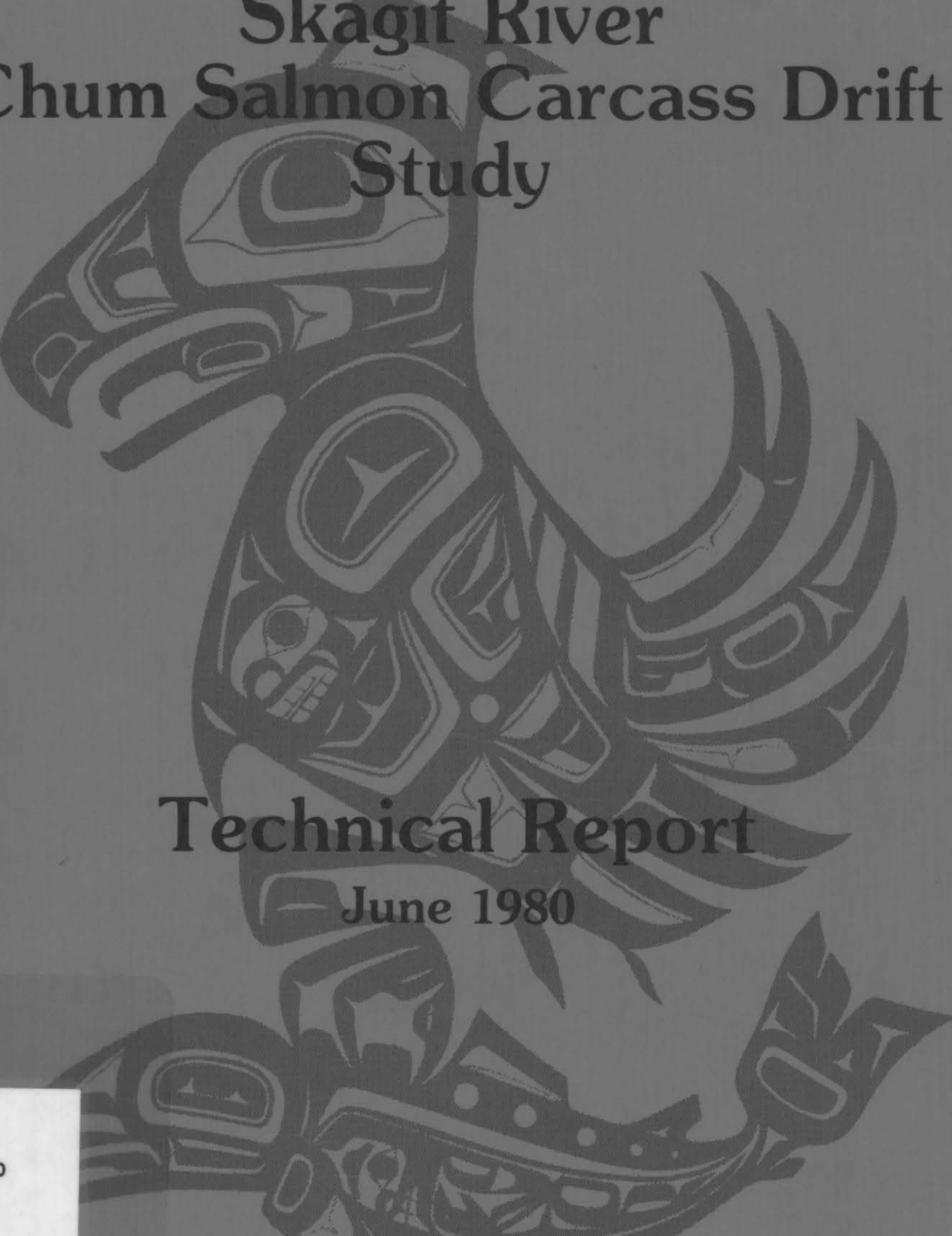
Skagit River Chum Salmon Carcass Drift Study



Technical Report

June 1980

SKAGIT RIVER
CHUM SALMON CARCASS DRIFT STUDY

for

City of Seattle
City Light Department

June 1980

James W. Glock
Bierly & Associates, Inc.
Wetland & Waterway Resource Consultants

Gregory Hartman
Ogden Beeman & Associates

Dr. Loveday Conquest
Center for Quantitative Sciences
University of Washington

Cover art by Earl Muldoe,
Ksan, British Columbia.
Original print entitled
"Eagle with Salmon", prin-
ted by Canadian Native
Prints Ltd.

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Introduction

Seattle City Light Department supplies electrical power to Seattle business, industry and residents. Much of the present power demand is met by electricity generated by a series of hydroelectric dams on the Skagit River, about 70 miles northeast of Seattle. As energy consumption continues to increase, City Light must develop new energy sources to meet immediate needs as well as future developments. One alternative being considered is the construction of an additional hydroelectric dam on the Skagit River at river mile (RM) 83.7 near the confluence with Copper Creek (Figure 1).

Prior to construction of the dam, the feasibility and environmental impacts of the project must be evaluated. Seattle City Light Department has sponsored a series of studies to determine the physical, biological and socio-economic conditions in the affected area and how they would respond to construction and operation of Copper Creek Dam (CH_2M/Hill, 1979a). Major direct impacts of construction are the inundation of 2,200 acres of land along 10 miles of the upper river between Copper Creek and Gorge Dam and the resulting loss of spawning and rearing habitat for salmon and steelhead.

During the environmental assessment process, concern was raised about secondary impacts of the dam (CH_2M/Hill, 1979b). Of particular concern are potential impacts to the population of bald eagles (*Haliaeetus leucocephalus* which winter in the area. The wintering bald eagles feed primarily on salmon carcasses which wash onto gravel bars and islands (Servheen, 1975).

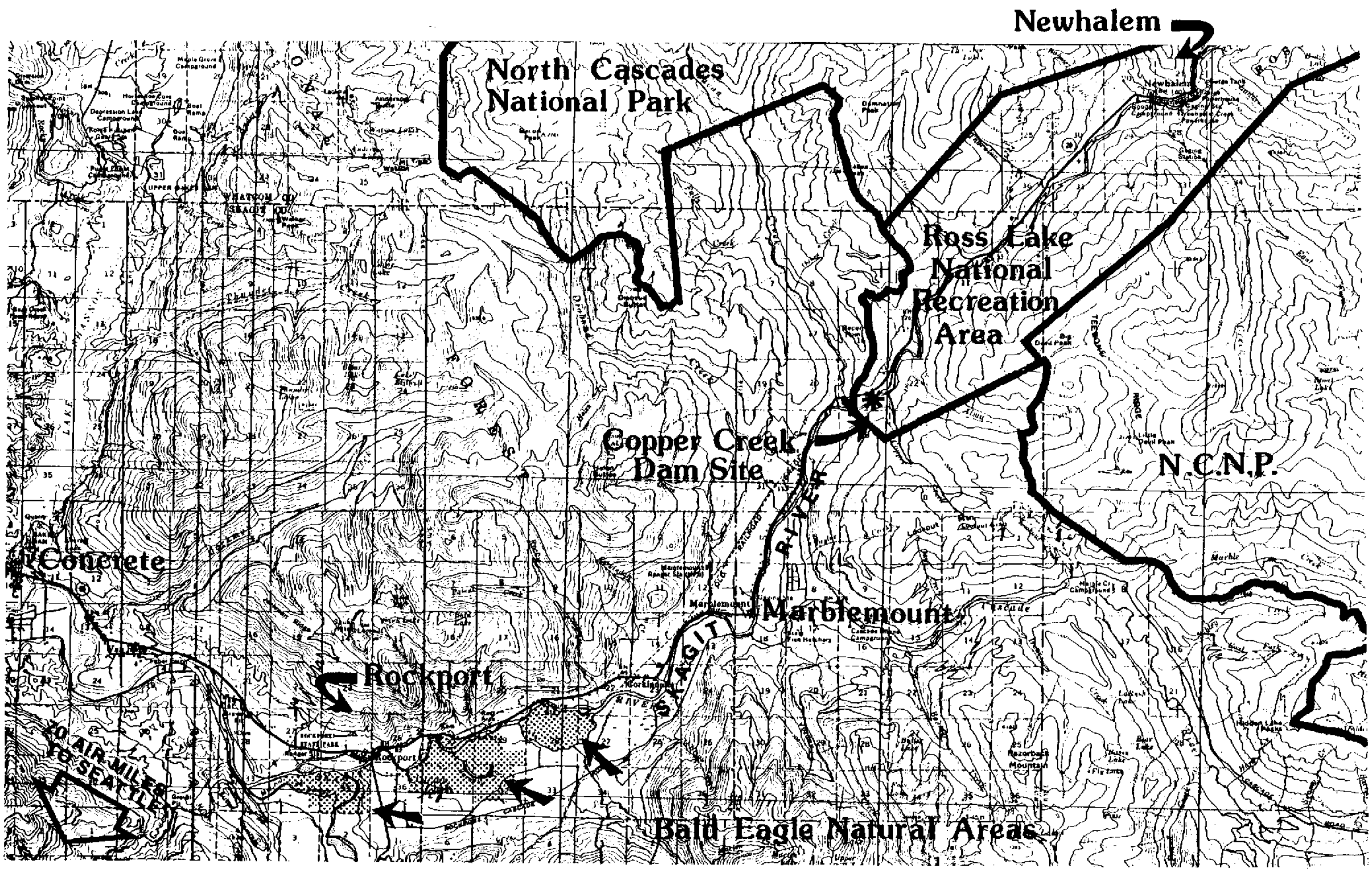


FIGURE 1
Location Map

Annually, 300-400 bald eagles winter in the area, concentrating near the town of Rockport (Figure 1). This wintering area is one of the larger concentrations of bald eagles remaining in the lower 48 states (Steenhof, 1978).

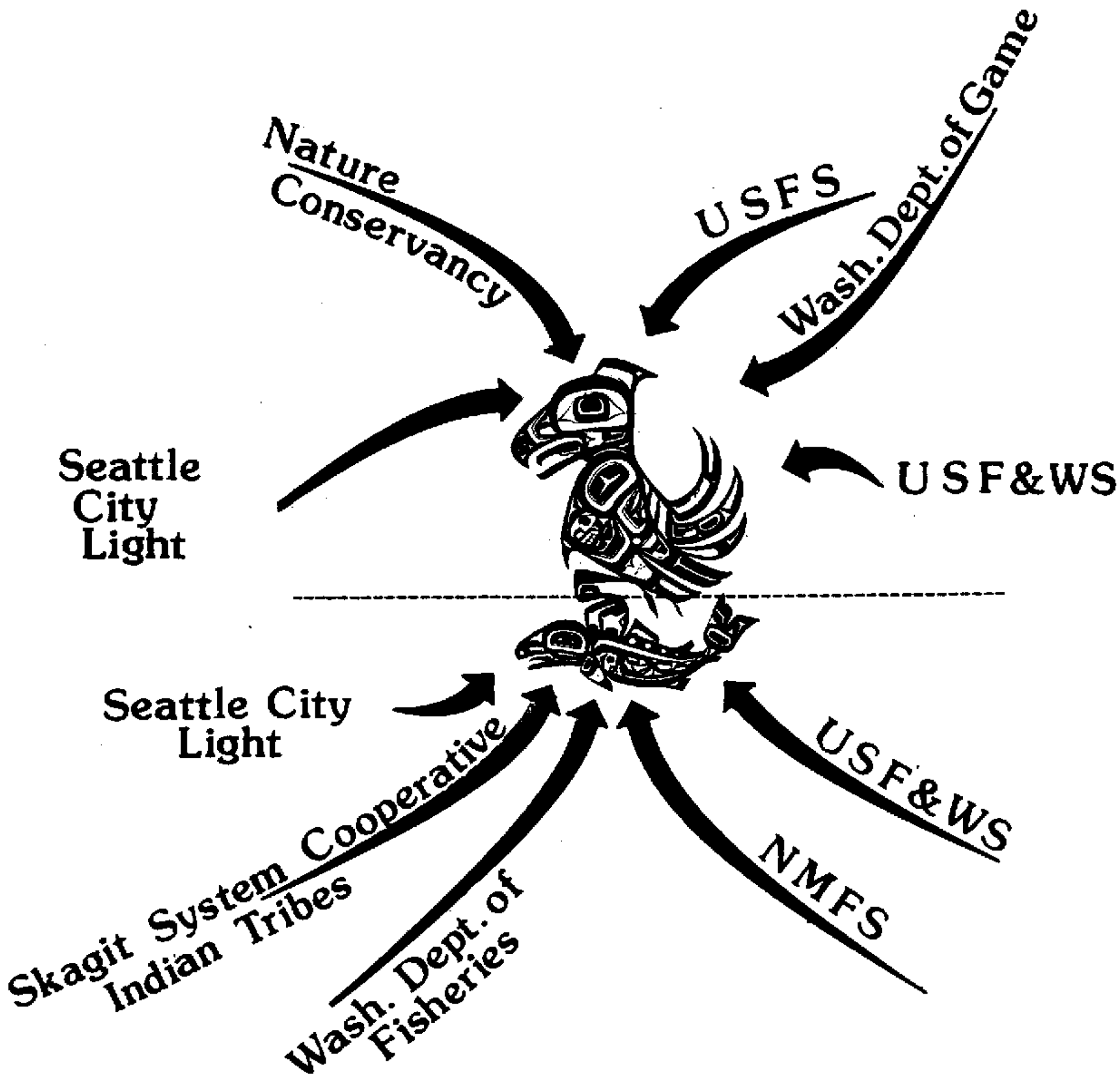
Because these eagles are dependent upon the supply of salmon carcasses, impacts on the salmon resources can directly affect survival. Observations in the past have suggested that the spawned-out salmon die and wash up on shore in the immediate vicinity of where they spawned. No detailed study has addressed the specific mechanisms of salmon carcass downstream drift identifying where the carcasses originate and how far they drift. If a significant portion of the carcasses eaten by eagles come from spawning areas above the proposed dam site, the loss of these fish would be an important consideration in evaluating the acceptability of the project.

On May 14, 1979, the Seattle City Council adopted Resolution 26044 that specified a work program for studies and a decision-making process concerning the Copper Creek Dam project. The resolution specified studies be undertaken to determine the impacts of the proposed project on wintering bald eagles that included analysis of salmon carcass drift.

Studies of the relationship between the salmon carcass food supply and wintering bald eagles are necessary to meet the requirements of NEPA, Federal Energy Regulatory Commission licensing application Exhibit W, and biological assessments sufficient for biological opinion pursuant to Section 7 of the 1978 Amended Endangered Species Act. The Seattle City Light Department has been working closely with an advisory committee of experts, environmental representatives, state and federal agencies and concerned citizens to coordinate the eagle studies (Figure 2).

FIGURE 2

Organization Concerns



The question of particular concern to all parties is whether the proposed dam would jeopardize the continued existence or have a significant effect on the population of wintering bald eagles in the area.

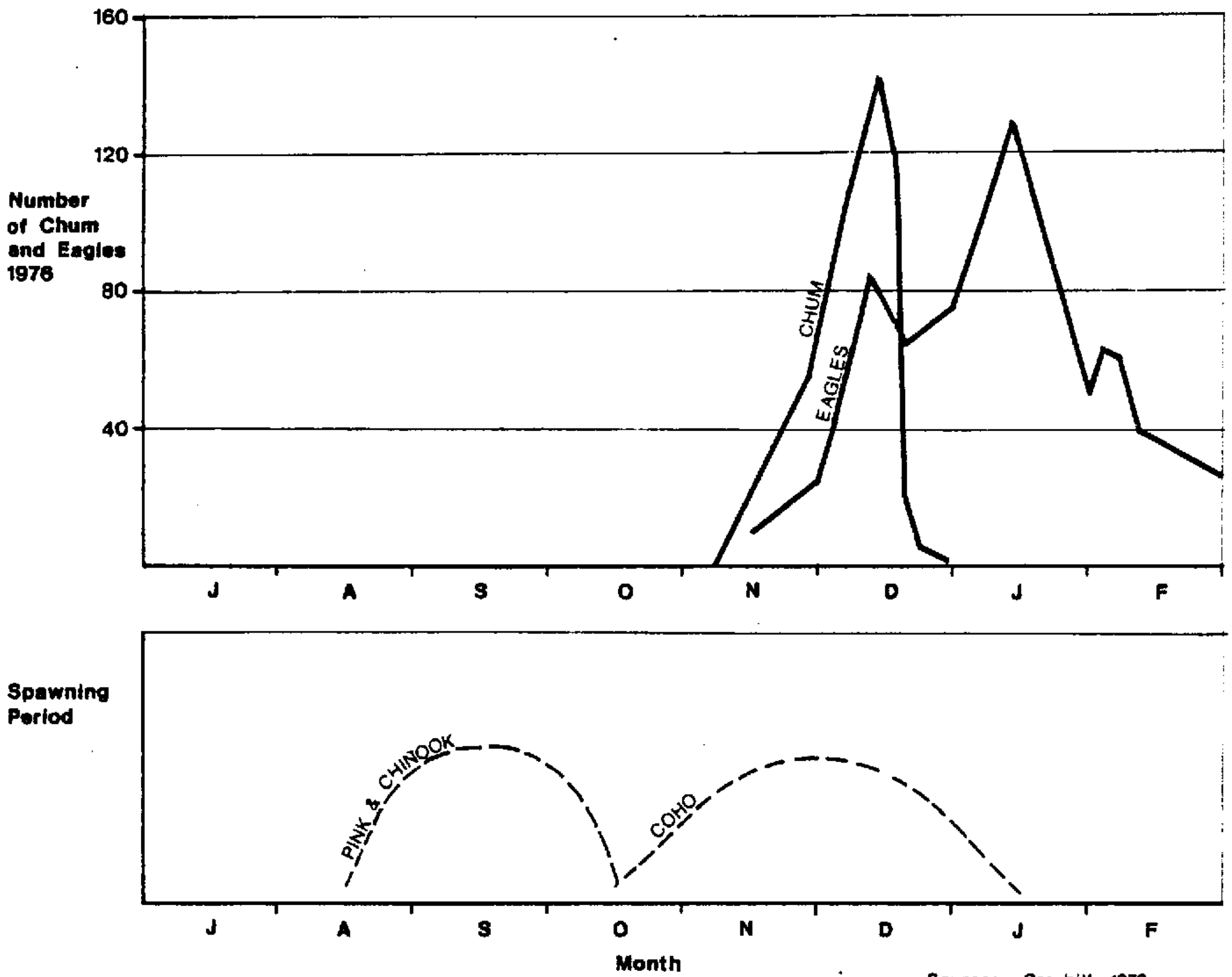
Setting

The Skagit Valley harbors one of the largest concentrations of wintering bald eagles in the western United States outside of Alaska (Steenhof, 1978; Nature Conservancy, 1976). The eagles feed on the salmon that spawn in the Skagit River during fall and winter (Servheen, 1975). Historically the Skagit has been one of the most productive salmon and steelhead rivers in the Puget Sound area. Four species of salmon are present in the project area. Chinook salmon (*Oncorhynchus tshawytscha*), the largest fish present, migrate into the area in summer and fall. Chinook salmon are not as abundant as the other salmon species in the Skagit River. Chinooks arrive early and spawn in deeper water and thus are not utilized significantly by the wintering eagle population. Pink salmon (*O. gorbuscha*) are present in large numbers only on odd-numbered years. This is the smallest salmon in the project area but generally the most abundant. Many rotting carcasses are still present when the earliest eagles arrive. Pink salmon contribute to the food source utilized by these birds early in the winter (Servheen, 1975).

Coho (*O. kisutch*) and chum salmon (*O. keta*) spawn later than the other species of salmon, and their presence overlaps the presence of wintering eagles (Figure 3). Coho salmon spawn primarily in tributaries of the Skagit River and are less available to foraging eagles. Bald eagles prefer open areas of the main river for foraging, and few coho carcasses drift from the tributary streams to gravel bars and banks of the main channel.

Chum salmon typically spawn in side channels and shallow areas of the main river. The major spawning areas, which have been identified by the Washington Department of Fisheries, are between the towns of Rockport and Marblemount. Chum salmon begin to arrive in early November and spawning continues into January (Figure 3).

FIGURE 3 FISH RUNS AND EAGLE ABUNDANCE



Sources: Graybill 1979
Nature Conservancy 1979
PNWRBC 1970

Eagles begin to arrive in the area soon after the onset of the chum salmon spawning run in November and remain through the winter. The primary food source during this period is chum salmon carcasses which wash onto gravel bars, islands, and shallow areas of the river where they become accessible to foraging birds (Servheen, 1975; Wiley, 1977). During years of high chum salmon abundance there may be thousands of carcasses strewn about, especially near the town of Rockport (Wiley, 1977). Bald eagles congregate in this area and their distribution appears to be related to carcass distribution. An eagle preserve has been established between the Sauk River and Rocky Creek, and both the Washington Department of Game and the Nature Conservancy own land dedicated to the maintenance of wintering bald eagles (Figure 1).

In order to determine the origin of salmon carcasses fed upon by the eagles, a study was designed to determine how carcasses are transported and distributed along the river. The chum salmon carcass drift study area extended from the town of Newhalem downstream to the confluence of the Skagit and Sauk Rivers. The primary study area extended from RM 90.5 (below Newhalem) to RM 78.0 (Marblemount).

Chum Salmon Carcass Drift Studies

In September of 1979 Seattle City Light Department prepared a workscope for studies of Wintering Bald Eagles and Eagle-Related Fisheries and Hydrologic Studies. The Eagle-Related Fisheries and Hydrologic Studies (Carcass Drift Studies) were designed to determine the potential effects of dam construction on salmon carcass availability downstream of the dam site. In October 1979 Montagne-Bierly Associates, Inc., was contracted to gather data on carcass drift by radio telemetric methods.

and relate the data to hydraulic data from the Skagit River study area.

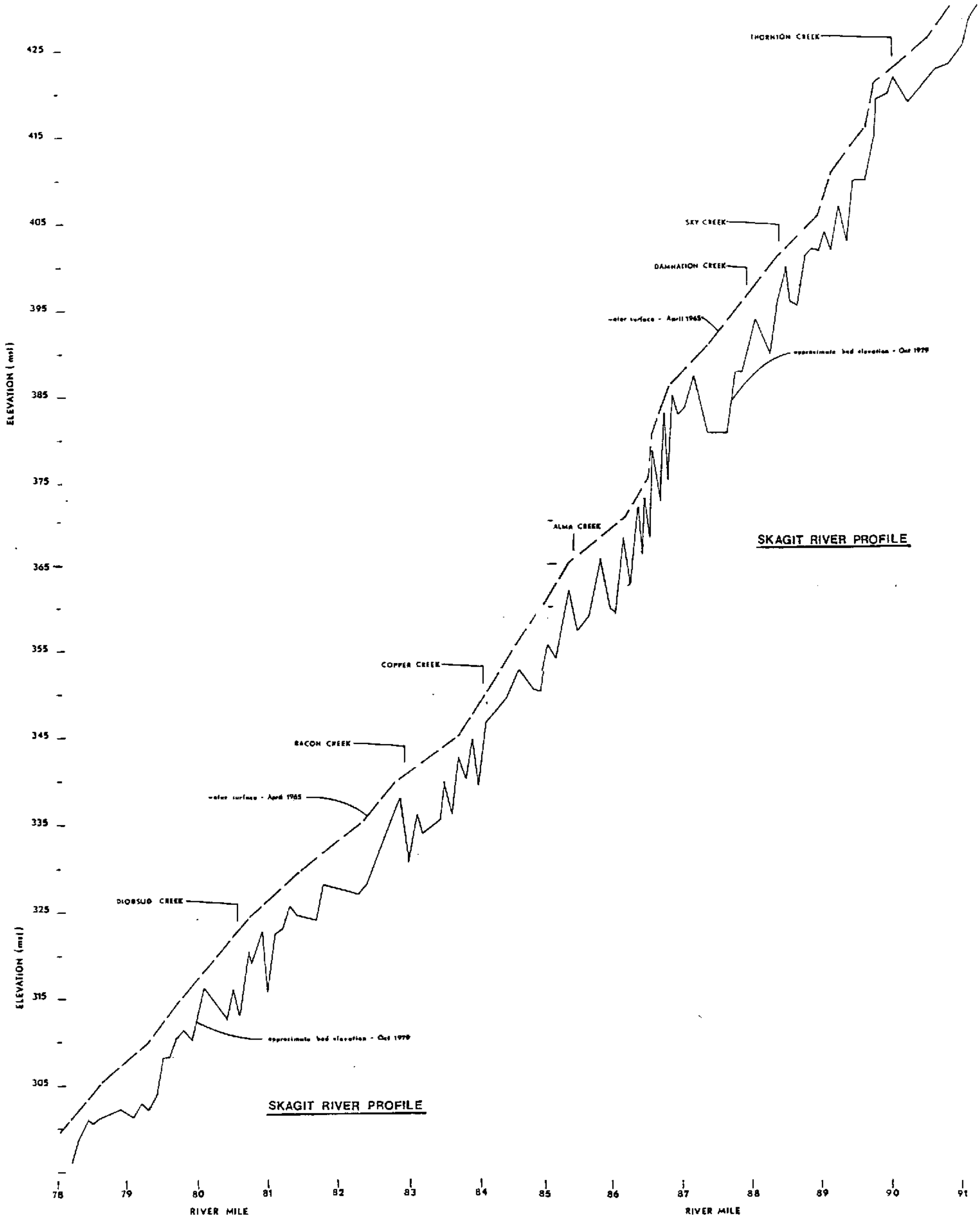
The salmon carcass drift study was designed to utilize radio telemetry devices specified by Seattle City Light Department to gather data sufficient to test the statistical significance of the impact of the proposed dam on carcass drift. The salmon carcass drift study was also designed to provide independent data on stream hydraulic processes potentially affecting carcass movement.

Hydraulic Studies

Physical characteristics of the Skagit River were measured in order to understand how the river affects carcass transport and distribution. A thalweg (line of maximum depth) survey was conducted to describe the Skagit River streamway within the project area (Figure 4). The river profile shows stream gradient and pool:riffle relationships. Cross-section depth profiles were measured at various locations so that river flow and water velocity could be computed.

The United States Geological Survey (USGS) has maintained four gaging stations in the project area that continuously measure river stage. These records indicate the volume of flow in cubic feet per second (cfs) of water. The gaging stations are located at Newhalem (RM 93.7), the Skagit River above Alma Creek (RM 85.8), and the Skagit River at Marblemount (RM 78.7). A fourth station, Skagit River above Bacon Creek (RM 83.0) has only been in operation since April of 1977, and does not provide the length of record (30-72 years) that the other gaging stations offer. The Marblemount gage is also of limited value because no records were obtained from 1941 through 1976.

FIGURE 4 RIVER PROFILE



Topographic information was derived from Washington State Highway Commission maps of Marblemount to Newhalem. Contour intervals of 5' were obtained by photogrametric methods using aerial photography dated April 15, 1965. Information was also obtained from the USGS, Marblemount quadrangle, 15 minute topographic series which provides 80 foot contour intervals.

Sediment samples were taken at the cross-section depth profile locations and analyzed to determine the size of particles (rocks, gravel, sand, etc.) deposited by the river in that area.

Hydraulic data analysis has concentrated on three factors which are highly influential on the salmon carcass "drift capability" of the river.

- Hydrology - the variations in flows and depths between high water and low water and the relative frequency of flow conditions, to relate river flow conditions during the tagging effort to other years.
- Hydraulics - the relationship between depth and velocities in the river and the river reach characteristics that help identify forces causing fish movement.
- Sediment transport - the impact of river flow on the movement of bedload to help understand the tendency of a carcass to move as bedload, or to be buried in the bed.

River Reach Characteristics

A river system can be characterized by its longitudinal slope. Stream velocities are proportional to the square root of river slope and many characteristics of a waterway are the result of river velocity. Mamak (1958) has described four categories of rivers by longitudinal slope (Table 1), and other characteristics.

Table 1. River classification based on slope of the channel bed. (Mamak, 1958)

Type	Slope
Mountain Streams	.050 - .002
Upper Rivers	.002 - .001
Middle Rivers	.001 - .0005
Lowland Rivers	less than .0005

The Skagit River between RM 79.0 and 92.0 has an average slope of .0019 which would place it into the "upper river" type of waterway. Individual reaches of 0.3 and 1.0 miles in length, however, have slopes ranging from 0.0012 to 0.0090, suggesting the study reach is in a transition from "mountain stream" to "upper river" classification. Topographic charts further verify this transition concept because the river is moving into a generally wider valley area with less steep terrain. This transition condition suggested the need to consider the study area in terms of shorter reach lengths. The longitudinal slope of five short reaches better defines the study area (Table 2).

Table 2. Characteristic river reaches in the Skagit River from RM 78 to 91.

River Mile	Channel Pattern	Bar Ratio	Average Slope
78.0 - 86.1	riffle/pool	1 every 2100'	0.00017
86.1 - 86.8	rapids/deep pool	1 every 740'	0.0042
86.8 - 89.0	riffle/pool	1 every 1940'	0.0017
89.0 - 90.0	braiding	1 every 1230'	0.0036
90.0 - 91.4	riffle/pool	1 every 1790'	0.0018

Bedload Transport

Computations of bedload transport for characteristic sediments of the Skagit can help to interpret monitoring data if fish carcasses tend to move along the bottom rather than float. Bedload transport information can also help to explain the likelihood of carcasses becoming buried in the bed sediments.

Bedload is defined as the material moving along the bed of the river. Bedload movement has been predicted for existing conditions on the Skagit River study area from standard equations (see Appendix A). A discharge flow approaching 12,000 cubic feet per second is necessary to begin appreciable movement of the existing bed material (Table 3).

Table 3. Discharge levels necessary to create significant movement of bedload on Skagit River.

Sediment Sample		Values for Incipient Motion	
River Mile	D50	Depth (ft)	Discharge (cfs)
78.2	55 mm	9.5	15,000
81.8	48 mm	5.6	10,600
84.1	47 mm	6.8	12,200
87.0	68 mm	9.4	12,700
90.5	59 mm	8.5	12,400

D50 = median grain diameter (i.e. sediment size)

Hydrologic Conditions

Variations in flows and depths between high water and low water have been analyzed to establish "normal" flow conditions to compare with flows during the fish tagging effort. The gaging station upstream of Alma Creek is most representative of flows between the spawning area and the dam.

The Newhalem gage provided important insight into the levels of flow that could be expected from Gorge Dam regulation. The Newhalem gage is located at RM 93.7 which is immediately downstream of Gorge Dam, and thus represents the regulated flow input to the total Skagit River flow in the spawning and carcass drift reaches.

Between the Newhalem gage and the Alma Creek gage there are twelve tributaries that add to the discharge from Gorge Dam. Major tributaries include Newhalem Creek (RM 93.3), Goodell Creek (RM 92.7), Thornton Creek (RM 89.9), Sky Creek (RM 88.0), and Damnation Creek (RM 87.4). The only identified tributary inflow downstream of the Alma gage and above the Copper Creek dam site is Alma Creek (RM 85.0).

Three tributaries to the Skagit River enter downstream of Alma Creek and upstream of the Marblemount gage. They are Copper Creek (RM 84.0), Bacon Creek (RM 82.8), and Diobsud Creek (RM 80.7).

Mean Daily Discharge

A 10-year record from October, 1968, through September, 1978, was used to derive the typical mean daily discharge for the months of November, December, January and February. Table 4 provides a summary of the representative winter flows recorded at both stations for the 10-year period.

Table 4. Ten-year average of mean daily flows as recorded at Newhalem Gage on the Skagit River and above Alma Creek (1968 - 1978).

MEAN DAILY FLOW (cfs)

	Newhalem Gage			Skagit River above Alma Creek		
MONTH	Minimum	Average	Maximum	Minimum	Average	Maximum
Nov.	1678	3531	5971	2287	4299	7397
Dec.	2314	5171	8840	2970	5885	9889
Jan.	2724	5427	8500	3370	6066	9665
Feb.	2583	4941	7025	3174	5449	7727

As a result of inflow from the smaller tributaries, the mean Skagit River discharge increased approximately 600 to 1100 cfs at the Alma Creek gage over the Newhalem gage.

From the average flow analysis, the best fit year (4 month period) was selected and plotted. Figures 5 and 6 depict the 10-year average discharge that typifies flows in the Skagit River at Newhalem and Alma Creek. These plots point out the major impact that operation of the hydroelectric plants has on Skagit River flow. In general, discharge is characteristically lower on the weekends during the November - February time span because of reduced demand for power. Also, flows greater than 7200 cfs, which is the flow equivalent to the generating capacity of the Gorge powerhouse turbines, are seldom experienced at the Newhalem gage. Discharge is dampened to volumes predominantly below 7200 cfs during high water periods.

Stream Discharge During Carcass Drift Study

Tagging of fish at the Skagit River study site commenced on December 6, 1979. Additional tagging and monitor efforts subsequently

FIGURE 5 10-YEAR AVERAGE DAILY FLOW AT NEWHALEM

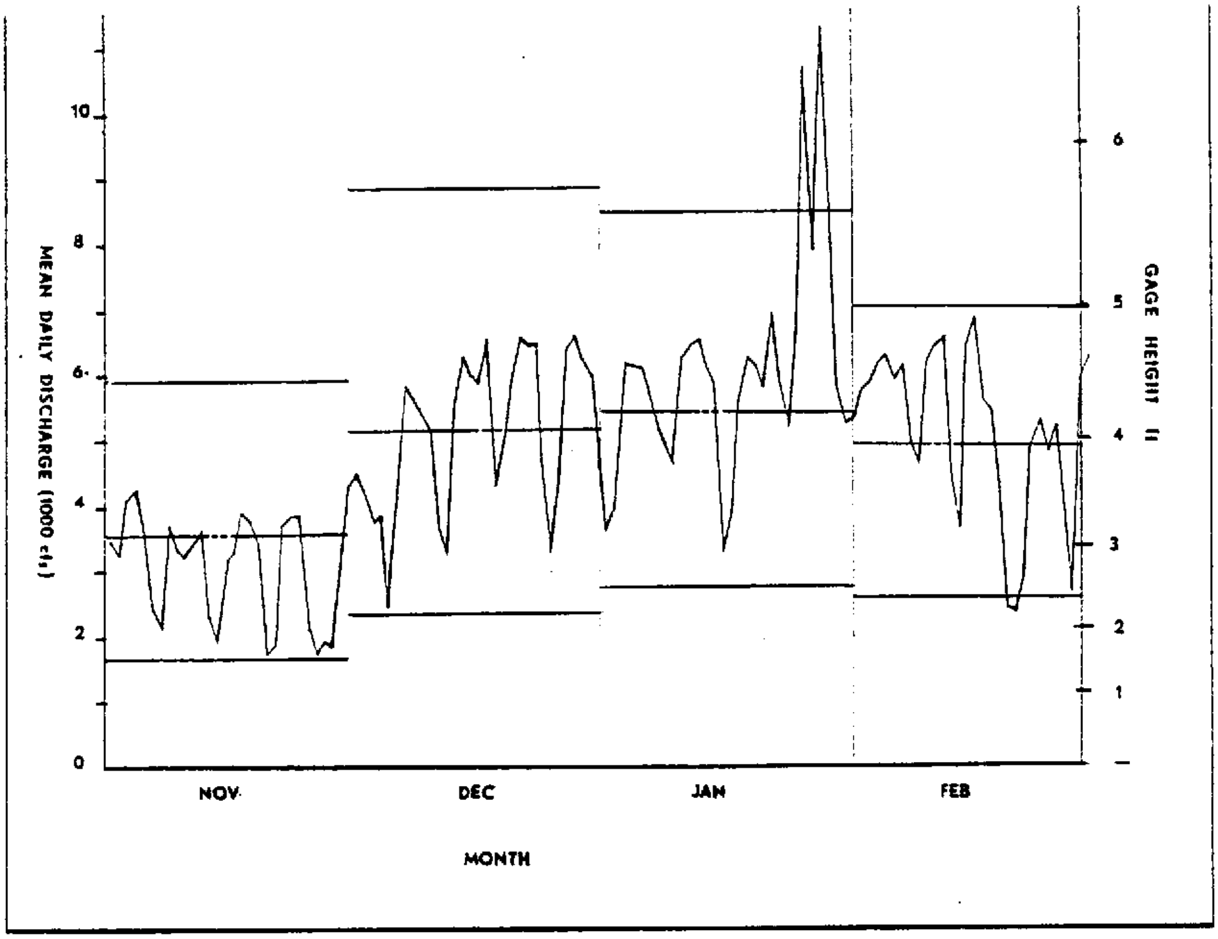
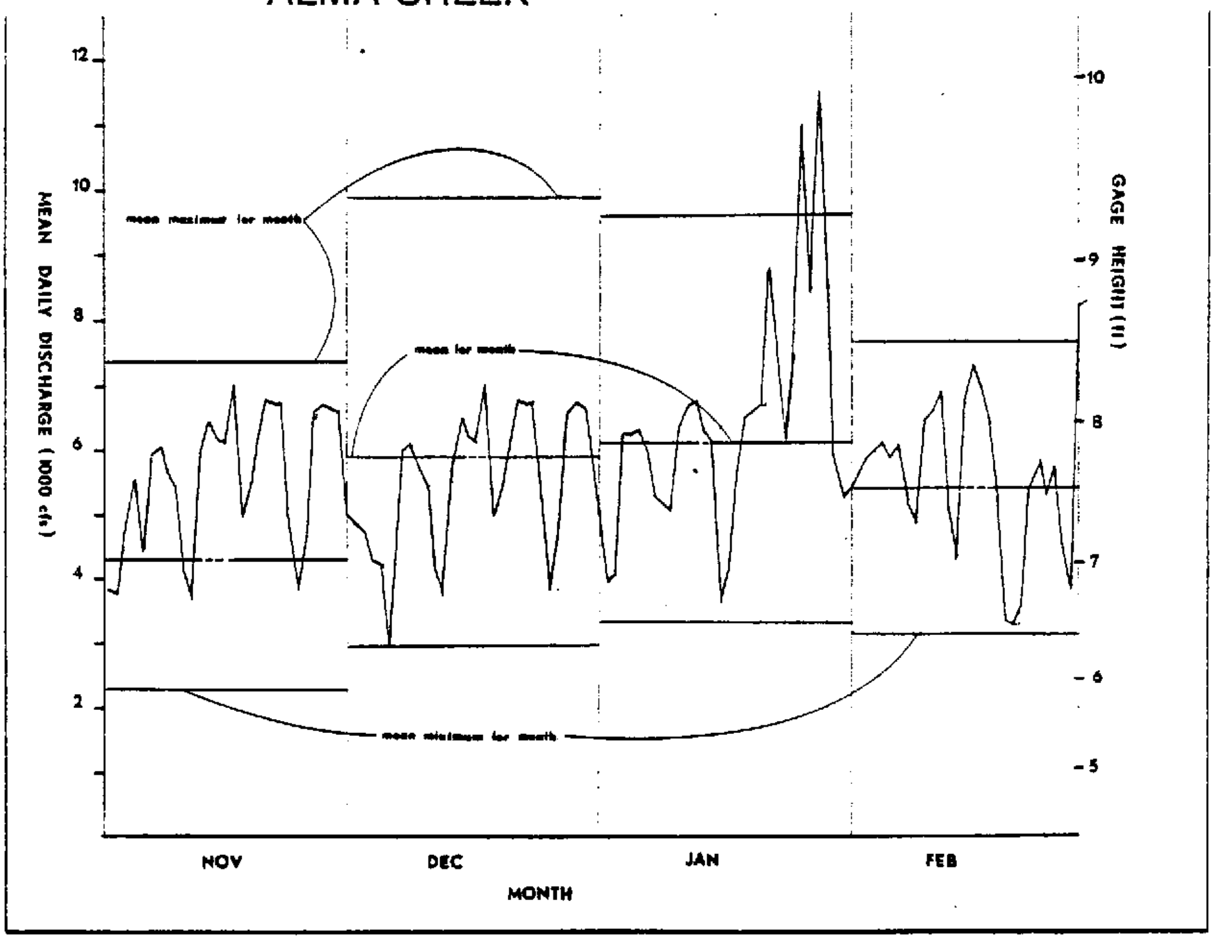


FIGURE 6 10-YEAR AVERAGE DAILY FLOW ABOVE ALMA CREEK



followed through December and into February of 1980. Flow conditions experienced during that time were recorded by USGS at their Alma Creek and Newhalem gages and by Seattle City Light at the Gorge Powerhouse. Actual discharge levels during the monitor period were compared to the average discharge levels from the 10-year record analysis.

The carcass drift study was completed under a higher than normal discharge condition. A mean daily discharge of 18,800 cfs was recorded at the Alma Creek gage on December 18, 1979. This condition has been equalled or exceeded only two percent of the 10-year time base. The average mean daily discharge for the entire month of December

Nevertheless, shorter periods within the month of December were reflective of average discharge conditions.

