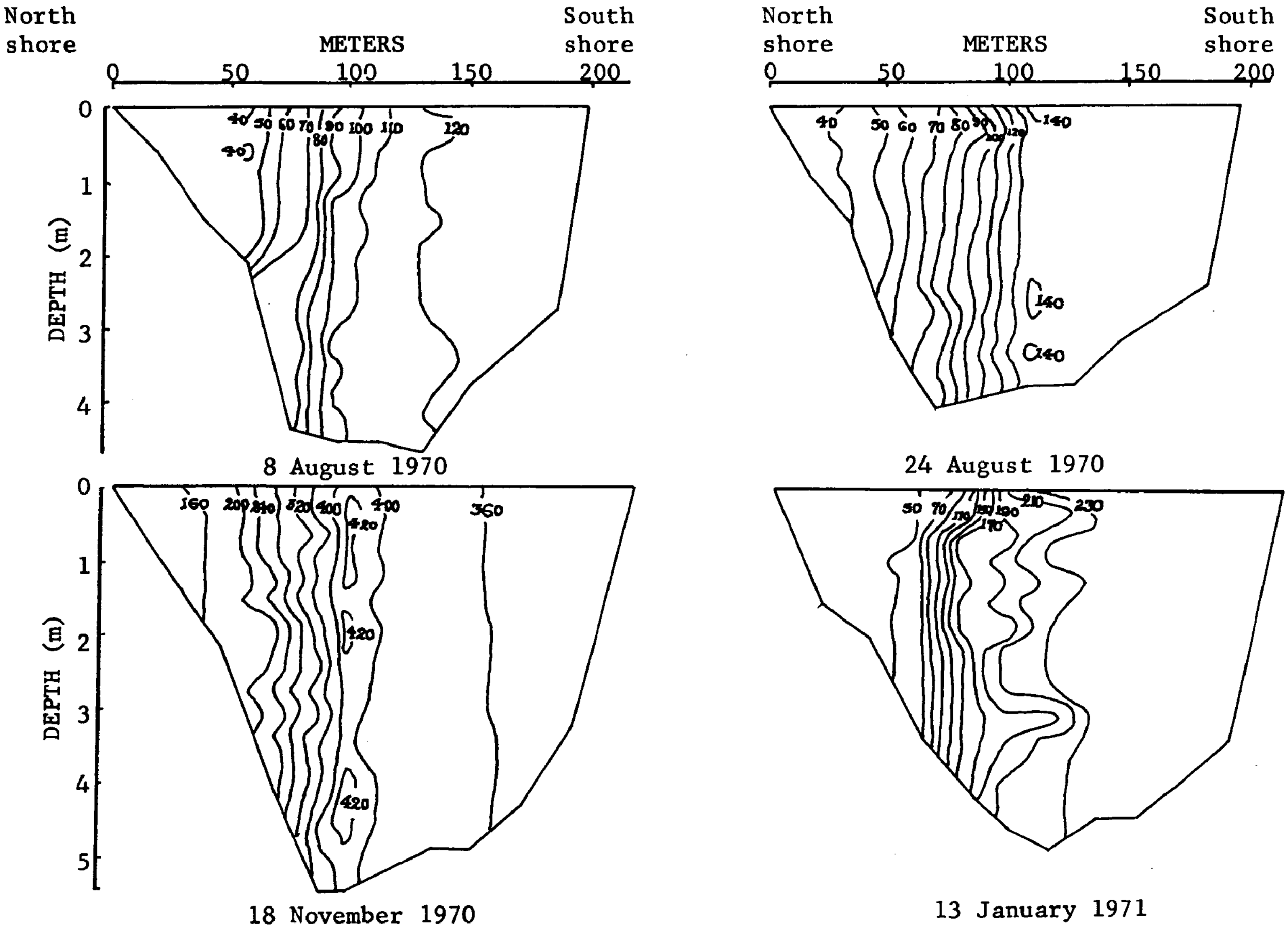


Figure 7. Total dissolved solids (mg/l) profiles 0.2 km downstream from the Snake-Clearwater confluence.

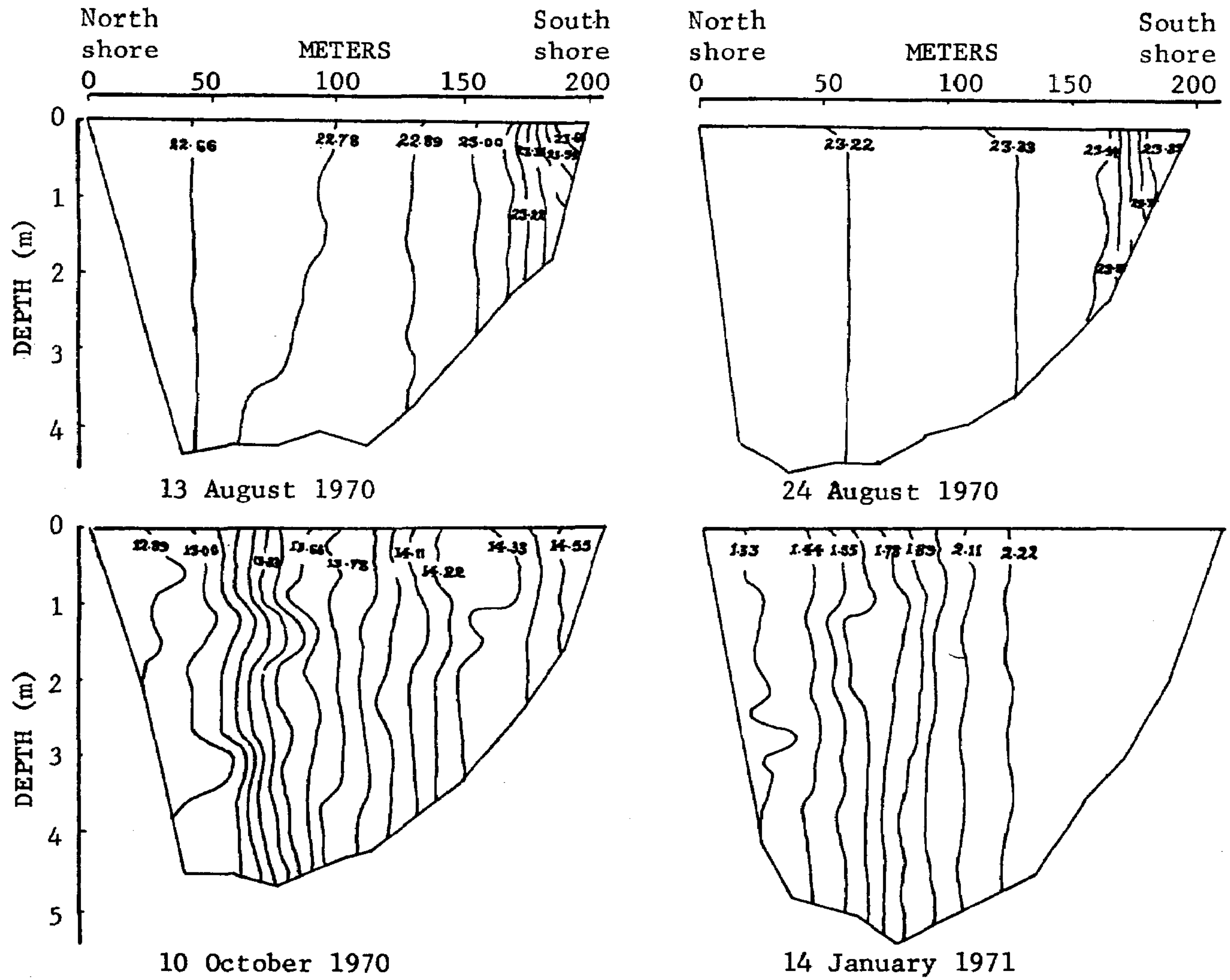


Figure 8. Temperature (C) profiles 2.4 km downstream from the Snake-Clearwater confluence.

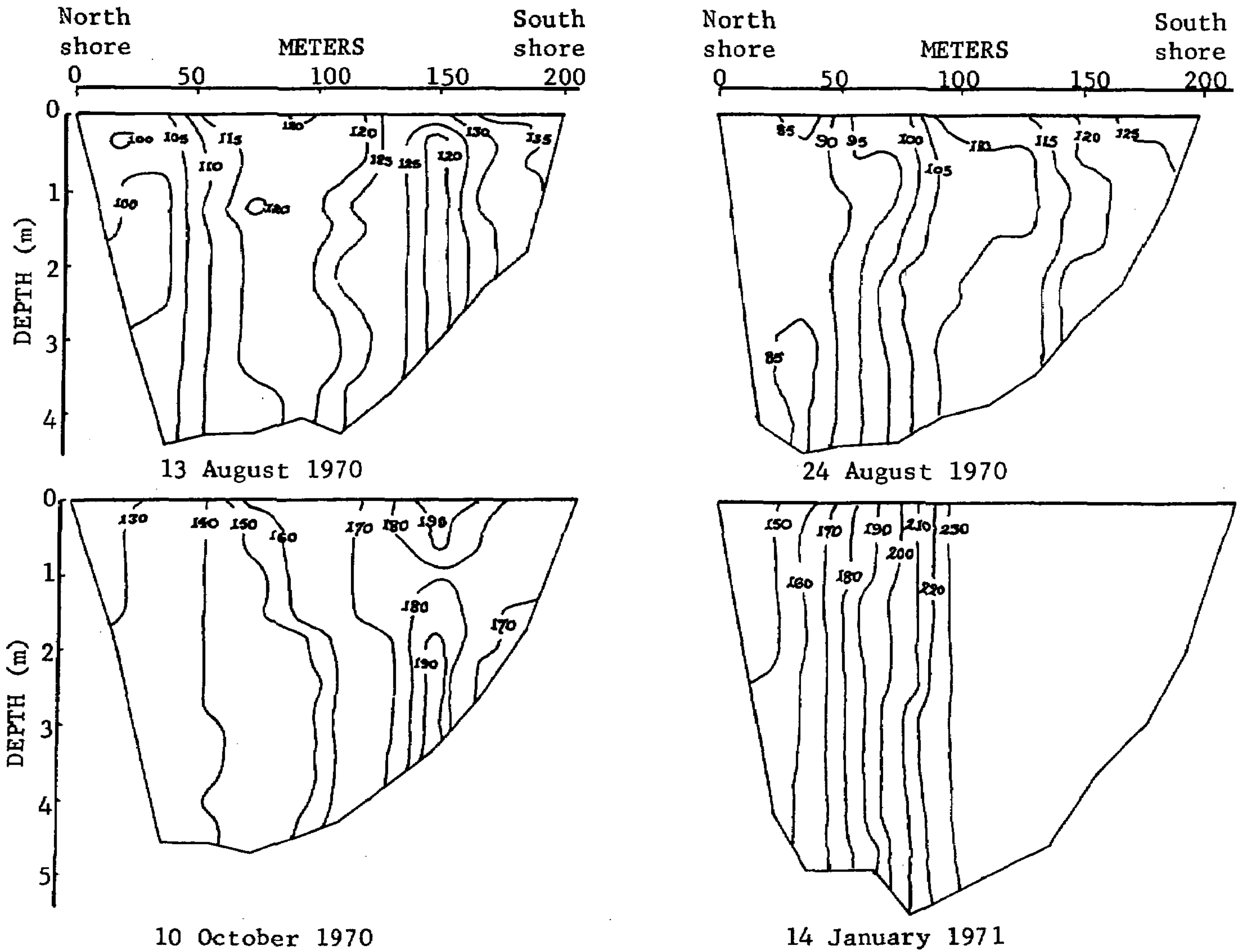


Figure 9. Total dissolved solids (mg/l) profiles 2.4 km downstream from the Snake-Clearwater confluence.

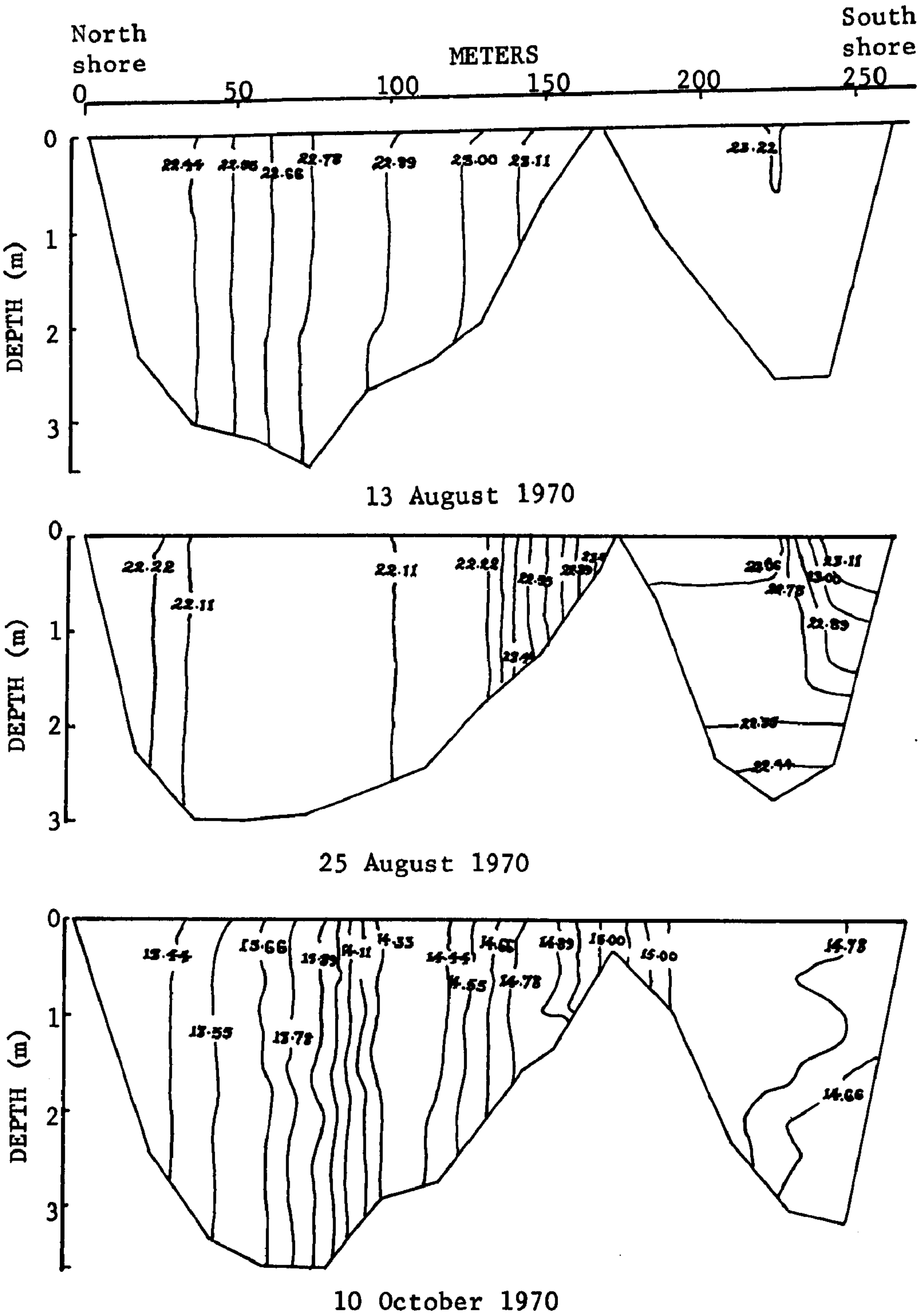


Figure 10. Temperature (C) profiles 6.1 km downstream from the Snake-Clearwater confluence.

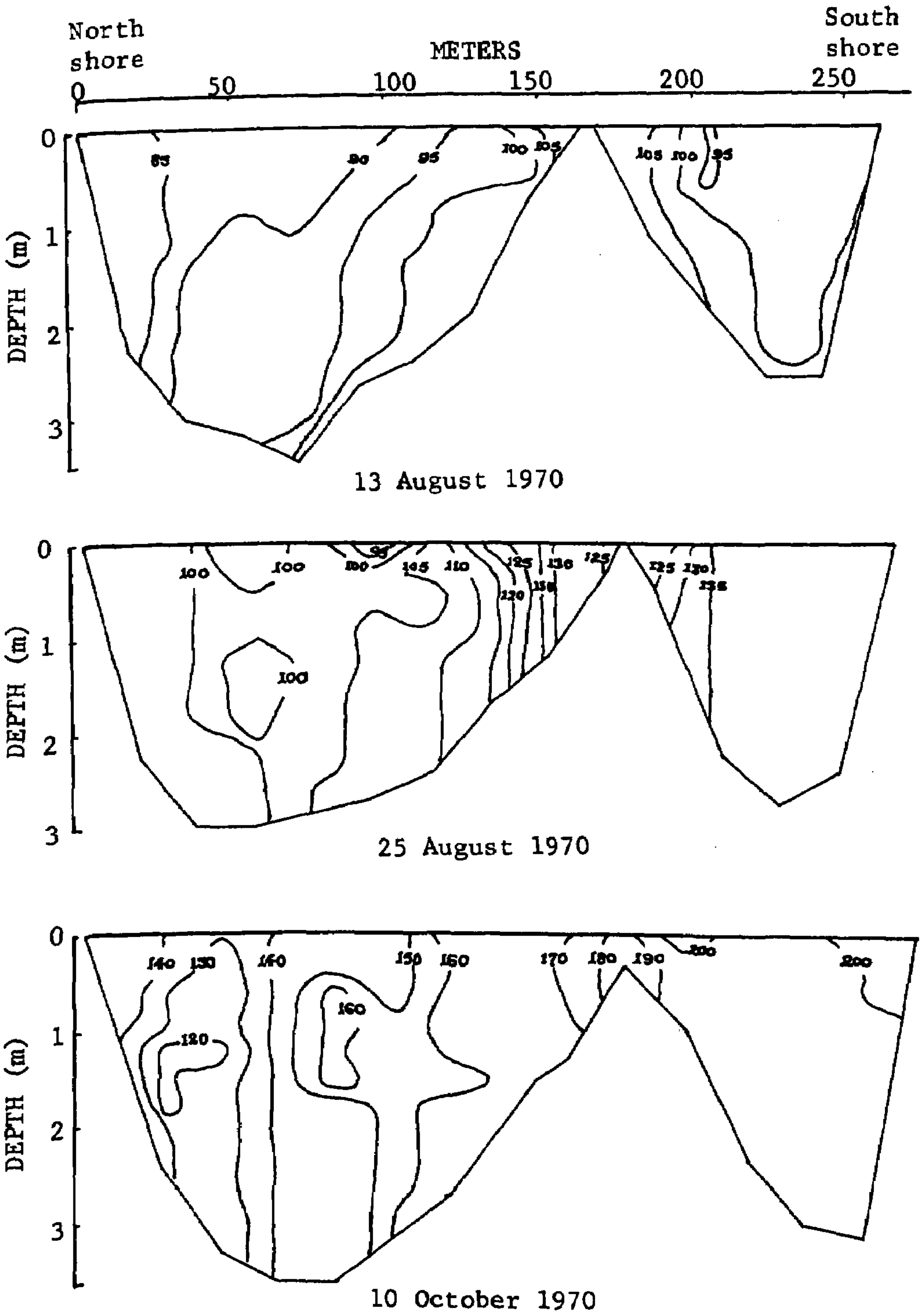


Figure 11. Total dissolved solids (mg/l) profiles 6.1 km downstream from the Snake-Clearwater confluence.

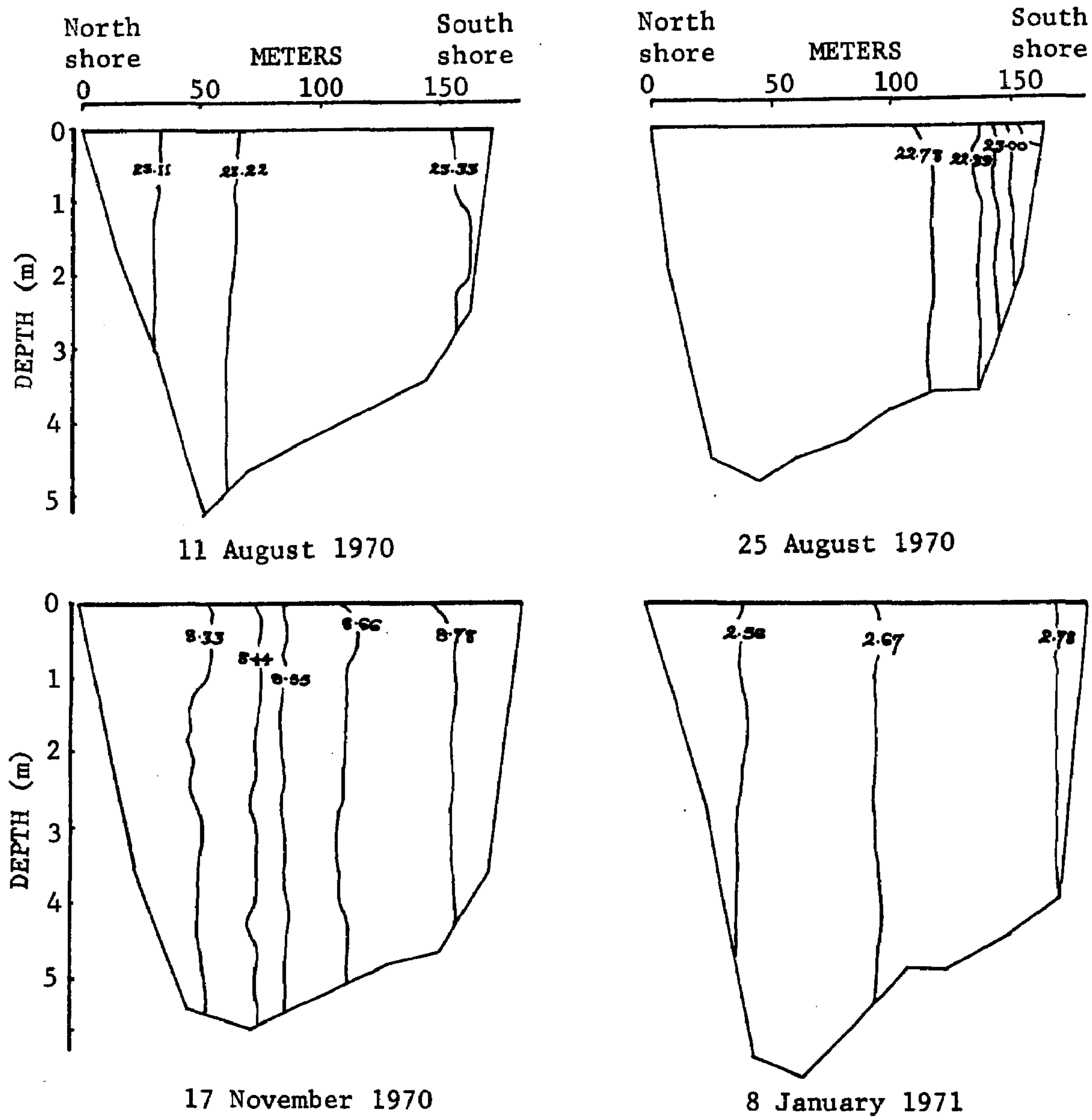


Figure 12. Temperature (C) profiles 10.6 km downstream from the Snake-Clearwater confluence.

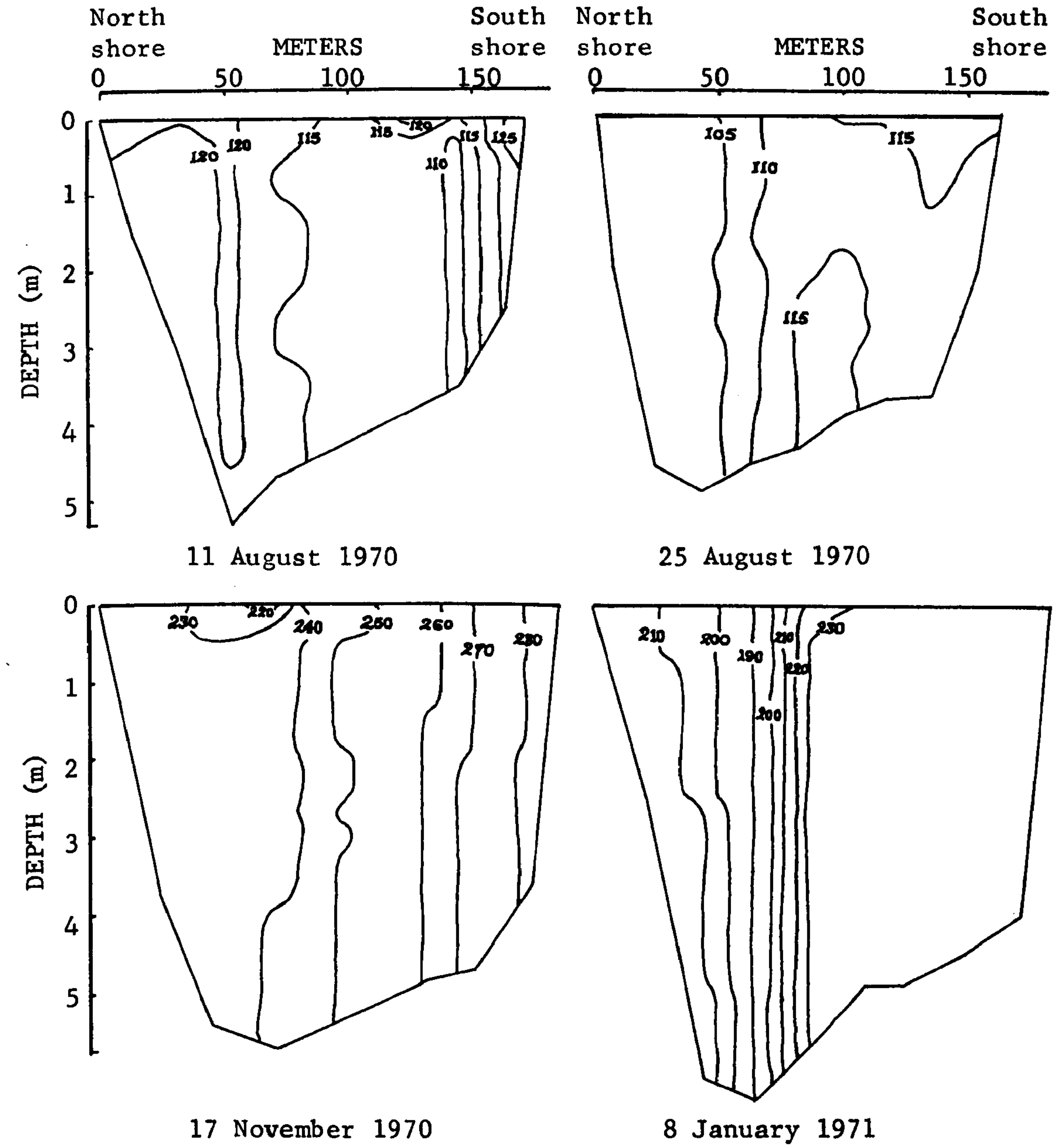


Figure 13. Total dissolved solids (mg/l) profiles 10.6 km downstream from the Snake-Clearwater confluence.

## 2.4 Km Below the Snake-Clearwater Confluence

The mixing interface occupied a 130 m section in midstream in early August (Figures 8 and 9). In early August, significant temperature change ($P \leq .01$) occurred across the entire stream width except for a 70 m section in midstream. The interface widened to a 130 m broken pattern at midstream in October but in January the interface narrowed to 90 m and approached the north shore.

## 6.1 Km Below the Snake-Clearwater Confluence

The portion of the cross-section from 165 m to the south shore was excluded from analysis since this is a slough area which is separated from the main stream flow.

The mixing interface, as indicated by temperature, occupied most of the stream width in early August and October but occurred only in a 40 m section near the south shore in late August when temperatures of the two rivers equalized (Figure 10). Temperature variation across the stream width was greatest in early August, decreased to the seasonal low in late August, and increased slightly in October.

No significant variation in TDS across the stream width occurred at this station during the study (Figure 11).

## 10.6 Km Below the Snake-Clearwater Confluence

The mixing interface, as indicated by significant temperature gradients, occupied the entire stream cross-section in early August but steadily narrowed through the fall and winter as flows increased (Figure 12).

The mixing interface, as indicated by TDS, occupied midstream sections in August. In November through January, the interface widened and moved toward the south shore as the Clearwater River flow made its largest contribution of the season to the total flow.

## WATER QUALITY

Because temperature and TDS profiles as well as top and bottom chemical samples showed near complete surface to bottom mixing in 1969, a near surface water sample was assumed to be representative of all depths.

There is a high range in temporal and spatial variation as shown in the cross-channel distribution of the measured water quality parameters and longitudinal mixing patterns (Figures A-1a to A-13c). Although all chemical data are presented in Figures A-1a to A-13c, a more meaningful pre-impoundment description of the pool area is shown by three-year mean cross-channel patterns (Figure 14).

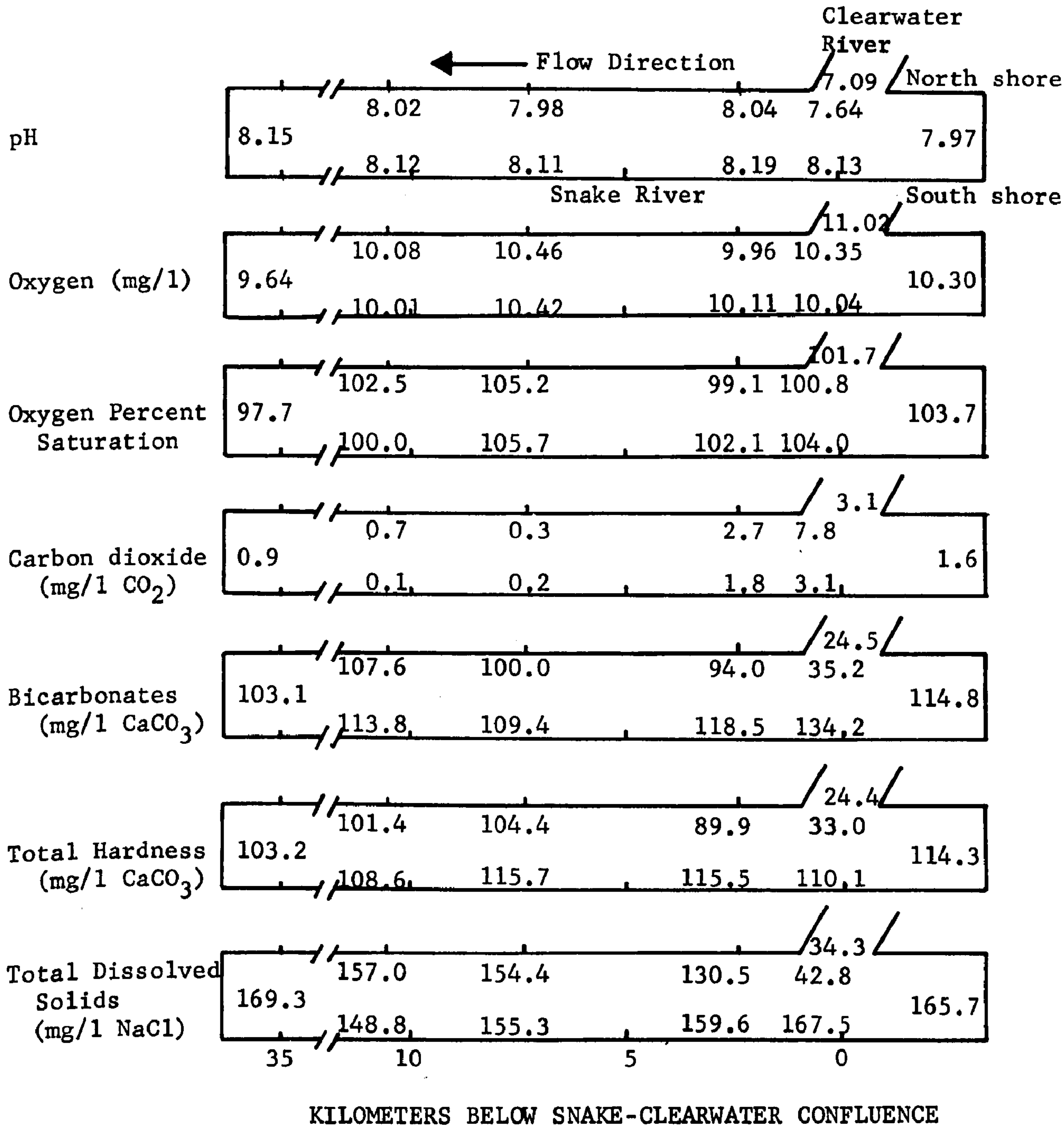


Figure 14. Average cross-channel patterns of water quality parameters in the Snake and Clearwater Rivers during adult steelhead migration - 1969, 1970, and 1971.

