ALASKA DEPARTMENT OF FISH AND GAME

SUSITNA AQUATIC STUDIES PROGRAM

REPORT NO. 7

RESIDENT AND JUVENILE ANADROMOUS FISH INVESTIGATIONS (MAY - OCTOBER 1984)

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PREFACE

This report is one of a series of reports prepared for the Alaska Power Authority (APA) by the Alaska Department of Fish and Game (ADF&G) to provide information to be used in evaluating the feasibility of the proposed Susitna Hydroelectric Project. The ADF&G Susitna Hydro Aquatic Studies program was initiated in November 1980.

The report covers studies of juvenile salmon and resident fish species of the Susitna River conducted from May through October 1984. In addition, some information on overwintering of resident fish radio-tagged in 1983 is included. The majority of the effort during the 1984 open-water season was on the lower river (from the mouth to the Chulitna River confluence). No studies were conducted this year in the area above Devil Canyon. This volume consists of four parts.

Part 1 (RSA Tasks 16A and 16B) covers the migration and growth of juvenile salmon. Coded wire tagging of chum and sockeye fry in the middle river (Chulitna River confluence to Devil Canyon) and collecting of all species of outmigrating fry at Talkeetna Station were similar to 1983 studies. In addition, a mark-and-recapture cold branding study was conducted in tributaries, sloughs, and side channels of the middle river to obtain an index of chinook and coho juvenile salmon abundance and residence time in these rearing areas. This study complements the coded wire tagging studies of chum and sockeye fry in the middle river. Also, outmigrant traps were operated at Flathorn Station (River Mile 22.4) near the mouth of the river to obtain a timing index of outmigration from the lower river.

Studies of the distribution and relative abundance of juvenile salmon and modelling of rearing habitat in the lower river are discussed in Part 2 (RSA Tasks 14 and 36). These studies were similar to those conducted in the middle river in 1983. Habitat suitability criteria developed for the middle river were used for the lower river unless evidence of different conditions in the lower river necessitated modifications. Habitat modelling results from 14 RJHAB model sites and 6 IFIM model sites are presented. The RJHAB and IFIM models were compared by using both at two sites.

Part 3 (RSA Task 14) contains the results of resident fish studies in both the middle and lower river. Monitoring of fish movement through use of radio tags was continued and index sites in the middle river were sampled as part of the long term monitoring effort. Population estimates for some species were made from multiple year mark-recapture data.

Part 4 (RSA Task 16A) is a statistical time series analysis of 1983 and 1984 discharge, turbidity, and juvenile salmon outmigration data in the middle river. This part represents the beginning of an effort to analyze, integrate, and summarize the five years of data collected by the Susitna Aquatic Studies Program. The final report on this five year summary will be completed a year from now.

DRAFT

TITLES IN THIS SERIES

Report Number	Title	Publication Date
1	Adult Anadromous Fish Investigations: May - October 1983	April 1984
2	Resident and Juvenile Anadromous Fish Investigations: May - October 1983	July 1984
3	Aquatic Habitat and Instream Flow Investigations: May - October 1983	September 1984
4	Access and Transmission Corridor Aquatic Investigations: May - October 1983	September 1984
5	Winter Aquatic Investigations: September 1983 to May 1984	March 1985
6	Adult Anadromous Fish Investigations: May - October 1984	1985
7	Resident and Juvenile Anadromous Fish Investigations: May - October 1984	1985

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PART 2

The Relative Abundance, Distribution, and Instream Flow Relationships of Juvenile Salmon in the Lower Susitna River.

THE RELATIVE ABUNDANCE, DISTRIBUTION, AND INSTREAM FLOW RELATIONSHIPS OF JUVENILE SALMON IN THE LOWER SUSITNA RIVER

DRAFT

Report No. 7, Part 2

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ABSTRACT

Juvenile salmon abundance and distribution were studied in the lower Susitna River and juvenile salmon habitat was modelled at 20 sites within the reach. Chinook, chum, and sockeye salmon juveniles made use of side channels, however, high turbidity limited use of side channels located in the Chulitna River plume. Coho salmon juveniles were found primarily in tributary mouths; sockeye, chinook, and chum salmon also used these areas. Sloughs were limited in occurrence and were not used heavily by any of the salmon species.

Both tributary mouths and side channel/slough sites were modelled using one of two habitat models. At tributary mouths, increases in weighted usable area with increases in mainstem discharge were due to the formation of backwaters which led to lower velocities and increases in cover and area. At side channels, chinook weighted usable area increased after overtopping due to increases in cover suitability (turbidity), velocity, and area. The weighted usable area response to changes in mainstem discharge for sockeye and chum salmon juveniles at side channels was also usually positive. Habitat indices at side channels for chinook, chum, and sockeye juveniles at mainstem discharges and side channel flows above the overtopping discharge declined as velocities became unsuitably high. Weighted usable area for these species sometimes did not decline at high discharges, however, because the total area of the site was also increasing.

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1.0 INTRODUCTION

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The Su-Hydro juvenile anadromous distribution and abundance studies initiated during 1981 and 1982 outlined the general distribution patterns of juvenile salmon and their habitat utilization (ADF&G 1981a, 1981b; 1983a, 1983b). The 1982 studies also investigated the response of selected areas to mainstem discharge changes and demonstrated species differences in the use of "hydraulic zones" (ADF&G 1983c). These zones were subsections of slough and tributary mouth areas. Some zones were affected by mainstem backwater, other zones were above the backwater, and other zones included mixing areas of the mainstem with slough or tributary flow. The relative use of the hydraulic zones by each species of juvenile salmon was analyzed to provide an incremental index of habitat availability at each site for each species. This analysis provided evidence that the relative use by juvenile salmon of these sites was affected by changes in mainstem discharge. Also the distribution of juvenile salmon suggested certain microhabitat factors within the zone such as turbidity and instream cover responded to discharge changes at a higher rate than did zone surface area.

Studies conducted during the 1983 open-water season concentrated on the instream flow relationships of juvenile salmon in the middle reach of the Susitna River between the Chulitna River confluence and Devil Canyon (Schmidt et al. 1984). Suitability criteria for juvenile salmon were developed and these were used in two types of habitat models to model the site-specific response of juvenile salmon habitat to variations in mainstem discharge. Additional information was also gathered on juvenile salmon abundance and distribution in the middle reach.

The 1983 studies suggested that juvenile chinook salmon made heavy use of mainstem side channels and used the turbid water in these areas as cover. Juvenile coho, chum, and sockeye salmon tended to occupy areas that were less influenced by mainstem flow.

In the Susitna River below the Chulitna River confluence (lower river), the braided nature of the river and lower gradient provides large amounts of potential side channel habitat for juvenile salmon. A study plan was formulated, therefore, to examine juvenile salmon distribution and the habitat availability of different morphological components of the lower Susitna River for juvenile salmon during the 1984 open-water season. The results of these studies, which include the responses of rearing juvenile salmon and their habitat within these morphological components to variations in mainstem discharge, are detailed in this paper. These results will be integrated with responses of side channel and slough complex wetted surface areas to variations in mainstem discharge in order to estimate the response of juvenile salmon habitat in the lower river to flow regulation.

Large scale aerial mapping of side channel and slough complex changes in area with variations in mainstem discharge is currently being performed by R & M Consultants, Inc. and E. Woody Trihey and Associates in association with these studies. Habitat types identified in the mapping include tributaries, tributary mouths, upland sloughs, side sloughs, primary side channels, secondary side channels, and turbid backwaters. Tributaries, tributary mouths, upland sloughs, and side sloughs are defined as in the upper river (Klinger and Trihey, 1984). Primary side channels have characteristics similar to the mainstem in the upper river and therefore offer little potential habitat for juvenile salmon and are not discussed in this report. Turbid backwaters are unbreached channels which contain turbid water from being breached at higher mainstem discharges and therefore are transitory in nature. Turbid backwaters are not addressed in this report but their habitat values are probably similar to barely breached side channels.

The major emphasis of this report is the evaluation of juvenile salmon use and related habitat values of secondary side channels. Some of the larger secondary side channels are considered primary side channels at higher mainstem discharges.

Tributary mouths and side sloughs were also evaluated. Due to their limited occurrence in the reach, upland sloughs were not sampled. The macrohabitat evaluation data presented here will be integrated with the aerial mapping data in later reports to formulate the reach-wide response of juvenile salmon habitat to discharge variations.

2.0 METHODS

2.1 Field Sampling Design

Three Juvenile Anadromous Habitat Study (JAHS) field crews, of two biologists each, examined rearing habitats used by juvenile salmon at selected side channels, tributary mouths, sloughs, and mainstem sites of the Susitna River between the Yentna River confluence (RM 28.5) and Chulitna River confluence (RM 98.5). JAHS sampling was conducted from river boats during the open-water season, with helicopter support enlisted as needed. The crews operated out of camps located on the Susitna River at the Deshka River (RM 40.6), Sunshine Station (RM 79.0), and Talkeetna (RM 97.5).

The JAHS field crews sampled three categories of sampling sites. Most of the sampling occurred at Resident Juvenile Habitat (RJHAB) model sites where the response of the site to changes in mainstem discharge was evaluated along with juvenile salmon use of the site. Crews also sampled Instream Flow Incremental Methodology (IFIM) model sites for fish distribution and abundance at which hydraulic habitat models were developed. The third category of sites, at which further data on fish distribution and habitat were gathered, were known as "opportunistic" sites. Further details on specific sampling techniques and methods used in the JAHS studies are given in ADF&G (1984a, 1984b).

2.1.1 Study locations and selection criteria

The sampling sites modelled were chosen from side channels, tributary mouths, and side sloughs, which met the following basic criteria:

A. The effects of mainstem discharge (stage and flow) on the sites are measurable.

B. The sites are documented or thought to contain potential habitat for rearing juvenile salmon.

C. The sites are accessible by boat at normal mainstem discharges during the open-water season.

The sites modelled with RJHAB and IFIM models are listed in Table 1 and their distribution is shown in Figure 1. Fourteen of the sites were modelled only with the RJHAB model, four with only IFIM models, and two with both RJHAB and IFIM models. Eight of the sites are located within slough or side channel complexes which were picked by R&M Consultants and E.W. Trihey and Associates as representative of lower Susitna River side channel complexes. Four of the sites are normally clear-water sloughs or tributary mouths while the other sites are turbid secondary side channels at normal summer flows. Secondary side channels selected ranged greatly in size, shape, and overtopping discharge. The majority of the habitat model sites are secondary side channels because the majority of the potential available habitat for juvenile fish in lower

Table 1. Juvenile Anadromous Habitat Study (JAHS) modelling sites on the Susitna River between the Yentna River and Talkeetna River confluences, 1984.

	Site	River Mile	RJHAB	IFIM
*	Hooligan Side Channel	35.2	X	
*	Eagles Nest Side Channel	36.2	X	
	Kroto Slough Head	36.3	X	
	Rolly Creek Mouth	39.0	X	
	Bear Bait Side Channel	42.9	X	
	Last Chance Side Channel	44.4	X	
	Rustic Wilderness Side Channel	59.5	X	
	Caswell Creek Mouth	63.0	X	
	Island Side Channel	63.2	X	X
	Mainstem West Bank	74.4		X
	Goose 2 Side Channel	74.8	X	
	Circular Side Channel	75.3		X
	Sauna Side Channel	79.8		X
*	Sucker Side Channel	84.5	X	
*	Beaver Dam Slough	86.3	X	
*	Beaver Dam Side Channel	86.3	X	
*	Sunset Side Channel	86.9		X
*	Sunrise Side Channel	87.0	X	
*	Birch Creek Slough	88.4	X	
	Trapper Creek Side Channel	91.6	X	X

* Located within side channel or slough complexes picked by R&M Consultants, Inc. and E. Woody Trihey and Associates as representative of lower Susitna River slough or side channel complexes.

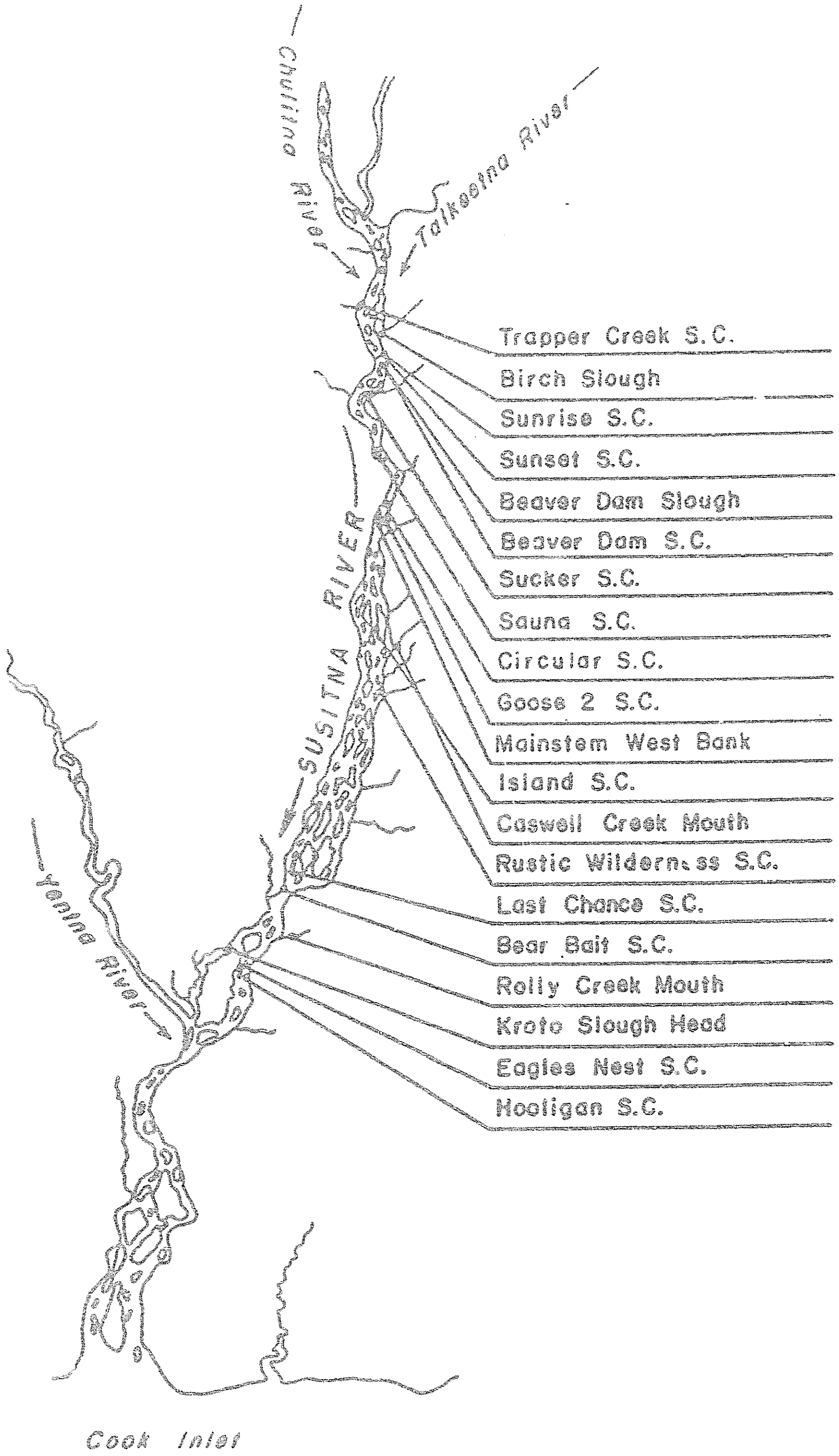


Figure 1. Location of study sites on the lower Susitna River at which juvenile salmon habitat was modelled, June through October 1984.

Susitna River mainstem affected areas is composed of secondary side channels.

Opportunistic sampling sites were selected by the sampling crews as potential habitat which upon sampling might provide for a better analysis of fish abundance and distribution. Sites sampled were more diverse than the RJHAB and IFIM sites and included areas within alluvial island complexes.

2.1.2 Field data collection

2.1.2.1 Resident Juvenile Habitat (RJHAB) model sites

Two types of data were collected at the RJHAB model sites. Habitat data were collected for the purpose of modelling the response of the site to changes in mainstem discharge. Fish distribution data were collected for use in verifying the habitat model data, documenting abundance and distribution, and modifying suitability criteria, if necessary. A discussion of the techniques used in the collection of habitat modelling data will be followed by a discussion of methodology used in the collection of fish sampling data.

Each of the RJHAB sites was sampled within a grid consisting of a series of transects with associated sampling cells which intersect the channel of the study site at right angles (Figure 2). Grids were located so that water quality within them was uniform and so that they encompassed

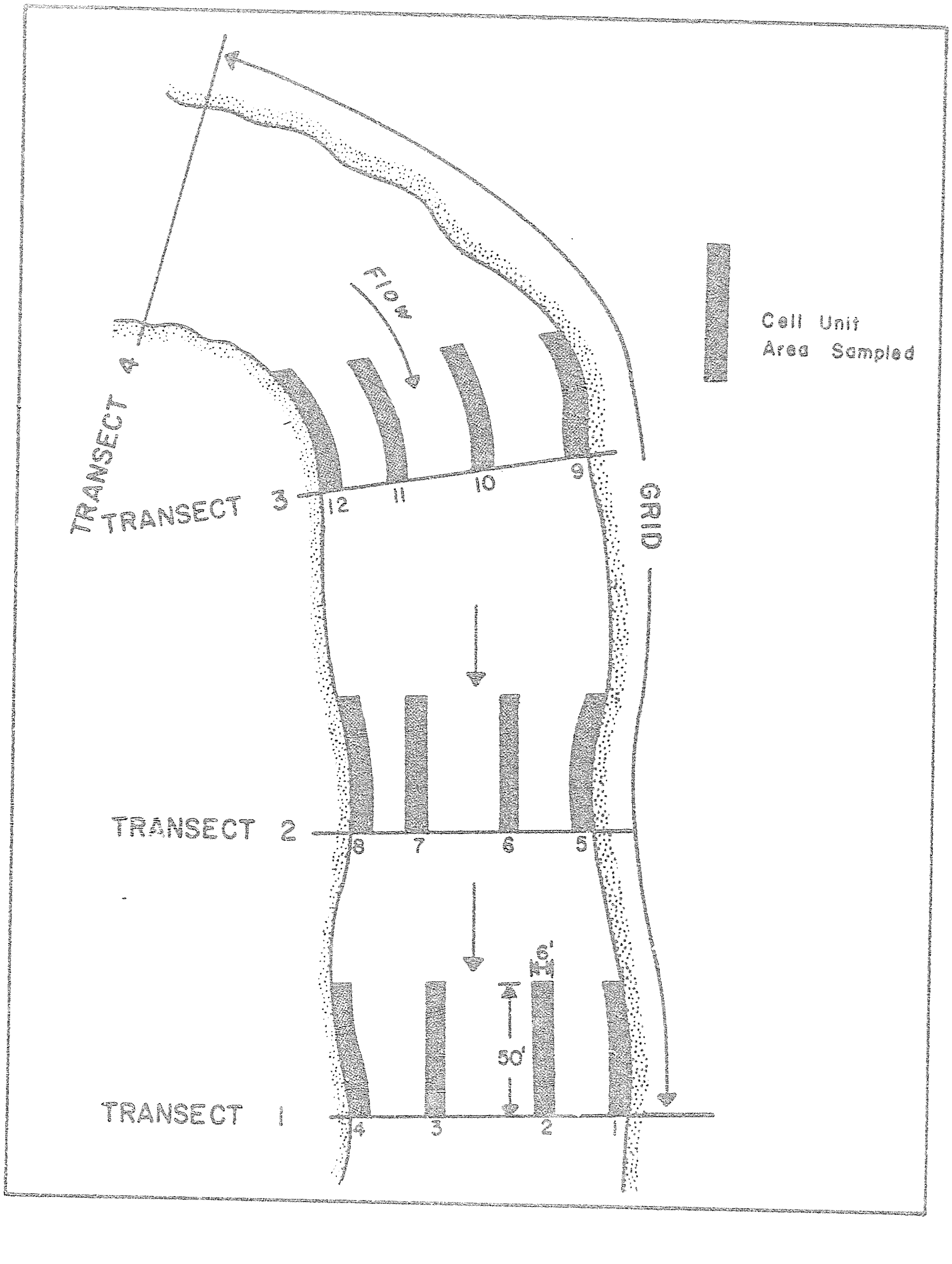


Figure 2. Arrangement of transects and sampling cells within a grid at a hypothetical RJHAB modelling site.

a variety of habitat types. Survey stakes and orange flagging were used to mark each transect within a grid. Initial measurements within each grid included distances and angles between transect bench marks. Transects were spaced from 50 to 300 feet apart in order to encompass a variety of habitat types within each grid. Aerial photos of all the RJHAB sites showing placement of all transects within each site are presented in Quane et al. (1985).

Up to four 6-by-50 foot rectangular sampling cells extending upstream from every transect within each grid were characterized by habitat measurements (Figure 2). If the top width of the wetted channel was greater than 42 feet, two of the four cells paralleled both edges of the channel and the third and fourth cells were located parallel to the shoreline cells so as to split the channel into thirds. If the channel measured 30 to 41 feet in width at the transect, there was a cell on each shoreline of the channel and one cell located approximately mid channel. If the wetted edge was 18 to 29 feet in width, there was one cell on each side of the channel parallel with the bank. If the channel was less than 18 feet in width, there was only one cell.

Transects were numbered consecutively beginning with the transect furthest downstream within the site. Cells were also numbered consecutively from right to left looking upriver. If there were less than four cells within a transect, cells were numbered as if the missing cells were present.

One or more staff gages were installed by Aquatic Habitat and Instream Flow Project (AH) personnel at each site to document changes in the stage at each site with changes in mainstem discharge. These gages provided an index to the changes in habitat and hydraulic conditions at the site between sampling occasions. AH staff also developed mainstem stage and site flow relationships and mapped the thalweg at selected sites.

Habitat modelling data were collected over a broad range of mainstem discharges. Emphasis was placed on data collection at mainstem discharges of 30,000 to 60,000 cfs as measured at the Sunshine USGS gaging station. When staff gage readings and observations indicated that the habitat at the site had not changed from a previous sampling occasion, no habitat data were taken.

Habitat data taken at each grid on a modelling occasion included the following. At each transect, the distance between the left and right edge of water and the left bank transect marker was measured. If the water quality within the grid or grids was uniform, one measurement of water pH, temperature, conductivity, and dissolved oxygen was taken. A turbidity sample was collected in a 250 ml plastic bottle and stored in a cool dark location prior to analysis. If the water quality within the grid appeared to vary because of mixed water sources, additional water quality and turbidity measurements were taken as necessary to describe these within grid variations.

In addition to the above measurements, each sampling cell within the grid was characterized by several habitat measurements. A representative depth and velocity were measured by taking one or more point measurements along the midline of each cell. The entire cell was walked so measurements taken were representative. A velocity measurement was taken at 0.6 of the distance from the top of the water column at one representative location for the entire cell.

Additionally, cover type and amount were estimated in each cell and coded into categories (Table 2). Initially, the total amount of cover of all types was estimated for the entire cell. Next, the primary and secondary cover type was recorded along with a percentage of the total for each. Cover was defined as hiding or escape cover for fish less than or equal to 100 mm in total length.

Table 2. Percent cover and cover type categories.

Group #	% Cover	Group #	Cover Type
1	0-5%	1	No object cover
2	6-25%	2	Emergent vegetation
3	26-50%	3	Aquatic vegetation
4	51-75%	4	Debris or deadfall
5	76-96%	5	Overhanging riparian vegetation
6	96-100%	6	Undercut banks
		7	Gravel (1"to 3" diameter)
		8	Rubble (3" to 5" diameter)
		9	Cobble (larger than 5" diameter)

In September, when the water levels in the Susitna River were low, the cover on all the transects within each site was systematically recorded.

One person did most of the recording so that observer bias was minimized. The cover was recorded by distance from the left bank transect marker along the transect line.

Fish distribution data were normally collected from a minimum of seven cells within each RJHAB site during each sampling occasion. Cells to be sampled were selected randomly by using a random numbers table (ADF&G 1985). If a cell was missing or could not be sampled, an additional cell was randomly chosen for sampling. Some cells could not be sampled due to high velocities or deep depths and, therefore, the sampling was not completely random. Each cell selected was then sampled for fish with one pass through the entire cell with a backpack electroshocker or beach seine.

The gear used was that thought most efficient for sampling the area, normally beach seines are more efficient in turbid water while electrofishing gear is most efficient in clear water (Dugan et al. 1984). The area of the cell sampled for fish was recorded so that catches in cells with areas different than 300 ft^2 could be adjusted to this standard cell size.

Additional selected cells were occasionally fished at the site if sampling of the random cells failed to capture many fish. In this case, the sampling crew fished areas which were thought to be "good" habitat. Areas fished were not limited to cells on the transects.

After each cell was sampled, juvenile salmon captured were identified to species and then released. The total length of each of the first 50 fish of each species in each size class was measured in millimeters.

If staff gage readings indicated the habitat at the site had not changed from a previous sampling period only limited habitat measurements were taken. These included water chemistry data and a turbidity sample. Fish distribution data were taken during each visit to the site, however. Each cell sampled for fish was al. characterized by a representative velocity, depth, and estimate of cover type and abundance.

2.1.2.2 Instream Flow Incremental Methodology (IFIM) sites

In addition to the RJHAB model sites, there were also six sites modelled for juvenile fish using the "instream flow incremental methodology" (IFIM) (Bovee 1982). A summary of this methodology and specific data collection and modelling techniques are presented in Appendix D of this report. All habitat data used in the IFIM models were collected and analyzed by Aquatic Habitat (AH) personnel. Two of the IFIM sites were also modelled with RJHAB models using the same transects in order to compare output from the two modelling methods. At these two sites, RJ personnel collected the RJHAB and fish distribution data and AH personnel collected the IFIM data, so the two models were independent.

Fish abundance and distribution data were also collected at the other four IFIM model sites. Sampling effort at these sites was secondary in importance to the sampling of the RJHAB sites. Cells were sampled for fish using the transects placed for the IFIM models. Cells were randomly selected and then sampled with the same procedures used at RJHAB sites. Cell numbering was the same as that used in the RJHAB studies. The distance from the transect end markers to the cell edge was measured, however, so that the location of the cell on the transect was specified. Other data collected at each cell fished included amount and type of cover, water depth, and water velocity. Water chemistry measurements and a turbidity sample were also taken at a selected location within the site.

2.1.2.3 Opportunistic sites

In addition to the RJHAB and IFIM sites, other sites were sampled for fish opportunistically as time permitted. The purpose of this sampling was to gather juvenile abundance and distribution information at a wider variety of sites and to gather data for further analysis of juvenile suitability criteria. No permanent grids or transects were marked at opportunistic sites. Selected 6-by-50 foot cells were sampled for juvenile salmon at the opportunistic sites. Water chemistry was measured at mid-site. Each cell sampled for fish was characterized to amount and type of cover, water depth, and water velocity as were cells sampled at RJHAB and IFIM sites, if time permitted.

Early in the sampling season, large differences in turbidity were noted between sites located on the east and west banks of the Susitna River mainstem below the Chulitna River confluence. In order to better understand the reason for these differences, turbidities were taken within the Talkeetna and Chulitna rivers just above their respective confluences with the Susitna and also in the middle Susitna River above its confluence with the Chulitna River. The turbidity measurements were then repeated in the lower Susitna River below the Chulitna River on the left (west) bank channel, center channel, and right (east) bank channel at intervals from RM 92.7 downstream to RM 60.6. Two sets of measurements were taken, one on July 19 and the other on August 16. The measurements were recorded within a four hour period on each date.

2.1.3 Schedule of activities and frequency of sampling

Field sampling trips, lasting approximately 7-10 days, were conducted bimonthly from June through mid-October. Each RJHAB site was sampled for fish on each sampling occasion if fish habitat was present. Habitat data were collected on at least three occasions when staff gage readings or observations suggested a change in the habitat within a site. The collection of habitat data was therefore very dependent upon mainstem discharge.

The IFIM sites were sampled at least once a month during the open-water season. Opportunistic sites were sampled as time permitted and some were only sampled once. Opportunistic sites were sampled mainly in September and early October when many of the RJHAB and IFIM sites were dewatered.

2.2 Data Analysis

All field data were recorded on the appropriate data forms and transmitted to the office where the fish distribution data and much of the habitat data were entered intc a mainframe computer data base. Data sorts, summary retrievals, and selected computer files were extracted from this data base as needed. Other habitat data were entered directly into basic programs or commercial software on a personal computer.

2.2.1 Physical data

Overtopping flows at the study sites were observed or estimated from staff gage measurements and flow observations. Data were grouped into nine half-month sampling periods from early June (June 1 - June 15) to early October (October 1 - October 15). Due to logistical constraints, the actual sampling periods did not always run from the 1st to the 15th and 16th through the end of the month.

An index to the amount and type of cover within the RJHAB and IFIM model sites was calculated by totalling the linear feet of all the cover types along the transects at a mainstem discharge within the range of 49,000 to 57,000 cfs. At Rolly Creek mouth, Caswell Creek mouth, and Beaver Dam Slough, the response of physical cover to changes in mainstem discharge was also plotted by totalling the cover along the transects at all measured discharges.

The response of RJHAB site wetted areas to mainstem discharge was also plotted using a BASIC language geometry program to calculate wetted area at each transect within a site on each modelling occasion. After fitting these points by hand using professional judgement, site areas at 3000 cfs increments were measured on the graphs with a digitizer. The IFG HABTAT program calculated wetted areas at the six IFIM sites as a function of side channel flow, and these were also plotted using a mainstem discharge-side channel flow relationship.

2.2.2 Abundance and distribution

The classification of macrohabitats used to examine differences in fish distribution among the sites was that discussed in Dugan et al. (1984). The sites were classified as tributary mouths, side sloughs, and side channels. Tributary mouths are sites which are influenced only by backwater effects from the mainstem as their heads do not overtop. Side channels are channels whose heads are overtopped by the mainstem while side sloughs are side channels whose heads are not currently overtopped. Birch Creek slough was classified as a tributary mouth in 1984 because road building activities in the upper part of the slough have closed the head off from the mainstem. Beaver Dam Slough was also classified as a tributary mouth because it only overtops at discharges greater than 80,000 cfs and normally runs clear. Beaver Dam Slough is much more similar to Rolly Creek mouth than to any of the other side sloughs in the lower reach.

Catches within cells with areas other than the standard 300 ft^2 were adjusted to correspond to this standard cell area. The analysis was then based on the adjusted mean catch per cell.

2.2.3 Habitat modelling of rearing salmon

2.2.3.1 Suitability criteria development

Suitability criteria used in modelling the response of juvenile salmon habitat to variations in mainstem discharge for the middle reach of the Susitna River have been developed in Suchanek et al. (1984). Since habitat data collection techniques used in 1984 were the same as those used during the 1983 field season, the middle river suitability criteria were examined and modified, if necessary, in Appendix A by examining lower river distribution data. The suitability criteria developed in Appendix A are used in all subsequent habitat modelling for the lower river.

2.2.3.2 Instream Flow Incremental Methodology (IFIM) models

The IFIM PHABSIM system of computer programs was developed by the U.S. Fish and Wildlife Service as a means of describing the mosaic of physical features of a stream which includes hydraulic variables such as depth and velocity and other features such as substrate or cover (Bovee 1982). A hydraulic model is first calibrated which describes the response of hydraulic variables such as depth and velocity to stream flow (Milhous et al. 1981). The HABTAT program is then used to incorporate output from the hydraulic model and substrate data with the suitability criteria to produce estimates of the habitat potential (weighted usable area) for a given life stage of a species. Weighted usable area (WUA) is calculated as follows (Bovee 1982):

$$WUA = C_{i,s} \times A_i$$

where: $C_{i,s}$ = the composite weighting factor (sometimes called the joint preference factor) for cover, velocity, and depth of the cell (i) for the species and life stage (s)

A_i = the surface area of the cell

Each cell is a small section of the study channel which is bounded by other cells or the shoreline and extends midway between transects. The WUA for the study site at a given discharge was calculated by totalling all the individual cell WUA's. The composite weighting factor was calculated by multiplying the suitability indices for cover, velocity, and depth of the cell together. WUA's at each study site were calculated at flows which corresponded to 3,000 cfs increments of mainstem discharge as measured at Sunshine gaging station.

Much more detailed descriptions of the IFIM data analysis methods and hydraulic simulation results are presented in Appendix D. Only selected WUA results as a function of mainstem discharge are presented here. All species and site combinations were run and are available on request but space limitations prevent presentation here. Site/species combinations presented were selected on the basis of fish catches at the site.

2.2.3.3 Resident Juvenile Habitat (RJHAB) models

The original RJHAB model was designed to calculate weighted usable areas for the habitat within a site without using hydraulic models (Marshall et al. 1984). The model divided the site into shoreline and mid-channel sections, and calculated weighting factors for cover and velocity for each section which were then multiplied together with area to produce a weighted usable area estimate at each of the discharges measured.

The original RJHAB model was greatly modified for the 1984 analyses. These changes were made so that the RJHAB model calculates weighted usable areas similarly to the HABTAT program described by Milhous et al. (1981) that is used in IFIM analysis. Also the cover coding has been standardized for input so that observer variations in rating cover at different discharges do not lead to variations in cover estimates unrelated to changes in wetted area.

The current RJHAB model is a spreadsheet developed on commercial software. Though no hydraulic model is developed, it closely resembles the HABTAT model in its procedures for calculating weighted usable areas within a site. Instead of calculating weighting factors for cover and velocity in shoreline and mid-channel sections on a given sampling occasion as did the original RJHAB model, each site is partitioned into "stream cells" each with a unique area, cover type, cover percentage, velocity, and depth. The site weighted usable area (WUA) is then the sum of the "stream cell" WUA's which are calculated by multiplying the area, cover, velocity, and depth suitabilities together.

The velocity and depth measurements of the 6' x 50' sampling cells are assumed to represent a much larger stream cell. The wetted surface area between transects was partitioned into one to four stream cells dependent upon wetted transect width (Table 3).

Table 3. Partitioning of wetted channel width into stream cells.

Wetted Channel Width	No. of Stream Cells	How Area Partitioned
>42 ft	4	Cell on each shoreline 6 ft in width, two center cells split the difference.
30-42 ft	3	Cell on each shoreline 6 ft in width, middle cell is the rest.
18-29 ft	2	Each cell with half the width.
18 ft	1	Entire width.

Occasionally, islands prevented a simple partitioning of the site but in each case, areas were partitioned so that sampling cells best represented a given stream cell. Once the wetted width of stream cells was partitioned, a computer program written in BASIC was used to calculate the surface area of each stream cell on each sampling occasion. The areas of islands were estimated from the observations and sketch maps and then subtracted from the area of each stream cell.

Cover suitabilities for each stream cell were calculated with a BASIC program which integrated the standard cover data taken on each transect with the partitioned wetted width of each stream cell. The cover suitability of each cover type on the stream cell wetted width was averaged with the other cover suitabilities present (proportional to their occurrence) to give an average cover suitability. For example, if the stream cell was 15 ft in width and ten ft of the width was a cover type with a suitability of 0.5 and the other five feet was a cover type with a suitability of 1.0, the average cover suitability for the cell would be : [(10 x 0.5)+(5 x 1.0)]/15 = 0.67.

The RJHAB spreadsheet then took the stream cell areas and cover suitabilities, and multiplied these with the depth and velocity suitabilities which it assigned to the sampling cell depth and velocity measurements. The products of these calculations (stream cell WUA's) are then totalled to calculate site WUA's for each sampling occasion. Weighted usable areas for chinook salmon in turbid and clear water and chum, coho, and sockeye salmon were all calculated concurrently.

Weighted usable areas were plotted over the range of mainstem discharges sampled. Since initial overtopping flows were estimated for each side channel, WUA response was extrapolated in the range around breaching using this information. Habitat indices were calculated by dividing the WUA of the site at a given discharge by the site area at the same discharge and these were also plotted. Only selected site and species combinations are presented here, all other WUA calculations are available upon request. Individual sampling cell measurements are also available upon request.

In order to compare output from the RJHAB model with that of the IFIM methodology, two sites (Island and Trapper Creek side channels) were modelled with both techniques. Output from both techniques were graphed as a function of mainstem discharge and then correlated with each other at the measured RJHAB discharges.

2.2.3.4 Model verification

Fish abundance data were collected at all of the IFIM and RJHAB sites. High mean catches per cell (CPUE's) should reflect high densities of fish within the site. Since WUA's partially reflect the size of a site, they do not by themselves reflect the habitat quality of a site. The habitat index calculated by dividing WUA by site area (at any given discharge), however, does reflect site quality, independently of site area.

Mean seasonal habitat indices for each site were calculated for each species with the following procedure. Mean daily discharges for each day between May 15 and October 15 were rounded to the nearest 3,000 cfs increment in the range from 12,000 to 75,000 cfs. The season for chum salmon ran from May 15 to July 15. If the discharge was greater than 75,000 cfs, the discharge was assumed to be 75,000 cfs because WUA's were calculated only up to 75,000 cfs. Corresponding WUA's and site areas corresponding to these discharges were then totalled to find the total WUA and site area for the season. The mean seasonal habitat index was then calculated by dividing the total WUA by the total site area. For chinook and chum salmon, WUA's were adjusted by a turbidity factor before the habitat index was calculated. The turbidity factor was calculated by fitting a suitability index from 0 to 1.0 on the distribution of mean chum and chinook juvenile salmon catch by 50 NTU turbidity increment. Site mean CPUE's were regressed against site habitat indices at each site.

3.0 RESULTS

3.1 Seasonal, Spatial, and Discharge Related Variations in Habitat

3.1.1 Macrohabitat type classifications of study sites

All the study sites were classified into one of three macrohabitat types: tributary mouths, side channels, or side sloughs. Classification and habitat characteristics of the twenty modelled study sites are given in Table 4. Initial overtopping discharges for the side channels ranged from approximately 8,000 to 46,500 cfs with flows controlled by the mainstem at least 50% of the time while the tributary mouth sites were never overtopped at flows less than 53,000 cfs and site flows were controlled by the mainstem less than 5% of the time. Backwater effects were the only effects attributable to mainstem discharge at the tributary mouths on all sampling occasions except at Beaver Dam Slough where discharges greater than 75,000 cfs caused the head to overtop and flow to increase through the site. Even at discharges greater than 75,000 cfs however, the major effect of mainstem discharge on Beaver Dam Slough was a backwater response.