Slightly above average flow conditions existed between December 1 and December 16, prior to the extreme flood flows on the Skagit River. Table 5 relates the average, minimum and maximum discharge values for December 1979 to the 10-year average values for the month of December. The first 16 days of December approximate average flow conditions.

The flow conditions from December 17 through 20 were a unique event. Based on the monthly frequency curve, it could be considered a one time in 50 year event for a December high flow. Hourly readings obtained indicate a maximum hourly discharge of 23,000 cfs.

Table 5. High, low and mean discharge during December 1979 as compared to the 10-year average values.

Time	Mean Daily Discharge - Skagit River Above Alma Creek (USGS gage)		
	Low	Mean	High
10-year average (1968-78)	2,970	5,885	9,889
Dec. 1-16, 1979	4,230	6,821	10,000
Dec. 17-20, 1979	8,040	13,160	18,800
Dec. 21-31, 1979	4,500	5,885	7,180

Flows after December 20, 1979, were reduced and again very closely approximate average flow conditions.

Tagging Studies

The primary goal of the chum salmon carcass drift study was to determine whether or not dam construction at Copper Creek would diminish carcass availability below the construction site. More specifically, the following two hypotheses were analyzed:

H_o: (The "null hypothesis") No significant difference exists between the proportion of salmon carcasses drifting downstream from above the site of the proposed Copper Creek dam prior to dam construction and the proportion drifting downstream after dam construction.

H_a: (The "alternate hypothesis") A significant difference exists between the proportion of salmon carcasses drifting downstream from above the Copper Creek dam prior to dam construction and the proportion drifting downstream after dam construction.

If a statistically significant proportion of fish drifted downstream the "null hypothesis" would be rejected and the "alternate hypothesis" would be accepted.

The formula for determining statistical significant at $\frac{\alpha}{2} = .025$ (the 95% confidence level) is

$$\frac{\hat{P} - P}{\sqrt{\frac{\hat{P}\ (1 - \hat{P})}{n}}} > 1.96$$

Where $\hat{P}$ = the proportion of tagged fish drifting past the dam site prior to dam construction

P = the proportion of fish which would drift past the dam site after construction, which would be 0

n = the number of tagged fish released = 79.

The calculated $\hat{P}$ necessary to reject H_o is .05, which means that if 4 tagged fish drifted past the dam site, the null hypothesis would be rejected.

The study was designed specifically to answer the question of what effect dam construction would have on salmon carcass drift. The study also attempted to determine the mechanisms of carcass transport and the importance of carcass transport to eagle feeding areas downstream.

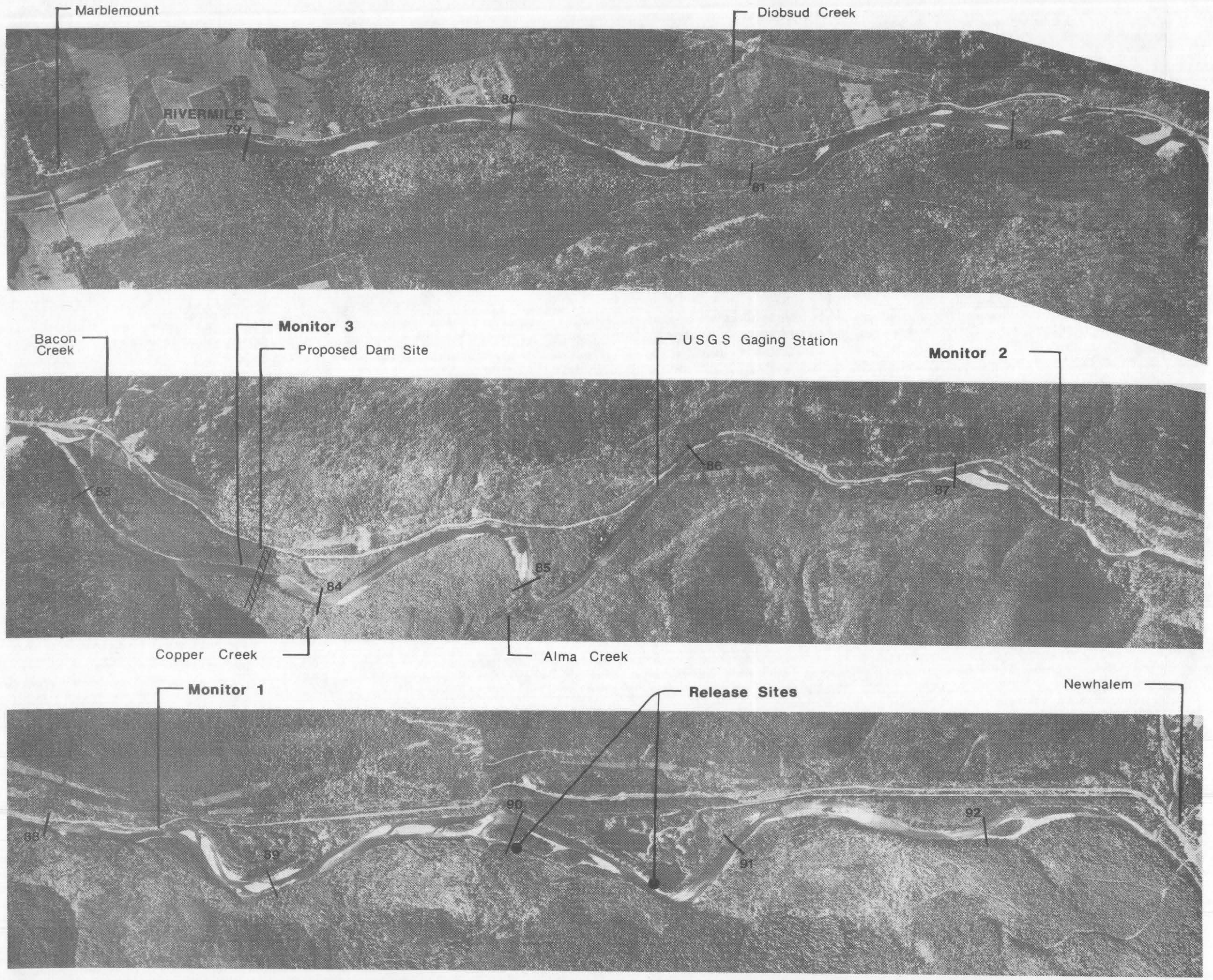
Previous studies of the Skagit River eagles indicated that chum salmon (Oncorhynchus keta) were the single most important food item during the mid-to-late winter (Servheen, 1975). The chum salmon is the main species spawning in the mainstem Skagit River in the proposed impoundment area that may provide carcasses for eagles to feed upon.

The study proposed to capture 200 spawned-out chum salmon at several major spawning sites above the proposed dam site, equip each one with a miniature radio transmitter, and monitor the movements and identify the final resting place of each. Radio telemetry equipment was specified by Seattle City Light Department as Smith-Root, Inc., P-40 transmitters, FDL-10 ER field data logger, and SR-40 receiver. Releases were to be staggered so that the numbers of tagged salmon would be a relatively constant proportion of the total number of salmon spawning in each area at any given time.

The 1979 chum salmon run was small, and fewer fish than expected were available for tagging. The Washington Department of Fisheries estimated that 430 adult chum salmon were present above Copper Creek. The fish concentrated at two spawning sites, so capture and release was restricted to these sites. Fish capture was further restricted by high water and turbidity which made it difficult to locate spawned-out fish. The combination of poor fish run and adverse river conditions made it possible to tag only 79 (76 live, 3 dead) fish in the area above Copper Creek (Table 6).

Capture and Tagging Techniques

Spawned-out fish were visually located near spawning sites at two locations. The first capture site was a side channel at RM 90.0 (Figure 7). The main entrance to the channel was blocked by a net so that no fish could escape. Both a gill net and a seine were used to trap the fish. At the second spawning site (RM 90.5) conditions were usually adequate to drift a gill net to capture the spawned-out salmon.



Skagit River Chum Salmon Carcass Drift Study

River Reach	River Mile
1	78.6-86.1
2	86.1-86.8
3	86.8-89.0
4	89.0-90.0
5	90.0-91.4

north

FIGURE 7
River Reaches

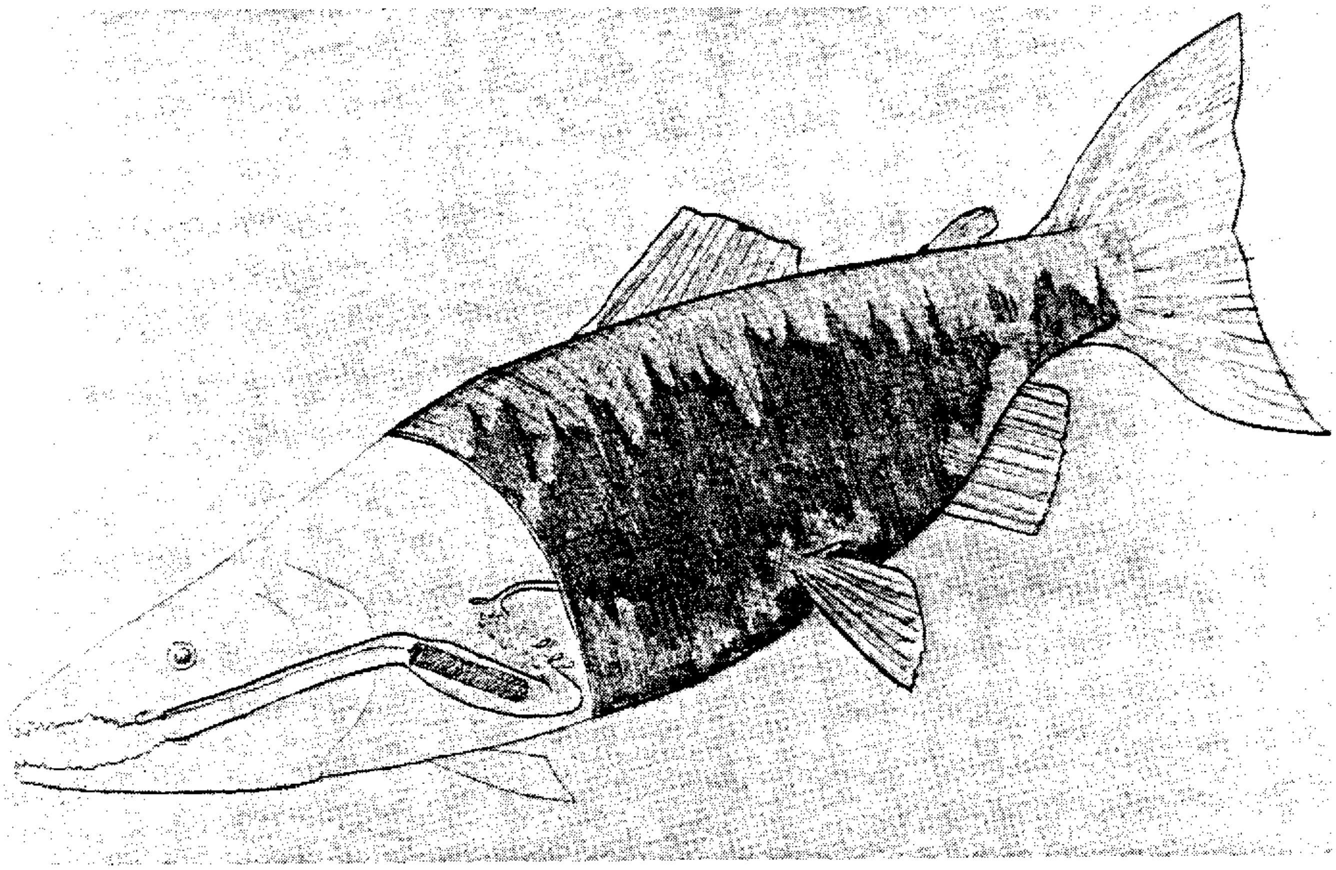
Release and Monitoring Sites

Table 6. Date, location and number of fish released.

Date	Site	Release	RM	Female	Male	Total
12/6/79	1	1	90.0	11	28	39
12/6/79	2	1	90.5	4	4	8
12/7/79	2	2	90.5	15	3	18
12/10/79	1	2	90.0	3	9	12
1/5/80	2	3	90.5	20	4	24
1/5/80	1	3	90.0	1	1	2
			TOTAL:	54	49	103

Each fish remained in the water until it could be measured and tagged. The fish were removed from the net as gently and quickly as possible and placed on a special stand for processing. Length and girth measurements were taken and the sex and spawning condition of each fish was recorded (Appendix B). A miniature radio transmitter, obtained through Seattle City Light, was gently pushed through the mouth into the stomach (Figure 8), and the wire antenna was fastened to the roof of the mouth with a fishhook to prevent the wire from damaging the gills and restricting respiration. The fish was then returned to the water and observed until it swam off. The total process took approximately 1-2 minutes. Live fish were tagged on December 6, 7, and 10 (Table 6). Studies by the National Marine Fisheries Service (Monan and Liscom, 1974a, 1974b, 1976) and other researchers have determined that radio tags of this type do not restrict movement or spawning of adult salmon. The use of radio tags allowed the fish to be tracked throughout the study area.

FIGURE 8 TAG INSERTION



In order to increase the sample size, compare live and dead fish drift and test different river flow conditions, 24 carcasses were released at Site 2 (RM 90.5) on January 5, 1980, after exhaustive searches failed to reveal any remaining spawning fish. The fish were collected from downstream sites and processed in the same manner as the live fish. Each had an orange streamer as well as a radio tag, and was placed in the water 15-30 feet from shore.

The radio tags (P-40 RF fish transmitters from Smith-Root, Inc.) were 19 mm in diameter and 9.0 cm long. Useful transmitting life was approximately 90 days, and the transmitting range was .25 - .50 miles.

The transmitters were tuned to 40.6 - 40.7 MH_z and five separate pulse codes were used to make a total of 50 individually identifiable frequency-pulse combinations. Tags were coded so that there were four replicates of each frequency-pulse combination. Only 26 of the possible combinations were utilized.

Tag Monitoring

Three multi-channel receivers with recording devices (Smith-Root, Inc. model FDL-10 ER) were used to detect and record any tags passing downstream at three locations. Selection of these monitor sites was based on local river hdyraulics, distance from fish release sites and river backeddy characteristics.

The hydraulic survey indicated several locations free of backeddies, obstructions and other features that might cause a carcass to become lodged or repeatedly carried past the monitor. None of these sites were in the upper two river reaches identified in the hydraulic study. Previous studies suggested carcasses would drift approximately one mile on the average (CH_2M/Hill, 1979a), indicating that few would drift out of the upper two river reaches. The first monitor was placed as near as possible downstream of the release areas (Figure 7) at RM 88.4. The second monitor was placed at RM 87.6 so that the drift time between the two monitor sites would be reduced. The intent was to provide data that could be correlated with hydraulic information in order to determine the manner in which a carcass is swept downstream. The third monitor was placed at the proposed dam site at RM 83.7, so that the "null hypothesis" could be tested.

It was originally specified that the antennas would be placed underwater so that only fish in the immediate vicinity would be recorded. After reviewing hydraulic and riverbed characteristics, it was determined that underwater antennas would be difficult to maintain. The antenna system designed for the study consisted of a single-strand copper-coated steel wire attached to a 3/16" diameter polypropylene rope strung 15-20 feet over the water from bank to bank. Thus it was necessary to find locations with large trees on opposite banks. The antennas did not extend the full distance across the river, but were cut to appropriate lengths for the wavelength of the transmitted signals. Each receiver was tuned to record only signals from tags within 100 feet of the antenna, thus limiting repetitive reception of the same tag as the signal fades in and out. This also reduced the chance of picking up signals from carcasses which snagged and remained nearby.

The stationary monitors provided a continuous record of fish passage past three points on the river. They monitored all ten channels simultaneously and recorded the channel and pulse rate of any transmission within range.

The recorders were checked daily during most of the study and were checked at least twice each week. The tapes were examined and any signals recorded were transcribed along with the time the signal was received (Appendix C). Simultaneous signals on the same channel were never encountered. Occasionally the monitors malfunctioned but were usually discovered and corrected within a few hours. Equipment malfunctions were related to battery problems and difficulties in the recording device. False signals were sometimes recorded, and were apparently related to two-way radios and tags lodged just out of normal receiving range. These signals would fade in and out, sometimes every few hours. These problems add a degree of uncertainty to the data collected.

A mobile tracking unit (Smith-Root Model RF-40) with battery pack and directional loop antenna was used whenever possible to verify tag movements. The unit was used in a vehicle, boat, or by foot. Individual tags could be monitored from a distance, and techniques were developed to locate tags to within a few feet.

Tag monitoring began on December 6 when the first fish were released. The first signals were recorded by Monitor 1 (RM 88.4) about 7 hours later. Monitors 1 and 3 remained in place until February 12, 1980, when the study ended. Monitor 2 (RM 87.6) was removed on December 19 after floodwaters destroyed the antenna. The overhead antenna for Monitor 3 (RM 83.5) was also destroyed on December 18 but was replaced with a temporary antenna until January 4. At that time another overhead antenna was installed. Data recorded by Monitors 2 and 3 during and immediately after the flood are incomplete. The mobile receiver was utilized extensively to determine how many tags had passed Copper Creek during this period and where the tags finally stopped.

Results

Live tagged fish were released at two sites on three separate days for a total of four releases (see Table 6). Downstream movement of tagged fish began within 24 hours and continued for several weeks, although most movement occurred within two weeks. In many cases it was possible to plot the movement of individual tags, as shown in Figure 9 and Appendix D. Plotting fish drift in this manner was instrumental in

FIGURE 9 PLOT OF INDIVIDUAL FISH DRIFT

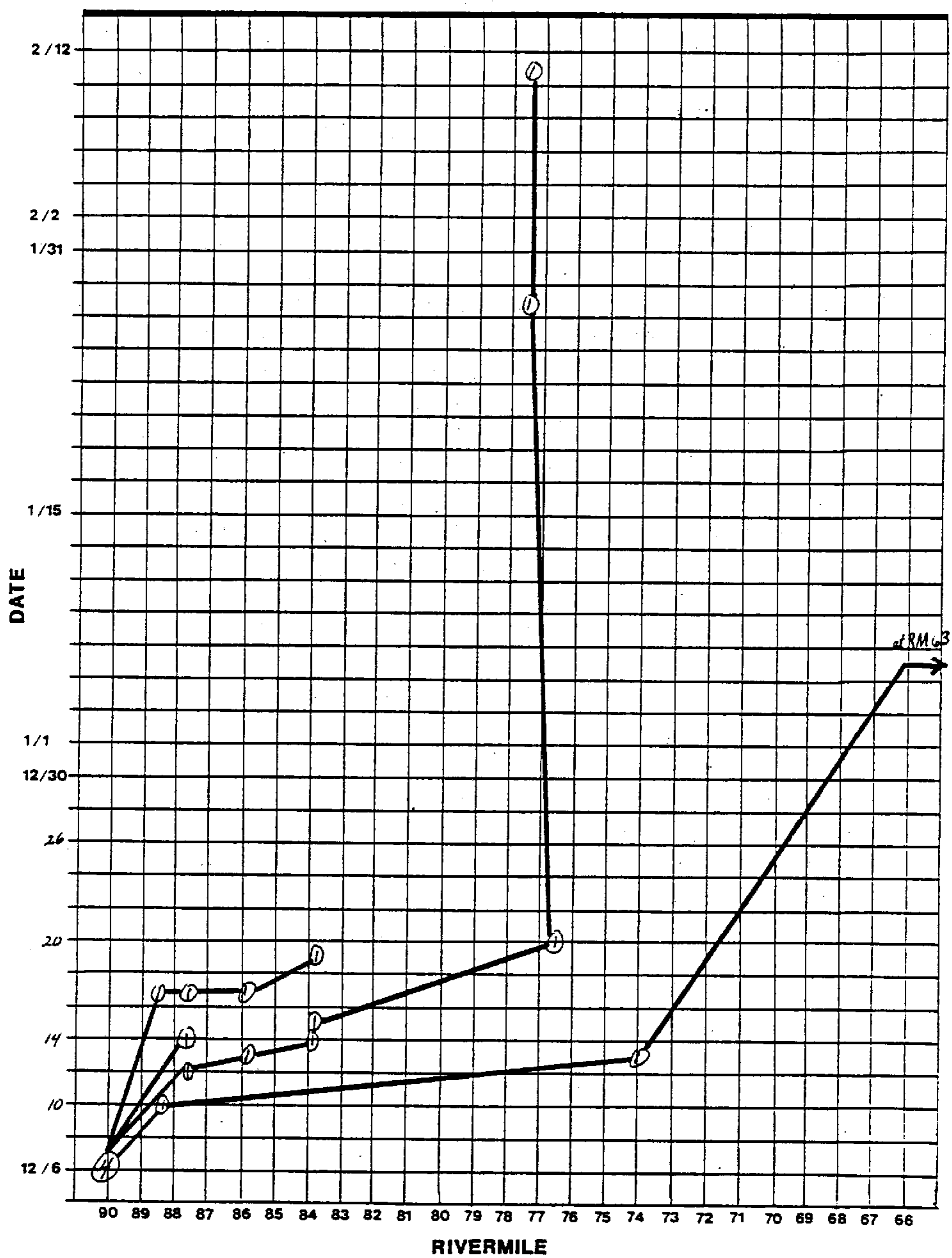
Recorded Locations of Tags

Release Date 12-6-79

Release Location R.M. 90.0

Channel 5

Pulse Rate 4



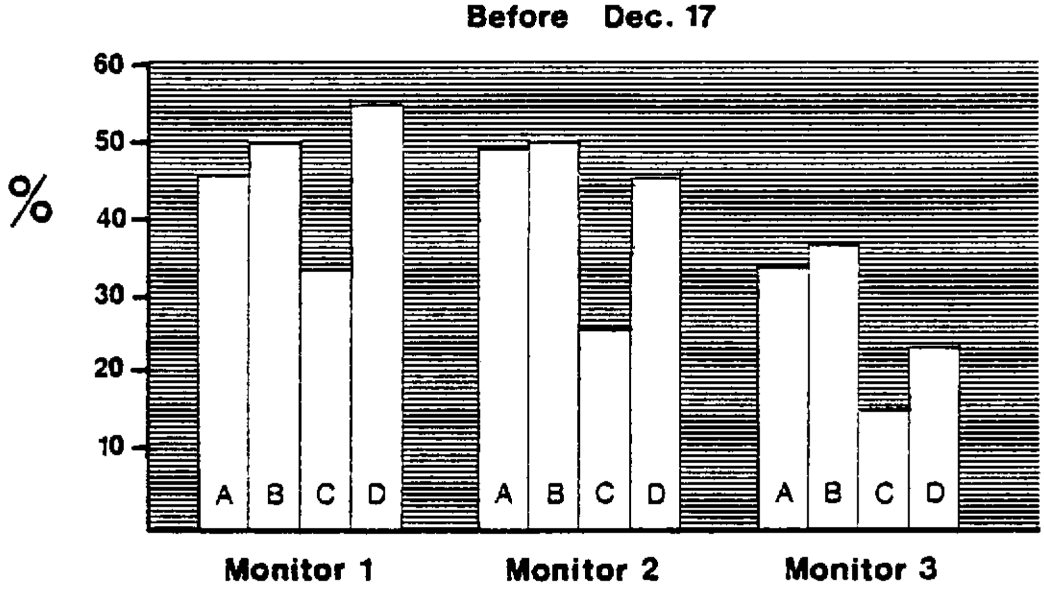
detecting false signals and determining equipment problems.

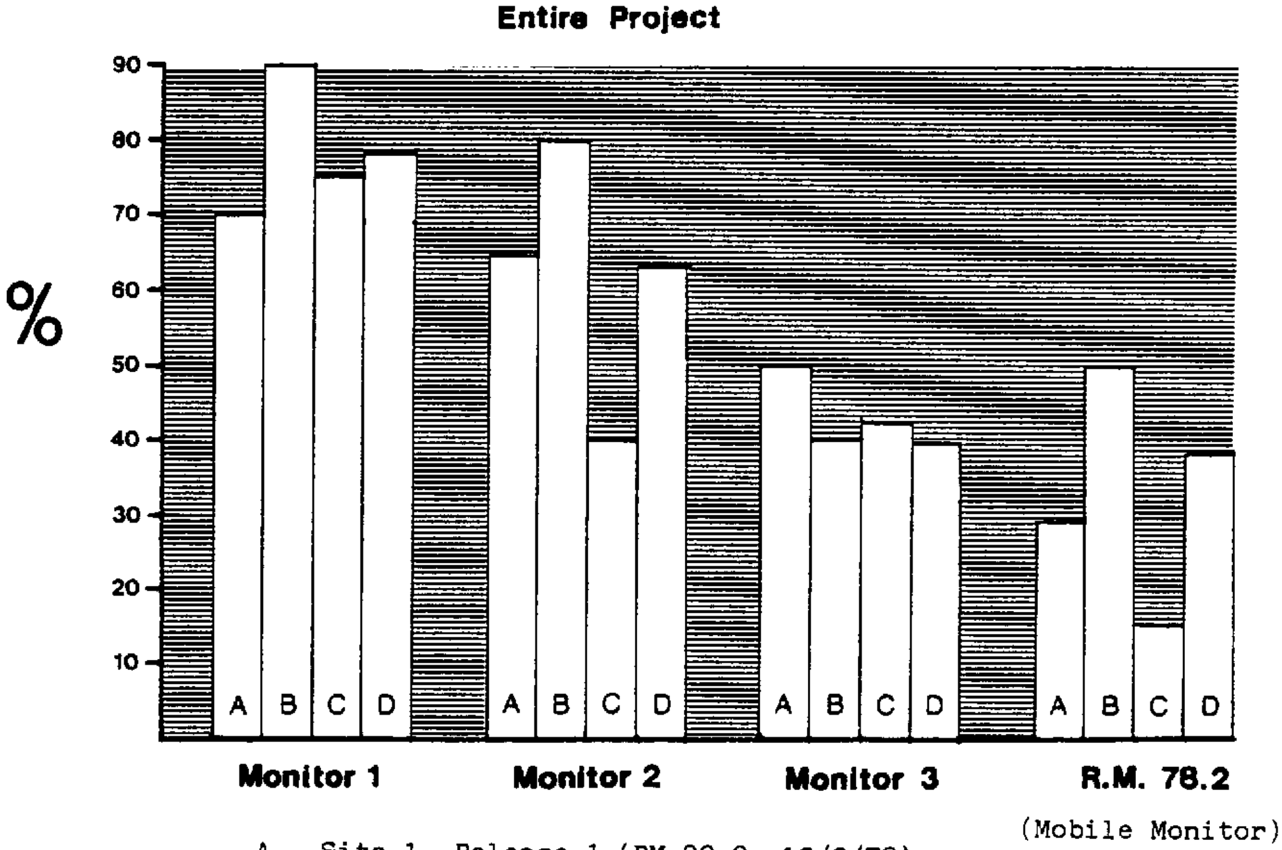
Data from the four releases of live fish were analyzed separately and combined for overall analysis. Streamflow conditions from December 6-16 were slightly above the 1968-78 average. Flood conditions prevailed from December 17-20, and presumably biased the drift data by sweeping an above-normal number of carcasses downstream. Therefore the most meaningful results are those obtained before the flood. During the period before the flood the percentage of fish drifting past Monitor 1 ranged from 33% (Site 1, Release 2) to 55% (Site 2, Release 2) as shown in Figure 10. Overall, 47% of the fish moved past Monitor 1 before December 17. Records from Monitor 2 showed a similar pattern but were slightly below Monitor 1. At the Copper Creek monitor (Monitor 3) 29% of the tags had been recorded by December 17.

The drift which occurred before the flood was more than 50% of the total drift recorded before the end of the study in February, as shown in Figure 11. This figure shows differences in the number of fish which drifted, especially in the upper river. Fewer tagged carcasses drifted than live fish in the upper areas, but a higher percentage of those which did drift arrived at RM 81 (near Diobsud Creek) or beyond. There was no significant difference between the proportion of carcasses and live fish drifting to RM 81 or beyond either before or after the flood.

By the end of the study at least 52% of the tagged fish were located below Copper Creek. This figure was arrived at by combining data from Monitor 3 and the mobile monitor. Equipment problems and high water made it impossible to determine the exact number. Boat surveys

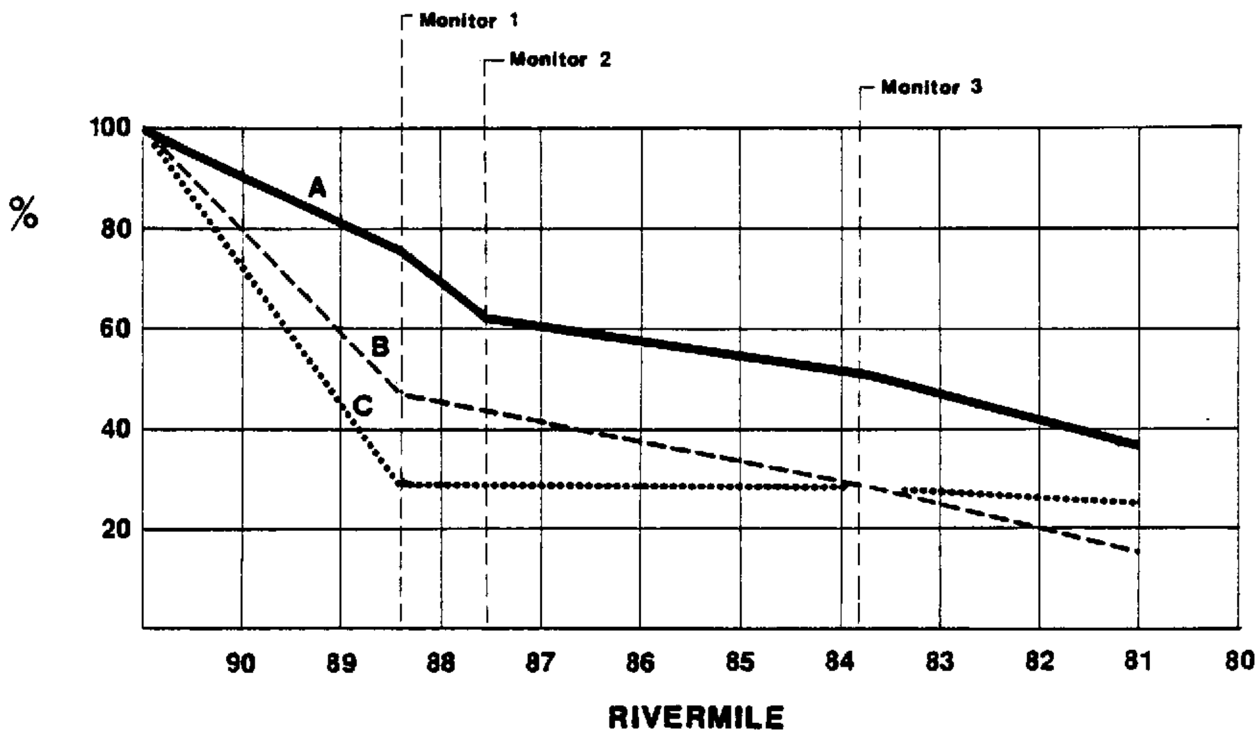
FIGURE 10 PERCENTAGE DRIFT PAST MONITORS





A - Site 1, Release 1 (RM 90.0, 12/6/79)
B - Site 2, Release 1 (RM 90.5, 12/6/79)
C - Site 1, Release 2 (RM 90.0, 12/11/79)
D - Site 2, Release 2 (RM 90.5, 12/7/79)

FIGURE 11 PERCENTAGE PASSING AT DIFFERENT TIMES



A - Final Total (12/6/79 - 2/4/80)

B - Before Flood Total (12/6 - 12/17/79)

C - Carcasses Total (1/5 - 2/14/80)

after the flood located more than 25% of the tags below the Marblemount Bridge. In most cases the exact location of each tag was narrowed to within a 30-50 foot radius. Only three tags from live fish were actually recovered. Other tags were located in deep water, buried, or out of sight of the survey crew at the time they were recorded.

Drift of tagged carcasses differed from that of the tagged spawners. In general, a carcass either began to drift immediately or did not drift past Monitor 1. Of the 24 carcasses released on January 5, 12.5% passed Monitor 1 within 12 hours, and an additional 8% passed in the next 24 hours. No more fish were recorded at Monitor 1 until January 25, and in mid-February the tally reached 29.2%.

At Copper Creek (Monitor 3), 12.5% of the carcasses were recorded within 5 days and 4% (1 tag) passed unrecorded. When the study was terminated, 29.2% of the carcasses had passed Copper Creek. This suggests that some carcasses selected for tagging differed in their susceptibility to drifting. Because of this, the carcass release was not included in the test of the "null hypothesis."

The null hypothesis states that dam construction would not reduce the number of chum salmon drifting below Copper Creek. Based on a sample size of 79 tagged fish and 52% passing the dam site, the null hypothesis was rejected. The dam would significantly reduce carcass drift below Copper Creek. The 95% confidence interval on the proportion of fish drifting past the dam site is 41% - 63%. That is, the exact proportion is probably not 52%, but lies between 41% and 63%. Because the flood affected the final tally, however, there is a degree of uncertainty in this data that cannot be statistically tested.

Carcass Transport Mechanisms

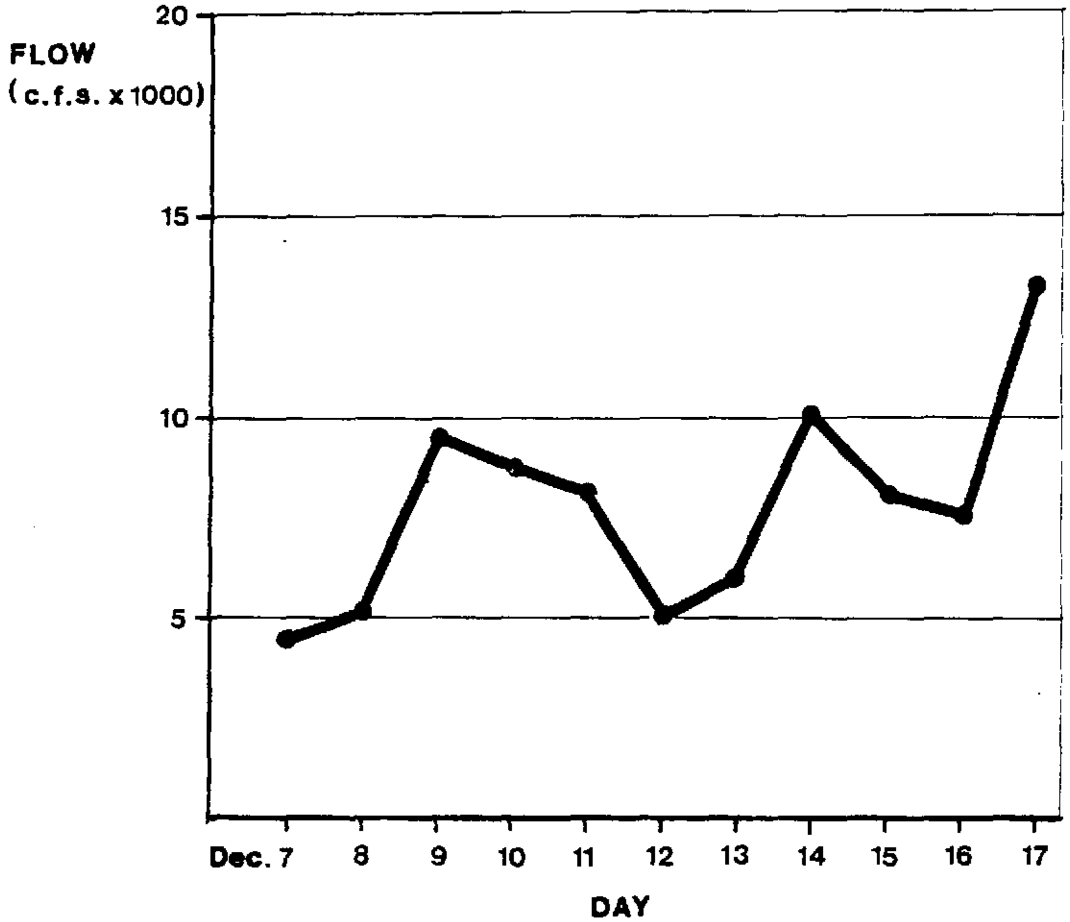
Aspects of river hydraulics were tested against monitor data to identify a numerical algorithm to relate carcass movement to river stage. Average hourly discharge, discharge-stream reach algorithms and average daily discharge were reviewed. During the data review, it was noticed that more tagged fish passed the monitors on days when river flow was high. During the 11 day period before the flood the average daily discharge at Alma Creek was compared to the number of fish recorded daily at Monitor 1 (Figure 12). Linear regression analysis confirmed that the number of fish recorded was correlated with river flow, but that the statistical correlation held true only on a daily and not hourly basis. The correlation coefficient (*r*) which is a measurement of how well the relationship holds, was .82 for Monitor 1 and .78 for Monitor 2 (Table 7). The *r* value for Monitor 3 was only .57, indicating the relationship is not as close. At greater transport distances the complexity of hydraulic factors increases, decreasing the usefulness of simple predictors. The best hydraulic algorithm for predicting carcass drift is average daily discharge.

Table 7. Linear regression analysis of daily fish drift and mean daily discharge at the Alma Creek gaging station.

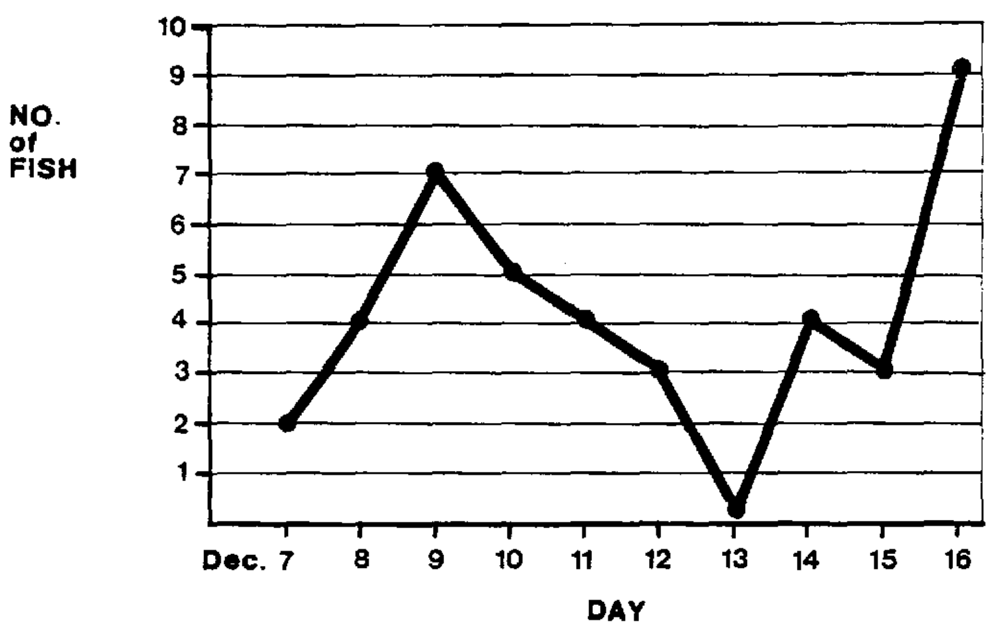
	Correlation Coefficient (r)	Slope (m)	Computed X Intercept	95% Confidence Limits
Monitor 1	.82	.000754	2755.0 cfs	0,6284
Monitor 2	.78	.000700	2928.7 cfs	0,6478
Monitor 3	.57	.000644	3800.3 cfs	--

FIGURE 12 COMPARISON OF FLOW TO NUMBER PASSING

Flow at Alma Creek Gaging Station



Fish Passing Monitor 1



The linear relationship was plotted (Figure 13) and the minimum average daily flow required to move fish downstream (the X intercept) was computed. This value was 2755 cfs for Monitor 1, meaning that a small percentage of fish will begin moving above that flow. This is lower than the lowest daily recorded December flow from 1968 - 1978, and far below average, indicating that at least a small degree of chum salmon drift occurs every year. The 95% confidence interval (0 - 6284 cfs), however, indicates that the minimum flow required to move a carcass may be considerably above or below the computed value. Also, because flows were above 4000 cfs except for a few hours during the study, it is impossible to tell if the linear relationship holds for low flow conditions.