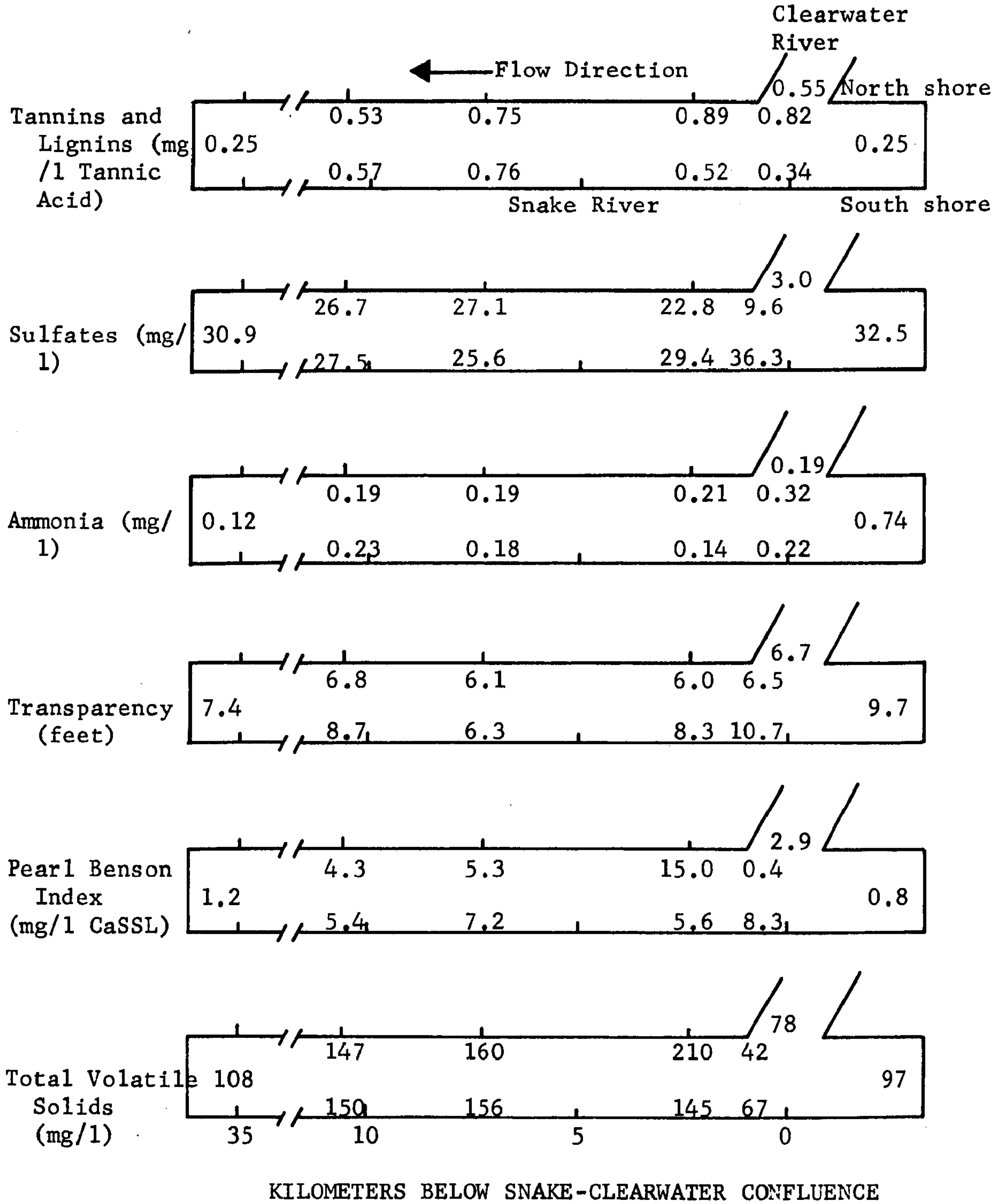


Figure 14 (Continued). Average cross-channel patterns of water quality parameters in the Snake and Clearwater Rivers during adult steelhead migration - 1969, 1970, 1971.

Mean water quality changes in the Snake River as a result of pollution inputs, especially the Kraft effluent, in the immediate Lewiston area were difficult to detect (Figure 14). In terms of toxic effects from chemical loading, the Snake River was not greatly altered. In the immediate 3 to 4 km below the confluence on the north shore or Clearwater River side, gross changes in benthic periphyton and insect communities were evident . . . diversity sharply dropped and "clean water forms" gave way to chironomids and isopods on a matrix of filamentous fungi. But none of the chemical parameters routinely measured showed the free-flowing Snake River, when fully mixed and leaving the steelhead tracking area, as obviously unsuitable for migrating salmonids. Mean oxygen percent saturation levels were five percent lower leaving the tracking area compared to river inflows (97.7% vs 103.7%). As reported in other work on the lower Snake River (Falter and Funk 1971), this decline in oxygen was the beginning of a slight oxygen sag which reached minimum levels 30 to 50 km below the confluence. Any tendency for an oxygen sag to develop, however, was so slight that on sunny days, the "spiking" of photosynthesis by pollutants in the Lewiston area caused a net oxygen increase in the area 5 to 50 km below the confluence.

Carbon dioxide was always low except for an increase to 7.8 mg/l just below the confluence on the north shore. This increase usually was found in the Kraft effluent plume before complete mixing occurred.

Total dissolved solids increased slightly in water leaving the tracking area (mean TDS leaving study area = 169.3 mg/l), mostly because of the mixing with the Kraft effluent which contained greater than 1000 mg/l TDS.

Tannins, sulfates, and ammonia were sometimes good indicators of the effluent plume, but once mixed with the river flow, these increases were usually undetectable (Figure 14). Ammonia levels were higher above than below the confluence because of ammonia inputs from cattle feedlots in the 15 miles upstream (Falter and Funk 1973).

Net increases were shown in the Pearl-Benson Index and total volatile solids even after complete mixing and dilution (Figure 14). The chemical station 2.4 km below the confluence had the highest Pearl-Benson Indexes and total volatile solids, indicating a major deflection of the Clearwater River flow and effluent plume closer to the north shore at this station.

## STEELHEAD MIGRATION PATHS AND BEHAVIOR

### General Patterns

The Snake River run of steelhead consists of two overlapping groups: Group A (destined for the Salmon, Imnaha, and Grand Ronde Rivers) enters the Snake River from July to September; while Group B (principally Clearwater River stocks) enters the Snake River from September to November.

In 1969 and 1970, as opposed to 1971, steelhead studied were larger individuals and a larger proportion of each year's fish were tracked later into the fall and winter (Table 1). Clearwater River fish comprised 15 and 18% of the total Snake River run in 1969 and 1970, but only 11% in 1971.

Since our major concern in this tracking program was to detail individual fish behavior in the Lower Granite area, individual fish paths are described for each fish tracked in 1969, 1970, and 1971 (Figures 15, 16, and 17).

In July, August, and part of September in all three tracking years, fish moved 24 hours a day. We could discern no rate or behavior differences between night movement and day movement at these times. After early October, however, fish rested with greater frequency and for longer periods; movements became very sporadic later in the season.

Fish in 1969 or 1970 were not tracked more than 2 km downstream from the release point. In 1971, however, one fish moved 50 km below the release point and was still moving actively downstream through Little Goose Reservoir at last sighting.

All fish showed a preference for traveling 20-30 m out from either shore in the Snake River (Figures 15, 16, 17, and 18). Tagged fish migrated in mid-channel only when crossing over to the opposite shore. No fish showed sustained upstream movement in mid-channel. The fish tracked through the shallow first kilometer of the Clearwater River (0.5-1.0 m deep) did, however, travel in mid-channel. As water temperature and fish movement dropped, some fish did remain stationary near the middle of the river.

Depending on water conditions, the sonic transmitter could be detected from 10 to 1000 m away but had an average range of 300-400 m in quiescent water of average late summer and fall transparency. The transmitter signal was masked by noises emitted from rocks rolling along the river bottom and by entrained air from rapids, therefore it was usually impossible to follow fish in rapids. When a fish entered a rapids area we went to the head of the rapids and waited for the fish to come through. The Kraft mill effluent also attenuated or reflected the transmitter signal in the first kilometer downstream from the Snake-Clearwater confluence. Occasionally we would locate a tagged fish in the effluent plume only to lose the signal immediately. The fish would often appear in the same general area again after several hours of search. Some fish that entered rapids were never located again in

Table 1. Characteristics of the summer steelhead runs and fish tracked in the lower Snake River, 1969-71.

| | | 1969 | 1970 | 1971 |
|---|---|---|---|---|
| Total steelhead over WWP Dam, July-December | | 9,522 | 8,876 | 7,601 |
| Total steelhead over Ice Harbor Dam, July-December | | 65,187 | 50,817 | 67,125 |
| Percent of Ice Harbor fish passing over WWP Dam, July-December | | 15% | 18% | 11% |
| Dates of fish tracking | | July 11-Jan. 6 | July 17-Nov. 18 | July 22-Nov. 7 |
| Number of fish tracked | | 24 | 28 | 37 |
| Fish length: | mean total length | 73.6 | 73.9 | 68 |
| | range | 61-93 | 64-87 | 55-97 |
| Water temperature range during track season (C) | Snake R. | 3.5-24.0 | 4.5-23.5 | 4.0-23.5 |
| | Clw. R. | 1.0-24.0 | 0.5-24.0 | 1.0-25.5 |
| River flow range during track season (cfs x 1000) | Snake R. | 17.1-37.6 | 18.4-39.9 | 20.7-49.5 |
| | Clw. R. | 1.8-10.0 | 2.6-9.6 | 3.0-11.2 |

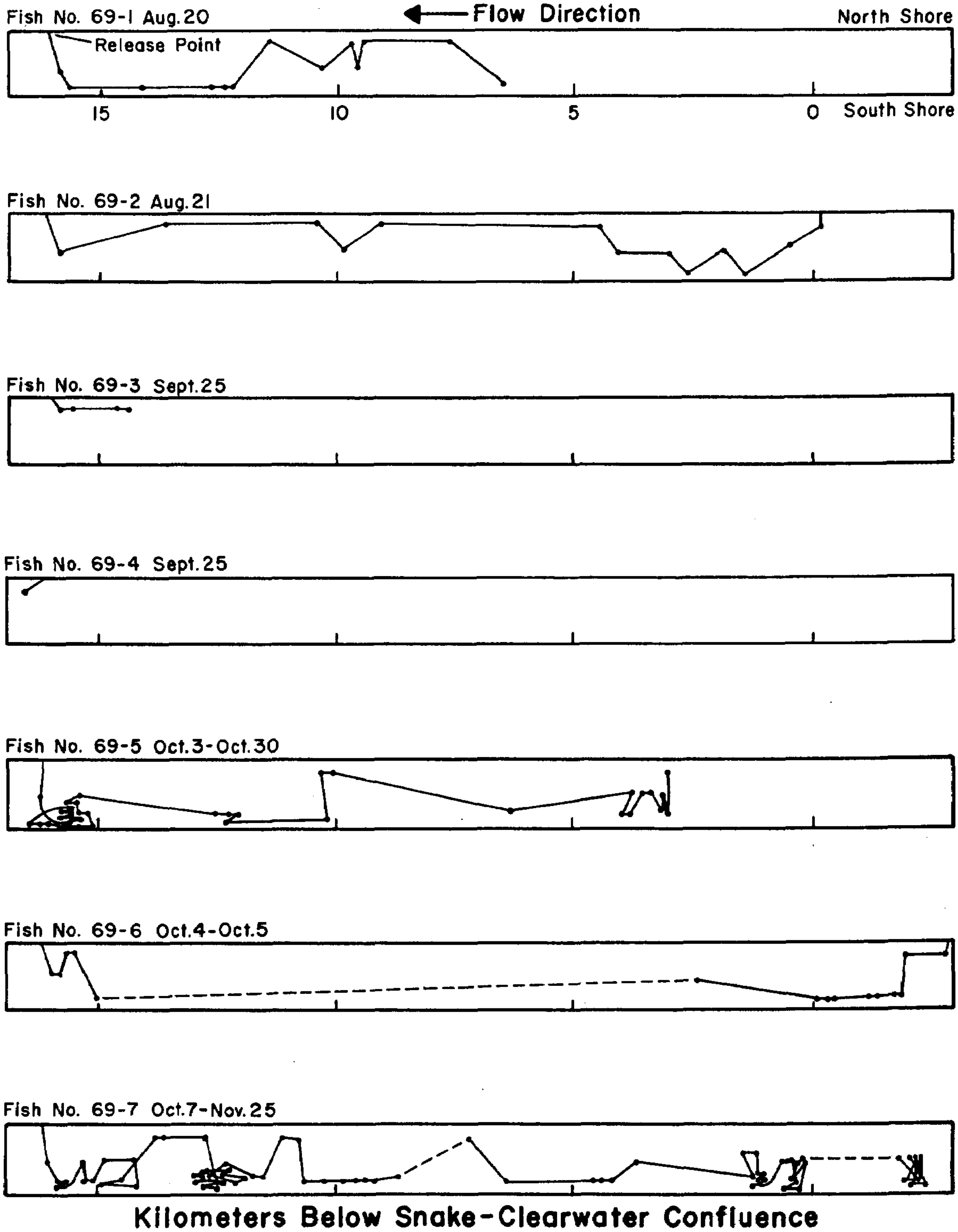


Figure 15. Adult steelhead migration paths in the Snake River, Lower Granite pool area, 1969.

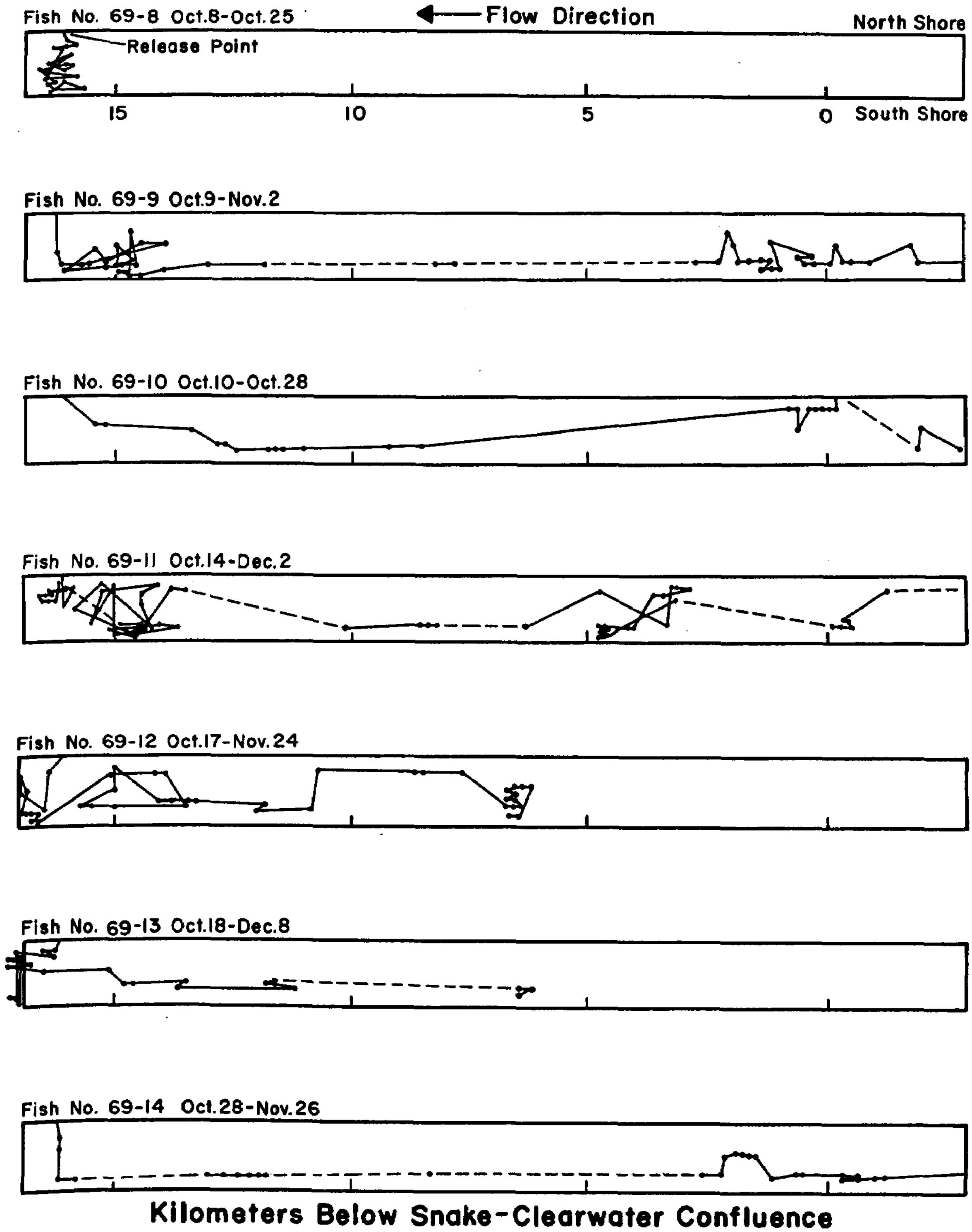


Figure 15 (Continued). Adult steelhead migration paths in the Snake River, Lower Granite pool area, 1969.

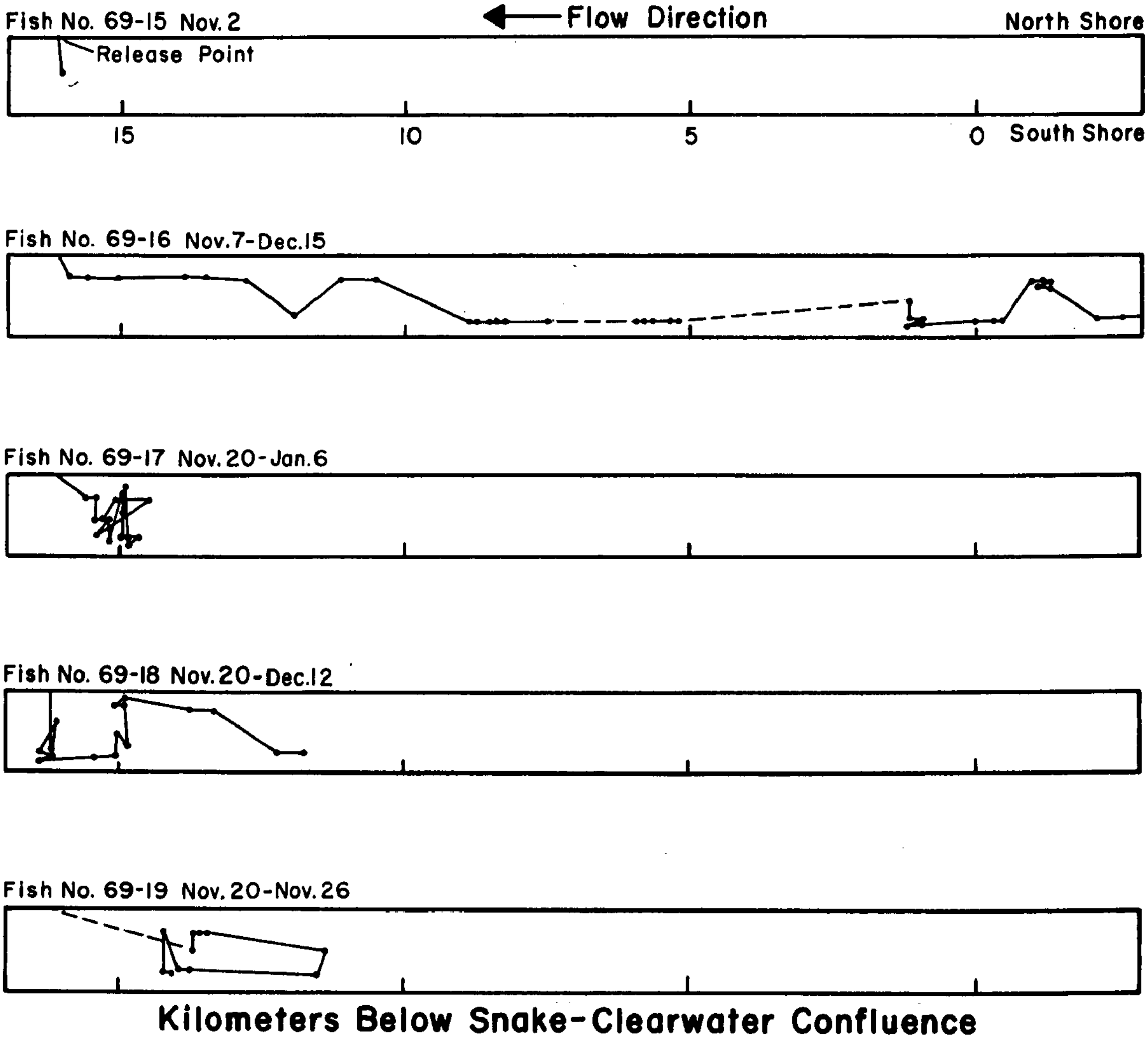


Figure 15 (Continued). Adult steelhead migration paths in the Snake River, Lower Granite pool area, 1969.

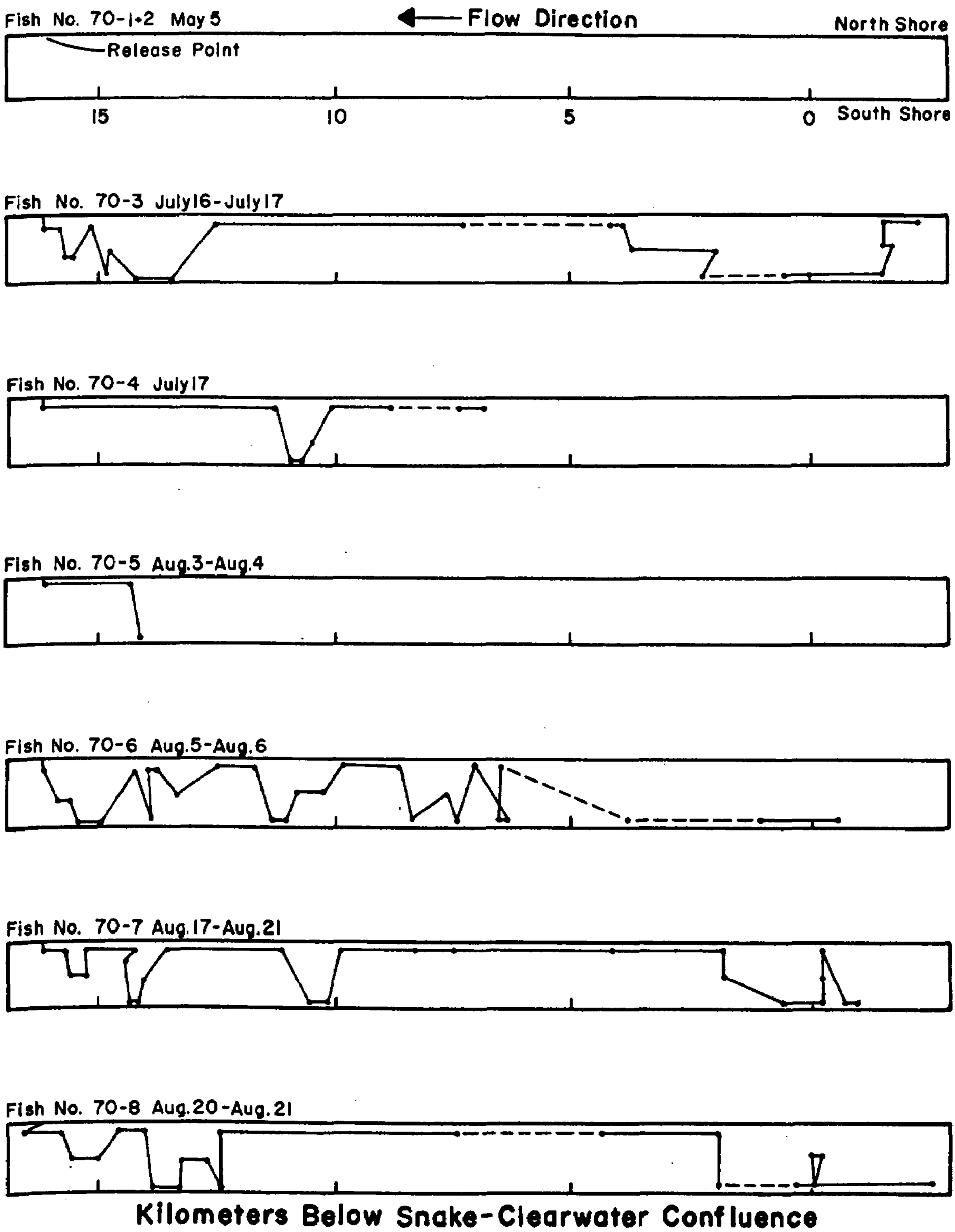


Figure 16. Adult steelhead migration paths in the Snake River, Lower Granite pool area, 1970.

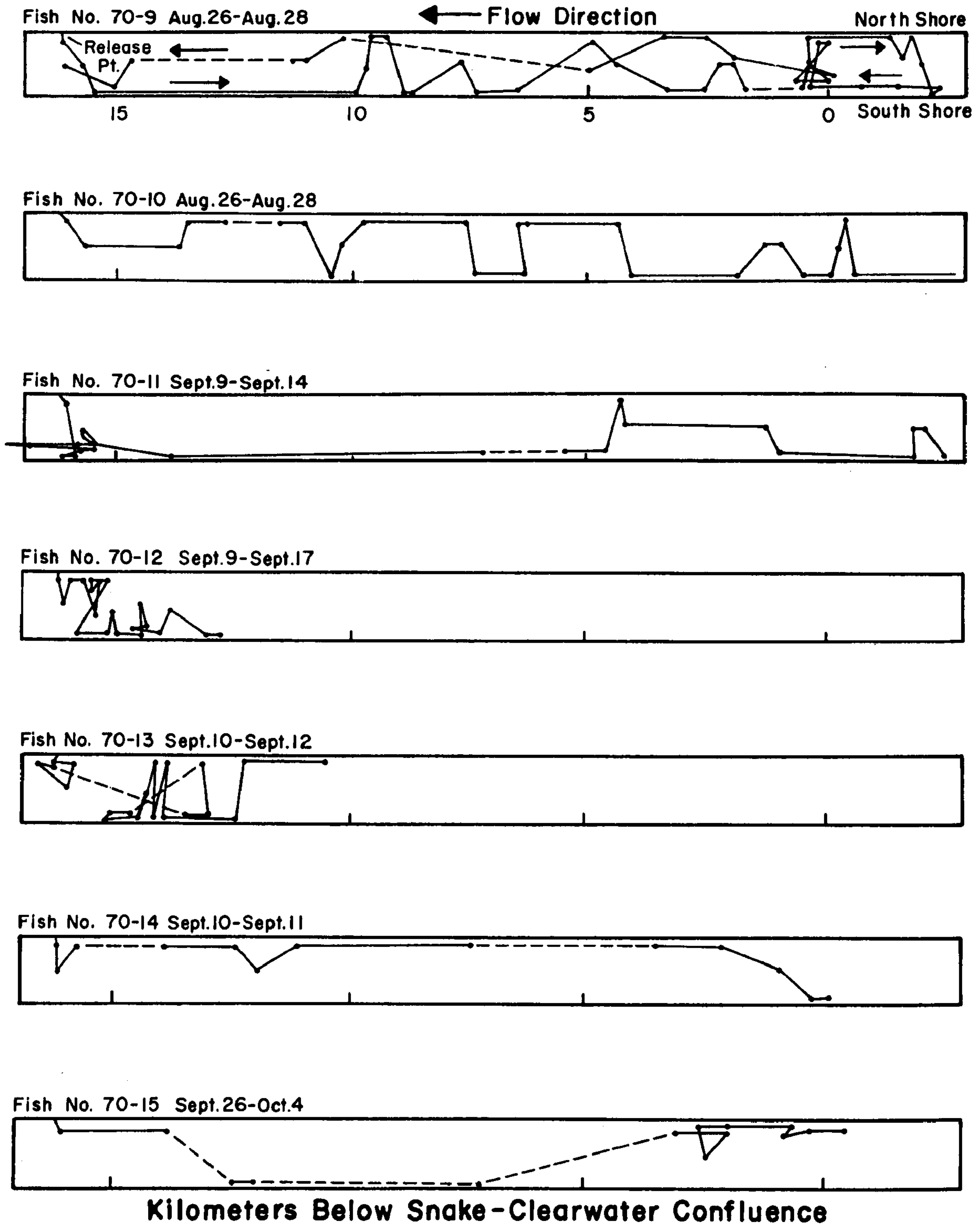


Figure 16 (Continued). Adult steelhead migration paths in the Snake River, Lower Granite pool area, 1970.

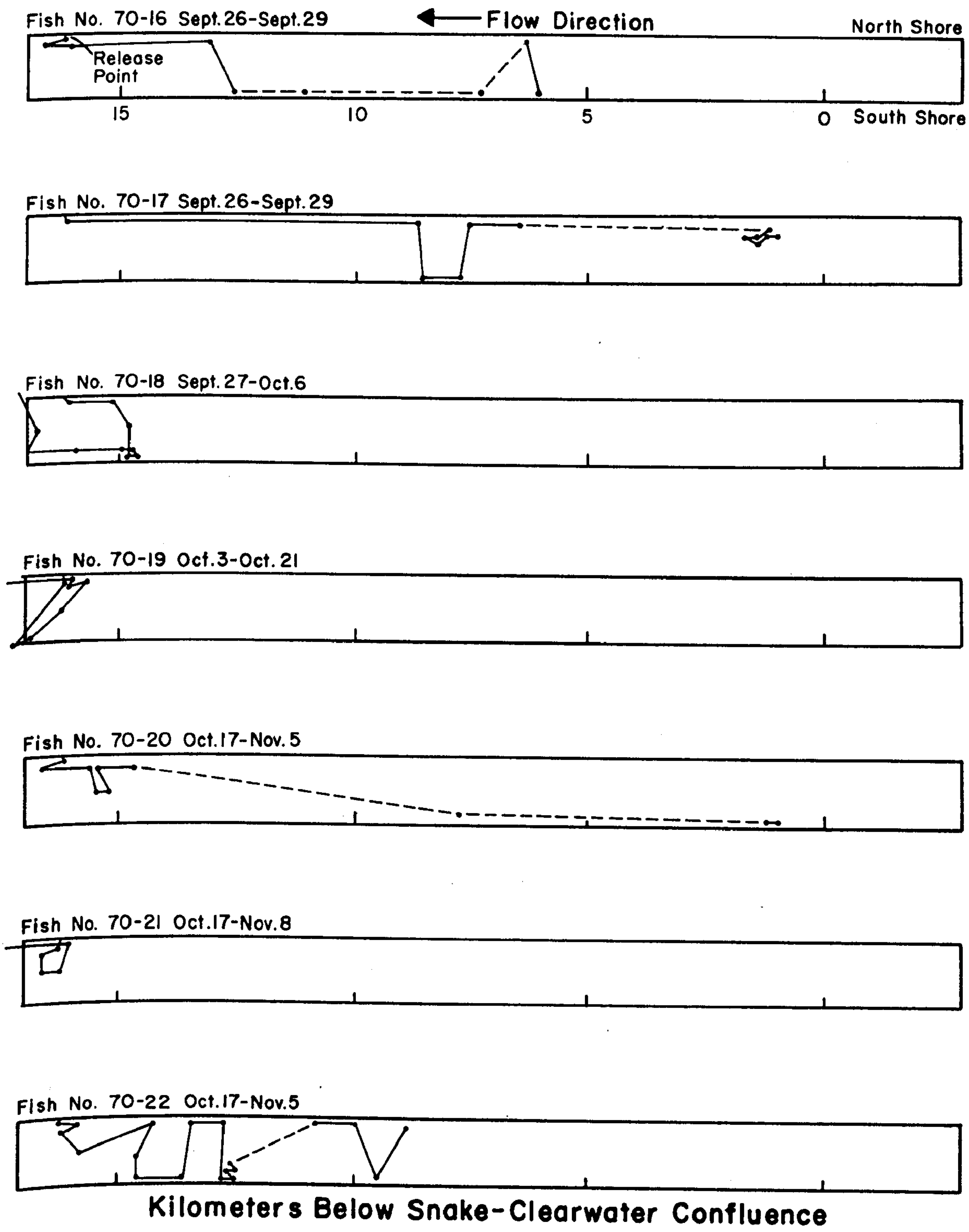


Figure 16 (Continued). Adult steelhead migration paths in the Snake River, Lower Granite pool area, 1970.

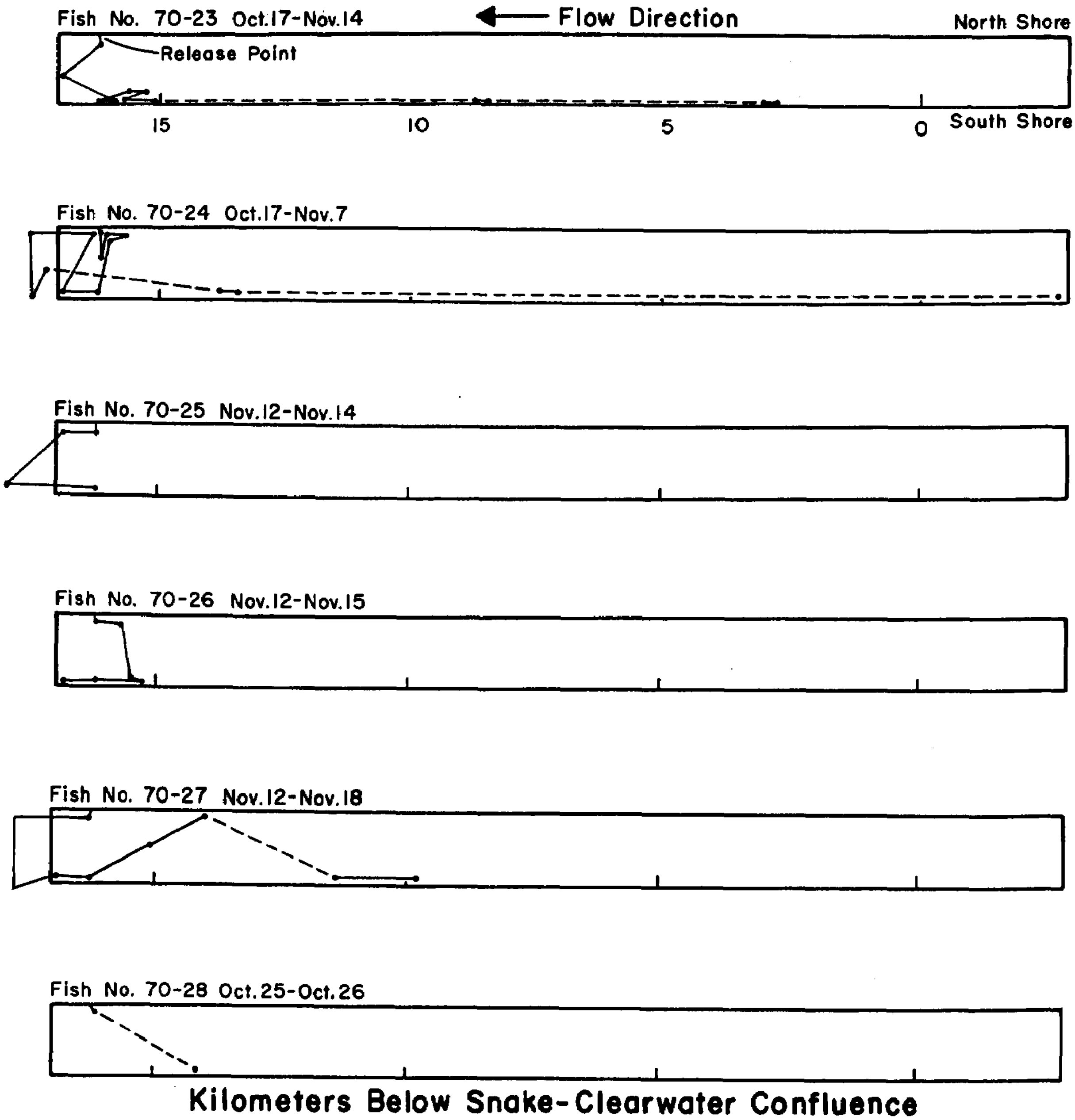


Figure 16 (Continued). Adult steelhead migration paths in the Snake River, Lower Granite pool area, 1970.