The side slough macrohabitat type was not represented by any of the sites when mainstem discharges were highest during the period from late June through early August. Side slough habitat increased with decreases in mainstem discharges.

Table 4. Classifications and habitat characteristics of study sites on the lower Susitna River at which juvenile salmon habitat was modelled, June through October 1984.

Site	River Mile	Initial Overtopping Discharge (cfs)	Percent of Time Flow Controlled by Mainstem in 1984[1]	Non-mainstem Water Sources
Side Channels (head open)/ Sloughs (head closed)				
Hooligan Side Channel	35.2	22,000	80	Pools only
Eagles Nest Side Channel	36.2	8,000	94	Unknown
Kroto Slough Head	36.3	33,500	62	Minor upwelling
Bear Bait Side Channel	42.9	35,000	64	Pools only
Last Chance Side Channel	44.4	25,000	79	Pools only
Rustic Wilderness Side Channel	59.5	19,000	86	Pools only
Island Side Channel	63.2	33,000	64	Major upwelling
Mainstem West Bank	74.4	20,000	86	Major upwelling
Goose 2 Side Channel	74.8	28,000	68	Minor upwelling
Circular Side Channel	75.3	35,000	64	Major upwelling
Sauna Side Channel	79.8	32,000	62	Minor upwelling
Sucker Side Channel	84.5	28,000	71	Minor upwelling
Beaver Dam Side Channel	86.3	46,500	50	Unnamed tributary
Sunset Side Channel	86.9	27,000	68	Major upwelling
Sunrise Side Channel	87.0	35,000	64	None
Trapper Creek Side Channel	91.6	35,000	57	Cache Creek
Tributary Mouths				
Rolly Creek Mouth	39.0	>100,000	0	Rolly Creek
Caswell Creek Mouth	63.0	>100,000	0	Caswell Creek
Beaver Dam Slough	86.3	>75,000	<5	Unnamed tributary
Birch Creek Slough[2]	88.4	53,000	<5	Birch Creek

[1] These percentages based on controlling breaching discharges presented in Quane et al. (1985) for the period from May 15 to October 15, 1984.

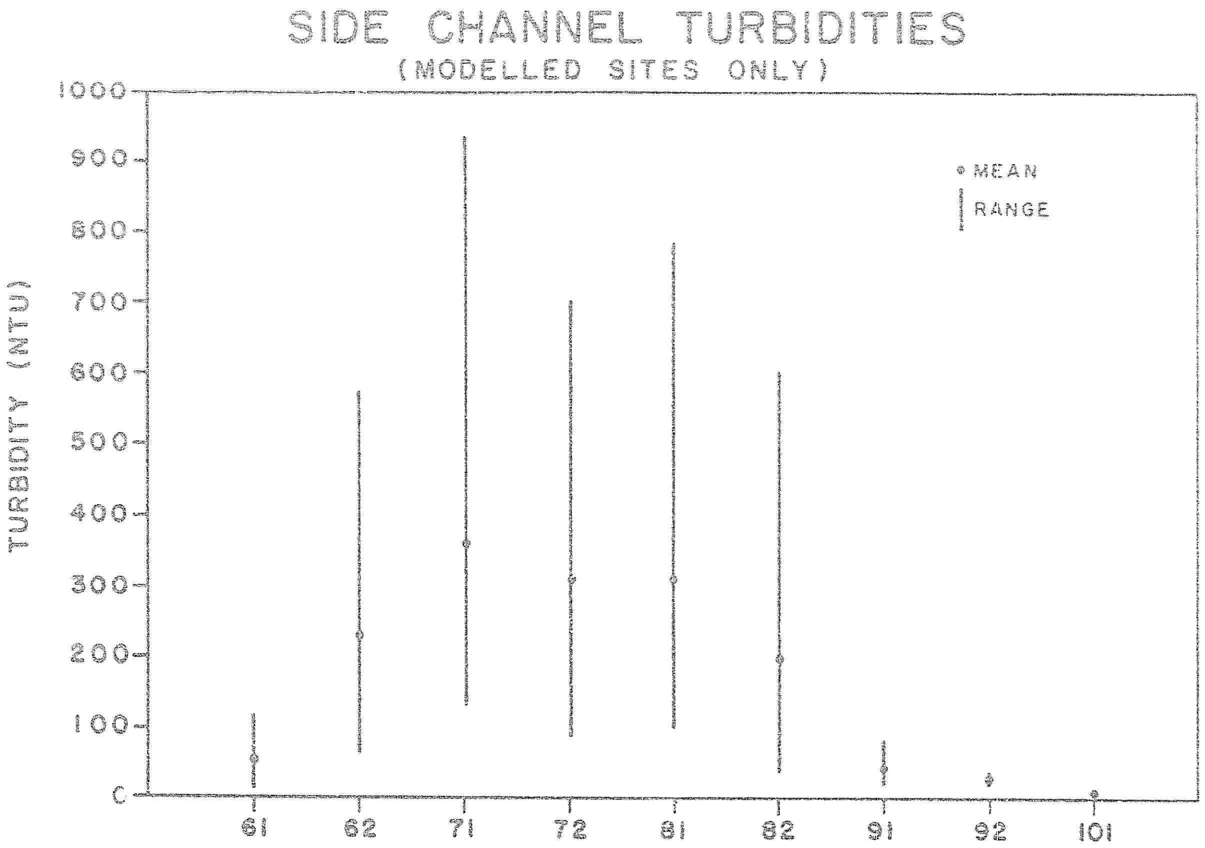
[2] A culvert at the head of this slough is frequently blocked and therefore little mainstem water flows into the slough, even if the slough head is overtopped. The effect of mainstem discharge on this site is minimal for this reason.

Major object cover differences among the modelling sites were differentiated by macrohabitat type. An index of cover for each site at a discharge of approximately 52,000 cfs (range 45,500 to 58,800 cfs) was calculated for between-site comparisons of cover (Table 5). The percentage of the site with the primary cover type, aquatic vegetation, varied from 8.5% to 68.5% for the tributary mouths, while none of the side channel/sloughs had any aquatic vegetation. Substrate in the form of large gravel (1-3" diameter) and rubble (3-5" diameter) was the primary cover type for an average of 62% of the area of side channels, while these two cover types only covered an average of 14% of the area of tributary mouth sites. The density of cover at tributary mouths was almost three times that of side channels also. Side sloughs, which by definition are dewatered side channels, often were even more cover poor than side channels.

Cover, in the form of turbidity was much more frequent within side channels than at tributary mouths. Turbidities were consistently much higher in the side channels than in the tributary mouths during the entire open-water season (Figure 3). A few turbidities of 100 to 150 NTU were recorded at Rolly Creek mouth and Beaver Dam Slough due to rapid increases in mainstem discharge which caused mainstem backwater to intrude into the sites, or in the case of Beaver Dam Slough, by a slight overtopping of the channel head by mainstem water. Turbidities within the side sloughs ranged from 1 to 19 NTU with a mean of 5.2 NTU.

Table 5. Percentages of lower river habitat modelling sites associated with nine cover-type categories. Percentages are based on the width of transect with each cover type. Cover index calculated by dividing total cover by total area of site.

				Percentage of Site With Primary Cover Type										
Side Channels/Sloughs	River Mile	Date	Discharge (cfs)	No Cover	Emergent Veg.	Aquatic Veg.	Large Gravel	Rubble	Cobble	Debris	Overhang. Riparian Veg.	U.C. Banks	Total	Cover Index
Hooligan Side Channel	35.2	7/14	52400	18.9	0.0	0.0	72.0	0.0	0.0	8.5	0.6	0.0	100.0	13.7
Kroto Slough Head	36.3	7/17	49600	56.4	0.0	0.0	8.6	0.0	0.0	33.5	1.6	0.0	100.1	1.8
Bear Bait Side Channel	42.9	7/13	52400	0.0	0.0	0.0	66.8	0.0	0.0	28.1	3.7	1.4	100.0	11.5
Last Chance Side Channel	44.4	7/12	54100	23.5	0.0	0.0	63.5	0.0	0.0	12.3	0.8	0.0	100.1	5.9
Rustic Wilderness Side Channel	59.5	8/12	52900	0.0	0.0	0.0	60.9	30.0	0.0	7.8	0.8	0.5	100.0	13.7
Island Side Channel	63.2	7/19	51600	13.4	0.0	0.0	62.0	21.6	0.0	0.0	1.4	1.6	100.0	10.5
Mainstem West Bank	74.4	Extrapolated		1.0	0.4	0.0	43.4	49.3	0.0	2.2	3.4	0.4	100.1	22.7
Goose 2 Side Channel	74.8	7/20	52600	2.0	0.9	0.0	24.3	51.8	13.7	3.5	3.5	0.2	99.9	22.5
Circular Side Channel	75.3	7/24	56600	20.4	0.0	0.0	48.4	21.3	0.0	5.3	4.6	0.1	100.1	9.3
Sauna Side Channel	79.8	7/23	56600	93.4	0.0	0.0	0.0	0.0	0.0	4.3	2.4	0.0	100.1	0.5
Sucker Side Channel	84.5	7/09	55400	80.2	8.4	0.0	6.6	0.0	0.0	3.9	1.0	0.0	100.1	1.1
Beaver Dam Side Channel	86.3	7/08	57100	55.9	0.9	0.0	18.6	5.9	0.0	18.6	0.0	0.0	99.9	1.9
Sunset Side Channel	86.9	7/22	57800	15.0	0.0	0.0	66.8	9.7	0.0	7.7	0.5	0.3	100.0	4.8
Sunrise Side Channel	87.0	7/07	58800	4.0	0.0	0.0	51.4	44.6	0.0	0.0	0.0	0.0	100.0	10.0
Trapper Creek Side Channel	91.6	8/19	57200	2.2	0.0	0.0	39.1	58.8	0.0	0.0	0.0	0.0	100.1	12.3
			MEAN	25.8	0.7	0.0	42.2	19.5	0.9	9.0	1.6	0.3	100.0	9.5
Tributary Mouths														
Rolly Creek Mouth	39.0	7/11	55100	6.9	25.2	46.2	0.0	0.0	0.0	21.5	0.1	0.0	99.9	24.2
Caswell Creek Mouth	63.0	8/18	45400	2.9	5.3	48.2	17.6	0.0	0.0	18.4	1.6	6.1	100.1	19.0
Beaver Dam Slough	86.3	7/08	57100	6.8	9.9	68.5	0.0	0.0	0.0	11.1	3.1	0.6	100.0	57.8
Birch Creek Slough	88.4	7/20	52600	36.8	0.5	8.5	29.2	9.0	0.0	13.6	2.2	0.3	100.1	6.3
			MEAN	13.4	10.2	42.9	11.7	2.3	0.0	16.2	1.8	1.8	100.0	26.8



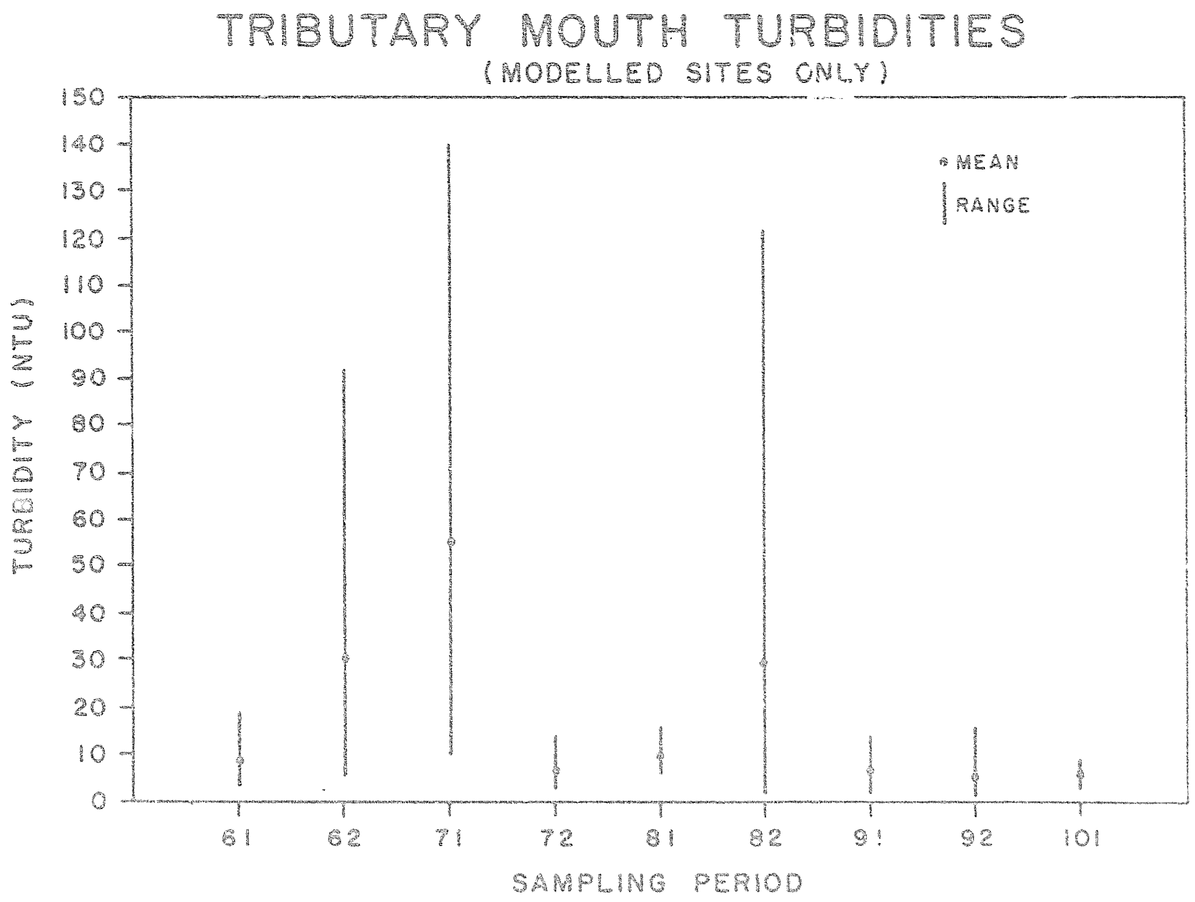


Figure 3. Turbidities of modelled side channels and tributary mouths on the lower Susitna River, June through October 1984.

3.1.2 Chulitna and Talkeetna River plume influences on turbidity of side channels

Turbidity measurements of the lower Susitna River taken in west bank, mid-channel, and east bank portions of the mainstem indicate that plume influences of the Chulitna and Talkeetna Rivers extend at least 20 to 30 miles downriver (Figure 4). On September 2, turbidities at RM 83.8 ranged from 60 NTU on the east bank, to 77 NTU in mid-channel and 88 NTU on the west bank. West bank turbidities are much higher than on the east bank, because the Chulitna River is three or more times as turbid as the Talkeetna River and middle reach of the Susitna River.

A comparison of turbidities at the modelled side channels located above RM 70 also suggests that the plumes have major effects on turbidities downstream. Mean turbidity at side channels located on the west bank (Mainstem West Bank, Sauna S.C., and Trapper Creek S.C.) during June through late August was 377 NTU. During the same time period, side channels located on the east bank (Goose S.C., Sunset S.C., and Beaver Dam, S.C.) had a much lower mean turbidity of 158 NTU. Mean turbidities for all the side channels modelled with the exception of Eagle's Nest Side Channel have been calculated in Appendix Table B-1.

CHULITNA, TALKEETNA PLUME EFFECTS

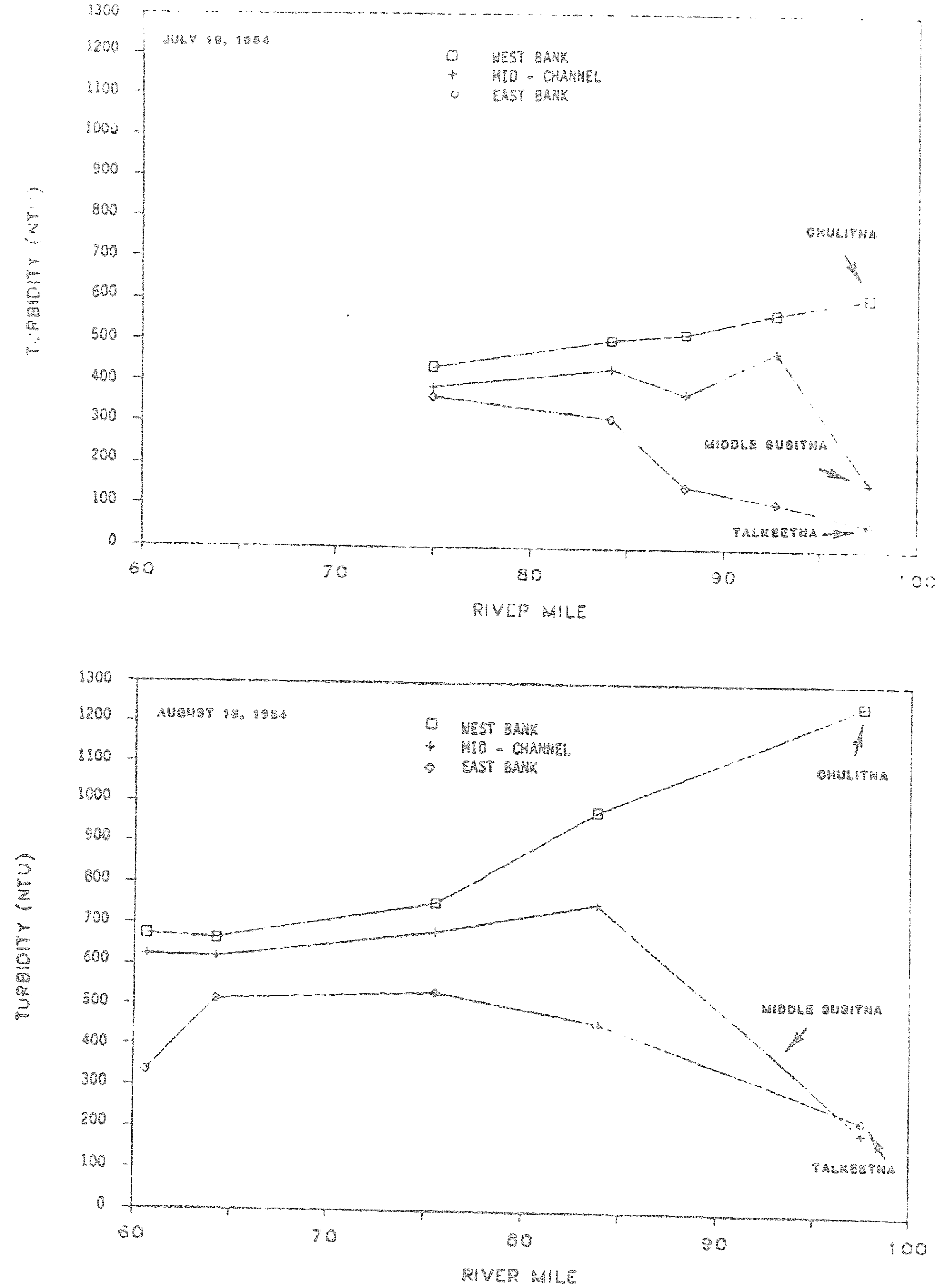


Figure 4. Comparison of turbidities in the lower Susitna River below the Chulitna and Talkeetna river confluence on July 19 and August 16, 1984.

3.1.3 Physical responses of sampling sites to mainstem discharge variations

Variations in mainstem discharge cause the heads of side channels to open and close, thereby affecting macrohabitat classifications due to the subsequent changes in water quality. Increases in side channel flows, areas, and the amount of cover also occur with increases in mainstem discharge after head overtopping. The relationships between side channel flows and mainstem discharge are presented in Quane et al. (1985).

Changes in area of the sites due to increases in mainstem discharge are important because increases may directly increase habitat. Area increases measured from aerial photos are being compiled for selected side channel and slough complexes by R&M Consultants Inc. and E. Woody Trihey and Associates. Also cover responses at tributary mouths caused by mainstem backwater effects are significant because object cover is an important component of these sites for juvenile salmon. Discharge related responses of site area for all sites pooled and cover for selected tributary mouths will be presented in the next two sections.

3.1.3.1 Area

The areas of the RJHAB study sites were calculated geometrically at modelled discharges, and then plotted against mainstem discharge. These points were then fit by hand using professional judgement. Area measurements at 3,000 cfs increments were then taken from these graphs in the range from 12,000 to 75,000 cfs. Since Eagles Nest Side Channel was modelled only at discharges less than 20,000 cfs, we did not try to extrapolate values over this range for this site. Similarly, area response at the six IFIM sites were calculated by the IFG program at side channel flows which corresponded to increments of 3000 cfs within the 12,000 to 75,000 cfs mainstem discharge range.

Individual area responses for all the modelling sites have been tabulated in Appendix Table B-4 at 3,000 cfs discharge increments. Also, side channel flows associated with these increments have been tabulated. By summing areas of the sites by macrohabitat type, the response of the area of all the sites pooled can be illustrated. The combined area of three tributary mouths increased greatly at discharges greater than 27,000 cfs (Figure 5). Since sloughs become side channels at greater discharges, slough habitat decreased with discharge while side channel habitat steadily increased (Figure 6). The slough habitat is broken into the two categories, total and accessible. The total category includes ponded water with no access from the mainstem while the accessible sloughs are those with potential access from the mainstem.

3.1.3.2 Cover

Since instream cover is an important component of fish habitat, the response of available cover to mainstem discharge at individual sites is of interest. Increases in instream cover at side channels are often accompanied by large increases in flows and related water column velocities. Therefore, increases in cover at side channels are often offset

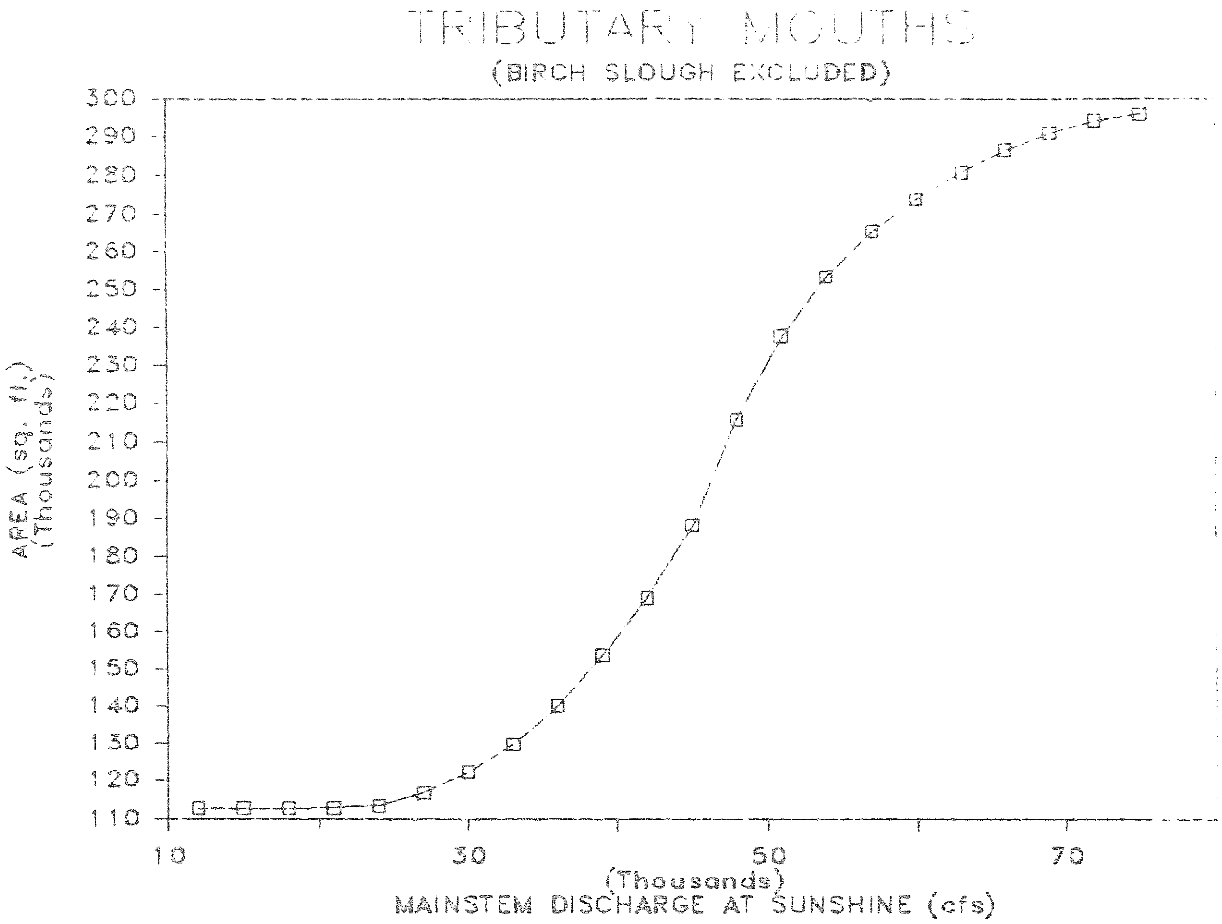


Figure 5. Area within modelled tributary mouths as a function of mainstem discharge at the USGS Sunshine gaging station, 1984.

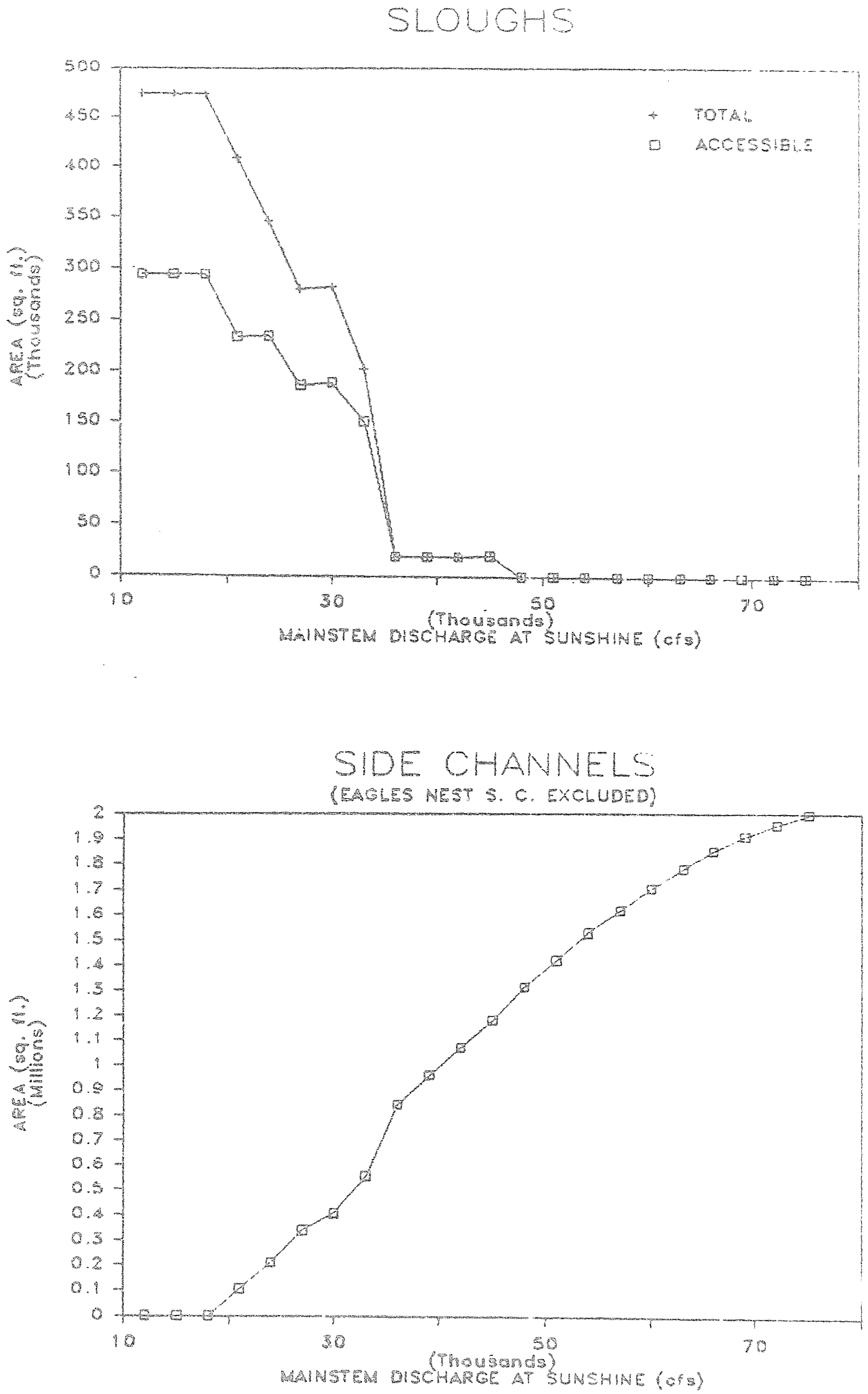


Figure 6. Area within modelled sloughs and side channels as a function of mainstem discharge at the USGS Sunshine gaging station, 1984.

by increases in velocities which make the site unsuitable. Turbid water in side channels may also provide cover for juvenile salmon and therefore, instream object cover may be less necessary under turbid conditions (Suchanek et al. 1984).

At tributary mouths, on the other hand, flows are independent of mainstem discharge, the water is often clear, and the primary effect of mainstem discharge is the formation of a backwater zone. Increases in mainstem stage typically decrease water velocities at tributary mouths while cover increases. Increases in cover at tributary mouths with increases in discharge may be of more importance than at side channels because the clear water provides little cover, and changes in velocities are relatively less. In the habitat modelling section, cover responses are integrated with velocity and depth changes for all the sites, but here only backwater instream cover responses at tributary mouths will be presented.

Cover responses to mainstem discharge at the four tributary mouths varied greatly. At Birch Creek Slough, there was no response of cover to changes in mainstem stage during the 1984 open-water season. This occurred because the sampling site was located so far up the channel that it was not influenced by mainstem stage during the 1984 sampling trips. At the other three sites, however, mainstem backwater effects were measurable.

At Beaver Dam Slough, only limited increases in total cover were caused by increases in mainstem discharge because most of the cover was aquatic vegetation (Figure 7). At Rolly Creek and Caswell Creek mouths, however, the amount of cover at the sites increased rapidly within the sites at discharges larger than 45,000 cfs. Increases in total cover at Rolly Creek mouth were caused primarily by increases in emergent vegetation while increases in both emergent and overhanging riparian vegetation were responsible for the large increase in total cover at Caswell Creek mouth.

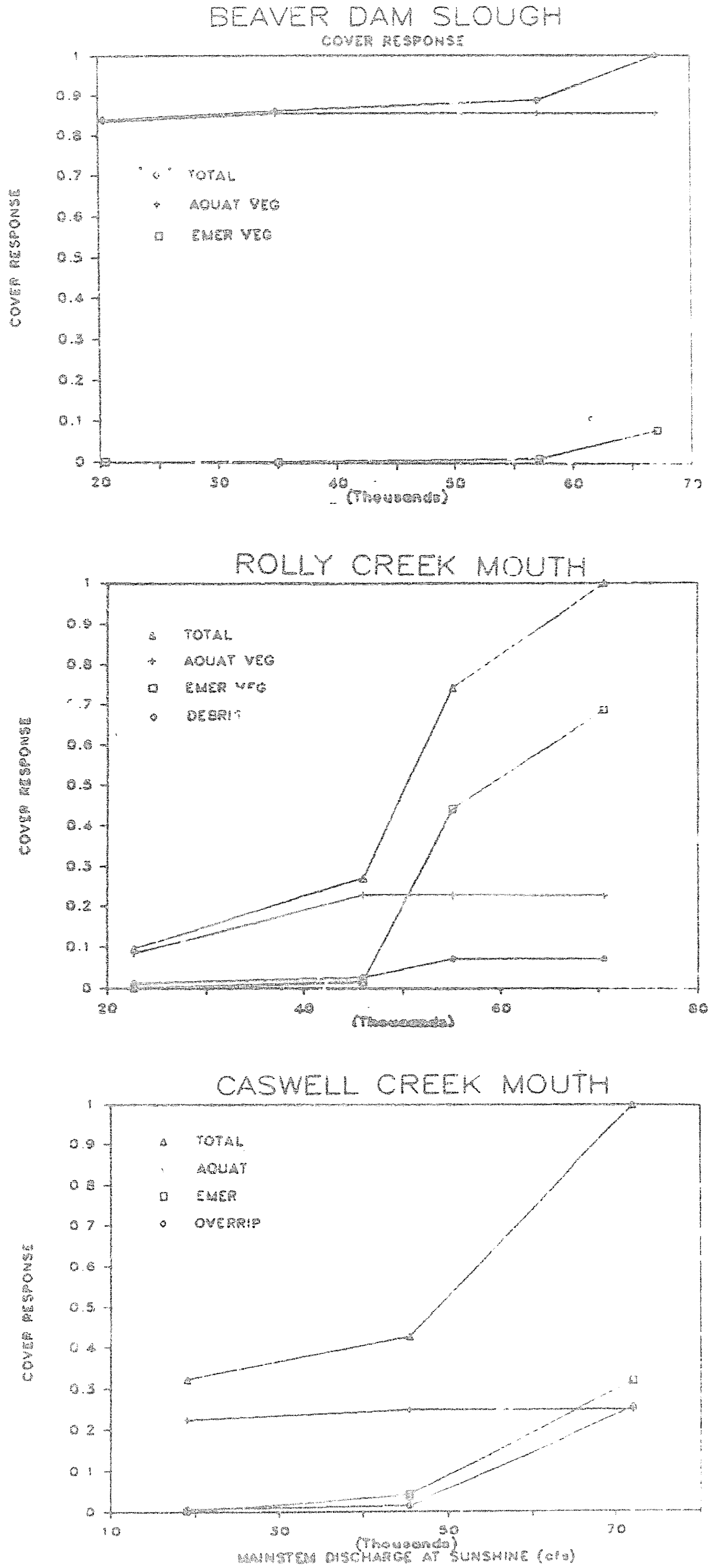


Figure 7. Instream cover response at Beaver Dam Slough, Rolly Creek and Caswell Creek mouths as a function of mainstem discharge at the USGS Sunshine gaging station, 1984.

3.2 Distribution and Abundance of Juvenile Salmon

Chinook, coho, chum, and sockeye salmon juveniles were captured at the twenty habitat model sites, but only one pink salmon fry was captured. Pink salmon outmigrate early and our methods are not effective at capturing them. A summary of the juvenile chinook, coho, chum and sockeye salmon catch and catch per cell (CPUE) data by site is given in Appendix Table B-2.

3.2.1 Chinook salmon

A total of 1,458 juvenile chinook salmon were collected in the lower reach of the Susitna River from June through early October. About 83% (1,209) of these fish were captured at the 20 habitat model sites. Age 0+ fry accounted for 93% of the chinook salmon juveniles captured. The percentage of 0+ fry increased from 66% in late June to 99% in early August. All chinook fry captured after early August were 0+ fish, indicating that 1+ chinooks had outmigrated from the study reach prior to August 15.

Chinook fry were widely distributed at the modelling sites from early June through late August (Figure 8). Last Chance Side Channel was the only site where no chinook juveniles were captured. Chinook juveniles were captured at 80% or more of the sites sampled in early June and late August. In September and early October, the proportion of sites where chinook salmon were captured decreased.

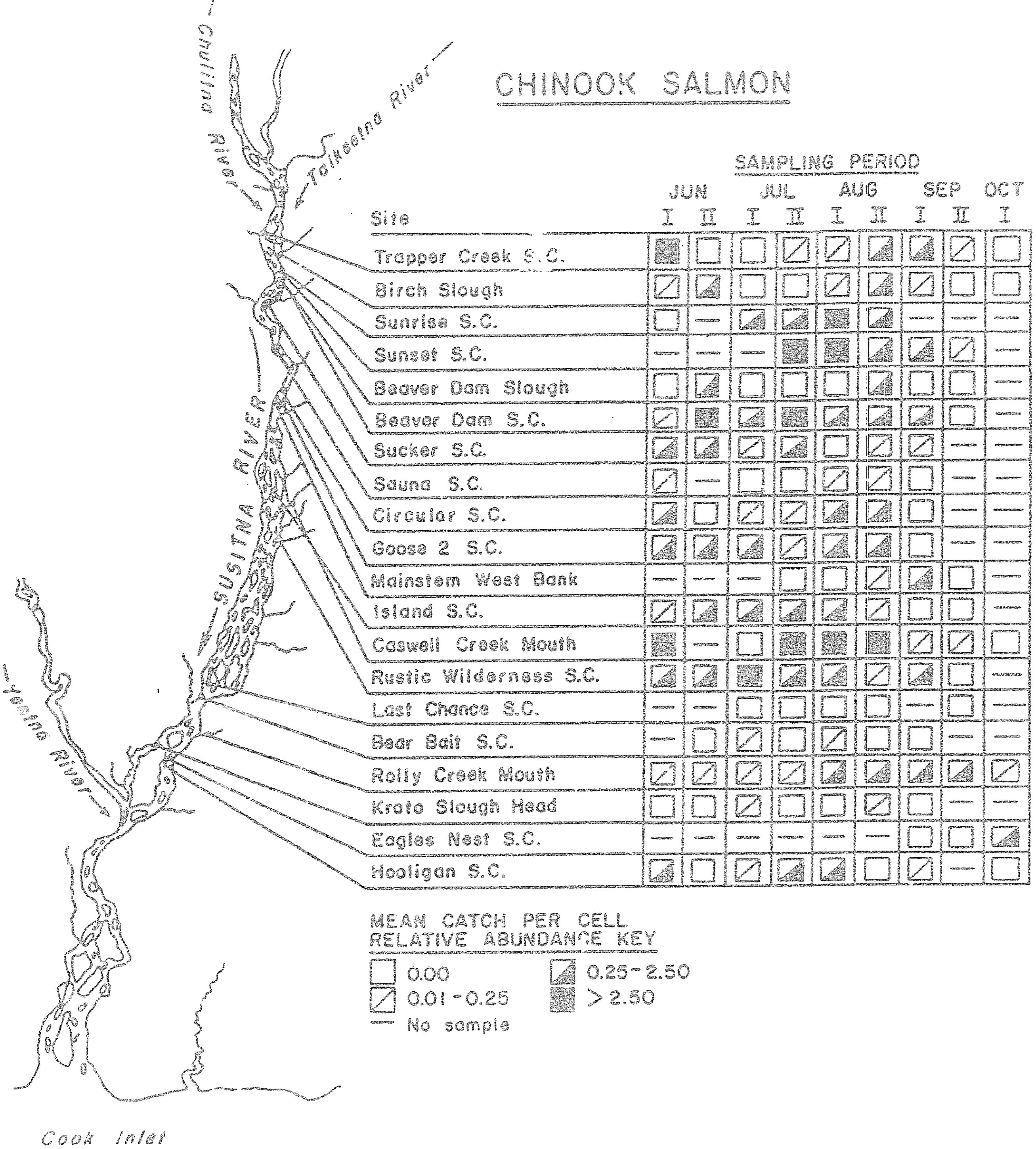


Figure 8. Seasonal distribution and relative abundance of juvenile chinook salmon on the lower Susitna River, June through mid-October 1984.