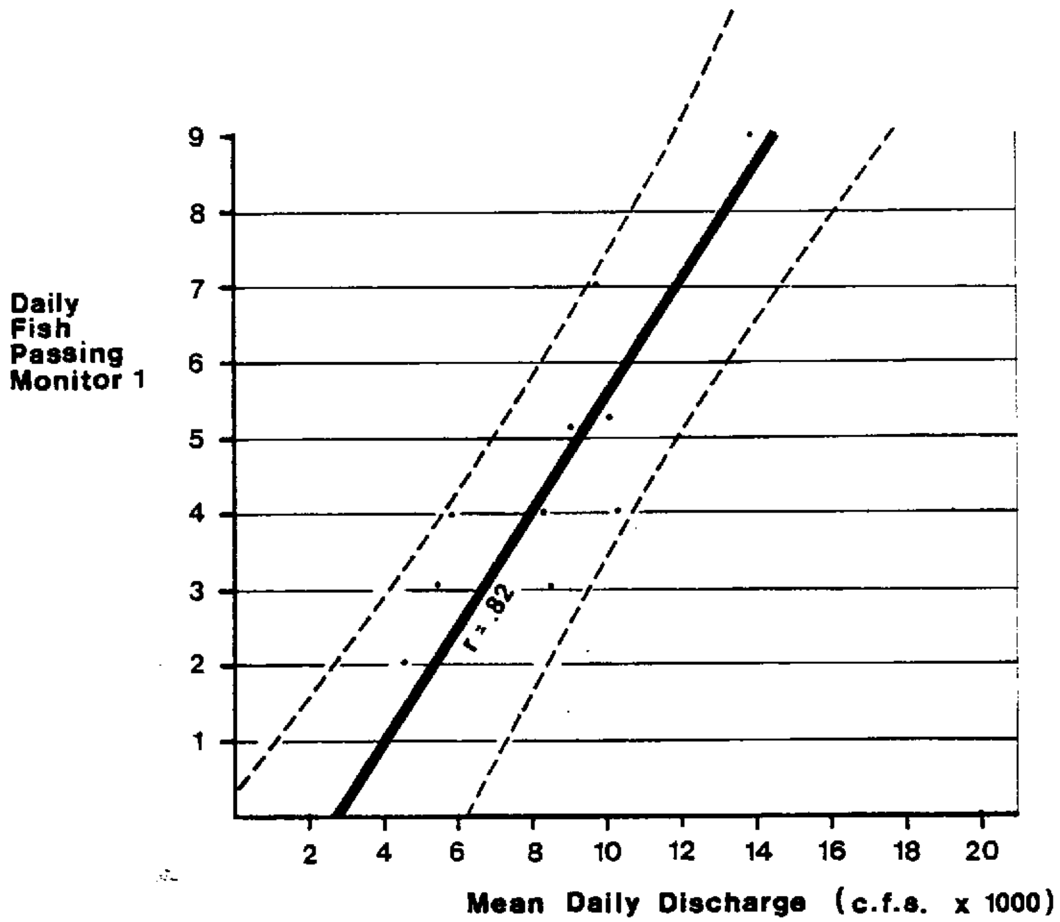
Multiple regression analysis was also performed and included average daily flow, daily tag recordings, and the number of days after the fish were released. In this analysis time also proved to be a significant variable, raising the r value from .82 to .90 for Monitor 1 (Table 8). River flow was the more important factor, but more fish moved a few days after tagging. This would be expected because vitality decreases with time after spawning and the fish grow weaker and die, usually within 7 - 10 days (Scott and Crossman, 1973).

Table 8. Multiple regression equations of fish drift, discharge, and time.

		Correlation Coefficient (r)
Monitor 1	$y = .001\ (X_1) - .33\ (X_2) - 2.19$	.90
Monitor 2	$y = .0009\ (X_1) - .31\ (X_2) - 2.18$	.85
Monitor 3	$y = .0005\ (X_1) + .20\ (X_2) - 2.38$	.59

y = number of fish passing daily
X_1 = mean daily discharge (cfs)
X_2 = number of days after release

FIGURE 13 PLOTTED LINEAR REGRESSION



Although more fish move with higher flows there is not a significant correlation between drift velocity and river flow (r = .52). Also, there was no statistical difference between the time to reach each of the three monitors. This is probably due to several factors, including fish vitality and behavior, river hydraulics and the distance between monitors. Apparently the tendency of post-spawned chum salmon to swim against the current or become lodged or snagged is greater than the tendency to float with the river current. These factors also made it impossible to determine how far a carcass drifts under given flow conditions. A major complicating factor is that river flow fluctuations occurred hourly with daily fluctuations ranging from about 200 cfs on December 11 to 15,000 cfs on December 17.

Carcass Distribution

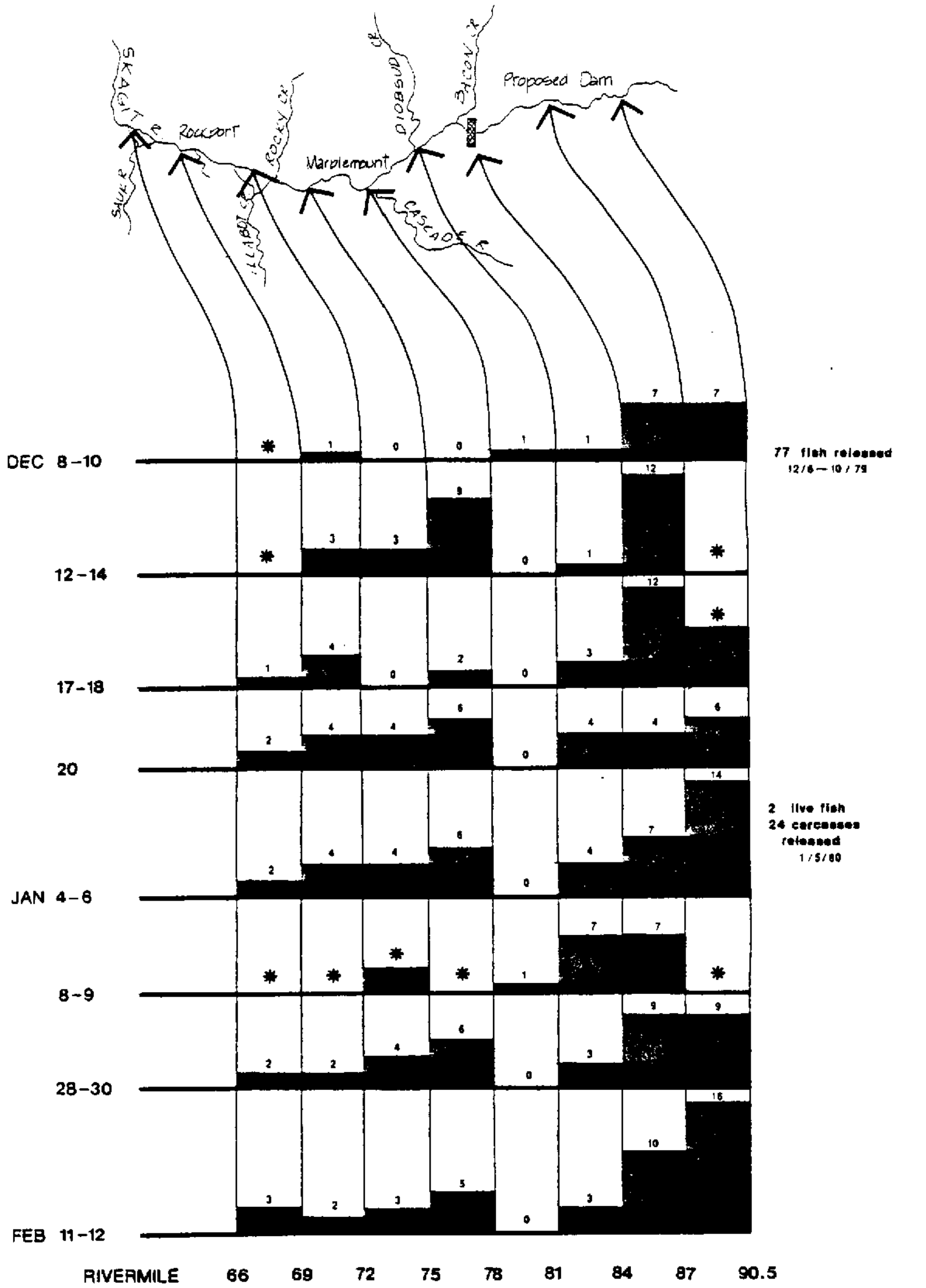
On December 13 a tag survey from Copper Creek to Rockport was conducted with the mobile monitor. To that time 25 tags had been recorded at Monitor 1, 23 at Monitor 2, and 7 at Monitor 3. During the survey 13 tags were located below Monitor 3. The discrepancy is due to equipment malfunction early in the study. Of the 13 tags, 5 were located in or near Marblemount Slough (RM 77.5), and 6 were between Marblemount and Sutter Creek (RM 71) within the Bald Eagle Natural Area.

A similar survey from RM 92.5 (near Goodell Creek) to the Sauk River (RM 67) was conducted on December 20. This survey, undertaken to ascertain the effects of the flood on carcass drift, encompassed the entire study area. Only 30 tags (39%) were recorded, indicating the remainder were no longer transmitting or had been swept farther downstream. Ten tags were above Copper Creek, mostly near the release sites or the river bend near Alma Creek. Because 19 tags had not been recorded by Monitor 1, the 9 tags which were unaccounted for must have stopped transmitting or been buried too deep for the signals to be detected. Similarly, 17 tags were lost between Monitor 1 and Monitor 3. In the turbulent floodwaters tags could have become dislodged from fish and been battered or buried by rocks and debris moving down the river. Results of tag surveys are summarized in Figure 14.

Tag recovery efforts were begun in January to determine ultimate fate and distribution of carcasses. Due to the relatively low number of tags still transmitting and the fact that no carcasses could be visually located, City Light directed that effort be expended to determine more precisely the number of tags still transmitting and subsequent movement of these tags.

Surveys for tags in the study area were conducted on January 4 - 6 (Newhalem to Concrete); January 9 (Copper Creek to Rockport); January 16 (RM 90.5 to RM 87.0); January 28-30 (RM 90.5 to Sauk River); February 11-12 (RM 90.5 to Sauk River).

FIGURE 14 MAP WITH TAG LOCATIONS



Conclusions and Discussion

The major conclusion of the carcass drift study is that construction of Copper Creek Dam would significantly reduce the number of fish drifting downstream past the dam. It is not possible from this study to determine the exact magnitude of the loss or the significance to the wintering eagle population, but several relationships have been identified.

This study mainly addressed the secondary impact of dam construction on downstream carcass drift. More than 50% of the fish tagged above Copper Creek in this study ultimately settled below the proposed dam site. Nearly every fish which moved past Copper Creek drifted to Marblemount or beyond. Because of the unusual hydraulic conditions during the study, however, this may not be typical of carcass drift and distribution.

A significant relationship between drift of tagged fish and river stage was observed. The length of time after release also affected the relationship with drift, primarily because the fish died a few days after tagging, making them unable to maintain their position in the river. The drift-stage relationship is critical, however, because it indicates that a small percentage of carcasses will drift under quite low flow conditions.

Even in a relatively dry year some carcasses would move downstream. The study also determined that more fish move with high flows. The high flows experienced during the study moved a higher proportion of tagged fish downstream. Analysis of carcass drift data excluding the flood related data provided insight to "normal" conditions. During the preflood period roughly 30% of the tags moved past Copper Creek. The

95% confidence interval on this figure is 18 - 40%, indicating that at least 18% of the fish which spawned above Copper Creek would move past the proposed dam site under average flow conditions.

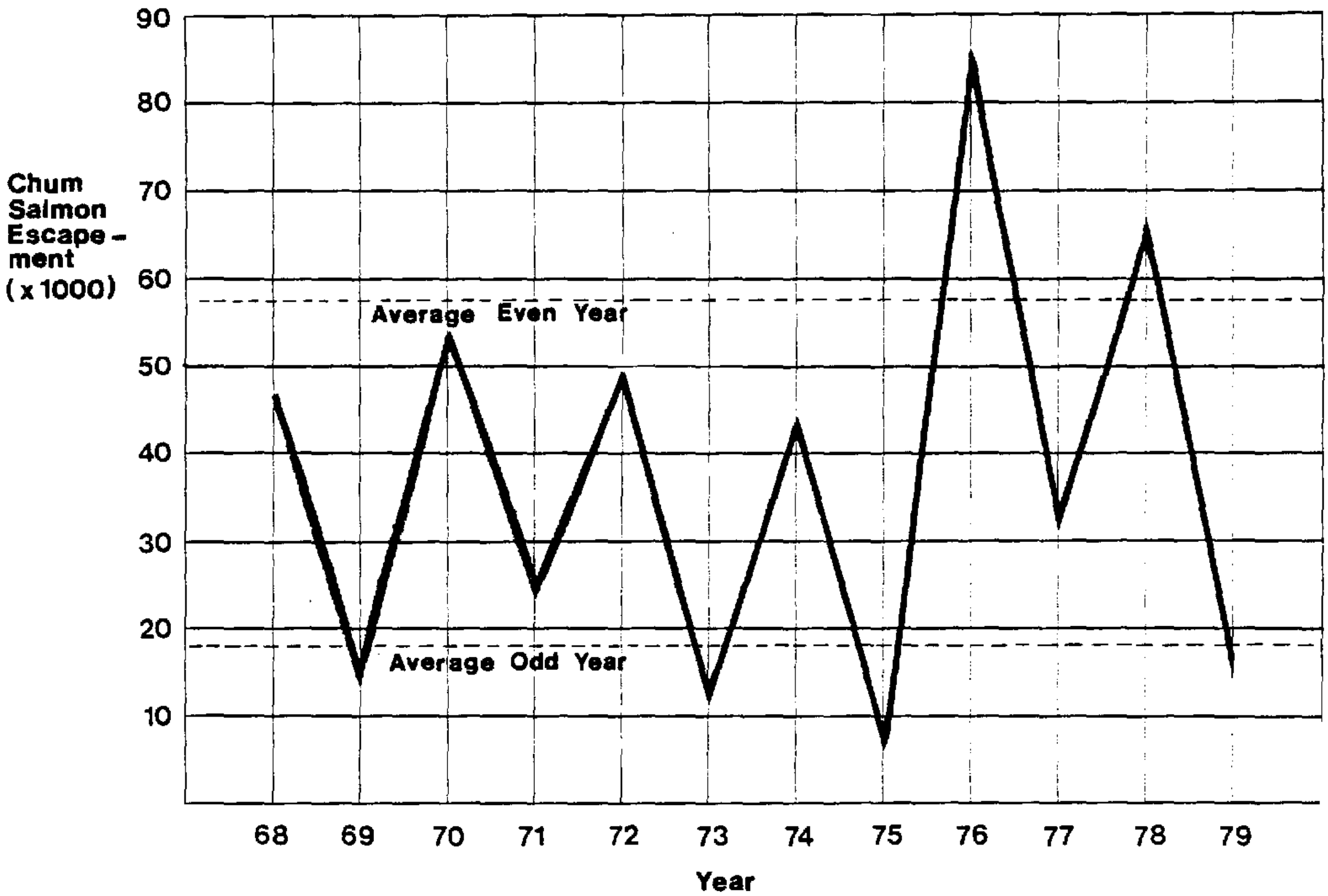
Although the question of statistical significance of carcass drift has been answered, the biological significance of carcasses drifting past the proposed dam is more difficult to assess.

Biological Significance of Carcass Drift

The number of spawning chum salmon in the Skagit River varies greatly from year to year. In odd-numbered years, when adult pink salmon are present in large numbers, fewer chum salmon return to the river. This fluctuation is shown graphically in Figure 15. The magnitude of these fluctuations indicates that run size may be a major determinant of the availability of carcasses, and there seems to be a relationship between run size (escapement) and the number of eagles observed (Figure 16). The proportion of chum salmon carcasses which become available to eagles is affected by the hydraulic conditions during and after the spawning period. In flood years a large percentage of the carcasses are washed downstream instead of being deposited on gravel bars. In years of low flow fluctuation the majority of the carcasses will stay in the immediate vicinity of spawning areas. Both of these factors influence the importance of fish above Copper Creek, which constitute 2 - 10% of the total chum salmon run (Washington Department of Fisheries data).

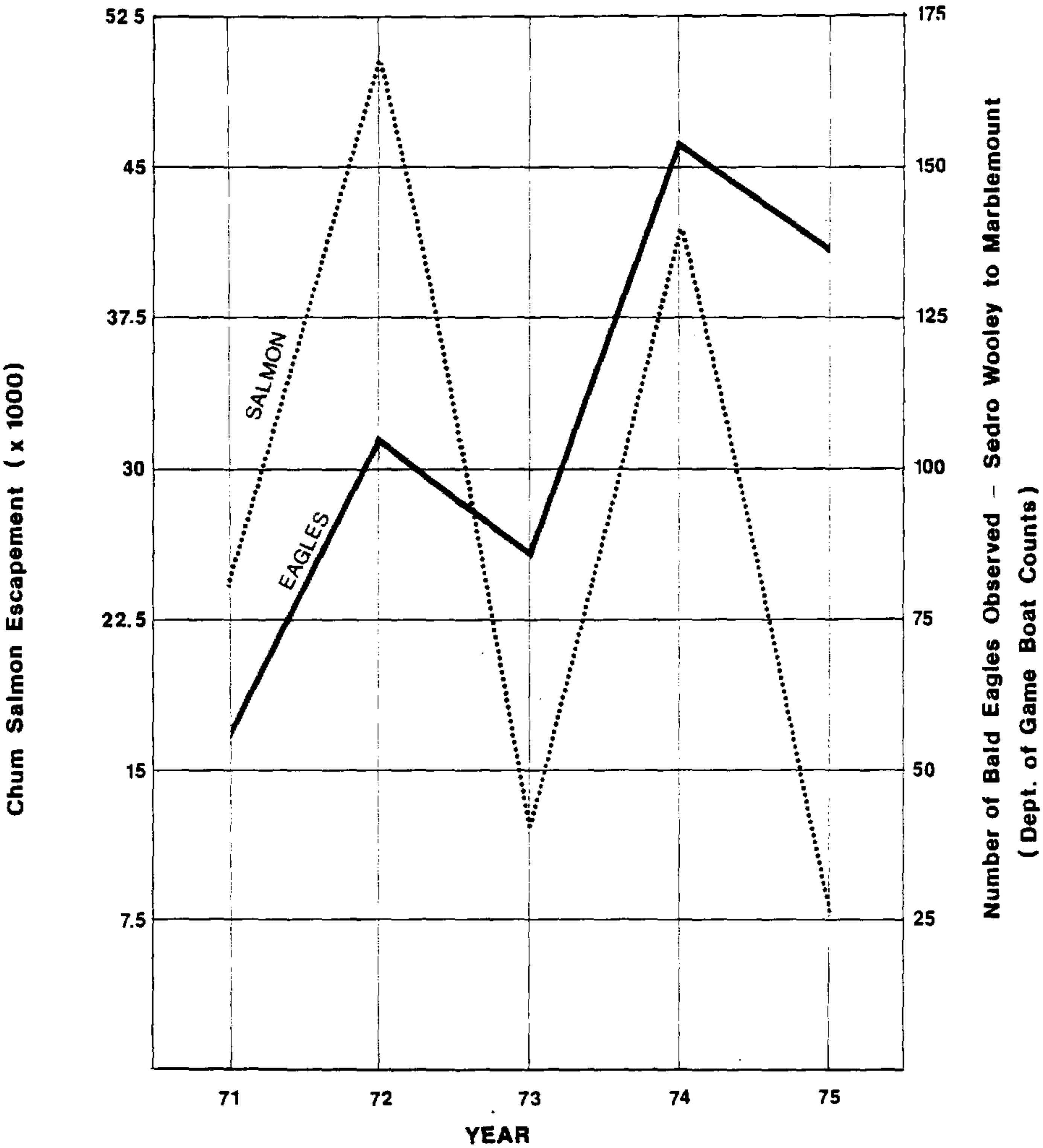
In years of large runs there is often an over-abundance of carcasses in the primary eagle feeding areas, and any contribution from above Copper Creek would probably not add significantly to eagle survival. If high flows wash most carcasses downstream, as occurred during

FIGURE 15 CHUM SALMON ESCAPEMENT 1968-1979



(Source: Washington Department of Fisheries)

FIGURE 16 CHUM SALMON ESCAPEMENT AND NUMBER OF EAGLES OBSERVED 1971-1975



this study, very few carcasses would remain near spawning grounds. In this case a significant portion of the carcasses present in the Bald Eagle Preserve may originate from spawning areas above Copper Creek. Although it was not possible to determine how many carcasses were available to the eagles, the biomass of fish which drifted past the dam site was estimated. Considering that a minimum of 18% of the spawning chum salmon above Copper Creek were washed downstream, and that the run size was 430 fish in that area (Washington Department of Fish), it is estimated that 77 fish drifted past Copper Creek. Using an average weight of 8.5 pounds per fish, this indicates that over 650 pounds of fish were swept below the dam before the flood. An eagle consumes approximately 5 pounds of fish per week (G. Hunt, personal communication), so at least 130 eagles could have been supported for one week by those carcasses. If 52% of the fish were swept downstream, as indicated by the final tally of tags drifting past Copper Creek, about 1900 pounds of fish were swept downstream. This could have fed 380 eagles for a week if all fish were deposited on gravel bars.

Projected average odd and even year chum salmon carcass drift is presented in Table 9. Based on the drift study results, construction of Copper Creek Dam could eliminate 100-3000 salmon carcasses from drifting past the dam site.

Table 9. Projected potential magnitude of chum salmon carcass drift in odd and even years.

	Total	Spawning in Study Area*	Carcass Drift** Past Dam Site
Average even year escapement	57,100	1710 - 5710	342 - 2855
Average odd year escapement	18,000	540 - 1800	108 - 900

* 3 - 10% of total escapement
**20 - 50% of total spawners in study area

The carcass drift study anticipated locating tagged carcasses on gravel bars downstream and comparing the numbers to the total number of carcasses present, thus indicating the relative importance of drift to carcass availability. Carcasses were to be located during gravel bar censuses during the eagle feeding studies and tagged carcasses were to be recovered during the drift studies. Bar surveys conducted by Biosystems Analysis, Inc., located very few available fish and no tagged fish.

Surveys using the mobile monitor were conducted to determine the locations of tagged fish. Those tagged fish that were recovered were found either buried under silt and debris or in deep water where eagles could not reach them. These observations suggest that few drifting carcasses became available to foraging eagles under the study conditions. Thus, estimates of fish biomass lost due to dam construction may not be directly applicable to eagle population maintenance under high flow fluctuation conditions.

The lack of visual observation of tagged fish may be important in another way. If it is an accurate indication that few fish become available to eagles once they begin to drift, then carcass drift is detrimental to eagles. Loss of protected areas due to inundation could be more harmful than disruption of downstream drift. Drift studies under more "average" conditions could be designed to determine the origin of carcasses which become available to eagles and thus, more directly assess the impact of carcass drift on the food supply of bald eagles wintering on the Skagit River.

Primary Impacts of Dam Construction

The primary impact of dam construction would be the loss of habitat for salmon and eagles above Copper Creek. The construction and operation would eliminate all salmon use of the area above the dam site as well as carcass drift past the dam site. Observations made during the carcass drift study indicate that carcasses which remained above Copper Creek provided a significant food source to eagles foraging in the study area, particularly late in the season (Biosystems Analysis, Inc., 1980). Although few fish carcasses of any species were sighted below Copper Creek, fish were consistently observed at two areas above Copper Creek. These two sites between RM 90.0 and RM 88.5 were used for spawning by coho salmon. Feeding bald eagles and fish remains were frequently observed indicating that these fish were utilized considerably. Inundation of these areas (RM 90 and RM 88.5) by dam construction would eliminate those upstream salmonid food sources. During years of high flows these areas may provide critical eagle nutrition which could not be obtained elsewhere.

The interaction between streamflow, chum salmon escapement and carcass availability has been observed previously. High flows have been previously documented to remove salmon carcasses from eagle feeding bars (Nature Conservancy, 1977; Wiley, 1978, and Servheen, 1975). The 1979-80 winter conditions of low chum salmon escapement and high flows resulted in very low carcass availability to eagles. Years of high escapement and little flow fluctuation result in a direct relationship between carcass abundance and eagle abundance (Servheen, 1975; and Wiley, 1978).

Low carcass availability appears to result in eagles ranging widely and utilizing other food sources including coho salmon and carrion (Biosystems Analysis, Inc., 1980; Servheen, 1975). High carcass availability appears to result in eagles concentrating in the Bald Eagle

Preserve area and utilizing the closely available salmon carcasses (Servheen, 1975).

Interactions between chum salmon escapement levels and flow fluctuation levels could have substantial implications on the importance of the resources in the Copper Creek impoundment area (Table 10).

Table 10. Hypothetical relationships between flow fluctuation - chum salmon escapement combinations and carcass distribution and eagle response.

Flow Fluctuation	Chum Salmon Escapement	Carcass Distribution	Eagle Response
High	High	many carcasses, most carried downstream	?
Low	High	many carcasses, most remain near spawning sites	use concentrated in Bald Eagle Natural Area
High	Low	few carcasses, all carried downstream	use upriver area for coho feeding
Low	Low	few carcasses, most remain near spawning sites	use upriver area for chum and coho feeding

Bibliography

Biosystems Analysis, Inc. 1980. The Impact of the Proposed Copper Creek Dam on the Skagit River's Wintering Population of Bald Eagles. Executive Summary. 11 p.

CH_2M/Hill. 1979a. Copper Creek Environmental Assessment Final Environmental Report. 261 p.

_________. 1979b. Copper Creek Environmental Assessment. Responses to Public Comments on Draft Environmental Report. Technical Report 18.

Essbach, Alban R., and R. Maxwell. 1969. A collapsable fish holding cage. Trans. Amer. Fish. Soc. 98:337-338.

Graf, Walter H. 1971. Hydraulics of Sediment Transport. McGraw-Hill. New York. p. 96.

Gray, Robert H., and J.M. Haynes. 1979. Spawning migration of adult chinook salmon (Oncorhynchus tshawytscha) carrying external and internal radio transmitters. J. Fish. Res. Board Can. 36:1060-1064.

Graybill, J.P., R.L. Burgner, J.C. Gislason, P.E. Huffman, K.H. Wyman, R.G. Gibbons, K.W. Kurko, Q.J. Stober, T.W. Fagnan, A.P. Stayman, D.M. Eggers. 1979. Assessment of the reservoir-related effects of the Skagit Project on downstream fishery resources of the Skagit River, Washington. Final Report for City of Seattle Department of Lighting by University of Washington Fish. Res. Inst. FRI-UW-7905. 602 pp.

King, H.W. and E.F. Brater. 1963. Handbook of Hydraulics. McGraw-Hill. St. Louis. pp 7-17.

Knight, Alexis E. 1975. A tuned-antenna radio-telemetry tag for fish. In Underwater Telemetry Newsletter V5, pp 13-16.

Leopold, L.B., John P. Miller, and M. Gordon Wolman. 1964. Fluvial Processes in Geomorphology. Freeman and Company. San Francisco

Liscom, Kenneth L. and G.E. Monan. 1976. Radio tracking studies to evaluate the effect of the spillway deflectors at Lower Granite Dam on adult fish passage, 1975. Nat. Mar. Fish Serv. report to Corps of Engineers, January 1976.

Mamak, Wiktor. 1958. River Regulation. Arkady. Warsaw, Poland. p. 12.

McLay, Colin. 1970. A theory concerning the distance travelled by animals entering the drift of a stream. J. Fish. Res. Bd. Canada 27:359-370.

McCleave, J.D. and K.A. Stred. 1975. Effect of dummy telemetry transmitters on stamina of Atlantic salmon (Salmo salar) smolts. J. Fish. Res. Board Can. 32:359-363.

Monan, Gerald E., J.H. Johnson, G.F. Esterberg. 1975. Electronic tags and related tracking techniques aid in study of migrating salmon and steelhead trout in the Columbia River Basin. Marine Fish Rev. 37(2). pp 9- 15.

Monan, Gerald E. and K.L. Liscom. 1976. Radio-tracking studies of summer chinook salmon and steelhead trout at and between Bonneville and The Dalles Dam. 1975. NMFS Report to the U.S. Army Corps of Engineers, April 1976. 51 p.

__________. 1974a. Radio-tracking studies of fall chinook salmon to determine effect of peaking on passage at Bonneville Dam, 1973. Nat. Mar. Fish. Serv. Report to corps of Engineers.

__________. 1974b. Radio-tracking of spring chinook salmon to determine effect of spillway deflectors on passage at Lower Monumental Dam, 1973. Nat. Mar. Fish. Serv. Report to U.S. Army Corps of Engineers. 20 p.

Nature Conservancy. 1977. Skagit River Bald Eagle Natural Area final report and management recommendations. 1976-77. Unpublished report.

__________. 1976. Skagit eagles: A management program for the Skagit River Bald Eagle Natural Area. Unpublished report. 52 p.

Scholz, A., D.M. Madison, A.B. Stasko, R.M. Horrall, and A.D. Hassler. 1972. Orientation of salmon in response to currents in or near the home stream. Amer. Zool. 12(4):654 [abstract].

Scott, W.B. and E.J. Crossman. 1973. Freshwater Fishes of Canada. Fish. Res. Board Can. Bulletin 184. pp 138-191.

Servheen, Christopher W. 1975. Ecology of the wintering bald eagles on the Skagit River, Washington. Unpublished M.S. thesis. University of Washington, Seattle.

Shepherd, Bruce. 1973. Transmitter Attachment and Fish Behavior in Under. Telem. News. Vol. 3(1). pp 8 - 11.

Skagen, Susan. 1979. Skagit River Bald Eagle Natural Area. Final Report and Management Recommendations 1978-79. (unpublished) 46 p.

Stalmaster, Mark V. 1976. Winter ecology and Effects of human activity on bald eagles in the Nooksack River Valley, Washington. Unpublished M.S. thesis, Western Washington State College, Bellingham, Washington.

Stasko, A.B., and D.G. Pincock. 1977. Review of underwater biotelemetry, with emphasis on ultrasonic techniques. J. Fish. Res. Board Can. 34:1261-1285.

Steenhof, Karen. 1978. Management of wintering bald eagles. U.S. Fish and Wildlife Service Publication. FWS/OBS-78/79. 59 p.

Wiley, Ken. 1978. Final Report, Skagit River Bald Eagle Natural Area, 1977-78. Unpublished report.

Winter, J.D., V.B. Kuechle, and D.B. Siniff. 1973. "An Underwater Radio Tracking System". Underwater Telemetry Newsletter, Vol. 3(2), December 11973. pp 1-5.

Appendix

APPENDIX A

Hydraulics Analysis

PHYSICAL ENVIRONMENT AND LOCATION

The Salmon Carcass Drift Study incorporates the Skagit River channel from the Gorge Powerhouse at Newhalem, river mile 94.2, downsteam to the vicinity of Marblemount, river mile 79.0. Observation of the river and identification of physical characteristics of the natural waterway have been accomplished to assist in analysis of factors causing salmon carcass drift.

Data Sources

From the engineering standpoint, there is substantial data available on the river reach in question and the flow characteristics. Extensive gaging records exist from three of four gaging stations in the Skagit River study reach. United States Geological Survey has maintained flow discharge records at Newhalem, river mile 93.7, the Skagit River above Alma Creek, river mile 85.8, and the Skagit River at Marblemount, river mile 78.7. A fourth station, Skagit River above Bacon Creek, river mile 83.0, has only been in operation since April of 1977, and does not provide length of record that the other gaging stations offer. The Marblemount gage is also of limited value because no records were obtained from 1951 through 1976.

Topgraphic information was derived from Washington State Highway Commission maps of Marblemount to Newhalem. Contour intervals of 5' were obtained by photogrametric methods using aerial photography dated April 15, 1965. Information was also obtained from the U.S.G.S., Marblemount quadrangle, 15 minute topographic series which provides 80 foot contour intervals.

Field measurements and samples were obtained to verify and complete the data information. A river run was made by boat on 30 October, 1979. During this trip, a thalweg depth reconnaissance was completed. Notes and depth measurements are included in appendix 1. Nine cross section soundings were also made during that trip, and included in appendix 2. Sediment samples were obtained and brought back to a testing lab for analysis. Representative sieve analysis of those samples are provided in appendix 3.

Aerial photos were also available from the U.S. Forest Service, U.S. Army Corps of Engineers and Seattle City Light.

The data analysis has concentrated on three factors which are highly influential on the salmon carcass "drift capability" of the river.

- o Hydrology - the variations in flows and depths between high water and low water periods and the relative frequency of flow conditions, to relate river flow conditions during the tagging effort to other years.

- o Hydraulics - the relationship between depth and velocities in the river and the river reach characteristics that help qualify rate of fish movement.

- o Sediment transport - the impact of river flow on the movement of bedload to help understand the tendency of a carcass to move as bed load, or to be buried in the bed.

<u>River Reach Characteristics</u>

Characteristics of a river system can be defined by several accepted methods. The river longitudinal slope is one of the first parameters to examine because velocities are proportional to the square root of river slope and many characteristics of a waterway are the result of river velocity.

A European engineer, Wiktor Mamak, has described rivers in four categories by characteristics, particularly longitudinal slope. The four categories and their slope values are presented in his book "River Regulation".

Type	Slope
Mountain Streams	.050 - .002
Upper Rivers	.002 - .001
Middle Rivers	.001 - .0005
Lowland Rivers	less than .0005

Table 1. River classification based on slope of the channel bed (from Mamak).

The Skagit River between river mile 79.0 and 92.0 has an average slope of .0019 which would place it into the "upper river" type of waterway. However individual reaches of 0.3 to 1.0 miles in length have slopes ranging from 0.0012 to 0.0090, suggesting the study reach is in a transition from a "mountain stream" to the "upper river" classification. Topographic charts further verify this transition concept because the river is moving into a generally wider valley area with less steep terrain. This transition condition suggested the need to consider the study area in terms of shorter reach lengths. The average total slope value has been revised to a more representive combination of short reaches to better relate the fish carcass movement.

The range of slopes that describe the study reach (.0012 to .0090) assure a relatively steep gradient condition, and subsequent theory predicts large grain size bed materials. This was verified by visual observation and sediment sieve analysis of the bed sediments. Under these natural river conditions, another parameter is available to qualify representative river reaches for better analysis. This is the analysis of bedforms.

The alternating pool and riffle, a bedform condition, is present in practically all channels which have bed materials larger than coarse sand, and is most characteristic of gravelbed streams. Measurement of the length of individual pools and riffles is partly a matter of judgment, but these type of waterways will have a length between deeps and shallows, sometimes called a bar ratio, spaced more or less regularly at a repeating distance equal to 5 to 7 widths. Applying this rule of thumb to the depth and channel measurements obtained in the field, a profile of the shallow and deep bed conditions has been developed.

Further qualification of a river reach or reaches has been made from the channel patterns that exist. A channel pattern is described as the configuration of a river as it would appear from an airplane. Recognized channel patterns are meandering, braided and straight.

In general there is no sharp distinction in a natural waterway between any of the recognized patterns. Rather, river pattern is a continuum from one to another, and straight reaches seldom exist in most natural waterways. In our attempt to classify representative reaches on the Skagit River, the braided channel pattern was very useful to establish a characteristic reach.

Braided channels are waterways that divide into several channels which successively meet and redivide, sometimes referred to as anastomosing. Braided channels typically have relative steep slopes, and pool and riffles are less well developed than in non-braided channels.

One length of channel in the study reach does display the braiding characteristics, and subsequently is classified differently than the other riffle/pool reaches. It also should be noted that this reach is the primary location of spawning during the study period.

Figures 1 and 2, the Skagit River Profile, graphically depicts the locations of the river with riffles and pools as they existed in October, 1979. Combining the bedform and slope information, the following river reaches were derived to provide insight into analysis of fish carcass movement.

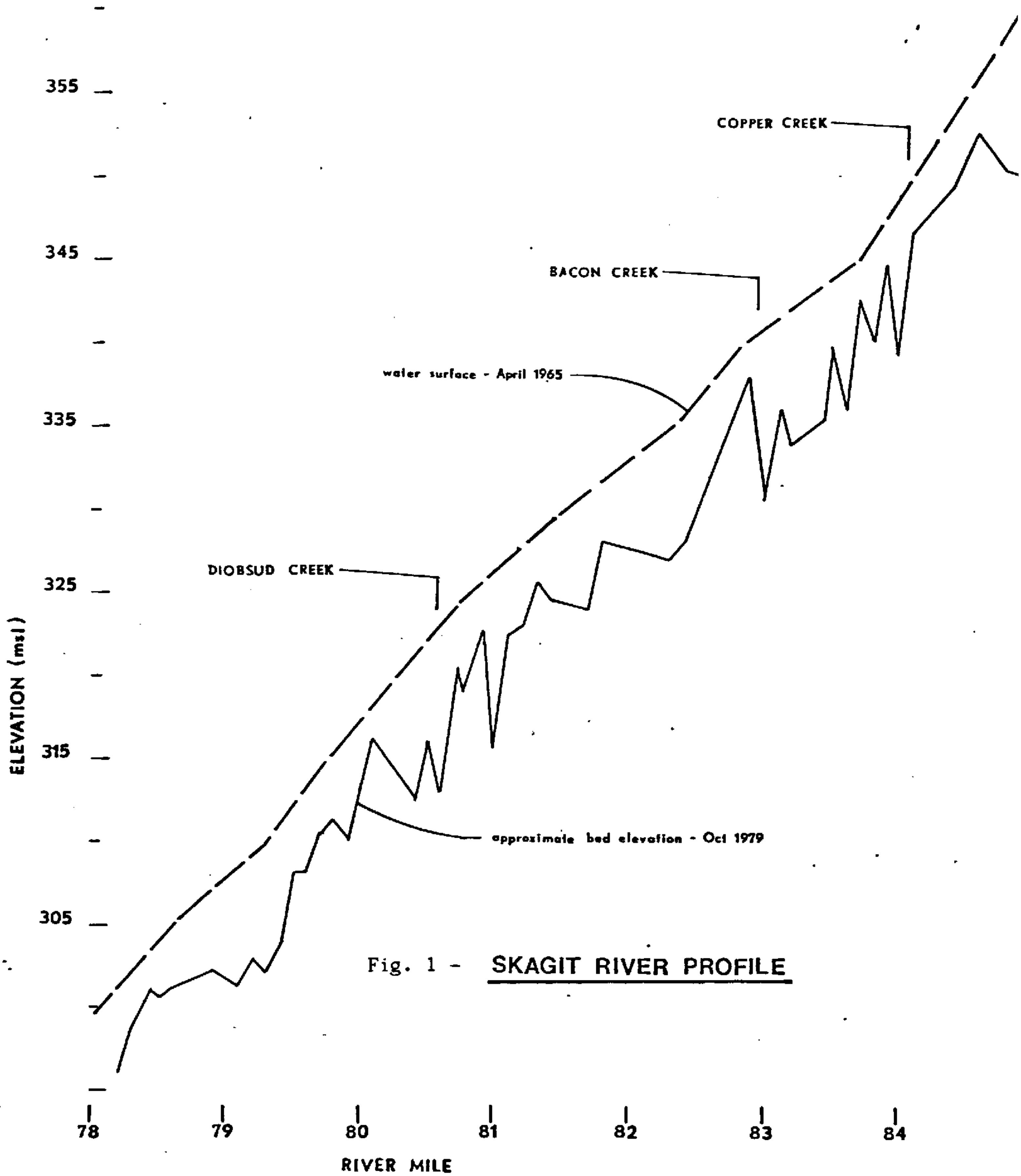


Fig. 1 - SKAGIT RIVER PROFILE

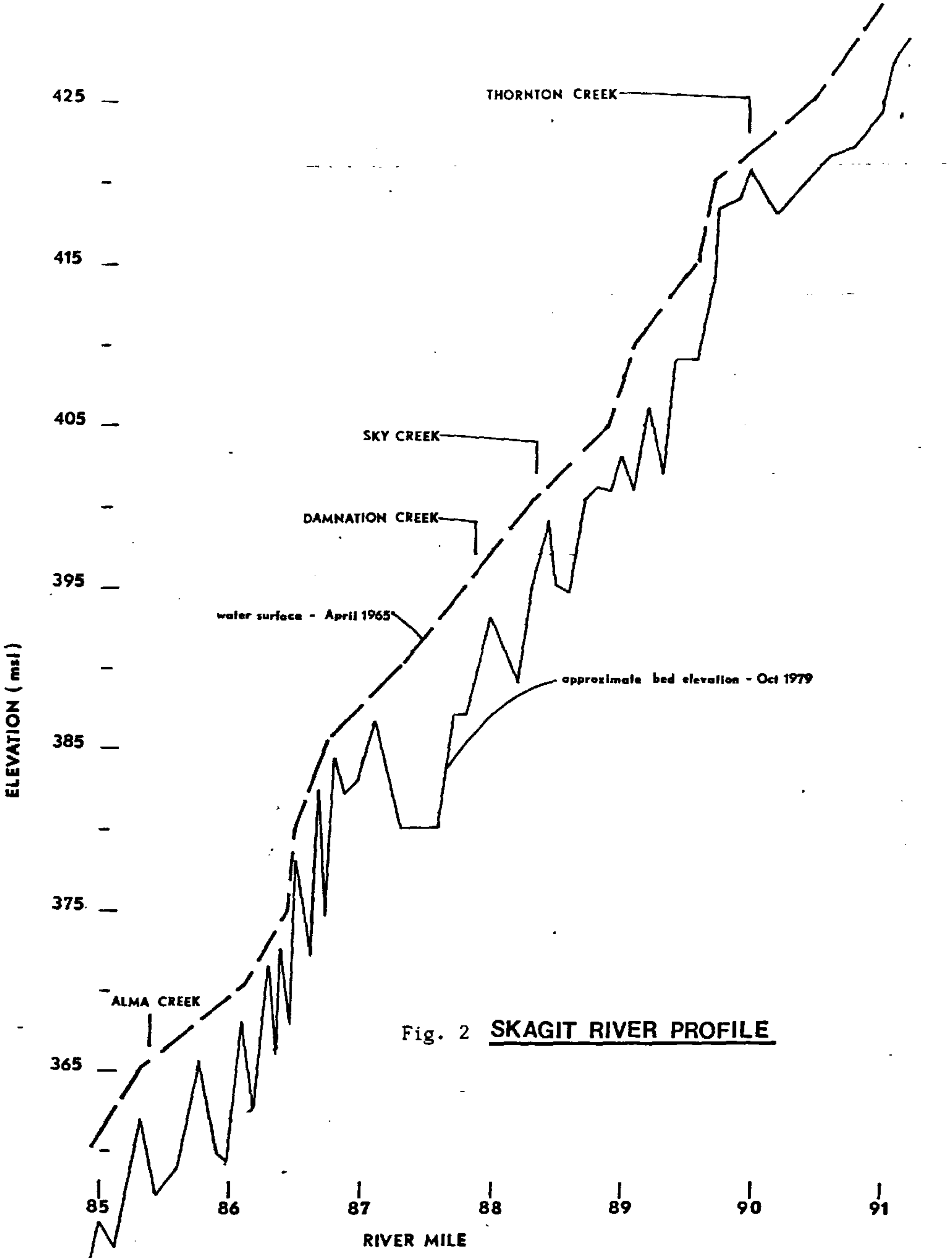


Fig. 2 **SKAGIT RIVER PROFILE**

River Mile	Description	Bar Ratio	Average Slope
78.1 - 86.1	riffle/pool	1 every 2100'	0.00017
86.1 - 86.8	rapids/deep pool	1 every 740'	0.0042
86.8 - 89.0	riffle/pool	1 every 1940'	0.0017
89.0 - 90.0	braiding	1 every 1230'	0.0036
90.0 - 91.4	riffle/pool	1 every 1790'	0.0018

Table 2. Characteristic river reaches in the Skagit River from river mile 78 to 91.