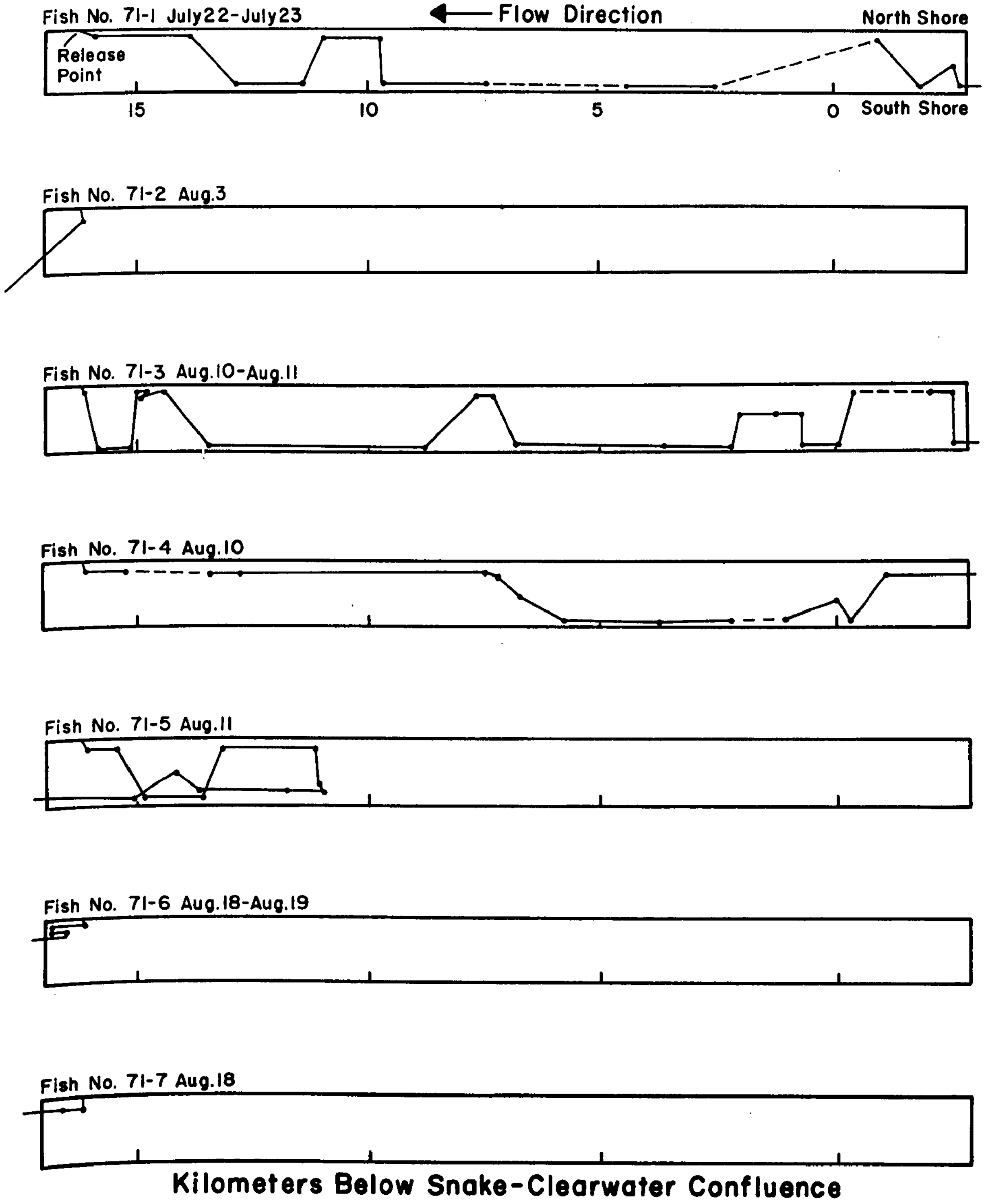


Figure 17. Adult steelhead migration paths in the Snake River, Lower Granite pool area, 1971.

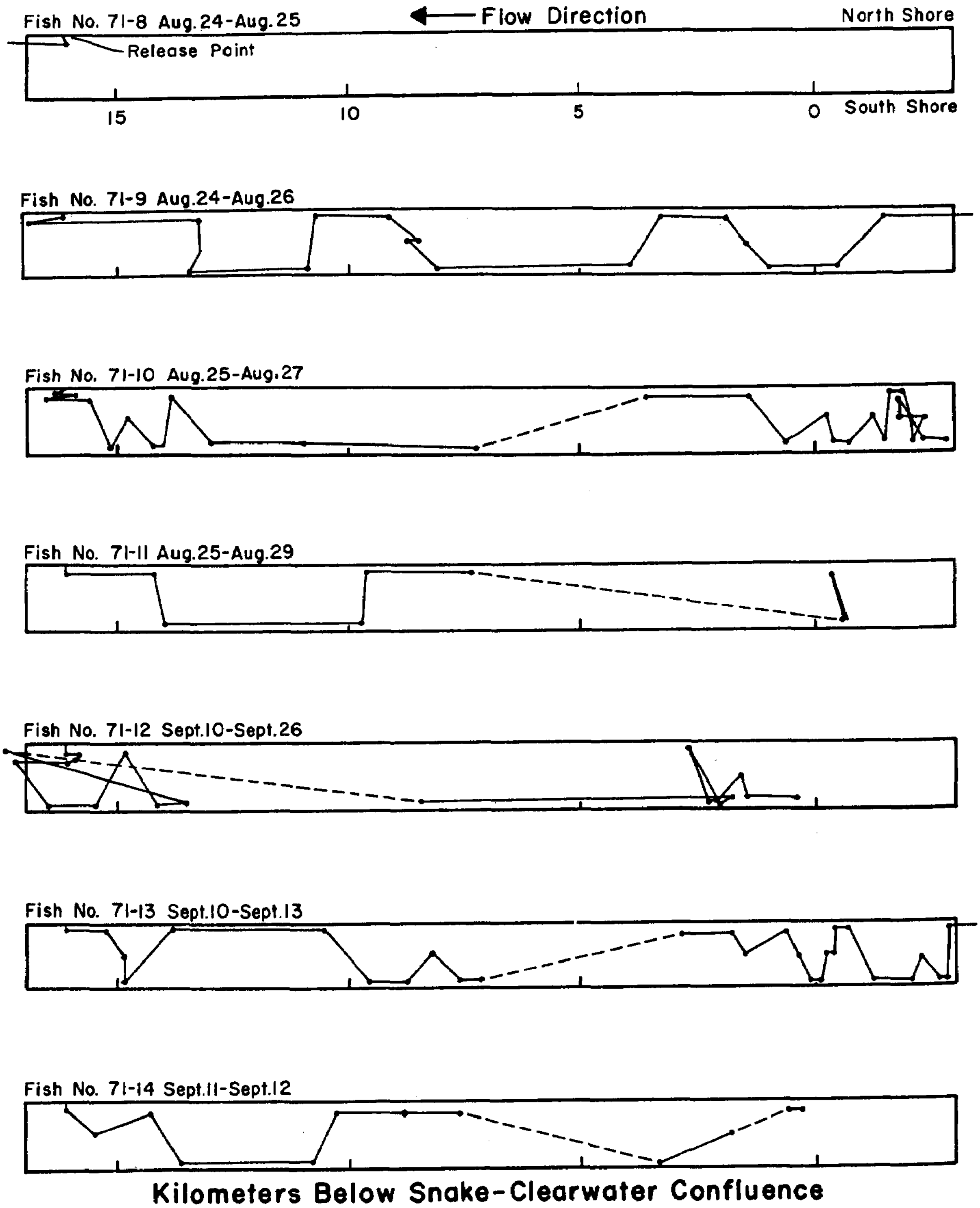


Figure 17 (Continued). Adult steelhead migration paths in the Snake River, Lower Granite pool area, 1971.

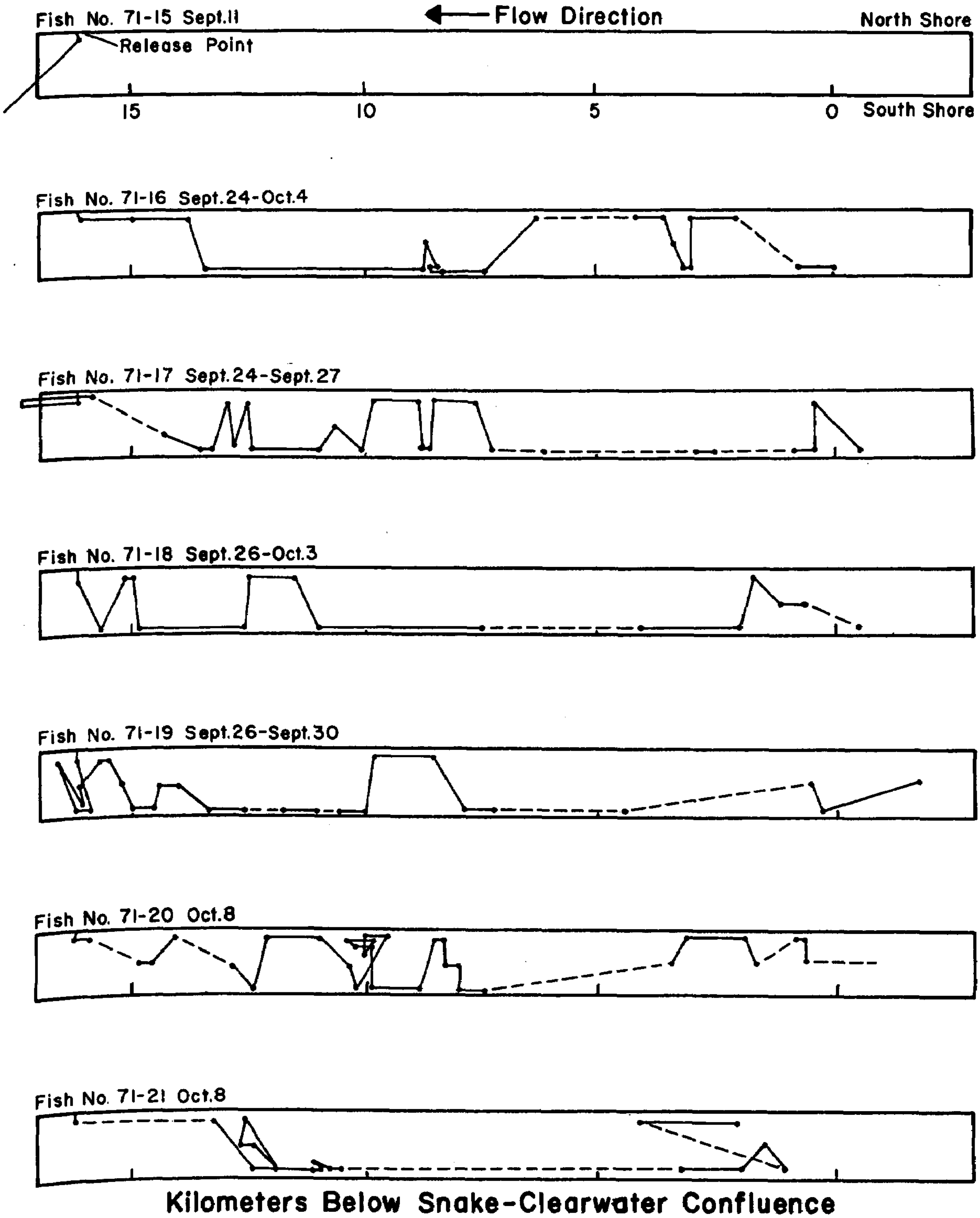


Figure 17 (Continued). Adult steelhead migration paths in the Snake River, Lower Granite pool area, 1971.

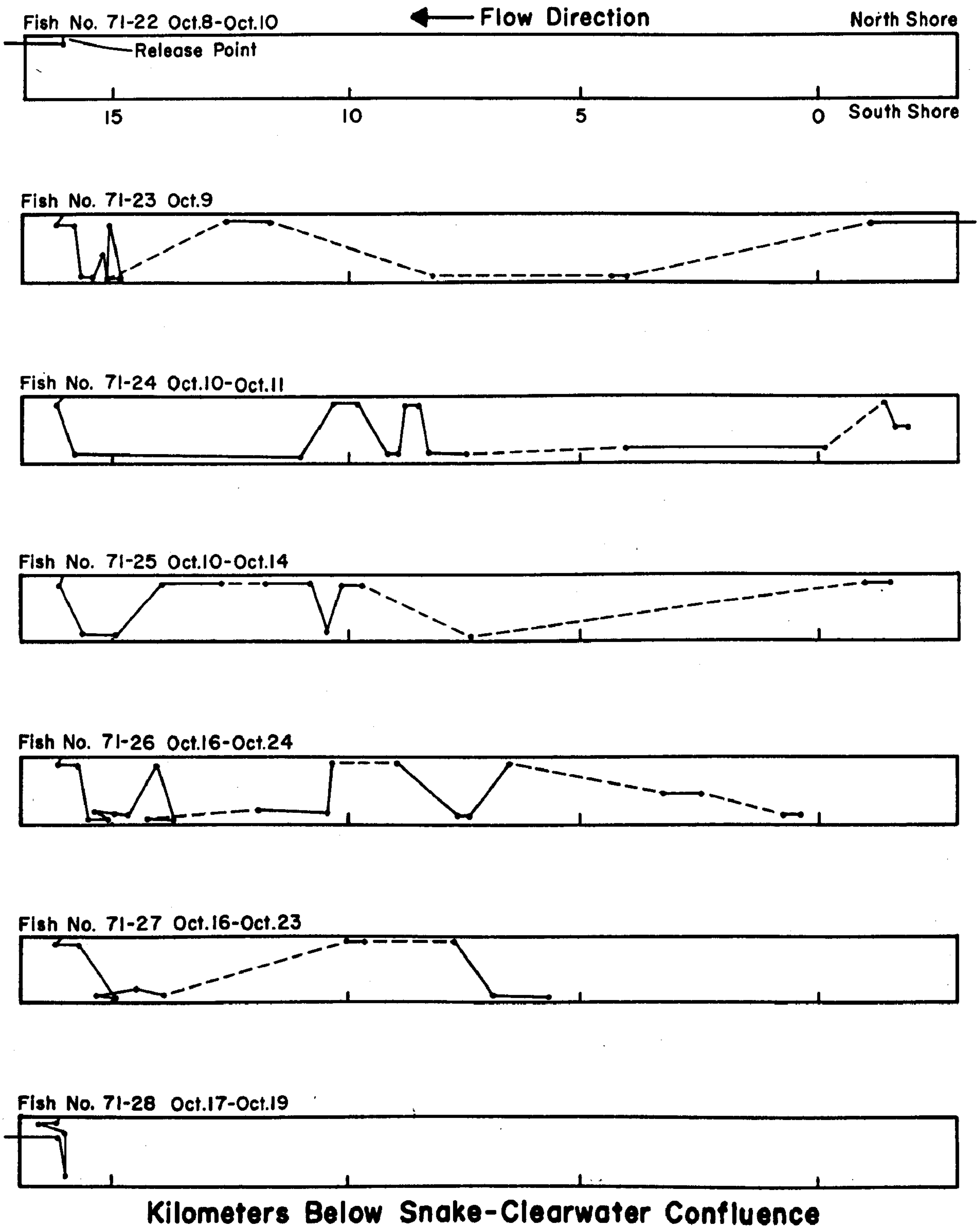


Figure 17 (Continued). Adult steelhead migration paths in the Snake River, Lower Granite pool area, 1971.

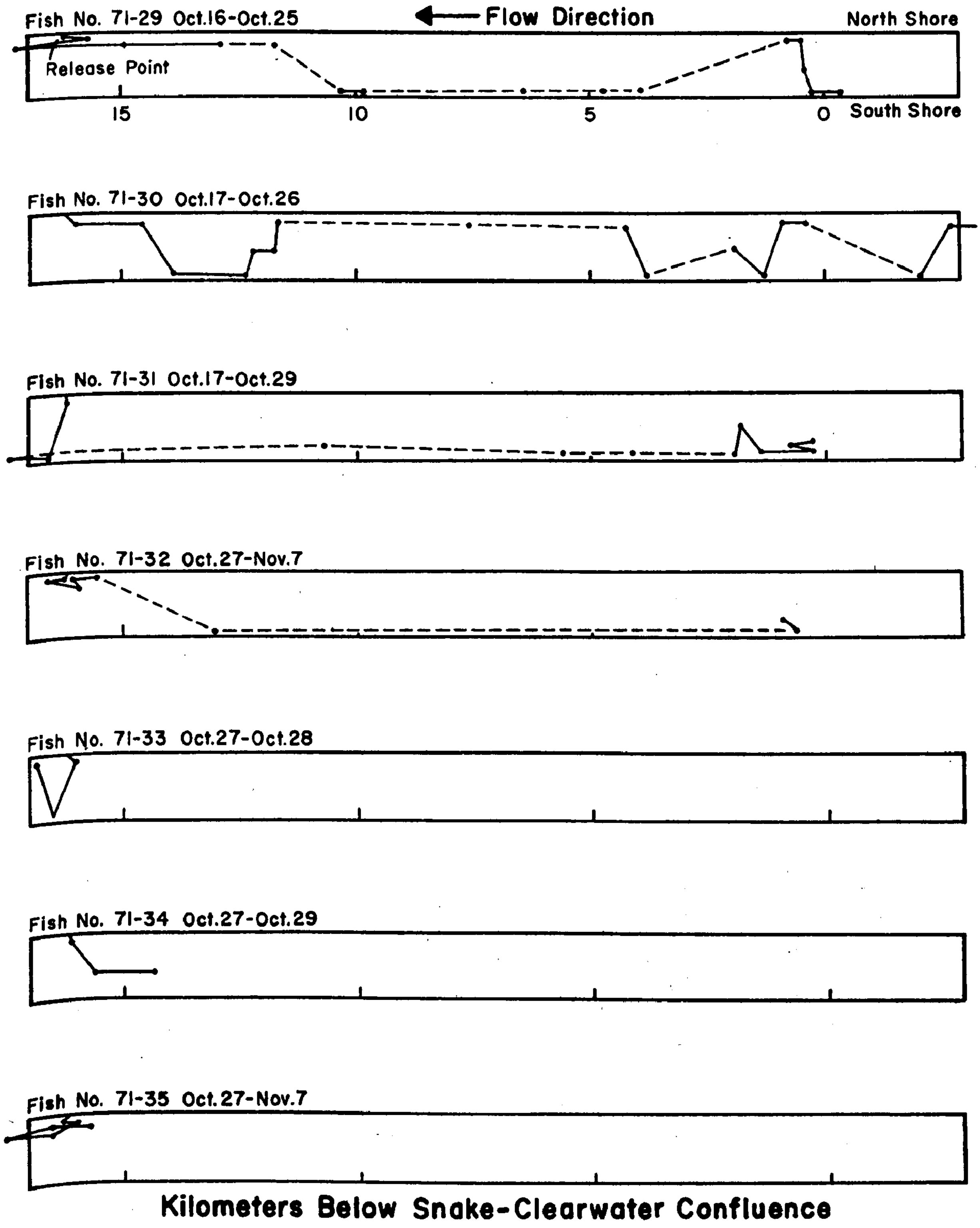


Figure 17 (Continued). Adult steelhead migration paths in the Snake River, Lower Granite pool area, 1971.

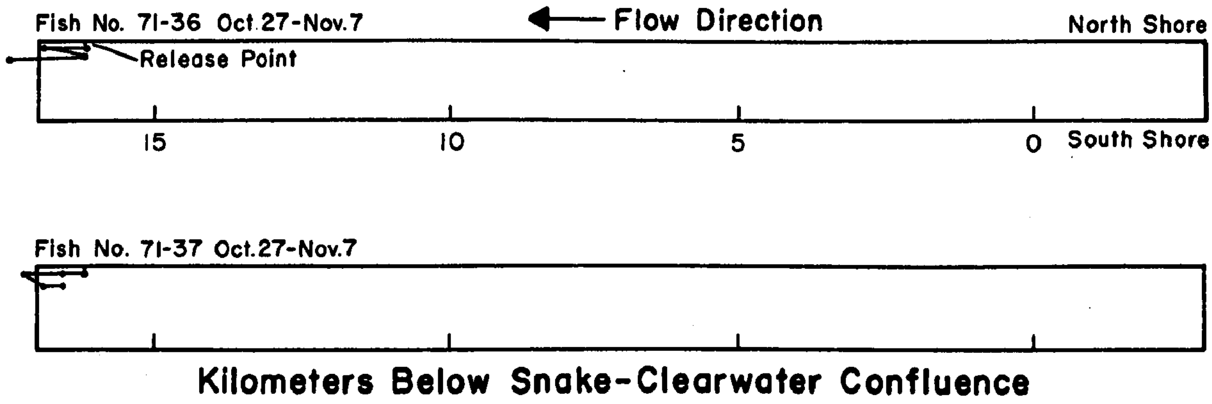


Figure 17 (Continued). Adult steelhead migration paths in the Snake River, Lower Granite pool area, 1971.


Figure 18. Distribution of steelhead in the Snake River, 1969-71. Width of bars expresses the percent of fish in each third of the river width.

spite of several days search as much as 25 km above and below the last known position. No explanation (other than transmitter failure) was found for these losses. Fish were never known to regurgitate tags either in the live box or after release. One tag stopped transmitting while the fish was still in the live box before release.

A total of 11 tags were recovered from sport fishermen. Five fish were caught while still being tracked. We had 3 recoveries in 1969; 1.5 km below confluence, 2 km below confluence, and directly across the river from the release point where the particular fish had been stationary for 3 weeks. In 1970 we had 4 recoveries; from the Salmon River near Riggins, Idaho, 3.5 km below the Snake-Clearwater confluence, one 1970 tag was found on the bank of the Selway River (a tributary to the Clearwater River) in April of 1971, and a tag was returned from a fish caught in the Grand Ronde River near Troy, Oregon. We had four 1971 tags recovered; from 1.5 km below the confluence, 0.8 km up the Clearwater River, and two 1971 tags recovered in the spring of 1972 . . . one was found on the bank of the Salmon River and another lodged in bottom rocks 0.5 km up Alpowa Creek.

All fish caught by fishermen were in good condition. More fish were probably caught but even though a publicized $10.00 reward was offered for recovered tags the tag is not readily visible to a person cleaning the fish. This high return of tags may indicate the tag and tagging procedures had a minimal effect on the fish's behavior. The shortest elapsed time between tagging and recovery of a fish by fishermen was 16 days.

Lateral Position in the Stream

Lateral distribution of steelhead across the Snake River is detailed in Figure 18. A well-defined preference for near-shore movement is shown.

Fish passage observations from 1969 and 1970 in the river section 0.1-0.4 km and 2.2-2.5 km below the Snake-Clearwater confluence were tested by Chi Square to determine whether fish numbers passing on the Clearwater or Snake side were significantly different than would be expected by the ratio of Clearwater fish to Snake fish for each year. The low number of fish following the Clearwater side through this section was not significantly different from the number that would be expected to pass upstream on that side based on Washington Water Power Dam counts of total numbers of fish up the Clearwater River ($P \leq .10$). We concluded that steelhead were not avoiding the Clearwater side, even though effluent concentrations were higher there.

## Rest Areas

Resting areas did increase in frequency as fish approached the confluence (Figure 19). As with cross-over points, the frequency of individual fish use of rest areas increased markedly later in the track season. Stopping points became more frequent and longer until November when resting or stopping times exceeded the six week tag life.

A favored rest area was 2.7-3.5 km below the confluence on both shores, even though highest mean Pearl-Benson Indexes and total volatile solids were on the north shore 2.5 km below the confluence (Figure 14). After mid-September, fish commonly sat for extended periods 100-200 m below the Clearwater River mouth.

At a rest stop, fish did not remain completely motionless. Normal resting behavior involved some milling around in an area 20-50 m in diameter, occasionally moving toward mid-channel, but not to the other side of the river. Resumption of upstream travel did not always follow milling activity, but greatly increased milling activity or "restlessness" usually preceded resumption of upstream travel.

We attempted to disturb several resting fish by shining a spotlight directly down on a known fish position at night. The fish did not avoid the light in less than 2.5 m water depth. Likewise, efforts to disturb a fish day or night by boat activity (propeller or jet boat) directly over the fish were successful only in water shallower than 2.5 m.

Attempts to observe tagged steelhead in deep water with SCUBA failed. A diver would position himself on the bottom in a predicted location to intercept an upstream moving fish, but the divers were consistently avoided. In one instance when a fish had been sitting in a slough for two weeks at 4.5 C, divers attempted unsuccessfully to observe the fish while guided by sonic trackers on the surface. The fish never left a 40 m diameter area and we were unable to force it from the slough into faster water. The fish settled down in the same area after the divers left.

## Depth of Migration and Preferred Current Velocity

Several times each year, we visually sighted tagged steelhead passing upstream over shoal areas. These observed steelhead were always within 10-20 cm of the bottom. Low velocity water was preferred to high velocity water. If a swift, turbulent stretch was ahead of a fish, the fish would often cross over below the rapids seeking out a lower velocity vector, whether the new path was shallow or deep water. Thus, in some areas fish often travelled several hundred meters through water only 1-2 m deep.

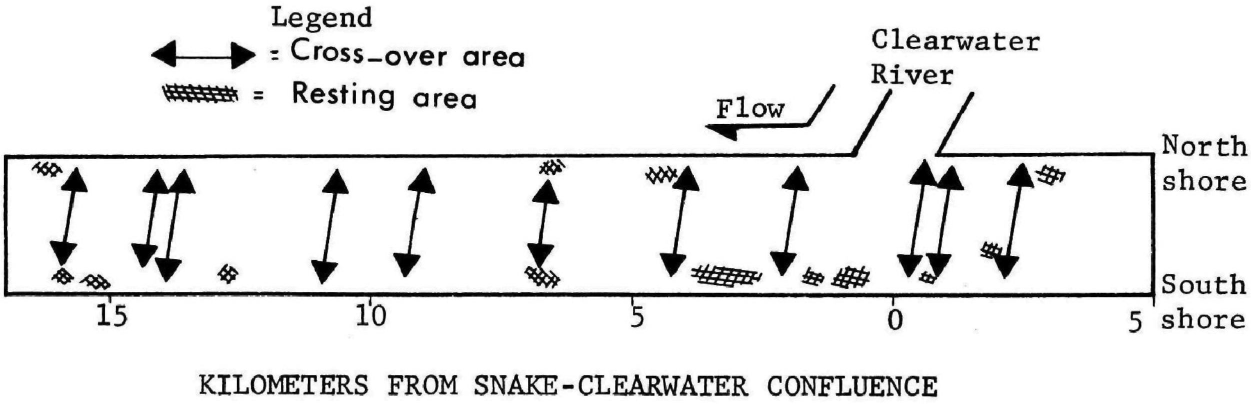


Figure 19. Principal cross-over and resting areas preferred by sonic-tagged steelhead migrating through the Lower Granite pool area, 1969-71.

Complete cross-sectional profiles of current velocity were taken 0.2, 1.6, and 10.6 km below the confluence, but we have presented current velocities from bottom to 1.5 m off the bottom since this is a depth representative of adult passage (Figure 20). A plot of steelhead locations through the velocity stations indicates that off-bottom current velocity is a more important determinant of lateral location than is either depth or distance from shore. At each station most fish passed through off-bottom current velocities of 0.2-0.5 m/sec over a wide range of depths and distances from shore.

Steelhead Travel Rates and Reversals

Steelhead travel rates and reversals (changes of direction) as related to 8 independent variables (fish length, day of year, water temperature, Clearwater River discharge, Snake River discharge, total combined discharge, barometric pressure, and moon phase) were analysed by computerized stepwise multiple regression on an IBM 360/40 computer. Dependent variables were total movement (up and downstream), net movement upstream, and reversals (noted as direction change up or downstream of greater than 100 m). Day and night behavior was compared separately and in combination.

The total variation attributable to the independent variables was usually quite low, ranging from 1 to 50% over the 27 sets of analyses (9 dependent variables x 3 years). Day of year showed the highest correlation in 9 of the 27 tests (Table 2) and was always one of the 3 most important independent variables. Water temperature showed the highest correlation in 8 out of the remaining 18 regressions and failed to appear in the top 3 rankings only once. Since day of year and water temperature vary inversely together and are closely related, we do not feel that these two variables can be realistically separated. This day of year or water temperature relationship showed highest correlation with steelhead behavior in 17 out of 27 tests. Barometric pressure was consistently poorly correlated, ranking in the top three variables only

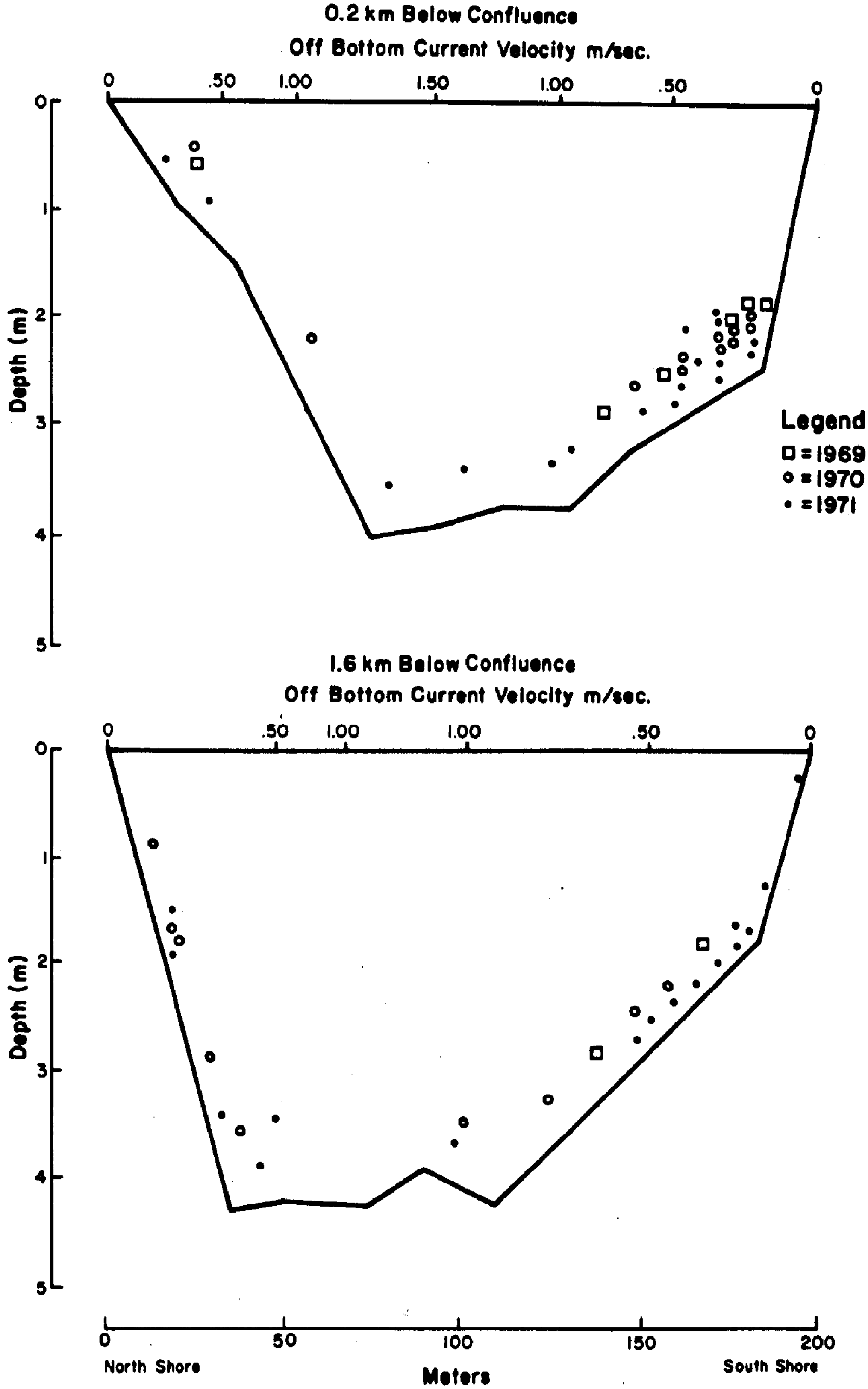


Figure 20. Observed position of steelhead 0.2, 1.6 and 10.6 kilometers below the Snake-Clearwater confluence in relation to current velocity 1 m off the bottom, 1969-71.