Mean juvenile chinook CPUE was highest at tributary mouths, where 1.5 fish per cell (fpc) were captured, although a side channel CPUE of 0.8 fpc was also substantial. Slough catch rates were consistently low (0.1 fpc). Mean catch rates at side channels remained generally constant throughout the season, while tributary mouth CPUE's peaked in August (Figure 9). The peak CPUE for tributary mouths occurred in late August at Caswell Creek mouth (20.2 fpc). The peak CPUE in a modelled side channel (4.4 fpc) occurred at Sunset Side Channel. CPUE's within the side channels peaked at turbidities of 100 to 150 NTU (Figure 10). The correlation between the mean turbidity for the modelled side channels and mean catch per cell of chinook salmon was -0.63 ($p<0.05$).

Catches at Trapper Creek Side Channel appeared to reflect the effect of turbidity upon chinook fry use. This west bank site was below the Chulitna River, the major turbidity source in the lower river. The site had a high CPUE for early June (2.7 fpc), then zero catches of chinook in late June and early July when turbidity levels were above 550 NTU. Chinook fry were captured at low levels on subsequent trips when the turbidities again decreased.

3.2.2 Coho Salmon

A total of 442 juvenile coho salmon were captured within the lower Susitna River study area. All but five of the juvenile coho salmon were captured within the habitat model sites. Three age classes of juvenile coho salmon were captured. Eighty-six percent of the juvenile coho

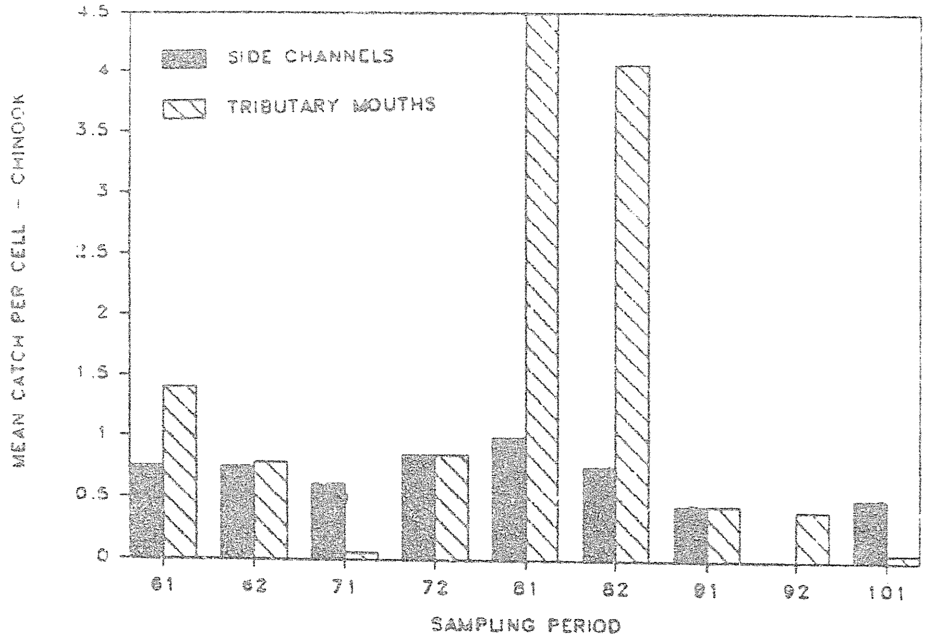


Figure 9. Juvenile chinook salmon mean catch per cell at side channels and tributary mouths on the lower Susitna River by sampling period, June through mid-October 1984.

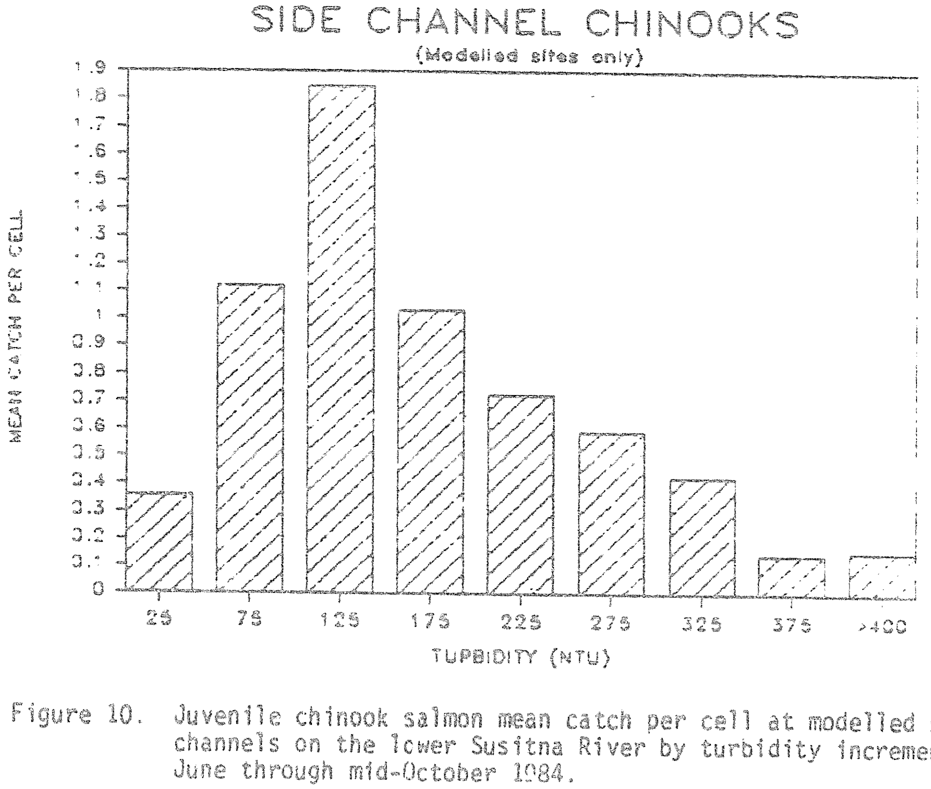


Figure 10. Juvenile chinook salmon mean catch per cell at modelled side channels on the lower Susitna River by turbidity increment, June through mid-October 1984.

captures were from the 1983 brood year (0+), 14% were from the 1982 brood year (1+) and one 1981 brood year (2+) juvenile was captured. The percentage of 1+ fry captured decreased from a high of approximately 50% in early June to approximately 2% in early October.

Juvenile coho salmon were unevenly distributed throughout the study area (Figure 11). Coho were captured at only 50% of the 20 modelled sites and only single coho captures were made at four of these sites. Juvenile coho CPUE's, in most instances, tended to be somewhat higher in late summer.

Distribution of juvenile coho salmon was extremely disproportionate among the three macrohabitat types. The tributary mouths had a mean juvenile coho CPUE of 1.2 fpc while sloughs and side channels had CPUE's of 0.02 and 0.01 fpc, respectively. Juvenile coho were captured at all four tributary mouths, five of the 16 side channels (31%) and two of the 14 sloughs (14%) sampled. Caswell Creek was the primary capture site, contributing over half of the total juvenile coho CPUE, with most captured from mid to late August.

The juvenile coho catch rate at tributary mouths ranged from near ten juveniles per cell at Caswell Creek in late August to zero fish per cell at several sites during various sampling periods (Figure 12). With the exception of Birch Creek Slough, coho CPUE's were higher during late summer and fall than during early summer sampling periods.

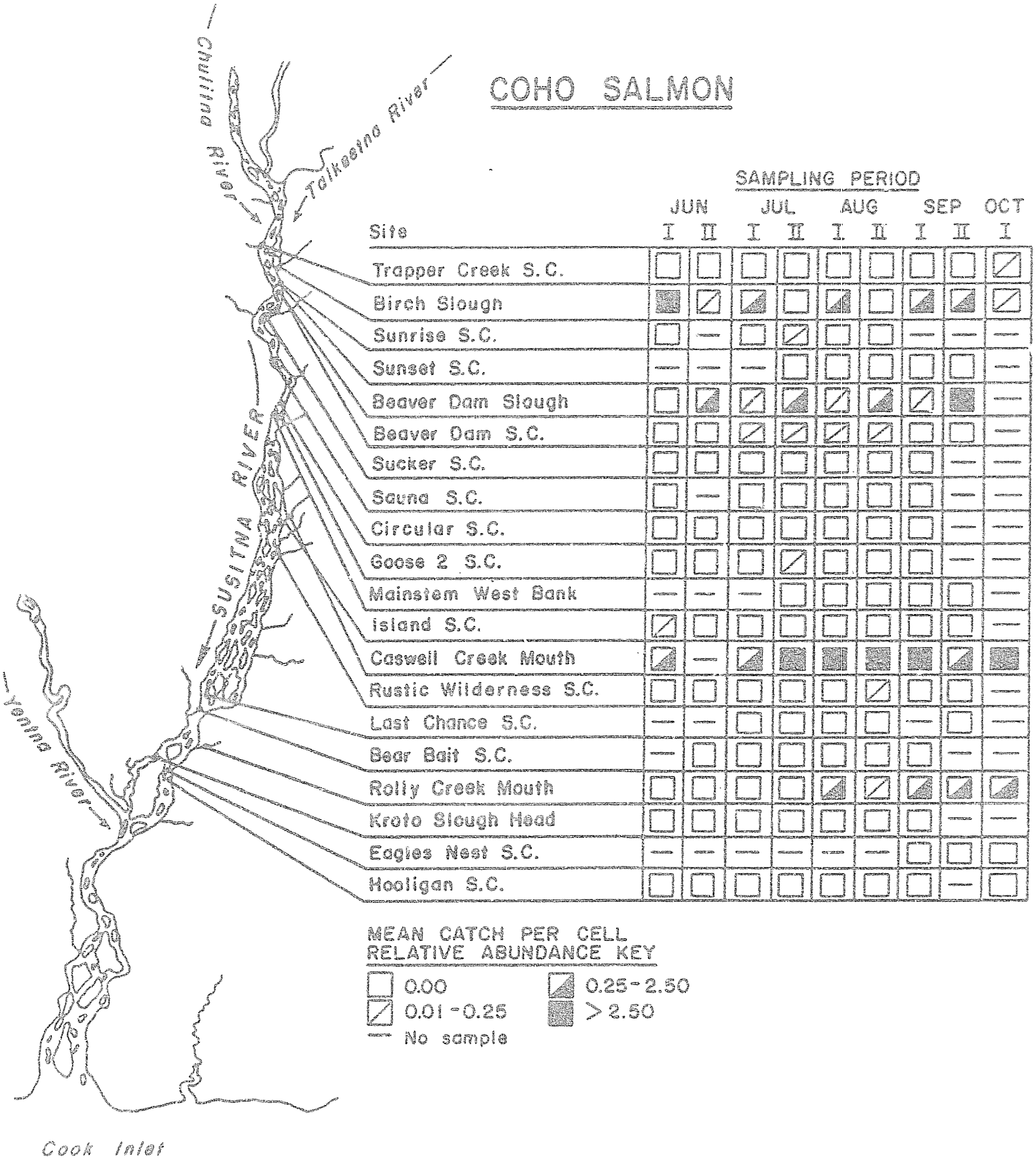


Figure 11. Seasonal distribution and relative abundance of juvenile coho salmon on the lower Susitna River, June through mid-October 1984.

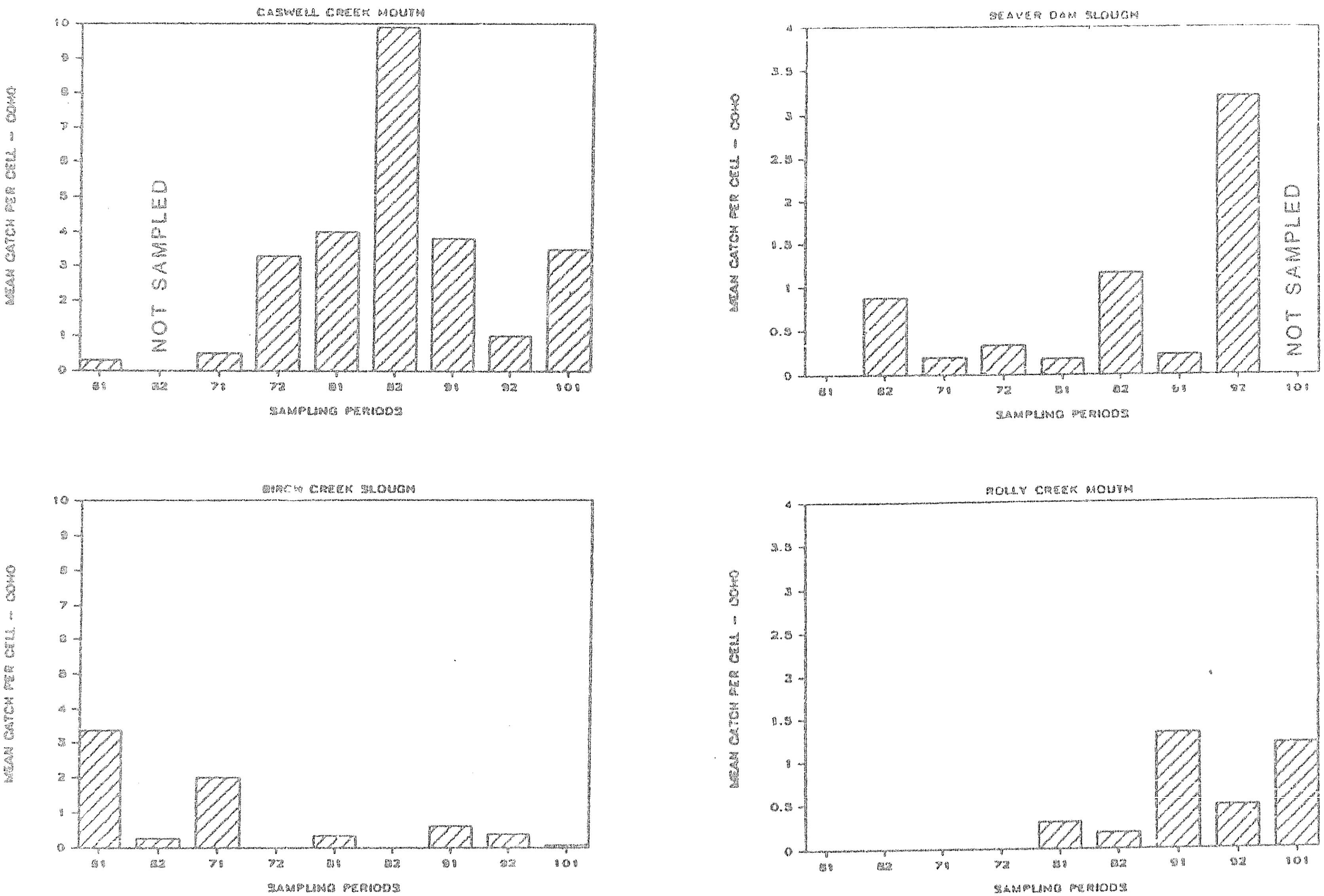


Figure 12. Juvenile coho salmon mean catch per cell at four tributary mouths on the lower Susitna River by sampling period, June through mid-October 1984.

3.2.3 Chum salmon

A total of 608 juvenile chum salmon were collected in the lower Susitna River. Only ten of these juvenile chum salmon were captured at opportunistic sites.

In early June, chum fry were captured at 13 of the 15 (87%) modelling sites sampled (Figure 13). By late July, chum were only captured at six of the 19 (32%) sites sampled. Over 99% of the total catch was made prior to August and no chum salmon fry were captured after August 15. The majority of sites with high CPUE's were located in the reach from Island Side Channel (RM 63.2) to Sucker Side Channel (RM 84.5).

Chum fry CPUE's declined steadily from early June to mid-August (Figure 14), reflecting outmigration of juvenile chum salmon from the Susitna system. In a pre-study trip in late May, chum fry were also collected at a number of lower river sites and appeared widely distributed in the river.

Juvenile chum CPUE's were highest in side channels (0.6 fpc) and tributary mouths (0.1 fpc). Slough CPUE's of juvenile chum were extremely low (0.01 fpc), however, sampling effort within sloughs was limited during the period from early June through early July. Tributary mouth densities are unequally distributed by a single site catch of 39 fry at Birch Creek Slough in late June. Chum catches within the side channels were affected greatly by turbidity as peak catches were made in side channels with a turbidity of less than 50 NTU (Figure 15).

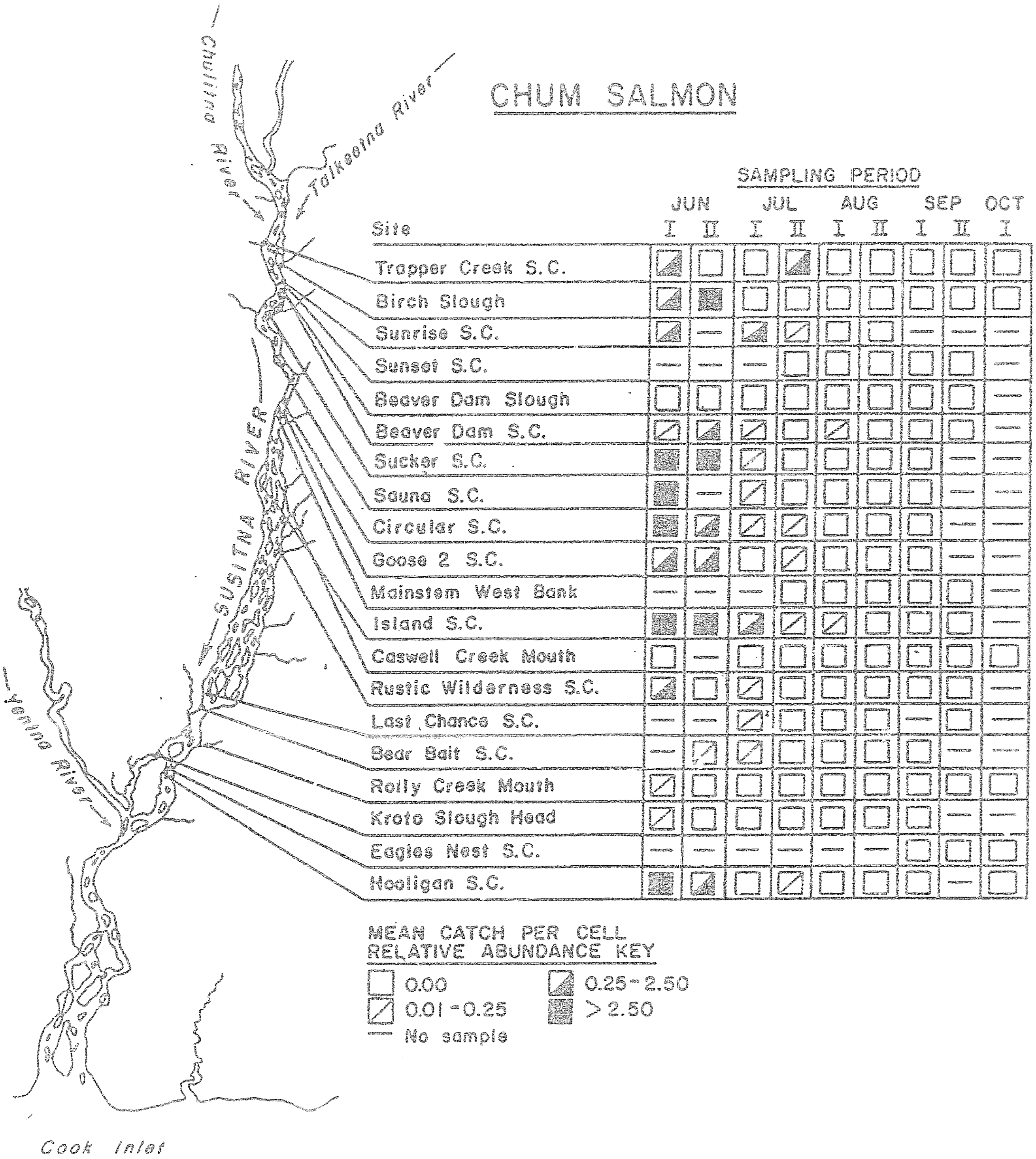


Figure 13. Seasonal distribution and relative abundance of juvenile chum salmon on the lower Susitna River, June through mid-October 1984.

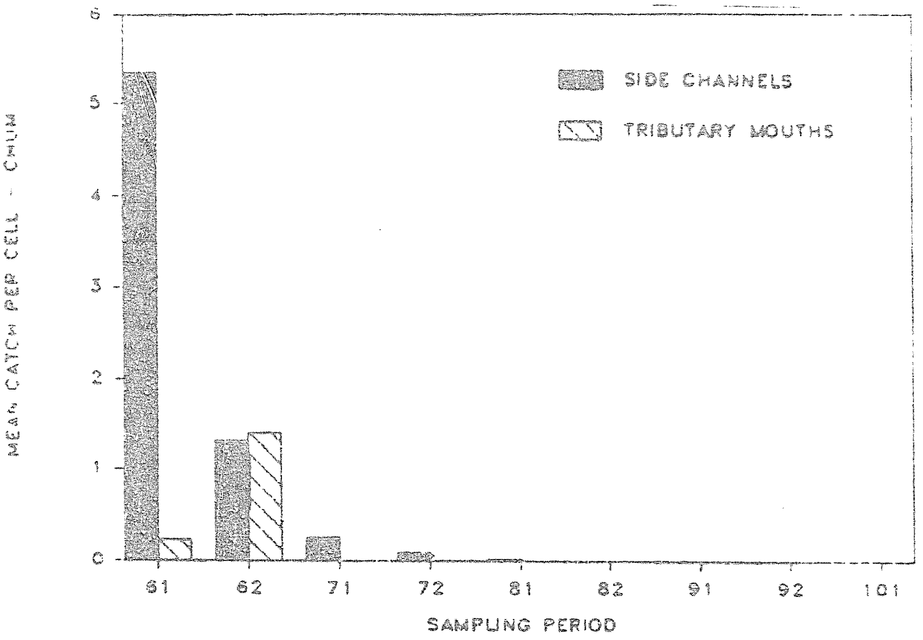


Figure 14. Juvenile chum salmon mean catch per cell at modelled side channels and tributary mouths on the lower Susitna River by sampling period, June through mid-October 1984.

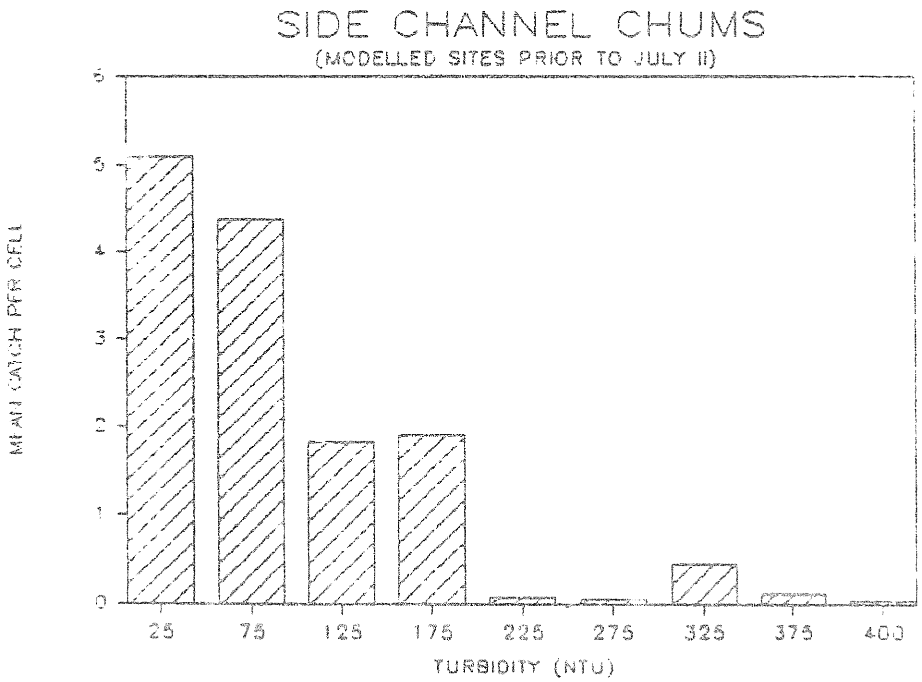


Figure 15. Juvenile chum salmon mean catch per cell at modelled side channels on the lower Susitna River by turbidity increment, June through mid-October 1984.

3.2.4 Sockeye salmon

A total of 412 juvenile sockeye salmon were captured in the lower Susitna River study reach from early June through early October. Ninety percent (369) of the juvenile sockeye salmon were captured at the habitat model sites. Age 0+ sockeye fry comprised 99% of the total season catch at modelled JAHS sites. No age 1+ sockeye were captured after June. Age 1+ sockeye were captured in early June at Hooligan Side Channel, a site which produced no further sockeye juveniles all season, and in late June at Beaver Dam Slough. Sockeye juveniles were most widely distributed within modelled sites upstream of Goose 2 Side Channel (Figure 16).

Tributary mouths exhibited the greatest densities of juvenile sockeye salmon with a mean catch of 0.7 fpc, and the highest CPUE at Beaver Dam Slough (1.2 fpc). Side channels had a mean sockeye CPUE of 0.1 fpc. Beaver Dam Side Channel had the highest CPUE for a side channel of 0.7 fpc. Side slough CPUEs of sockeye juveniles were minimal (0.03 fpc). Side channel CPUE's remained fairly constant at low levels through August in comparison to tributary mouth CPUE's which varied greatly (Figure 17). No sockeye juveniles were captured in side channels after August, however, sampling was limited.

The greatest mean CPUE for side channel sockeye fry was found at turbidities between 100 and 150 NTU (Figure 18). The numbers of sockeye juveniles captured in Beaver Dam Side Channel, immediately below and

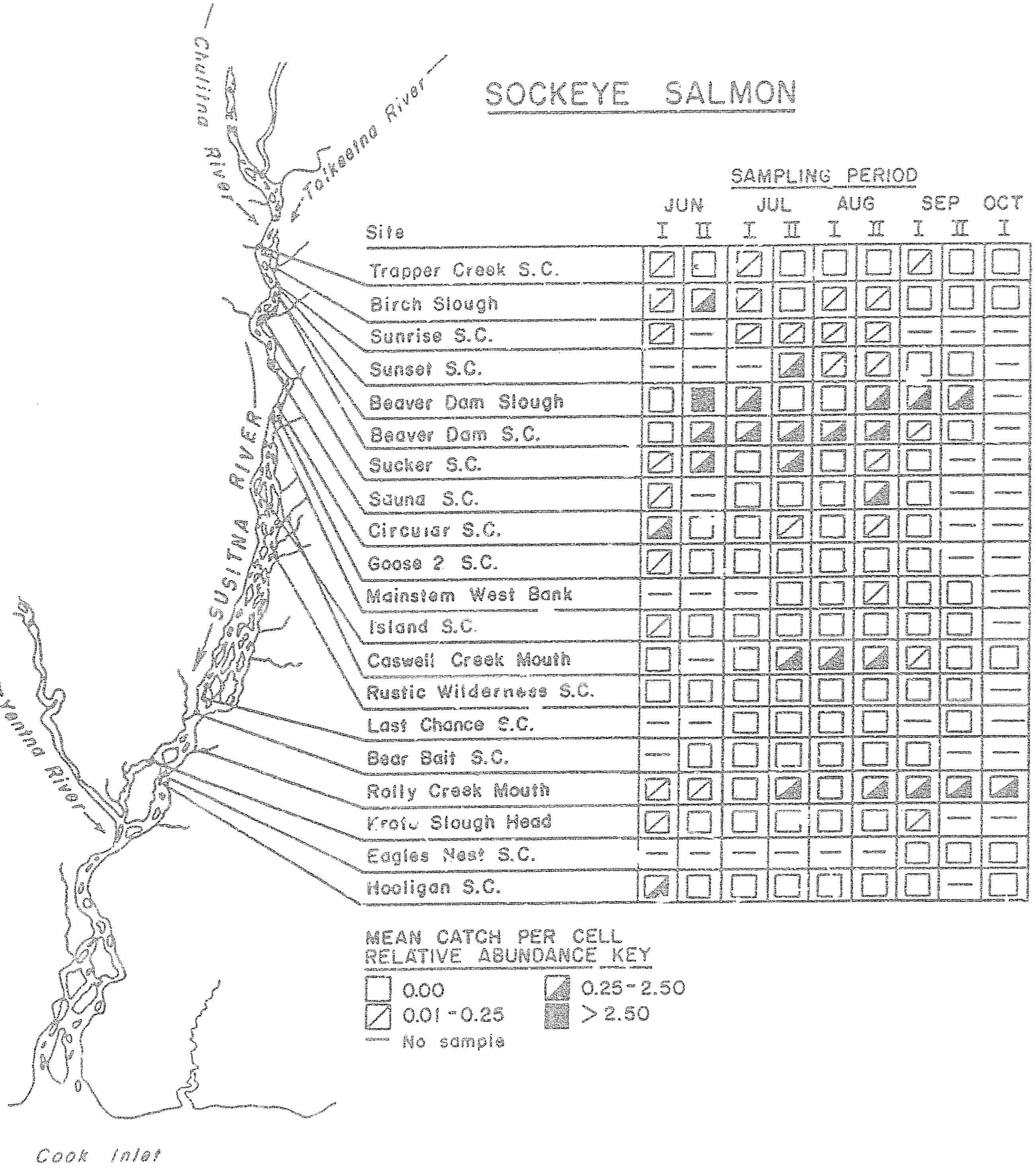


Figure 16. Seasonal distribution and relative abundance of juvenile sockeye salmon on the lower Susitna River, June through mid-October 1984.

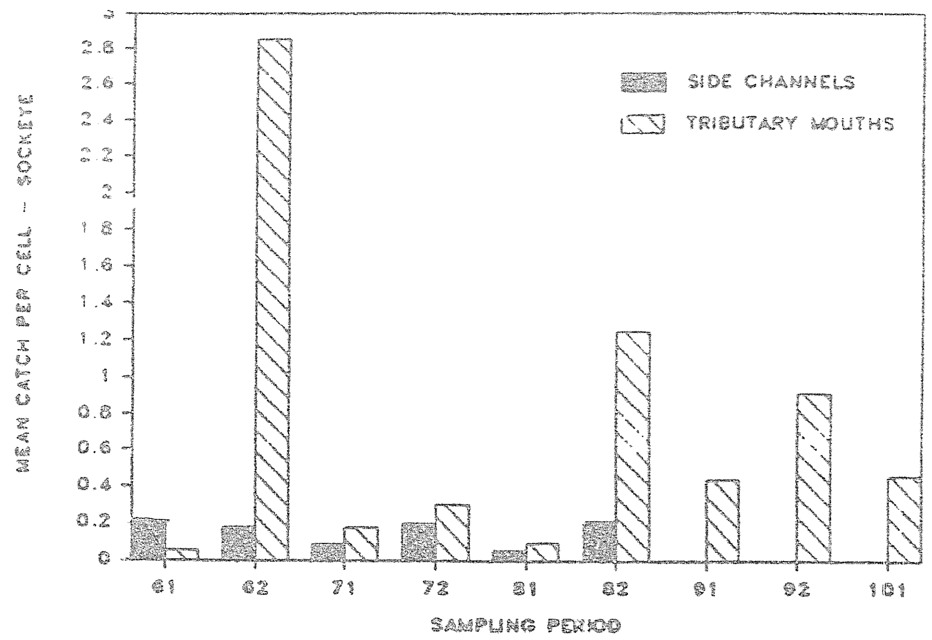


Figure 17. Juvenile sockeye salmon mean catch per cell at side channels and tributary mouths on the lower Susitna River by sampling period, June through mid-October 1984.

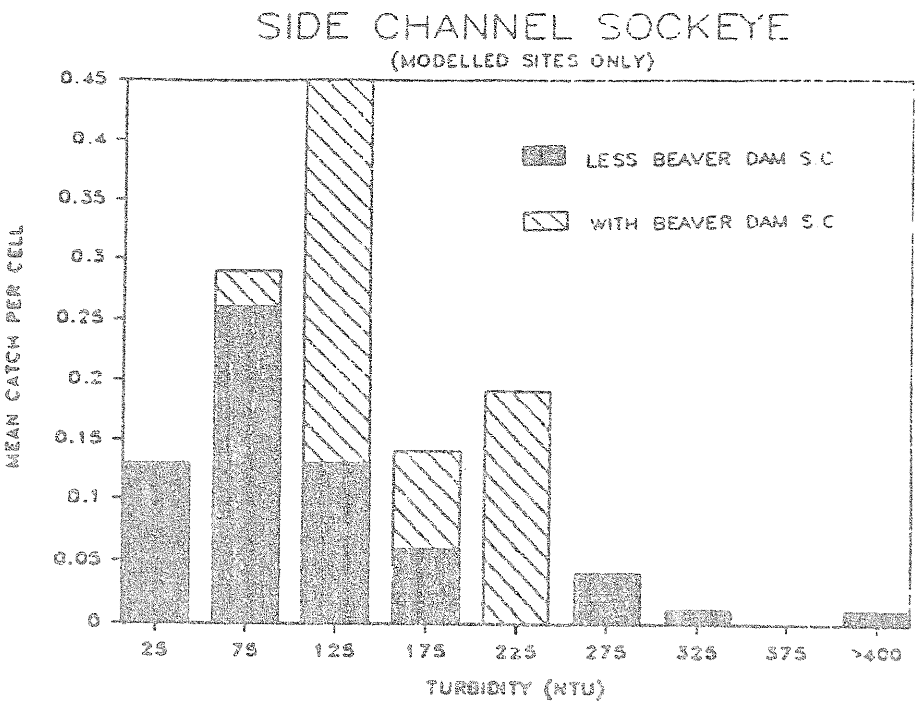


Figure 18. Juvenile sockeye salmon mean catch per cell at modelled side channels on the lower Susitna River by turbidity increment (with and without Beaver Dam Side Channel), June through mid-October 1984.

contiguous with Beaver Dam Slough, may have been enhanced by site to site movement. With Beaver Dam Side Channel captures excluded, the peak CPUE occurred at turbidities between 50 and 100 NTU.

Catches at Beaver Dam Slough and Beaver Dam Side Channel also showed the effects of turbidity as related to cover on the distribution of sockeye juveniles (Figure 19). During late June through August, Beaver Dam Side Channel was breached by the mainstem and turbid, and sockeye CPUE's were high. However, in early June and September, the site was much clearer and few sockeye juveniles were caught in the now cover poor environment. In Beaver Dam Slough, however, which has abundant aquatic vegetation cover, CPUE's of sockeye juveniles in late August and September were quite high. Catches at Rolly Creek also increased in late August and remained fairly high through early October (Figure 19).

3.3 Habitat Modelling of Rearing Juvenile Salmon

Two types of habitat modelling techniques were used to model the response of juvenile salmon habitat at the study sites to variations in mainstem discharge. The two methods are: (1) the RJHAB model developed in Marshall et al. (1984) and (2) the IFIM hydraulic models discussed by Bovee (1982). Suitability criteria for important microhabitat variables are necessary as inputs to both models and criteria specific to the lower reach of the Susitna River for juvenile chinook, coho, chum, and sockeye salmon have been developed in Appendix A.

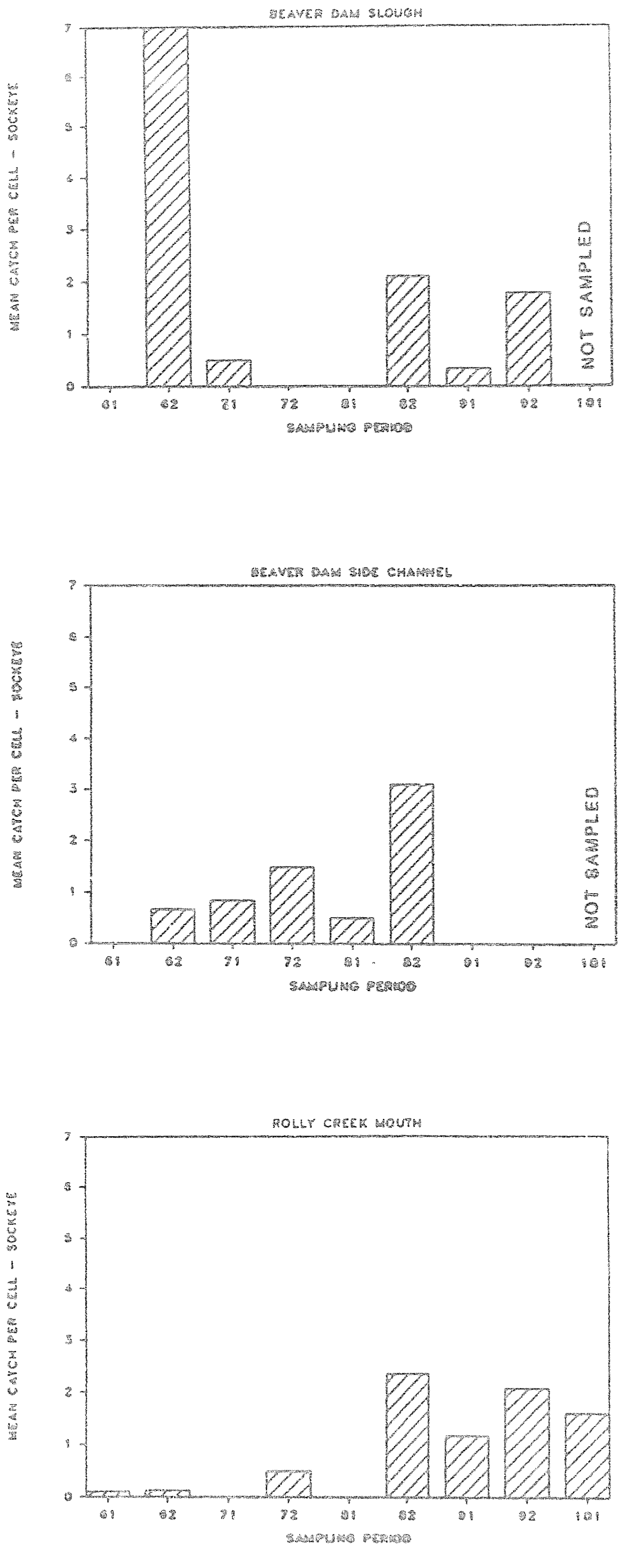


Figure 19. Juvenile sockeye salmon mean catch per cell at Beaver Dam Slough, Beaver Dam Side Channel, and Rolly Creek Mouth by sampling period, June through mid-October 1984.