A graphical presentation of the simplified, or average slope, for the Skagit River study is compared to the actual bed slope in figure 2.

Velocity-Discharge Relationship

The mechanics of open channel flow are complex. However, many open channel problems can be treated in terms of an approximate solution based on assumption of steady flow. For the Skagit River conditions, it is convenient to use an empirical formula, Mannings Equation.

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$ where

V = average river velocity

R = hydraulic radius: (ratio of cross sectional area over wetted perimeter)

S = rate of head loss per unit length; approximately equal to slope of river

N = roughness coefficient

The wide variation in the roughness coefficient values (n) together with the significant effect it has on flow calculations, places a high premium on judgment and experience in selecting proper values. It is neccessary to test n values against actual river stage and slope data to assure coefficient adequacy.

Measurements were made on sight during the October field effort. Although velocity measurements were not obtained, discharge values were subsequently available from USGS gaging station records. Application of the actual discharge values from USGS records, the continuity equation for stream flow and the Manning Equation allows computation of representative n values. The continuity equation is:

$Q = VA$ where

Q = discharge in river
V = average velocity
A = channel area perpen-
perpendicular to flow

Representative roughness coefficient values were computed and are shown in table 3.

River Mile	Description	n
79.0	riffle/pool	.045
84.6	riffle/pool	.040
86.5	rapids/deep pool	.070
87.8	riffle/pool	.030
89.4	braiding	.055
90.5	riffle/pool	.050

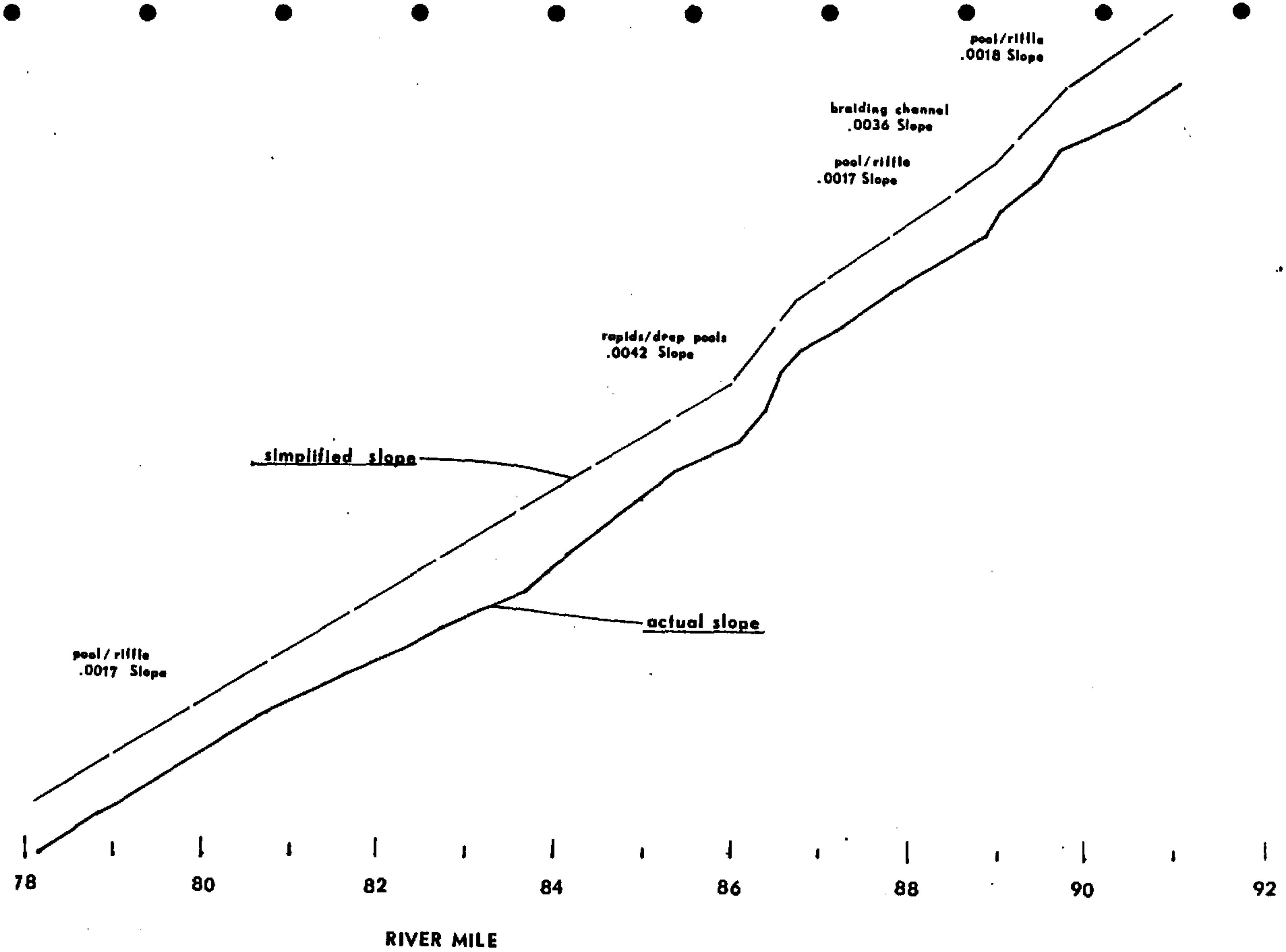


Figure 3. Simplified bed slope of the Skagit River between Newhalem and Marblemount.

Table 3. Representative values for Mannings 'n', calculated for the Skagit River.

Roughness coefficient values commonly used in design have been incorporated in standard tables. Referring to a table provided by King and Brater in the Handbook of Hydraulics, an n value of 0.030 to 0.045 is appropriate for natural stream channels under somewhat varied conditions of stage, bar and pool conditions.

An n value above 0.045 is indicative of a greater roughness condition, such as would be expected in the rapids and braided channel reaches where natural flow obstacles are visually predominant.

Cross section surveys obtained on 30 October, 1979 are used to establish stage versus hydraulic radius (area divided by wetted perimeter) relationship. Applying the roughness coefficient values as derived and assuming a constant slope, the stage-discharge velocity curves for various locations along the study length were derived. Figures 4 through 10 graphically depict the curve relationship.

Bed Load Transport

It is necessary to establish the bed load movement criterion for the Skagit River. Understanding the range of flows and rate of bedload transport that can occur in the Skagit can help to interpret monitoring efforts if fish carcass tend to move as bed load rather than suspended load. The information can also help to explain conditions if monitor tags tend to disappear, that is become buried in the bed sediments between recording stations.

Bed load is defined as the material moving along the bed of the river and not moving in the water column as floating or suspended sediments. Theoretically sound and tested equations are available to allow prediction of bed load movement for existing conditions.

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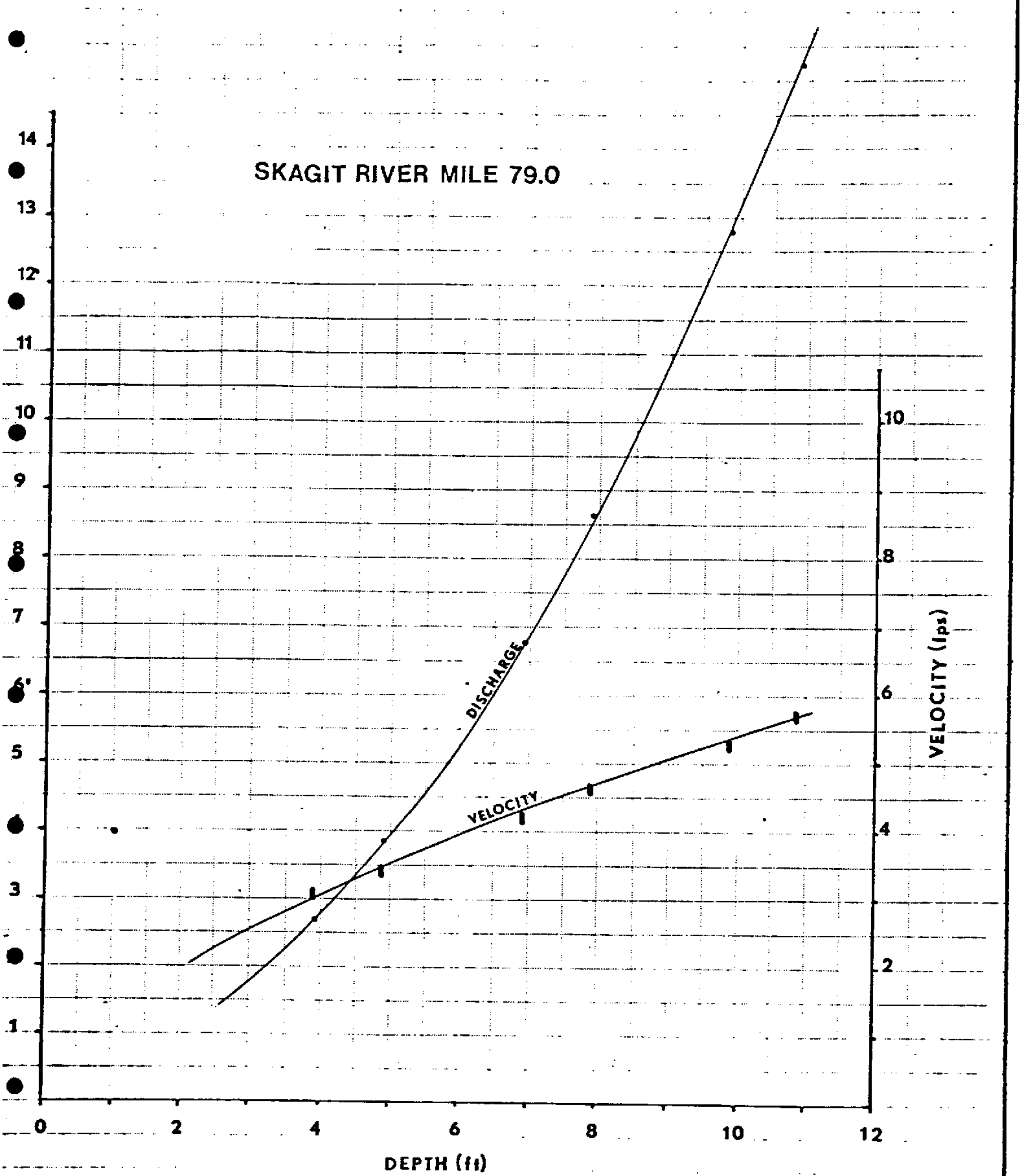

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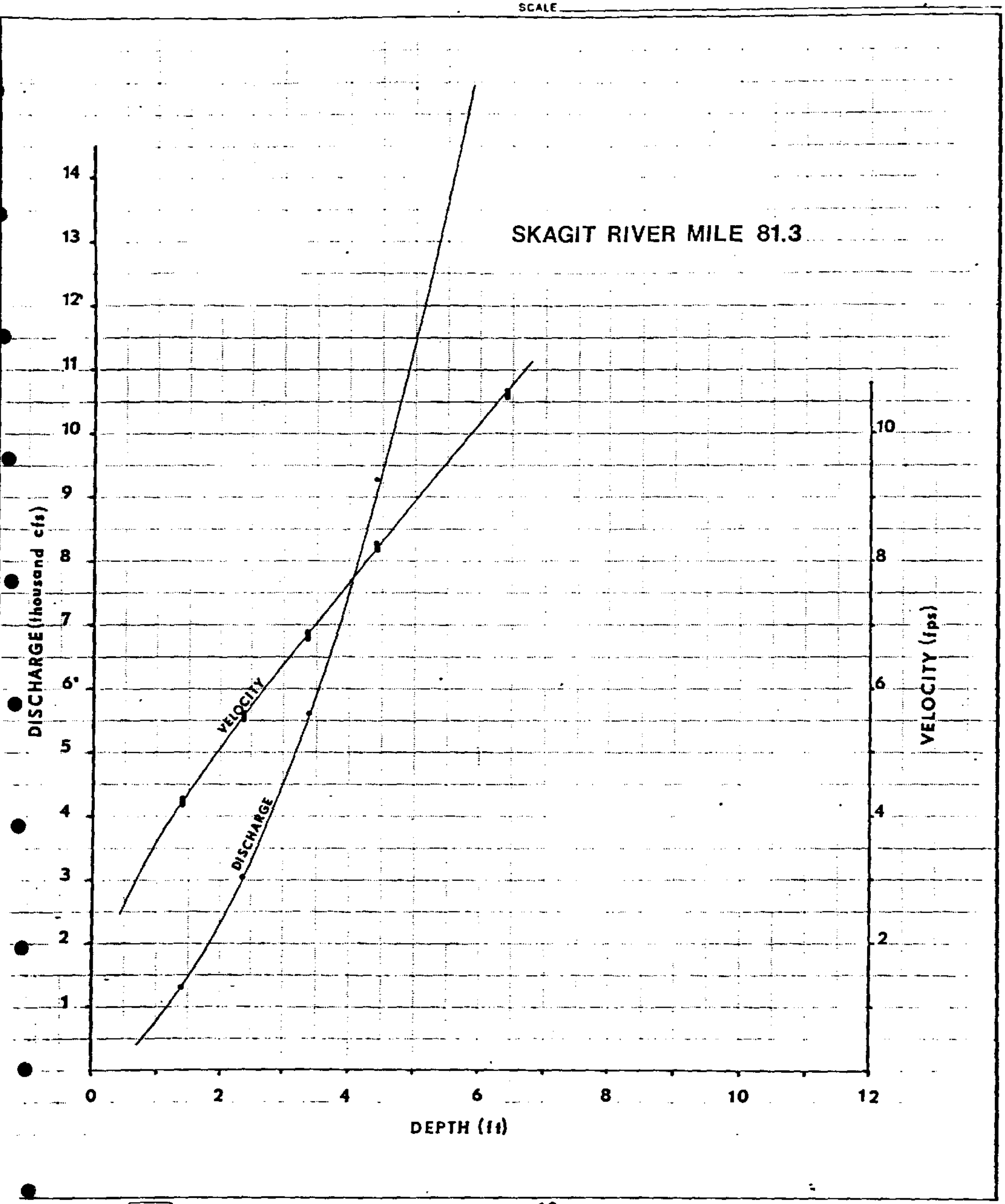

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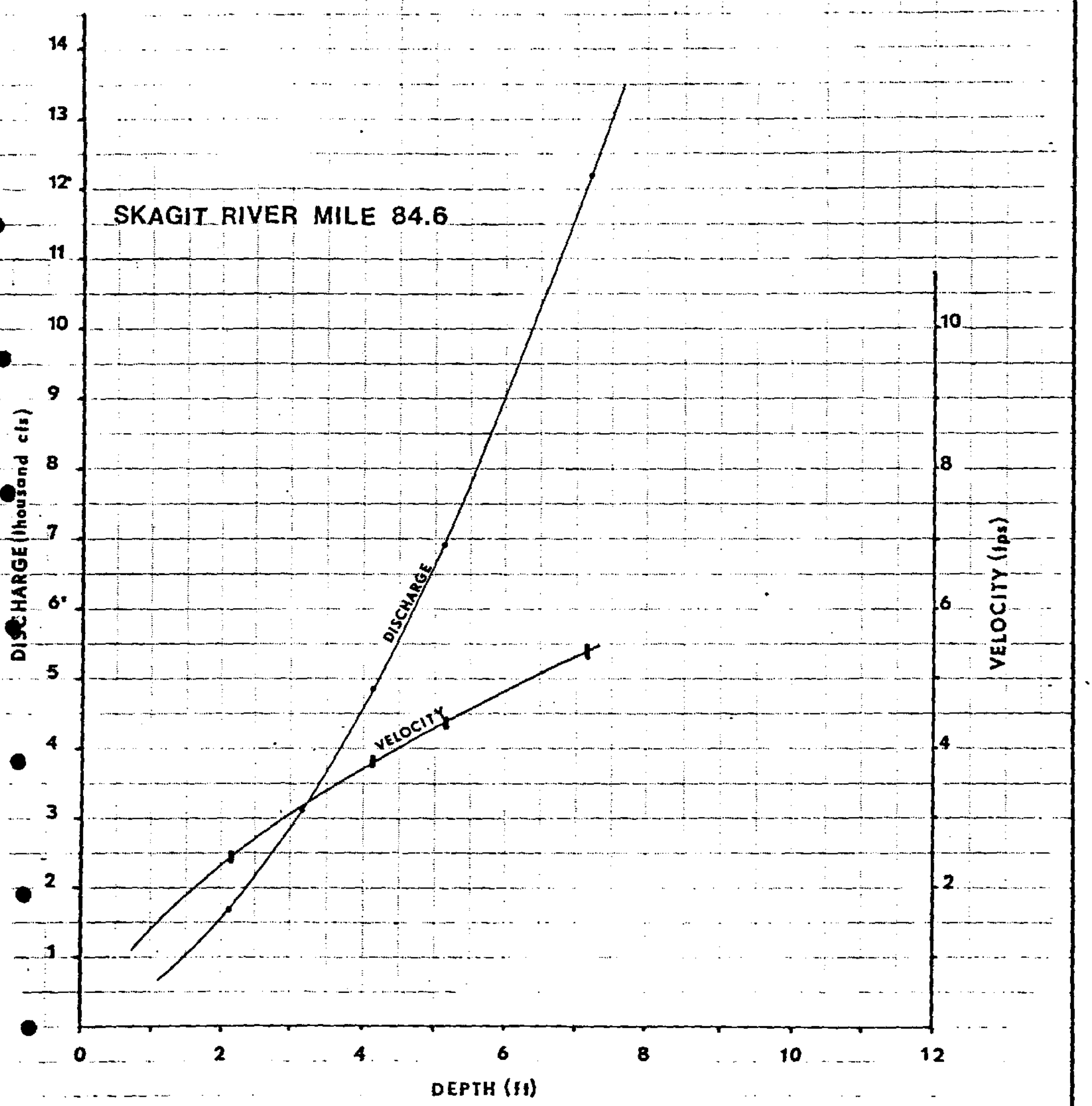

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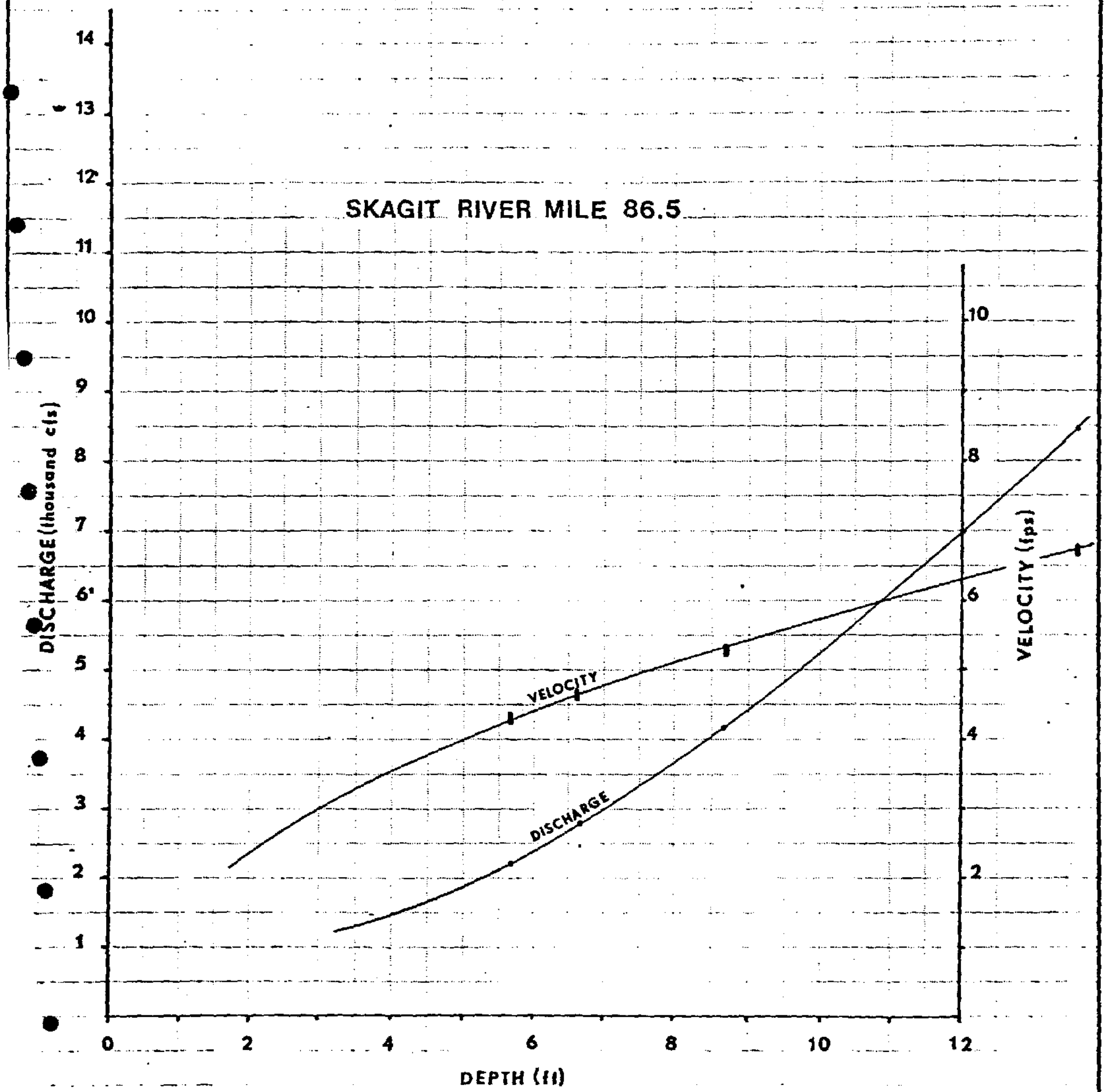

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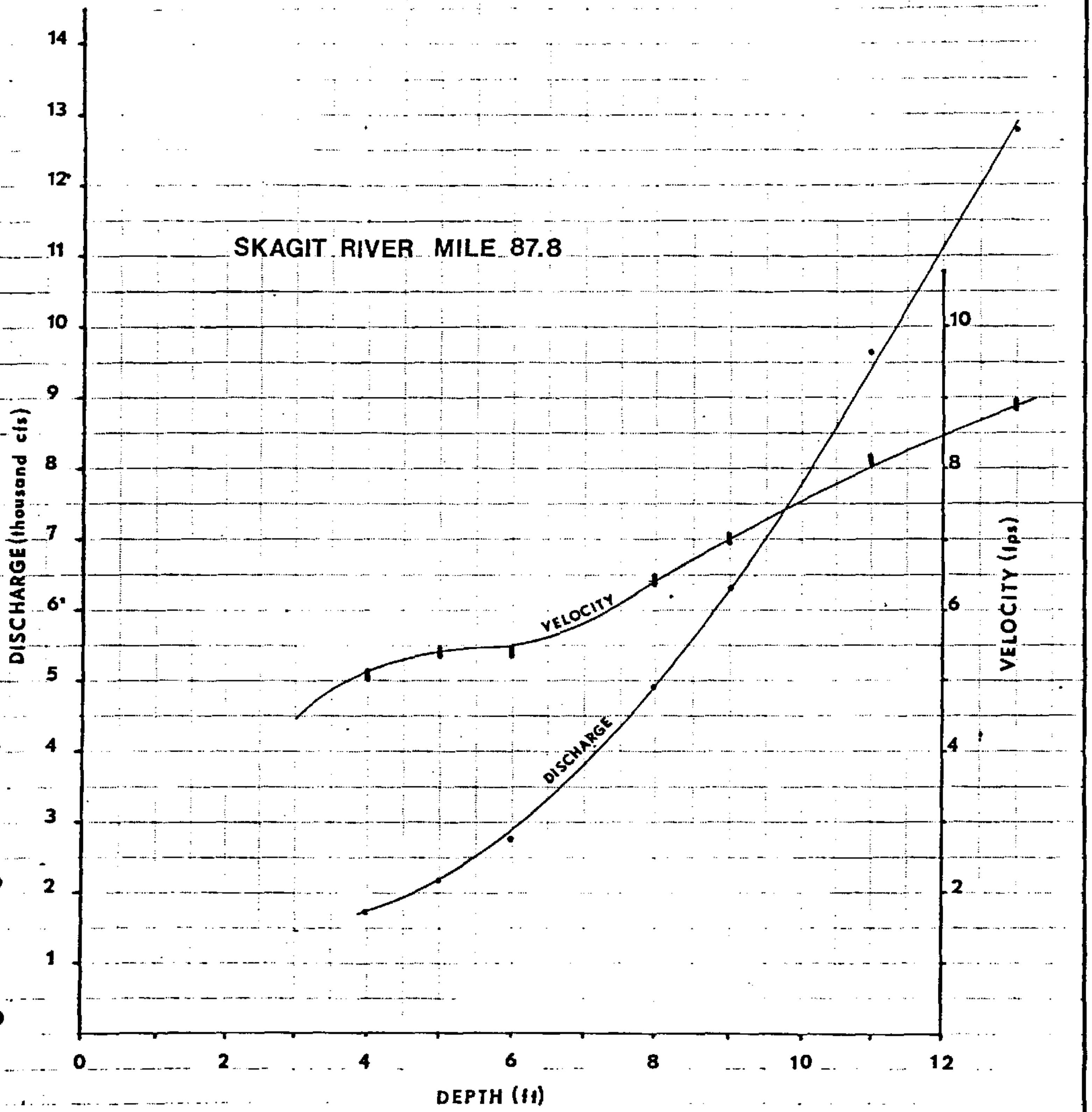

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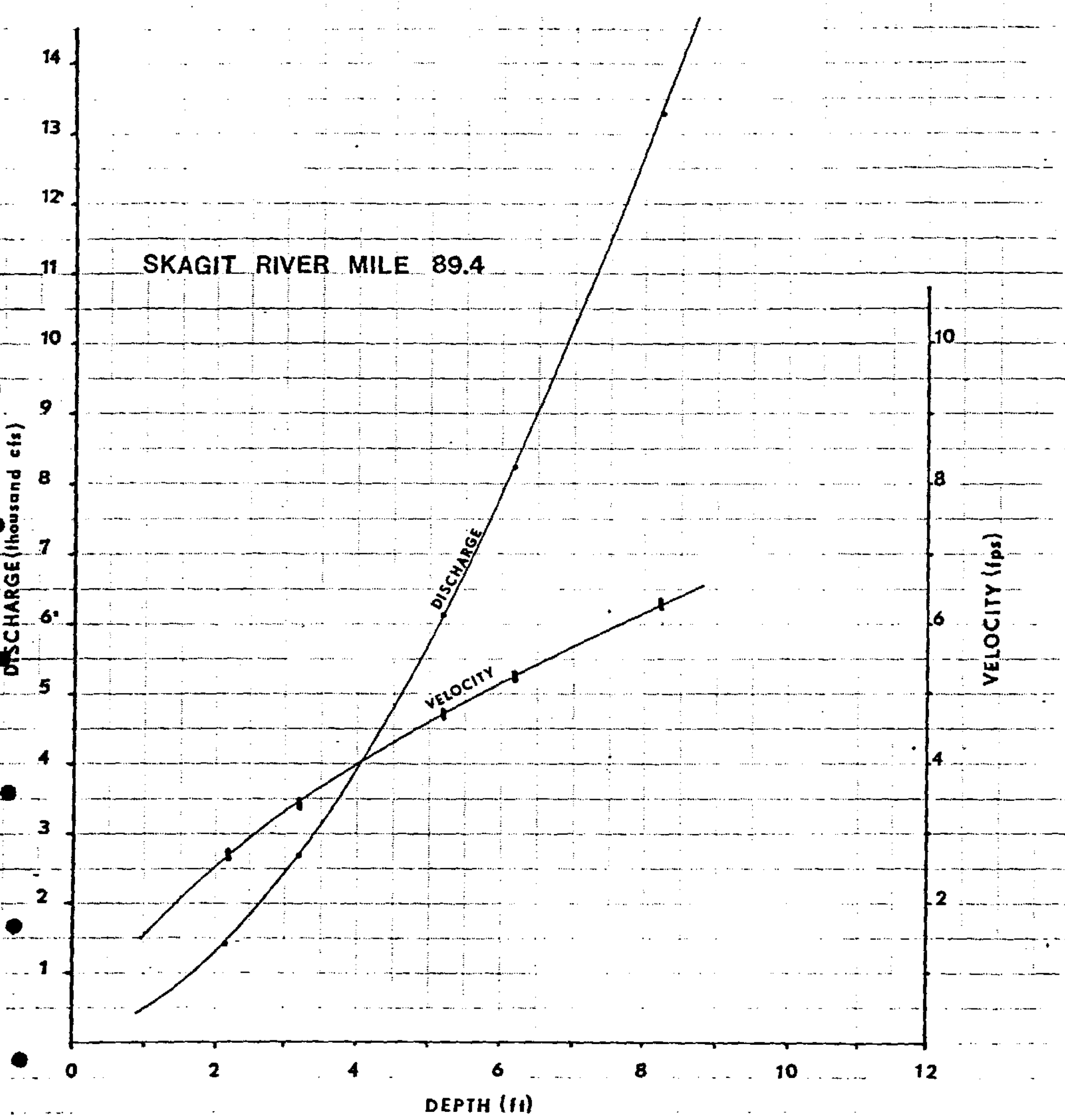

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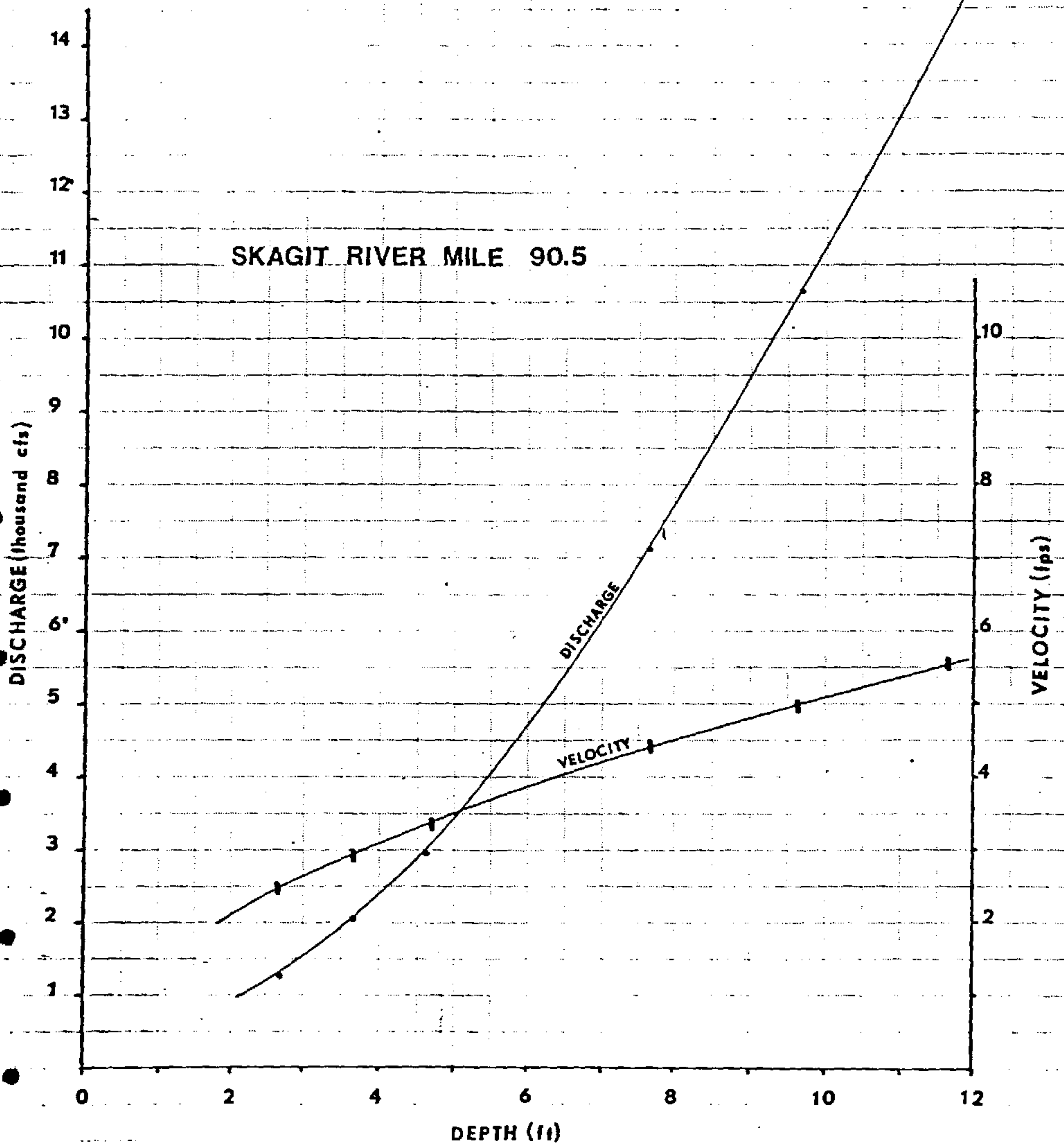

In flowing rivers, the weight of water, gravity and the slope of the water surface cause a shear stress on the bed materials. When this shear stress becomes high enough, certain sediment particles will begin to move. With increase in shear stress, heavier particles will begin to move and finer particles will move faster. In a river with an erodible bed, it is possible for the water to move the bed in increasing quantities causing the bed to scour. As shear stress is reduced, due to falling river levels or enlargements in river cross section geometry, bed load movement will be reduced. Material moving along the bed will no longer be moved resulting in deposition of the material or shoaling. In theory, the bed load capacity of the river will always be satisfied. If capacity exceeds supply, scour will occur. If supply exceeds capacity, shoaling will occur.

Representative sediment samples were obtained from the Skagit River bed and analyzed in the laboratory by sieve analysis. Results of the sieve analysis is provided in appendix 3. It is expected that natural armoring of the coarse bed sediments would occur under normal flow fluctuations. Armoring is the action whereby smaller grained sediments erode from the bed surface, leaving only larger, non-transportable sediments. These heavier sediments then align themselves with the flow to virtually create a sediment barrier to further erosion. As a result, only the higher velocities associated with flood conditions can initiate bed load movement. When movement has started, the armoring condition is removed to allow transport of finer sediments below the surface. As flows subsequently rise and fall after the flood, the eroded gravels are replaced by gravels moved into the reach from upstream sources, and the armoring process is repeated.

Empirical relationship derived by Shields and presented in text by Graf provides the relationship between incipient motion of sediment and velocity of the water. The bed roughness of the grains is large enough to create turbulent bed conditions such that the following equation is appropriate:

$$\frac{Tcr}{(V_s - V)d} = 0.047$$

where

Tcr = critical shear stress on the sediment

V_s = specific weight of sediment

V = specific weight of water

d = median diameter of particles

Summary of flow calculations to initiate armored bed sediment transport for various locations on the Skagit River are given in table 4. A discharge flow approaching 12,000 cubic feet per second appears necessary to begin appreciable movement of existing bed load.

Sediment Sample		Values For Incipient Motion	
River Mile	D50	Depth (ft)	Discharge (cfs)
78.2	55 mm	9.5	1,500
81.8	48 mm	5.6	10,600
84.1	47 mm	6.8	12,200
87.0	68 mm	9.4	12,700
90.5	59 mm	8.5	12,400

Table 4. Discharge levels necessary to create significant movement of bed load on Skagit River.

HYDROLOGIC CONDITIONS

Variations in flows and depths between high water and low water periods have been analyzed to establish relativity of flow conditions during the fish tagging effort. The USGS gaging stations provide excellent flow data to derive discharge frequency and volume. The gaging station upstream of Alma Creek is considered most representative of flows between the spawning area and the dam.

The Newhalem gage provided important insight into the levels of flow that could be expected because of dam regulation. The gage is located at river mile 93.7 which is immediately downstream of the dam, and thus presents exactly the regulated flow input of the total Skagit River flow in the spawning and carcass drift reaches.

Between the Newhalem gage and the Alma Creek gage, river mile 93.7 and 85.8 respectively, there are twelve minor and major tributaries that add to the Newhalem gage flow. Major tributaries include Newhalem Creek (river mile 93.3), Goodell Creek (river mile 92.7), Thornton Creek (river mile 89.9), Sky Creek (river mile 88.0) and Damnation Creek (river mile 87.4). The only identified tributary inflow downstream of and between the Alma gage and the Copper Creek dam site is Alma Creek (river mile 85.0).

Three tributaries to the Skagit River enter downstream of Alma Creek and upstream of the Marblemount gage. They are Copper Creek (river mile 84.0), Baron Creek (river mile 82.8) and Diobsud Creek (river mile 80.7).

The relative small inflow volume of the referenced tributaries to the main stem Skagit flow combined with the location of the gaging stations to the dam site made it appropriate to use the Newhalem and Alma Creek gage records for fish drift analysis.

Mean Daily Discharge

A 10 year record from October, 1968 through September, 1978 was used to derive the typical mean daily discharge for the months of November, December, January and February. Tables 5 and 6 provide a summary of the representative flows that were recorded at both stations in the 10 year period.

	Mean Daily Flow (cfs) Newhalem Gage		
Month	Minimum	Average	Maximum
Nov.	1678	3531	5971
Dec.	2314	5171	8840
Jan.	2724	5427	8500
Feb.	2583	4941	7025

Table 5. 10 year average of mean daily flows as recorded at Newhalem Gage, on the Skagit River (1968 - 1978).

	Mean Daily Flow (cfs) Skagit River Above Alma Creek		
Month	Minimum	Average	Maximum
Nov.	2287	4299	7397
Dec.	2970	5885	9889
Jan.	3370	6066	9665
Feb.	3174	5449	7727

Table 6. 10 year average of mean daily flows as recorded at Skagit River, upstream of Alma Creek (1968 - 1978).

As a result of inflow from the smaller tributaries, the mean Skagit River discharge increased approximately 600 to 1100 cfs at Alma Creek gage over the Newhalem gage.

From the average flow analysis, the best fit year (4 month period) was selected and plotted. Figures 11 and 12 depict the 10 year average discharge that typifies flows in the Skagit River at Newhalem and Alma Creek. These plots point out the major impact that operation of the hydroelectric plants have on Skagit River flow. In general, discharge is characterisically lower on the weekends during the November through February time span because of reduced demand for power. Also, flows greater than approximately 7200 cfs are seldom experienced at the Newhalem gage. That is the flow equivalent to the generating capacity of the Gorge powerhouse turbines. Discharges beyond that flow would include spill of reservoir water behind the dam due to a combination of high flow and a full reservoir.