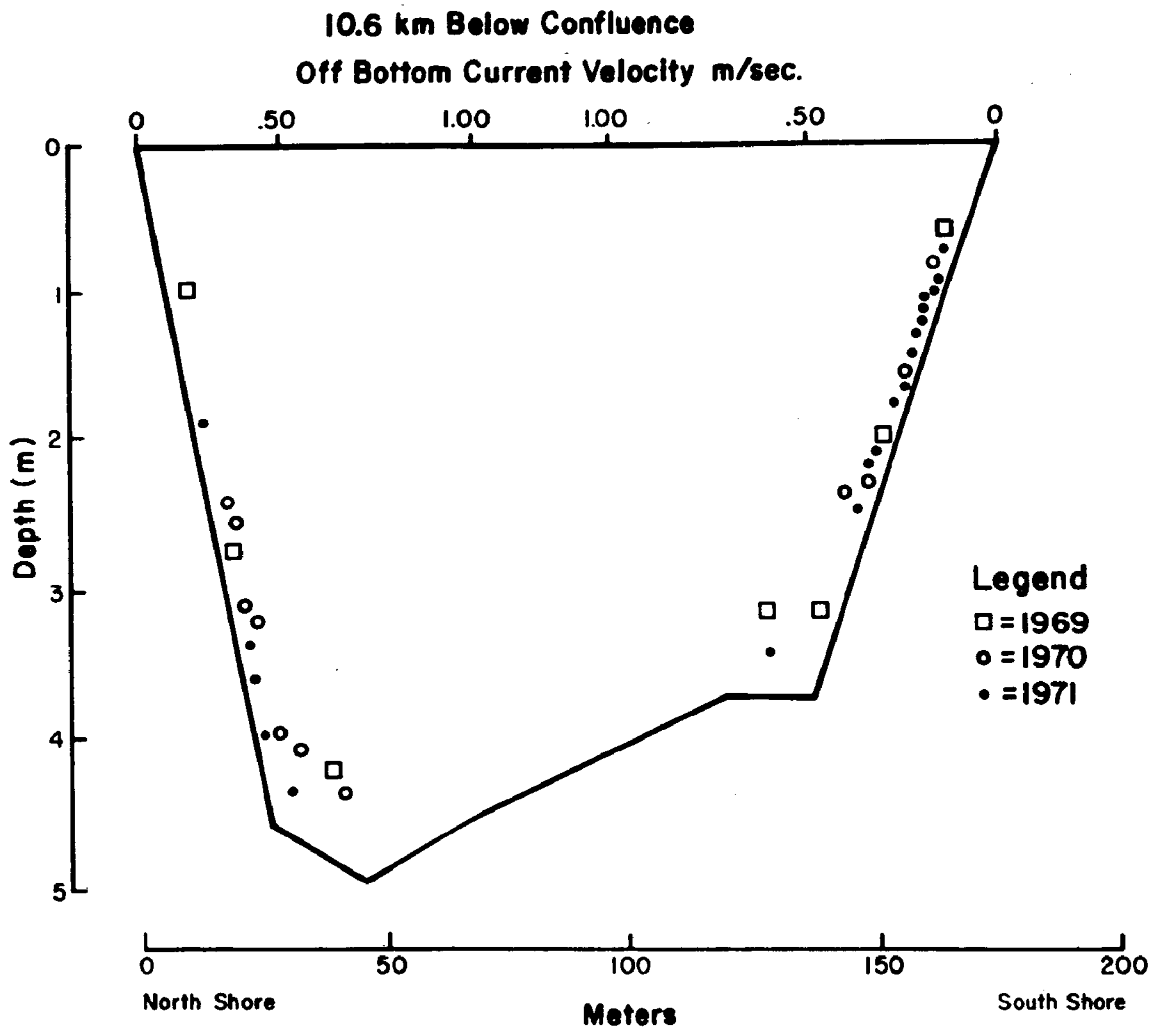


Fig. 20 (continued). Observed position of steelhead 0.2, 1.6 and 10.6 kilometers below the Snake-Clearwater confluence in relation to current velocity 1 m off the bottom, 1969-71

Table 2. Ranking of independent variables according to their apparent relation to steelhead movement. Low ranking indicates early selection in the regression equation, hence higher multiple correlation.

| Year | Rank | Total Movement | Net Movement | Total Reversals | Day Only Movements | | | Night Only Movements | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Total | Net | Reversals | Total | Net | Reversals |
| 1969 | 1 | Day of Year r=0.4959 | Water Temp. r=0.3493 | Fish Length r=0.0905 | Water Temp. r=0.4653 | Water Temp. r=0.4193 | Day of Year r=0.1805 | Day of Year r=0.3683 | Total Flow r=0.2310 | Fish Length r=0.1173 |
| | 2 | Fish Length r=0.5506 | Fish Length r=0.3755 | Moon Phase r=0.1197 | Fish Length r=0.4866 | Fish Length 4=0.4575 | Water Temp. r=0.4090 | Total Flow r=0.4099 | Clw. R. Flow r=0.2537 | Snake R. Flow r=0.1551 |
| | 3 | Snake R. Flow r=0.5738 | Total Flow r=0.3942 | Snake R. Flow r=0.1353 | Total Flow r=0.4913 | Snake R. Flow r=0.4685 | Moon Phase r=0.4431 | Moon Phase r=0.4158 | Day of Year r=0.2617 | Bar. Pressure r=0.1639 |
| 1970 | 1 | Water Temp. r=0.5683 | Day of Year r=0.4501 | Snake R. Flow r=0.1596 | Water Temp. r=0.5935 | Day of Year r=0.4796 | Snake R. Flow r=0.1857 | Day of Year r=0.6523 | Day of Year r=0.5358 | Water Temp. r=0.1865 |
| | 2 | Clw. R. Flow r=0.5859 | Clw. R. Flow r=0.4745 | Water Temp. r=0.1900 | Fish Length r=0.5986 | Moon Phase r=0.4919 | Total Flow r=0.2091 | Clw. R. Flow r=0.6909 | Clw. R. Flow r=0.5593 | Day of Year r=0.2744 |
| | 3 | Snake R. Flow r=0.5929 | Snake R. Flow r=0.4797 | Day of Year r=0.2802 | Day of Year r=0.6008 | Clw. R. Flow r=0.4945 | Fish Length r=0.2261 | Bar. Pressure r=0.7124 | Bar. Pressure r=0.6035 | Snake R. Flow r=0.3541 |
| 1971 | 1 | Day of Year r=0.6133 | Water Temp. r=0.2699 | Total Flow r=0.1556 | Day of Year r=0.6181 | Water Temp. r=0.2171 | Snake R. Flow r=0.2153 | Water Temp. r=0.4845 | Clw. R. Flow r=0.1562 | Moon Phase r=0.2766 |
| | 2 | Moon Phase r=0.6225 | Moon Phase r=0.2852 | Water Temp. r=0.1670 | Moon Phase r=0.6252 | Moon Phase r=0.2470 | Moon Phase r=0.2434 | Fish Length r=0.5032 | Moon Phase r=0.2026 | Clw. R. Flow r=0.3073 |
| | 3 | Fish Length r=0.6261 | Clw. R. Flow r=0.3011 | Snake R. Flow r=0.2435 | Water Temp. r=0.6262 | Clw. R. Flow r=0.2719 | Bar. Pressure r=0.2521 | Bar. Pressure r=0.5111 | Day of Year r=0.2549 | Water Temp. r=0.3282 |

5 times. Moon phase never ranked below 3rd but was the 1st selected variable only once. Ranking of river discharge showed little pattern and fluctuated widely.

During the July through December steelhead migration period, dissolved constituents of the Snake River varied from lowest to highest natural annual levels (Figures A-7a, b, and c). Therefore, a meaningful analysis had to subdivide a year's migration data into groups according to the naturally occurring water quality variation. Rapid week to week variation in the Snake River water chemistry limited comparable fish groups to a month's duration. The resulting breakdown of steelhead data into groups relating to natural seasonal changes in water quality left too few degrees of freedom for strong positive correlation.

We averaged total movement, net movement, and reversals over all 3 study years and compared them to water temperature, river flow, and barometric pressure (Figures 21, 22, and 23). The apparent relationship of total and net movement to temperature is readily seen as rates change from a mean rate of 0.5 km/day at 3 C to 15.3 km/day at 23.5 C (Figure 21). Reversals show no relationship with temperature.

The rate-flow relationship (Figure 22) probably is a further expression of the already described rate-temperature relationship. Total and net movement are high at low flows (high temperatures), low at intermediate flows (typical of fall and early winter cold flows), then high again at high flows (early summer when river temperatures are rising rapidly). Reversals show no relationship with flow.

Total and net movement show an optimal relationship with barometric pressure (Figure 23). Maximum total and net rates are 5.0 and 3.0 km/day at 28.45 in. Hg. Migration rates drop at higher and lower barometric pressures. Reversals show no obvious relationship with barometric pressure.

Above vs Below Confluence Migration Rates

Comparison of the combined Snake and Clearwater movements above versus below confluence net upstream movement shows that 1970 fish moved 43% faster above the confluence than below it. In 1971 fish above the confluence moved 38% slower than they moved below the confluence (Table 3). Dworshak Dam, a high storage project on the North Fork of the Clearwater River closed its gates on September 27, 1971, thereby reducing the Clearwater flow by one-half. Fish tracked after that date had a higher occurrence of milling and reversals in the lowest 2 km of the Clearwater River. Such behavior would reduce the net upstream rate.

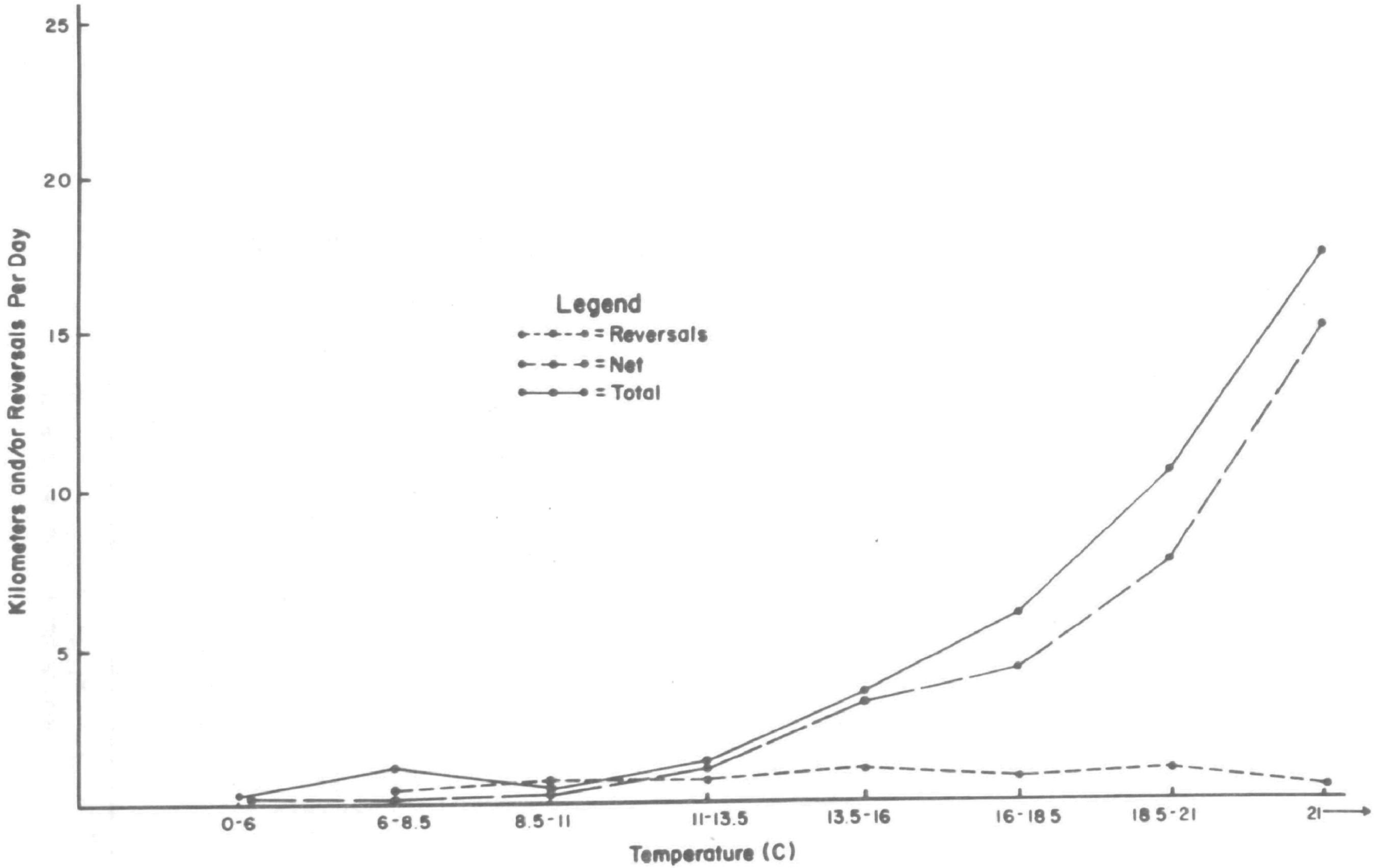


Figure 21. Three year average kilometers and/or reversals per day compared to temperature (C), 1959, 1970, 1971.

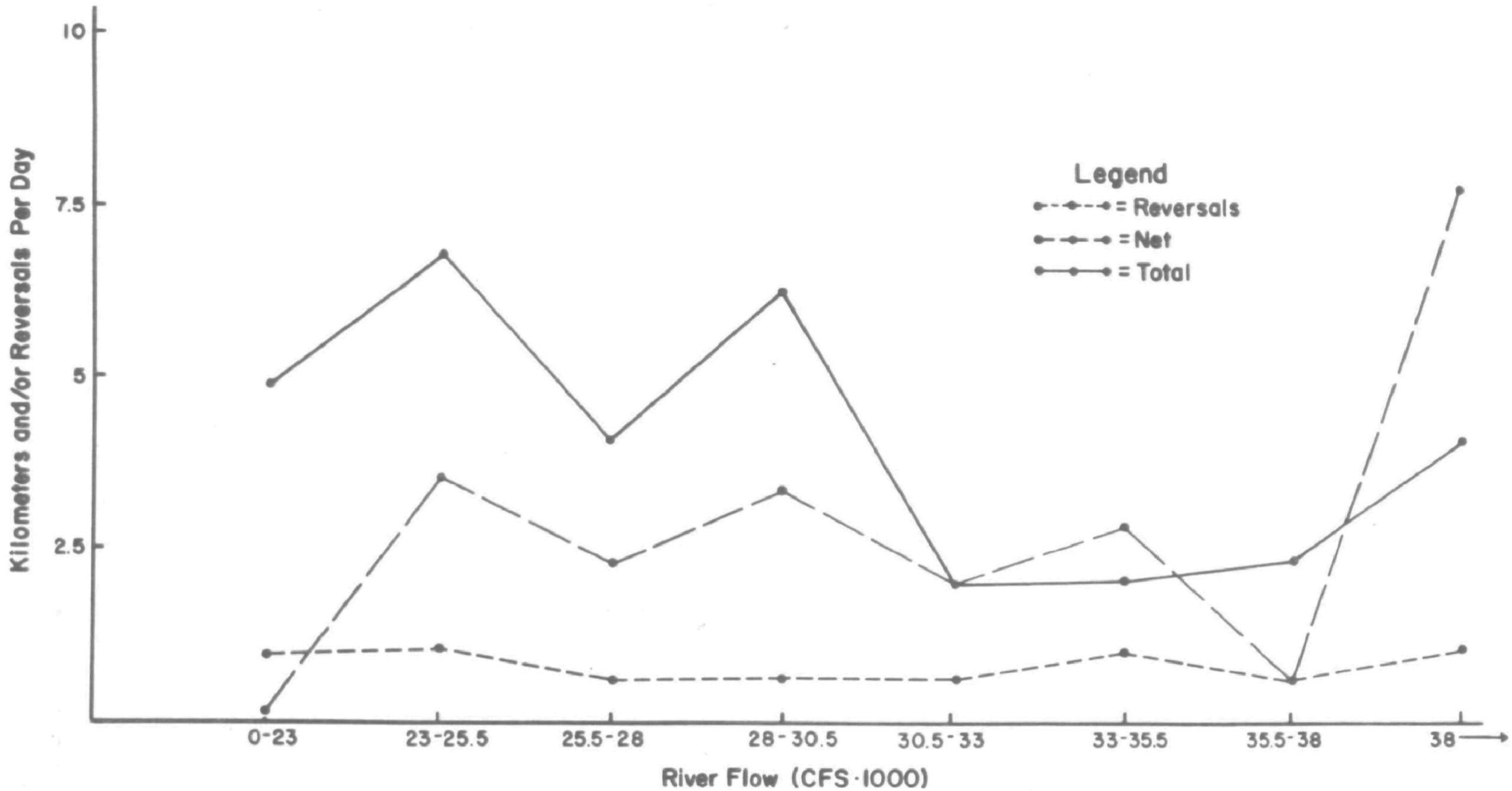


Figure 22. Three year average kilometers per day and/or path reversals per day compared to Snake River flow volume, 1969, 1970, and 1971.

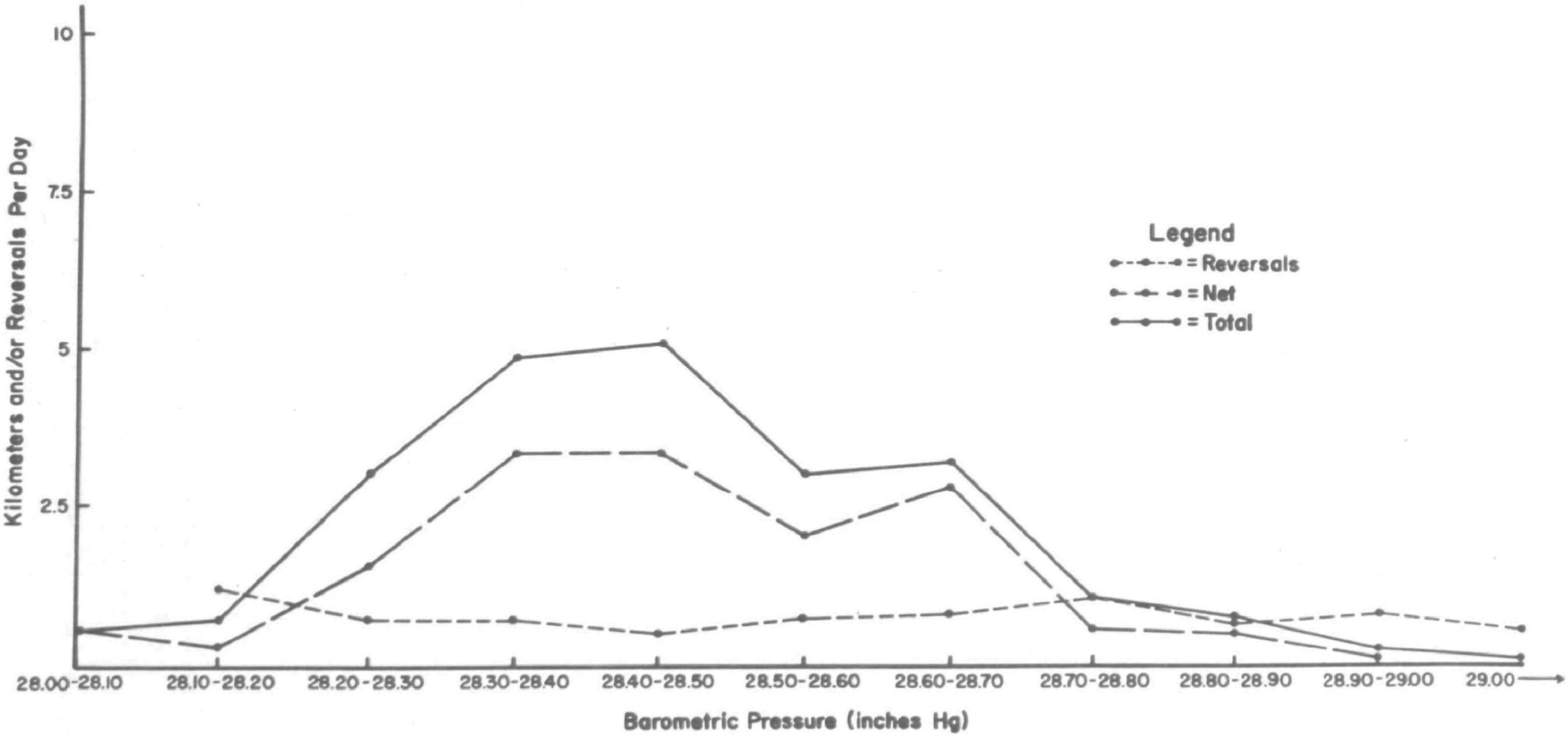


Figure 23. Steelhead migration rate (total and net kilometers per day) and/or reversals per day compared to barometric pressure. Averaged over 1969, 1970 and 1971.

Table 3. Comparison of net upstream combined Snake and Clearwater movement (km/day) above and below the confluence. Only fish with net upstream movement and tracks of less than six days duration are represented.

| | | Average net upstream movement below confluence | Average net upstream movement above confluence |
|---|---|---|---|
| 1970 | km/day | 10.71 | 15.30 |
| | 95% Confidence Interval | 5.80----------15.62 | 6.26----------24.34 |
| 1971 | km/day | 16.65 | 10.32 |
| | 95% Confidence Interval | 9.94----------23.36 | 3.06----------17.58 |

## SECTION VII

## DISCUSSION

Chemical parameters showed that no serious pre-impoundment water quality problems exist in the Lower Granite pool area because of rapid mixing. Bacteriological indicators, however, have shown that this portion of the Snake River is below the bacterial standards for Class A waters in the state of Washington (Falter and Funk 1973).

Existing reservoirs on the lower Snake River do not thermally stratify; the water is in relatively constant exchange with the atmosphere (Falter and Funk 1973). Lower Granite Reservoir is not expected to thermally stratify. Therefore, after the proposed secondary treatment of incoming domestic and Kraft wastes, we do not anticipate large masses of toxic water in the reservoir.

Analysis of mixing patterns of the Snake and Clearwater River flows below their confluence showed that dilution of the Kraft mill effluent stream into the two flows occurs so rapidly that high concentrations of the effluent are not detectable beyond 0.2 km below the confluence. At 20,000 cfs, mixing of the two flows was essentially complete 16 km below the confluence, but when the total flow exceeded 40,000 cfs, the two flows still were not completely mixed 35 km downstream.

Under present river conditions the high-temperature Kraft effluent dilutes rapidly to a level where resulting Snake River temperatures and water quality showed no apparent blockage or gross atypical migrational behavior in sonic-tagged steelhead.

In late August, 1970, maximum concentrations of approximately 2.6% Kraft effluent occurred in midriver, 0.2 km below the confluence. In November, 1970, concentrations of approximately 1.3% Kraft effluent were found. Both of these values were well below the adverse concentration for juvenile sockeye salmon (Alderdice and Brett 1957). According to Jones (1953) Bond showed that steelhead trout did not avoid paper mill wastes in concentrations ranging from 1.5% to 4.5% although coho salmon avoided concentrations of 4.3% and chinook salmon avoided concentrations of 1.5%. These results indicate that effluent concentrations even 0.2 km below the outfall are below threshold avoidance levels for steelhead.

Impoundment of the study area could conceivably allow concentration of Kraft effluent in low-velocity shoreline areas where the toxic effects of Kraft effluent may adversely affect migrating adult steelhead. Probability of poor mixing occurring is slight since PFI will be replacing the single port discharge with a 120 m long submerged diffuser running the width of the river at the confluence.

Temperatures of the Snake River leaving the study area ranged from 3.0 C to 23.5 C with the fluctuations resulting primarily from seasonal climatic changes. Temperature increases from Kraft effluent entering the river at temperatures above 30 C and volumes of approximately 113,500 to 121,000 $m^3$/day were usually undectable. The great dilution effect of the river water accounted for the difficulty in identifying Kraft effluent by temperature as little as 200 m below the outfall.

Differences in river temperature or other aspects of water quality across the stream width was not shown to significantly affect the lateral position in the stream of migrating adult summer steelhead.

Multiple correlation showed steelhead travel rates to be most highly correlated with time of year and water temperature. Extreme variation between individual fish kept correlation coefficients very low.

Net and total upstream movement was less than 1 km/day in the 0-11 C temperature range, then increased to 5 km/day at 18.5 C, and increased very rapidly to 16 km/day at 21 C. This correlation does not prove a cause and effect relationship between temperature and rate of movement. However, other evidence implies that a cause and effect relationship may exist for temperature. Body temperatures of most fish do not differ more than 0.5 C-1.0 C from that of the surrounding water. Therefore, changes in the metabolic rate, hence rate of migration, relate closely to changes in temperature of the surrounding water. Changes in temperature can trigger the start of processes such as migration and spawning (Nikolsky 1963).

## SECTION VIII

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## SECTION IX

## APPENDIX

APPENDIX - (Continued)

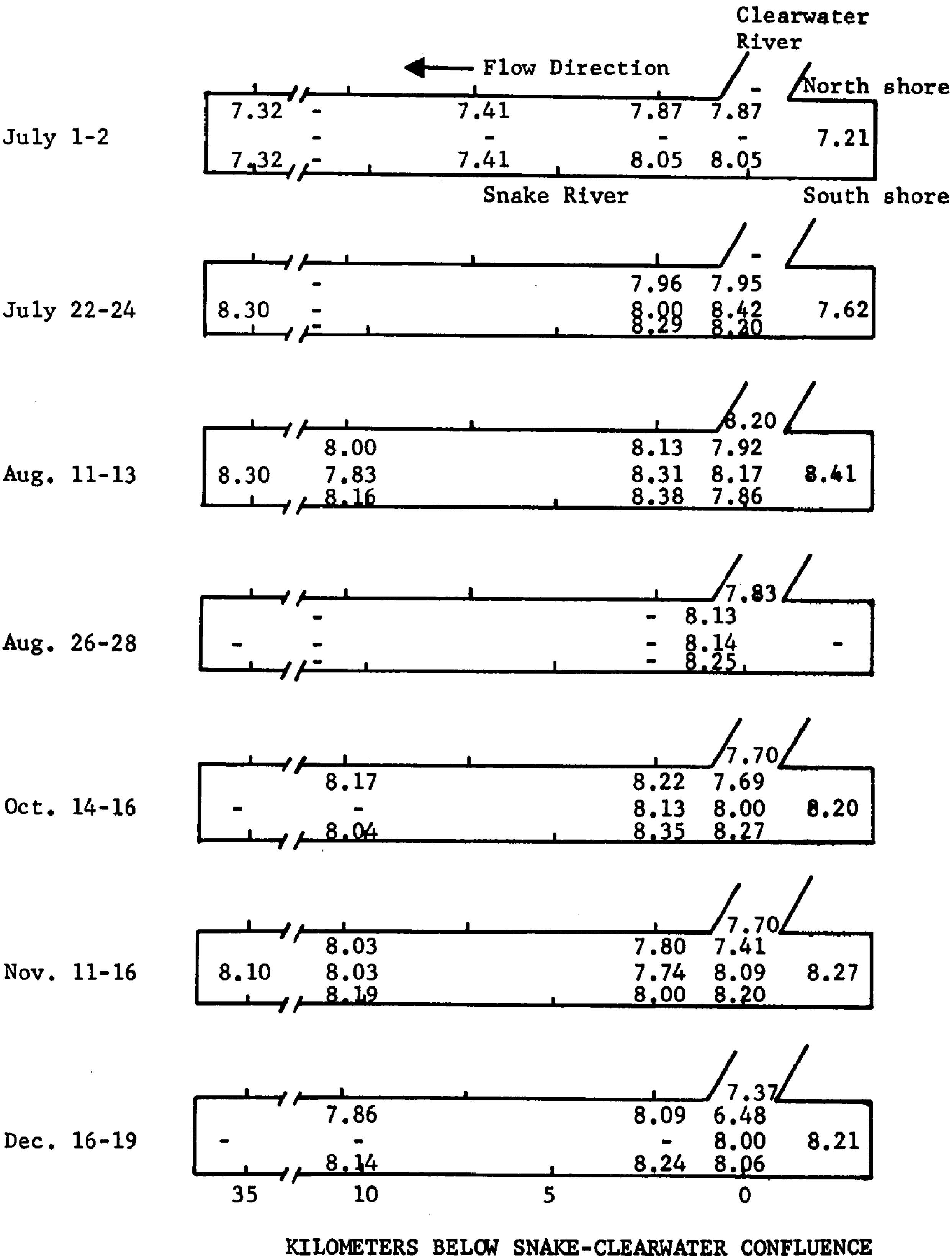


Figure A-1a. Cross-channel pH patterns in the Snake and Clearwater Rivers during adult steelhead migration, 1969.

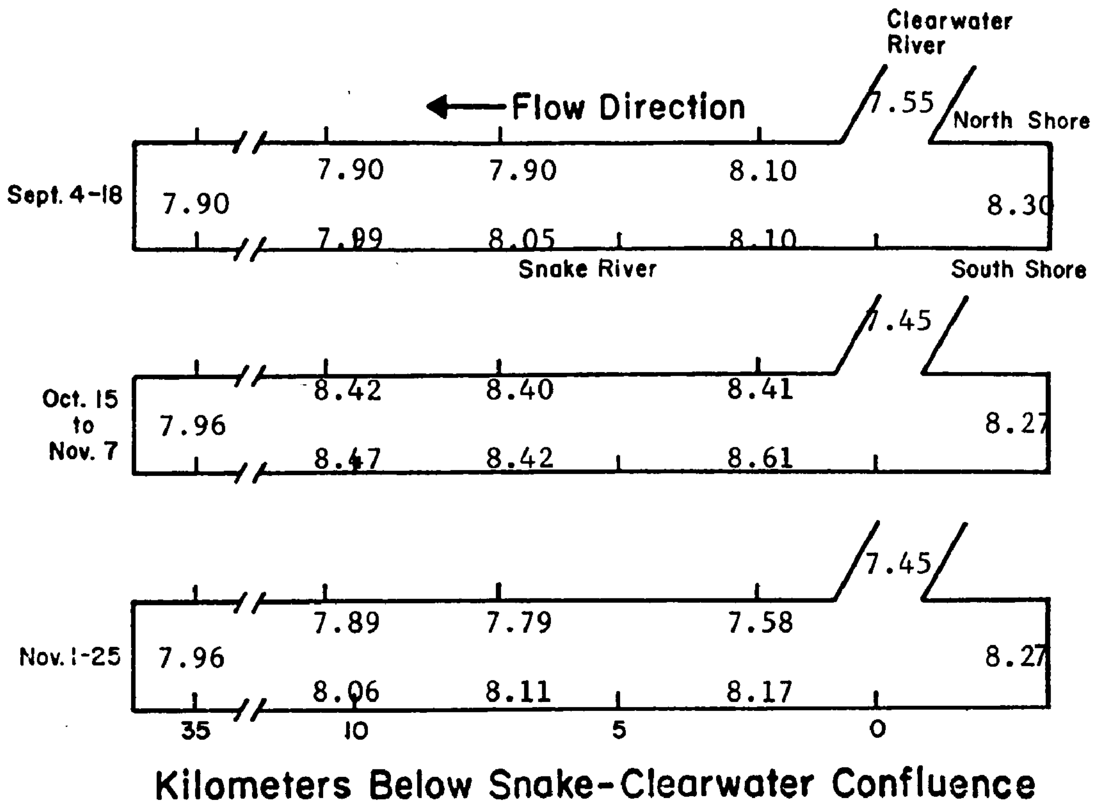


Figure A-1b. Cross-channel pH patterns in the Snake and Clearwater Rivers during adult steelhead migration, 1970.