In the following discussion, results are presented by individual species. Within the presentations of results for each species, modelling results from selected sites using the RJHAB or IFIM models are presented, discharge effects upon juvenile salmon habitat for the pooled sites are presented, and models are tested for verification.

No results from the Birch Creek Slough and Eagles Nest Side Channel modelling sites are presented here. At Birch Creek Slough, there was no measurable effect of mainstem discharge upon the site as the mainstem backwater at discharges less than 75,000 cfs did not extend to the site and a blocked culvert at the head of the slough stopped mainstem water from flowing through the site from the head. The Eagles Nest Side Channel site was modelled only twice at mainstem flows of 14,900 and 20,400 cfs and therefore could not be readily extrapolated to discharges of 75,000 cfs. All of the other sites were modelled at three or more discharges and results were extrapolated to discharges over the range of 12,000 to 75,000 cfs. The WUAs and site areas at the RJHAB sites were not adjusted to a reach length of 1,000 ft as were the IFIM WUAs. Lengths of all the RJHAB sites are listed in Appendix Table B-3, so that the WUAs could be adjusted if desired.

The instream flow results have been generated only to discharges of 75,000 cfs because it is very difficult to collect data at these discharges. Also, most of the side channel sites have very large flows at 75,000 cfs and are poor habitat for juvenile fish. At higher discharges, the entire flood plain becomes full and the flows are barely constrained within the side channels. Refuge for the juvenile fish at these times presumably include large backwater areas and small side channels which are very infrequently flooded.

At two of the model sites, Island and Trapper Creek side channels, both the RJHAB and IFIM models were run on the same transects. Comparative results for these two models are given in Appendix C. The summary figures presented here incorporate data from the RJHAB model at these two side channels.

The ability of the RJHAB models to extrapolate WUA between discharges of 12,000 and 75,000 cfs was evaluated subjectively by rating them from unacceptable to good (Table 6). Some models were rated fair because there were no habitat measurements taken at discharges just above overtopping of the side channel. Eagle's Nest Side Channel was rated unacceptable because measurements were taken on only two occasions at discharges less than 21,000 cfs.

The IFIM models were evaluated according to hydraulic criteria on the basis of excellent to acceptable (Appendix D). Acceptable ranges of the models usually extend to over 60,000 cfs (Table 7). The models were run and WUAs generated at side channel flows which corresponded to discharges ranging to 75,000 cfs, so reliability at these flows is unknown. At discharges below overtopping, the WUAs at a site flow of 5 cfs were used as a minimum, except at Trapper Creek Side Channel where the non overtopped flow was assumed to be 14 cfs.

Table 6. Evaluation of RJHAB model quality for extrapolating WUAs over the range of 12,000 to 75,000 cfs as measured at Sunshine gaging station, 1984.

Site	Number of Habitat Measurements	Model Quality
Hooligan Side Channel	5	Good
Eagle Side Channel	2	Unacceptable
Kroto Slough Head	4	Fair
Rolly Creek Mouth	4	Good
Bear Bait Side Channel	4	Fair
Last Chance Side Channel	5	Fair
Rustic Wilderness Side Channel	5	Good
Caswell Creek Mouth	3	Fair
Island Side Channel	5	Good
Goose 2 Side Channel	4	Fair
Sucker Side Channel	4	Good
Beaver Dam Slough	4	Good
Beaver Dam Side Channel	3	Good
Sunrise Side Channel	4	Fair
Birch Slough	3	Good
Trapper Creek Side Channel	4	Good

Table 7. Discharge ranges of IFIM models at lower Susitna River sites for which hydraulics are rated acceptable, 1984. Data taken from Appendix D.

Site	Acceptable Range
Island Side Channel	35,000 to 70,000 cfs
Mainstem West Bank	18,000 to 48,000 cfs
Circular Side Channel	36,000 to 63,000 cfs
Sauna Side Channel	44,000 to 63,000 cfs
Sunset Side Channel	32,000 to 67,000 cfs
Trapper Creek Side Channel	20,000 to 66,000 cfs

Since suitability criteria for chinook salmon juveniles have been developed for both turbid (>30 NTU) and clear (<30 NTU) conditions, several assumptions have been made. The tributary mouth sites have been assumed to be clear (<30 NTU) at all discharges less that 75,000 cfs. This is not always the case as occasionally turbid mainstem water may back up into the site with a rapid increase in mainstem stage. Also spring runoff or large storms might increase turbidities over 30 NTU. Available data, however, have indicated turbidities are normally less that 30 NTU (Figure 3).

At side channel/slough sites, turbidities were assumed to be always greater than 30 NTU when the site was breached and less than 30 NTU when the site was not breached. In early June, September, and early October, turbidities in side channels were sometimes less than 30 NTU (Figure 3). Many of the model sites were not overtopped during these periods with low discharges. Turbidities in sloughs were usually much less than 30 NTU.

3.3.1 Chinook Salmon

Chinook salmon juveniles were captured at all of the study sites with the exception of Last Chance Side Channel (Figure 8). Since chinook juveniles were widely distributed, modelling results from all sites modelled with RJHAB and IFIM techniques will be presented.

Graphs of the weighted usable area responses to mainstem discharges for all sites not presented here are included in Appendix B. Appendix B also contains the tabulated values of weighted usable areas at 3000 cfs increments as digitized from these graphs (including site graphs presented here). Also tabulated are habitat indices which were calculated by dividing the weighted usable area at a given discharge by the site area at the same discharge.

At the Rolly Creek, Caswell Creek, and Beaver Dam Slough tributary mouth sites, the responses of weighted usable area to mainstem discharge were very similar. The Rolly Creek mouth weighted usable area response to discharge is presented here as an example (Figure 20). The great increase in weighted usable area with discharge is due to the effect of mainstem backwater causing large increases in area, depth, and amount of cover.

At side channel/slough sites, the responses of weighted usable areas to mainstem discharge varied somewhat. Normally, the weighted usable area increased greatly after overtopping and then decreased with further increases in mainstem discharge as at Kroto Slough Head (Figure 20). The increase in weighted usable area right after overtopping is due to increases in area and also increases in cover suitability as the turbidity provides cover in otherwise cover poor habitat. As discharge increases along with site flow, velocities initially become more suitable, but then as site flows increase, velocities became unsuitable and the WUA decreases.

At Sucker Side Channel, backwater effects buffer the velocities from becoming too high and so weighted usable area gradually increases after

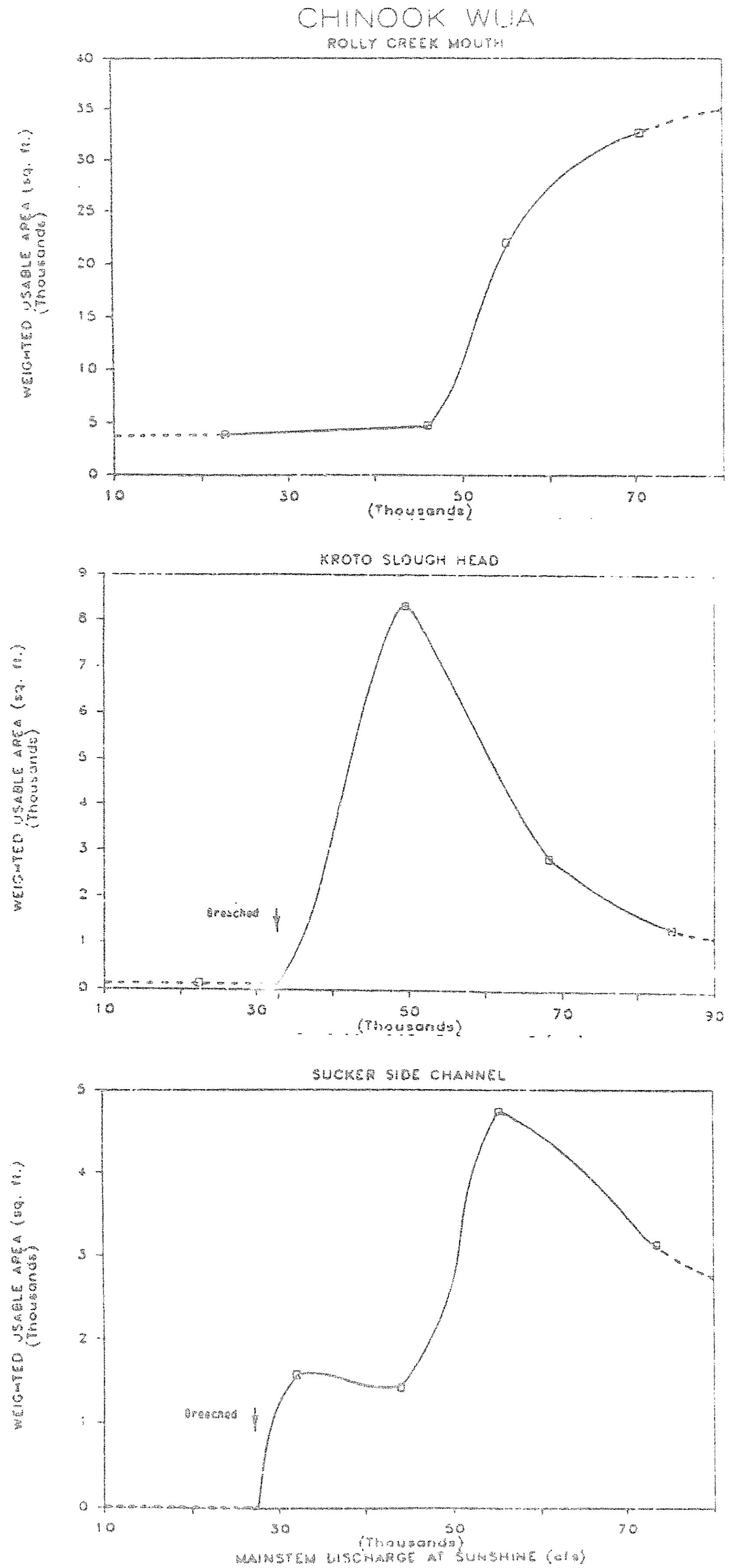


Figure 20. Weighted usable area for juvenile chinook salmon at the Rolly Creek Mouth, Kroto Slough Head, and Sucker Side Channel study sites as a function of mainstem discharge, 1984.

overtopping (Figure 20). At 70,000 cfs, WUA's begin to decline at this site, however, as velocities and depths become unsuitable. At other sites, WUA held quite constant after overtopping or slowly increased (see Appendix B).

When WUA's from three tributary mouths are pooled there is no large change in WUA until approximately 45,000 cfs when the WUA increases greatly with discharge (Figure 21). By dividing the WUA at 3000 cfs increments by pooled area for the three sites and plotting the habitat index, it becomes apparent that the change in WUA is not simply due to increases in site area. Increases in habitat indices are due to increases in the amount of instream cover, more suitable velocities, and deeper water which may also provide cover.

When WUA's from the modelled side channels/sloughs are pooled, WUA's increase greatly to approximately 40,000 cfs and then very gradually decline (Figure 22). Habitat indices for the pooled side channels show a similar rise to a peak at 40,000 cfs but then a rapid decrease to approximately 60,000 cfs when the habitat index levels off. The relatively more rapid decrease in the habitat index is due primarily to velocities and depths becoming very unsuitable at the higher discharges.

Turbidity has been shown to be an important determinant of chinook distribution (Figure 10) and varies from east to west downstream from the Chulitna and Talkeetna river confluences (Figure 4). In formulating the pooled side channel/slough response of juvenile salmon habitat, it

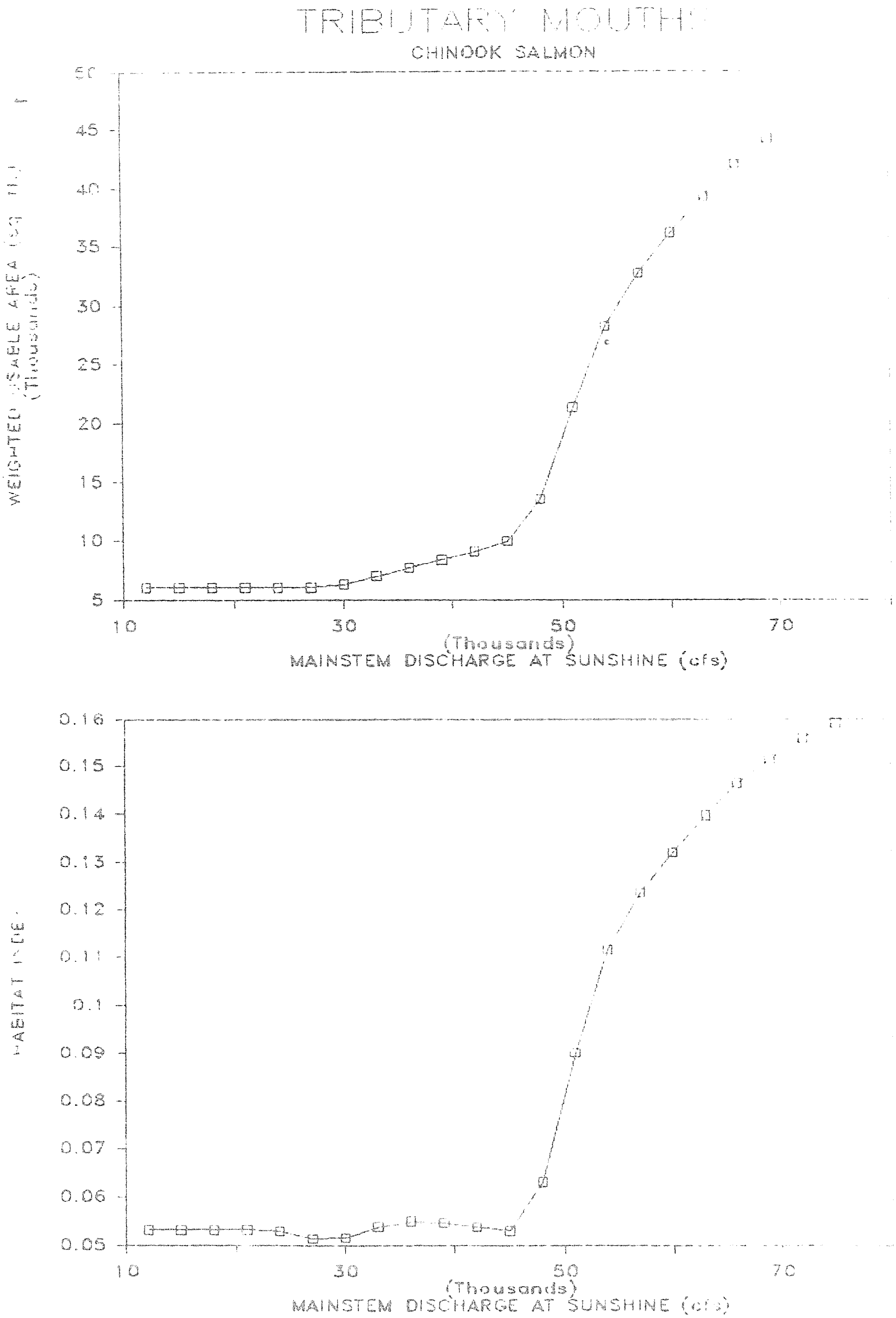


Figure 21. Weighted usable area and habitat indices for juvenile chinook salmon at tributary mouth study sites as a function of mainstem discharge, 1984.

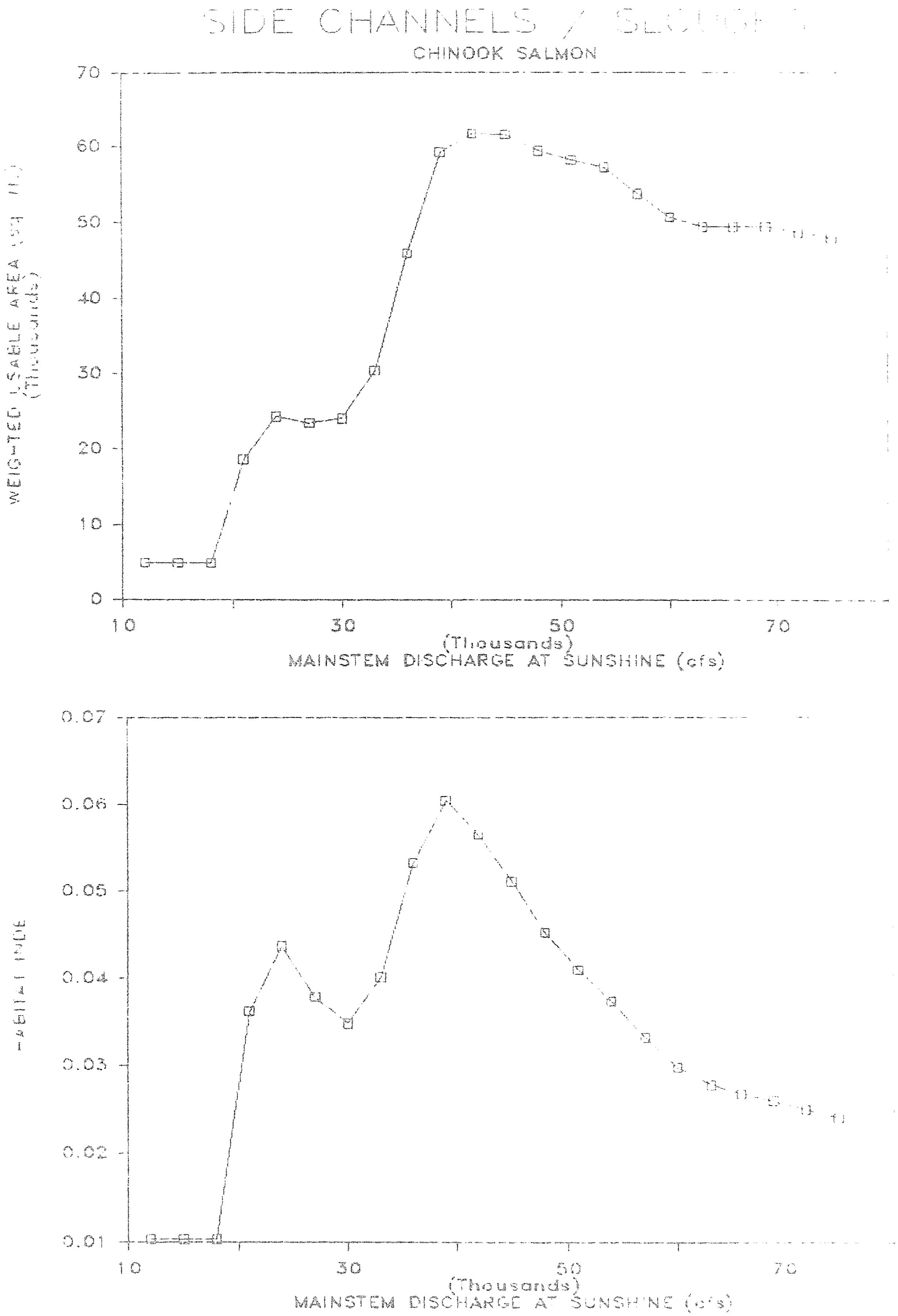


Figure 22. Weighted usable area and habitat indices for juvenile chinook salmon at side channel/slough study sites as a function of mainstem discharge, 1984.

may be desirable to weight factors such as turbidity which vary from site to site.

Although turbidity data for the model sites are limited, an average turbidity for the side channels modelled was calculated in Appendix Table B-1. A preliminary suitability index for turbidity can also be fit to the data in Figure 10 (Table 8). When these data are tied together we can weight WUA estimates for the sites differently (Table 9).

When the WUA estimates for each site are adjusted by these factors and then WUA's are again totalled, the WUA and habitat index response adjusted for turbidity for the side channels combined can again be examined (Figure 23). There is very little change from the previous unadjusted graph in the shape of the WUA response curve. Similarly, the shape of the habitat index responses curve has also been changed very little by these adjustments.

The mean seasonal chinook salmon habitat index for the 15 side channels and four tributary mouths were calculated and compared with mean chinook catch (Figure 24). The positive relationship was statistically significant ($p \leq 0.001$) but not very strong. Most of the correlation was due to the large catch (5.16 fpc) and habitat index (0.19) at Caswell Creek mouth. Another outlier is Beaver Dam Slough with a habitat index of 0.17 and a mean catch of 0.17 chinook per cell.

Table 8. Preliminary juvenile chinook salmon turbidity criteria derived from lower Susitna River distribution data, 1984.

Turbidity (NTU)	Suitability
< 200	1.00
201 - 250	0.65
251 - 300	0.55
301 - 350	0.40
> 350	0.15

Table 9. Weighting factors for turbidity by site for analysis of juvenile chinook salmon habitat use, 1984.

Site	Mean Turbidity (NTU)	Turbidity Weighting Factor
Hooligan Side Channel	377	0.15
Kroto Slough Head	388	0.15
Bear Bait Side Channel	254	0.55
Last Chance Side Channel	365	0.15
Rustic Wilderness Side Channel	118	1.00
Island Side Channel	215	0.65
Mainstem West Bank	279	0.55
Goose 2 Side Channel	194	1.00
Circular Side Channel	241	0.65
Sauna Side Channel	266	0.55
Sucker Side Channel	140	1.00
Beaver Dam Side Channel	139	1.00
Sunset Side Channel	152	1.00
Sunrise Side Channel	121	1.00
Trapper Creek Side Channel	499	0.15

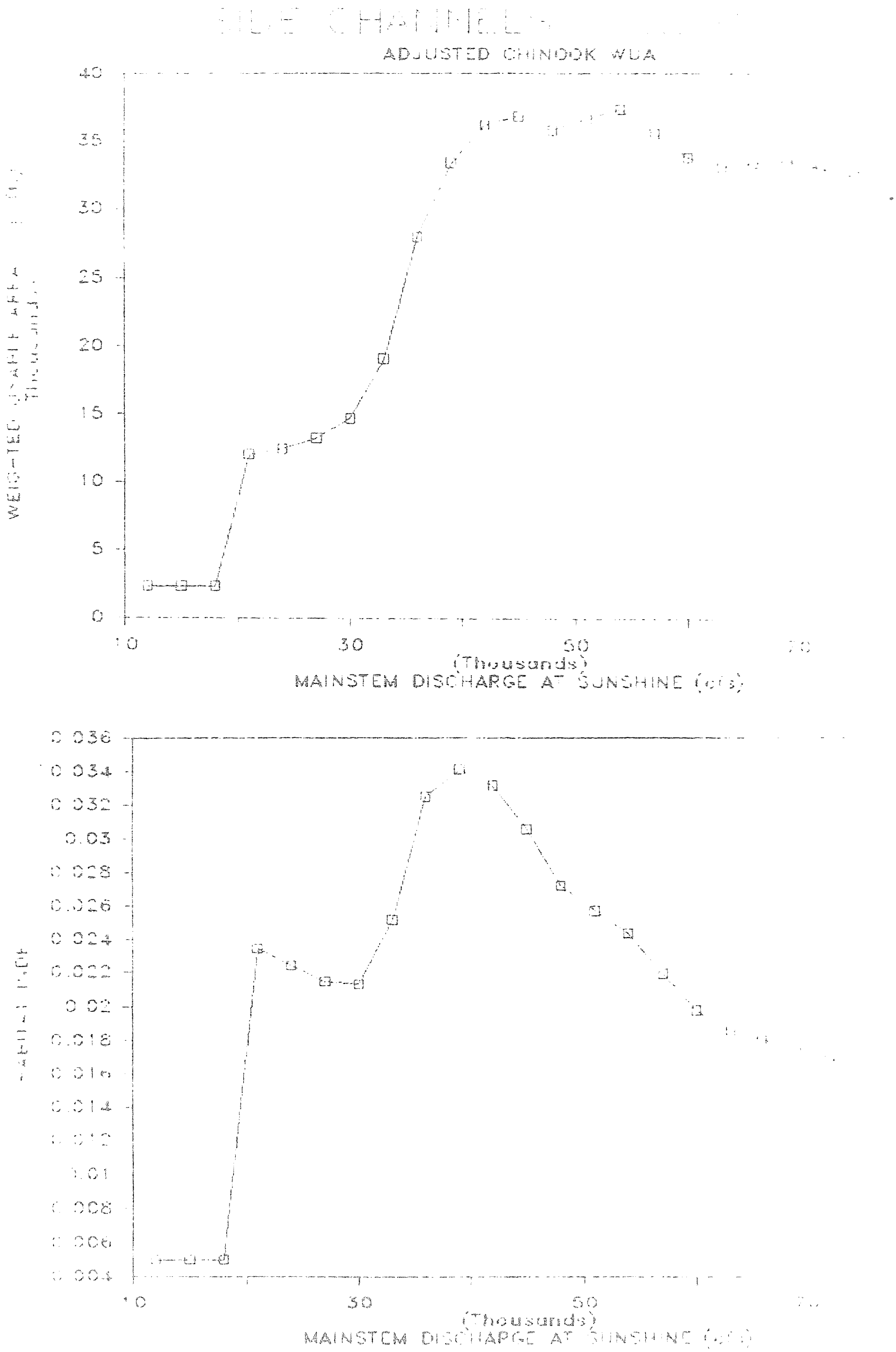


Figure 23. Adjusted weighted usable area and habitat indices for juvenile chinook salmon at side channel/slough study sites as a function of mainstem discharge, 1984.

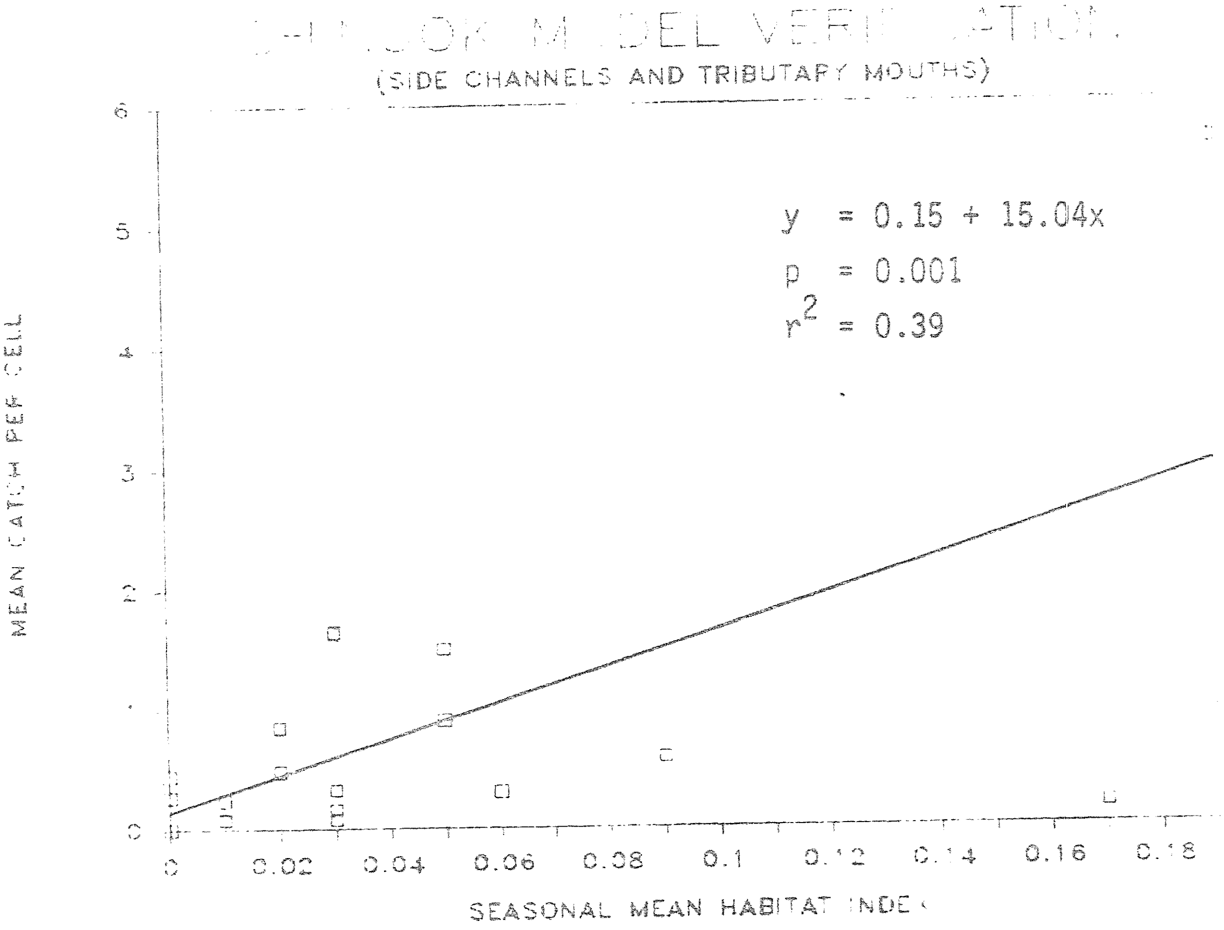


Figure 24. Juvenile chinook salmon mean catch per cell versus seasonal mean habitat indices at side channel and tributary mouth modelling sites on the lower Susitna River, 1984.

3.3.2 Coho salmon

Since coho salmon were captured in number only at the tributary mouth sites, only results from these sites will be presented here. In Appendix B, values of WUA's and habitat indices at 3000 cfs increments for these areas are presented.

The response of WUA to mainstem discharge at the three tributary mouths varied (Figure 25). At Caswell Creek mouth, WUA increased as discharge increased. This increase was due to increases in area and the amount of preferred cover. At Rolly Creek mouth, the WUA first decreased with discharge and then began to increase greatly. The initial decrease was due to the formation of zero velocity backwater from a free flowing state without major increases in cover or area, but then the WUA increased due to increases in area and usable cover. At Beaver Dam Slough, these effects of back water formation and increases in cover offset one another so that there was little change in WUA with discharge.

When the WUA's from all three sites are summed (Figure 26), there is little change in WUA until approximately 50,000 cfs when the WUA begins to increase greatly with discharge. When the effect of change in area is taken out by calculating a habitat index, site quality decreases initially as the backwater is formed and then begins to increases as cover increases due to the backwater.

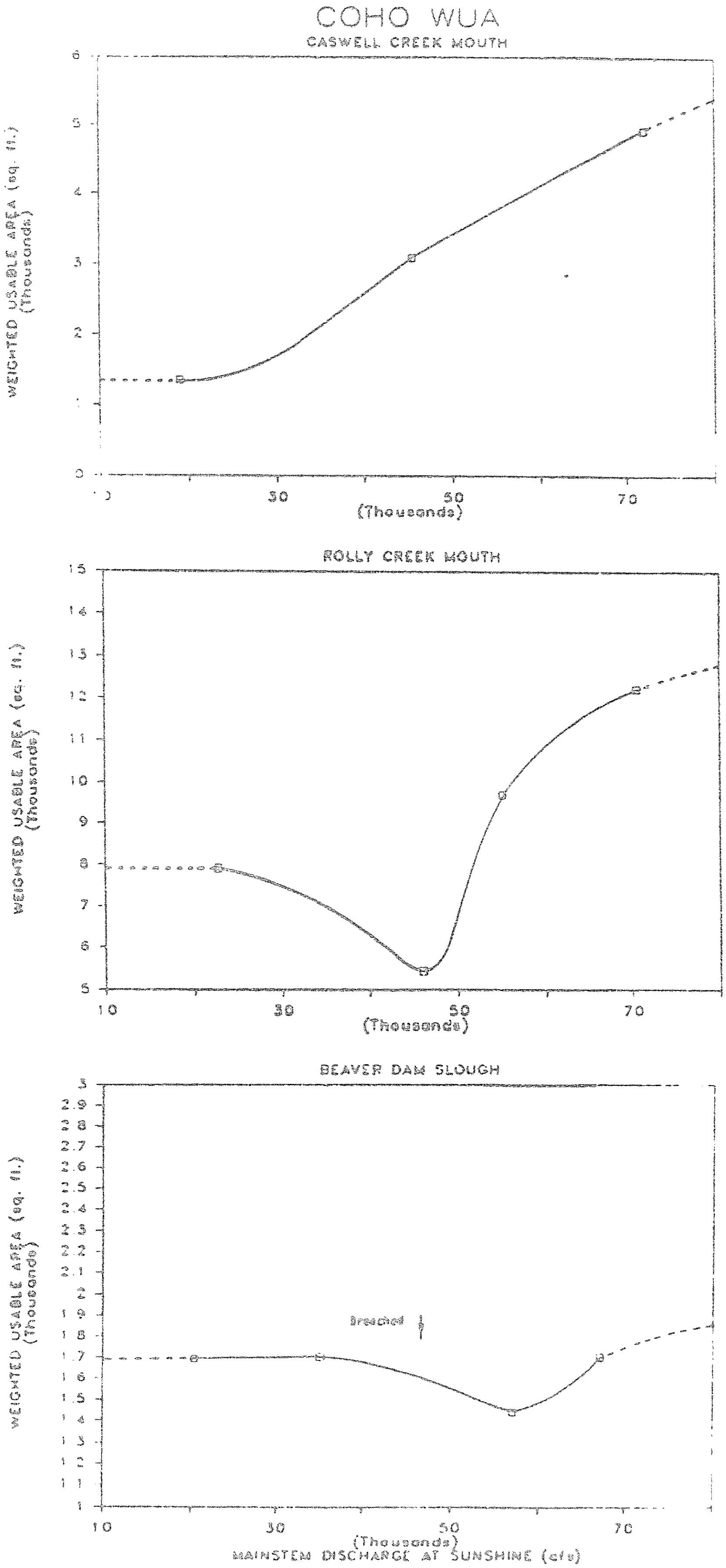


Figure 25. Weighted usable area for juvenile coho salmon at the Caswell Creek , Rolly Creek and Beaver Dam Slough tributary study sites as a function of mainstem discharge, 1984.

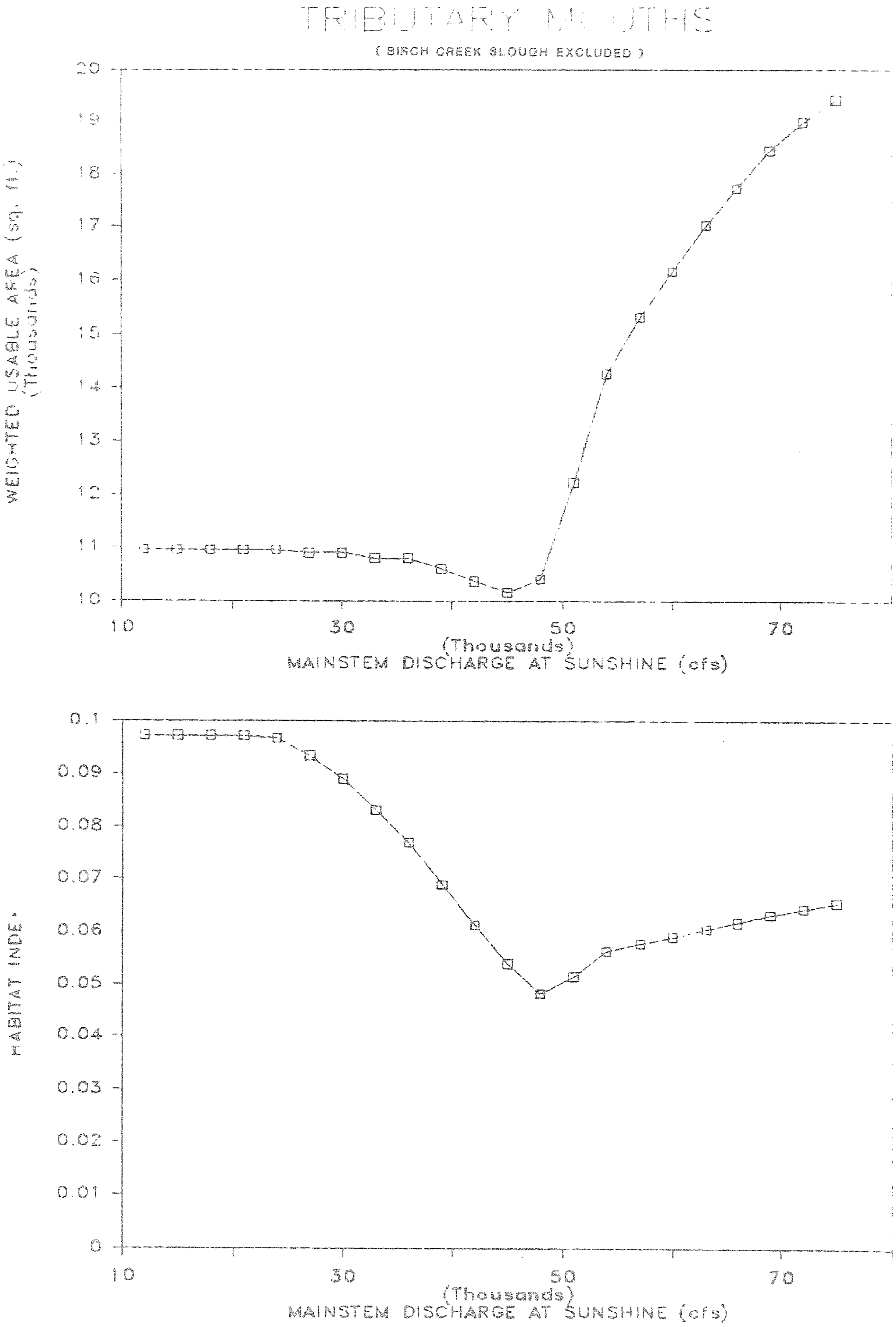


Figure 26. Weighted usable area and habitat indices for juvenile coho salmon at tributary mouth study sites excluding Birch Creek Slough as a function of mainstem discharge, 1984.