Operation of the powerhouse to generate power, and the reservoir to store flow does limit the predominant flow pattern on the Skagit River system. Discharge is dampened to volumes predominantly below 7200 cfs, during high water periods. With storage capability, the low flow periods are augmented to assure a minimum flow above 1000 cfs. Tables 7 and 8 present the best fit four months for the average, maximum and minimum typical discharge at Newhalem and Alma Creek.

Mean Daily Flow (cfs)
Four Month Analysis
Skagit River At Newhalem

Typical Year	Minimum	Average	Maximum
Minimum yr (1970-71)	1060	4094	6,670
Average yr (1971-72)	1140	4856	11,300
Maximum yr (1975-76)	2310	6243	24,100

Table 7. Comparison of the mean daily flow values on the Skagit River at Newhalem during November, December, January and February for a 10 year record (USGS gage, 1968-1978).

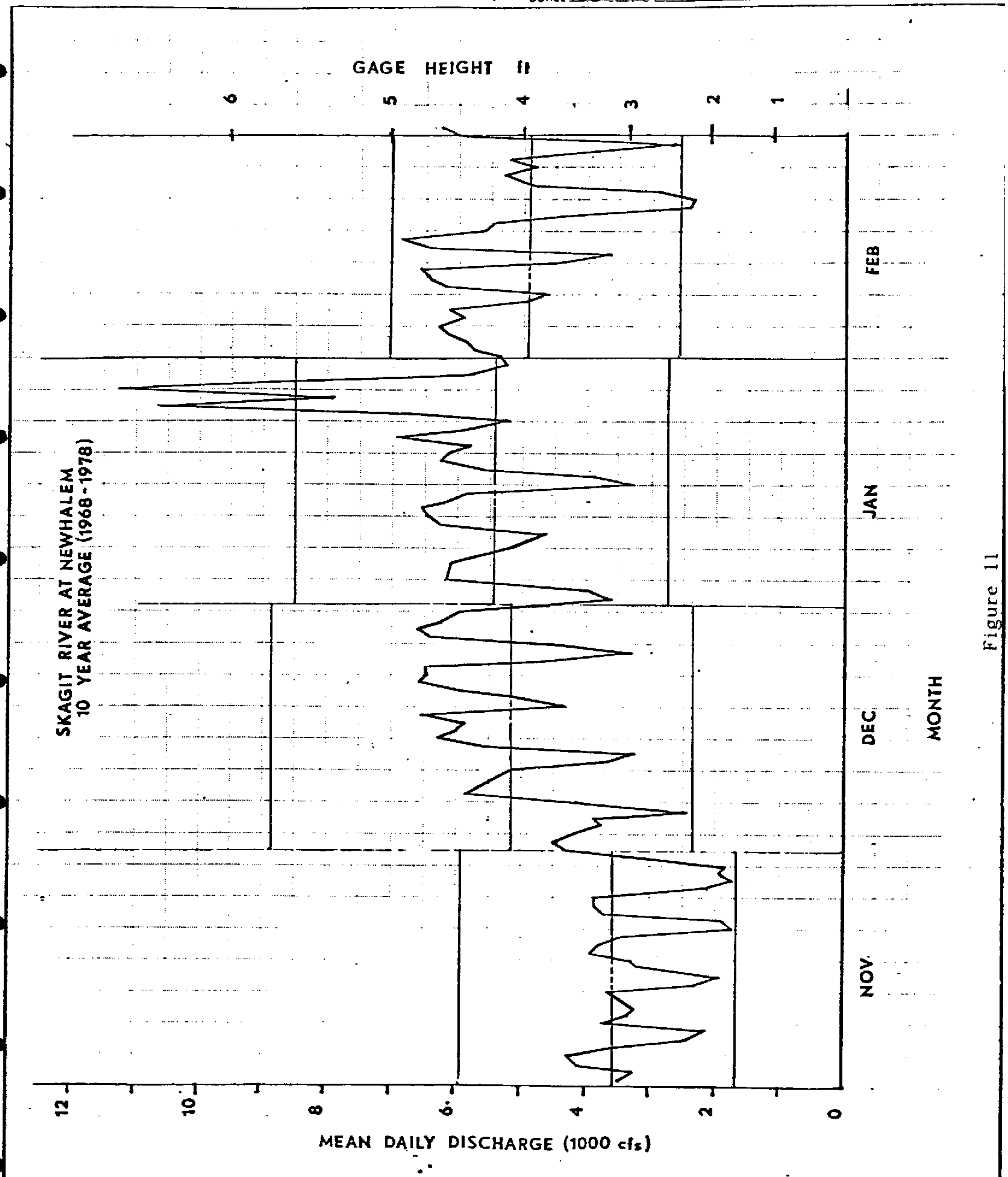
SKAGIT RIVER AT NEWHALEM
10 YEAR AVERAGE (1968-1978)
GAGE HEIGHT ft
6
5
4
3
2
1
NOV.
DEC
JAN
FEB
MONTH
12
10
8
6
4
2
0
MEAN DAILY DISCHARGE (1000 cfs)

Figure 11

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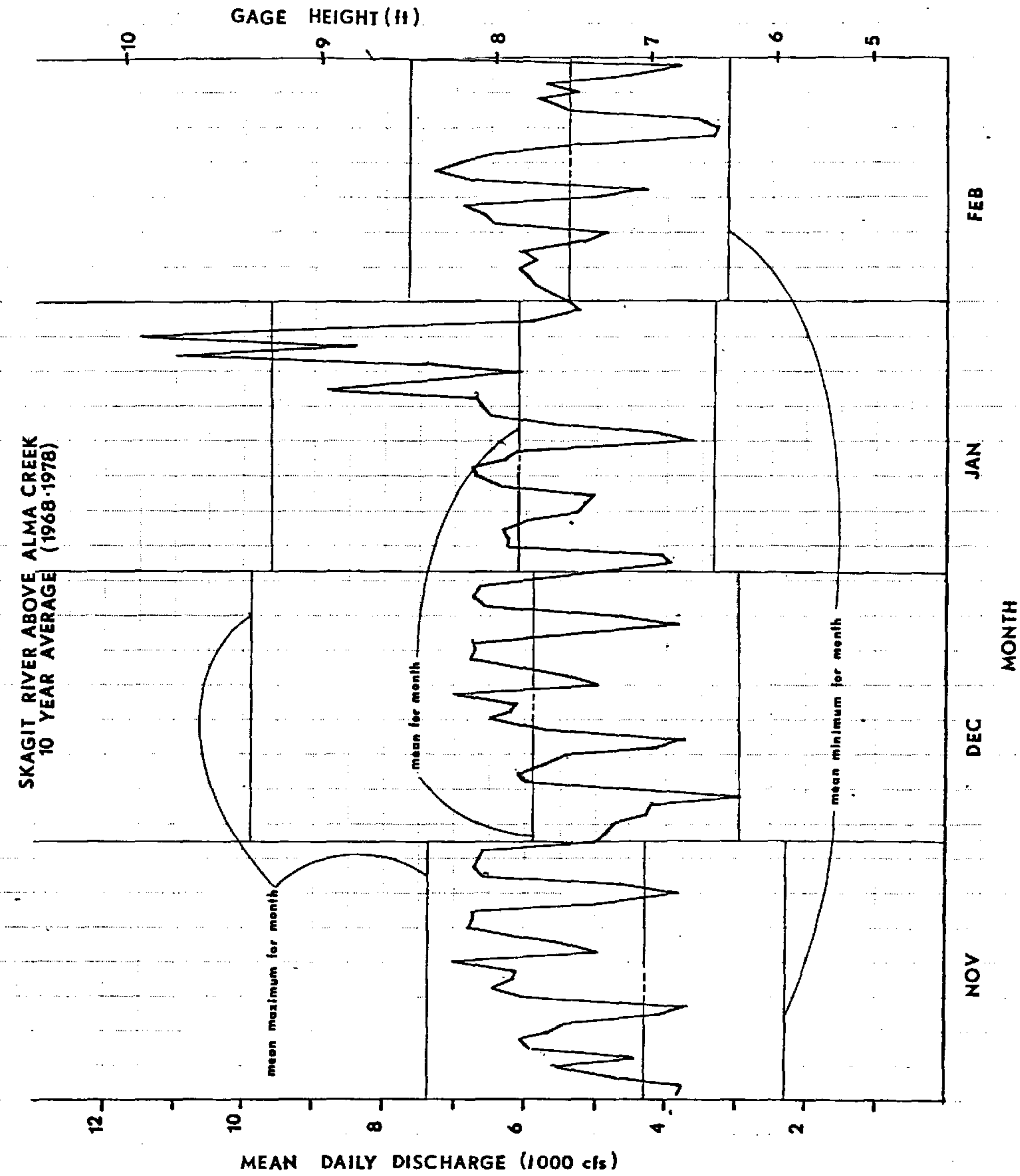

Figure 12

Mean Daily Flow (cfs)
Four Month Analysis
Skagit River Above Alma Creek

Typical Year	Minimum	Average	Maximum
Minimum yr (1972-73)	1370	4477	7,690
Average yr (1971-72)	2290	5350	11,500
Maximum yr (1975-76)	3340	7224	27,000

Table 8. Comparison of the mean daily flow values on the Skagit River above Alma Creek during November, December, January and February for a 10 year record (USGS gage, 1968-1978).

Discharge Frequency

Monthly records of the mean daily discharge were utilized to derive a 10 year flow frequency. The records were considered for the November through February time period which preceded and followed the prime salmon spawning time.

Figures 13 and 14 graphically depict the per cent of time that flow exceeds a given discharge at the Newhalem gage and Alma Creek gage respectively.

A plot of the flow frequency at Newhalem depicts the influence that the power plant operation has on the main stem flows. Figure 15 is a seventeen year flow frequency for a 12 month record. The non-regulated condition when reservoir spill occurs is at the 7200 cfs discharge or higher. This condition occurs only 10% of the time, while maximum flows approaching 20,000 cfs occur less than 1% of the time.

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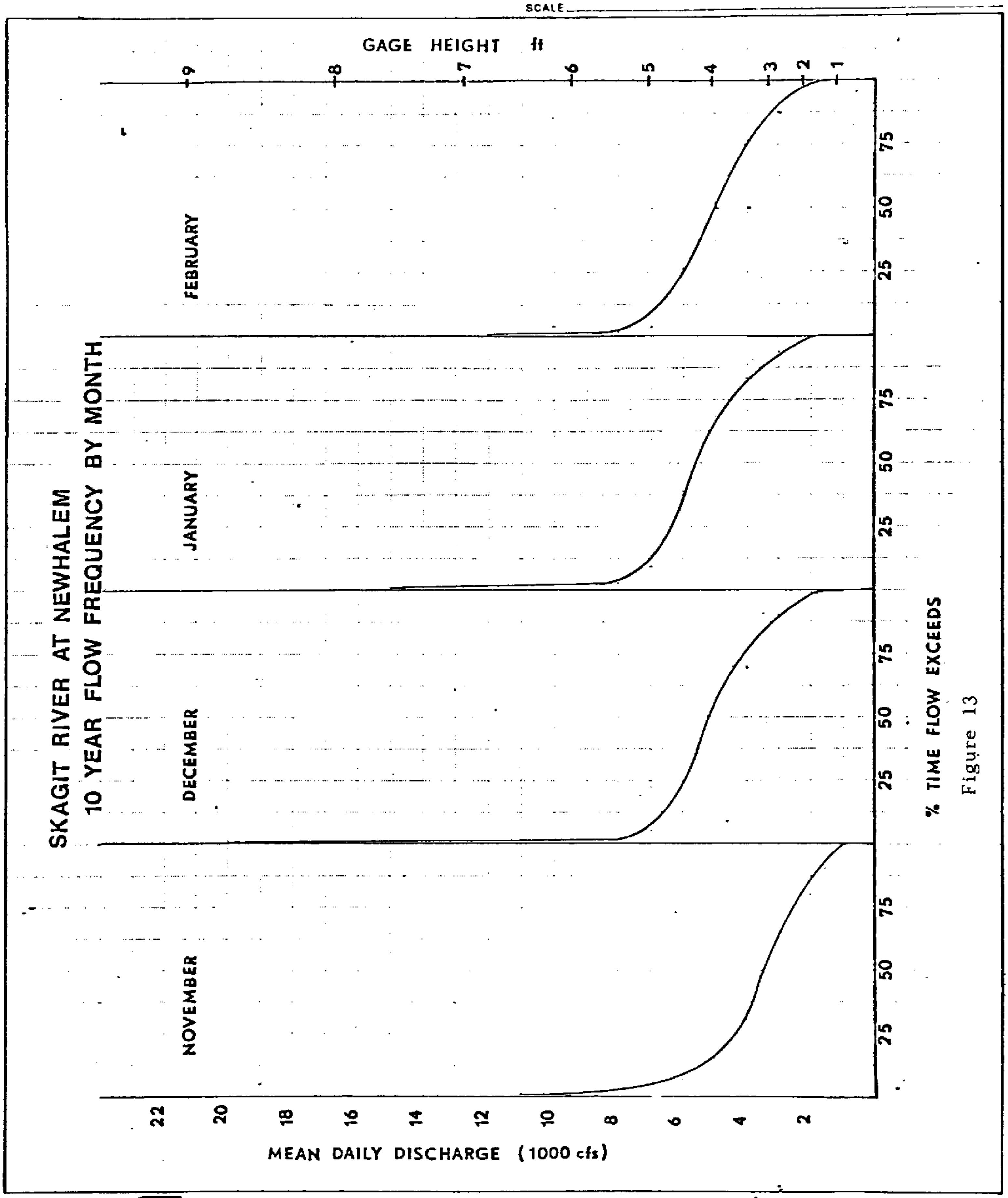

Figure 13

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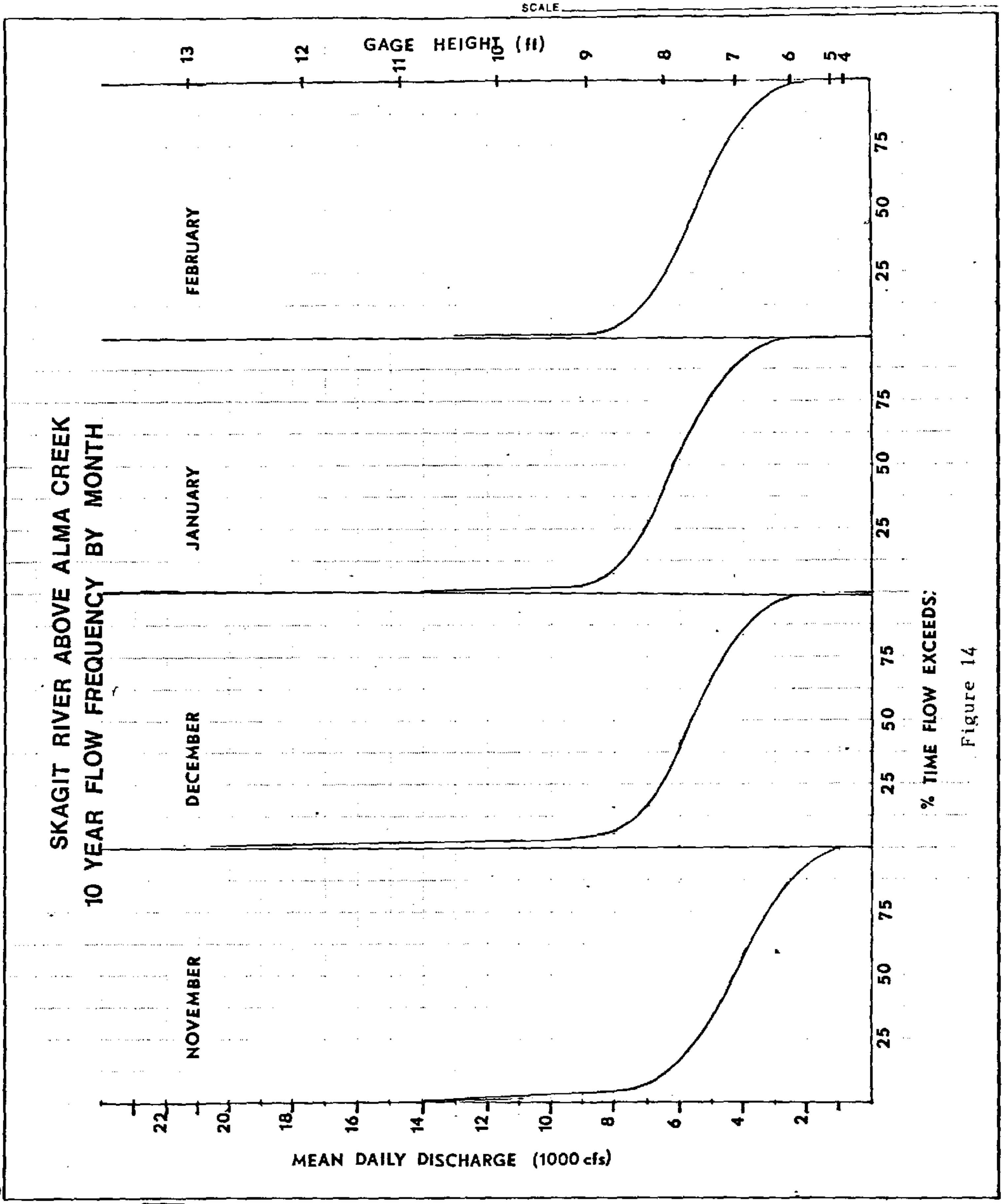

Figure 14

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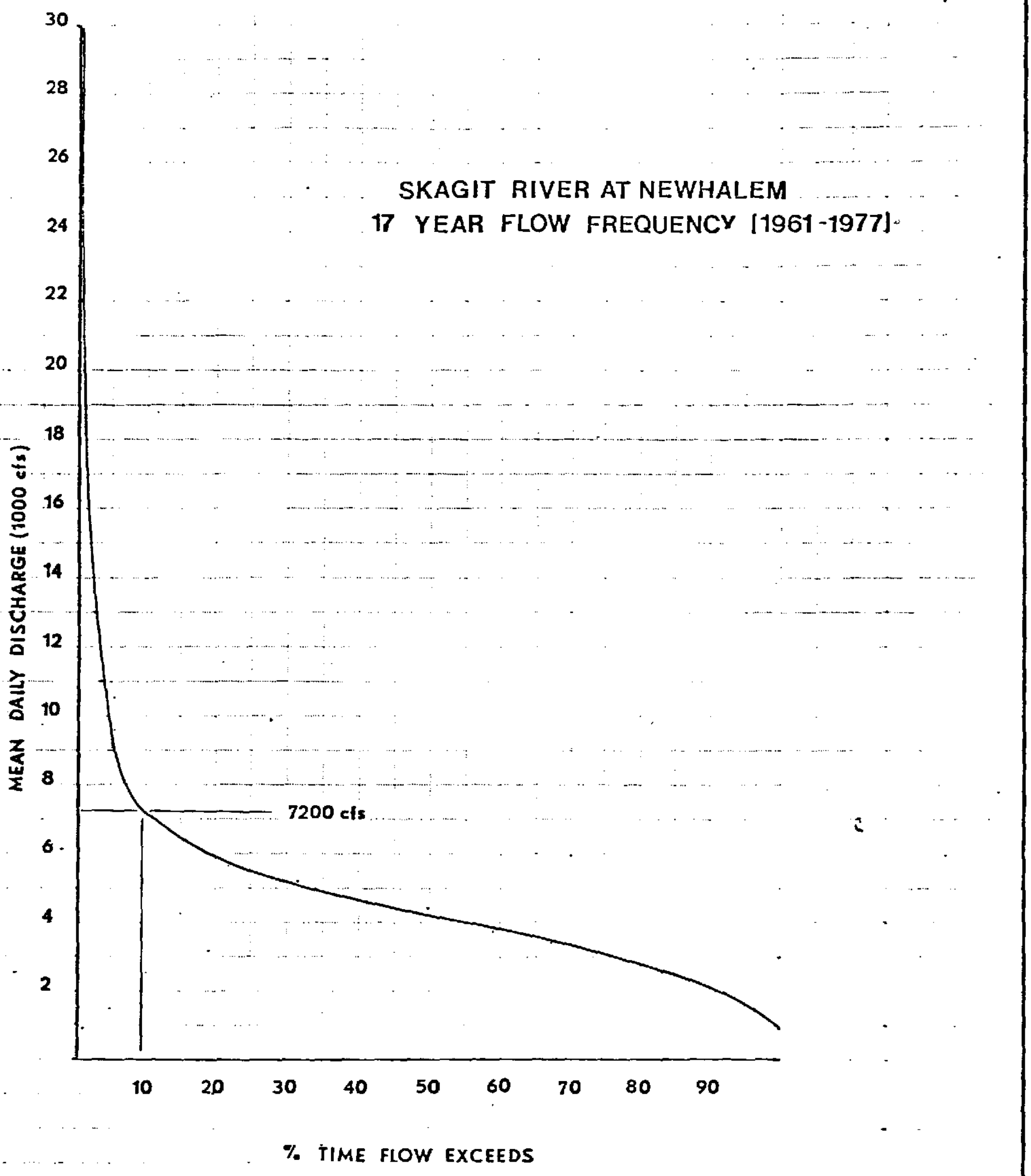


Bibliography

Mamak, Wiktor; "River Regulation" Arkady; Warsaw, Poland; 1958. (p. 12).

King, H.W. and Brater, E.F.; "Handbook of Hydraulics", 5th Edition; McGraw-Hill Book Company, St. Louis; 1963. (p. 7-17).

Graf, Walter H.; "Hydraulics of Sediment Transport"; McGraw-Hill Book Company, New York; 1971. (p. 96).

Leopold, L.B.; Miller, John P. and Wolman, M. Gordon; "Fluvial Processes in Geomorphology"; W.H. Freeman and Company, San Francisco; 1964.

APPENDIX 1

Skagit River Thalweg Survey

SKAGIT RIVER RECONNAISSANCE

30 October 1979

Overcast: 50^{o}-60^{o} f.

Party: Greg Hartman
Ken Bierly
Rollie Montagne
Jim Glock
Gary Goneia

Direction of Survey - Marblemount to Newhalem
Approx., River Mile 78.2 to 91.4

Time	River Mile	Depth	Comments
			Sample #1, rt. bank at Marblemount Bridge (R.M. 78.2)
11:20	78.2	5.0	at Marblemount Bridge
	78.3	3.5	
	78.4	2.5	Gravel Bar on rt. bank; small surface riffle
	78.5	3.5	
	78.6	4.0	at Gaging station
11:30	78.8	4.5	
	78.9	5.0	channel on left bank
	79.0		x-line #1
	79.1	7.0	
11:37	79.2	6.5	
	79.3	8.0	House on left bank
	79.4	7.5	channel on rt. side
	79.5	4.0	
	79.6	5.0	flat gravel bar just above water surface 30' wide, rt. side

Skagit River Reconnaissance
Page two.

Time	River Mile	Depth	Comments
	79.7	4.5	house
	79.8	4.0	same continuous bank heights as x-line #1
11:50	79.9	6.5	
	80.0		House on left bank at end of road
11:55	80.1	2'-3'	x-line #2
	80.2	4.5'	
12:02	80.4	8'-9'	flat gravel bar just above water surface, 30' wide left side.
		5.5	
		9'+	downstream of Diobsud Creek mouth
12:04	80.6	over 10'	at mouth Dobsud Creek channel 100' wide
	80.7	4'	Significant quantity of sediment at mouth of creek; forces channel width to neck down to 100' width or less.
12:10	80.8	6'	mouth of Back channel (high water channel) on left bank
	80.9	3'-4'	Redd's noted on left side of channel
	81.0	9'-10' & over	
	81.1	4'-5'	riffles on surface; small
	81.2	5'	
	81.3	3'-4'	u/s entrance of high water channel on left bank
12:25	81.3		x-line #3
	81.4	5'	
	81.6	6'	
	81.7	7.5	

Time	River Mile	Depth	Comments
	81.8	4	Sample #2:- left bank
LUNCH			
13:30	82.3	8'	
	82.4	8'-9'	
	82.8	4'-6'	D/S of Bacon Creek Mouth. Large quantities gravel on each bank. Channel flow width 75' to 100'; 4'-6' drop in water surface through reach. 4'-6' deep at downstream end of drop. Gravel banks cut approximately 6'. Surface turbulent.
	82.9		x-line #4; immediately upstream of drop; between gravel bank deposits.
	83.0	10'	u/s of Bacon Creek Mouth
	83.1	6'	
	83.2	8'	Smooth water surface
	83.4	8	
	83.5	4'	
	83.6	8'	
	83.7	2'-3'	Cross over riffle; surface medium turbulent
13:45	83.8	6'-8'	
	83.9	2'-3'	Cross over riffle D/S of Copper Creek mouth
	84.0	8'-10'	Large sediment quantities at mouth of Copper Creek; channel width restricted by sediment deposition.
	84.1	3'	Sample #3, gravel bar; left side many salmon carcass, left bank (over 100)

Skagit River Reconnaissance
Page four.

Time	River Mile	Depth	Comments
	84.4	4'	passed over many redds from 84.1 to 84.4
	84.6	4'	x-line #5
	84.8	6'	
	84.9	10' & over	smooth water surface
	85.0	6'	Channel has changed since USGS topog chart made. Back eddy present on left side.
	85.1	10' & over	
14:00	85.2	5'	
	85.3		x-line #6; narrowed channel just d/s of medium-large rapids
		3'	just u/s of rapids, sediment deposit from Alma Creek, not as much as previous creeks.
	85.4	8'-9'	Alma Creek mouth
	85.5		u/s end of channel change
	85.6	7'	rippling water surface
		7'	
		6'	
14:10	85.7	4'	
	85.75	2'-3'	
	85.8	4'-6'	Gaging station - smooth surface
	85.9	9'-10' & over	
	86.0	10' & over	120'-150' wide; monitor ? may be good site
			100' or less width, deep Very large rapids (4) in reach
			RIP CITY

Time	River Mile	Depth	Comments:
	87.0	4'	Sample #4
	87.1	3'	Gravel island, +2'+3'; we used rt. bank channel
	87.2	6'	rt. bank channel
	87.3	+10'	u/s of gravel island, saw many Redd's in last 0.1 mile
	87.6	+10'	smooth water surface
	87.7	7'-9'	Damnation Creek, few gravels apparent (may be higher stage)
14:50	87.8	8'-9'	
	87.9		x-line #7; moderate riffle on water surface
	88.0	4.5'	smooth
	88.2	10' & over	
	88.3	5'	Sky Creek mouth, little deposit
	88.4	2.5'	moderate to large riffle
	88.5	6'	smooth surface
	88.6	7.5'	smooth surface
	88.7	3'	
	88.8	3'	Low gravel island (d/s end of braiding reach); less than 1' above surface, we use rt. bank channel
15:00	88.9	4'	Second gravel island; 3' above water surface.
	89.0	4'	u/s of second gravel island
			Sample #5

Note: Channel changed from quad sheet.

Time	River Mile	Depth	Comments
	89.1	9'	Bigger, low island with trees.
	89.2	5'	used left channel
		10'	narrow channel width
		4'	u/s of islands, cross over riffle with 3'-4' drop in water surface, moderate riffles on surface & through large gravels.
	89.6	6'	Gravel bar, rt. side @ +1'-2' with water running over.
	89.7	6'	same condition reoccurs as at R.M. 89.6.
	89.8	2'	Cross over riffle, gravel islands at +2'
		4.5	Braiding continues
	89.9	2'	
	90.0	1'	Hit bottom, Thornton Creek mouth, several channels, braiding condition
	90.1	3'	low bank with trees on rt. side. overtopped at low stages.
	90.2	5'	low bank with trees, rt. side
	90.3	9.5'	
	90.4		u/s of islands (braiding) creek enters on rt. bank
	90.6	4.5	another island, gravel bar type with cutting at channel, 3'-4' drop in water surface, moderate size riffles on surface
	90.7		x-line #8
	90.8	6'	smoother waters
15:30	91.0	6'	
	91.1	4'	point bar at turn
	91.2	4'	riffle condition, 2 ft. cut drop x-line #9

APPENDIX 2

Crosslines On Skagit River

CROSSLINES ON SKAGIT RIVER

30 October 1979

Reference distances modified, relative to Seattle City Light topog surveys.

<u>X-Line #1</u>: (11:34; R.M. 79.0, 260' wide)

Lft. bank	+12' high, 1 on 3 slope
15'	5'
40'	8'
65'	7.5
(℄) 130'	6.5
160'	5.5
195	4.0
Rt. Bank	+12' high, 1 On 2 slope, trees

<u>X-Line #2</u>: (11:55; R.M. 80.1, 240' wide)

Lft. bank	(same as #1)
20	3'
60	3.5'
(℄) 120	3.0
140	2.0'
150	2.5'
160	3.0'
180	4.0'
Rt. Bank	(same as #1)

<u>X-Line #3</u>: (12:20, R.M. 81.3, 290' wide)

Lft. bank	
70	2'
(℄) 145	3
210	4
240	3.5
260	3
Rt. bank	

<u>X-Line #4</u>: (13:38; R.M. 82.8, 130' wide)

Lft. bank	120-150' gravel bar @ +1' to 2' above water
0	+2
120	+2
123	2
180	5'
220	6'
230	7'
Rt. bank (@ 10' - 20')	

<u>X-Line #5</u>: (13:52, R.M. 84.6, 310' wide)

Lft. bank	(highway slope)
10	4'
40	3.5'
80	3.5'
(℄) 160	3.5
240	3.5
260	3.5
290	3' (20' from rt. bank)

X-Line #6: (14:00; R.M. 85.3, 130' wide)

Lft. bank	
10'	8'
40'	8'
70'	7'
(3/4) 100	6'

X-Line #7: (14:50; R.M. 87.8, 130' wide)

Lft. bank	+6' high
40	2'
50	4'
65'	7'
90'	9'
110'	7' (20' from rt. bank)

X-Line #8: (15:45; R.M. 90.5, 220' wide)

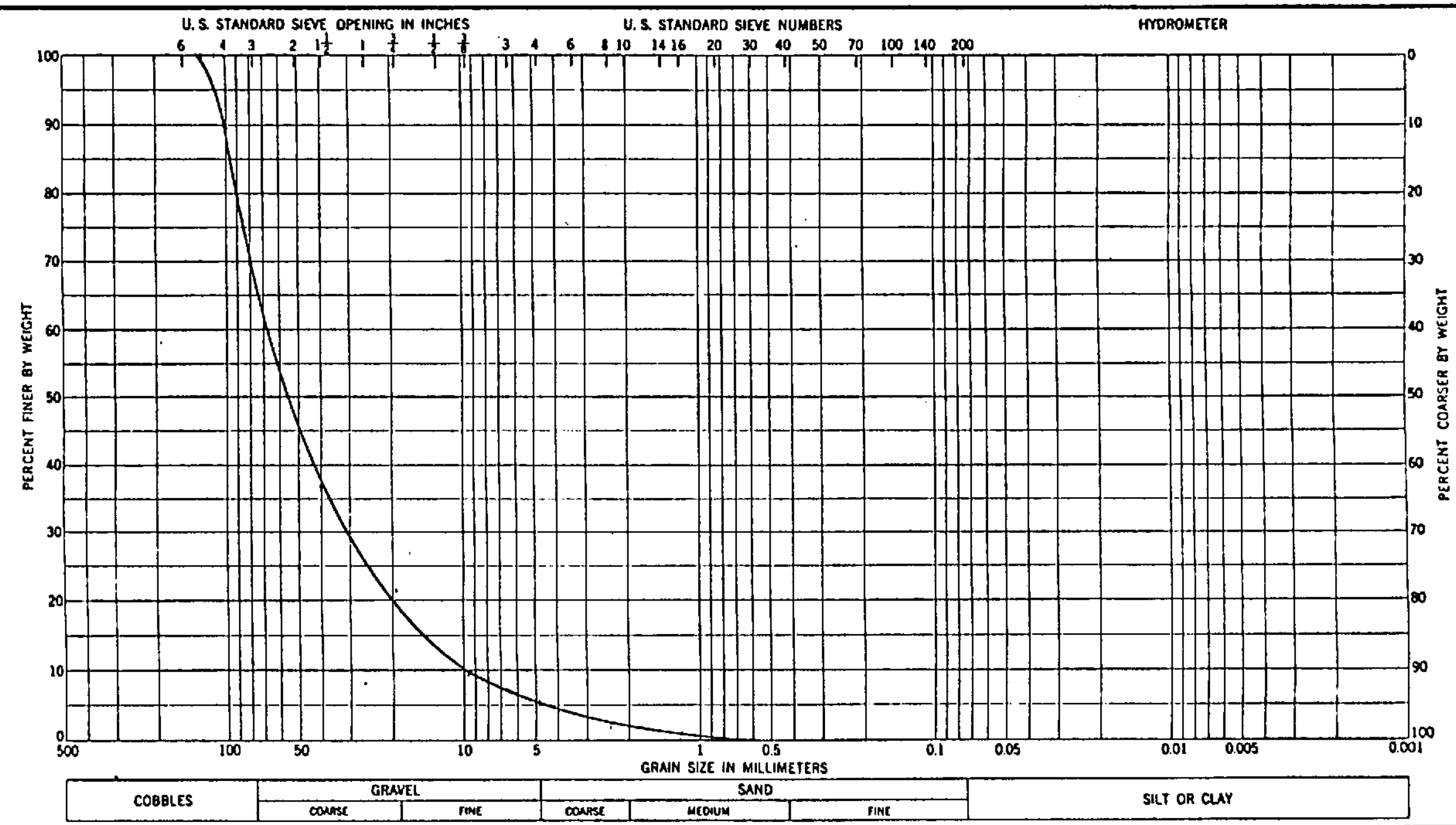
Lft. bank	1 on 2
15'	2
20'	2.5
30'	3
40'	4
45'	4.5
50'	5
55'	5.5
110	6
(3/4) 160	5
185	4

X-Line #9: (15:35; R.M. 91.2, 290' wide)

Lft. bank	+1 to +2 gravel riffle
20'	4
100'	4
150'	4
220'	3
240'	2 (50' to rt. bank)
Rt. Bank	1 on 10

APPENDIX 3

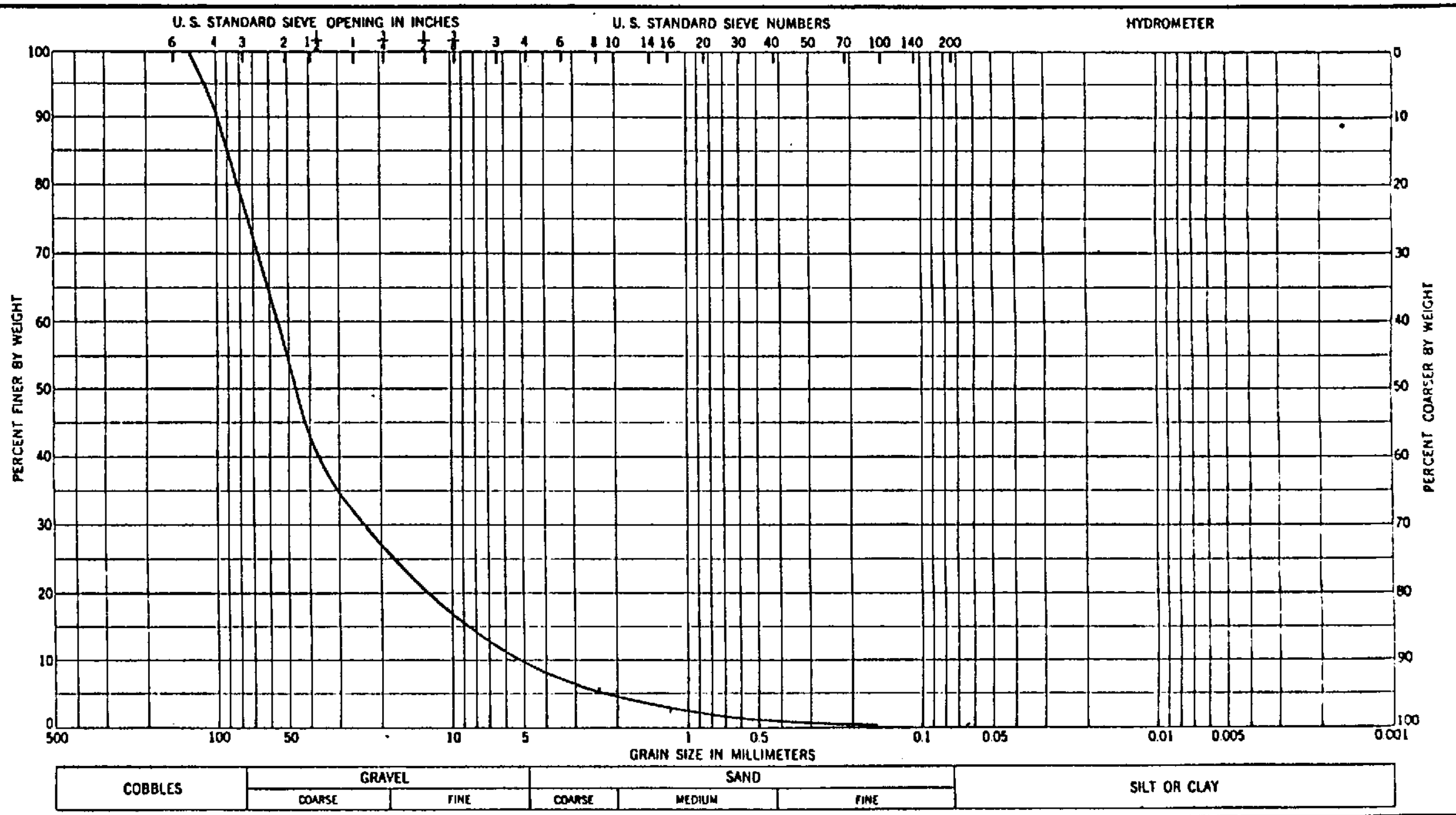
Bed Sediment Samples, Skagit River



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
1		Skagit River Mile 78.2 at Marblemount Oct. 30, 1979				

GRADATION CURVES

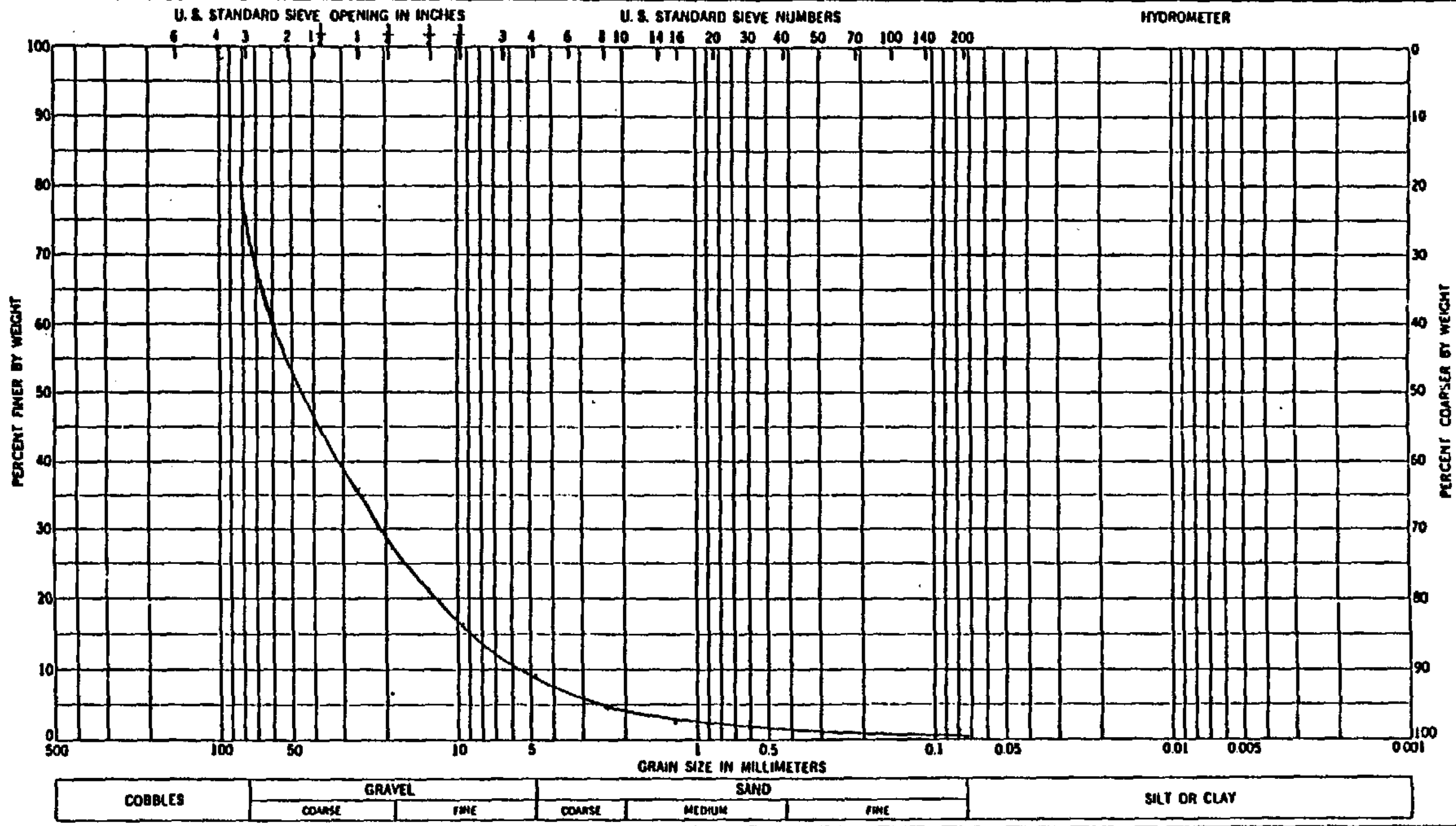
OGDEN BEEMAN AND ASSOCIATES
620 S.W. 5th Avenue
PORTLAND, OREGON 97204
(503) 223-8254