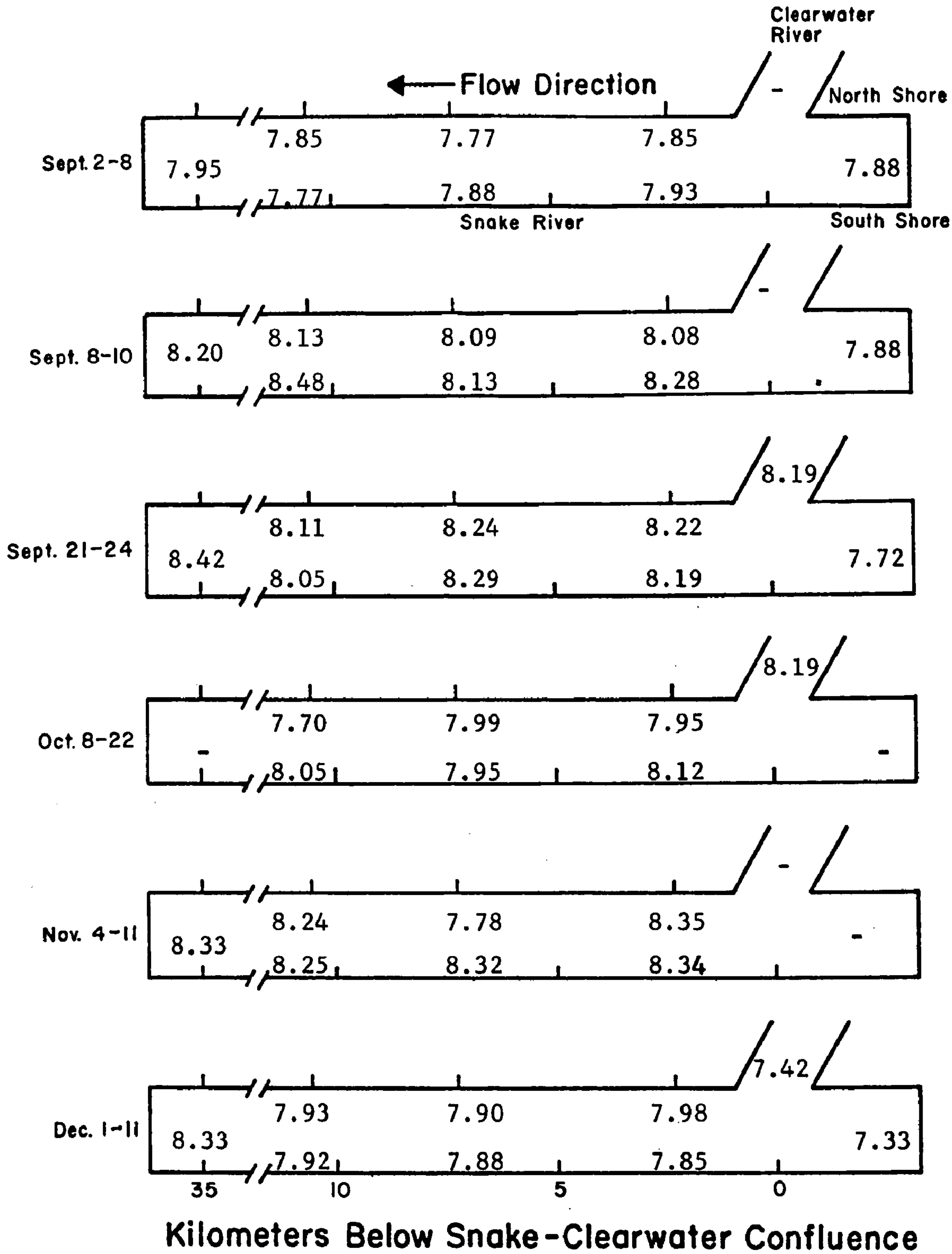


**Figure A-1c.** Cross-channel pH patterns in the Snake and Clearwater Rivers during adult steelhead migration, 1971.

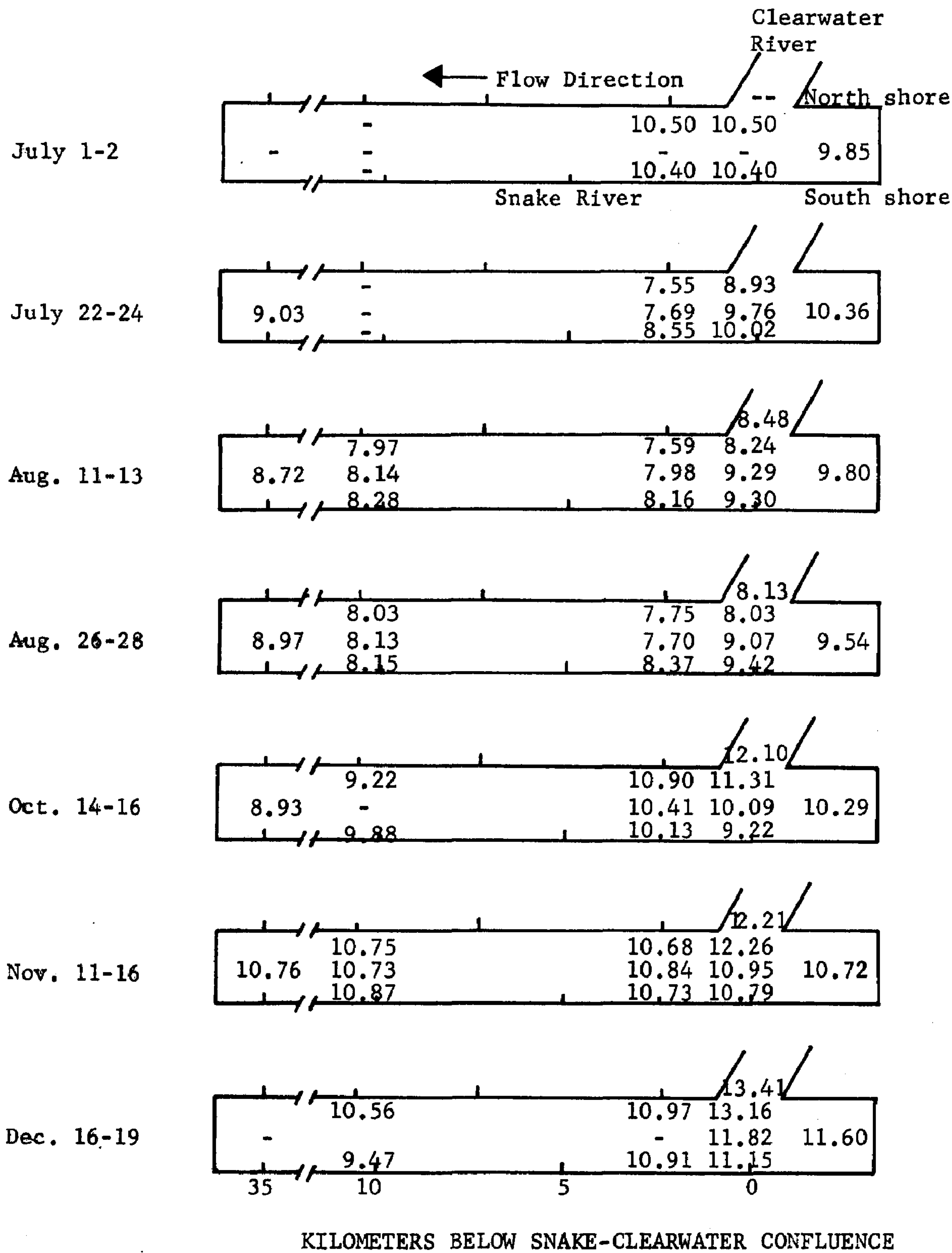


Figure A-2a. Cross-channel oxygen patterns (mg/l) in the Snake and Clearwater Rivers during adult steelhead migration, 1969.

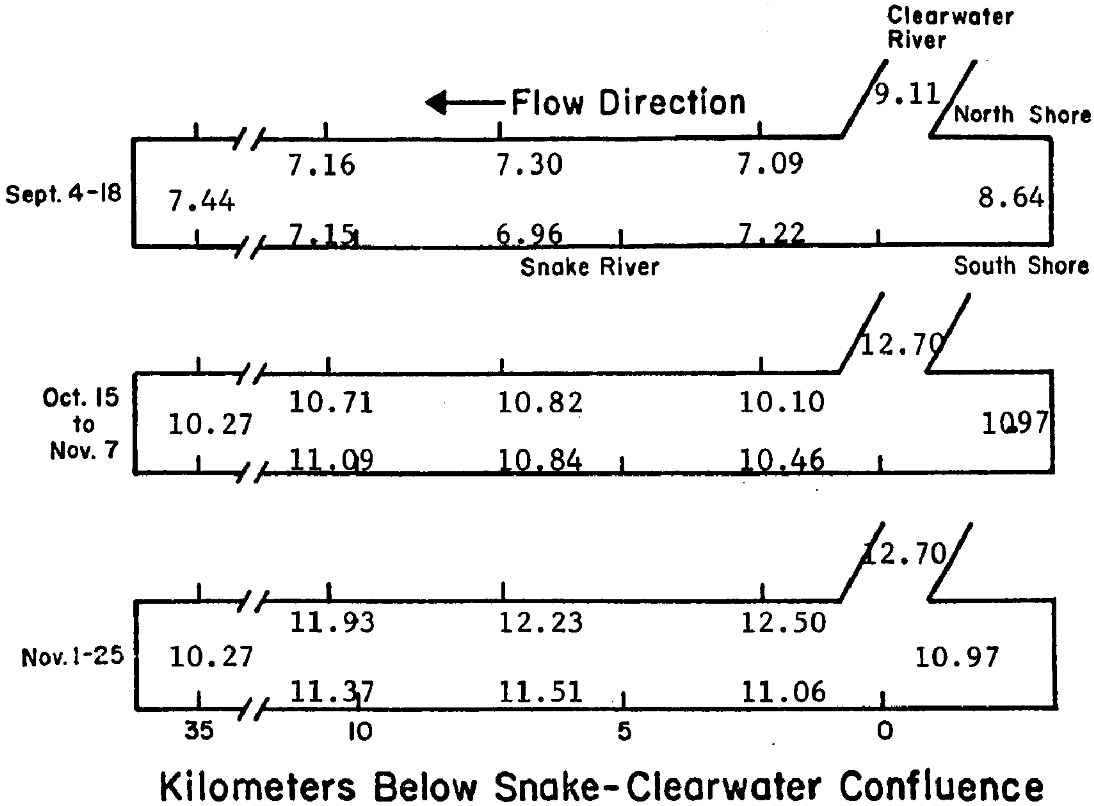


Figure A-2b. Cross-channel oxygen patterns (mg/L) in the Snake and Clearwater Rivers during adult steelhead migration, 1970.

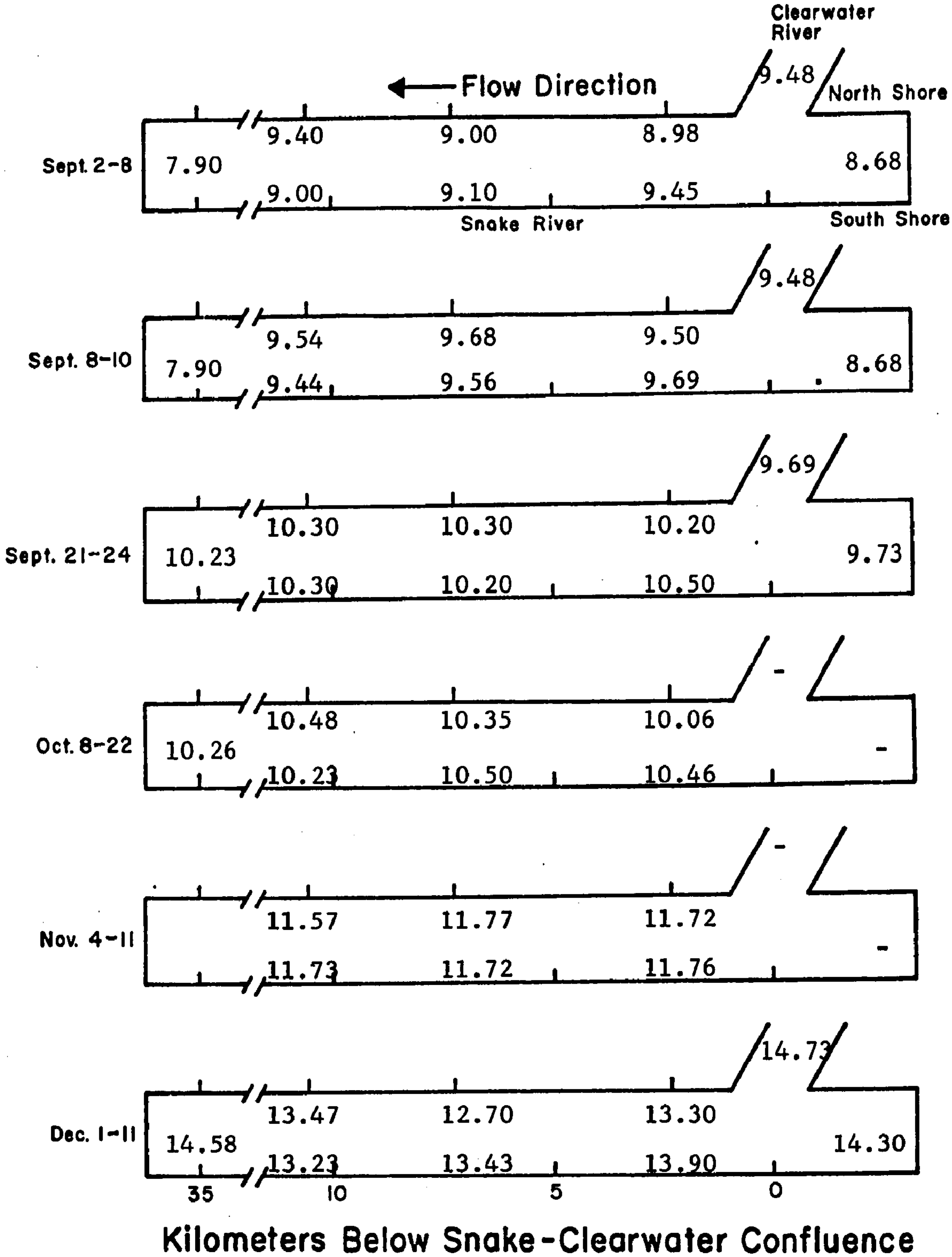


Figure A-2c. Cross-channel oxygen patterns (mg/L) in the Snake and Clearwater Rivers during adult steelhead migration, 1971.

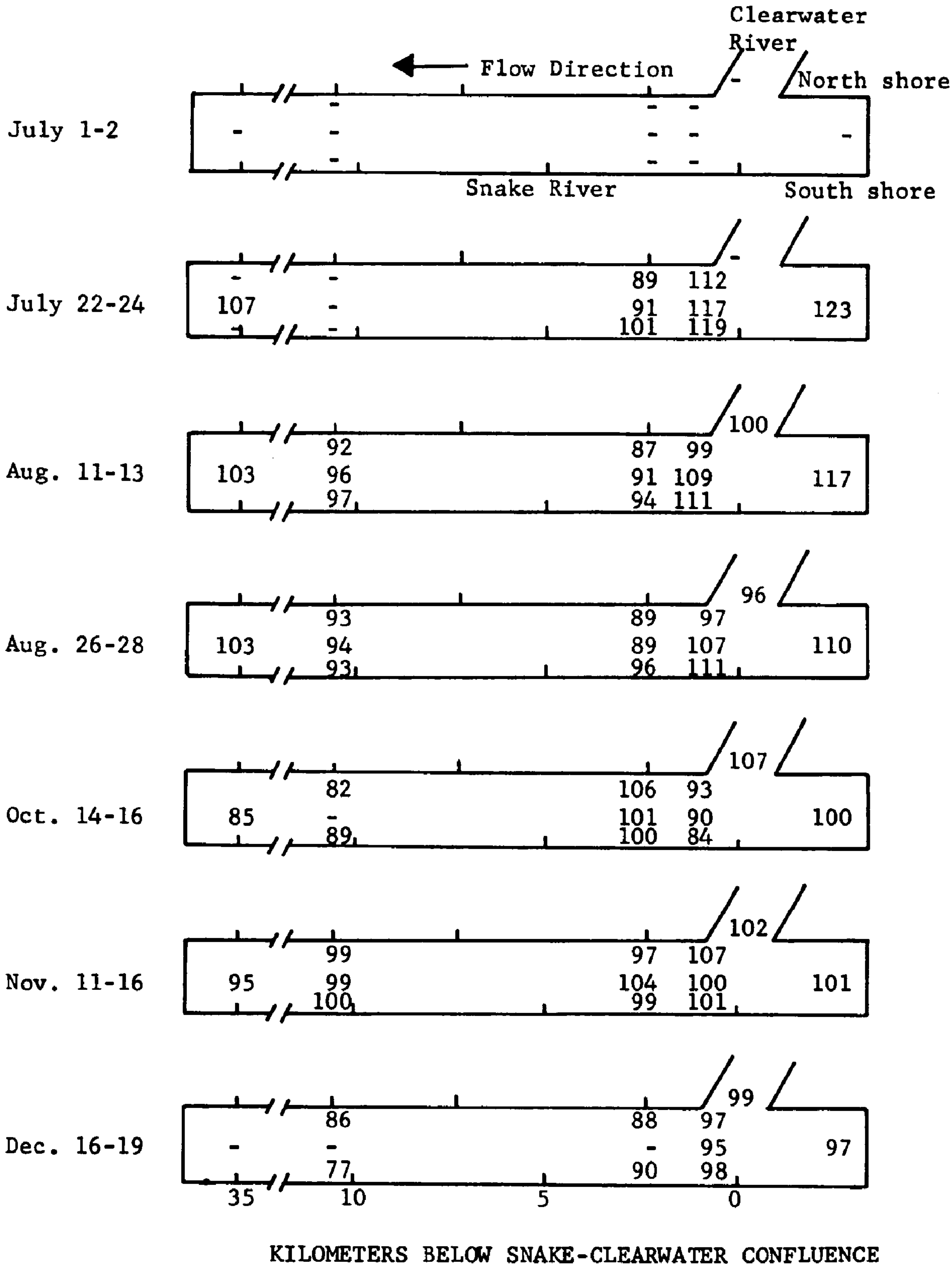


Figure A-3a. Cross-channel oxygen saturation patterns (percent saturation) in the Snake and Clearwater Rivers during adult steelhead migration, 1969.

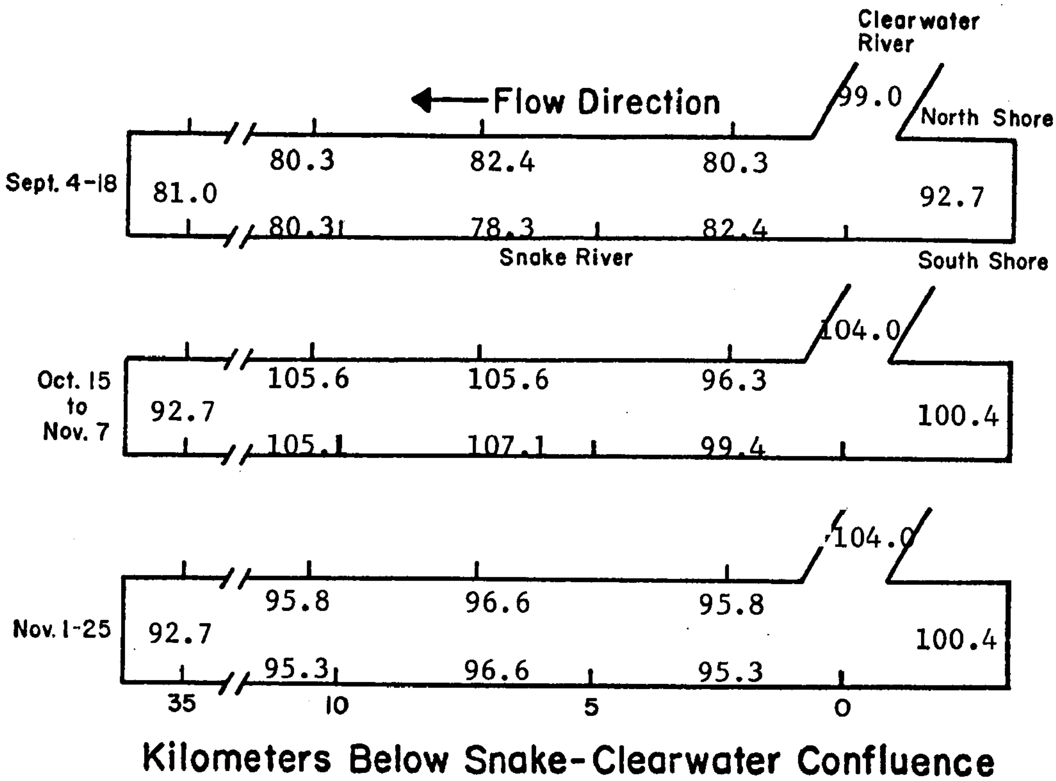


Figure A-3b. Cross-channel oxygen saturation patterns (percent saturation) in the Snake and Clearwater Rivers during adult steelhead migration, 1970.

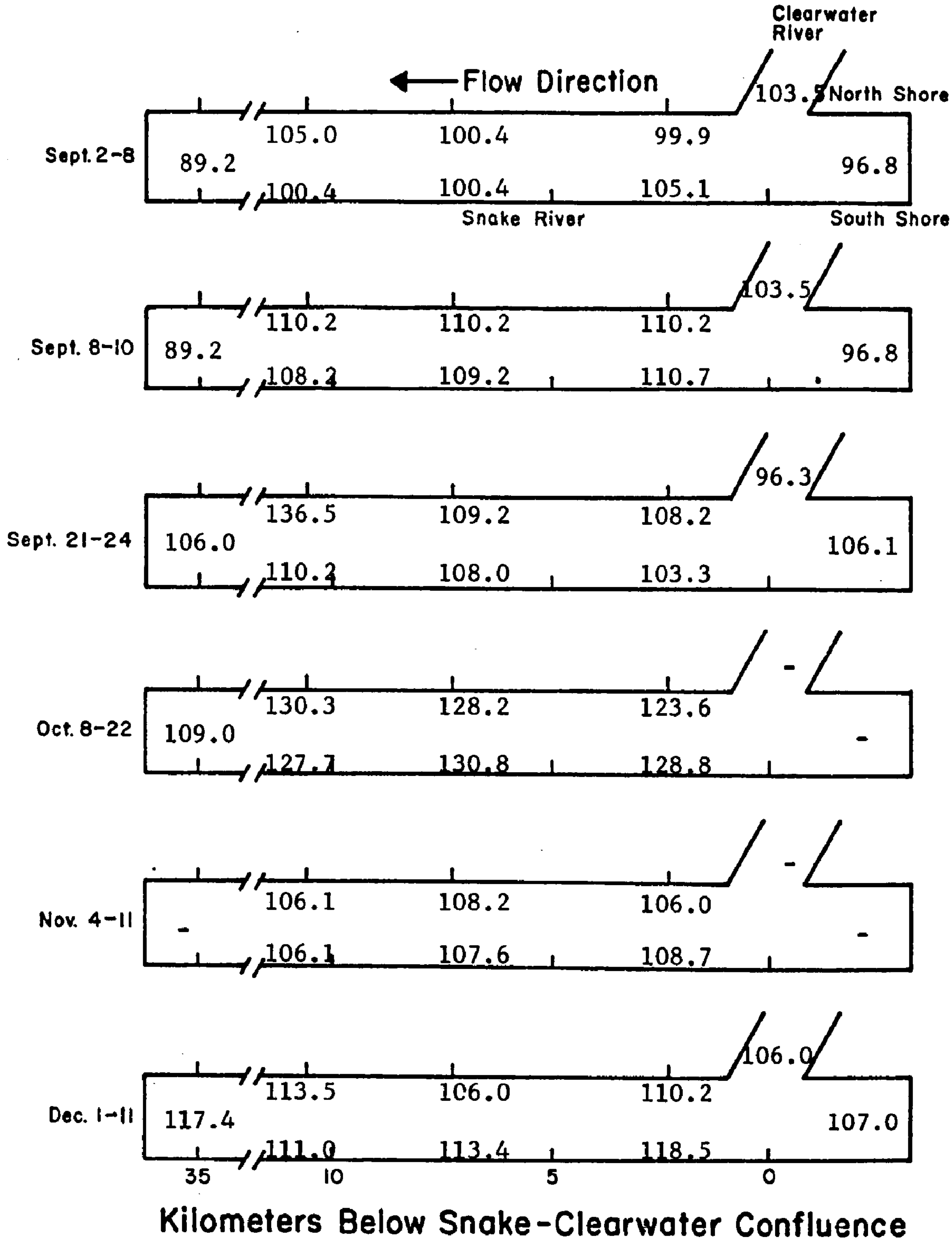


Figure A-3c. Cross-channel oxygen saturation patterns (percent saturation) in the Snake and Clearwater Rivers during adult steelhead migration, 1971.

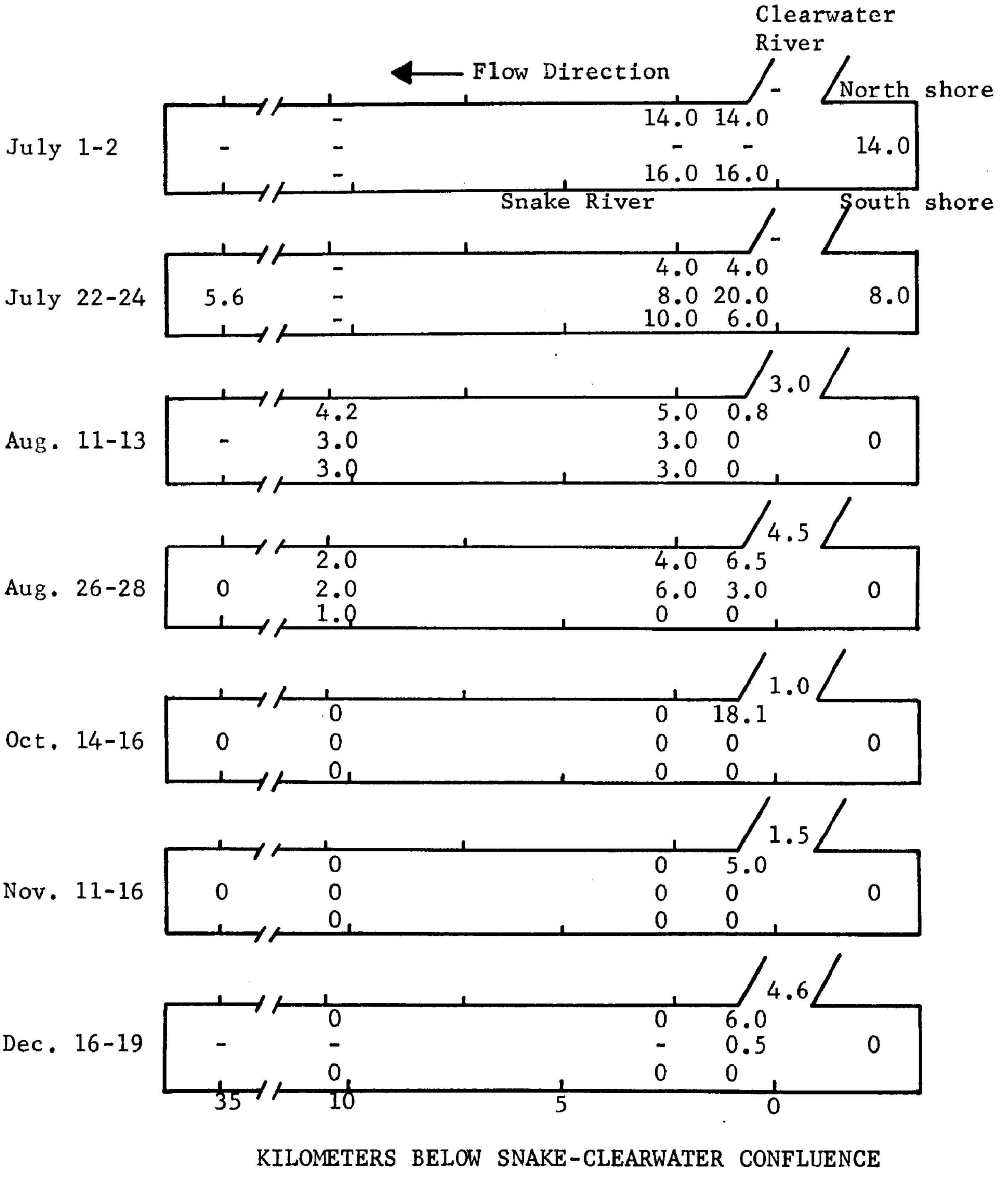


Figure A-4a. Cross-channel carbon dioxide patterns (mg/L free $CO_2$) in the Snake and Clearwater Rivers during adult steelhead migration, 1969.

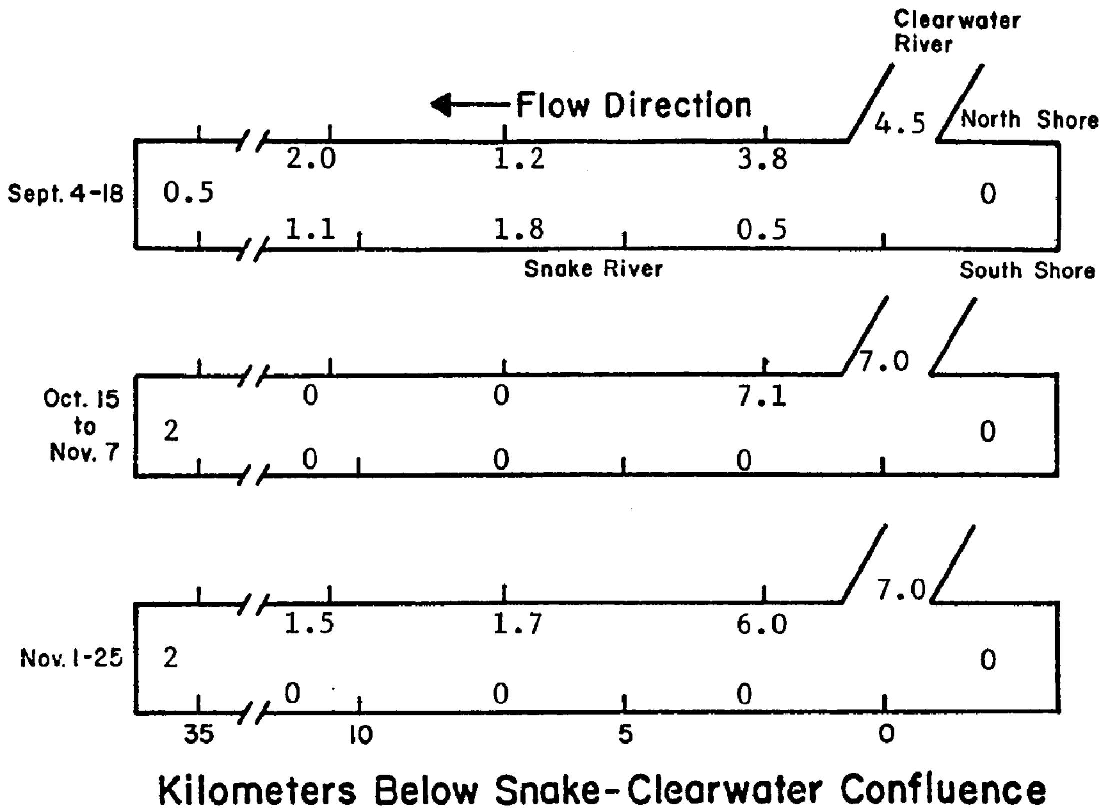


Figure A-4b. Cross-channel carbon dioxide patterns (mg/L free $CO_2$) in the Snake and Clearwater Rivers during adult steelhead migration, 1970.

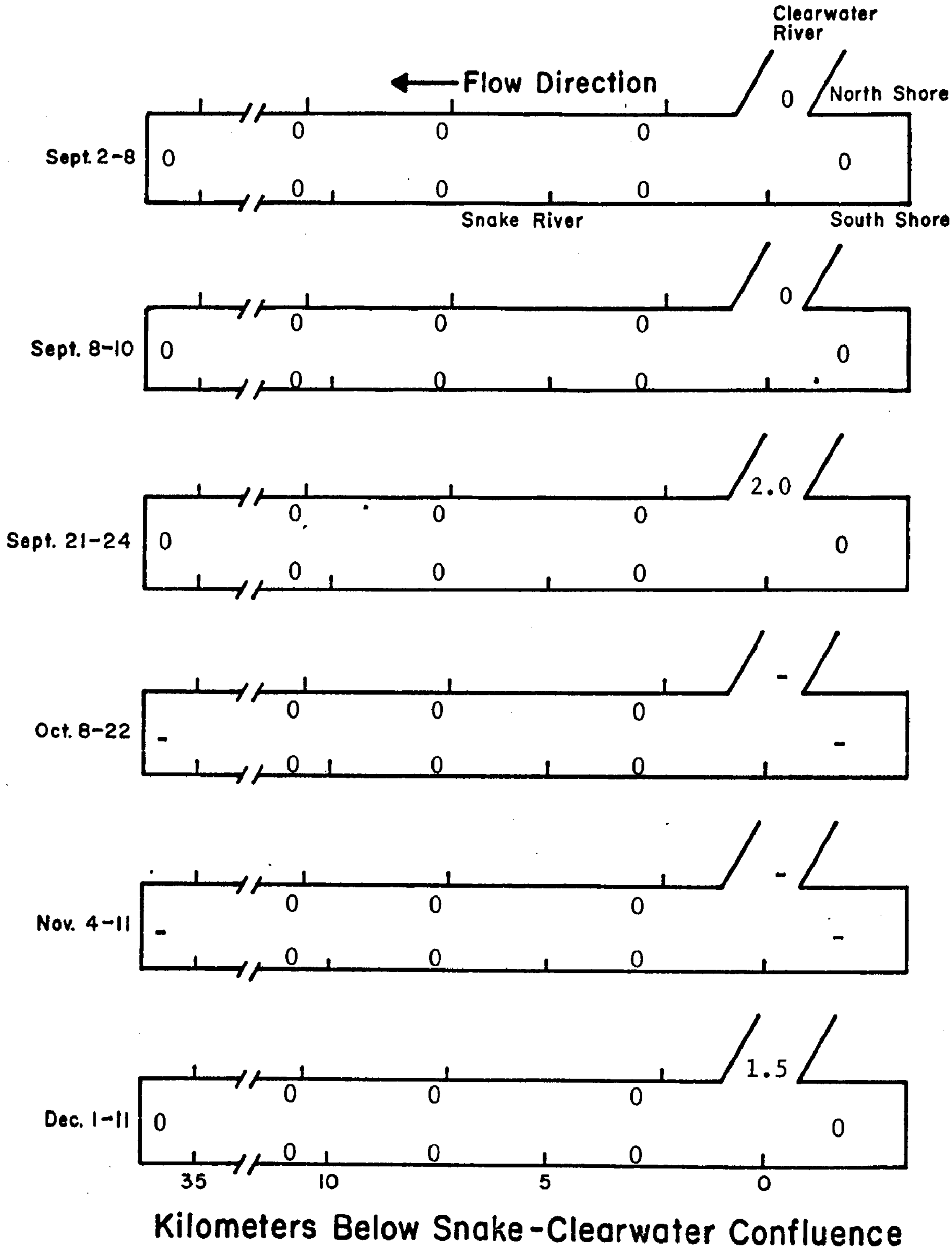


Figure A-4c. Cross-channel carbon dioxide patterns (mg/L free $CO_2$) in the Snake and Clearwater Rivers during adult steelhead migration, 1971.