The mean habitat index for the season (May 15 to October 15) was calculated for the four tributary mouths. Since Birch Creek Slough was a natal area, only catches from mid-July through mid-October were used in calculating the mean site catch. The mean catch per cell of coho juveniles increased with the mean habitat index but a linear regression was not statistically significant at the 0.05 level (Figure 27). None of the side channels had mean seasonal habitat indices greater than 0.05 and most were 0.03 or less, primarily due to the lack of suitable cover types.

3.3.3 Chum salmon

Chum salmon were widely distributed at all of the side channel sites sampled during early June through July 15 (Figure 13). Therefore, graphs of the WUA response as a function of mainstem discharge for all the side channel/ slough sites not presented here are included in Appendix B. Also tabulated in Appendix B are values of WUA's and habitat indices at 3000 cfs increments as digitized from the graphs.

Responses of WUA's at the sites to increases in mainstem discharge were variable. At Rustic Wilderness Side Channel, WUA greatly increased after overtopping and then declined with further increases in discharge as velocities and depths became unsuitable (Figure 28). At other sites such as Last Chance Side Channel, the increase in WUA after overtopping was much less great while at Trapper Creek Side Channel (Figure 29), WUA's decreased after overtopping. At Sunset Side Channel, WUA

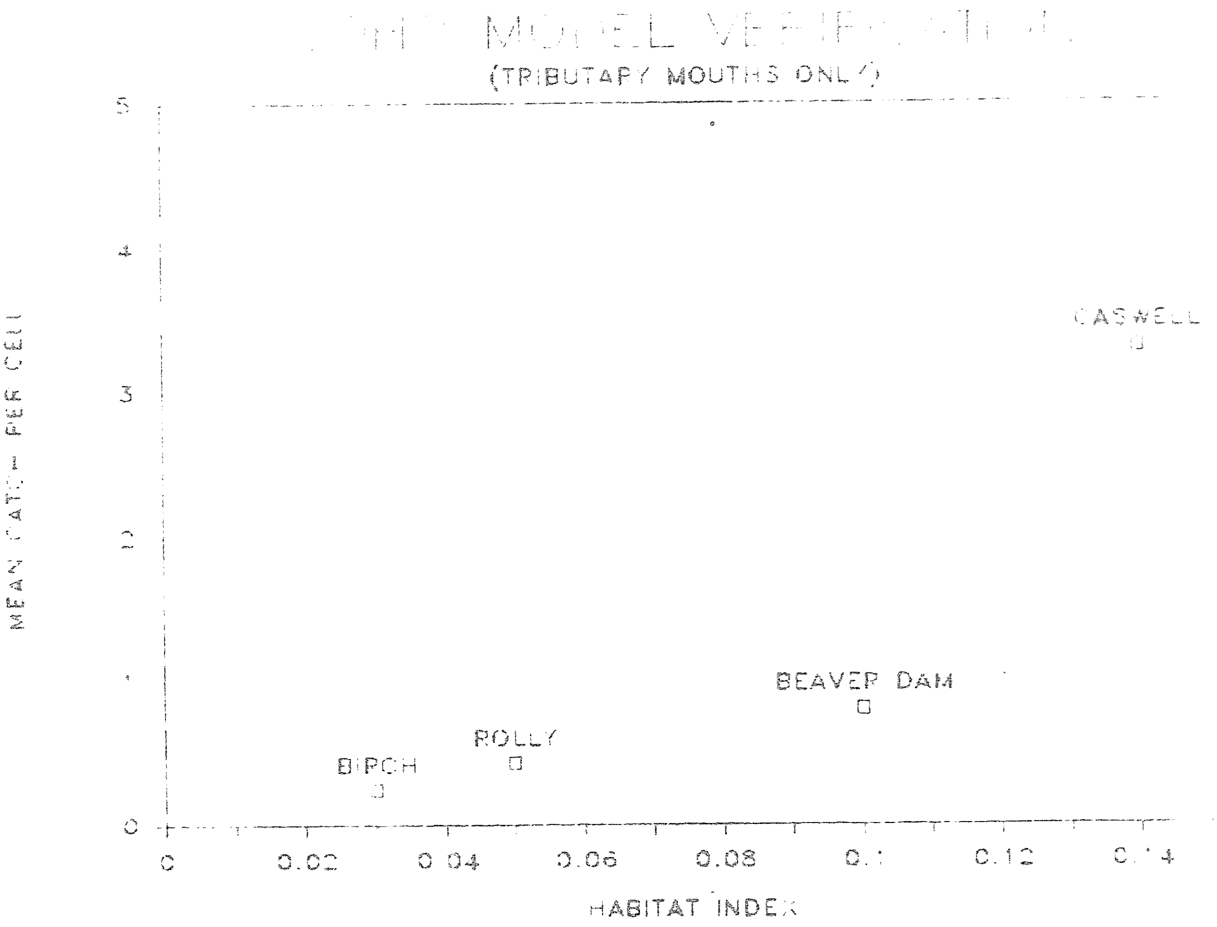


Figure 27. Juvenile coho salmon mean catch per cell versus seasonal mean habitat indices at tributary mouth modelling sites on the lower Susitna River, 1984.

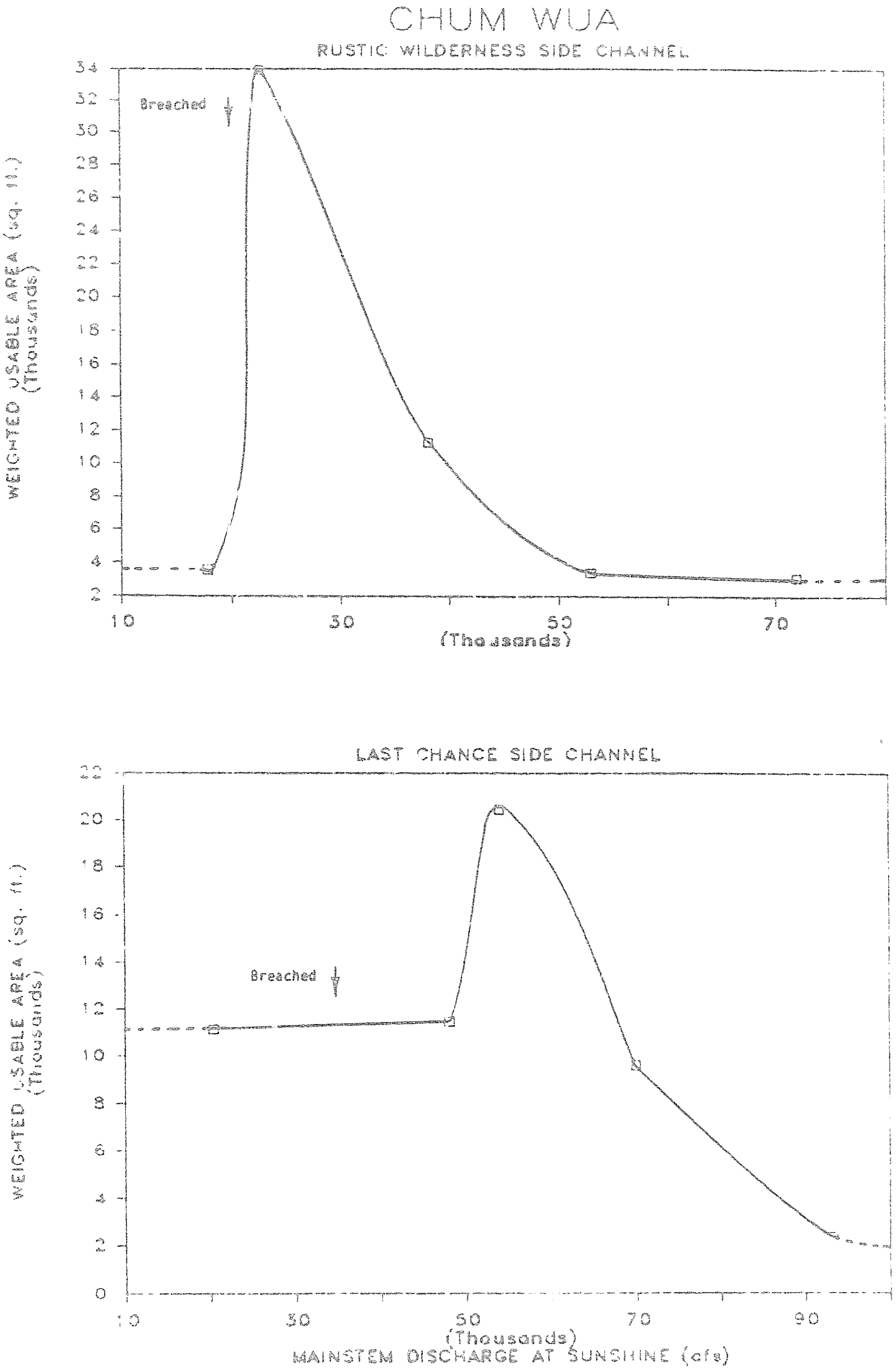


Figure 28. Weighted usable area for juvenile chum salmon at the Rustic Wilderness and Last Chance Side Channel study sites as a function of mainstem discharge, 1984.

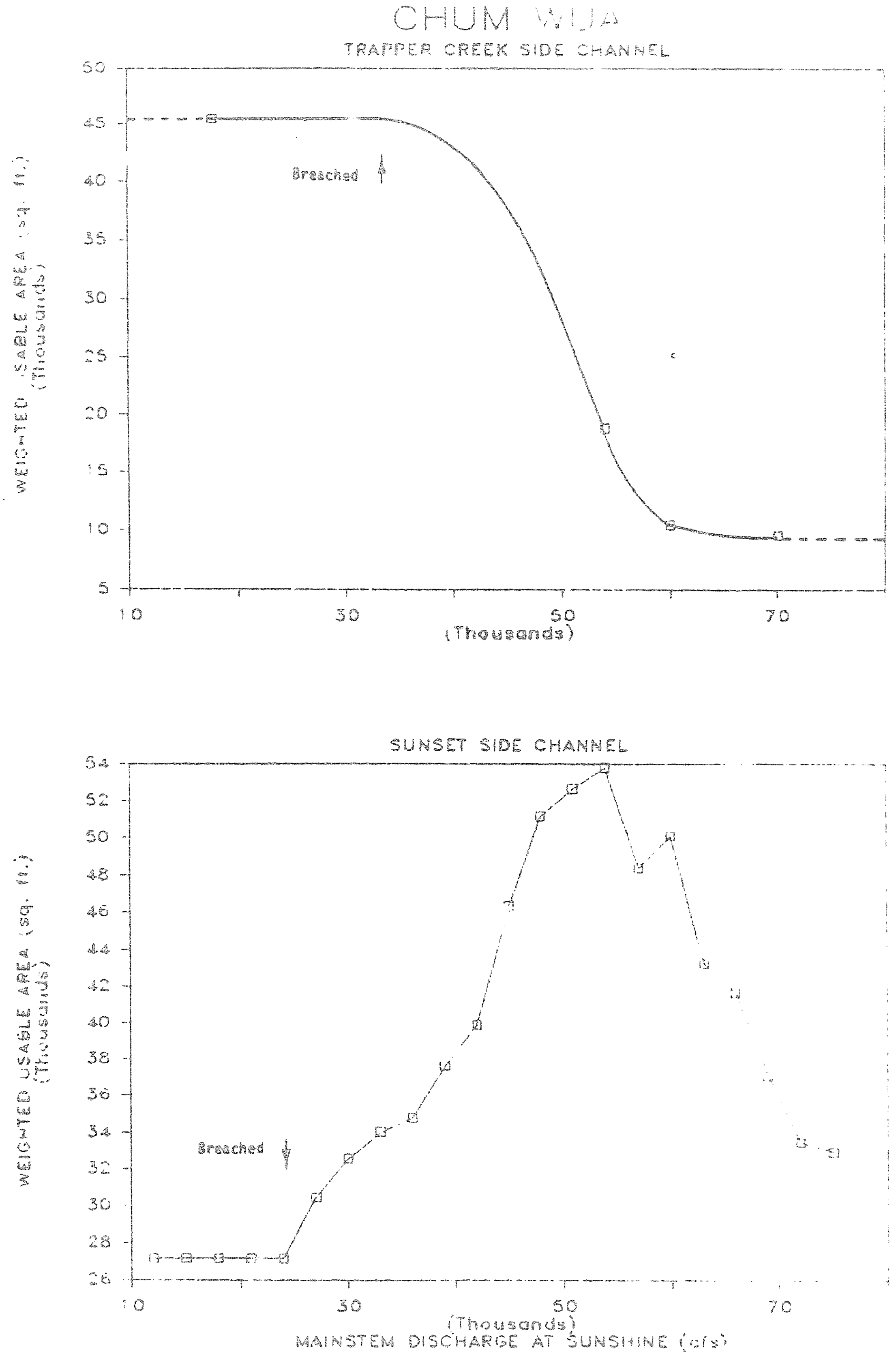


Figure 29. Weighted usable area for juvenile chum salmon at the Trapper Creek and Sunset Side Channel study sites as a function of mainstem discharge, 1984.

increased after overtopping until about 53,000 cfs when WUA quickly declined. The other sites also showed variations of these response curves (see Appendix B figures).

When WUA's from all the modelled side channel/slough sites are pooled, the peak in WUA's for the sites occurs at a discharge of 40,000 to 52,000 cfs (Figure 30). Above this discharge range, WUA's decrease rapidly due to unsuitable high velocities and deep depths. Habitat indices for the same pooled sites are constant through about 24,000 cfs and then decrease steadily.

Chum salmon use of side channels is affected by turbidity (Figure 15) and since turbidity varies from site to site, WUA's for each site should be adjusted for turbidity. Since chum salmon outmigration is mostly completed by July 15, turbidity data contained in Appendix Table B-1 through July 15 were examined. Since turbidities greater than 200 NTU appear to affect use greatly (Figure 15), site WUA's were adjusted for periods when the turbidity exceeded 200 NTU. Adjustment factors for the sites ranged from 0.50 to 1.0 (Table 10).

When the chum salmon WUA's were adjusted for turbidity and again totalled, very little changes were noted in the shape of the WUA or habitat index response curves although of course both WUA's and habitat indices decreased (Figure 31).

Mean chum salmon adjusted habitat indices were calculated for the period from May 15 through July 15 and compared with mean chum catch during the

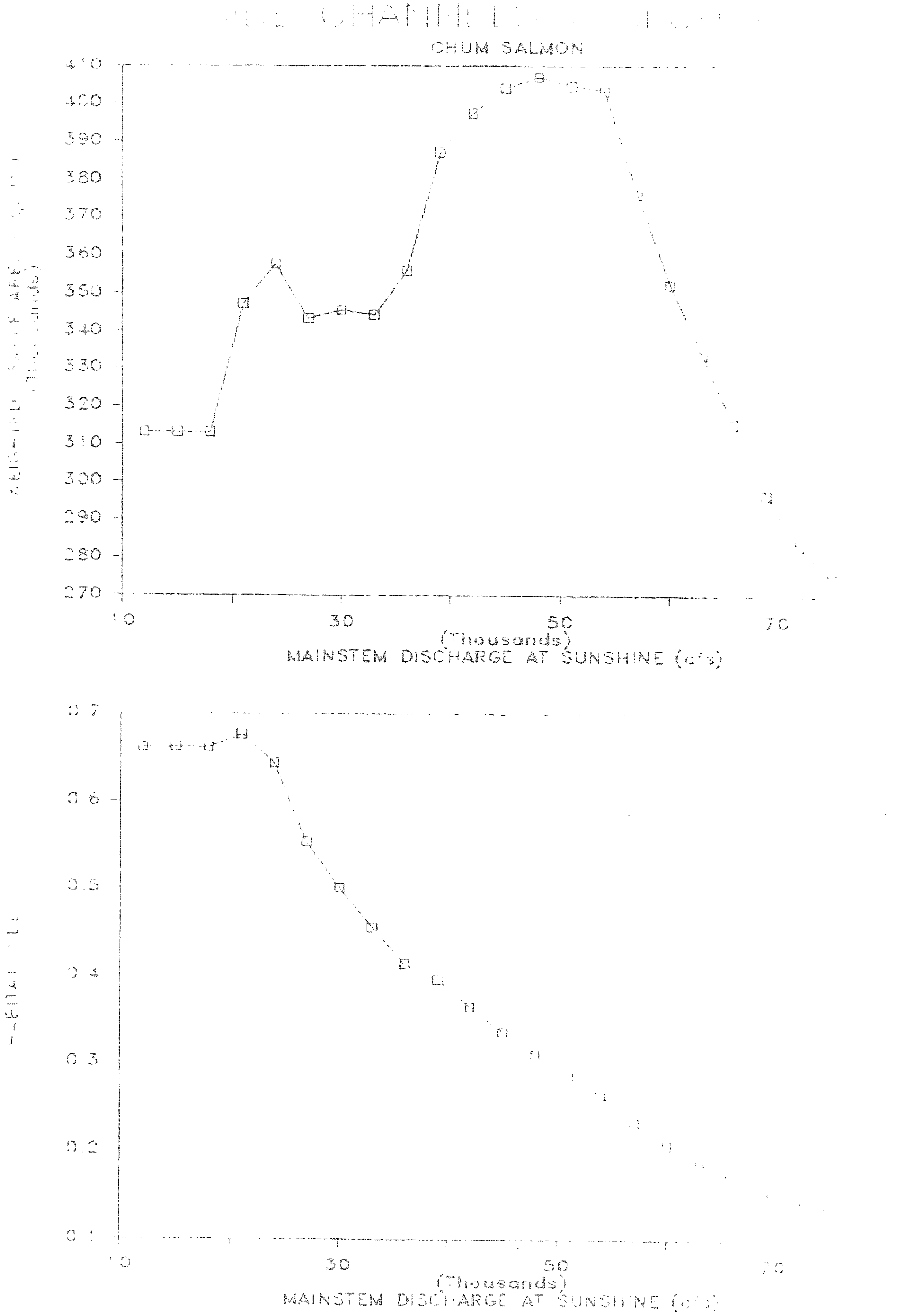


Figure 30. Weighted usable area and habitat indices for juvenile chum salmon at side channel/slough study sites as a function o. mainstem discharge, 1984.

Table 10. Weighting factors for turbidity by site for analysis of juvenile chum salmon habitat use.

Site	Sampling Period When Turbidity Exceeds 200 NTU	Turbidity Weighting Factor
Hooligan Side Channel	June 16-30	0.50
Kroto Slough Head	June 16-30	0.50
Bear Bait Side Channel	June 16-30	0.50
Last Chance Side Channel	June 16-30	0.50
Rustic Wilderness Side Channel	July 16-30	1.00
Island Side Channel	July 1-15	0.75
Mainstem West Bank	June 16-30	0.50
Goose 2 Side Channel	July 1-15	0.75
Circular Side Channel	July 1-15	0.75
Sauna Side Channel	June 16-30	0.50
Sucker Side Channel	July 1-15	0.75
Beaver Dam Side Channel	July 1-15	0.75
Sunset Side Channel	July 1-15	0.75
Sunrise Side Channel	July 1-15	0.75
Trapper Creek Side Channel	June 16-30	0.50

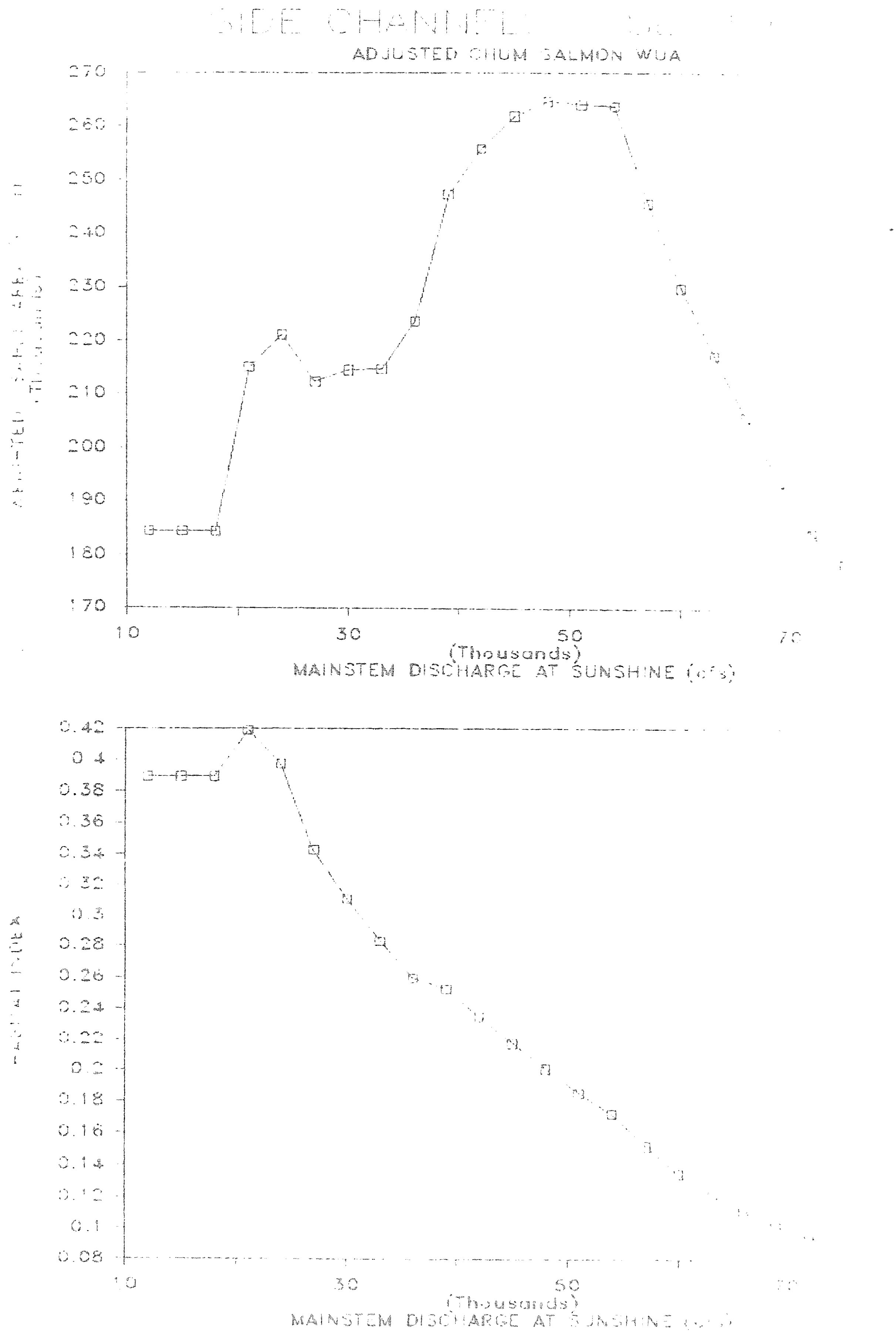


Figure 31. Adjusted weighted usable area and habitat indices for juvenile chum salmon at side channel/slough study ites as a function of mainstem discharge, 1984.

same time period (Figure 32). There was no sampling effort at two of the side channels, Mainstem West Bank and Sunset Side Channel, during this time so they are not included in this graph. There was no significant ($p > 0.05$) correlation between the seasonal habitat index and chum catch although the correlation (0.53) did suggest a relationship.

3.3.4 Sockeye Salmon

Sockeye salmon were most numerous at the tributary mouth sites with most side channels having some use (Figure 16). Presented here or in Appendix B are graphs of the WUA responses to discharge of the three tributary mouths and the four side channels (Beaver Dam, Sucker, Sunrise and Sunset) which were found to have sockeye salmon present more than half the times sampled.

The typical response of WUA at the tributary mouths to increases in discharge was a steady increase as shown here by the modelling results from Rolly Creek (Figure 33). The WUA increased as the backwater zone increased because sockeye find zero velocity water most suitable and because site area and cover also increased greatly with discharge. The WUA response at Sucker Side Channel was similar to that of the tributary mouths as WUA generally increased with discharge after overtopping. This site is influenced greatly by backwater effects from the side channel at its mouth. At Beaver Dam and Sunrise Side Channels, WUA increased after overtopping and then declined somewhat (Figure 34). At Sunset Side Channel, WUA fluctuated up and down with discharge in no real pattern (Figure 35).

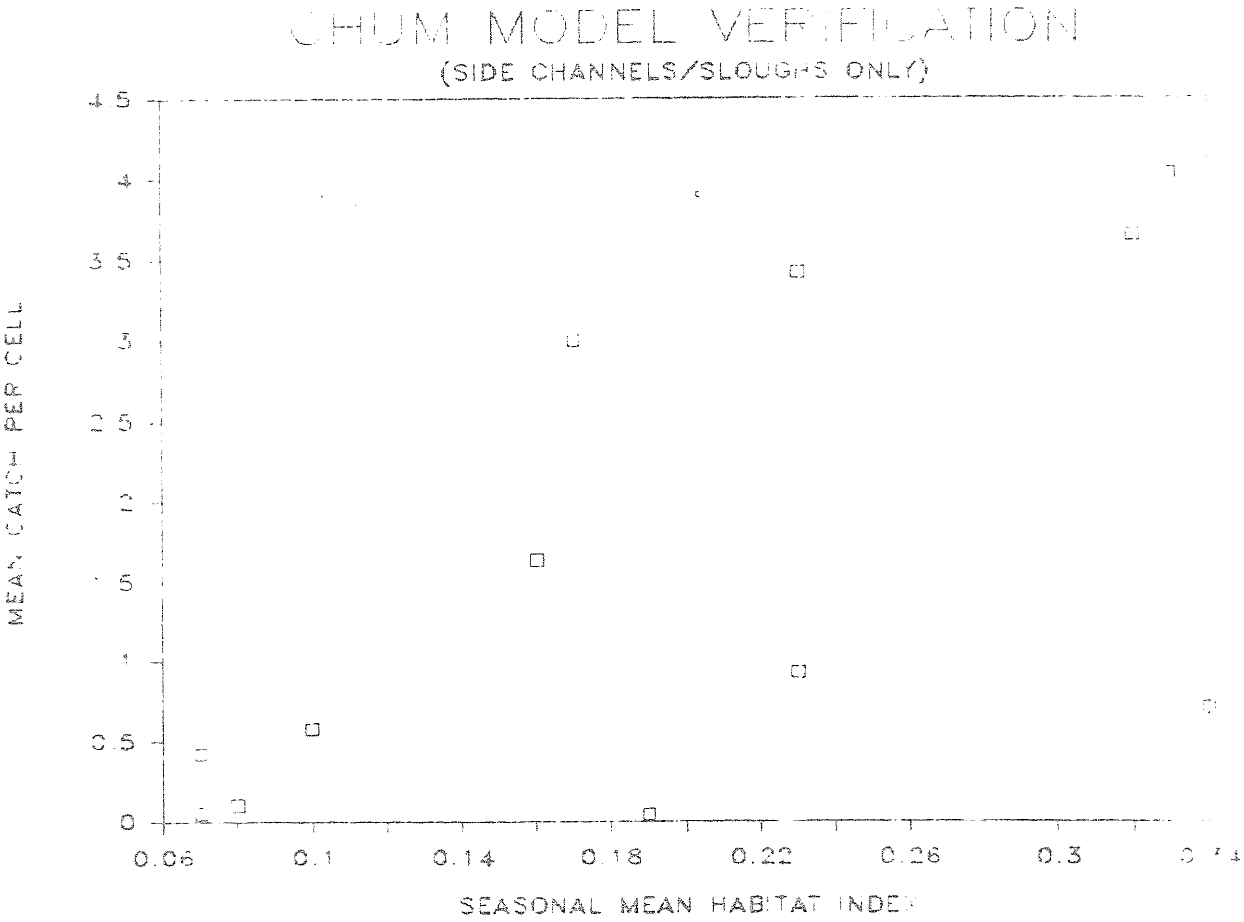
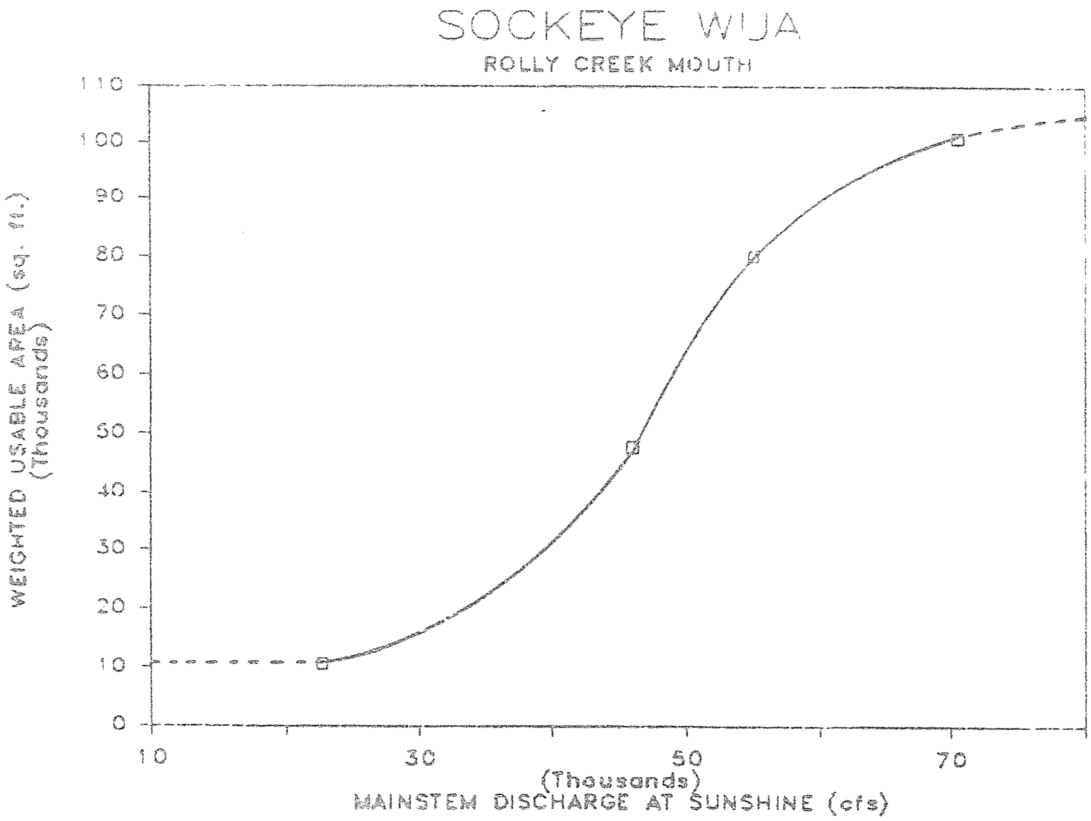


Figure 32. Juvenile chum salmon mean catch per cell versus seasonal mean habitat indices at side channel and slough modelling sites on the lower Susitna River, 1984.



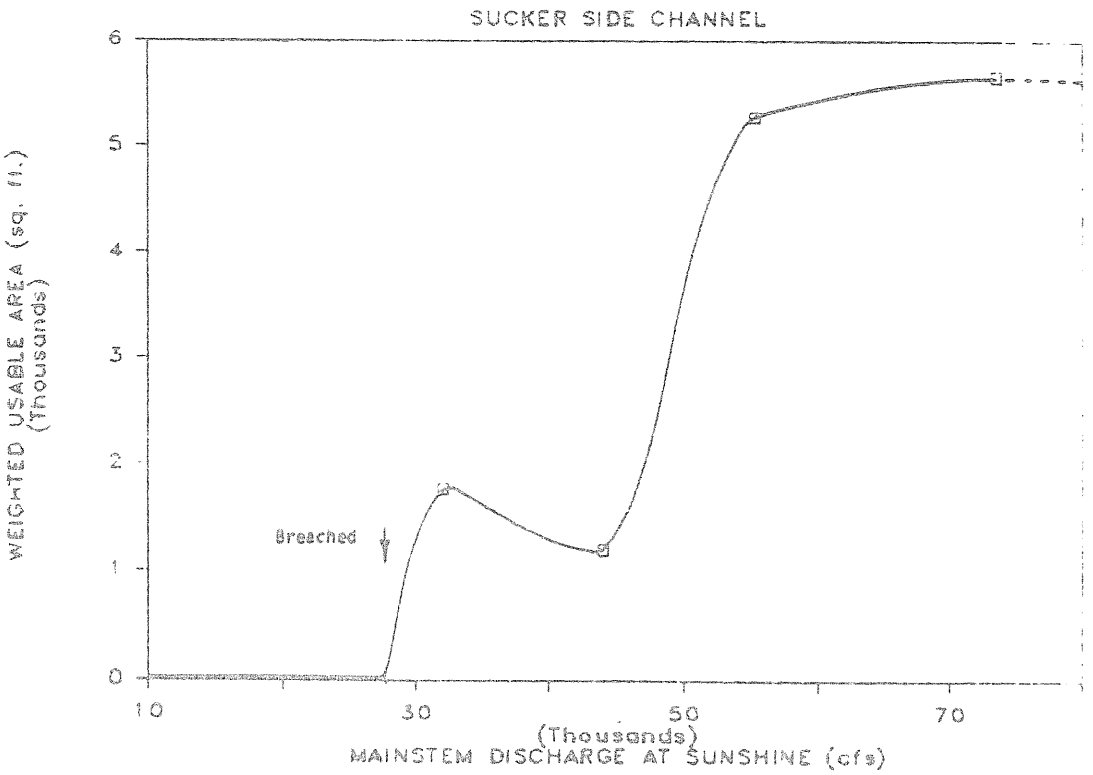


Figure 33. Weighted usable area for juvenile sockeye salmon at the Rolly Creek Mouth and Sucker Side Channel study sites as a function of mainstem discharge, 1984.

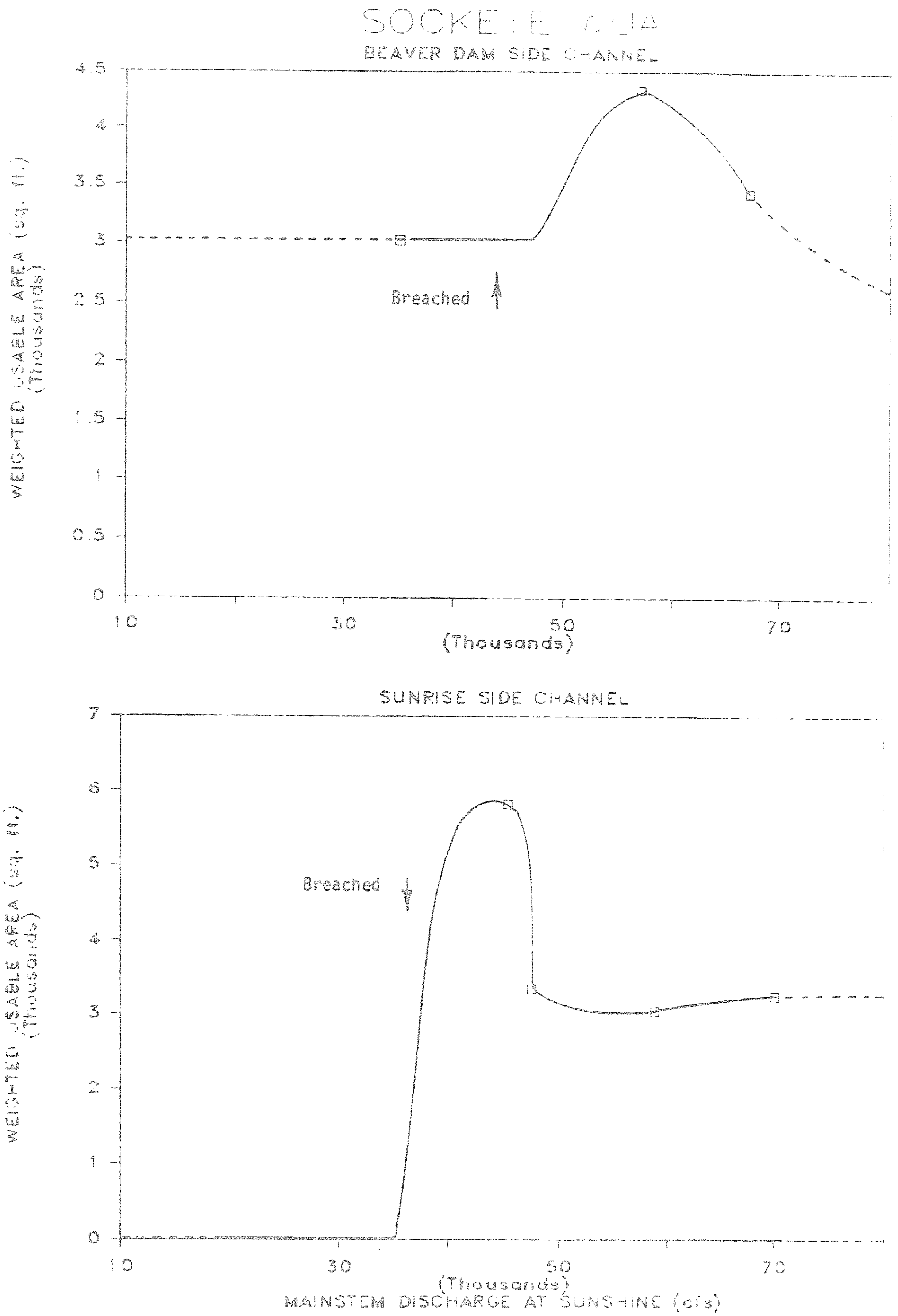


Figure 34. Weighted usable area for juvenile sockeye salmon at the Beaver Dam and Sunrise Side Channel study sites as a function of mainstem discharge, 1984.