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
2		Skagit River Mile 81.8 Oct. 30, 1979				

OGDEN BEEMAN AND ASSOCIATES
620 S.W. 5th Avenue
PORTLAND, OREGON 97204
(503) 223-8254

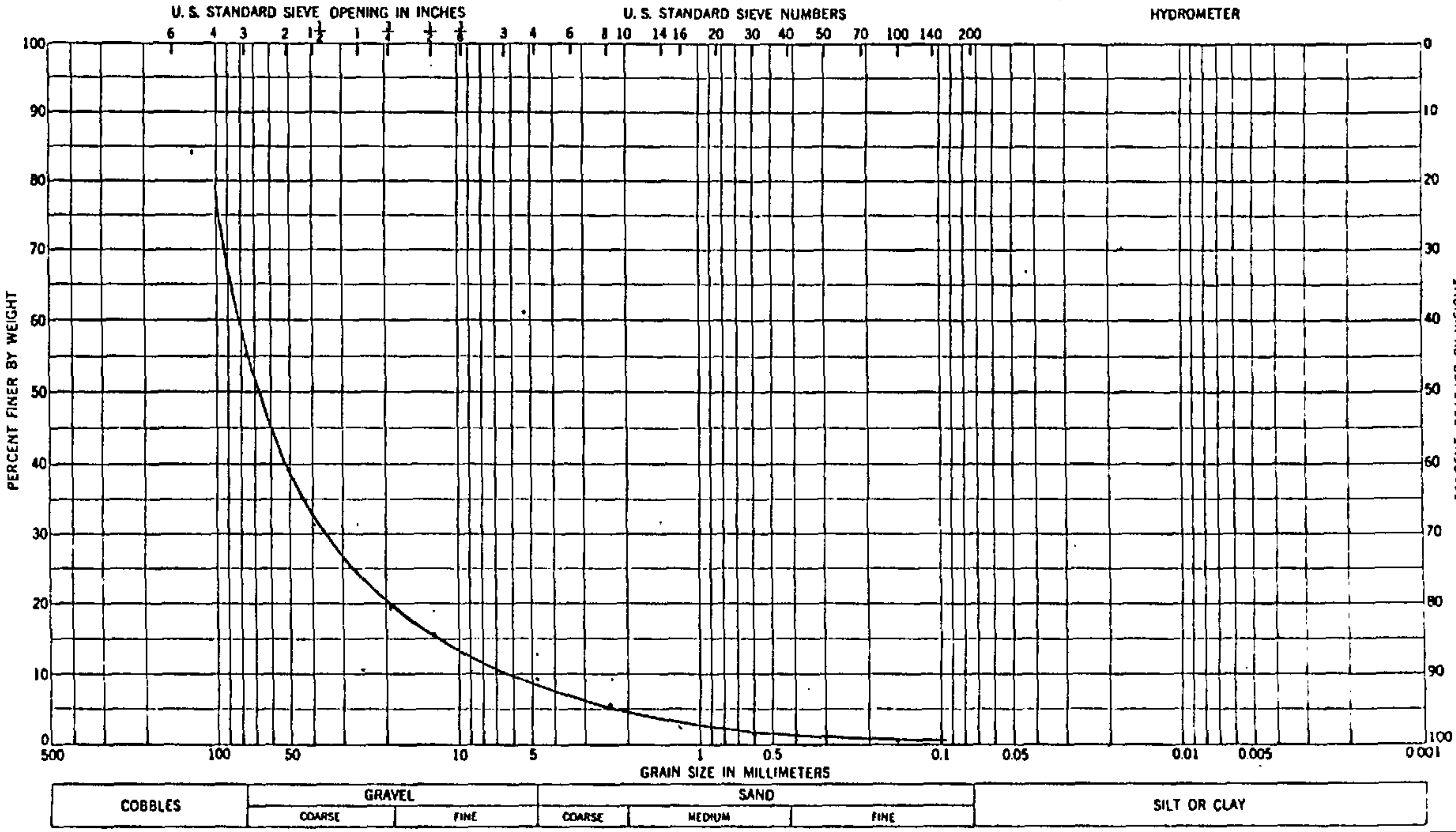
GRADATION CURVES



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
3		Skagit River Mile 84.1 u/s of Copper Creek Oct. 30, 1979				

GRADATION CURVES

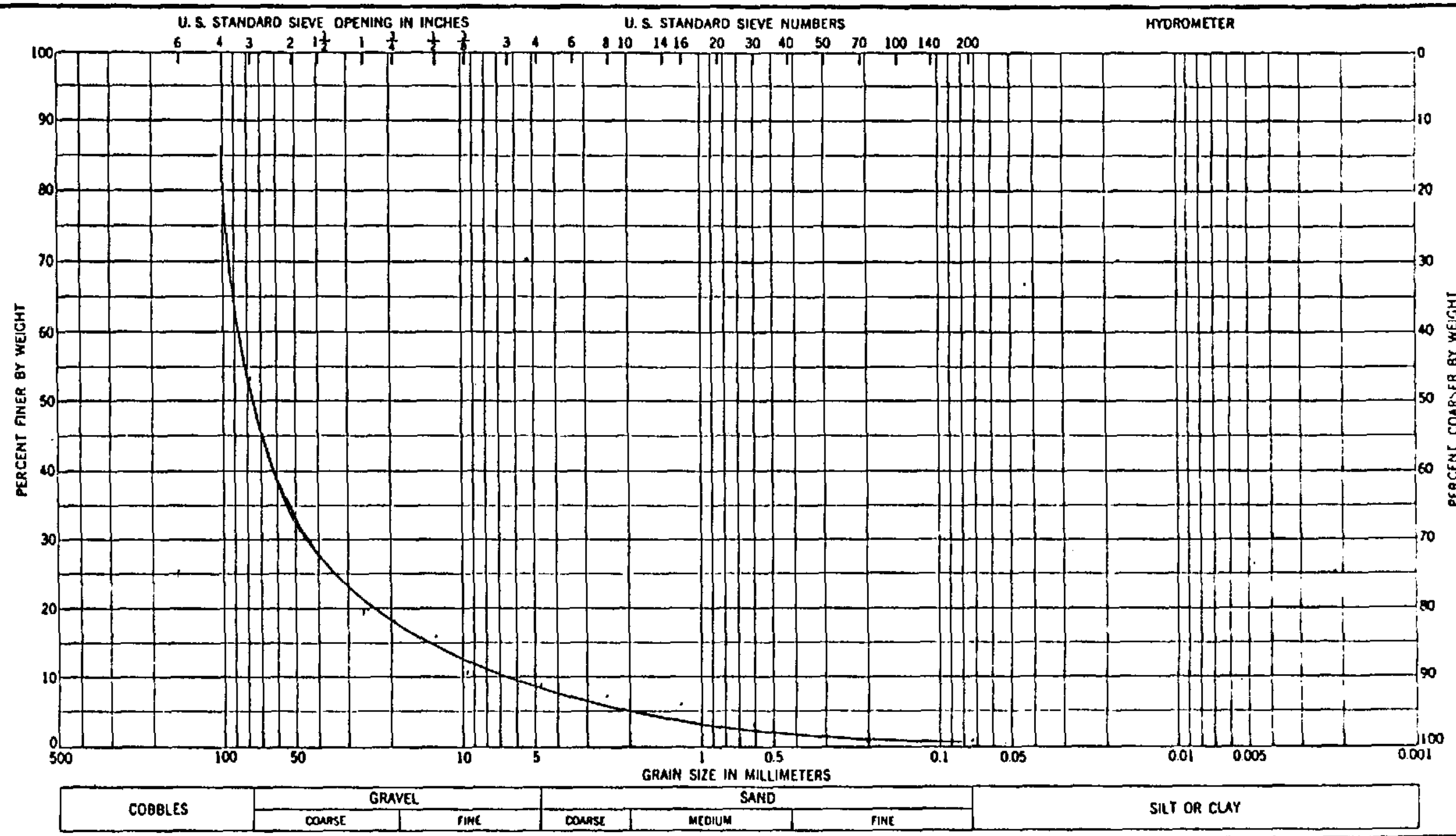
OGDEN BEEMAN AND ASSOCIATES
620 S.W. 5th Avenue
PORTLAND, OREGON 97204
(503) 223-8254



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
4		Skagit River Mile 87.0 Oct. 30, 1979				

OGDEN BEEMAN AND ASSOCIATES
620 S.W. 5th Avenue
PORTLAND, OREGON 97204
(503) 223-8254

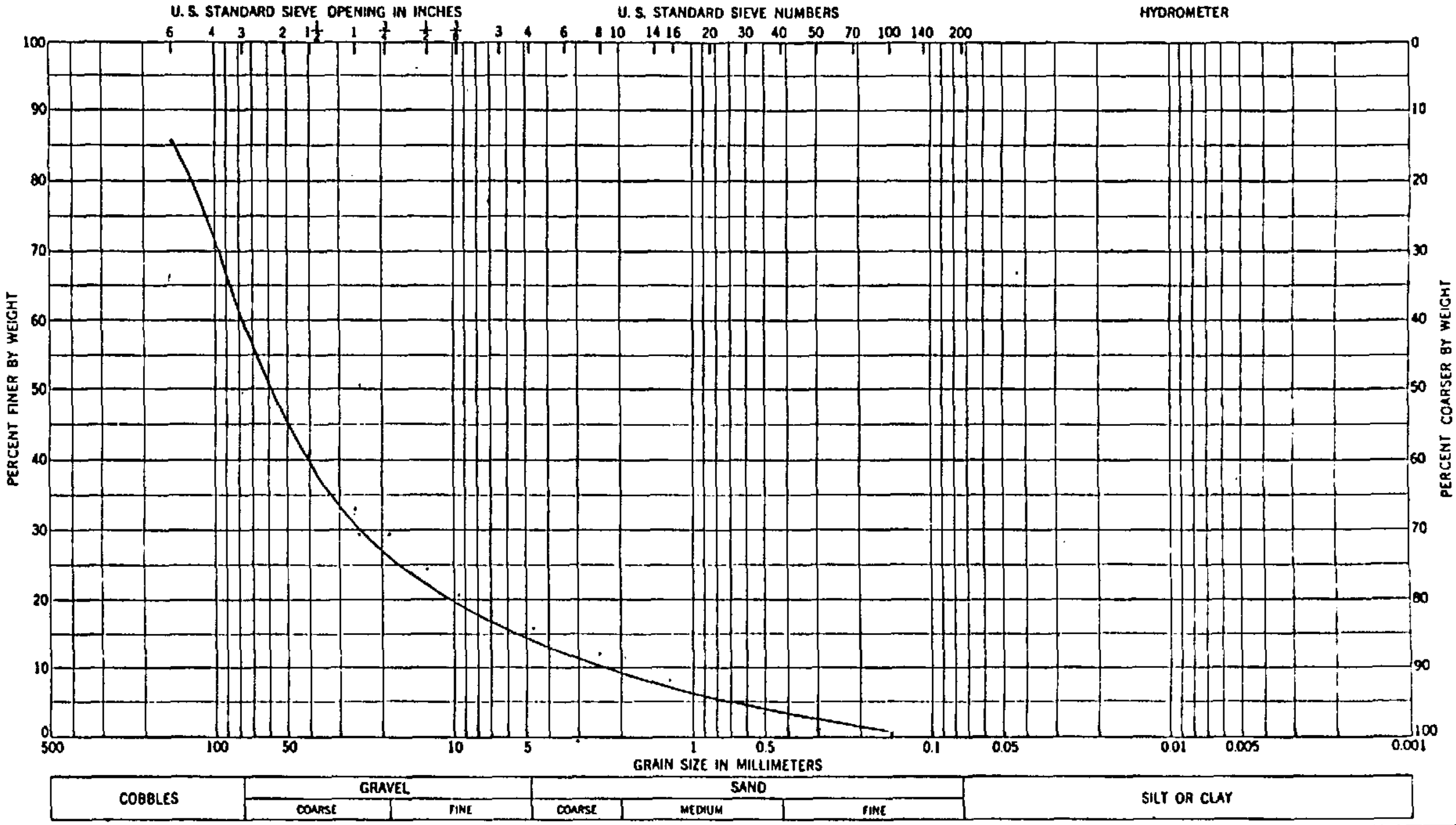
GRADATION CURVES



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
5		Skagit River Mile 89.0 Oct. 30, 1979				

GRADATION CURVES

OGDEN BEEMAN AND ASSOCIATES
620 S.W. 5th Avenue
PORTLAND, OREGON 97204
(503) 223-8254



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
6		Skagit River Mile 90.5 Oct. 30, 1979				

OGDEN BEEMAN AND ASSOCIATES
620 S.W. 5th Avenue
PORTLAND, OREGON 97204
(503) 223-8254

GRADATION CURVES

APPENDIX B

Fish Data and Tag Assignment

FISH RELEASE DATA

TIME		TAG				LOCATION			FISH					
Date (MO DA YR)	Time	Chan.	Freq.	Pulse		River Mile	Mon	Site#	Sex	Len	Gird	Tag	Vit.	
1 20 679	1000	4		1.0		90.0		1	1	740	380	178	2	
				.					1	813	457	175	2	
				.					1	864	783	157	1	
				.					1	826	452	176	2	
		2		.					1	813	432	136	2	
				.					2	762	406	135	1	
				.					1	187	406	137	2	
				.					1	876	508	138	1	
		5		.					1	826	452	197	2	
				.					1	737	394	198	1	
				.					1	864	457	195	2	
				.					1	737	350	196	2	
		1		.						781	470	118	2	
				.						702	521	116	2	
				.						713	432	115	1	
				.						864	457	117	2	
		3		.					2	711	318	158	2	
		3		.					2	744	330	157	2	
	1150	3		.					2	613	330	156	2	
	1305	1		4.0					1	[illegible]	374	127	2	
	1305			.					1	73[illegible]	406	12[illegible]	[illegible]	
	1320			.					1	884	457	130	1	
	1325			.					1	838	432	128	[illegible]	
		2		.					1	762	414	148	1	
				.					2	737	356	147	2	
				.					2	787	356	149	2	
	1400			.					1	762	351	150	2	
		3		.					1	787	432	159	1	
		3		.					1	737	457	170	2	
		3		.					1	864	521	168	2	

FISH RELEASE DATA

TIME		TAG				LOCATION			FISH				
Date MO DAY YR	Time	Chan.	Freq.	Pulse		River Mile	Mon#	Site#	Sex	Len	Gird	Tag	Vit.
120679	1415	3		4.0		90.0		1	2	737	342	167	2
		4							1	686	342	190	1
									1	799	419	188	1
									2	724	330	189	2
									2	660	310	187	2
	1425	5							1	724	381	209	1
	1425								2	648	279	208	2
	1430								1	711	381	207	2
	1430								2	737	356	210	3
	1550	1		0.5		90.5		2	2	673	279	114	2
									2	781	330	113	1
									2	787	342	111	
									1	813	406	112	
	1600	2							1	864	483	134	
	1600								2	711	330	132	
	1610								1	889	483	133	3
	1610								1	711	533	131	3
120779	1235	3							2	749	368	153	2
									2	711	318	152	2
									2	711	305	151	2
									1	711	381	154	1
	1245	4							2	673	330	172	2
									2	673	330	174	
									1	737	403	171	
		2							2	686	318	173	
		3								655	318	194	
	1255	1								648	279	192	
	1255									686	318	193	
	1300									737	343	191	
	1300	1		2.0					1	787	406	120	2

FISH RELEASE DATA

TIME		TAG				LOCATION			FISH					
Date (MO DAY YR)	Time	Chan.	Freq.	Pulse		River Mile	Mon#	Site#	Sex	Len	Gird	Tag	Vit.	
120779	1300	1		2.0		90.5		2	2	762	356	121	2	
	1315	1		2.0						640	292	122		
	1315	1		2.0						659	305	119		
	1315	3		2.0						659	305	161		
	1325	3		2.0						711	330	159		
121079	1340	6		0.5		90.0		1	1	876	533	218	1	
	1342								1	737	432	215	1	
	1344								1	762	381	217	1	
	1348								1	762	381	216	2	
	1350	7							2	737	356	237	2	
	1354								1	724	394	235	1	
	1356								1	737	394	236	1	
	1358								2	711	318	238	2	
	1400	8							1	940	533	255	1	
	1402								1	724	394	256	1	
	1408								2	762	381	257	1	
	1410								1	724	381	258	1	

FISH RELEASE DATA

TIME		TAG				LOCATION			FISH				
Date (MO DAY YR)	Time	Chan.	Freq.	Pulse		River Mile	Mon	Site#	Sex	Len	Gird	Tag	Vit.
010580	1530	6	649	4.0		20.5		2		812	406	231	3
		6	648	4.0					1	914	533	232	1
		6	648	4.0					2	826	356	233	
		6	650	4.0					1	876	470	234	
		9	680	0.5					2	737	368	275	
		9	679	0.5						660	330	276	
		9	680	0.5						800	368	277	
		9	679	0.5						899	330	278	
		7	659	4.6						699	279	251	
				.						762	356	252	
				.						711	330	253	
				.					1	899	508	254	
		8	670	.					2	686	318	271	
			669	.					2	698	305	272	
			669	.					1	902	483	273	
			669	.					2	711	305	274	
		9	679	.						673	279	291	
				.						686	279	292	
				.						673	242	293	
										597	279	294	
		10	690							787	406	311	
			690	.						724	330	312	
			690	.						787	394	313	
			[illegible]9	.						762	343	314	
	0910		691	0.5		20.0		1	1	881	507	295	2
	0910		691	0.5		20.0		1	2	635	0[illegible]7	296	2

Release Site 1
December 6, 1979

SEX & NUMBER			CONDITION			SIZE				
Sex	Number	%	Prespawned	Spawned	Dead	Average Length (mm) $\bar{X}$	S_x	Average Girdth(mm) $\bar{Y}$	S_y	Ratio Y / X
Male	28	72	11	17	0	792.18	63.02	429.96	46.20	.54
Female	11	28	1	9	1	720.45	43.64	359.92	34.20	.50
TOTAL	39	100	12	26	1	771.95	66.28	403.44	60.53	

Release Site 2
December 6, 1979

Male	4	50	0	2	2	870.00	43.14	476.25	52.43	.55
Female	4	50	0	4	0	739.50	57.00	320.25	28.08	.43
TOTAL	8	100	0	6	2	804.75	83.99	398.25	92.03	

Release Site 2
December 7, 1979

Male	3	17	1	2	0	745.00	38.63	397.67	14.43	.52
Female	15	83	0	15	0	689.33	39.65	321.00	23.25	.47
TOTAL	18	100	1	17	0	698.61	43.89	333.78	36.53	

Release Site 1
December 10, 1979

SEX & NUMBER			CONDITION			SIZE				
Sex	Number	%	Prespawned	Spawned	Dead	Average Length (mm) $\bar{X}$	S_x	Average Girdth (mm) $\bar{Y}$	S_y	Ratio Y / X
Male	9	75	8	1	0	776.22	77.82	424.78	63.31	.55
Female	3	25	1	2	0	736.67	25.50	351.67	31.72	.48
TOTAL	12	100	9	3	0	766.33	69.58	406.50	69.74	

Release Site 2
January 5, 1980

Male	4	17	0	0	4	895.25	16.40	498.50	27.89	.56
Female	20	83	0	0	20	722.05	61.00	332.65	41.78	.46
TOTAL	24	100	0	0	24	750.92	86.35	360.29	74.36	

Release Site 1
January 5, 1980

Male	1	50	0	1	0	889.00		509.00		.57
Female	1	50	0	1	0	635.00		267.00		.42
TOTAL	2	100	0	2	0	762.00		388.00		

GRAND TOTALS:						
Male	49	20	23	6	803.10	938.02
Female	54	2	31	21	713.13	333.89
TOTAL	103	22	54	27		

APPENDIX C

Stationary Monitor Data

Monitor 1 Record

$\boxed{1}$ = tag passed unrecorded

RELEASE	TAG	12/7	12/8	12/9	12/10	12/11	12/12	12/13	12/14	12/15	12/16	12/17	12/18+	Total
1	1-1		1									1	1	3
	1-4					1							2	3
	2-1		1									1		2
	2-4				1		1					1		3
	3-1								2				1	3
	3-4	1		1			1							3
	4-1		1	1										2
	4-4			1		1			1			1		4
	5-1			2						1				3
99	5-4											1		2
Total		1	3	5	1	2	2	0	3	1	0	5	4	28
2	1-5		1		1	1						1		4
8	2-5			1								1	1	3
Total		0	1	1	1	1	0	0	0	0	0	2	1	7
3	6-5	—	—	—	—						2		2	4
	7-5	—	—	—	—					1			1	2
12	8-5	—	—	—	—	1						1	1	3
Total						1	0	0	0	1	2	1	4	9
4	1-2			1	1					1				3
	3-5	1			1				1					3
	*3-2						1						1	2
	4-5				1						1		1	3
18	5-5										1	1	1	3
Total		1	0	1	3	0	1	0	1	1	2	1	3	14
All Releases Total		2	4	7	5	4	3	0	4	3	4	9	12	$\boxed{58}$

* 2 only released

Monitor 2 Record

$\boxed{}$ = tag passed unrecorded

RELEASE	TAG	12/7	12/8	12/9	12/10	12/11	12/12	12/13	12/14	12/15	12/16	12/17	12/18+	Total
1	1-1		1									1	1	3
	1-4					1							1	2
	2-1		1									1		2
	2-4						1					1		2
	3-1								1					1
	3-4	1		1		1								3
	4-1		1	1					1					3
	4-4			1		1			1			1		4
	5-1			1		1				1				3
39	5-4						1		1					2
	Total	1	3	4	0	4	2	0	4	1	0	4	2	25
2	1-5			1	1	1							1	4
8	2-5					$\boxed{1}$						1	1	3
	Total	0	0	1	1	2	0	0	0	0	0	1	2	7
3	6-5										1	1		2
	7-5									1				1
12	8-5					1						1		2
	Total					1	0	0	0	1	1	2	0	5
4	1-2			1	1					1		1		4
	3-5		1						1				1	3
	*3-2						1							1
	4-5				1									1
18	5-5										$\boxed{1}$		1	2
	Total	0	1	1	2	0	1	0	1	1	1	1	2	11
All Releases Total		1	4	6	3	6	3	0	5	3	2	8	6	$\boxed{48}$

* 2 only released

Monitor 3 Record (includes Mobile Monitor record)

DATE

RELEASE		TAG	12/7	12/8	12/9	12/10	12/11	12/12	12/13	12/14	12/15	12/16	12/17	12/18+	Total
1		1-1								1				2	3
		1-4												1	1
		2-1		1									1		2
		2-4						1							1
		3-1		1											1
		3-4						1							1
		4-1			1		1			1					3
		4-4						1					2		3
		5-1				1							1	1	3
	39	5-4						1		1	1			1	4
Total			0	2	1	1	1	4	0	3	1	0	4	5	22
2		1-5				2								1	3
	8	2-5						1					1	1	3
Total			0	0	0	2	0	1	0	0	0	0	1	2	6
3		6-5											2		2
		7-5										1			1
	12	8-5						1					1		2
Total							0	1	0	0	0	1	3	0	5
4		1-2											1		1
		3-5								2				1	3
		*3-2						1							1
		4-5										1		1	2
	18	5-5													0
Total				0	0	0	0	1	0	2	0	1	1	2	7
All Releases Total			0	2	1	3	1	7	0	5	1	2	9	9	$\boxed{40}$

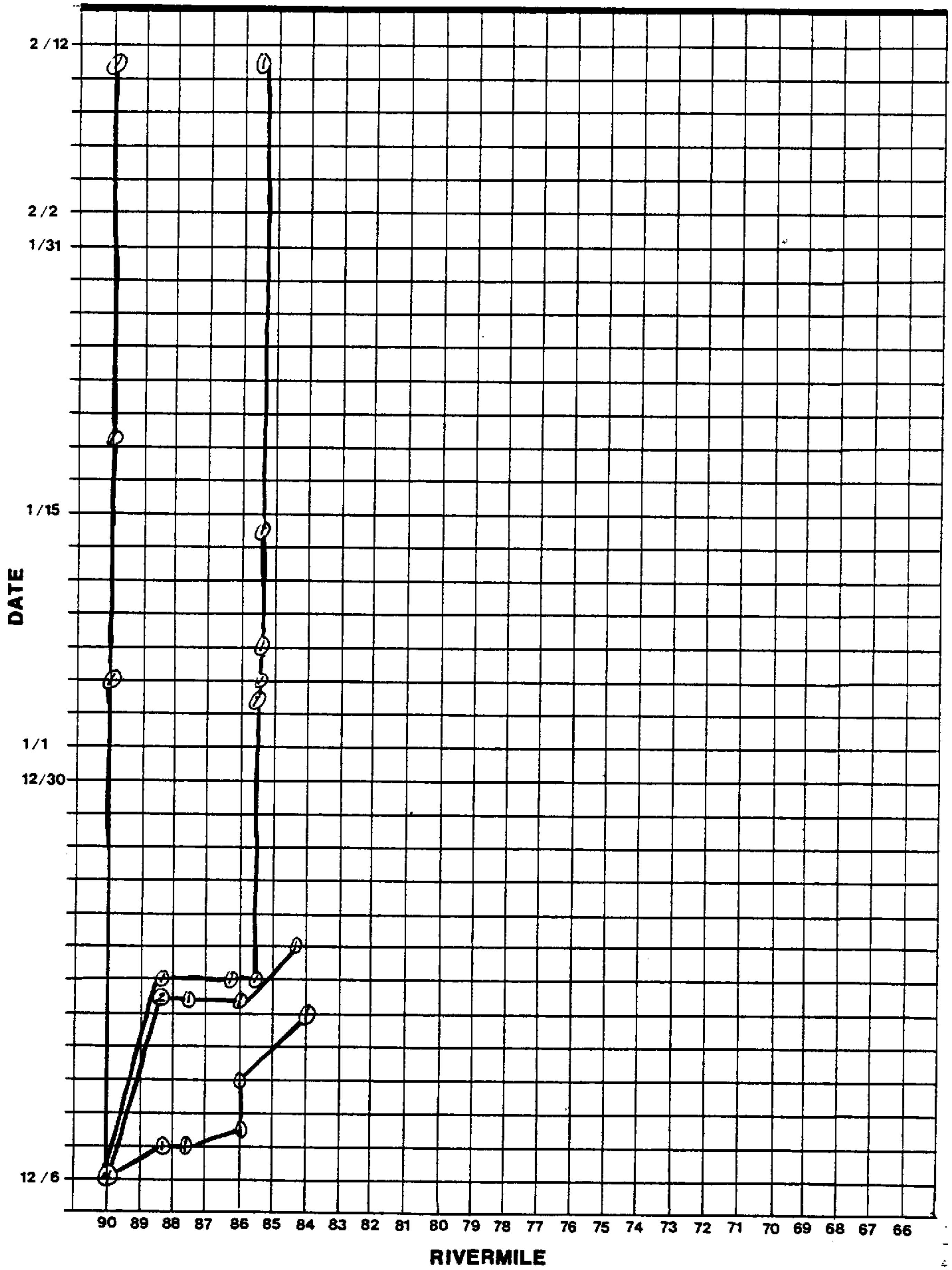
* 2 only released

APPENDIX D

Time Distance Plots of Individual Tags

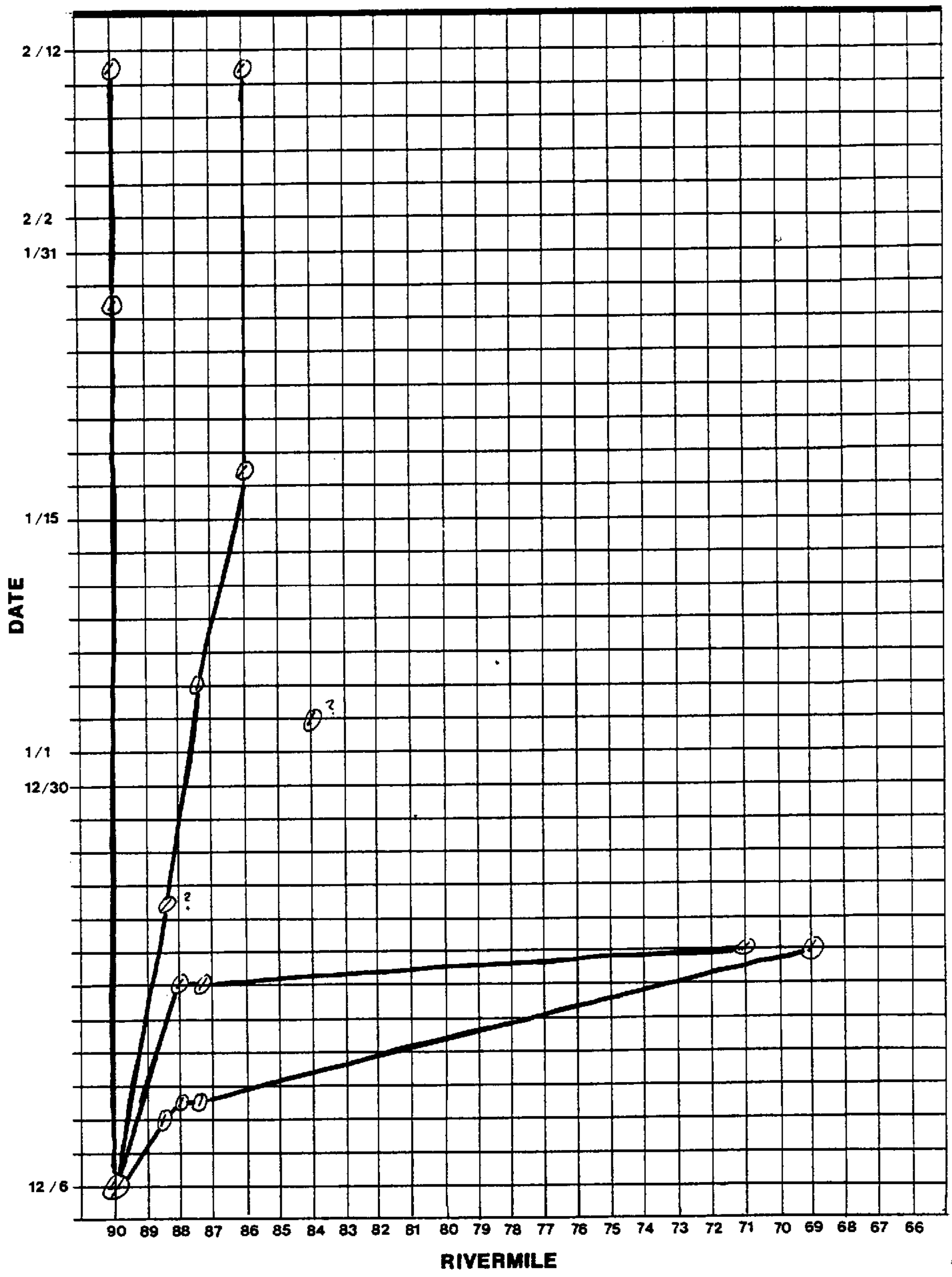
Release Date 12/6/79
Release Location R.M. 90.0
Channel 1
Pulse Rate 1

Recorded Locations of Tags



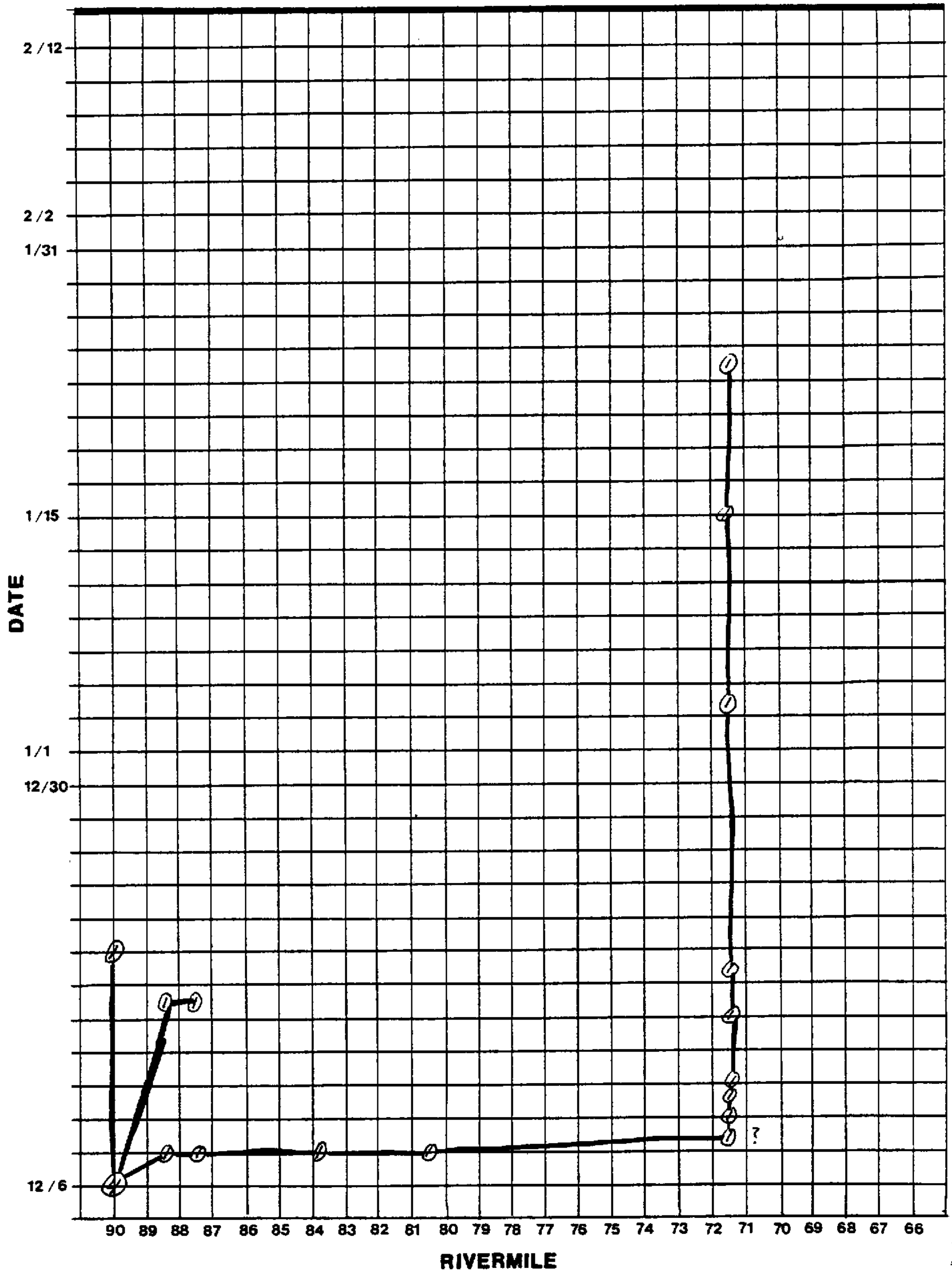
Release Date 12/6/79
Release Location R.M. 90.0
Channel 1
Pulse Rate 4

Recorded Locations of Tags



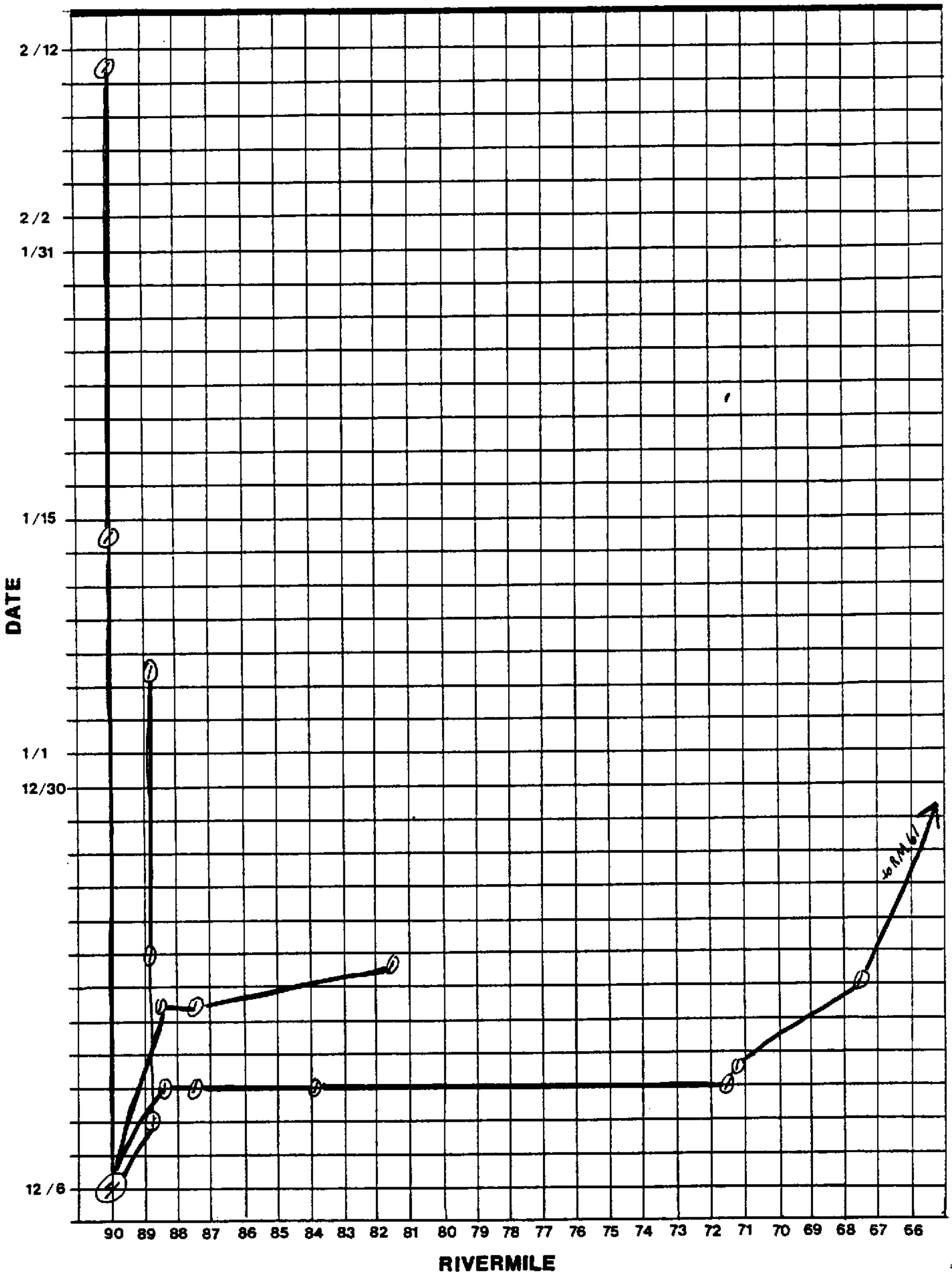
Release Date 12-6-79
Release Location R.M. 90.0
Channel 2
Pulse Rate 1