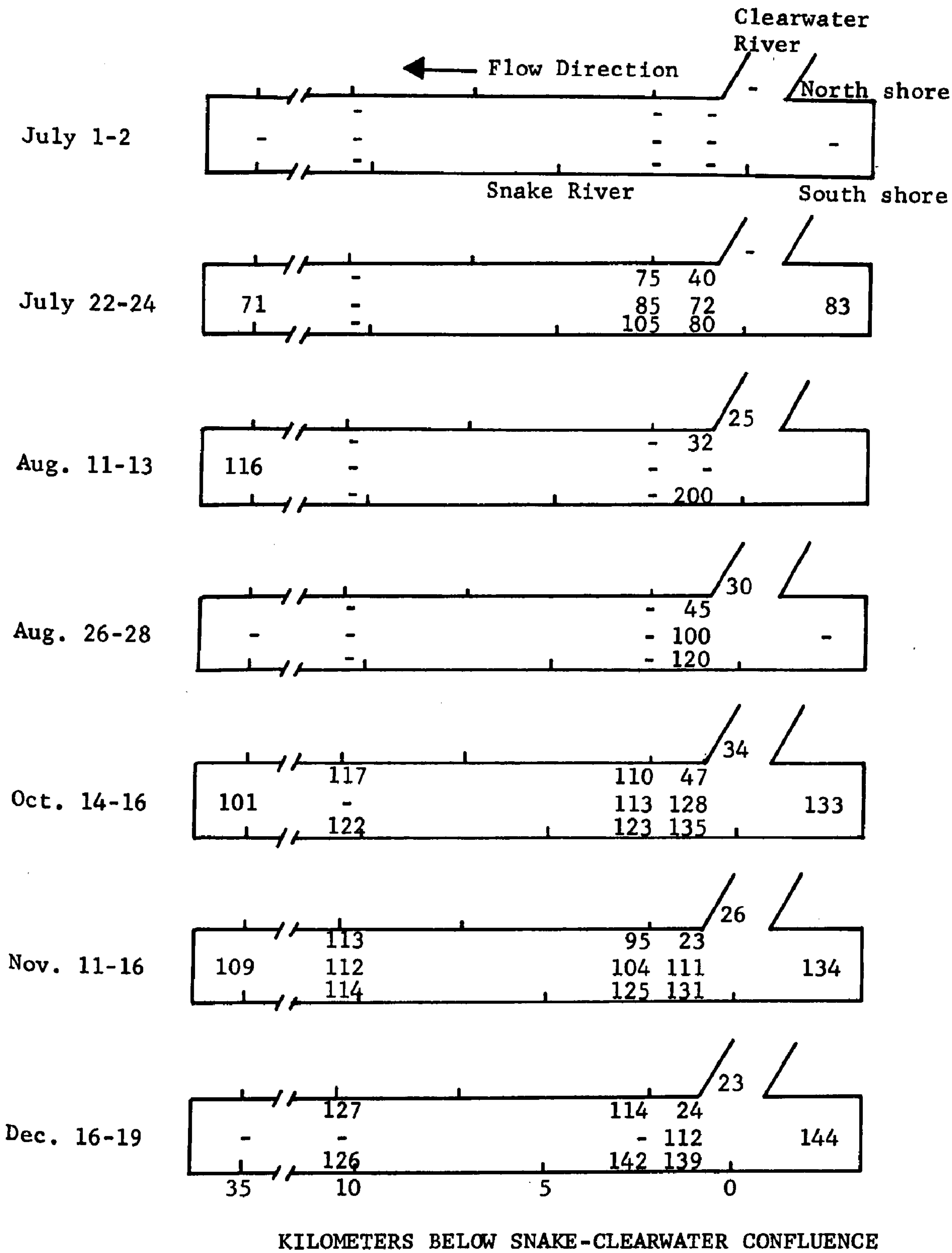


Figure A-5a. Cross-channel bicarbonates patterns (mg/L $CaCO_3$) in the Snake and Clearwater Rivers during adult steelhead migration, 1969.

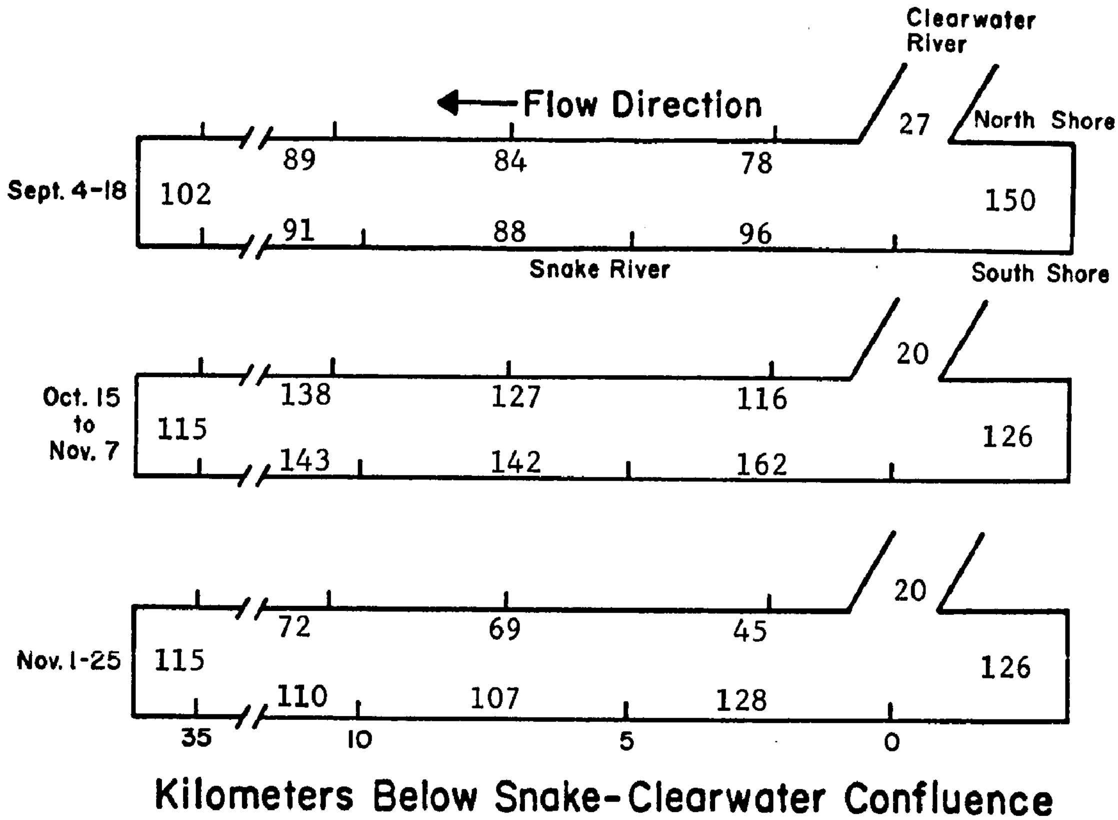


Figure A-5b. Cross-channel bicarbonates patterns (mg/L $CaCO_3$) in the Snake and Clearwater Rivers during adult steelhead migration, 1970.

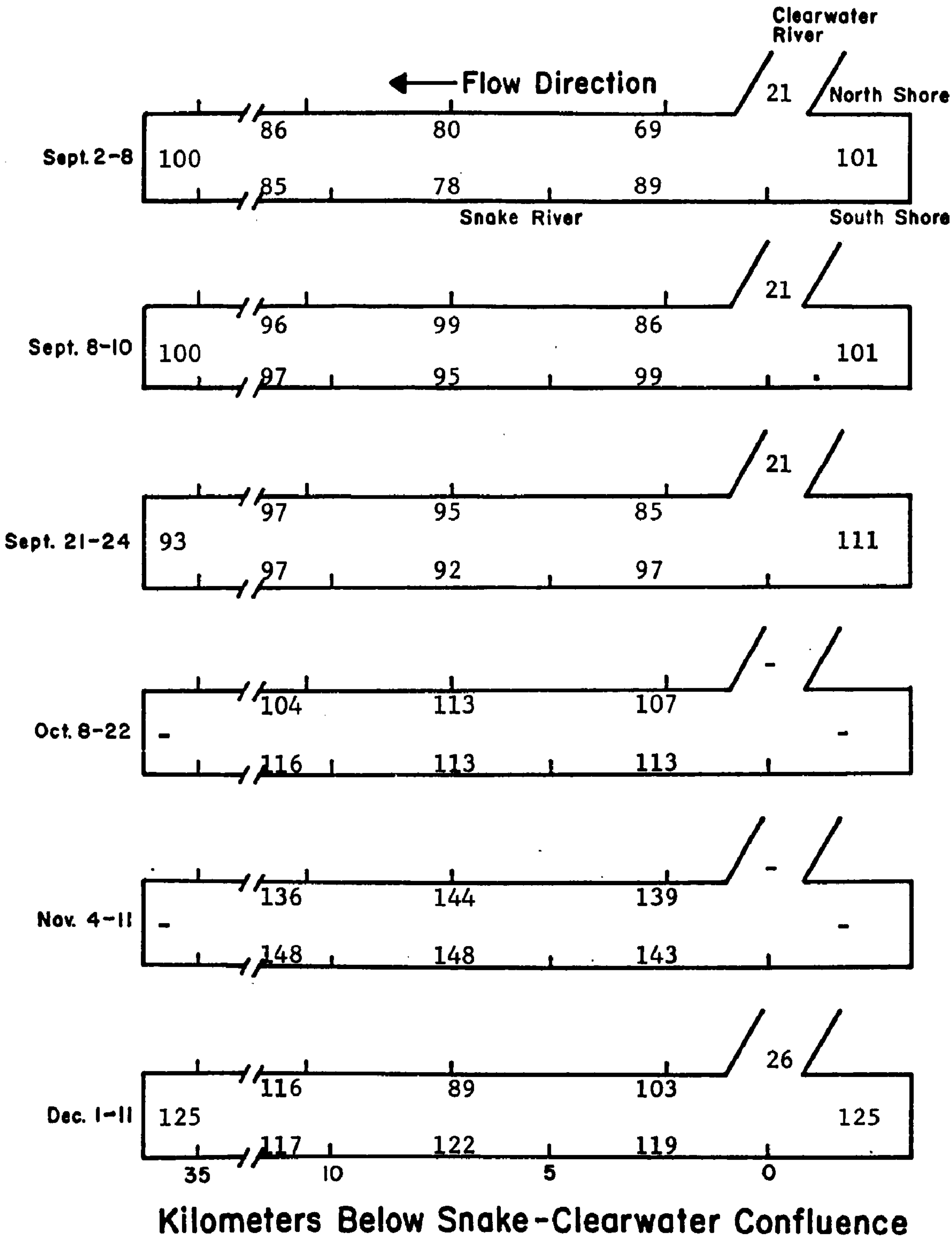


Figure A-5c. Cross-channel bicarbonates patterns (mg/L $CaCO_3$) in the Snake and Clearwater Rivers during adult steelhead migration, 1971.

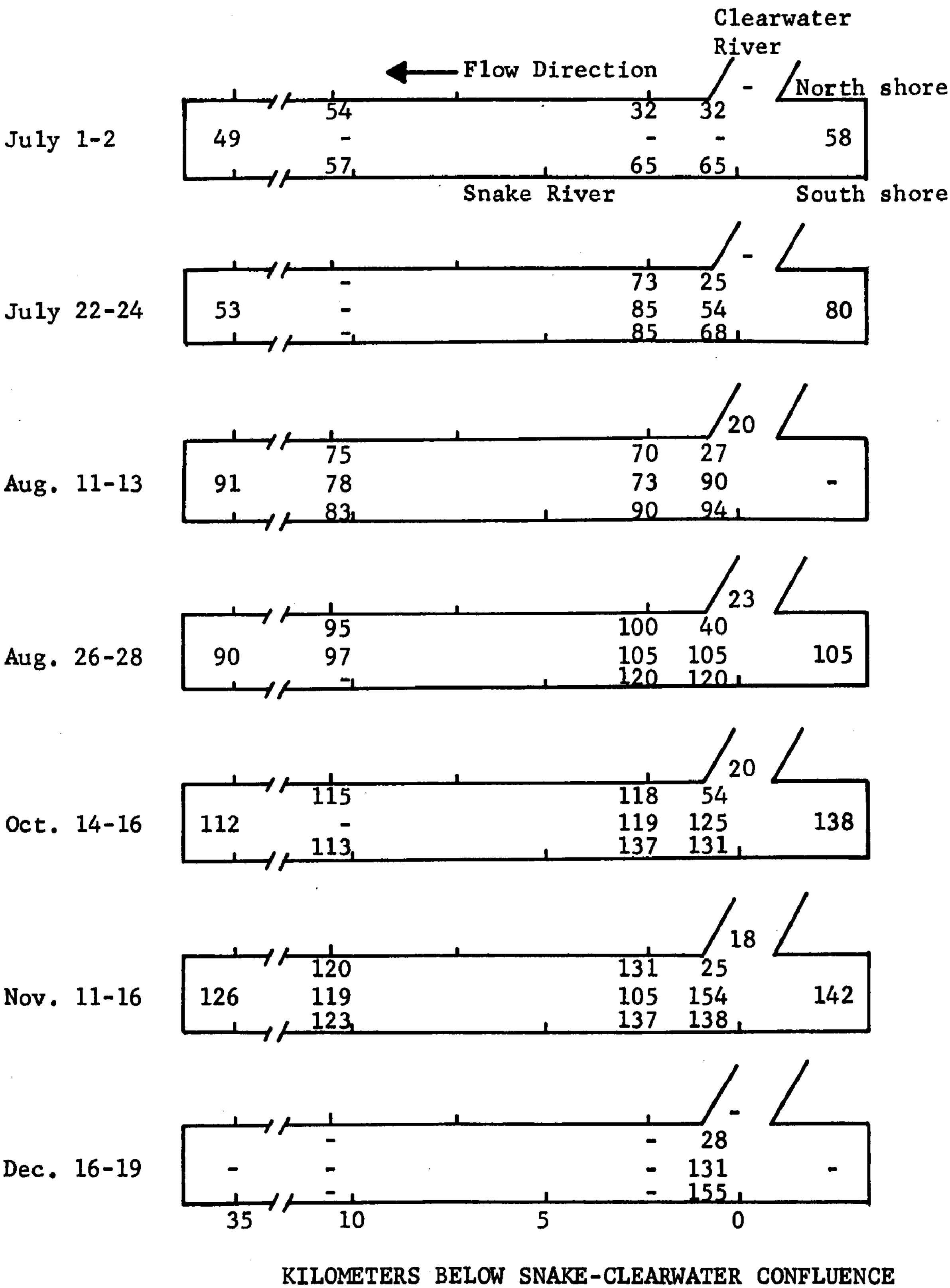


Figure A-6a. Cross-channel total hardness patterns (mg/L $CaCO_3$) in the Snake and Clearwater Rivers during adult steelhead migration, 1969.

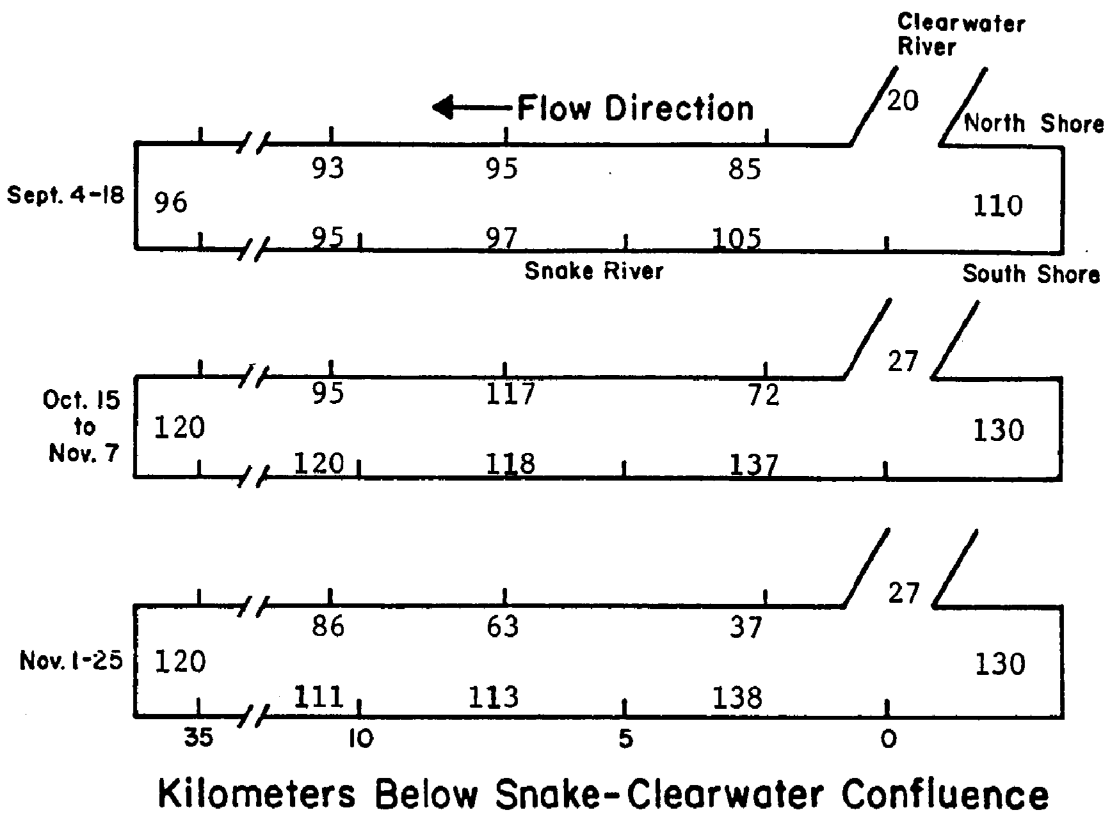


Figure A-6b. Cross-channel total hardness patterns (mg/L $CaCO_3$) in the Snake and Clearwater Rivers during adult steelhead migration, 1970.

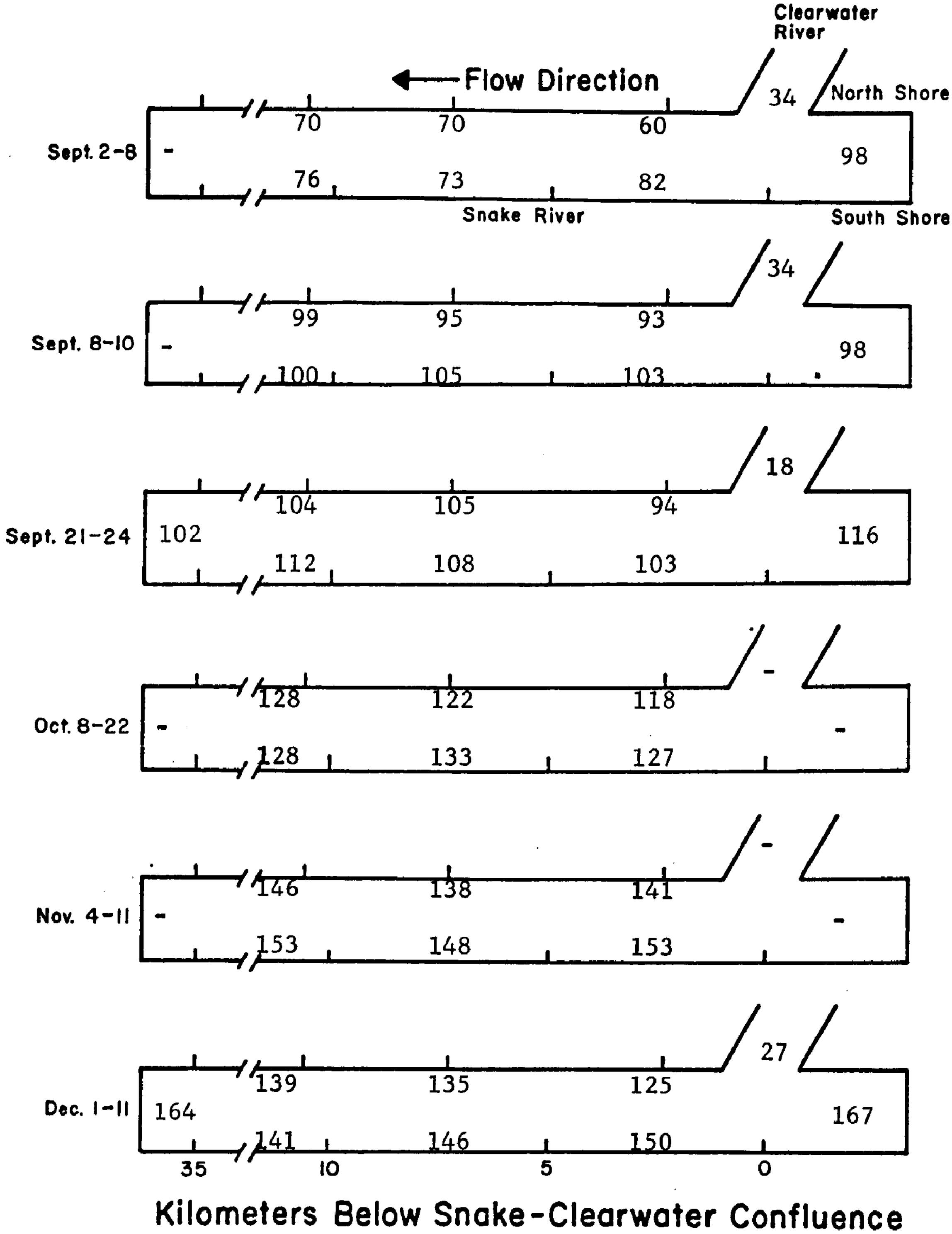


Figure A-6c. Cross-channel total hardness patterns (mg/L $CaCO_3$) in the Snake and Clearwater Rivers during adult steelhead migration, 1971.

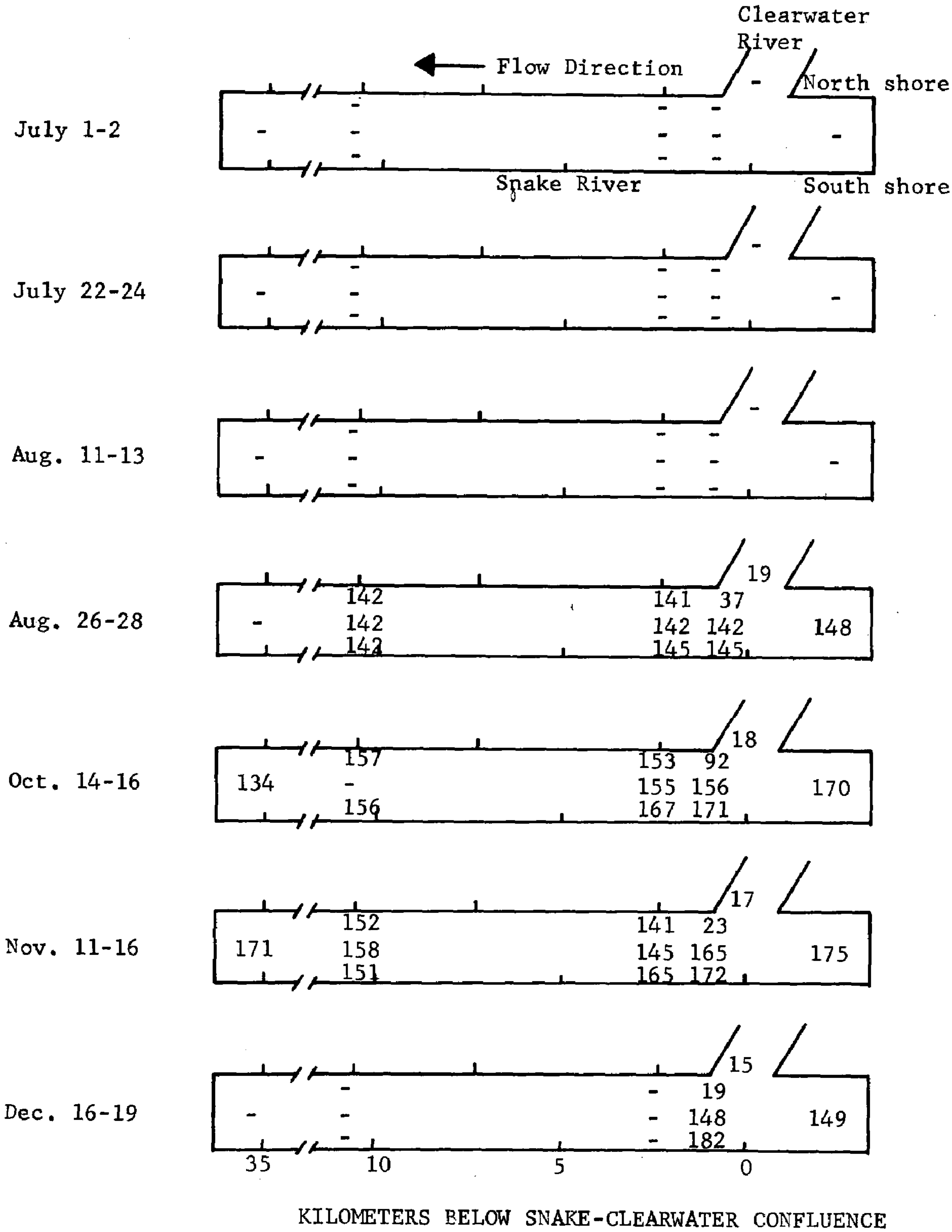


Figure A-7a. Cross-channel total dissolved solids patterns (mg/L NaCl) in the Snake and Clearwater Rivers during adult steelhead migration, 1969.

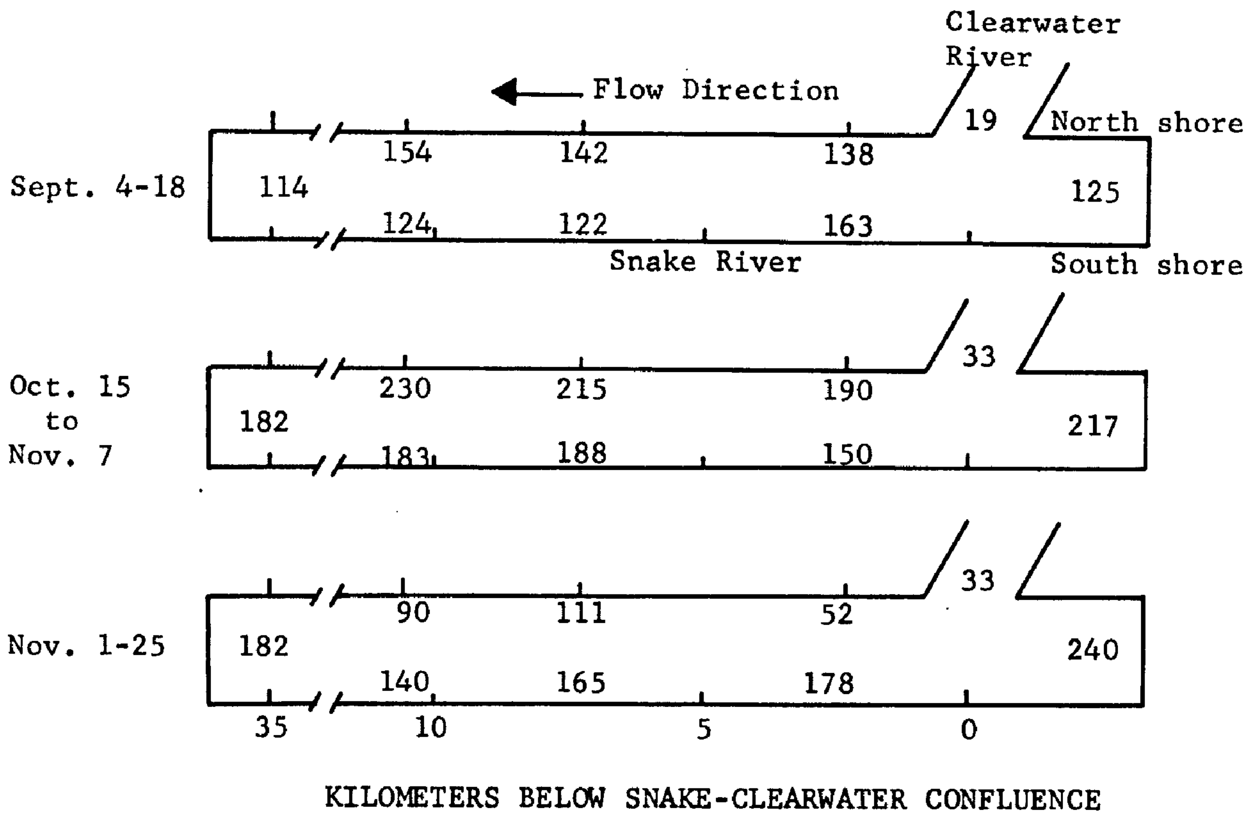


Figure A-7b. Cross-channel total dissolved solids patterns (mg/L NaCl) in the Snake and Clearwater Rivers during adult steelhead migration, 1970.

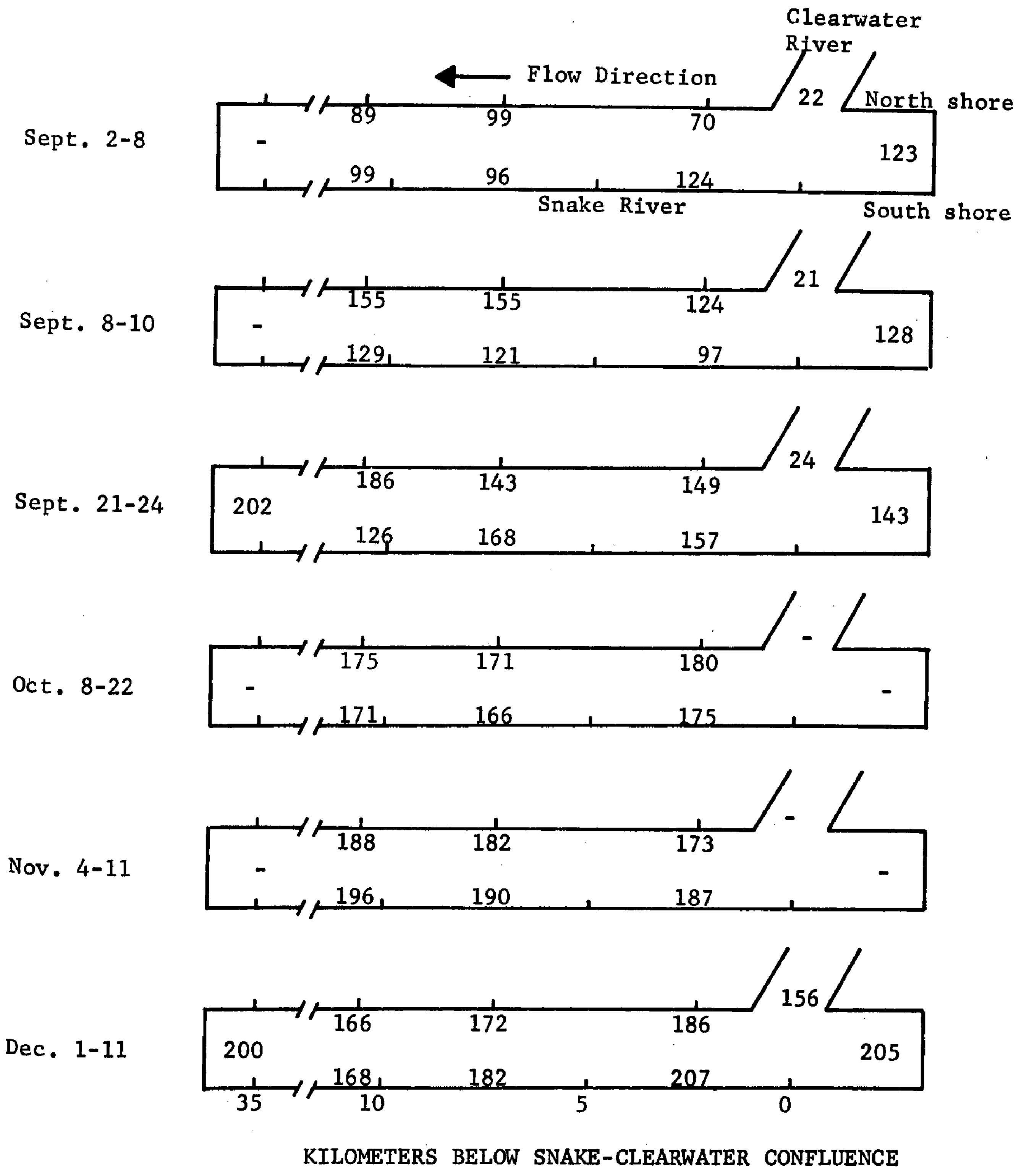


Figure A-7c. Cross-channel total dissolved solids patterns (mg/L NaCl) in the Snake and Clearwater Rivers during adult steelhead migration, 1971.