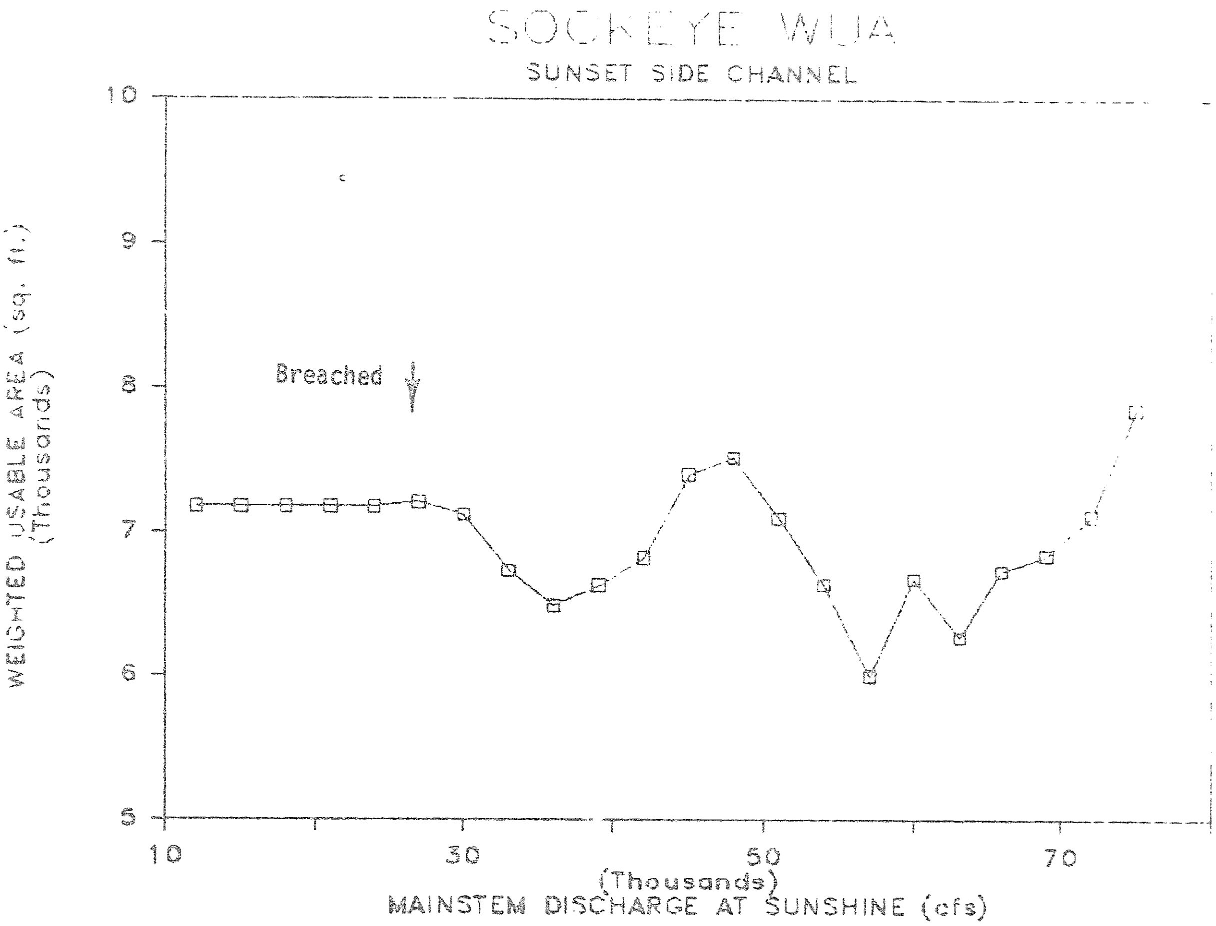


Figure 35. Weighted usable area for juvenile sockeye salmon at the Sunset Side Channel study site as a function of mainstem discharge, 1984.

At the combined tributary mouth sites, both WUA and habitat indices increased above discharges of approximately 30,000 cfs (Figure 36). At the pooled side channel/sloughs, on the other hand, WUA's also increased after approximately 30,000 cfs while habitat indices generally declined from the peak at 12,000 to 24,000 cfs (Figure 37). The decrease in the habitat index is due to the steadily increasing velocities in the side channels with increases in flow. No adjustments in turbidity are necessary for the four side channel/slough sites as these have very similar turbidity regimes, being located on the same general location of the river. Use of many of the other side channels is probably limited by turbidity.

The mean seasonal habitat index for sockeye salmon at the four tributary mouths and four side channel sites was calculated for the period from May 15 to October 15, 1984. The mean catch of sockeye salmon juveniles was positively related to the mean habitat index (Figure 38). High turbidities and velocities within the other side channels presumably limited use by sockeye salmon juveniles.

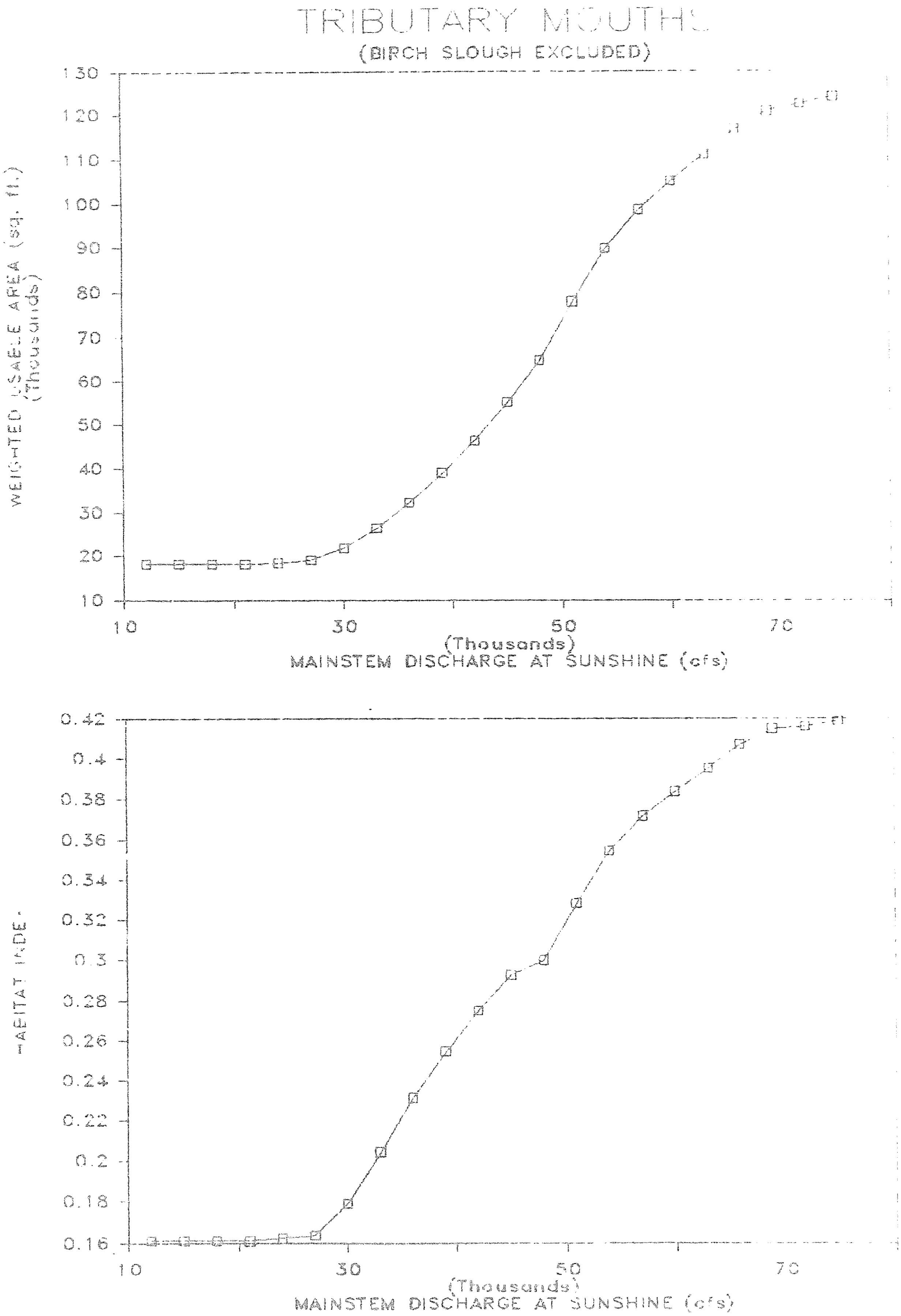


Figure 36. Weighted usable area and habitat indices for juvenile sockeye salmon at tributary mouth study sites on the lower Susitna River as a function of mainstem discharge, 1984.

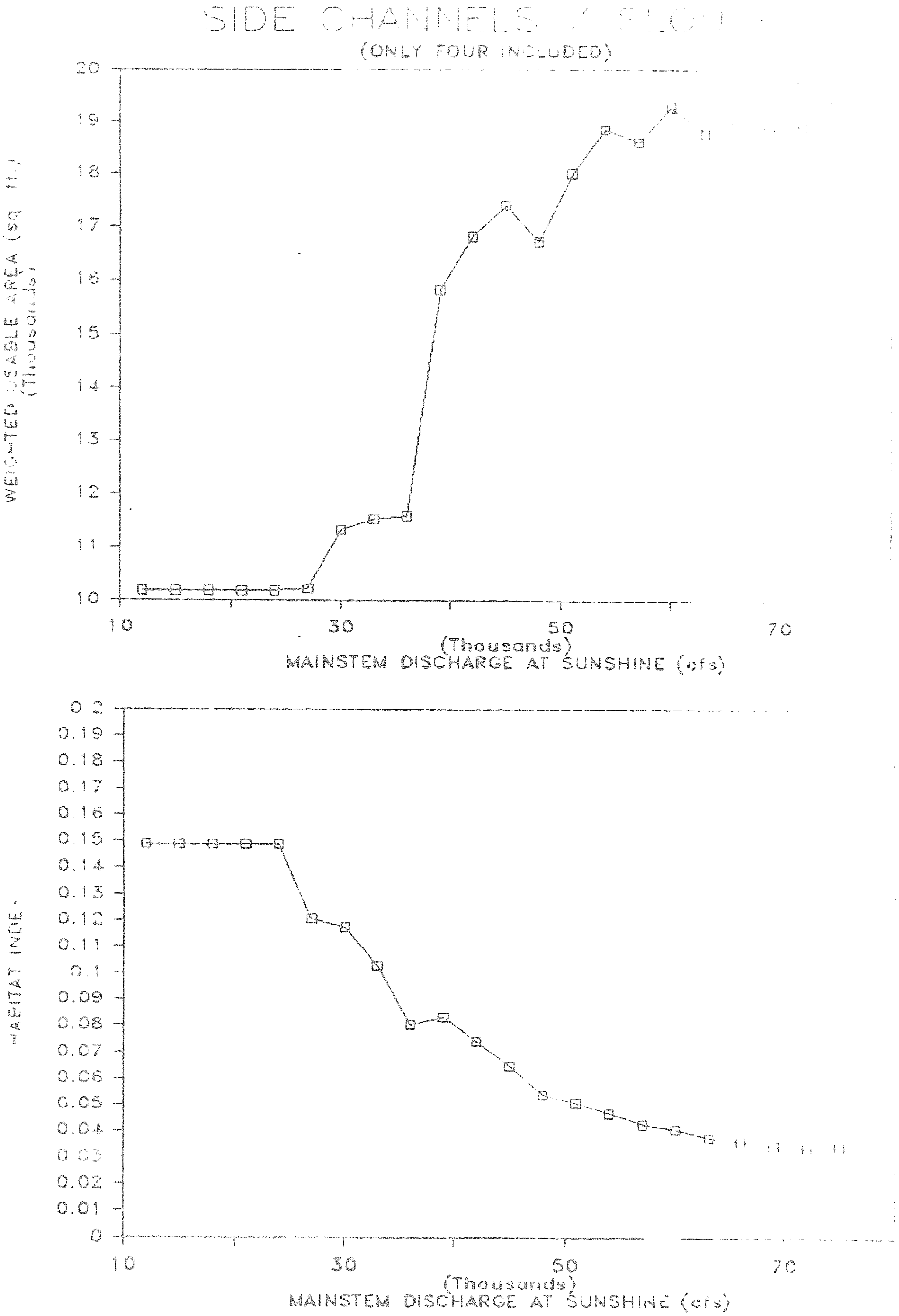


Figure 37. Weighted usable area and habitat indices for juvenile sockeye salmon at side channel and slough study sites on the lower Susitna River as a function of mainstem discharge, 1984.

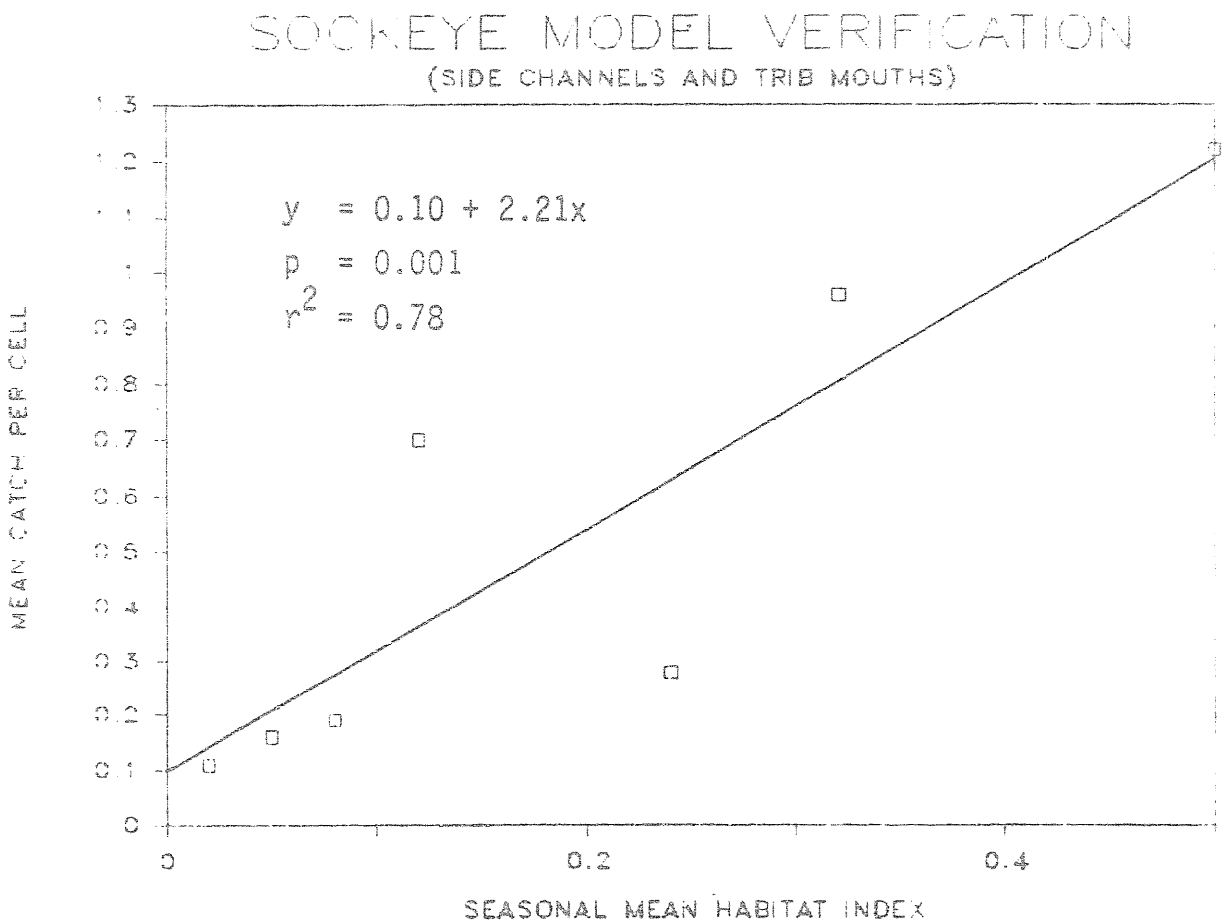


Figure 38. Juvenile sockeye salmon mean catch per cell versus seasonal mean habitat indices at side channel and tributary mouth modelling sites on the lower Susitna River, 1984.

4.0 DISCUSSION

4.1 Chinook Salmon

Chinook salmon were widely distributed throughout tributary mouths and side channels of the lower Susitna River. Densities of juvenile chinook were highest within tributary mouths. This distribution of chinook fry substantiates earlier observations (ADF&G 1981c) that densities of chinook are generally highest at tributary mouths. Middle Susitna River data from 1983 also showed the highest densities within tributaries (Dugan et al. 1983). Caswell Creek mouth had the highest CPUE of juvenile chinook salmon and appears to be a major rearing or holding area.

Chinook salmon juveniles used side channels for rearing in both the middle and lower Susitna River after moving from the tributary natal areas. The redistribution of chinook fry from natal areas to lower density rearing areas has been observed in the Deshka River (Delaney et al. 1981) and Montana Creek (Riis and Freise 1978). This phenomenon reflects a downstream movement or dispersal of the 0+ age fish (ADF&G 1981c). Most of the 1+ chinook juveniles have outmigrated by August 1.

Use of tributary mouths is limited by the amount of instream cover and suitable velocities. Also depth may be important to chinook juveniles in tributaries because it probably provides cover in slightly turbid water (10 to 20 NTU) (Appendix A). At Caswell Creek mouth, catches of juvenile chinook were low in September as the mainstem water stage dropped and the site became much shallower, with higher velocities, and greatly reduced cover.

Use of side channels by chinook juveniles for rearing is widespread; however, use is limited by turbidity. Side channels located in the Talkeetna River plume had much higher use than those located in the more turbid Chulitna River plume or those located further downstream where the water of these two tributaries are mixed. Side channel catch rates of juvenile chinook (in similar habitat) in the middle Susitna River in 1983 were approximately four times higher than those in the lower river in 1984 (Dugan et al. 1984).

Since lower river side channels are used less by chinook than middle Susitna River side channels, it is not surprising that sloughs are also used less in the lower reach. As water levels decreased in the fall and side channel heads dewatered, there were very few chinook fry at slough sites in the lower river to take advantage of the lowered turbidity. Also the side sloughs are normally very cover poor. Upwelling in sloughs may be important, however, because of their potential value as overwintering areas.

Instream flow effects upon juvenile chinook salmon are related to backwater effects at the tributary mouths and to breaching and side channel flows as well as backwater at the side channel/slough sites. When a side slough is not overtopped by the mainstem, cover and access into the site are usually poor.

At tributary mouths, backwater effects increase chinook use significantly because of increases in instream cover and depth and decreases in water velocity. Also turbid backwater from the mainstem sometimes intrudes into the sites with rapid rises in mainstem stage. Pooled data from three tributary mouths showed major increases in WUA at mainstem discharges greater than 45,000 cfs.

If the study sites would have been chosen further upstream in the tributary mouths, WUAs would have begun to increase at a higher discharge so the 45,000 cfs figure is not absolute. At Birch Creek Slough, for example, there were no measurable effects of backwater to mainstem discharges of 72,000 cfs. In general, increases in mainstem discharge increase the amount of juvenile chinook salmon habitat at tributary mouths. Also, these backwaters may increase access into tributaries where rearing could occur by decreasing water velocities at the mouth.

Within side channel/slough sites, mainstem discharge is very important. When sloughs are breached the water becomes turbid and provides cover for the chinook juveniles in otherwise cover-poor habitat. Turbidity, however, may also limit use of the side channels by being too high (Figure 10). Turbidity varies seasonally. High turbidities generally occur from mid-June through September (especially during high discharges), and turbidities are low during the rest of the year. Turbidity also varies spatially within the river. Chulitna and Talkeetna river plume effects extend at least 20 miles downriver (Figure 4). Sites located within the Talkeetna River plume have much lower turbidity and higher juvenile chinook salmon use.

Mainstem discharge initially increases chinook WUA within a side channel/slough after it overtops but with further increases in flow, WUA usually remains constant or declines while the proportion of usable chinook habitat usually slowly declines as flows increase. The RJHAB model shows a decline in WUA with increasing discharge which is greater than that shown by the IFIM model (Appendix C).

The results obtained by pooling WUA from all modelled sites should not be directly extrapolated to represent the entire lower reach. The modelled side channels represented a wide range of sizes and shapes of channels with diverse breaching flows, but they are only a small fraction of the side channels present within the lower river. The most important side channels in the lower Susitna River for juvenile chinook salmon rearing are located within the low turbidity plume of the Talkeetna or Susitna rivers. Other side channels or side channel complexes should be weighted according to their mean turbidity level.

4.2 Coho Salmon

Juvenile coho salmon occurrence in the lower river was almost exclusively within tributary mouths. Tributaries and tributary mouths were also the primary capture sites for juvenile coho salmon in the middle Susitna River (Dugan et al. 1984). The lower reach has little upland slough macrohabitat which was found to be a significant rearing and overwintering area for juvenile coho salmon in the middle Susitna River.

The heavy use of tributary mouths by juvenile coho may be due to their documented tendencies to favor waters with relatively low levels of turbidity. Sigler et al. (1984), for example, found that a larger number of juvenile coho salmon emigrated from experimental laboratory channels with turbidities of 25-50 NTU than from clear water channels. In another laboratory study, Bisson and Bilby (1982) established that coho salmon avoided turbidities exceeding 70 NTU. Turbidities in Susitna River side channels uring June through August often greatly exceed 100 NTU.

Since juvenile coho salmon are dependent upon visibility and background contrast in their food selection (Mundie 1969), turbidity may affect feeding. Juvenile coho salmon feeding effectiveness may be impaired by turbidity levels of 70-100 NTU (Alabaster 1972). Noggle (1978) found that juvenile coho predation on caddis larvae decreases to zero at a sediment load of approximately 300 mg/l.

The four tributary mouths sampled exhibited marked differences from one another in relative abundance and seasonal use. Rolly Creek and Beaver Dam Slough CPUE's, generally increased from early summer into late fall (Figure 12). This occurrence may be due to both the immigration of coho juveniles and a decrease in site area which increased coho densities. The area of Rolly Creek was reduced by approximately 63% from late June and July to September and early October, while the area of Beaver Dam Slough was reduced by approximately 33% during the same time period.

In Birch Creek Slough, on the other hand, a relatively high CPUE occurred in early summer with much smaller values throughout the summer and fall. The relatively high CPUE's in early summer are probably due to a natal effect as Birch Creek has a spawning run of coho salmon (Barrett et al. 1985).

A comparison of juvenile coho catch rates between tributary mouths and the Talkeetna outmigrant trap (RM 103.0) suggests that a redistribution of juveniles into suitable rearing habitat peaks from late July to early August. The catch per hour of 0+ coho at the Talkeetna outmigrant trap increases during this time period while CPUE at various tributary sites undergo marked changes in relative abundance also. Birch Creek Slough, which habitat modelling indicates to be relatively poor coho tributary mouth rearing habitat (Figure 27), shows a reduction in CPUE in late July, following natal emigration, while Caswell Creek, a site evaluated as having relatively good rearing habitat, has increasing CPUE's beginning at this time. A study conducted by Delaney and Wadman (1979) in the Little Susitna River found emigration of emergent fry from natal areas after the end of June.

Instream flow effects of the lower Susitna River upon juvenile coho salmon are limited to the backwater zone effects at tributary mouths because coho juveniles make little use of the side channel/slough sites. Initially backwater may decrease the amount of habitat slightly as the tributary mouths change from free flowing to a backwater zone but then WUA generally increases as the amount of cover increases with further increases in stage. Overall the WUA generally increases with mainstem discharge. Also, the backwater may improve access into small tributaries and beaver ponds where rearing and overwintering may occur.

Studies of coho salmon distribution in 1982 by zone showed that the coho generally preferred free-flowing tributaries over backwater zones (ADF&G 1983), however, cover in the free-flowing tributaries was often better than in the backwater areas. For example, Birch Creek Slough generally has poor cover while Birch Creek itself has abundant emergent and aquatic vegetation in which coho were abundant.

4.3 Chum Salmon

The use of minnow trapping during 1981 and 1982 juvenile anadromous studies makes comparisons of lower river catch and CPUE data with 1984 studies difficult because chum salmon are rarely captured in minnow traps. The necessity for very early sampling, almost concurrent with ice-out, becomes important when studying chum salmon juveniles. Their early season movement and short time in the Susitna River system makes detailed conclusions difficult.

Chum salmon fry CPUE's by macrohabitat type contrast with the 1983 data for the middle reach (Dugan et al. 1984), which indicated heaviest use of tributaries and side sloughs. The 1983 catch rates, however, reflect the prevalence of natal sloughs in the middle reach, while the lower reach contains few natal side channel/side sloughs and also few upland sloughs. Also, side channels were not extensively sampled until July in 1983.

Chum salmon spawning activity was observed in 1984 in several side channel sites where none had ever been observed (Barrett et al. 1985). The presence of adult spawning in these areas indicates that under certain conditions side channels provide suitable spawning habitat in the lower river. Chum salmon fry observed in some of the side channels may be rearing near their natal areas.

The exact stimulus for the outmigration of chum salmon from the Susitna River is not known but probably reflects a combination of factors (Roth et al. 1984). Increased turbidity and higher flows were noted as possible initiating cues to innate behavior toward increased movement, culminating in outmigration. Turbidity in most sites rose above the indicated preference range (<200 NTU) by the middle of July. The sharp decline in CPUE, from early June (3+ fpc) to late June (1+ fpc) follows the peak monthly Susitna discharge of 17 June (USGS Sunshine provisional data), and the mid-June peak of chum outmigration past the Talkeetna trap. There was no difference in the average lengths of outmigrant chum salmon captured at Talkeetna and Flathorn stations (Part 1 of this report) which suggests that fish from the middle reach outmigrate through the lower reach without rearing. Since turbidity may trigger outmigration in the middle reach, it seems reasonable that chum salmon fry would not rear in the lower reach where the turbidity is even higher.

Since chum salmon outmigration is mostly completed by mid-July, flow effects are limited to this time period for this species. Chum salmon made heavy use of the side channels during this time while use of the tributary mouths was much more limited. Apparently chum salmon do not move into the tributary mouths much, as presumably most of their movements are gradually downstream and out of the system. Most of the use of the side channels for rearing occurs before the turbidities become too high.

Use of the side channels is limited by depth and velocity only as instream cover seems unimportant (Appendix A). Chum fry were captured primarily in shallow sampling cells (<1.0 ft) which had a relatively low velocity and low to moderate cover. This distribution suggests these fish are rearing as Hunter (1959) reported that chum salmon migrate in the center of the channel where water velocity is greatest. After breaching, side channels WUA's sometimes may increase or decrease but the proportion of the area that is suitable generally decreases as velocities and depths become unsuitable. Turbidities also quickly increase seasonally so that some side channels become turbid more quickly than others dependent upon the turbidity regimes in the Chulitna, Talkeetna, and Susitna rivers.

Since chum salmon side channel WUA's respond very similarly to those of chinook salmon at individual sites, it appears that an analysis of response to changes in mainstem discharge for chinook would also hold for chum salmon. A time series analysis of flow regimes, would only need to take place through mid-July for chum salmon, however, while chinook salmon fry occur throughout the season in side channels.

4.4 Sockeye Salmon

Tributary mouths were the primary capture sites for sockeye salmon in the lower river while in the middle river sockeye salmon were captured primarily at side sloughs (Dugan et al. 1984). Side sloughs were the primary spawning areas in the middle river, while tributary/lake systems are the major spawning areas in the lower reach (Barrett et al. 1985). Since side sloughs were the primary spawning areas for sockeye salmon in the middle reach, large catches of juvenile sockeye in these side sloughs were due to natal effects.

Few sockeye juveniles were captured in early June at modelled JAHS sites. This low incidence was probably due to lack of natal habitat in mainstem influenced areas of the lower river. Outmigrant trap catches at Talkeetna (RM 103.0) and Flathorn (RM 22.4) indicate that sockeye fry are redistributing in the system by the middle of June (Roth et al. 1985). The greatest catch per cell of juvenile sockeye occurred at the modelled sites during late June.

The consistently low CPUE's in side channel sites suggest these areas are of limited value for juvenile sockeye rearing. Possibly these juvenile sockeye catches represent transient populations. An exception may be Beaver Dam Side Channel and other side channels located in the Sunshine side channel complex where lower turbidities may allow juveniles to rear.

Beaver Dam Slough probably had moderate numbers of sockeye present throughout the season. This site resembles a lake system as it has low velocities, high cover and relatively warm temperatures during the entire open- water season. This site might be used as overwintering habitat, but it was not sampled after September so we have no data to support this hypothesis.

Rolly Creek mouth produced only low CPUE's of sockeye fry until early August. Emergent and aquatic vegetation were profuse at this site in mid season periods, however, which made sampling difficult. After late August, the numbers of chinook, coho, and sockeye juveniles increased. Although high numbers of these salmon fry were caught late in the season, the habitat at low water levels is less suitable for over-wintering than at Beaver Dam Slough. Extended late season sampling and surveys in April and May would be necessary to determine use of these two sites for overwintering by sockeye salmon juveniles.

Instream flow effects upon sockeye salmon rearing occur at both the tributary mouths and in side channels. Occurrence of sockeye juveniles in side channels appears to be limited by turbidity as the only four side channel sites where juvenile sockeye were captured more than half the times sampled were in the Talkeetna River plume. Even at these four sites, numbers of sockeye fry captured were usually small.

At tributary mouths, larger numbers of sockeye fry were found. In these sites, the formation of backwater zones probably has a major effect in increasing WUA for sockeye salmon juveniles. The response of the increase in WUA for sockeye is similar to that of chinook salmon. Access into suitable rearing and overwintering areas may also occur with the increase in backwater. For example, access into potential rearing areas as Whitsol Lake may be inhibited if Kroto Slough Head is not overtopped. Also several other small tributaries along the Kroto Slough side channel may be inaccessible if flows are below those required for overtopping.

Typically, WUAs for sockeye increase after overtopping of the side channels but then gradually decrease with further increases in discharge as side channel velocities became unsuitable. Sometimes backwater areas may form at the mouths of side channels (for example, Sucker Side Channel) and modify this relationship somewhat so that WUA may even increase with increases in discharge for much longer periods. Generally, the proportion of area that is usable within side channels decreases with flow as velocities become less suitable.

5.0 CONTRIBUTORS

Dana Schmidt provided the study design. David Sterritt, Robert Marshall, Karl Kuntz, John McDonell Richard Sundet, and Stuart Pechek collected field data along with Dale Corzine and Mike Domeier. Pat Morrow, Isaac Queral, Tommy Withrow, Glenn Freeman, Doug Sonnerholm, Sharie Methvin, and Chris Kent under the direction of Tim Quane installed staff gages, mapped the thalwegs, and helped with physical data analysis. Donna Buchholz keypunched the data and Chuck Miller, Kathrin Zosel, Gail Heinemann, and Allen Bingham managed the mainframe computer data base. Cartography was done by Carol Hepler and Roxanne Peterson. Jim Anderson and Jeff Bigler ran the weighted usable areas for the IFIM models and also collected field data. Diane Hilliard helped choose study sites for the IFIM models. The typing was done by Skeers Word Processing.

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7.0 LITERATURE CITED

Alabaster, J.S. 1972. Suspended solids and fisheries. Proceedings of the Royal Society of London. B. 180:395-406.

Alaska Department of Fish and Game. 1981a. Phase 1 final draft report. Subtask 7.10. Juvenile anadromous fish study on the Lower Susitna River (November 1980-October 1981). Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Anchorage, Alaska.

______. 1981b. Phase 1 final draft report. Volume 1 (December 1980-October 1981). Subtask 7.10. Aquatic habitat and instream flow project. Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Anchorage, Alaska.

______. 1983a. Susitna Hydro aquatic studies phase II basic data report. Volume 3 (1 of 2). Resident and juvenile anadromous fish studies on the Susitna River below Devil Canyon, 1982. Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Anchorage, Alaska.

______. 1983b. Susitna Hydro aquatic studies phase II basic data report. Volume 3 (2 of 2: Appendices A-H). Resident and juvenile anadromous fish studies on the Susitna River below Devil Canyon, 1982. Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Anchorage, Alaska.

______. 1983c. Susitna Hydro aquatic studies phase II report. Synopsis of the 1982 aquatic studies and analysis of fish and habitat relationships (2 of 2: Appendices A-K). Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Anchorage, Alaska.

______. 1984a. Susitna Hydro aquatic studies (May 1983 - June 1984) procedures manual (1 of 2). Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Anchorage, Alaska.

______. 1984b. Susitna Hydro aquatic studies (May 1983 - June 1984) procedures manual (2 of 2: Appendices). Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Anchorage, Alaska.

______. 1985. (In Preparation). Susitna aquatic studies procedures manual (May 1984 - June 1985). Alaska Department of Fish and Game, Susitna Aquatic Studies. Anchorage, Alaska.

Barrett, B.M., F.M. Thompson, and S.N. Wick. 1985. 1984 salmon escapement studies in the Susitna River drainage (Draft) Report No. 4. Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Anchorage, Alaska.

Bisson, P.A., and R.E. Bilby. 1982. Avoidance of suspended sediment by juvenile coho salmon. North American Journal of Fisheries Management 4:371-374.

Bovee, K.D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Instream Flow Information Paper. No. 12. U.S. Fish and Wildlife Service. FWS/035-82/26.

Delaney, K.J., K. Hepler, and K. Roth. 1981. Deshka River chinook and coho salmon study. Alaska Department of Fish and Game, Division of Sport Fish. Federal Aid in Fish Restoration, Project AFS-49, Vol. 22.

______, and R. Wadman. 1979. Little Susitna River juvenile chinook and coho study. Alaska Department of Fish and Game. Division of Sport Fish.

Dugan, L.J., D.A. Sterritt, and M.E. Stratton. 1984. The distribution and relative abundance of juvenile salmon in the Susitna River drainage above the Chulitna River confluence. Part 2 in Schmidt, D.C., S.S. Hale, D.L. Crawford, and P.M. Suchanek (eds.). 1984. Resident and juvenile anadromous fish investigations (May - October 1983). Susitna Hydro Aquatic Studies. Report No. 2. Alaska Department of Fish and Game. Anchorage, Alaska.

Hunter, J.G. (1959). Survival and production of pink and chum salmon in a coastal stream. Journal of the Fisheries Research Board of Canada. 16(6):835-886.

Klinger, S., and E.W. Trihey. 1984. Response of aquatic habitat surface areas to mainstem discharge in the Talkeetna to Devil Canyon reach of the Susitna River, Alaska. E. Woody Trihey & Associates. Anchorage, Alaska.

Marshall, R.P., P.M. Suchanek, and D.C. Schmidt. 1984. Juvenile salmon rearing habitat models. Part 4 in Schmidt, D.C., S.S. Hale, D.L. Crawford, and P.M. Suchanek (eds.). 1984. Resident and juvenile anadromous fish investigations (May - October 1983). Susitna Hydro Aquatic Studies. Report No. 2. Alaska Department of Fish and Game. Anchorage, Alaska.

Milhous, R.T., D.L. Wegner, and T. Waddle. 1981. User's guide to the physical habitat simulation system. United States Fish and Wildlife Service. Biological Services Program FWS/OBS-81/43.

Mundie, J.H. 1969. Ecological implications of the diet of juvenile coho in streams. p. 135-152. In T.G. Northcote (ed.), symposium on salmon and trout in streams. H.R. MacMillan Lectures in Fisheries, Univ. B.C., Vancouver.

Noggle, C.C. 1978. Behavioral, physiological and lethal effects of suspended sediment on juvenile salmonids. Master's thesis, University of Washington, Seattle, Washington, USA.

Quane, T., P. Morrow, I. Queral, T. Keklak, and T. Withrow. 1985. Technical memorandum in support of Task 14 (Lower River Resident and Juvenile Anadromous Fish Studies). Alaska Department of Fish and Game, Susitna Aquatic Studies. Anchorage, Alaska.

Riis, J.C., and N.V. Friese. 1978. Preliminary environmental assessment of hydroelectric development on the Susitna River. Alaska Department of Fish and Game. Div. of Sport Fish and Comm. Fish., Anchorage, Alaska.

Roth, K.J., D.C. Gray, and D.C. Schmidt. 1984. The outmigration of juvenile salmon from the Susitna River above the Chulitna River confluence. Part 1 in Schmidt, D.C., S.S. Hale, D.L. Crawford and P.M. Suchanek (eds.). 1984. Resident and juvenile anadromous fish investigations (May - October 1983). Susitna Hydro Aquatic Studies. Report No. 2. Alaska Department of Fish and Game. Anchorage, Alaska.

Sigler, J.W., T.C. Bjornn, and F.H. Everest. 1984. Effects of chronic turbidity on density and growth of steelheads and coho salmon. Transactions of the American Fisheries Society. 113:142-150.

Suchanek, P.M., R.P. Marshall, S.S. Hale, and D.C. Schmidt. 1984. Juvenile salmon rearing suitability criteria. Part 3 in Schmidt, D.C., S.S. Hale, D.L. Crawford and P.M. Suchanek (eds.). 1984. Resident and juvenile anadromous fish investigations (May - October 1983). Susitna Hydro Aquatic Studies. Report No. 2. Alaska Department of Fish and Game. Anchorage, Alaska.

DRAFT

APPENDIX A

LOWER SUSITNA RIVER
JUVENILE SALMON REARING SUITABILITY
CRITERIA

TABLE OF CONTENTS

INTRODUCTION

Habitat suitability criteria are necessary for use in evaluating fish habitat using the instream flow incremental methodology (Bovee 1982). The criteria express the value of a habitat variable such as velocity on a zero (unusable) to one (optimum) basis for a given fish species and life stage. The suitability criteria are coupled with the habitat present within a study site to produce estimates of equivalent optimal habitat called weighted usable area.

Juvenile salmon rearing suitability criteria have been used to model the response of juvenile salmon habitat to variations in mainstem discharge of the middle reach (Chulitna River confluence to Devil Canyon) of the Susitna River (Hale et al. 1984, Marshall et al. 1984). The suitability criteria used in these studies were developed specifically for the middle Susitna River by Suchanek et al. (1984). EWT&A (1985) modified a few of the same suitability criteria for use in impact analysis of chinook salmon rearing in the middle Susitna River.

In 1984, some of the juvenile salmon habitat modeling effort was directed toward evaluating responses of juvenile salmon habitat in the lower Susitna River (below the Chulitna River confluence) to discharge variations. Since habitat data collection techniques used in 1984 were similar to those used during the 1983 studies, suitability criteria specific to the lower reach can be developed. The purpose of this appendix is to verify the applicability of the suitability criteria developed in 1983 by Suchanek et al. (1984) for use in the lower river habitat studies. The general philosophy was to use the 1983 middle river criteria curves for the lower river unless the 1984 studies in the lower river provided evidence for modifications.