Recorded Locations of Tags



Release Date 12-6-79
Release Location R.M. 90.0
Channel 2
Pulse Rate 4

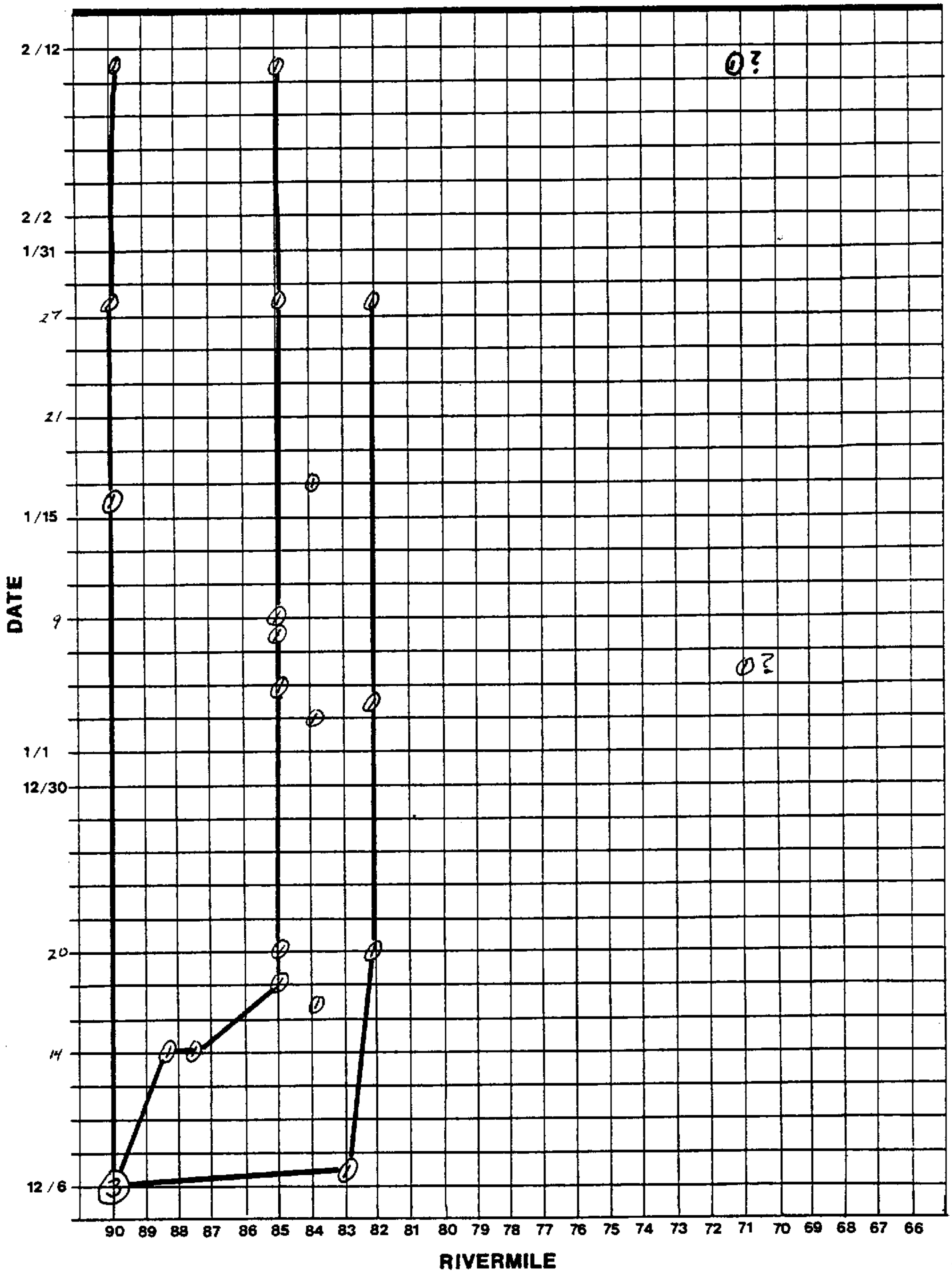
Recorded Locations of Tags



Recorded Locations of Tags

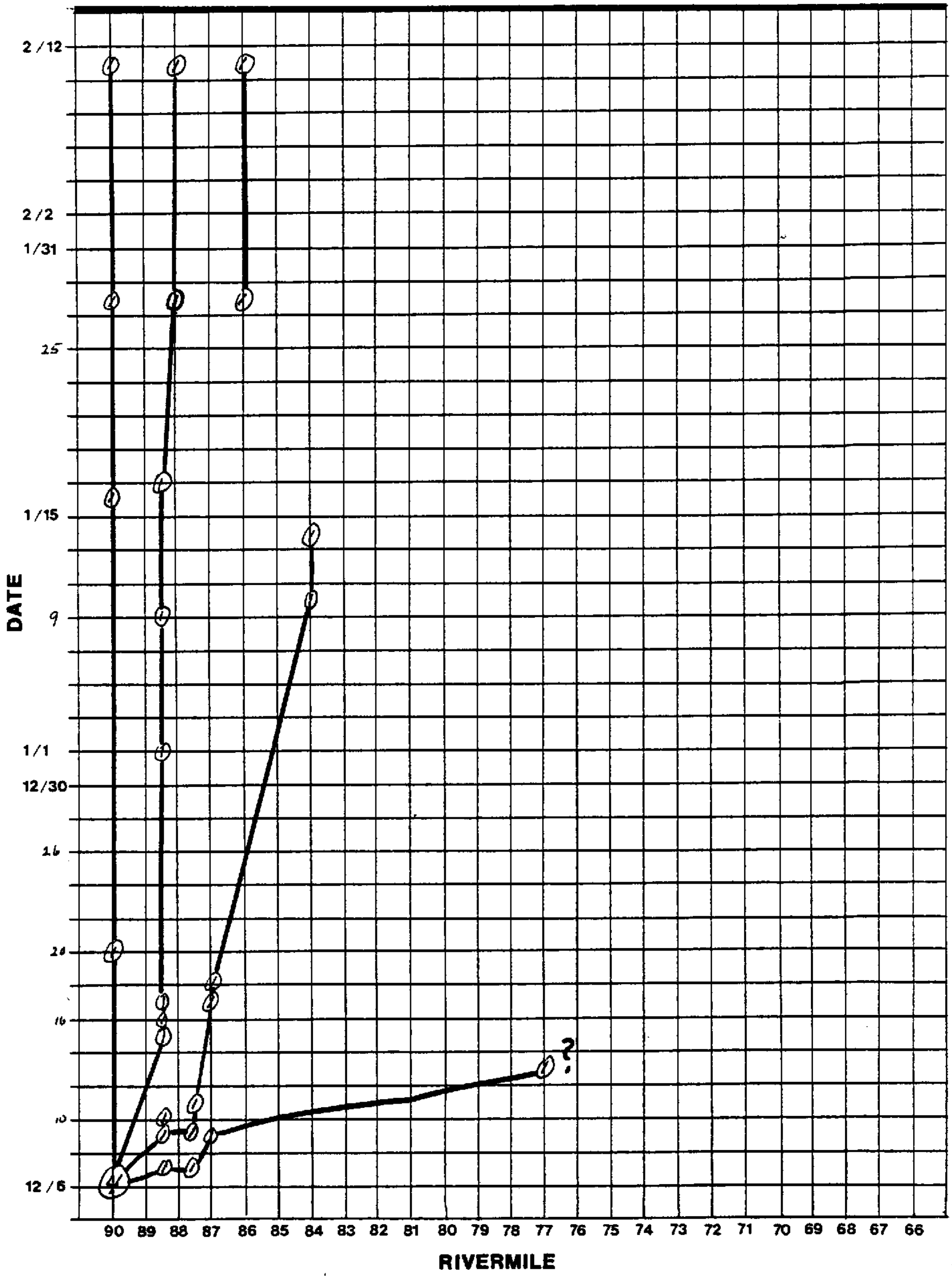
Release Date 12-6-79
Release Location R.M. 90.0
Channel 3
Pulse Rate 1

3 tags only *



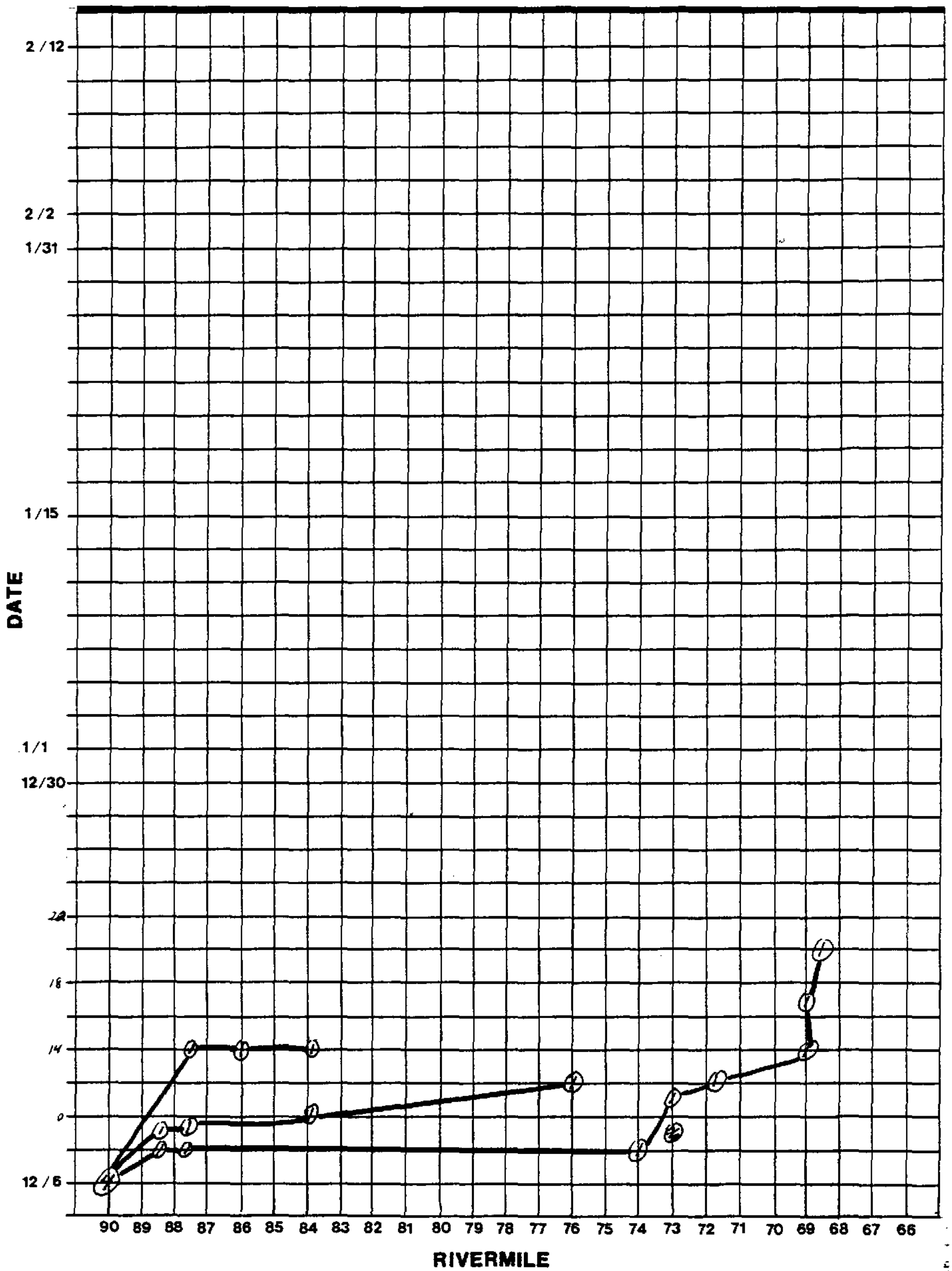
Release Date 12-6-79
Release Location R.M. 90.0
Channel 3
Pulse Rate 4

Recorded Locations of Tags



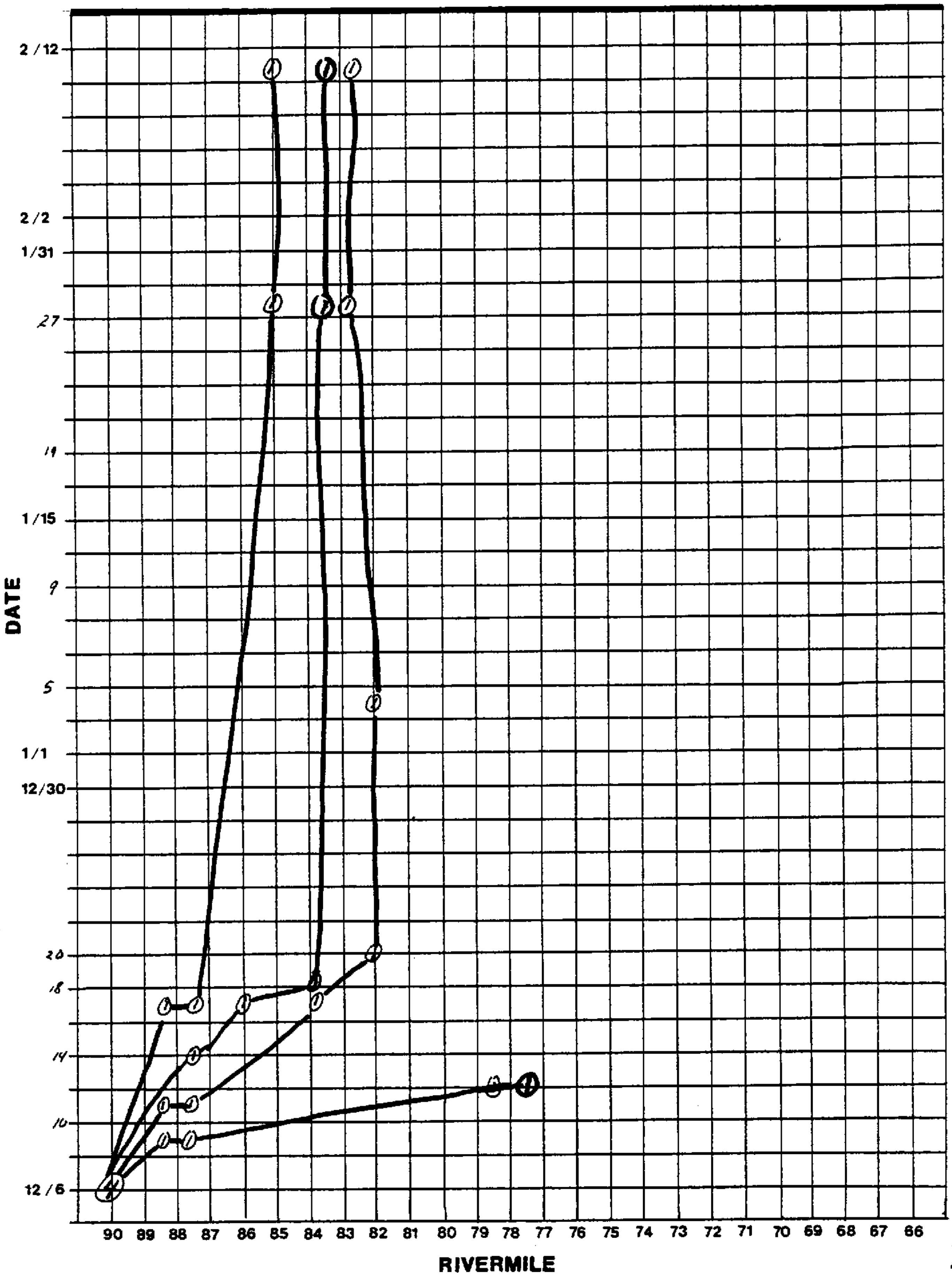
Recorded Locations of Tags

Release Date 12-6-79
Release Location R.M. 90.0
Channel 4
Pulse Rate 1



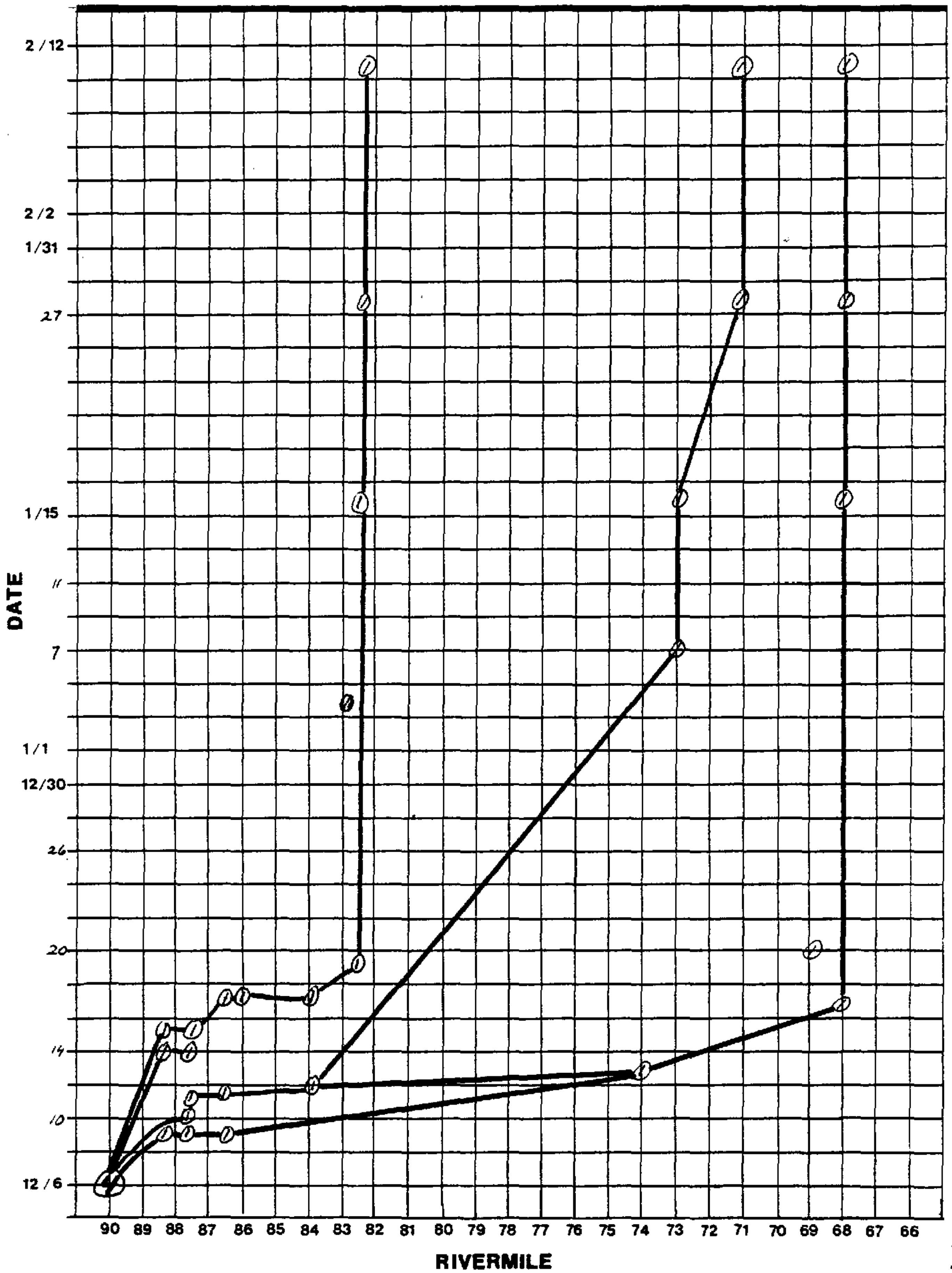
Recorded Locations of Tags

Release Date 12-6-79
Release Location R.M. 90.0
Channel 4
Pulse Rate 4



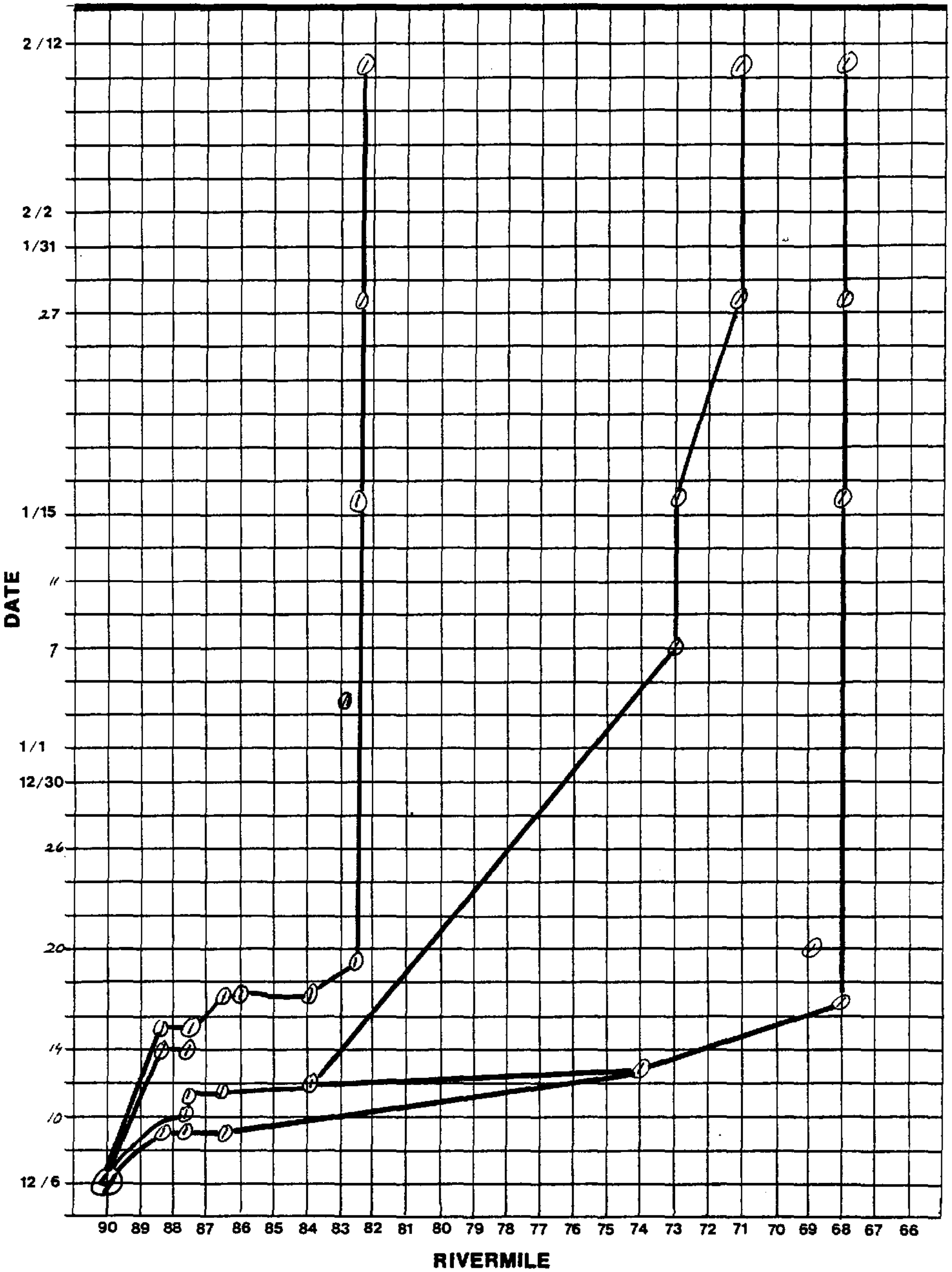
Recorded Locations of Tags

Release Date 12-6-79
Release Location R.M. 90.0
Channel 5
Pulse Rate 1



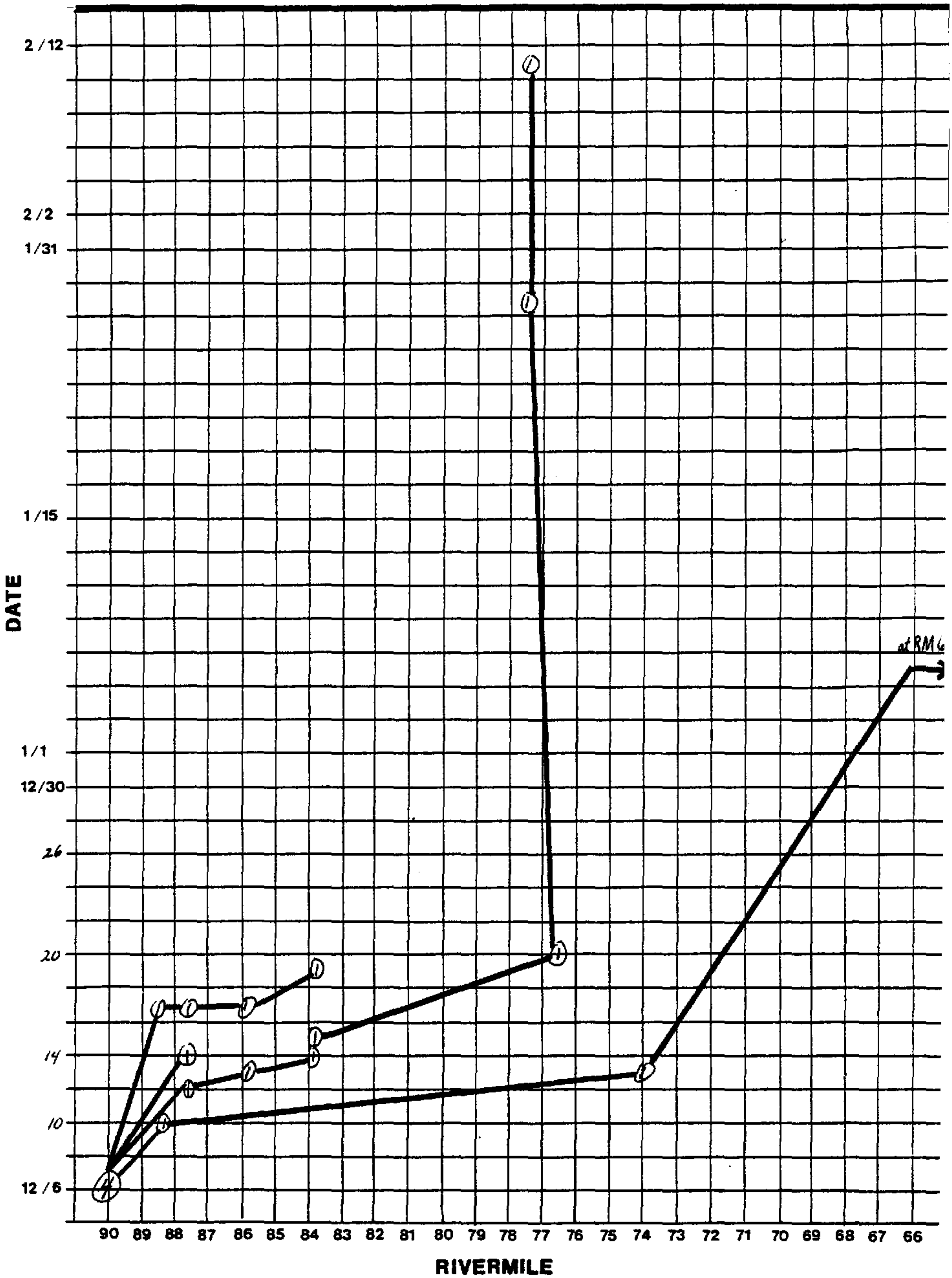
Recorded Locations of Tags

Release Date 12-6-79
Release Location R.M. 90.0
Channel 5
Pulse Rate 1



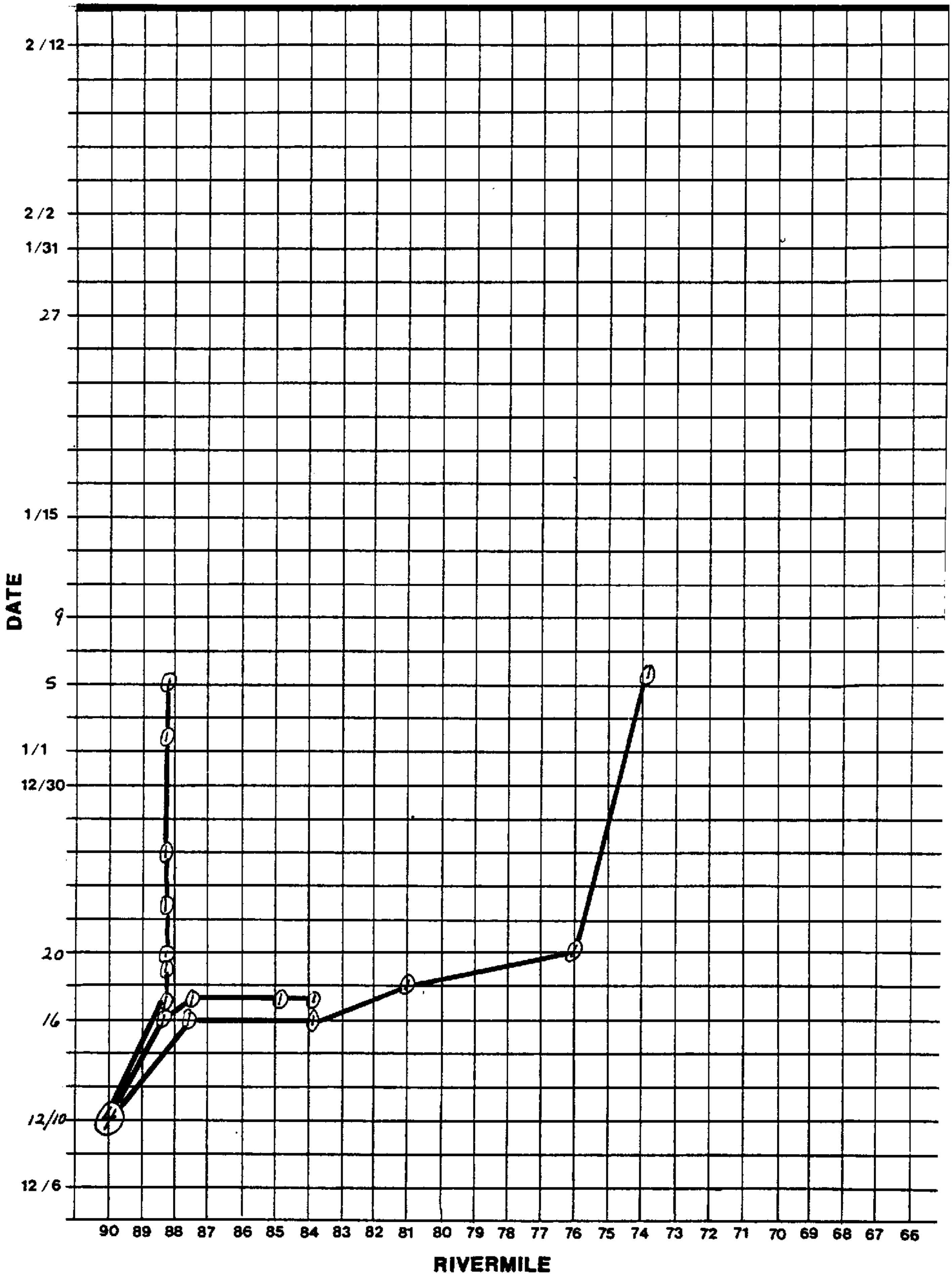
Release Date 12-6-79
Release Location R.M. 90.0
Channel 5
Pulse Rate 4

Recorded Locations of Tags



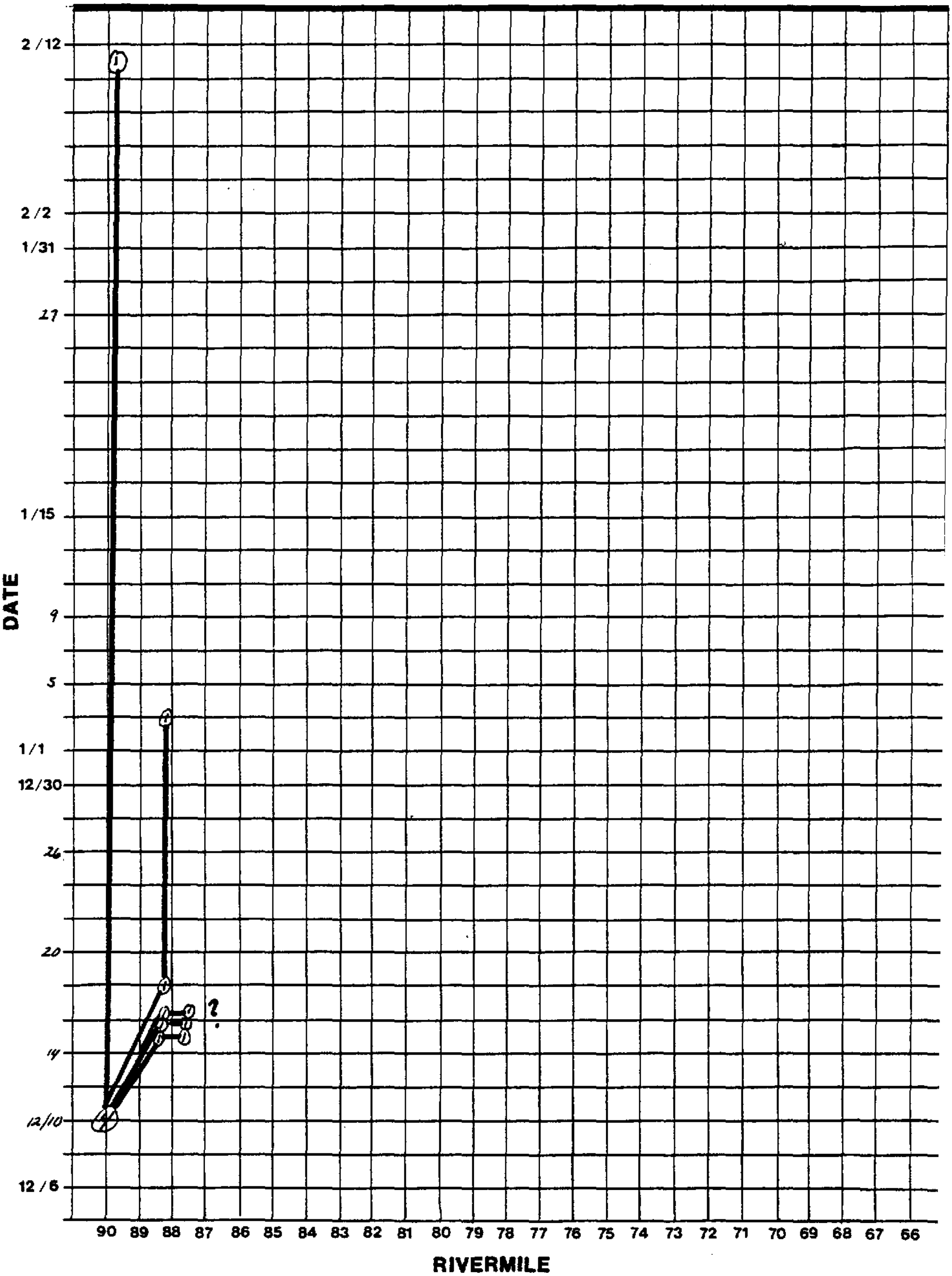
Release Date 12-10-79
Release Location R.M. 90.0
Channel 6
Pulse Rate .5

Recorded Locations of Tags



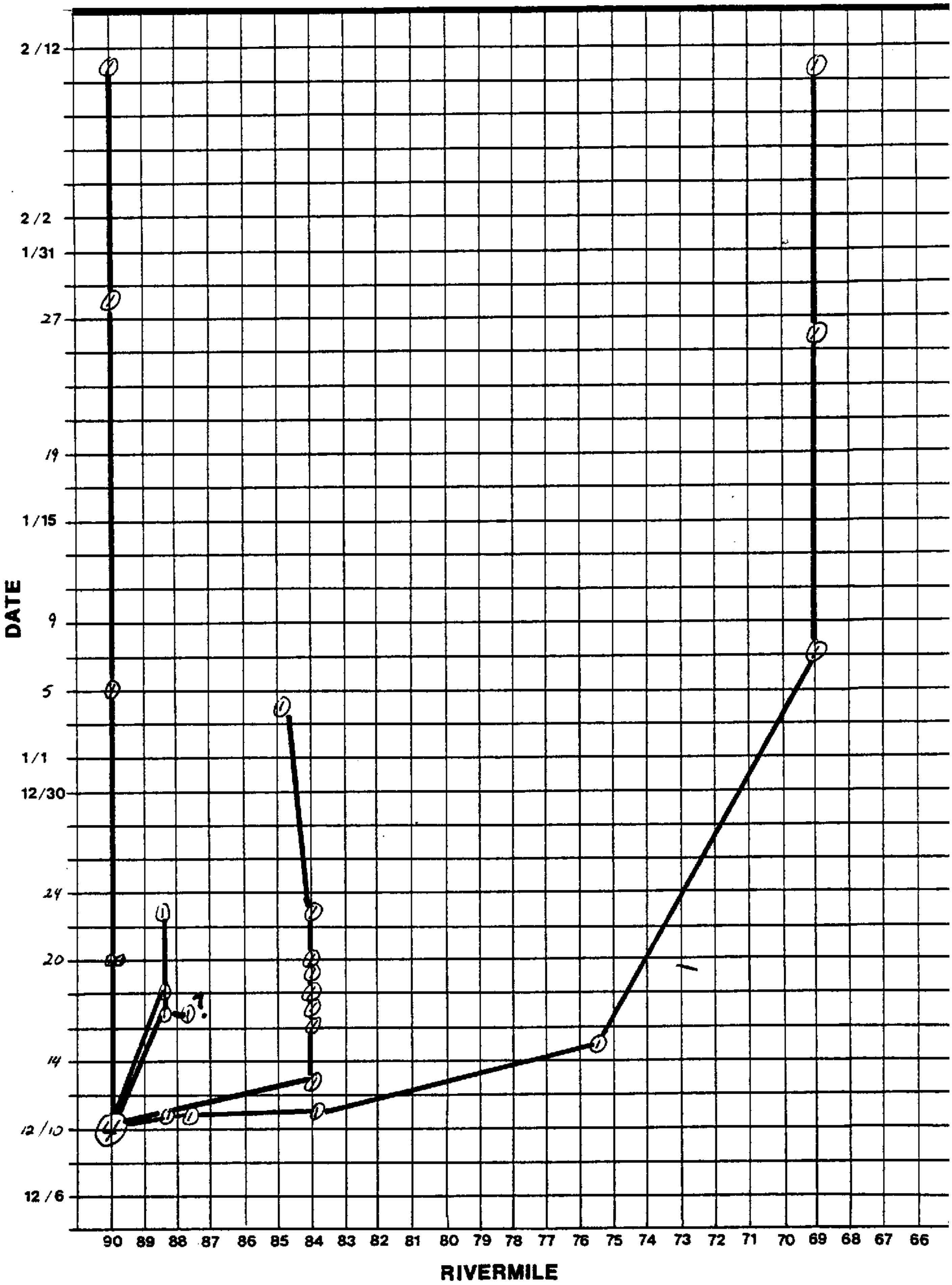
Recorded Locations of Tags

Release Date 12-10-79
Release Location R.M. 90.0
Channel 7
Pulse Rate .5



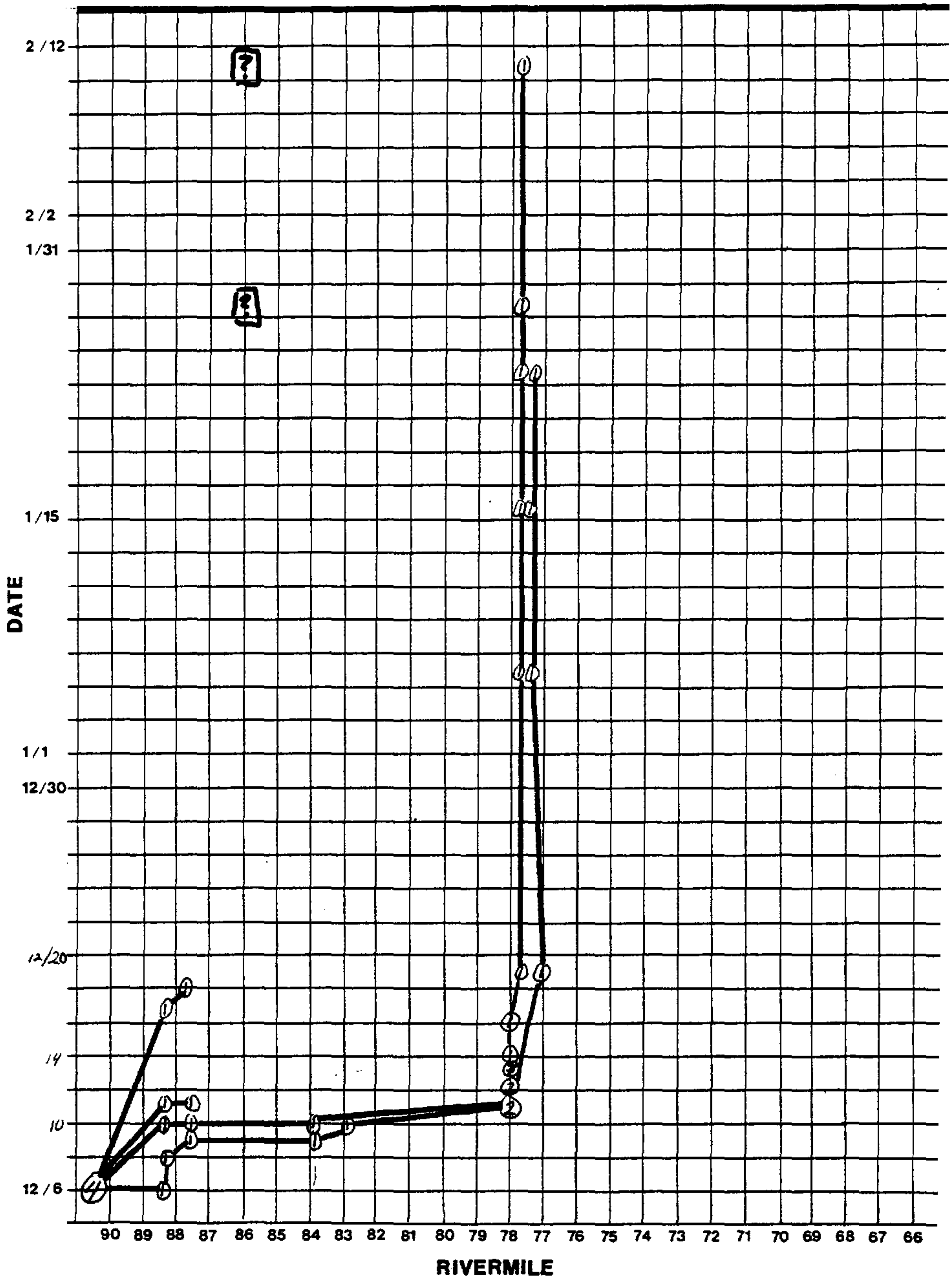
Release Date 12-10-79
Release Location R.M. 90.0
Channel 8
Pulse Rate .5