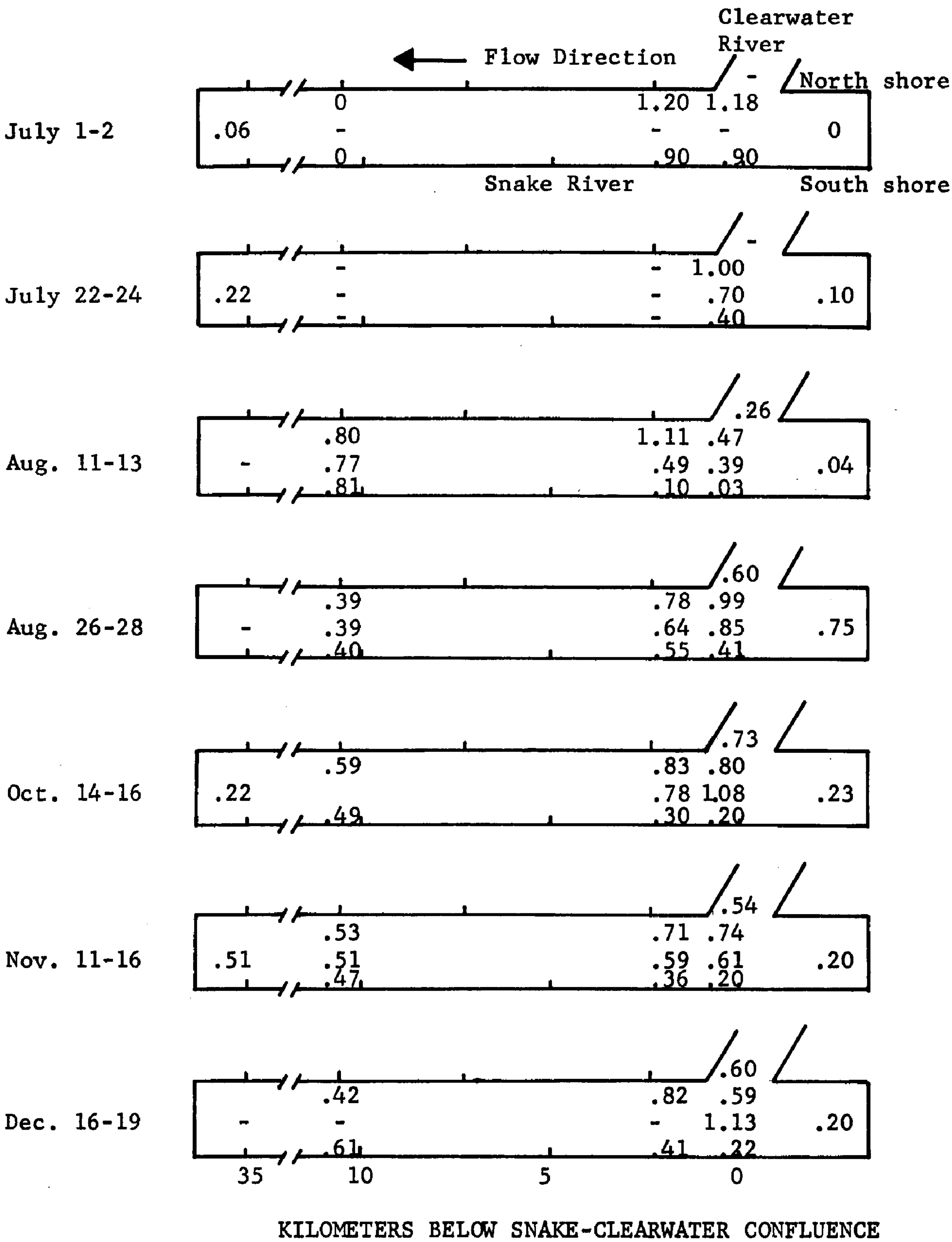


Figure A-8a. Cross-channel tannins and lignins patterns (mg/L Tannic Acid) in the Snake and Clearwater Rivers during adult steelhead migration, 1969.

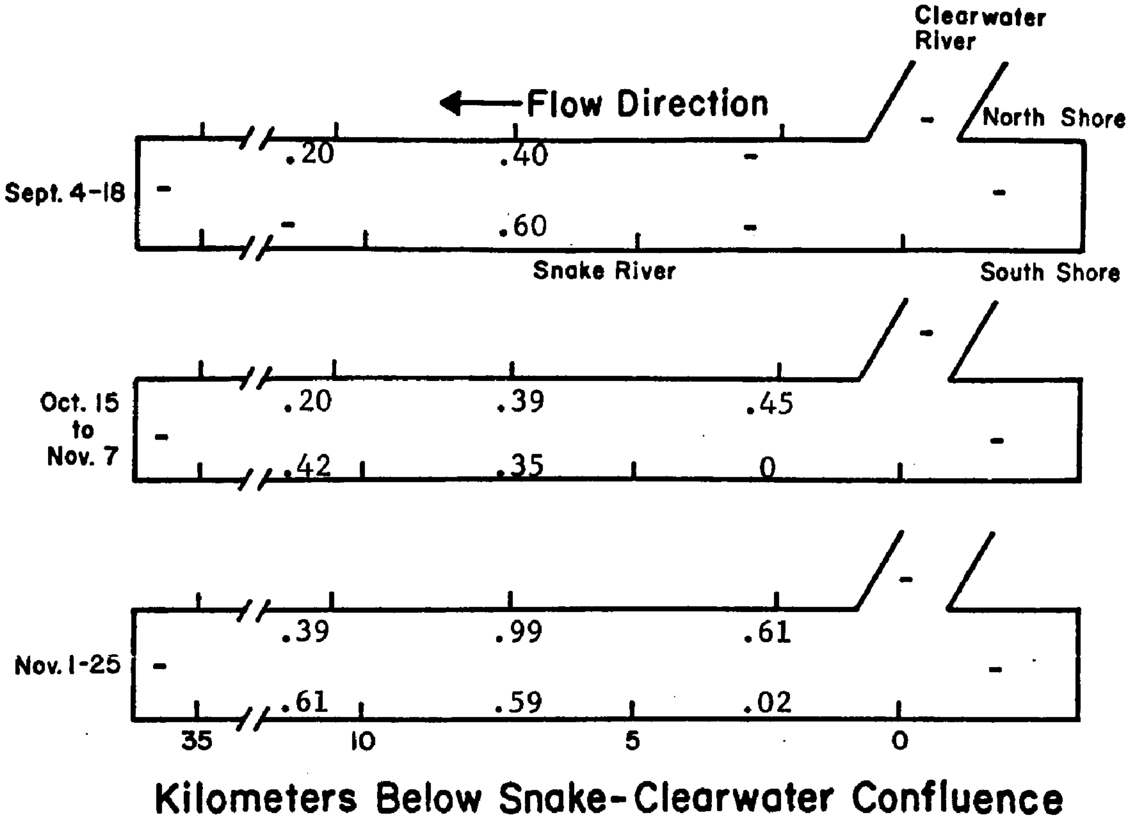


Figure A-8b. Cross-channel tannins and lignins patterns (mg/L Tannic Acid) in the Snake and Clearwater Rivers during adult steelhead migration, 1970.

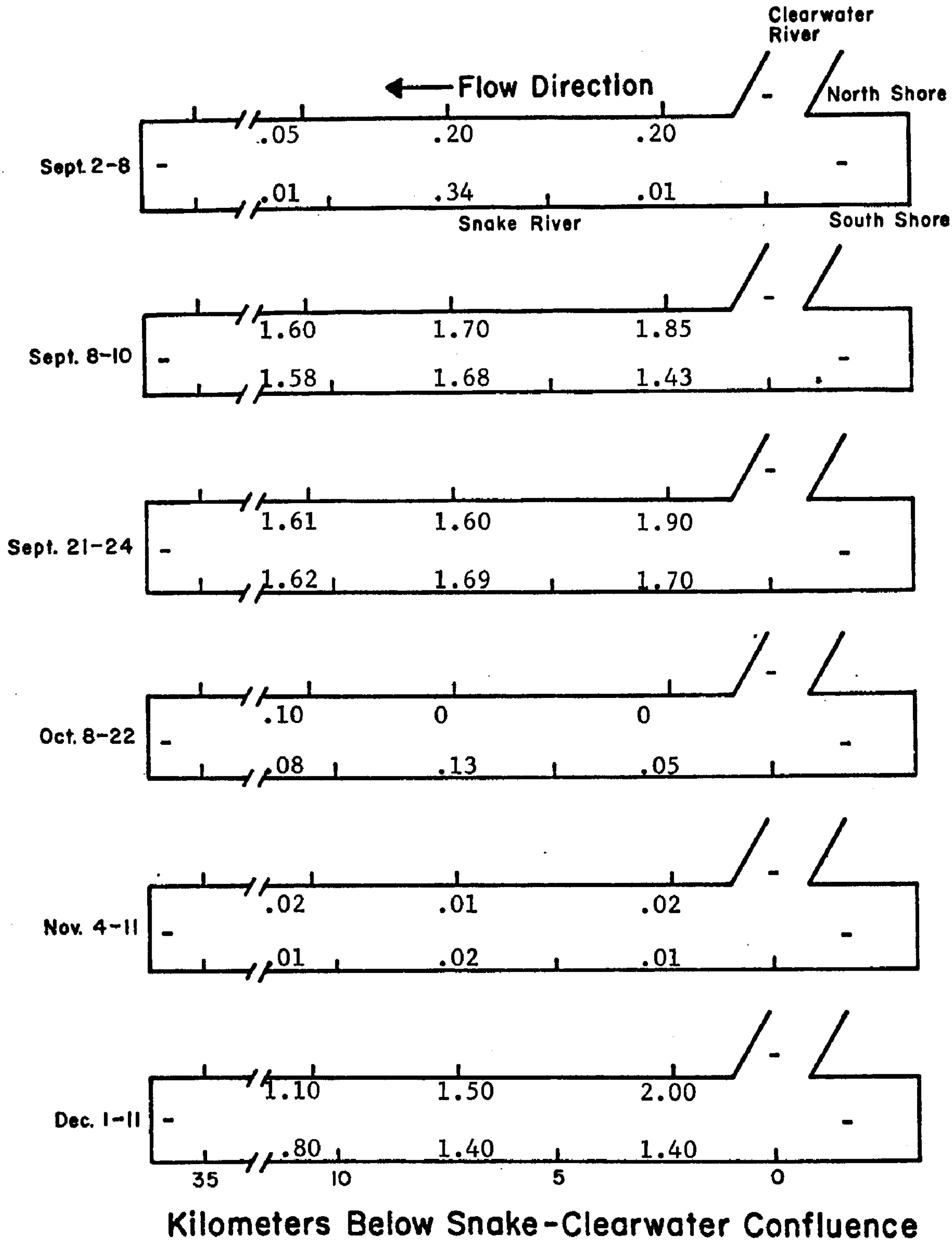


Figure A-8c. Cross-channel tannins and lignins patterns (mg/L Tannic Acid) in the Snake and Clearwater Rivers during adult steelhead migration, 1971.

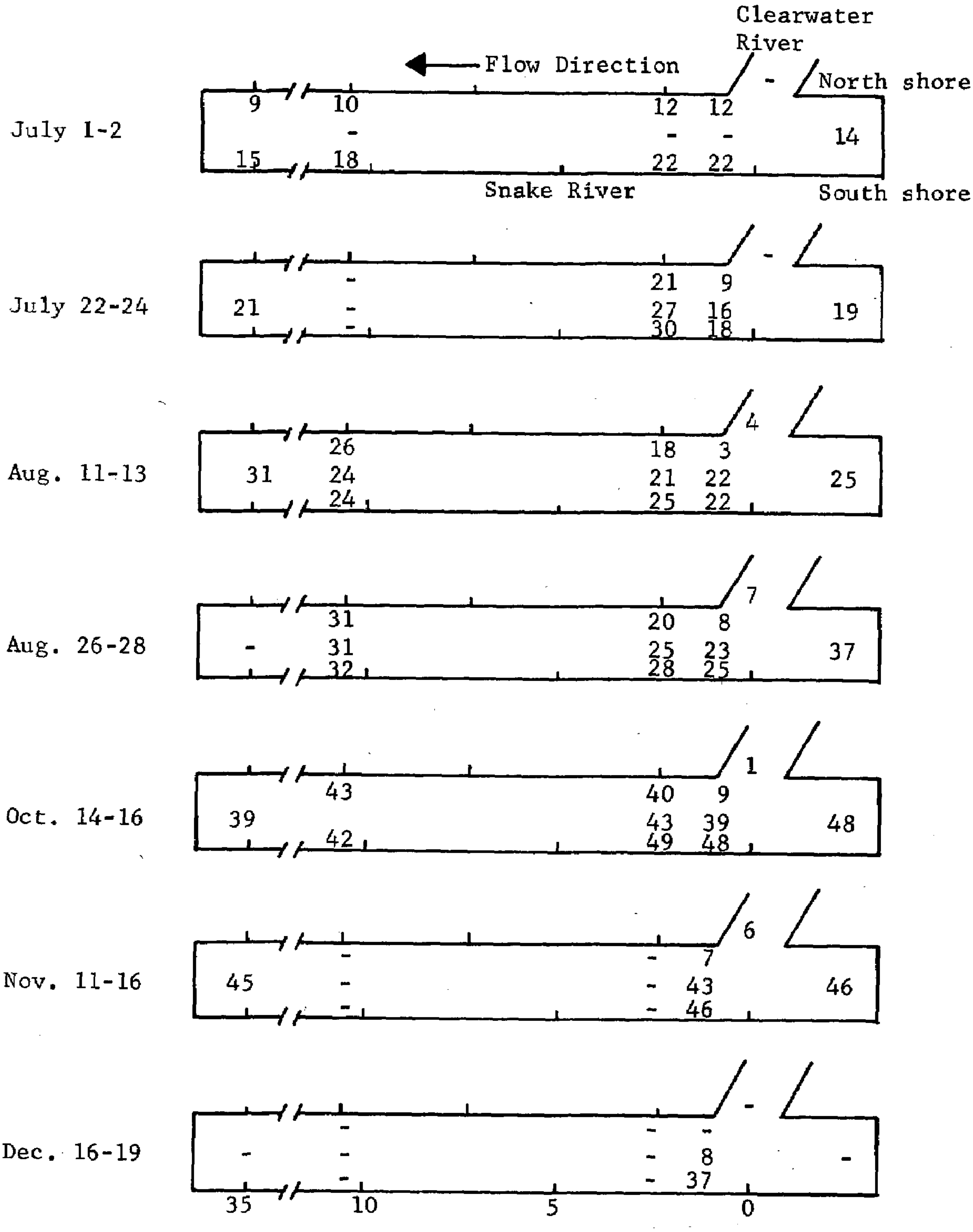


Figure A-9a. Cross-channel sulfate patterns (mg/L $SO_4$) in the Snake and Clearwater Rivers during adult steelhead migration, 1969.

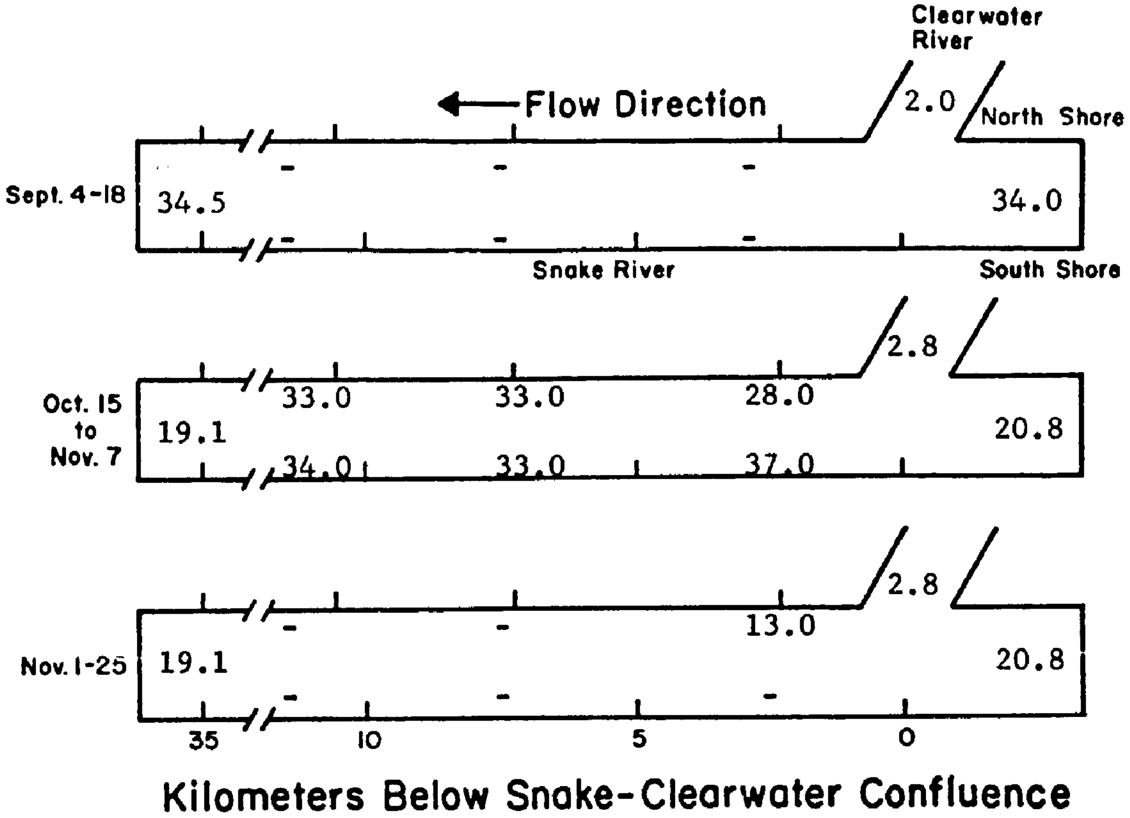


Figure A-9b. Cross-channel sulfate patterns (mg/L $SO_4$) in the Snake and Clearwater Rivers during adult steelhead migration, 1970.

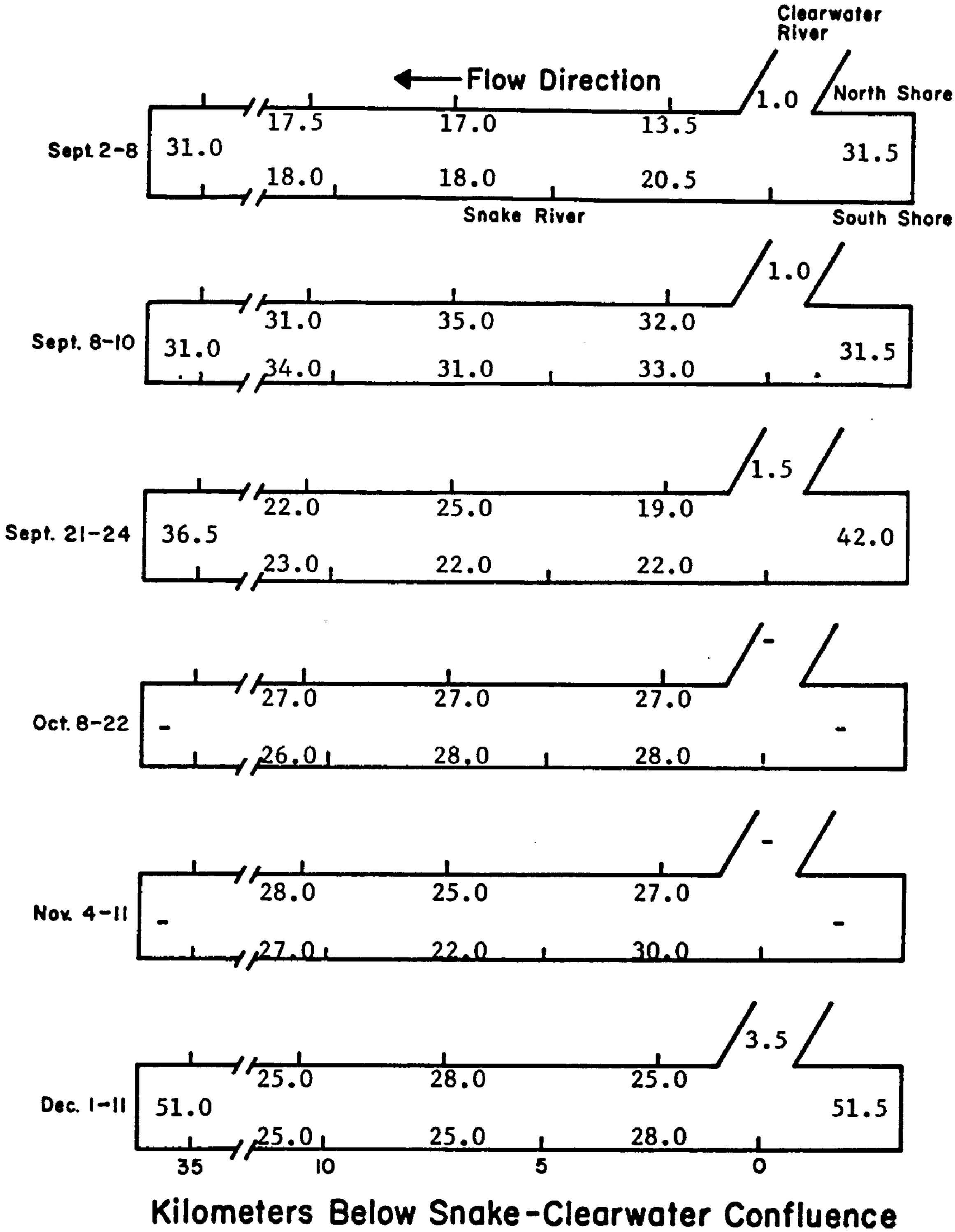


Figure A-9c. Cross-channel sulfate patterns (mg/L $SO_4$) in the Snake and Clearwater Rivers during adult steelhead migration, 1971.

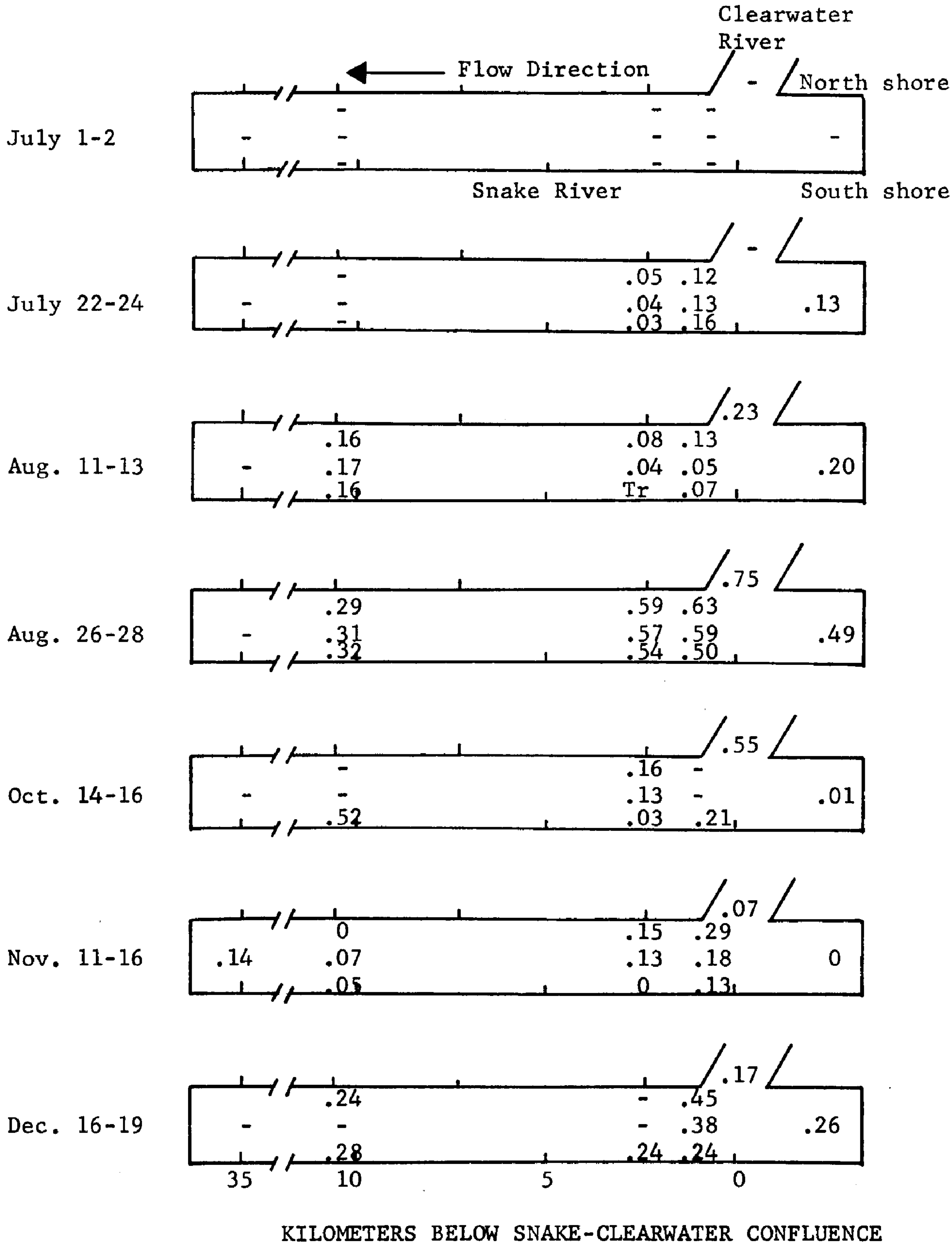


Figure A-10a. Cross-channel ammonia patterns (mg/L $NH_3$) in the Snake and Clearwater Rivers during adult steelhead migration, 1969.

*Tr = Trace

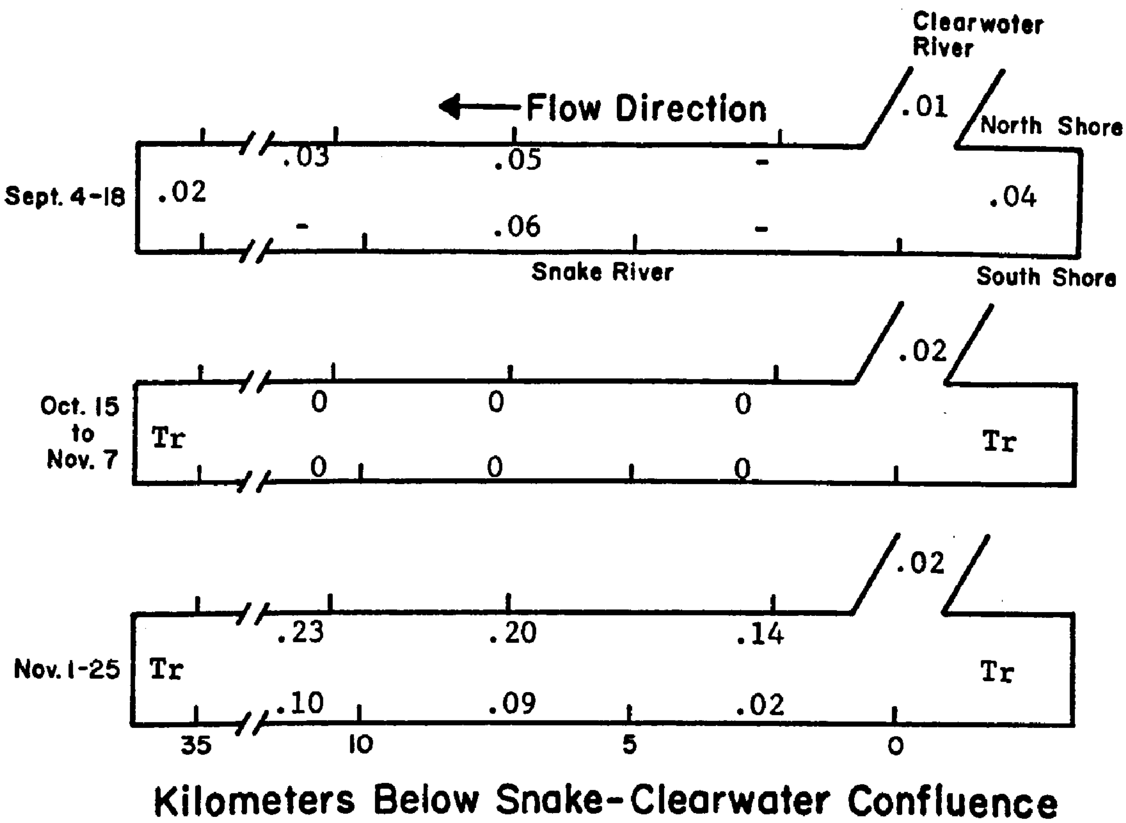


Figure A-10b. Cross-channel ammonia patterns (mg/L $NH_3$) in the Snake and Clearwater Rivers during adult steelhead migration, 1970.

*Tr = Trace

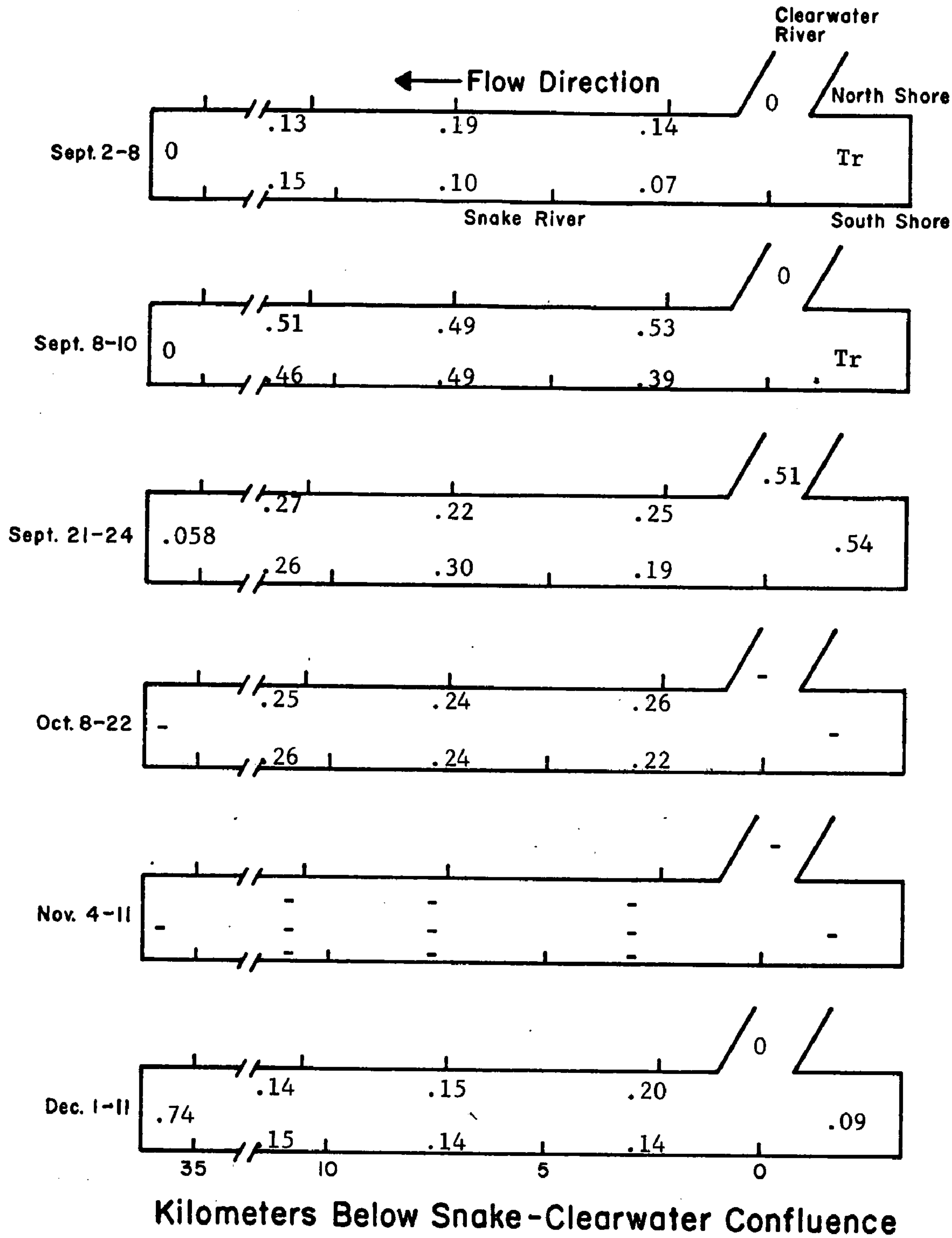


Figure A-10c. Cross-channel ammonia patterns (mg/L $NH_3$) in the Snake and Clearwater Rivers during adult steelhead migration, 1971.