METHODS

The field sampling methodology used is detailed in Section 2.1 of this report. This methodology is very similar to that used during the 1983 studies (Suchanek et al. 1984) and will only be briefly summarized here. Sampling sites included 20 habitat model sites normally sampled twice a month and 31 opportunistic sites which were usually only sampled once.

At each site, 6 ft x 50 ft rectangular cells were sampled for fish and then habitat variables were measured in each cell. Cells were selected randomly at model sites although sometimes additional selected cells with "good" habitat were sampled. At opportunistic sites, cells were selected to encompass a variety of habitat conditions within what was thought to be usable habitat. Habitat measurements taken at each cell sampled included a representative mean column velocity and depth and estimates of primary cover type and percent total cover (Appendix Table A-1).

Appendix Table A-1. Percent cover and cover type categories.

Group #	% Cover	Group #	Cover Type
1	0-5%	1	No object cover
2	6-25%	2	Emergent vegetation
3	26-50%	3	Aquatic vegetation
4	51-75%	4	Debris or deadfall
5	76-96%	5	Overhanging riparian vegetation
6	96-100%	6	Undercut banks
		7	Gravel (1" to 3" diameter)
		8	Rubble (3" to 5" diameter)
		9	Cobble (larger than 5" diameter)

The data collected were examined for suitability criteria development by using the procedures described in Suchanek et al. (1984), with a few modifications.

Suitability was represented by mean catch per cell for chinook and coho salmon and proportional presence (proportion of cells sampled in which fish were captured) was used as the suitability measure for chum and sockeye salmon. Data were pooled by species for analysis but some data were excluded from analysis by using results from the distribution and abundance analysis (Section 3.2) which indicated factors other than the microhabitat variables of velocity, depth, and cover were greatly affecting distribution. Cells excluded varied by species and are detailed in the results section. The beach seine and electrofishing data were pooled for analysis because the sampling method used to sample a cell was thought to be most effective given the sampling conditions.

Groupings of habitat variables were identical to those used in 1983. Percent object cover categories 76-95% and 96-100% were pooled because of small sample sizes. Velocity and depth were pooled in groups identical to those used in 1983 with the exception that cells with depths of 0.1 feet were examined separately. In 1983, only two cells with a depth of 0.1 feet were sampled, and therefore insufficient data were available for examination of suitability of this depth.

Comparisons of the 1983 data with the 1984 data were made by plotting the suitability criteria derived in 1983 on the same graph with comparable 1984 data. On the depth and velocity graphs this was done by normalizing the suitability to 1.0 for the 1984 depth or velocity increment with the highest suitability and then plotting the 1983 suitability criteria normalized to the same scale. The 1984 percent cover data were first regressed against catch per cell or proportional presence, and, if significant, the regression line was plotted and the suitability normalized to 1.0 for the highest cover category. The 1984 percent cover suitability line was then plotted on the same graph, by using the normalized 1.0 as the starting point. The suitability of cover type for each species was calculated with the 1984 data using the methods described in Suchanek et al. (1984). The suitabilities calculated were then graphed against the cover type suitabilities calculated in 1983.

Variations in histogram distributions are to be expected on a univariate basis given that percent cover, cover type, velocity, and depth together affect suitabilities of a cell. Therefore, composite weighting factors were calculated for each cell using the 1983 suitability criteria and revised 1984 criteria and then these weighting factors were compared with catch. Composite weighting factors were calculated by multiplying suitability indices for cover type, percent cover, and velocity together. For chinook and coho salmon, Pearson correlation coefficients were calculated between composite weighting factors and catch per cell [transformed by natural log (X + 1)]. Chi-square association tests were run between chum and sockeye proportional presence and composite weighting factor value intervals calculated using the 1984 criteria data.

Intervals of composite weighting factors were specified by dividing the data into four groups of approximately equal sizes by value of the composite weighting factor. Pearson correlation coefficients and results of the chi-square analysis were then compared with the same analyses done in 1983. Most of the statistical tests and data manipulations were done with the Statistical Package for the Social Sciences (SPSS) (Nie et al. 1975).

If the fit of the 1984 data to the 1983 suitability criteria did not seem close upon visual inspection, the 1983 criteria were modified. One of the procedures for modification was as follows. If, for example, the 1984 velocity distribution data appeared to match closely the 1983 velocity criteria, the 1983 velocity criteria were input as suitabilities and averaged over each increment of a variable such as depth for which a modification of suitability was desired. These averages were then multiplied by the mean catch of fish per cell divided by the mean suitability. The actual mean catches per cell by depth increment were then divided by the adjusted mean velocity suitability. If this ratio was less than 1.0, this would indicate less use of a depth increment than expected given the average suitability for velocity. If the ratio was greater than 1.0, the use would be more than expected by adjusting for the effect of velocity. Sometimes this procedure would be effective in taking out variation caused by the other variable. If necessary, this procedure was used to adjust for effects of two or more variables.

If the above procedure was not effective in discounting the extraneous variation, then the criteria were modified using professional judgement. Correlations or chi-square association tests were then calculated between mean catch and calculated composite weighting factors using the modified criteria.

RESULTS

Abundance and distribution data (Section 3.2) have shown that the number of all four species of salmon was very small at sloughs in the lower reach. Even sampling cells at sloughs with good habitat failed to have any significant number of fish present in comparison with similar cells at the other macrohabitat types. Fish were therefore responding to factors other than the availability of suitable microhabitat in their use of sloughs. For this reason, data collected at sloughs were eliminated from suitability criteria analyses to avoid comparing similar cells with large differences in mean catch.

Chinook Salmon

Chinook salmon suitability criteria were developed for both clear (<30 NTU) and turbid (>30 NTU) water in 1983 as fish distribution was very different in the two categories (Suchanek et al. 1984). The catch in cells without object cover was much greater in turbid water than in clear water. The data collected in the lower river have shown that turbidity may limit the distribution of chinook salmon by being too high

(Figure 10). Since cells with good habitat were sampled when high turbidity was limiting use by chinook salmon fry, we decided to eliminate sampled cells with turbidities greater than 350 NTU.

After eliminating cells in sloughs and cells with turbidities greater than 350 NTU, 1155 cells were available for analysis of chinook distribution. Of the 1155 cells, 400 were sampled in water with a turbidity of 30 NTU or less. Mean adjusted catch (catch adjusted to a cell of 300 ft^2) per cell of chinook fry in the clear water cells was 1.3, while mean adjusted catch per cell in the turbid cells was 1.1.

A scatter plot of chinook salmon catch in cells without object cover versus turbidities ranging to 100 NTU was examined. No notable inflections in catches of chinook salmon fry were noted over this range, although gradual increases in catches occurred across the range. It seemed reasonable, therefore, to keep the same 30 NTU breakpoint between high and low turbidity data for this year's analysis.

Clear Water

Correlations among the values of habitat attributes and clear water (<30 NTU) chinook catch range to 0.32 in absolute value and a number of the correlations are statistically significant (Appendix Table A-2). In addition to these data, partial habitat data were recorded for four additional clear water cells and these additional data are used in subsequent analyses.

Appendix Table A-2. Kendall correlation coefficients between habitat variables and chinook catch by cell (N=396) for all gear types, in clear water.

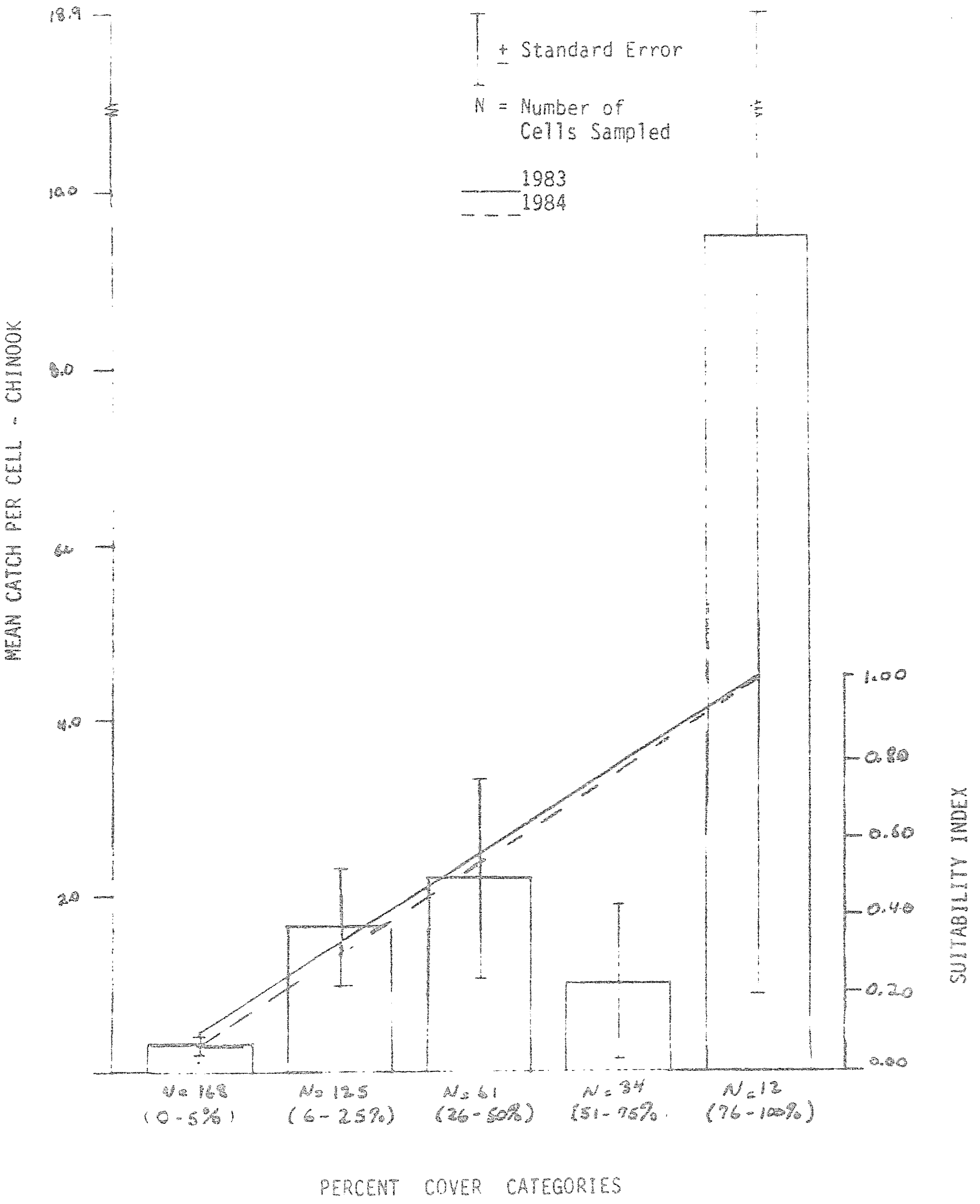
	Percent Cover	Cover Type	Velocity	Depth	Chinook
Percent Cover	1.00				
Cover Type	0.08*	1.00			
Velocity	-0.32**	0.04	1.00		
Depth	0.03	-0.08*	-0.04	1.00	
Chinook	0.07	0.09*	-0.09*	0.21**	1.00

* Significantly different from 0 at $p<0.05$.
** Significantly different from 0 at $p<0.01$.

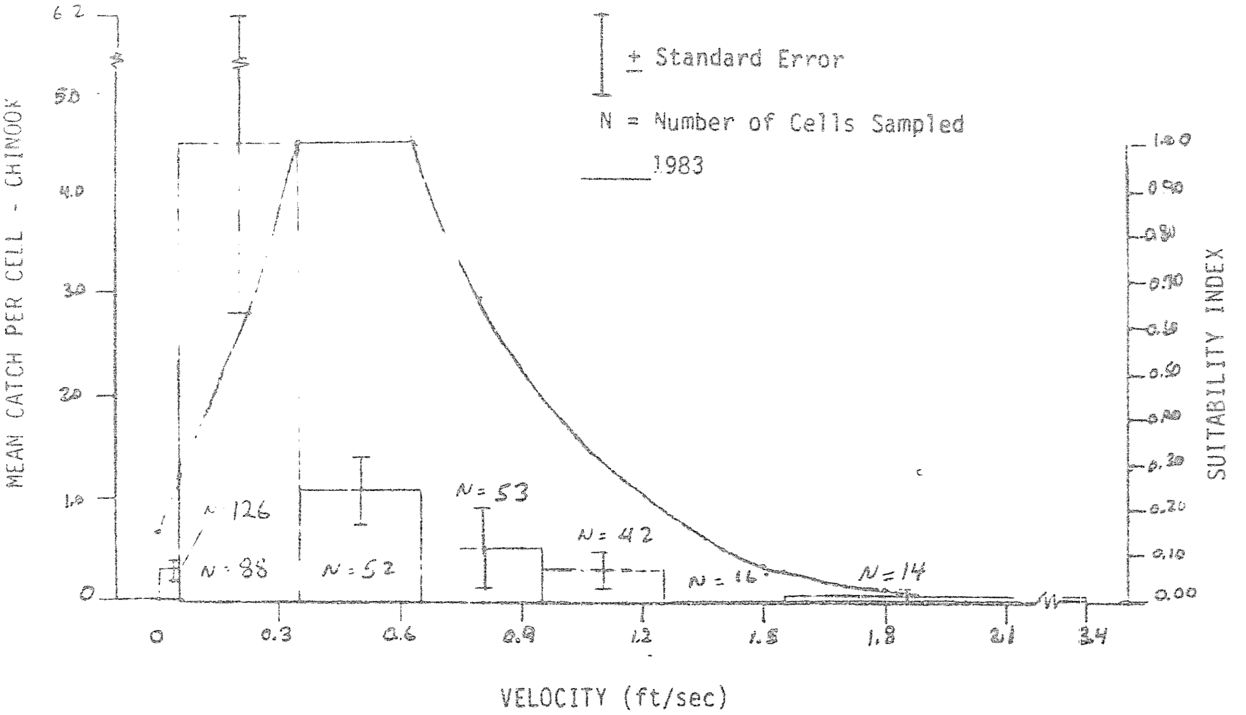
Composite weighting factors for all cells sampled were calculated by using the 1983 suitability criteria and also with modification of the velocity criteria as proposed by EWT&A (1985) and then correlated with chinook catch transformed by natural log (x + 1). In clear water, the correlation in 1983 was 0.43 but the correlation with the 1984 data was only 0.31 for the original criteria data and 0 26 with the change in velocity criteria proposed by EWT&A (1985). It was therefore deemed desirable to modify the criteria where large differences in individual criteria were found.

Least squares regressions were run between chinook catch per cell and the percent cover categories in clear water. There was a significant positive regression which is very similar to the suitability line developed in 1983 when the Y axis is normalized to a suitability of one (Appendix Figure A-1). The 1983 suitability criteria was therefore retained as a good estimate of this relationship.

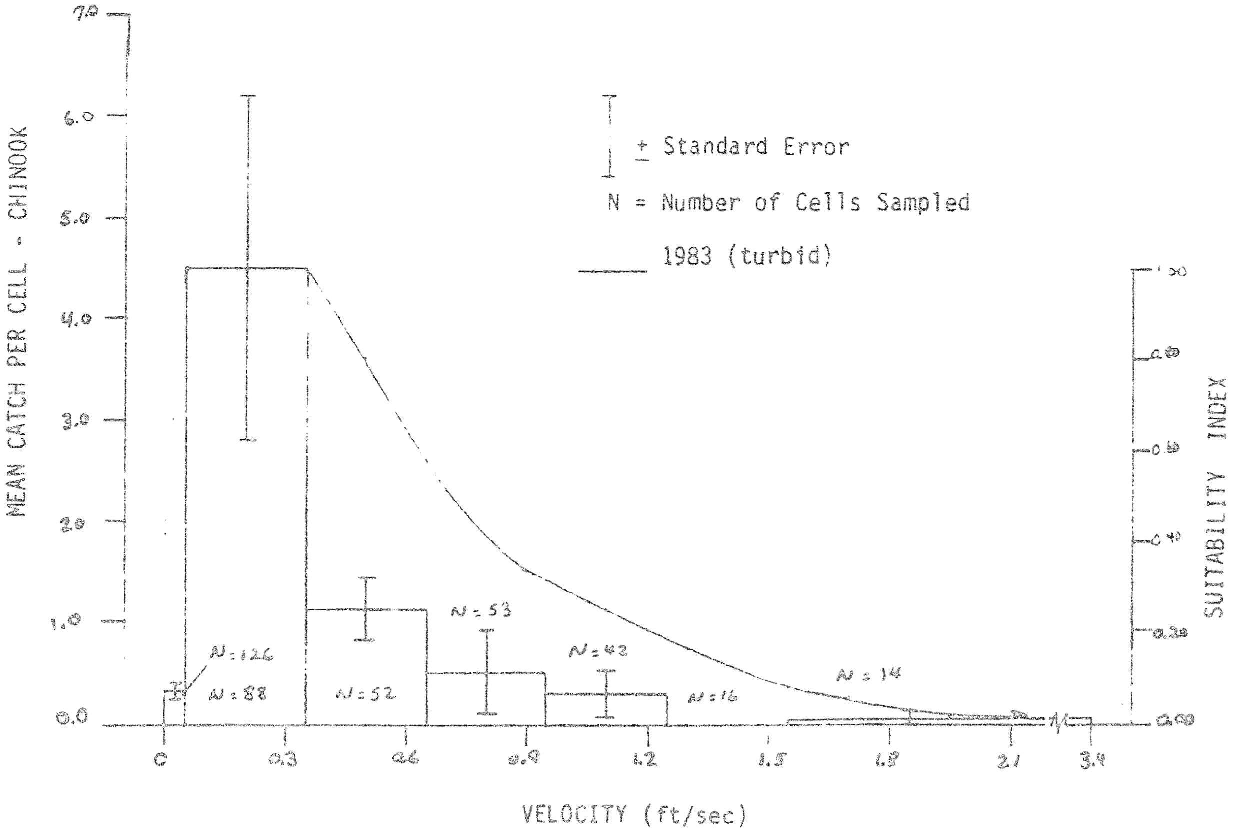
The distribution of mean catch per cell of chinook fry by velocity interval in clear water in 1984 shows that peak catches were made in sampling cells with a velocity ranging from 0.1 to 0.3 fps (Appendix Figure A-2). By normalizing this peak to a suitability of 1.0 and then overlaying the 1983 criteria, it appears that chinook use lower velocity water in the lower reach under clear conditions. It was noted that the 1984 clear water distribution of catch by velocity interval was very similar to the 1983 turbid water velocity suitability criteria and



Appendix Figure A-1. Mean catch of juvenile chinook salmon per cell by percent cover category (bars) in clear water of the lower Susitna River, 1984 and comparison of fitted suitability indices (lines) calculated in 1984 and for the middle Susitna River, 1983.



Appendix Figure A-2. Mean catch of juvenile chinook salmon per cell by velocity intervals (bars) in clear water of the lower Susitna River, 1984 and fitted suitability index (line) developed for the middle Susitna River, 1983.



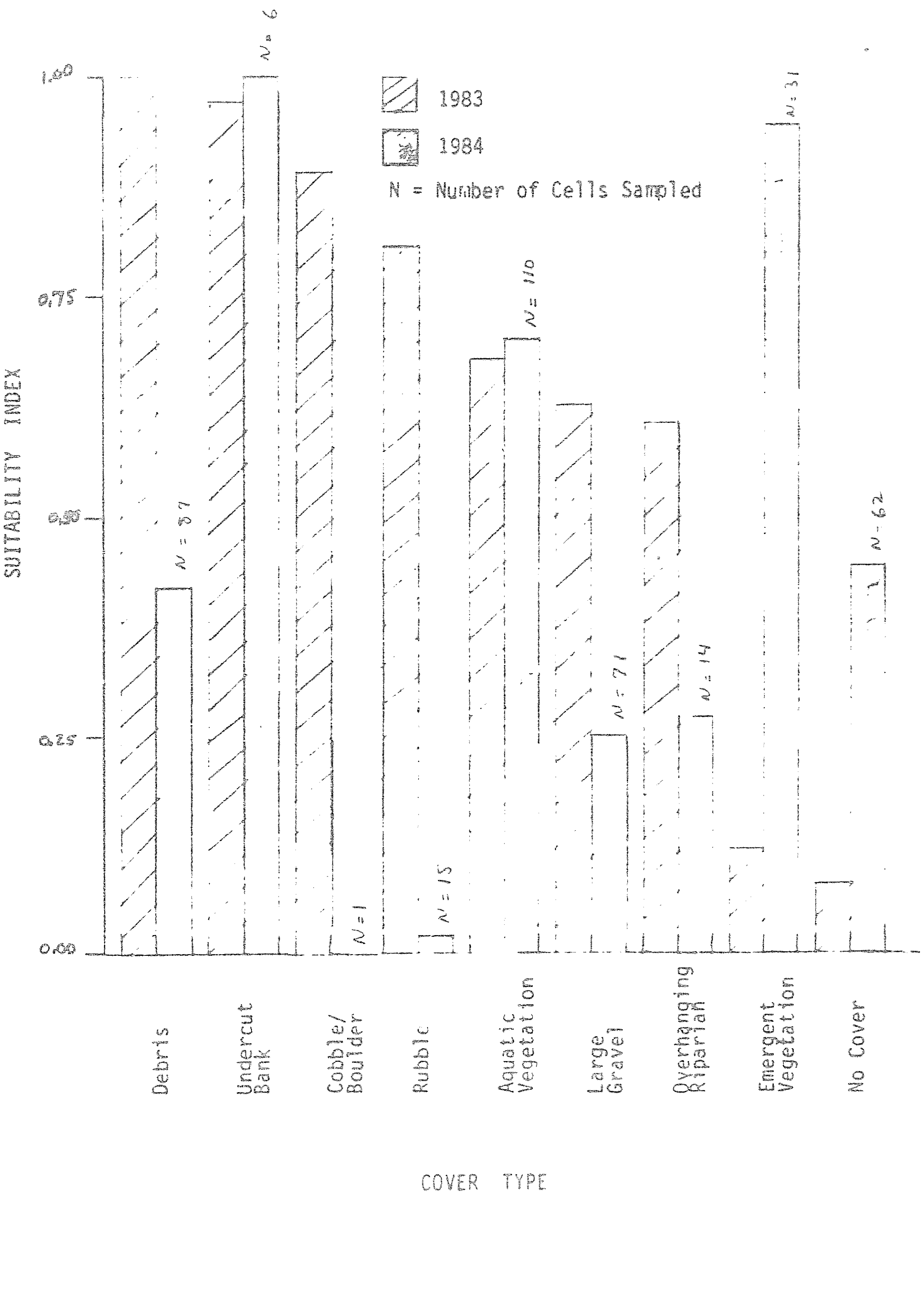
Appendix Figure A-3. Mean catch of juvenile chinook salmon per cell by velocity intervals (bars) in clear water of the lower Susitna River, 1984 and fitted suitability index (line) developed for turbid water in the middle Susitna River, 1983.

therefore this criteria was plotted against the 1984 data (Apperdix Figure A-3). Since it was so similar, it was taken as a good estimate of the lower river velocity suitability for chinooks in clear water.

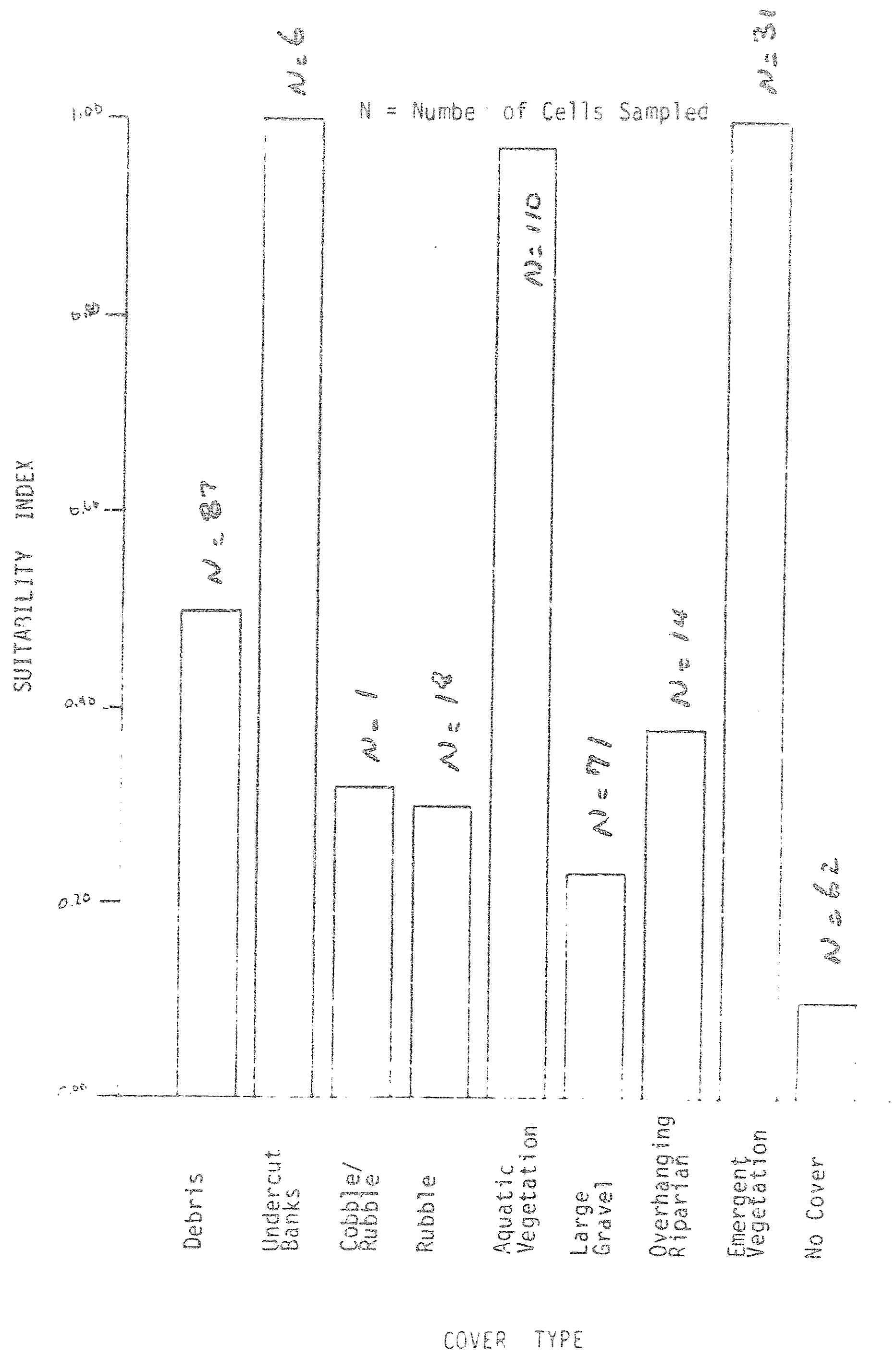
Cover type suitabilities derived in 1984 for chinook in clear water contrast sharply with those derived in the middle reach in 1983 (Appendix Figure A-4). Debris was used much less by chinook in the lower reach while emergent vegetation was more heavily used. The sample size of the cobble/boulder cover category was only one and therefore this cover type could not be evaluated. Catches in the cells without object cover were also relatively higher in 1984 than in 1983.

Therefore, we believed that 1983 suitability for cover types would not apply in the lower reach. By adjusting for the effects of velocity and percent cover, better estimates of cover type suitability for the lower river were formulated from the 1984 data (Appendix Figure A-5). Since cobble and boulder sample sizes were low, suitabilities for these cover types were kept proportional in suitability to large gravel as was the case in 1984. Since the "no cover" catches were relatively large, we arbitrarily lowered the suitability for no cover cells to 0.10, the suitability found in 1983.

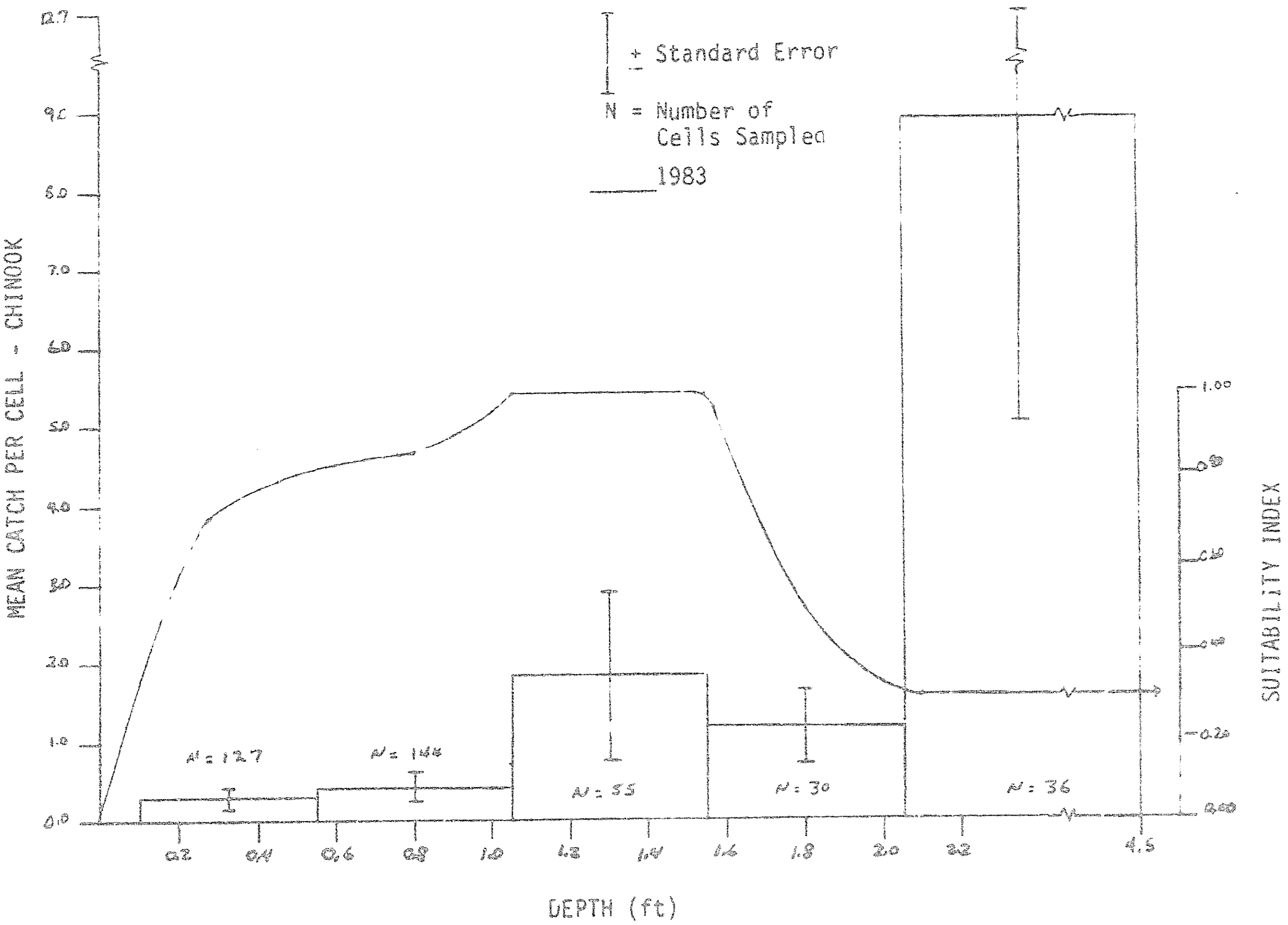
A heavy use of deep, clear water by chinooks was found in 1984 while in 1983 the data suggested a peak in use of cells 1.0 to 1.5 feet deep (Appendix Figure A-6). In 1983, an evaluation of depth found it had little effect on increasing the correlation of fish catch with composite weighting factors using it. Depth was used, however, in the 1983



Appendix Figure A-4. Comparison of cover type suitability indices for juvenile chinook salmon in clear water calculated from 1984 lower Susitna River distribution data and 1983 distribution data.



Appendix Figure A-5. Cover type suitability indices for juvenile chinook salmon in clear water calculated from 1984 lower Susitna River distribution data.



Appendix Figure A-6. Mean catch of juvenile chinook salmon per cell by depth intervals (bars) in clear water of the lower Susitna River, 1984 and fitted suitability index (line) developed for the middle Susitna River, 1983.

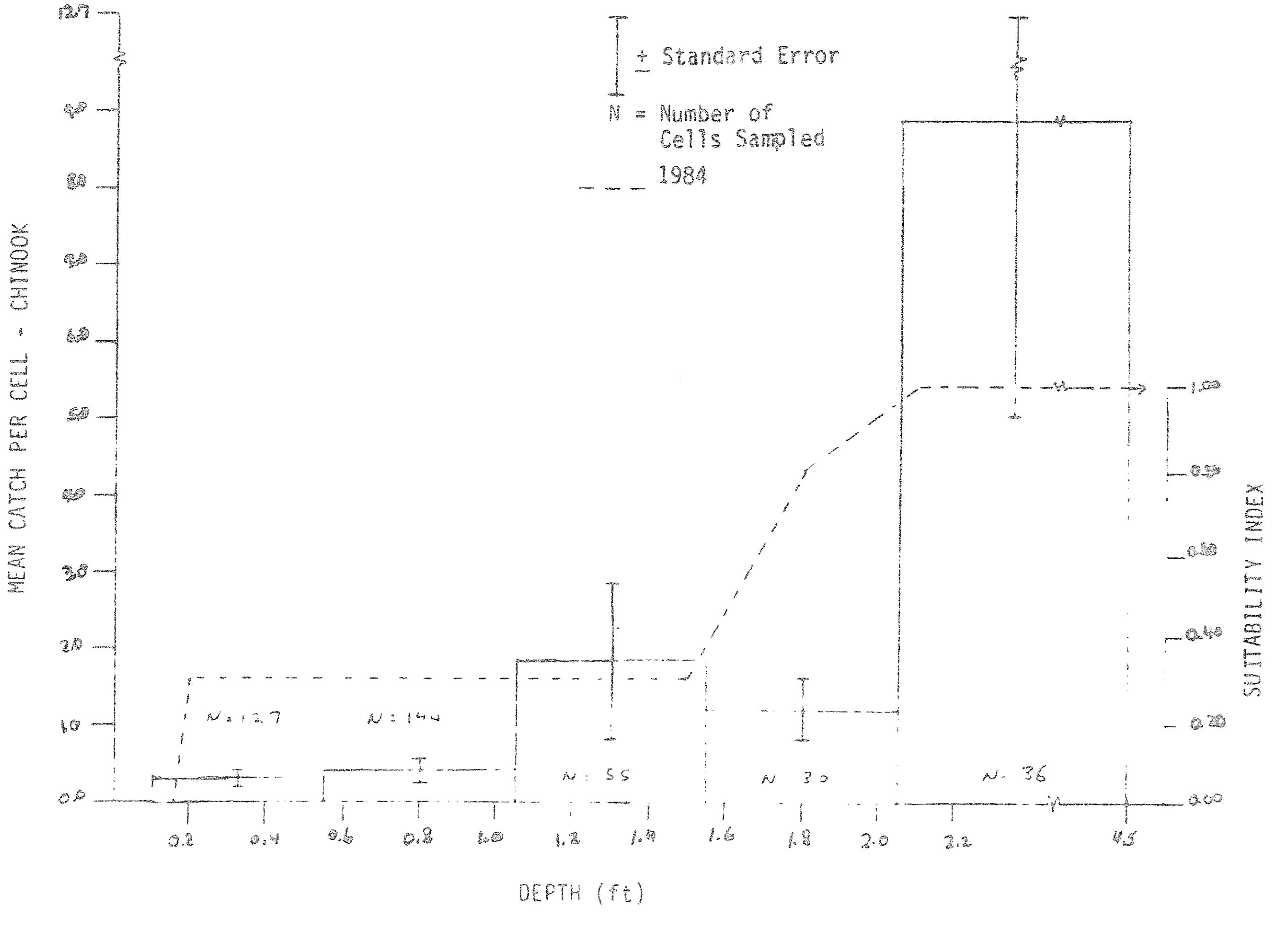
modelling efforts as having no value if less than 0.14 ft and having a suitability of 1.0 if greater than 0.15 ft. In order to evaluate depth, suitability criteria were fit to the data using professional judgement after first adjusting for mean velocity and percent cover suitability (Appendix Figure A-7).

After the modifications to the cover suitability and depth criteria were made, we then correlated transformed chinook catch with the composite weighting factors calculated with the 1983 percent cover criteria and turbid water velocity criteria along with the 1984 lower river cover type and depth suitability criteria. The correlation was 0.61, substantially higher than the original 1983 criteria. If depth was eliminated from the calculations, the correlation dropped to 0.26 and if primary cover type was dropped the correlation dropped to 0.52. Therefore it seemed reasonable to keep the new modified cover type and depth criteria as inputs.

Turbid Water

Correlations between the values of habitat attributes and chinook catch in turbid water range to 0.39 in absolute value and a number are statistically significant (Appendix Table A-3). Partial habitat data were recorded for 11 additional turbid cells and these additional data were used in subsequent univariate histograms.

Correlations between composite weighting factors calculated with the 1983 turbid water criteria and 1984 chinook catch was 0.31, while



Appendix Figure A-7. Mean catch of juvenile chinook salmon per cell by depth intervals (bars) in clear water of the lower Susitna River, 1984. Suitability index (line) fitted by hand using professional judgement.

Appendix Table A-3. Kendall correlation coefficients between habitat variables and chinook catch by cell (N=744) for all gear types, in turbid water.