Recorded Locations of Tags



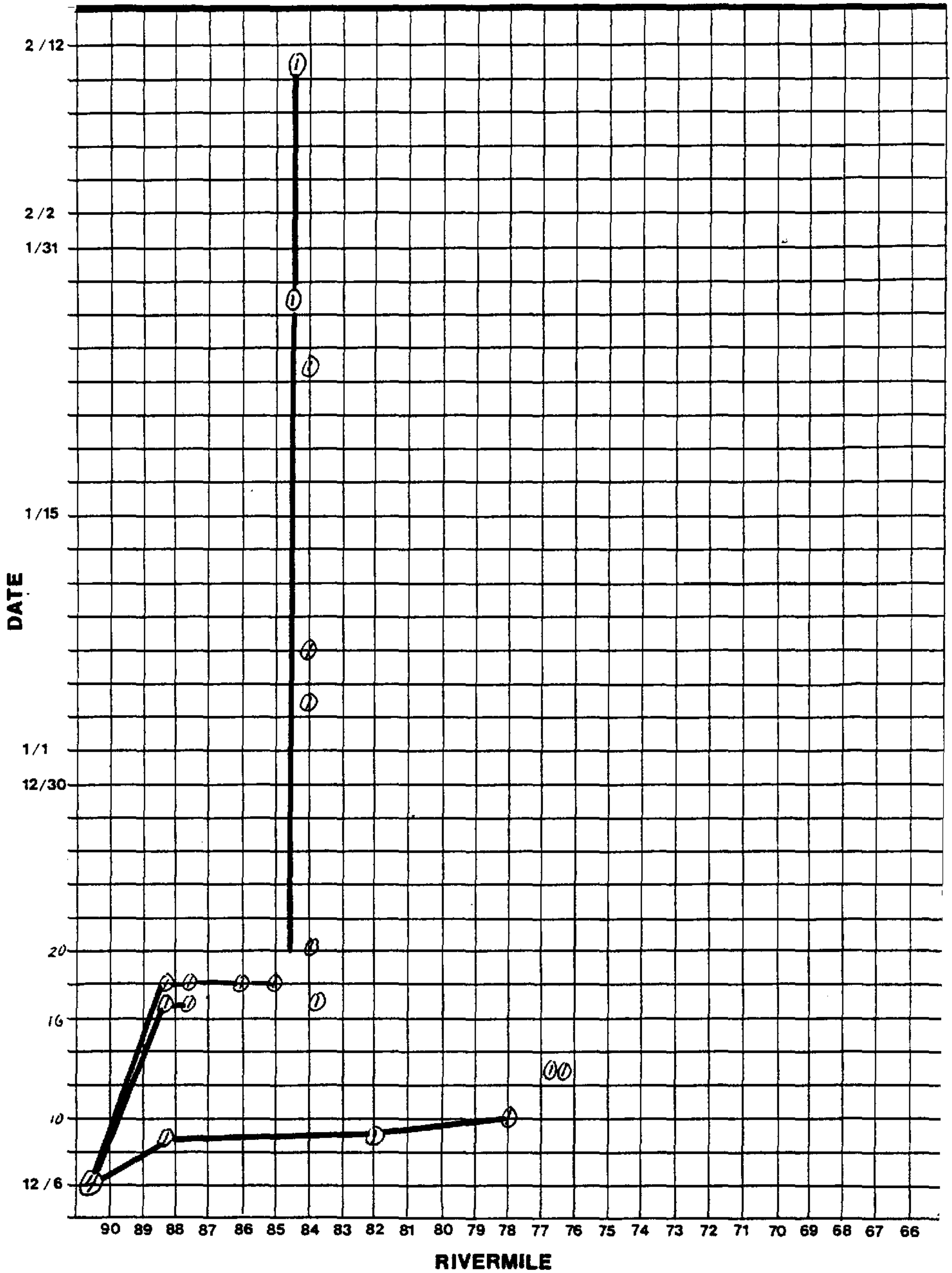
Recorded Locations of Tags

Release Date 12-6-79
Release Location R.M. 90.5
Channel 1
Pulse Rate .5



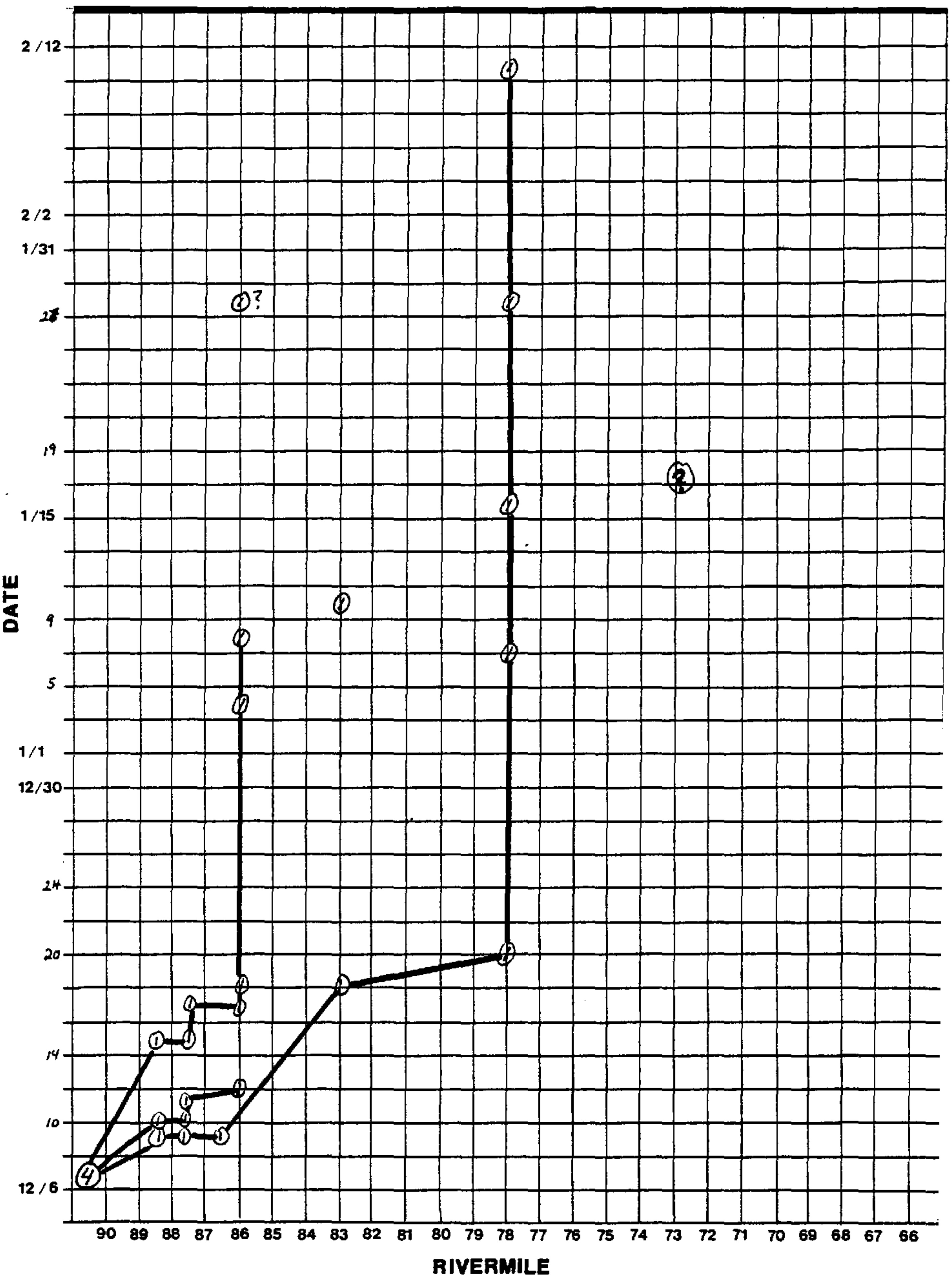
Recorded Locations of Tags

Release Date 12-6-79
Release Location R.M. 90.5
Channel 2
Pulse Rate .5



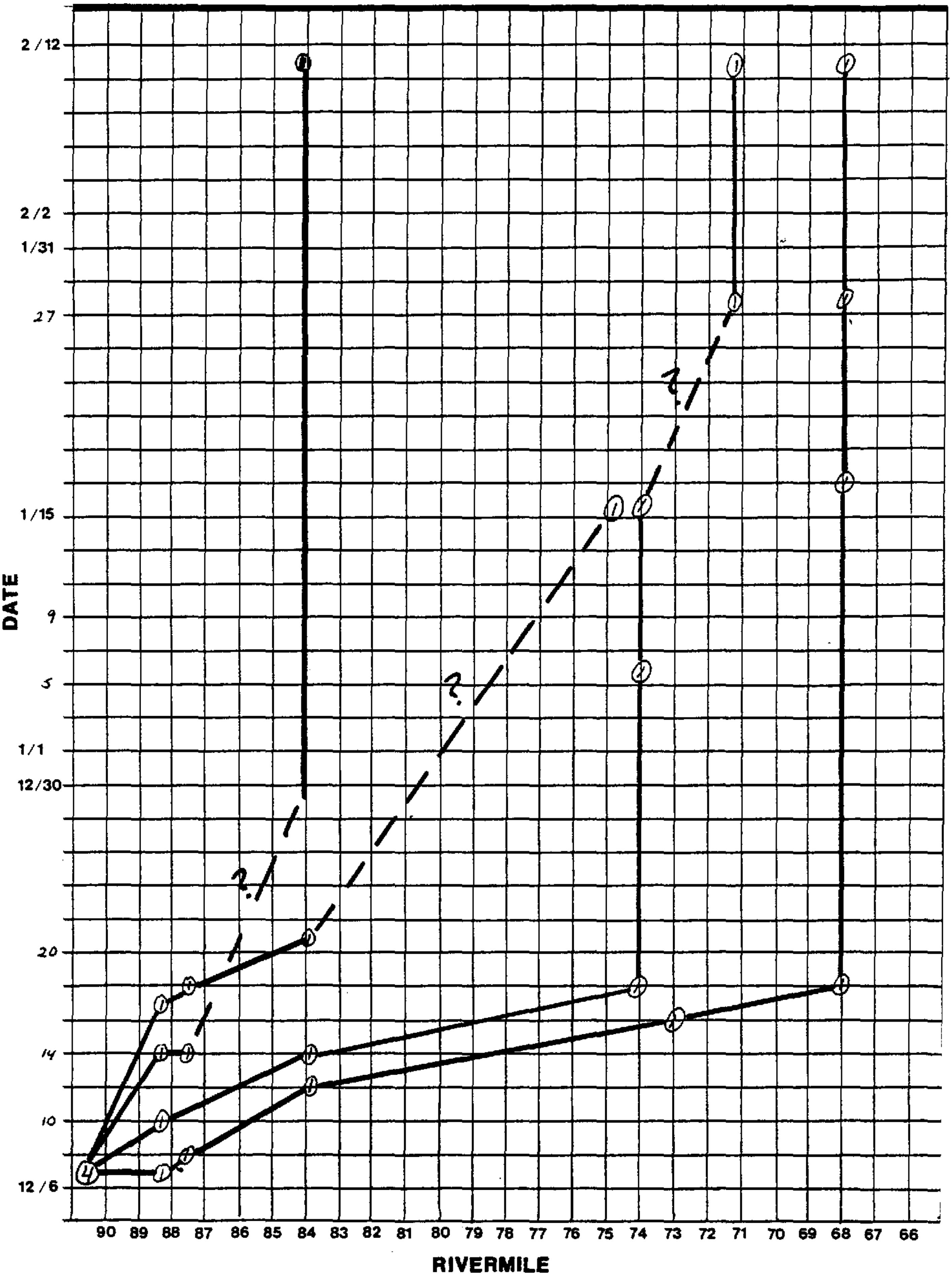
Recorded Locations of Tags

Release Date 12-7-79
Release Location R.M. 90.5
Channel 1
Pulse Rate 2



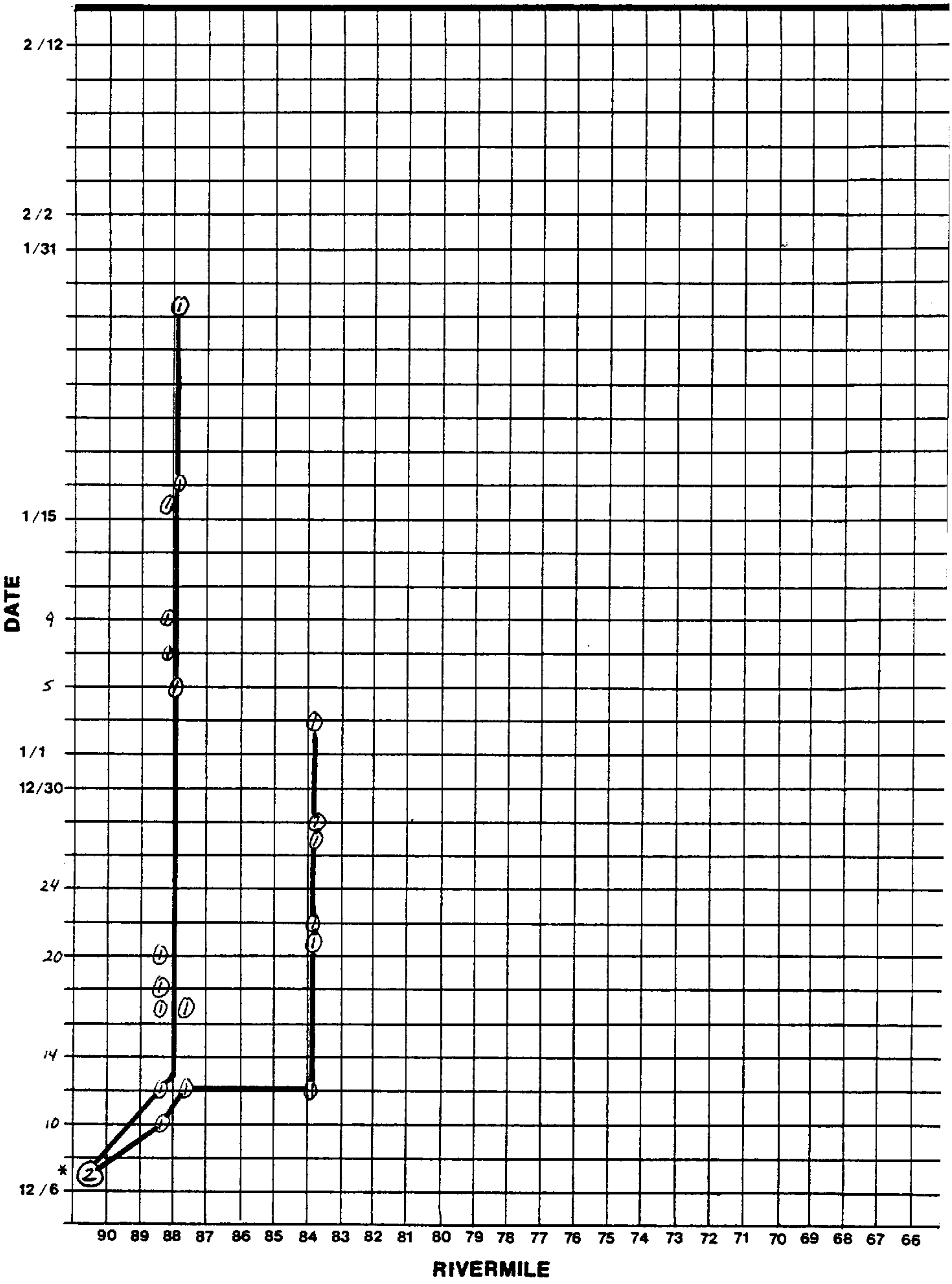
Release Date 12-7-79
Release Location R.M. 90.5
Channel 3
Pulse Rate .5

Recorded Locations of Tags



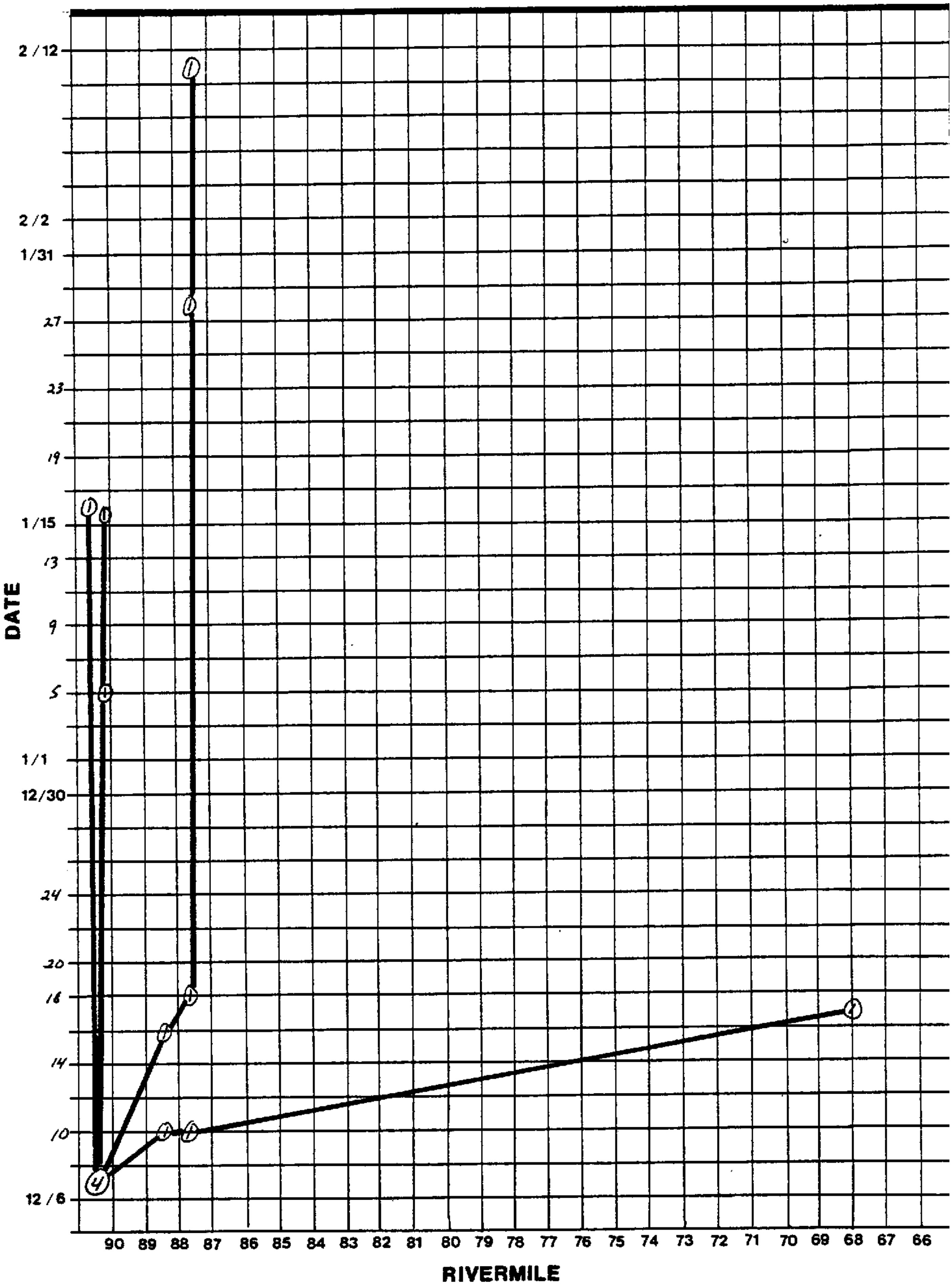
Recorded Locations of Tags

Release Date 12-7-79
Release Location R.M. 90.5
2 tags only * Channel 3
Pulse Rate 2



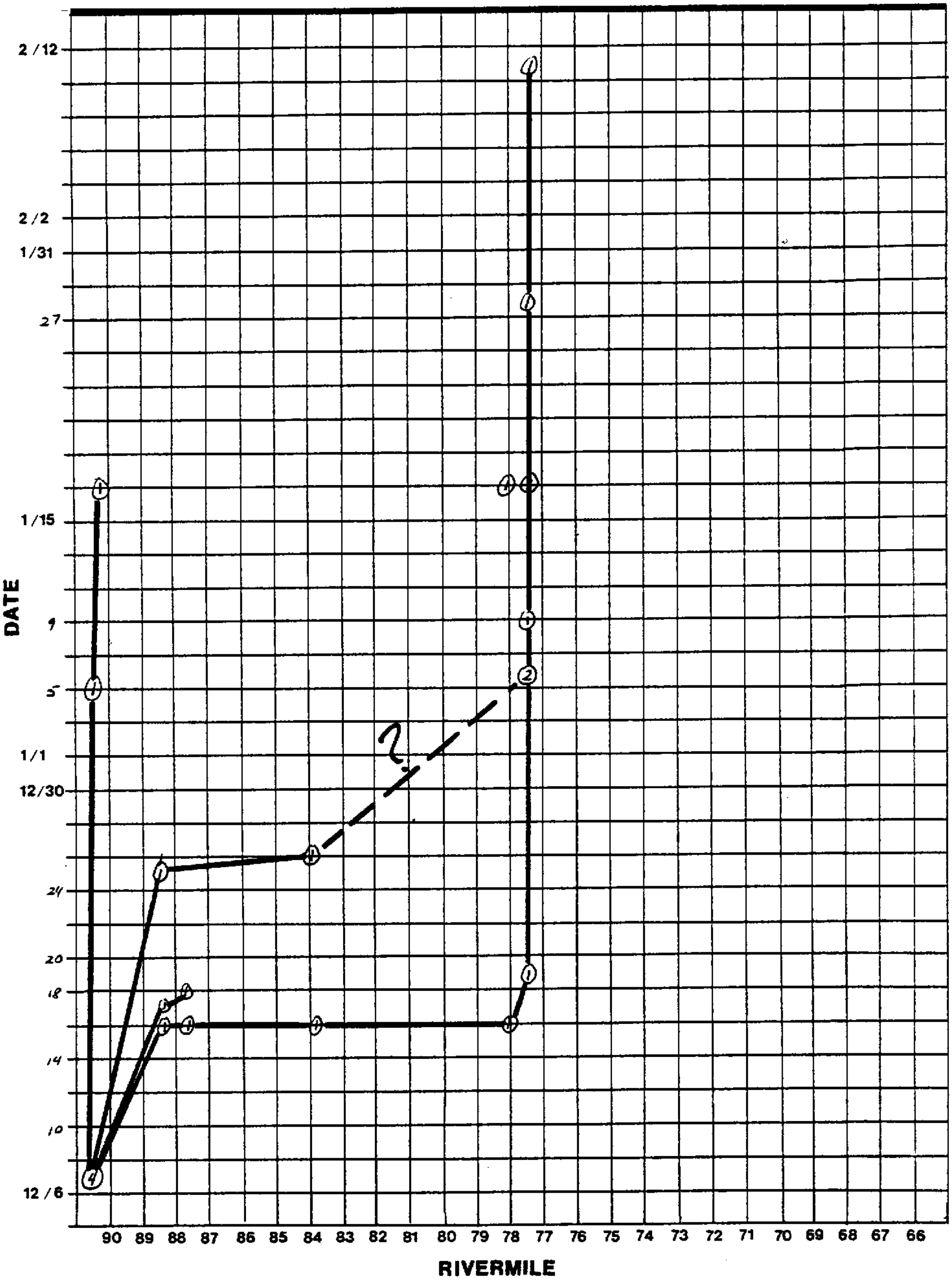
Recorded Locations of Tags

Release Date 12-7-79
Release Location R.M. 90.5
Channel 4
Pulse Rate .5



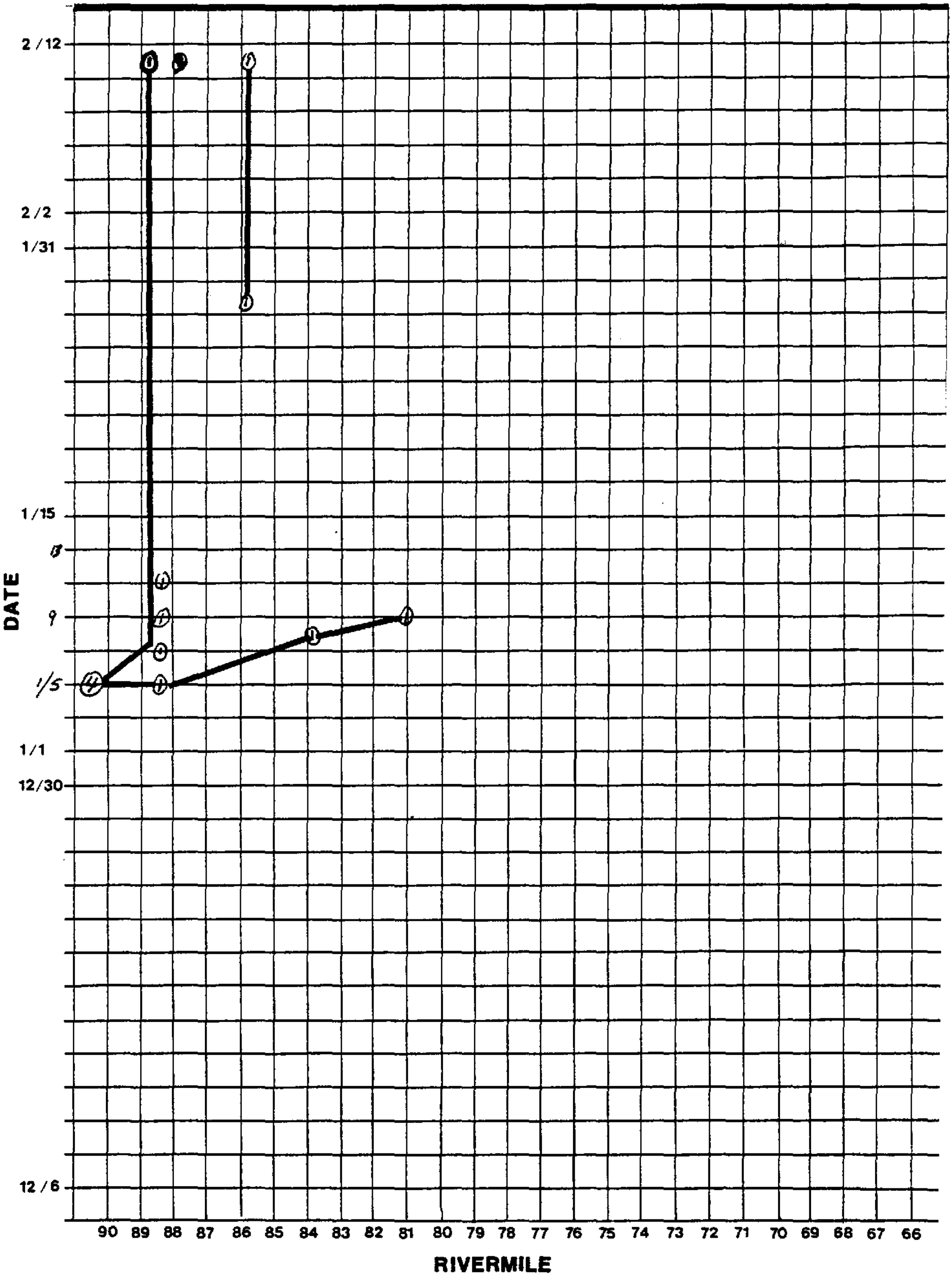
Recorded Locations of Tags

Release Date 12-7-79
Release Location R.M. 90.5
Channel 5
Pulse Rate .5



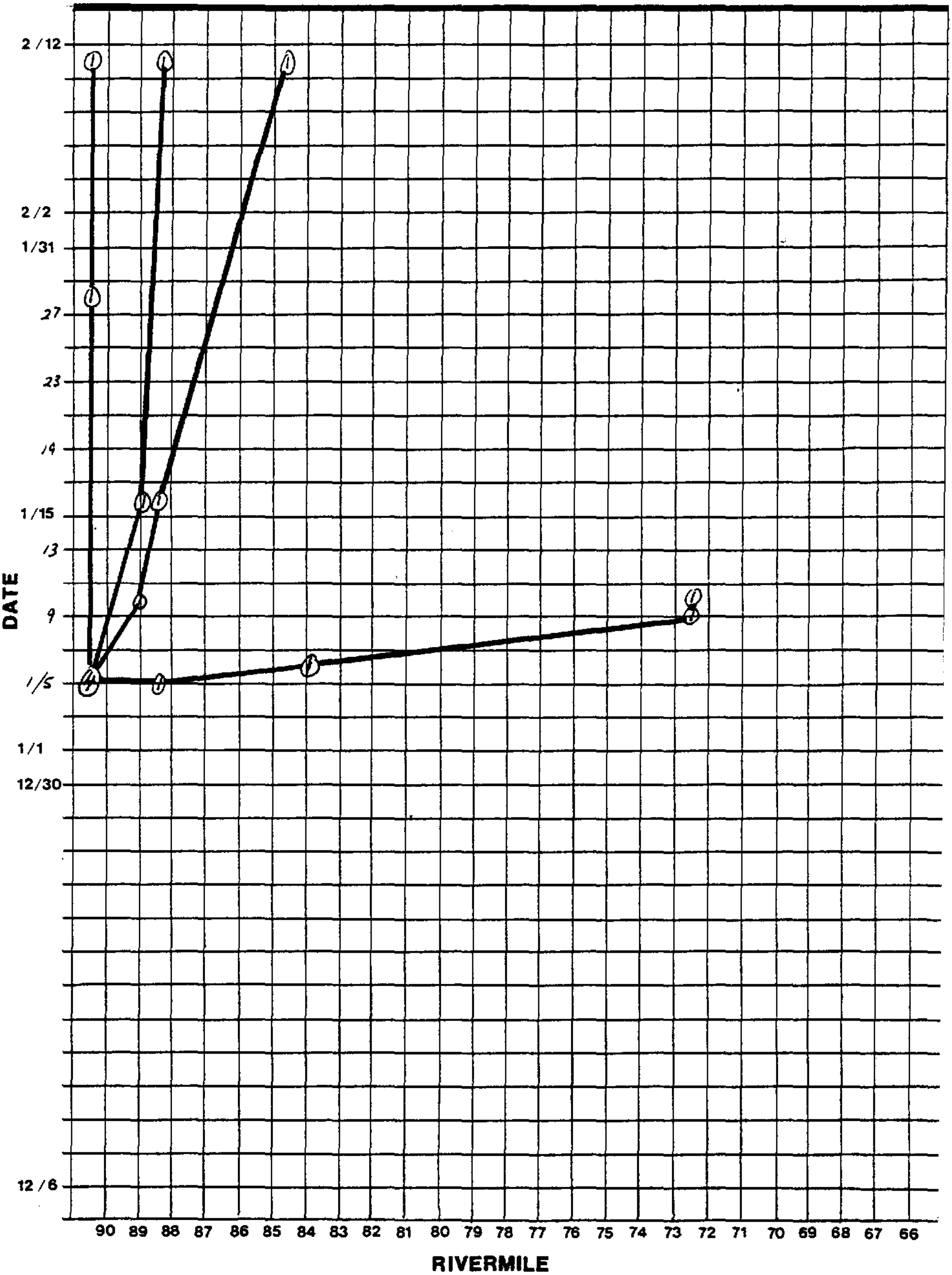
Release Date 1-5-80
Release Location R.M. 90.5
Channel 7
Pulse Rate 4

Recorded Locations of Tags



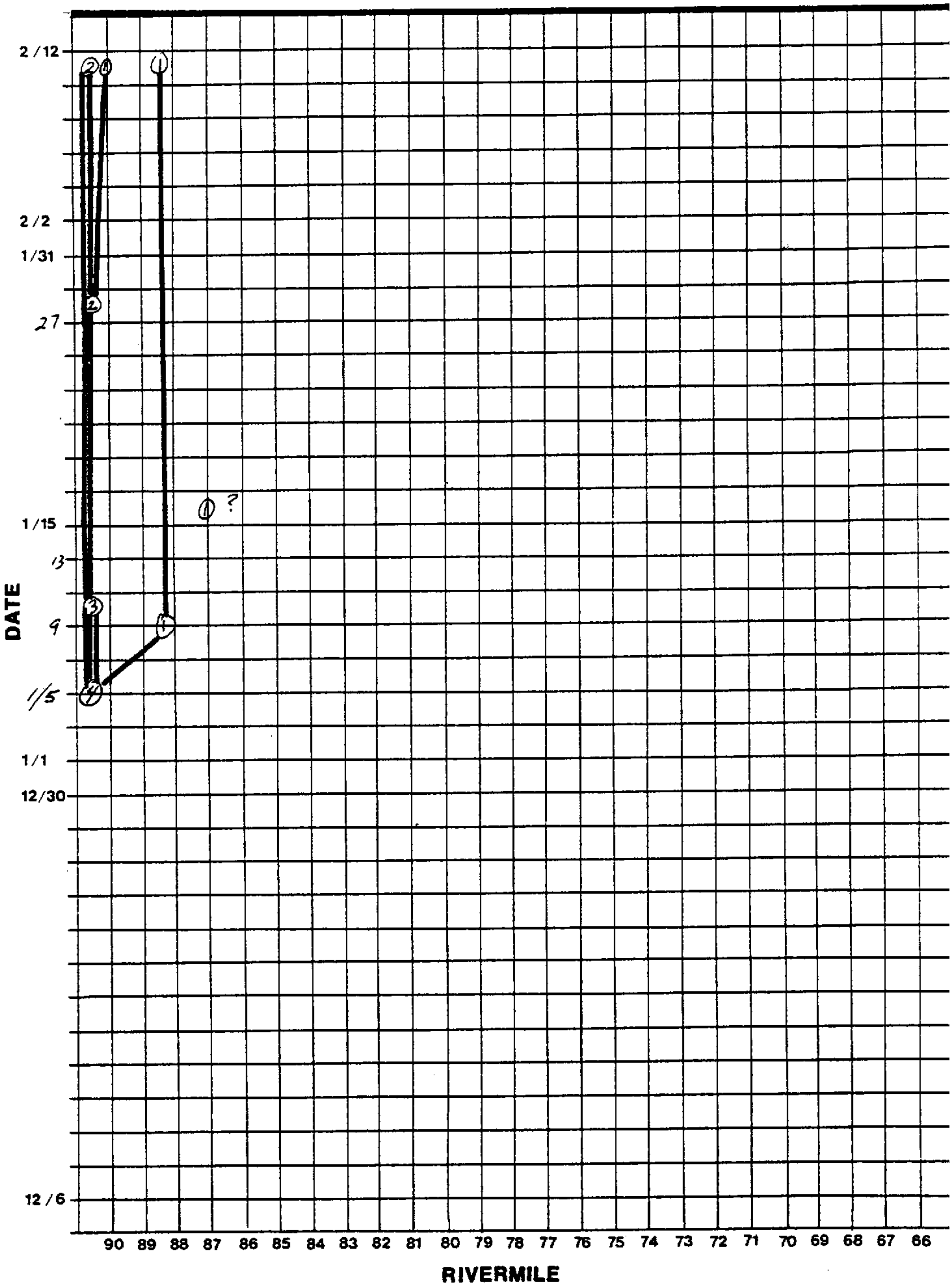
Recorded Locations of Tags

Release Date 1-5-80
Release Location R.M. 90.5
Channel 8
Pulse Rate 4



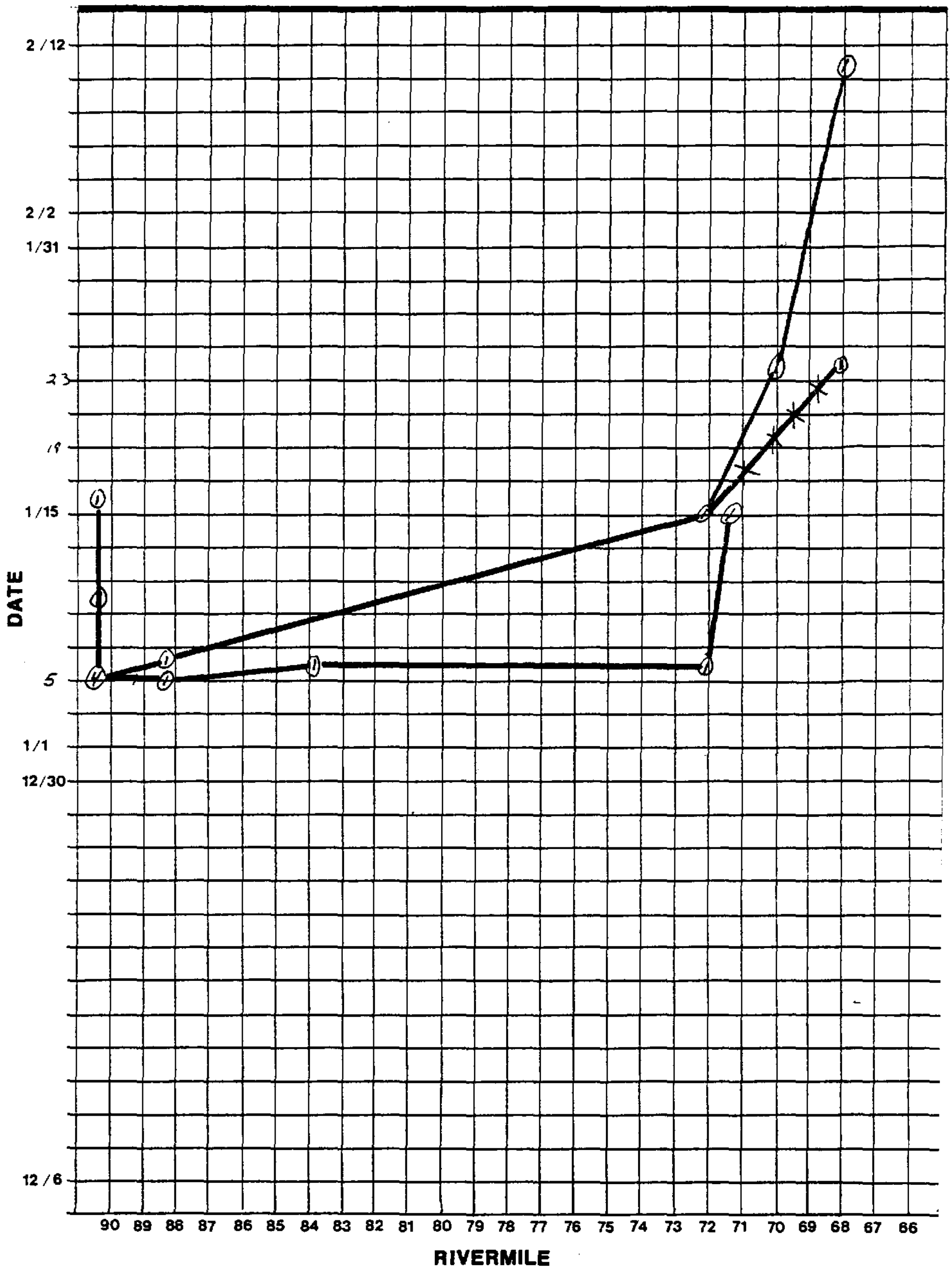
Recorded Locations of Tags

Release Date 1-5-80
Release Location R.M. 90.5
Channel 9
Pulse Rate .5



Release Date 1-5-80
Release Location R.M. 90.5
Channel 9
Pulse Rate 4

Recorded Locations of Tags



Recorded Locations of Tags

Release Date 1-5-79
Release Location R.M. 90.0
* Channel 10
2 tags only * Pulse Rate .5