*Tr = Trace

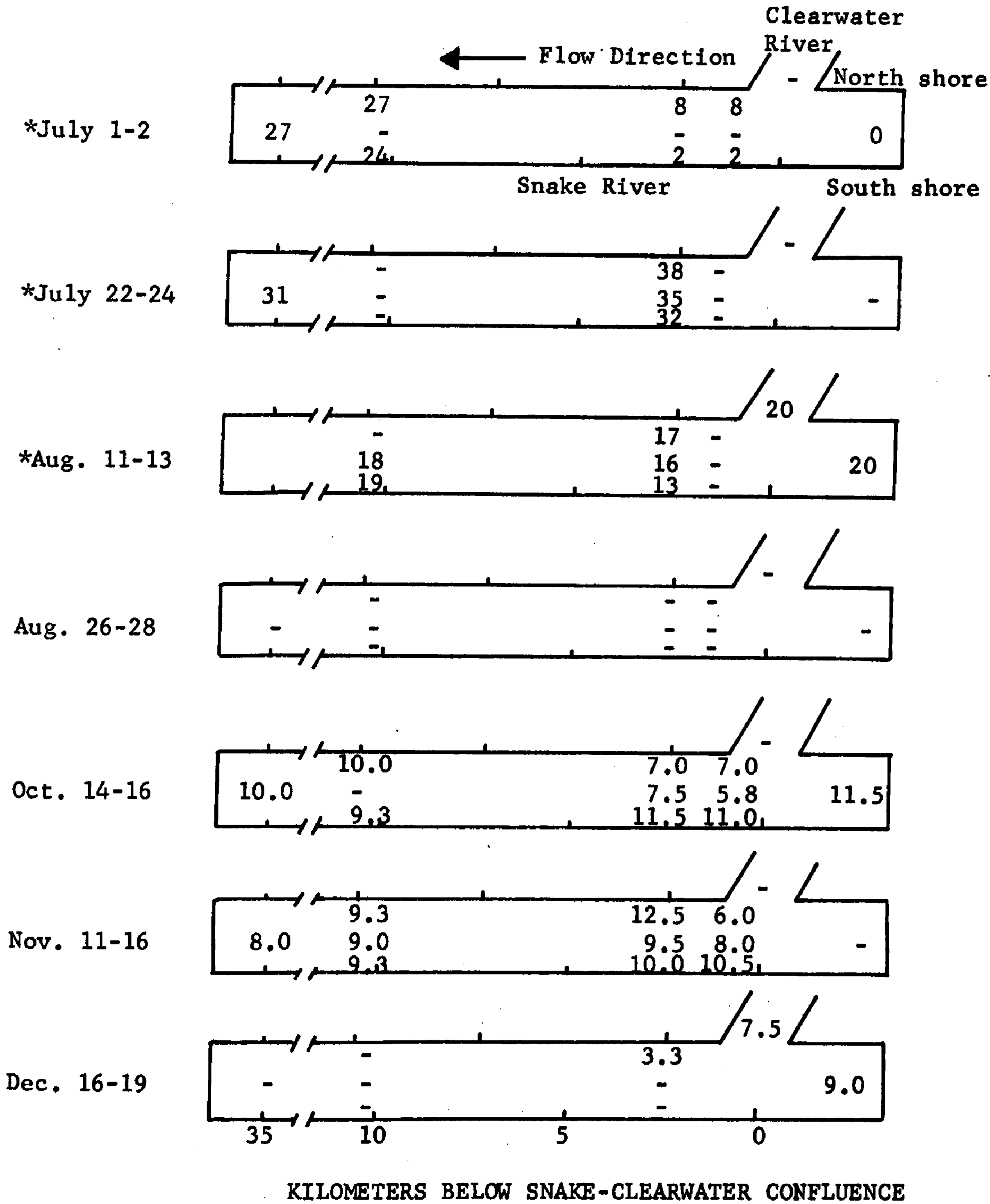


Figure A-11a. Cross-channel transparency patterns (Secchi Disc feet) in the Snake and Clearwater Rivers during adult steelhead migration, 1969.

*indicates turbidity readings in JTU's.

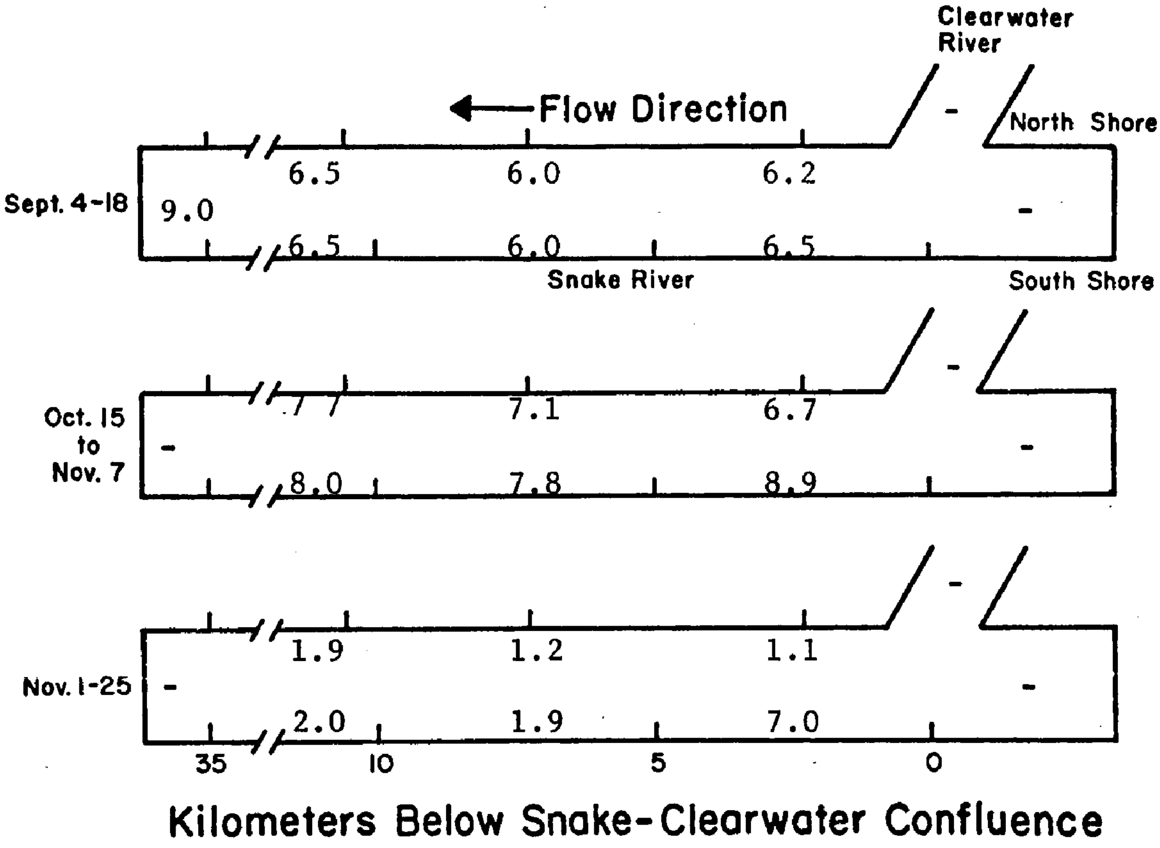


Figure A-11b. Cross-channel transparency patterns (Secchi Disc feet) in the Snake and Clearwater Rivers during adult steelhead migration, 1970.

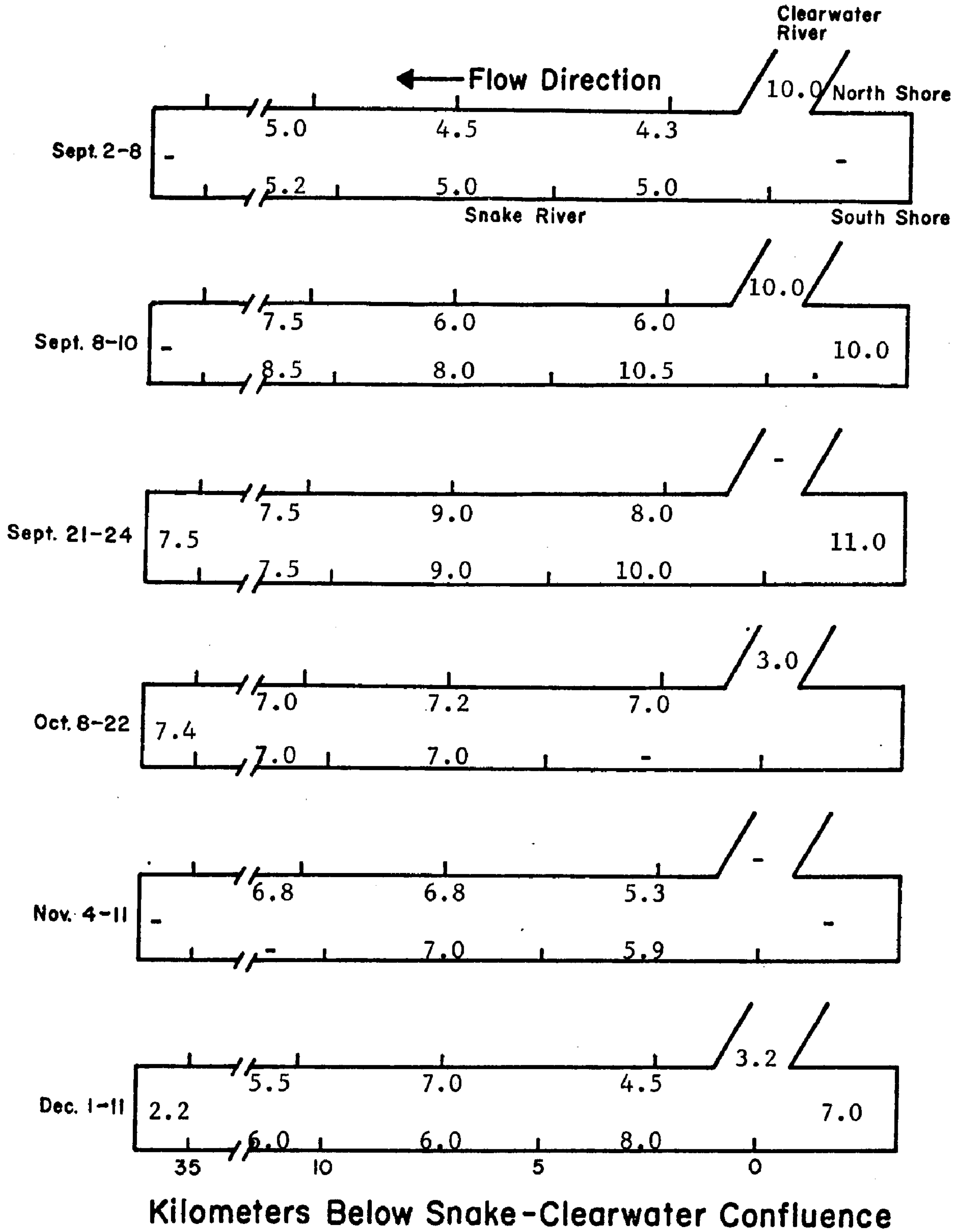


Figure A-11c. Cross-channel transparency patterns (Secchi Disc feet) in the Snake and Clearwater Rivers during adult steelhead migration, 1971.

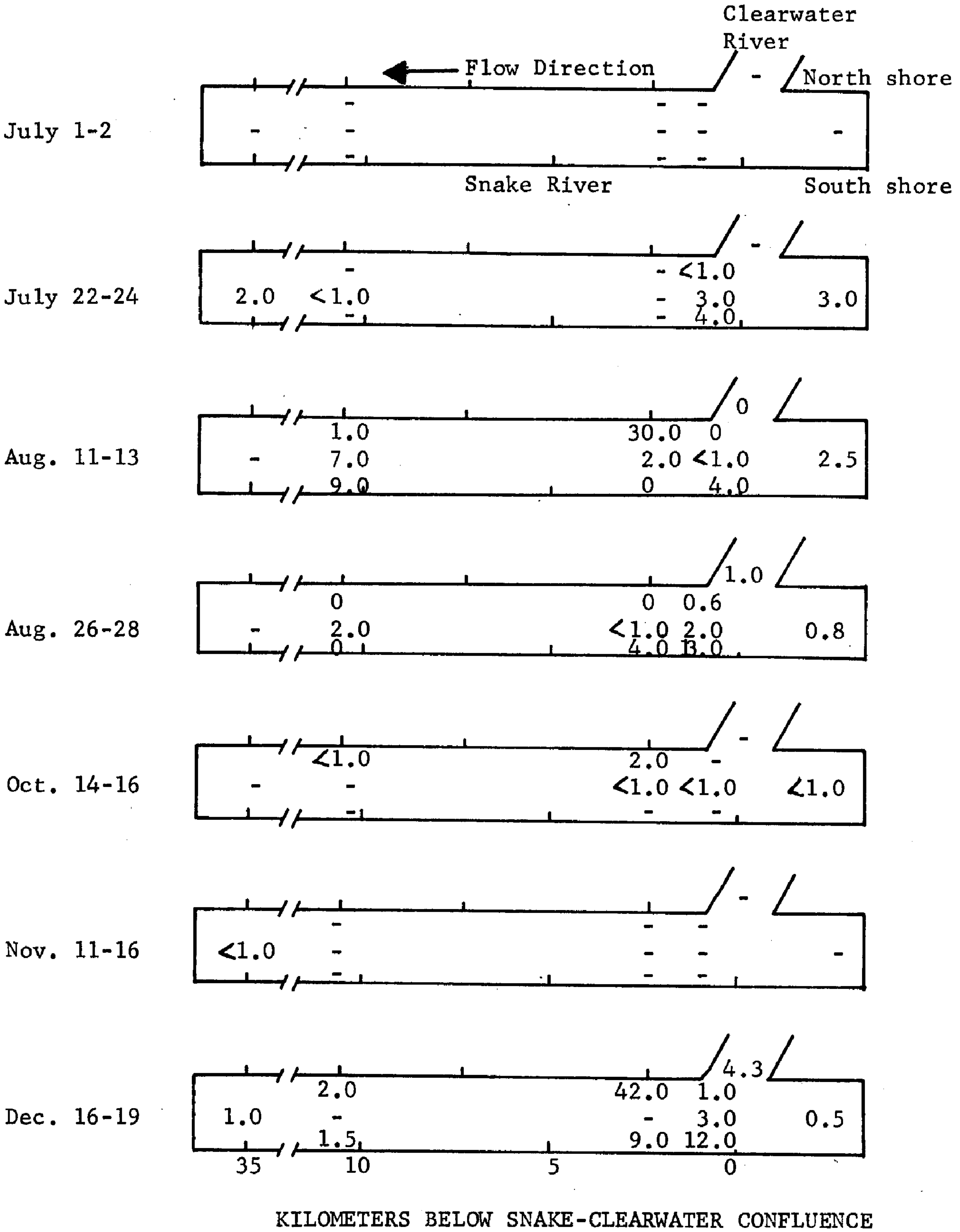


Figure A-12a. Cross-channel Pearl-Benson Index patterns (mg/L Standard Calcium Spent Sulfite Liquor Solids) in the Snake and Clearwater Rivers during adult steelhead migration, 1969.

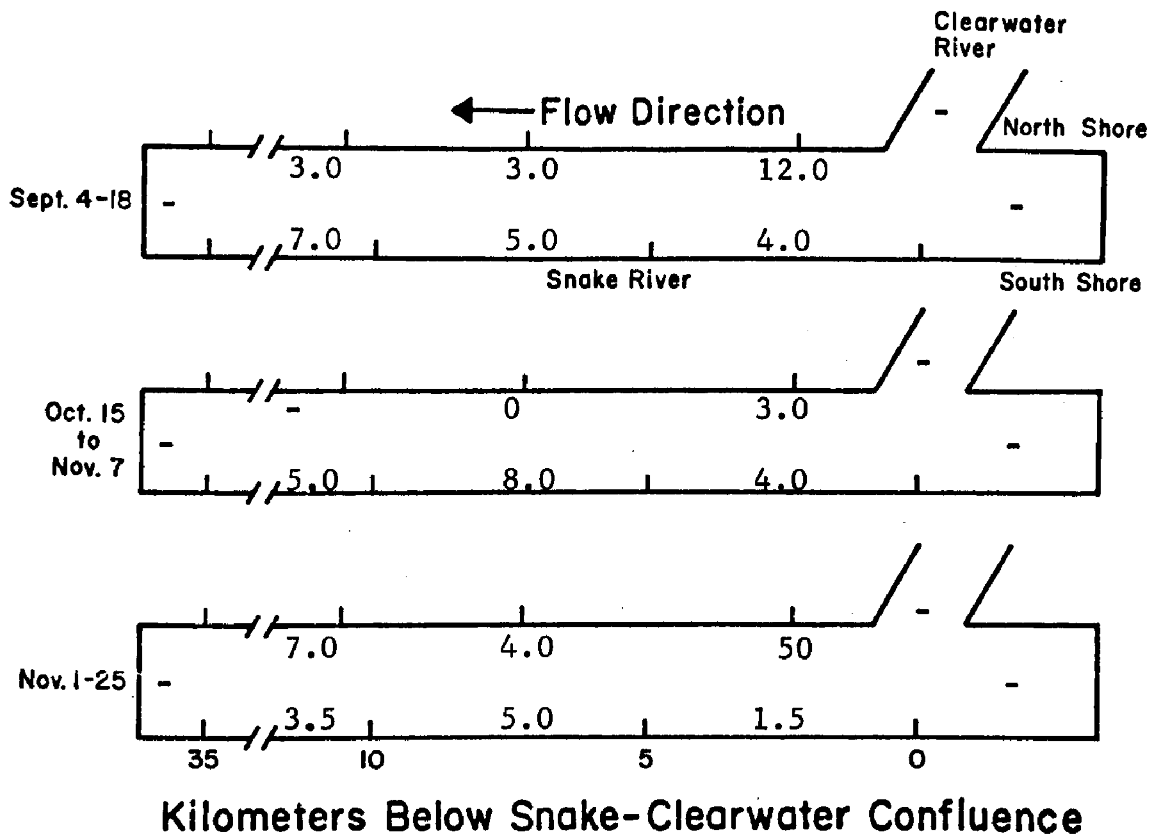


Figure A-12b. Cross-channel Pearl-Benson Index patterns (mg/L Standard Calcium Spent Sulfite Liquor Solids) in the Snake and Clearwater Rivers during adult steelhead migration, 1970.

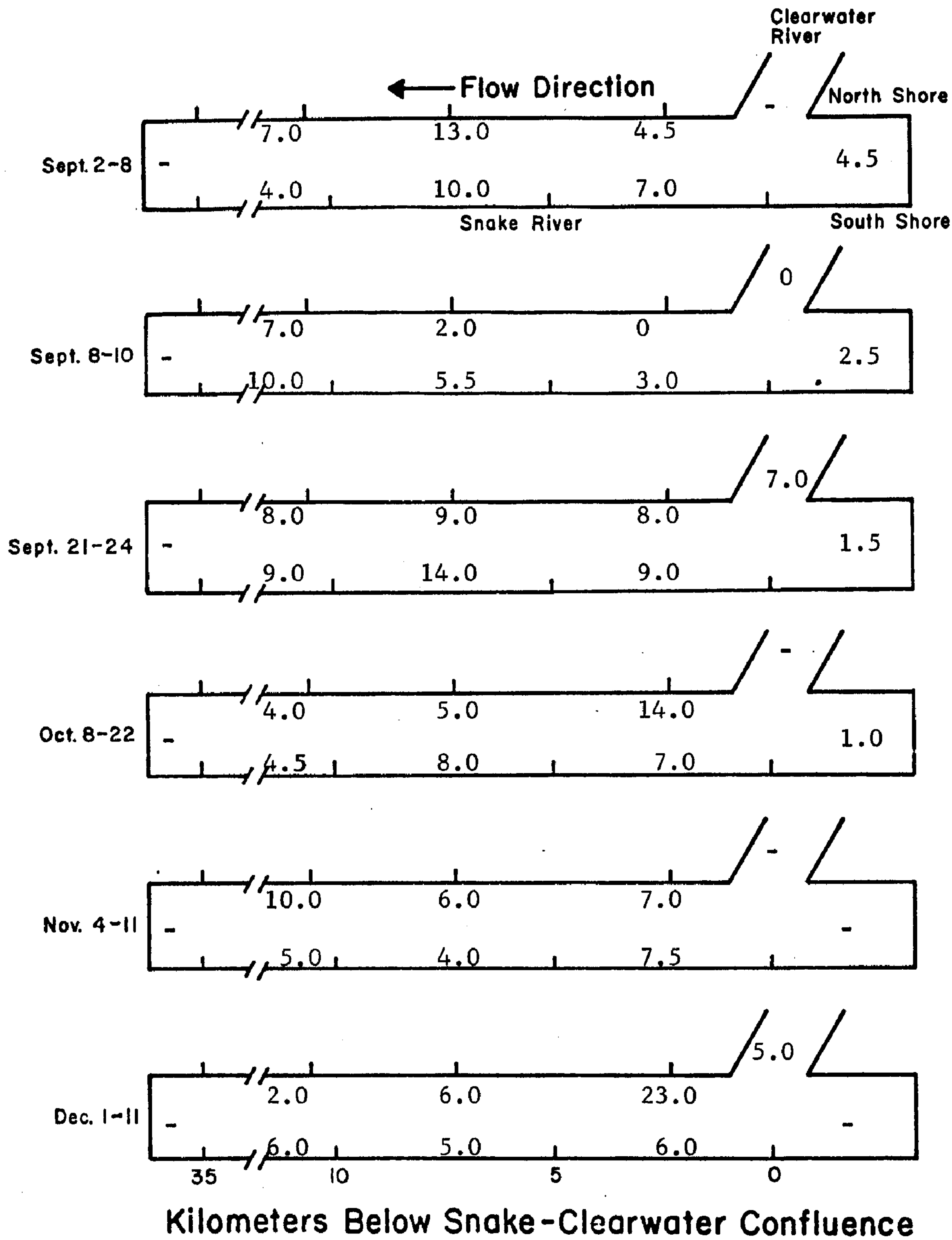


Figure A-12c. Cross-channel Pearl-Benson Index patterns (mg/L Standard Calcium Spent Sulfite Liquor Solids) in the Snake and Clearwater Rivers during adult steelhead migration, 1971.

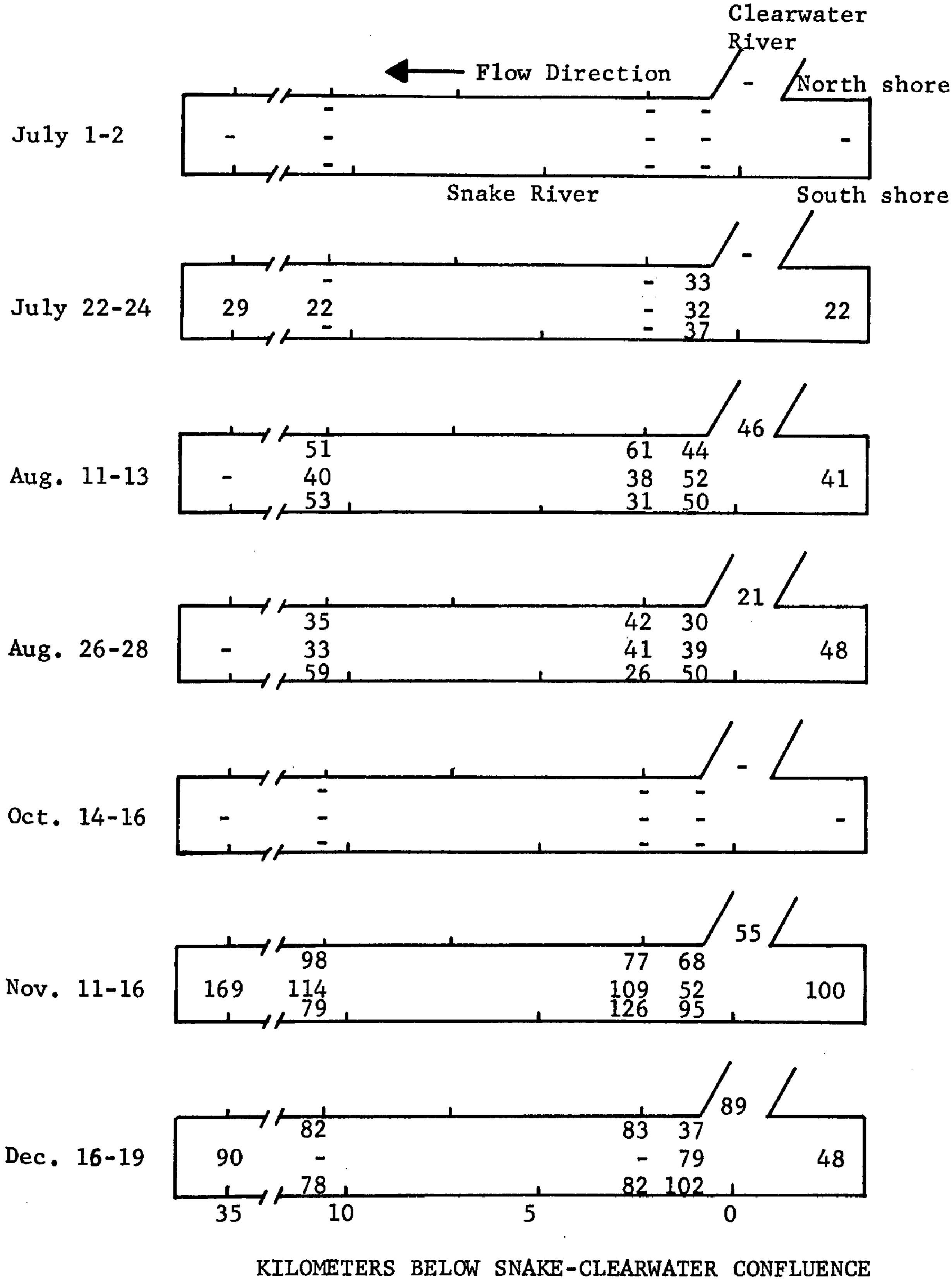


Figure A-13a. Cross-channel Total Volatile Matter patterns (mg/L Total Volatile Matter) in the Snake and Clearwater Rivers during adult steelhead migration, 1969.

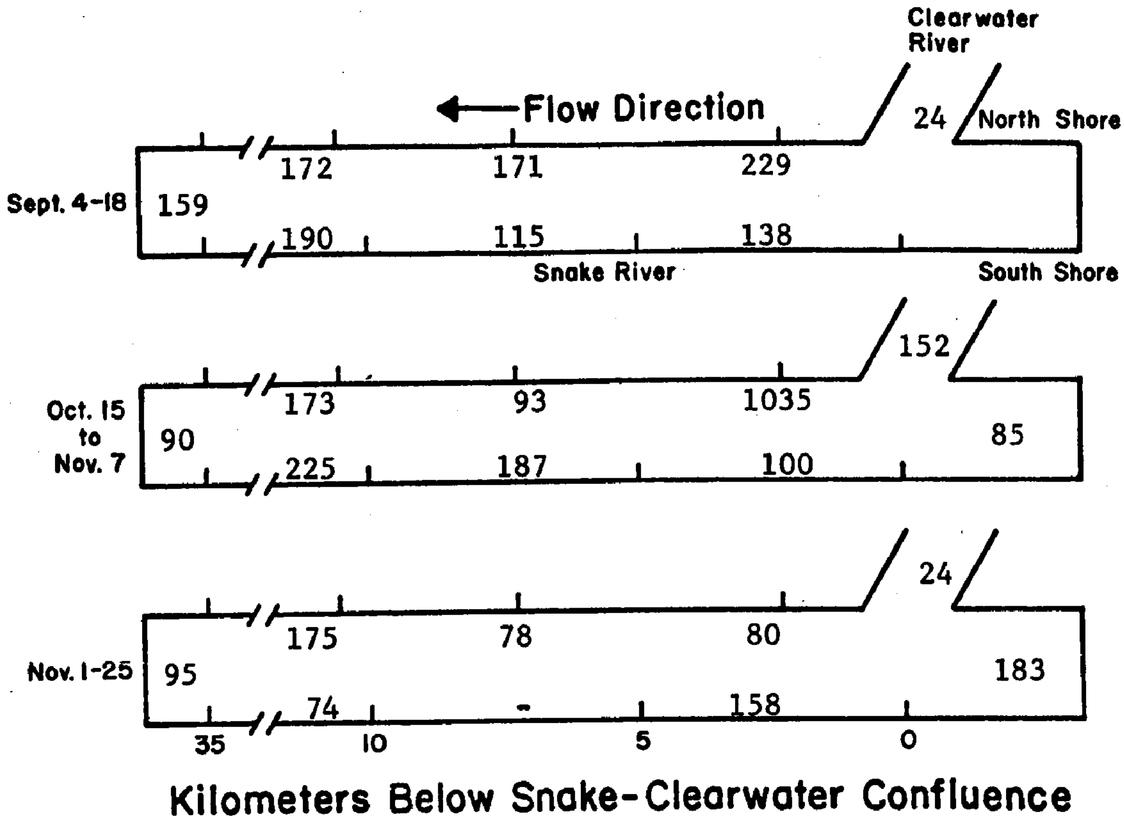


Figure A-13b. Cross-channel Total Volatile Matter patterns (mg/L Total Volatile Matter) in the Snake and Clearwater Rivers during adult steelhead migration, 1970.

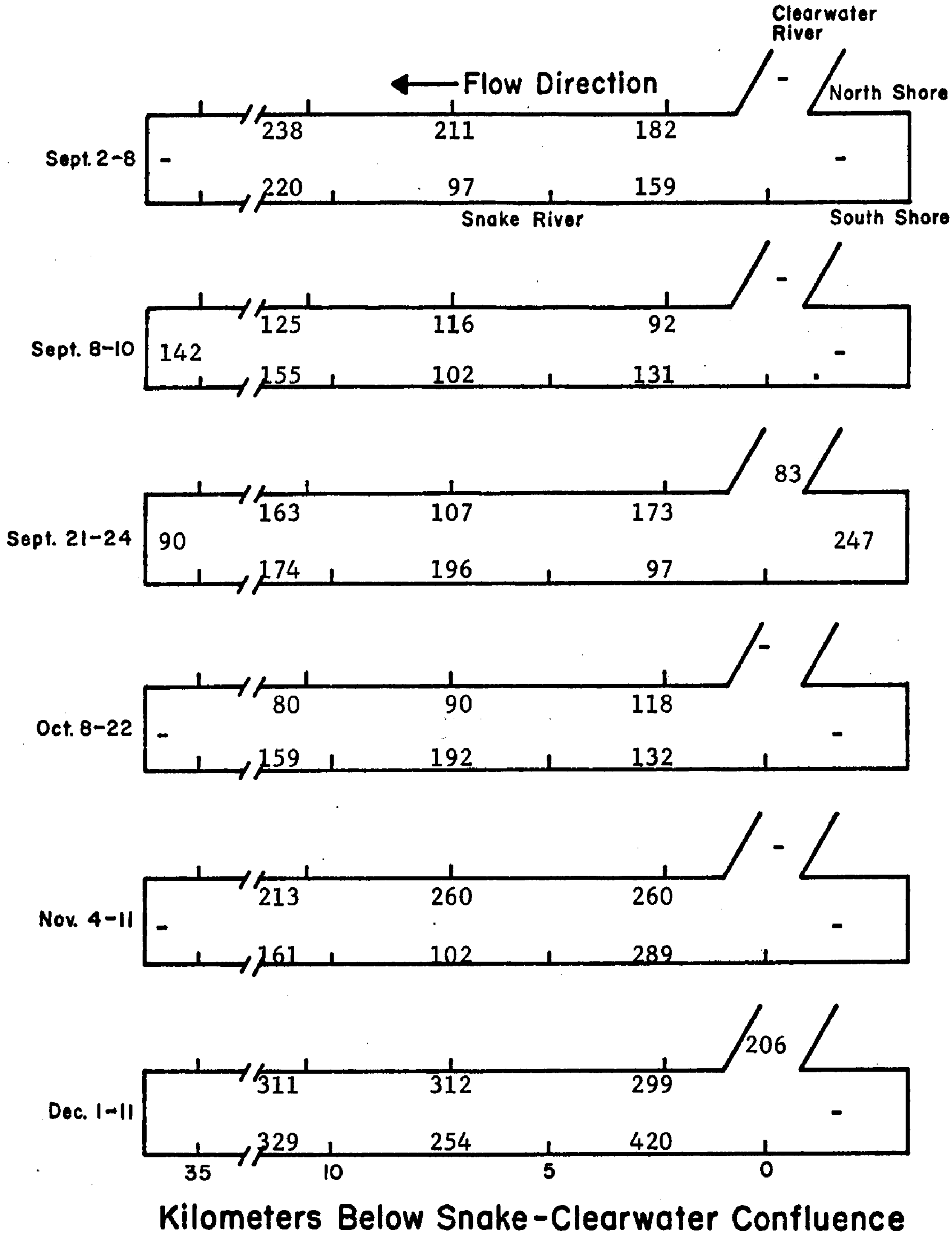


Figure A-13c. Cross-channel Total Volatile Matter patterns (mg/L Total Volatile Matter) in the Snake and Clearwater Rivers during adult steelhead migration, 1971.

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16. Abstract

We conducted a three-year field study in 1969-1971 to assess the relationship of Kraft mill effluent and pre-impoundment water quality to adult steelhead trout (Salmo gairdneri Richardson) behavior in the Snake River, Idaho-Washington. Steelhead were tagged with ultrasonic tags and followed through a 25 km section of the proposed Lower Granite Reservoir. We measured limnological parameters and compared with fish behavior. Mixing patterns of the Clearwater River with the Snake River were also assessed.

Mean water quality changes in the Snake River as a result of pollution inputs in the study are very subtle. In terms of toxic effects from chemical loading, Snake River water quality is not greatly altered except in the immediate area of pollution input; we did not observe steelhead avoidance of these localized problem areas.

No significant correlation could be made between any chemical water quality parameter and steelhead behavior. However, as temperature dropped below 15 C fish movement slowed, fish generally stopped moving at night, and resting periods increased in length and number. Steelhead showed a preference to move in water with off-bottom current velocities of 0.2 to 0.5 m/sec and showed a definite pattern of crossover and resting points.

17a. Descriptors

/*Steelhead trout/*Kraft mill effluent/oxygen/water pollution effects /*migration behavior/water temperature/water velocity/*ultrasonic transmitters/pre-impoundment water quality

17b. Identifiers

Snake River/Idaho-Washington/Lewiston, Idaho/anadromous fish/migration

17c. COWRR Field & Group

18. Availability

19. Security Class. (Report)

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