	Percent Cover	Cover Type	Velocity	Depth	Chinook
Percent Cover	1.00				
Cover Type	0.39**	1.00			
Velocity	0.05*	0.16**	1.00		
Depth	0.06*	0.26**	0.21**	1.00	
Chinook	-0.02	0.00	-0.17**	-0.15**	1.00

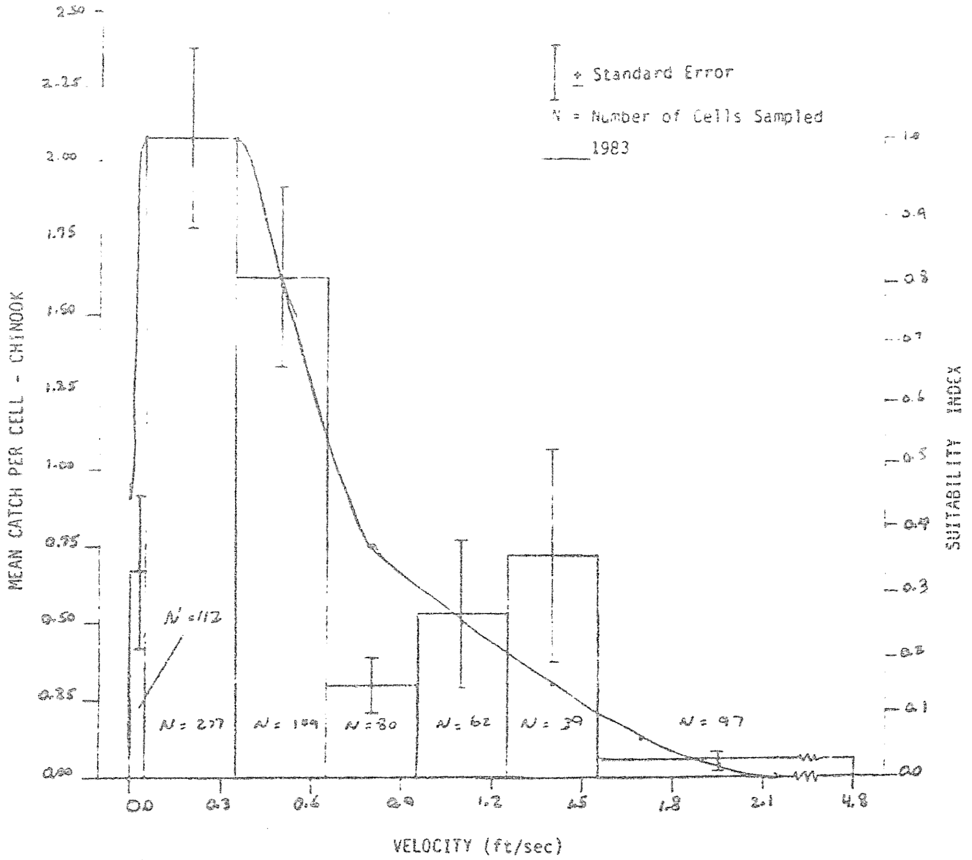
* Significantly different from 0 at $p<0.05$.
** Significantly different from 0 at $p<0.01$.

composite weighting factors calculated by incorporating the cover modifications proposed by EWT&A (1985) were correlated with an r-value of 0.26. Comparable correlation with the 1983 data was 0.38. These data again suggested that some modifications could be made, especially given the changes already made in the clear water cover type suitabilities.

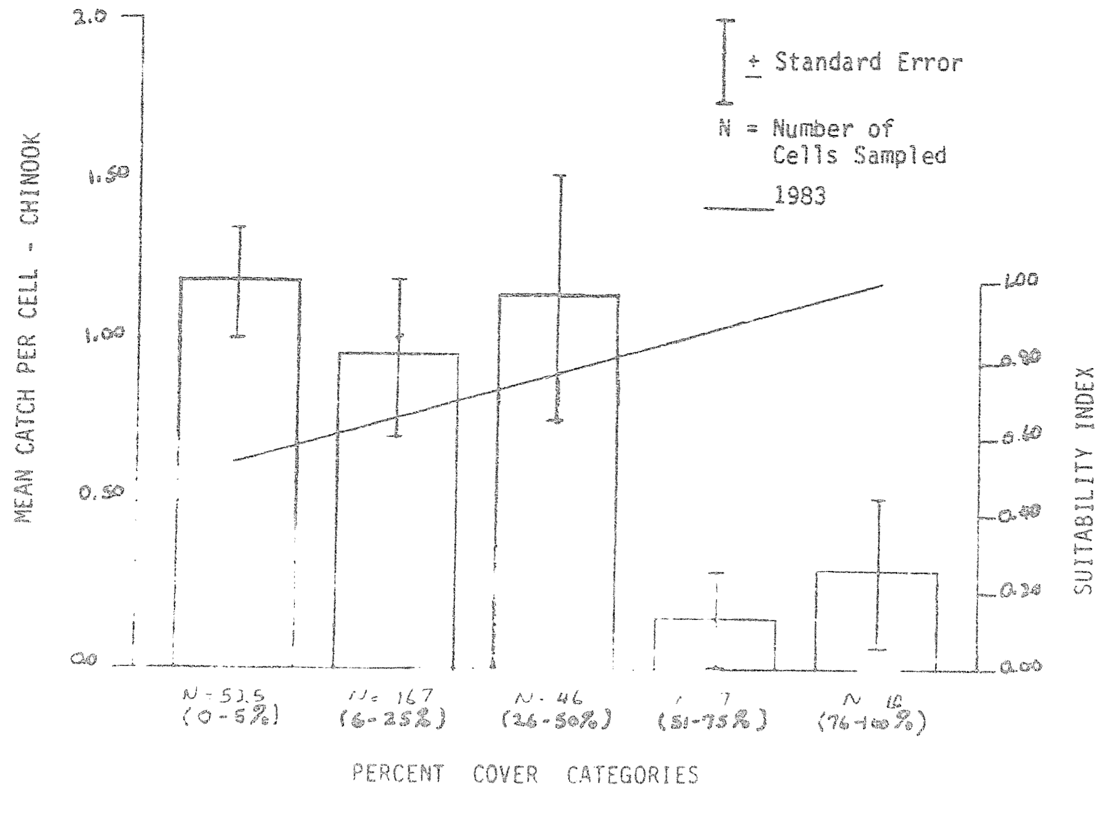
A comparison of 1984 velocity distribution data and the 1983 velocity suitability criteria for chinook salmon showed few differences (Appendix Figure A-8), and therefore was accepted as the 1984 criteria curve.

Least squares regressions were run between chinook catch per cell and the percent cover categories in turbid water. There was no significant relationship between catch per cell and percent cover category and mean catch per cell decreased with increases in cover (Appendix Figure A-9). By adjusting for velocity, a slight trend upward was noted over the first three categories. The percent cover criteria developed in 1983 was therefore accepted as reasonable, as intuitively, increases in the amount of object cover would seem more desirable for fish.

In 1983, cover type for chinook in turbid water was not evaluated. EWT&A (1985) modified the turbid water criteria, however, so that they more closely reflected the clear water criteria developed in 1983. In 1984, mean catches of chinooks in turbid water were highest in the emergent vegetation, rubble, and debris-deadfall categories, but catches were only slightly higher than in the cover category "no cover".



Appendix Figure A-8. Mean catch of juvenile chinook salmon per cell by velocity intervals (bars) in turbid waters of the lower Susitna River, 1984 and fitted suitability index (line) developed for the middle Susitna River, 1983.



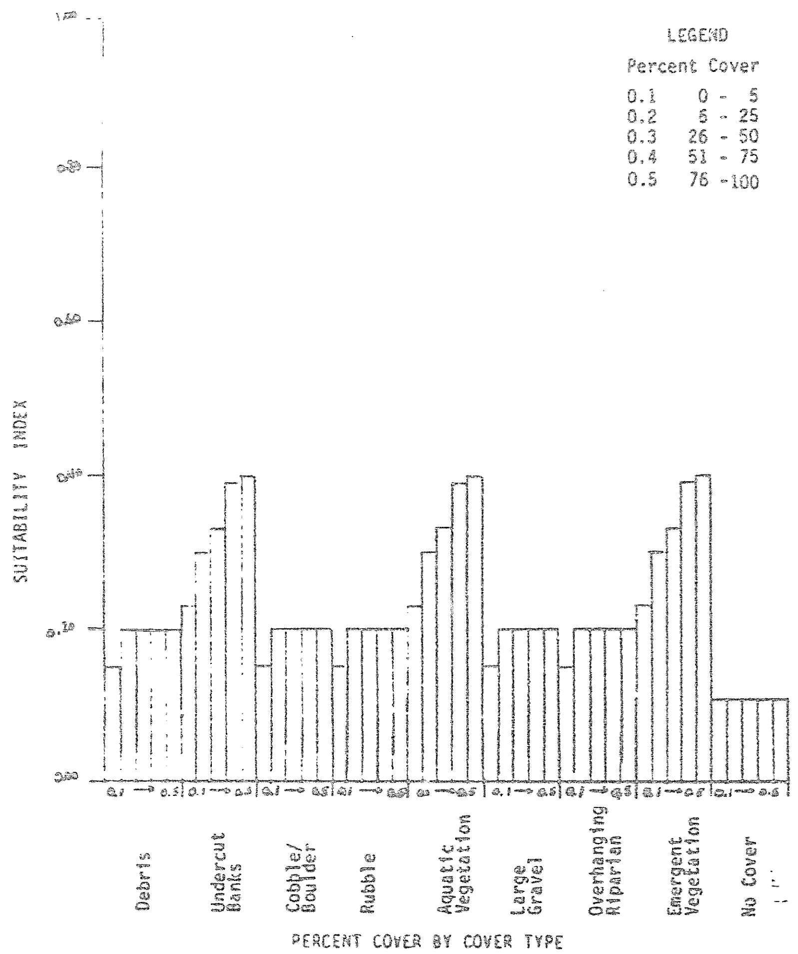
Appendix Figure A-9. Mean catch of juvenile chinook salmon per cell by percent cover category (bars) in turbid water of the lower Susitna River, 1984 and fitted suitability index (line) calculated for the middle Susitna River, 1983.

Cover type was evaluated in 1984 by using the method of EWT&A (1985) for calculating turbidity factors from the fitted regressions of percent cover in clear and turbid water and their associated chinook mean catches. Turbidity factors were calculated (Appendix Table A-4) and then applied to the revised lower river cover suitability data. These revised suitabilities were much too low for many categories given observed catches and therefore a suitability of 0.15 was assigned as a minimum for cover type suitability in turbid water based on observed mean catches. Using this method, none of the suitabilities for cover type in conjunction with percent cover in turbid water are greater than 0.40 (Appendix Figure A-10).

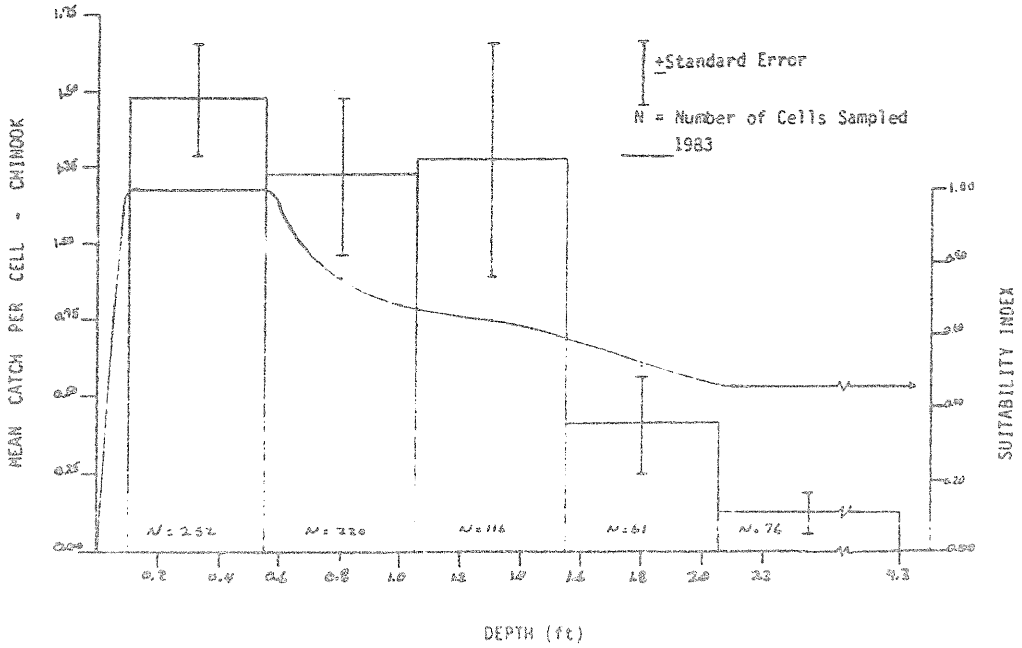
Appendix Table A-4. Calculations of turbidity factors for 1984 lower river data.

Percent Cover	Number of Fish Per Cell (Fitted to a Line) Clear	Turbid	Turbidity Factor
0-5%	0.5	1.1	2.2
6-25%	1.5	1.3	0.9
25-50%	2.5	1.5	0.6
51-75%	3.5	1.7	0.5
76-100%	4.5	1.9	0.4

In turbid water, peaks in chinook use were found in water less than 0.5 ft deep in both 1983 and 1984 (Appendix Figure A-11). In 1983, since fitting the depth suitability line to the data did not increase the composite weighting factor much, the depth criteria used for clear water (0 if less than 0.14 ft, 1.0 if greater than 0.15 ft) was used for modelling.



Appendix Figure A-10. Cover type suitability indices for juvenile chinook salmon in turbid water developed from 1984 lower Susitna River chinook clear water distribution data.



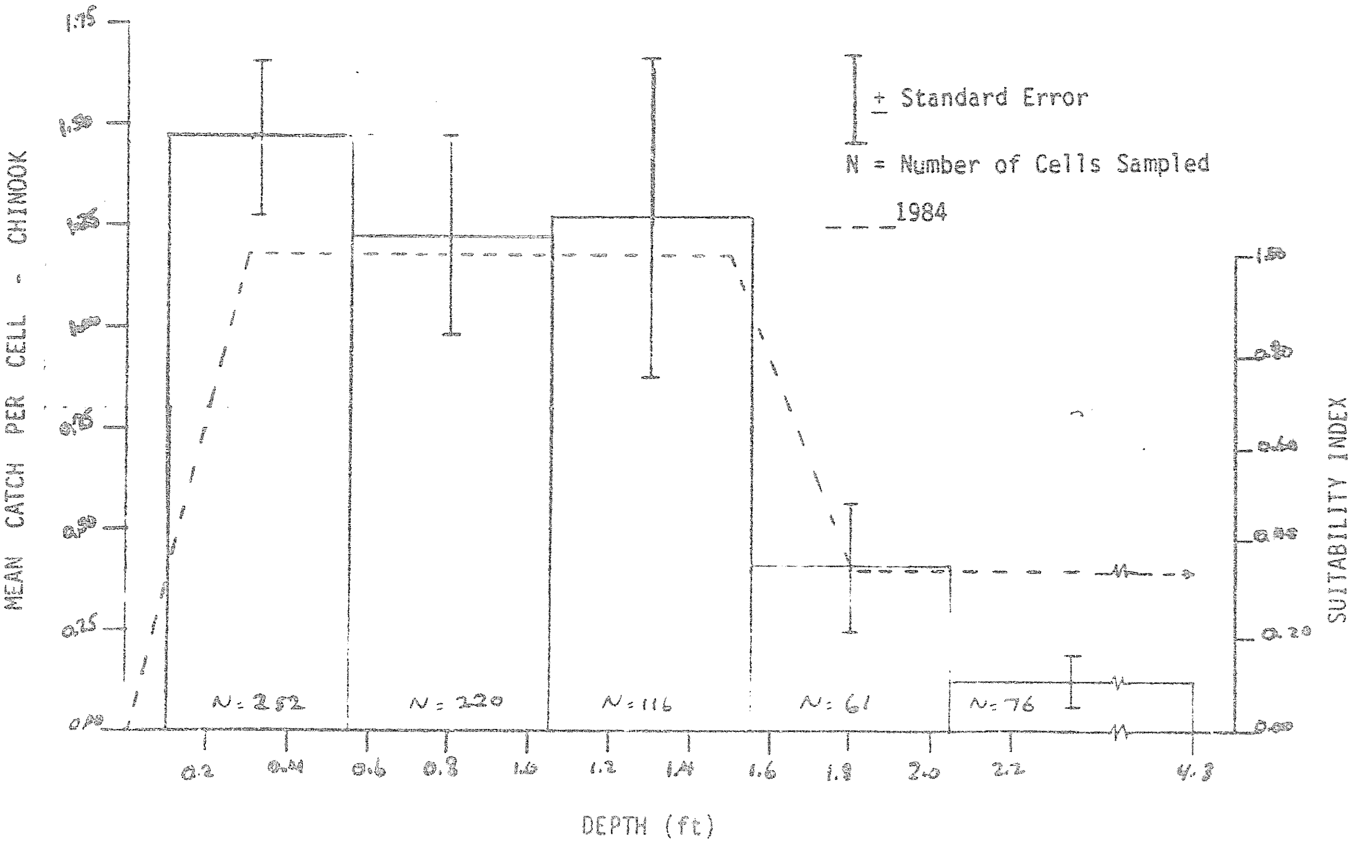
Appendix Figure A-11. Mean catch of juvenile chinook salmon per cell by depth intervals (bars) in turbid water of the lower Susitna River, 1984 and fitted suitability index (line) developed for the middle Susitna River, 1983.

In 1983 there was only one turbid cell sampled with a depth of 0.1 feet and therefore the value of cells with this depth could not be evaluated. For purposes of IFIM modelling, this depth was assigned a suitability of 0, while in the RJHAB model data this depth did not occur. In turbid water, 21 cells of 0.1 depth were fished in 1984 and the mean catch was 0.5 chinook juveniles per cell. These data suggest that under turbid conditions the value of these shallow cells is greater than 0. A suitability criteria line was fit to the 1984 turbid water depth data by first adjusting for the effects of velocity (Appendix Figure A-12). The optimum depth ranged from 0.3 to 1.5 fps.

Once all the criteria were modified, correlations were calculated between catch transformed by natural log (x + 1) and the composite weighting factor calculated by multiplying the suitabilities for velocity, cover, and depth together. The correlation was 0.33, and if depth were removed the correlation dropped to 0.28. If cover, on the other hand were removed from the composite weighting factor, the correlation increased to 0.36. Intuitively, since instream cover has value in turbid water, it seemed reasonable to keep velocity, cover, and depth in the modelling.

Coho Salmon

Juvenile coho salmon suitability criteria were developed only for clear water in 1983. Very few coho were captured in macrohabitat types other than tributary mouths in the lower reach and therefore only tributary



Appendix Figure A-12. Mean catch of juvenile chinook salmon per cell by depth intervals (bars) in turbid water of the lower Susitna River, 1984. Suitability index (line) fitted by hand using professional judgement.

mouth data were used in suitability criteria comparisons. Most of the turbidities in the tributary mouths were less than 30 NTU although on two occasions, turbidities were over 100 NTU.

A total of 345 cells with complete habitat data were sampled in tributary mouths and another 2 cells with partial habitat data were sampled. Mean adjusted catch in the cells sampled was 1.2 fpc. Correlations among the values of habitat attributes and coho catch ranged to 0.43 in absolute value (Appendix Table A-5). Cover type was most highly correlated with coho catch.

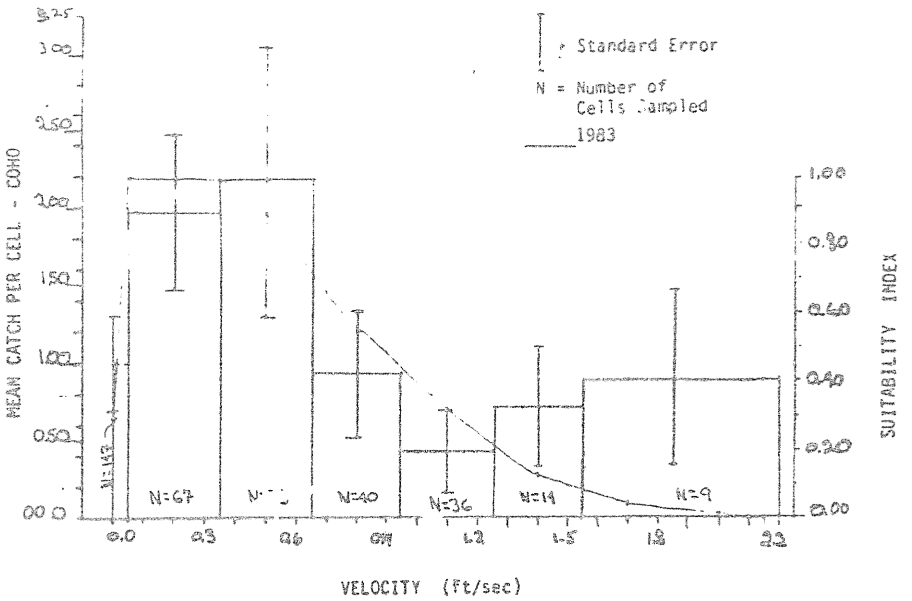
The distribution of mean coho catch per cell by velocity interval in 1984 matched quite closely with the suitability criteria derived in 1983 for the middle river (Appendix Figure A-13). The 1983 velocity criteria were therefore chosen as representative for the lower river.

A regression of coho catch to percent cover category was significant (Appendix Figure A-14). When the 1983 and 1984 data were normalized to 1.0 on the Y-axis for the 76-100% category, however, the 1983 suitability line had a much greater slope, and suitability for 0-5 percent cover in 1983 was 0.12, while in 1984 it was 0.33. After adjusting for the effect of velocity, the distribution of catches by percent cover interval appeared to be more similar to the 1983 distribution and since the sample size in 1983 was larger, the 1983 percent cover suitability relationship was chosen for use in the lower river.

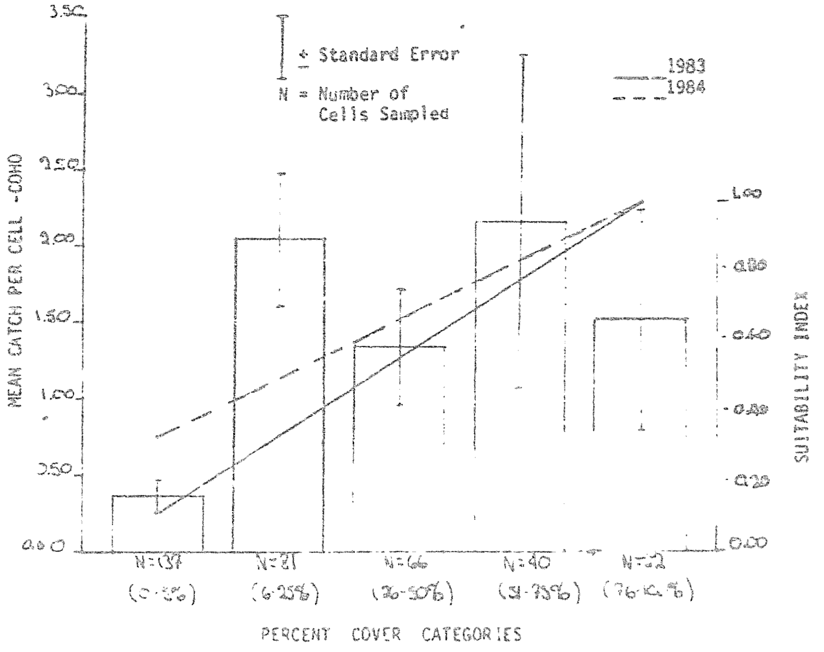
Appendix Table A-5. Kendall correlation coefficients between habitat variables and coho catch by cell (N=345) in clear water.

	Percent Cover	Cover Type	Velocity	Depth
Percent Cover	1.00			
Cover Type	0.05	1.00		
Velocity	-0.43**	0.02	1.00	
Depth	0.05	-0.09*	-0.14**	1.00
Coho	0.09*	0.23**	-0.01	0.05

* Significantly different from 0 at $p<0.05$.
** Significantly different from 0 at $p<0.01$.



Appendix Figure A-13. Mean catch of juvenile coho salmon per cell by velocity intervals (bars) in the lower Susitna River, 1984 and fitted suitability index (line) developed for the middle Susitna River, 1983.



Appendix Figure A-14. Mean catch of juvenile coho salmon per cell by percent cover category (bars) in the lower Susitna River, 1984 and comparison of fitted suitability indices (lines) calculated in 1984 and for the middle Susitna River, 1983.

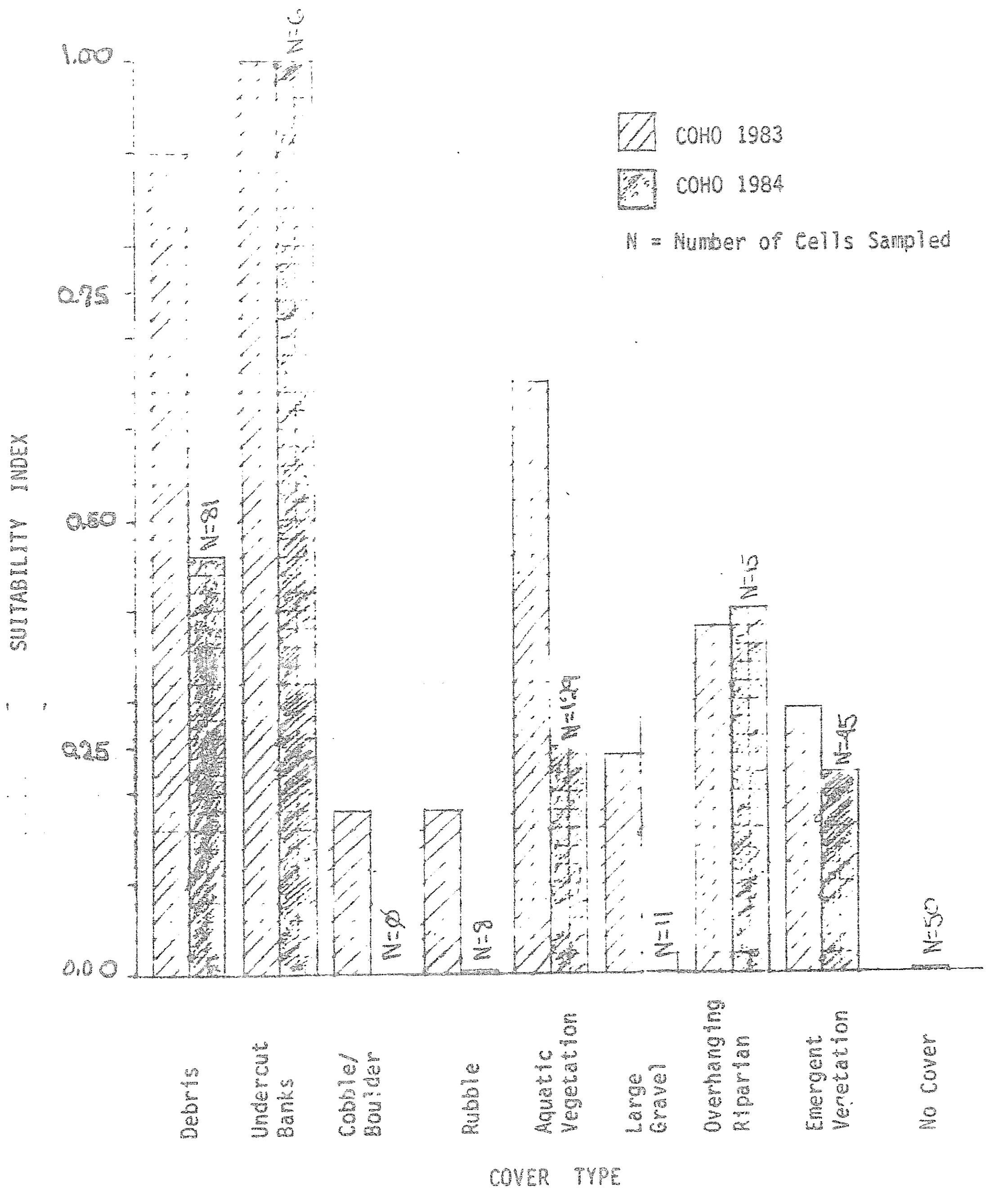
Initial calculations of the suitability of cover type for coho salmon indicated that suitabilities in the lower river were similar to those found in 1983 (Appendix Figure A-15). After adjusting for the effects of velocity and percent cover, these estimates of cover suitability for the other six cover types were revised and will be used in 1984 lower river calculations (Appendix Figure A-16). Since sample sizes for the three substrate cover types were small, the suitability of 0.10 calculated in 1983 for rubble and boulders was used for these three categories.

The distribution of CPUE's for depth was very different from that found in 1983 (Appendix Figure A-17). By adjusting for the effects of velocity, percent cover, and cover type there still was no trend in depth suitabilities and therefore depth suitability was not changed from that used in 1983.

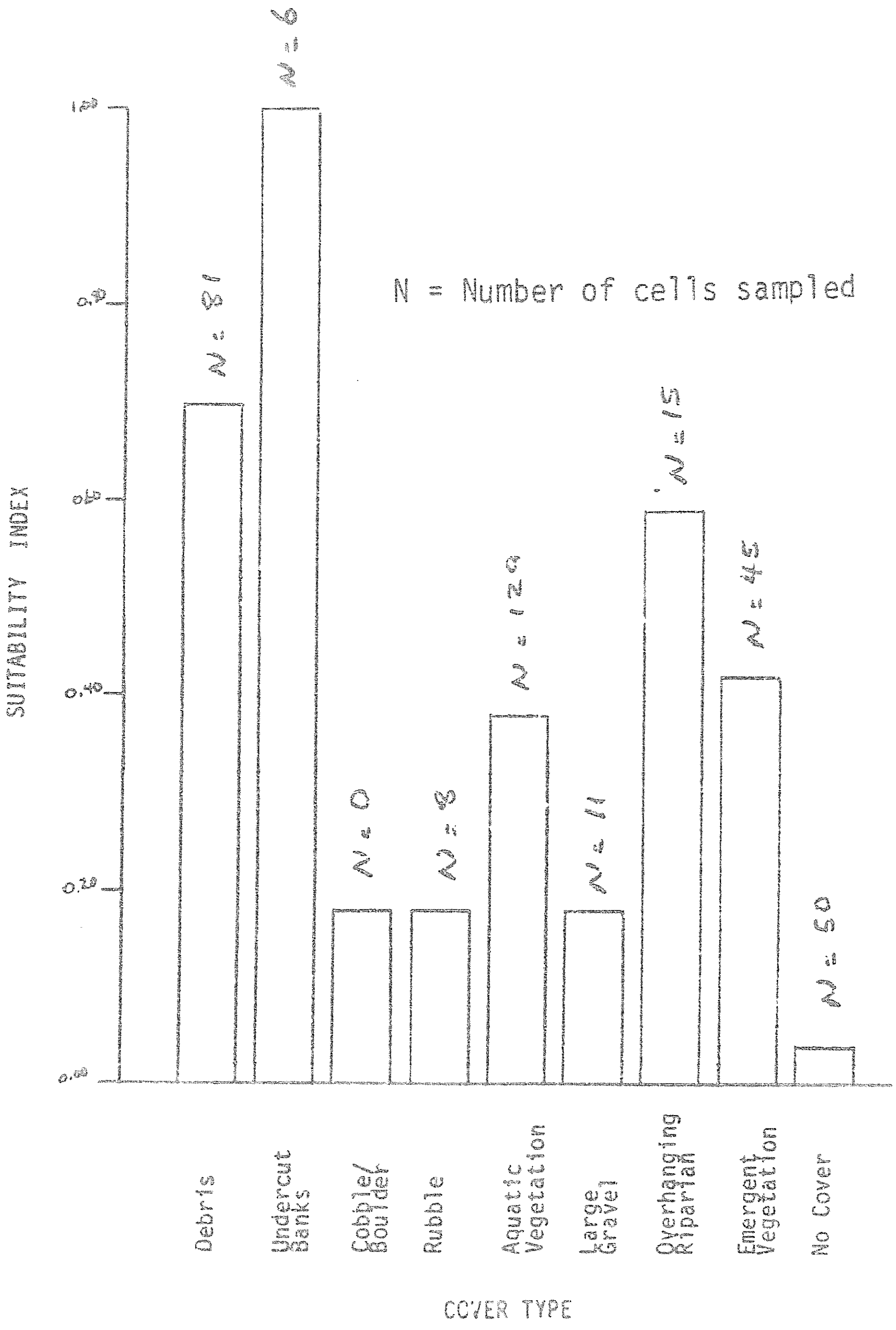
Sockeye Salmon

Juvenile sockeye salmon suitability criteria were developed by pooling data over gear type and turbidity level in 1983. Since abundance and distribution data have indicated that sockeye salmon use of lower river side channels is limited by high turbidities (Figure 18), cells with turbidities greater than 250 NTU were eliminated from suitability criteria development.

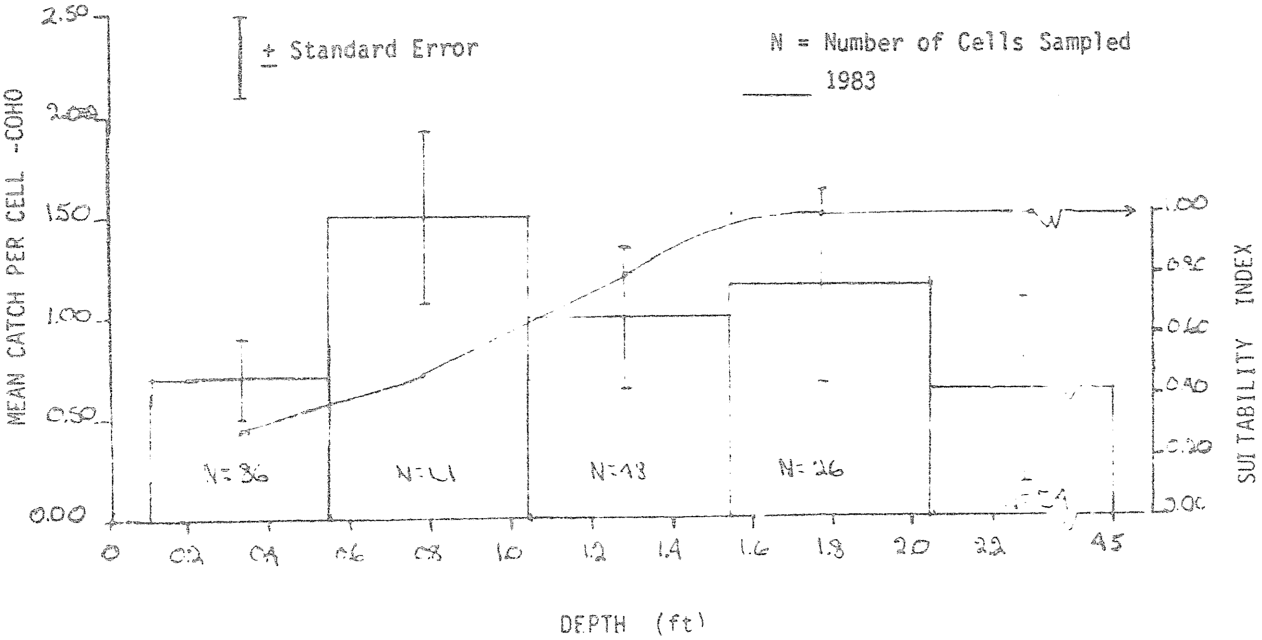
After cells with turbidities greater than 250 NTU were eliminated, 922 cells with complete habitat data were available for analysis. Sockeye



Appendix Figure A-15. Comparison of cover type suitability indices for juvenile coho salmon calculated from 1984 lower Susitna River distribution data.



Appendix Figure A-16. Cover type suitability indices for juvenile coho salmon calculated from 1984 lower Susitna River distribution data.



Appendix Figure A-17. Mean catch of juvenile coho salmon per cell by depth intervals (bars) in clear water of the lower Susitna River, 1984 and fitted suitability index (line) developed for the middle Susitna River, 1983.

were captured in 117 (12.7%) of these cells. Correlations among the habitat variables ranged to 0.65 in absolute value and velocity was most highly correlated with sockeye catch (Appendix Table A-6). In addition to these cells, partial habitat data were collected at six additional cells and these data are used in subsequent univariate histograms.

The distribution of proportional presence by velocity interval was very similar to that found in 1983 (Appendix Figure A-18). There was no use of velocities greater than 1.2 fps, however, and in 1983 there also was no use of velocities greater than 1.2 fps although sample sizes were smaller. Since no use of these velocities has been found, the lower river velocity suitability criteria were modified so that velocities greater than 1.2 fps have 0 suitability (Appendix Figure A-18).

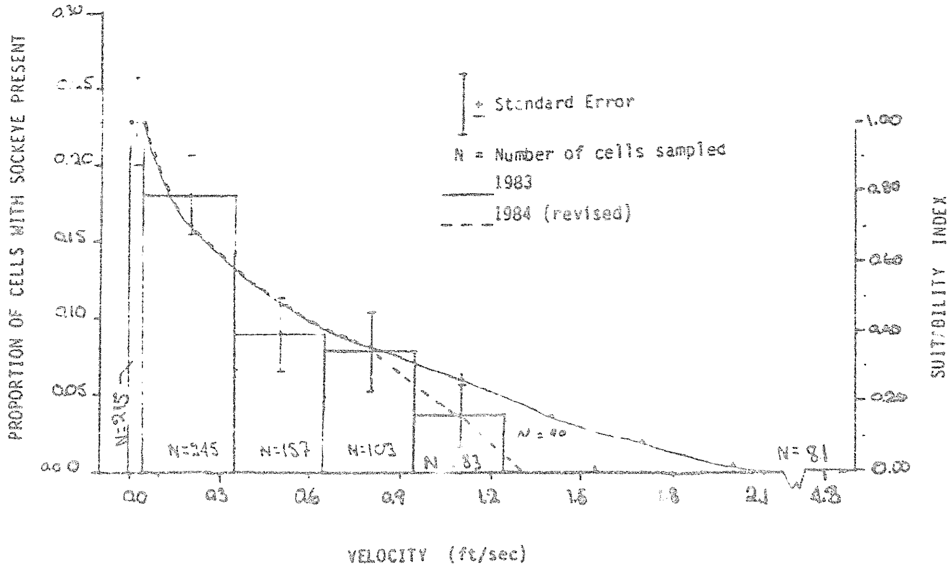
Distribution of proportional presence by percent cover categories was similar to that found in 1983 (Appendix Figure A-19). The 1983 suitability relationship was therefore selected for use in 1984.

The distribution of proportional presence by cover type categories was somewhat different than that found in 1983 (Appendix Figure A-20). Suitabilities for the cover types used in 1984 will be those developed in 1984 with the following two exceptions. Since sample sizes were small (less than 25) for the cover type categories, undercut banks and overhanging riparian vegetation, the suitabilities calculated in 1983 were averaged with the 1984 suitabilities to give a value intermediate between the two.

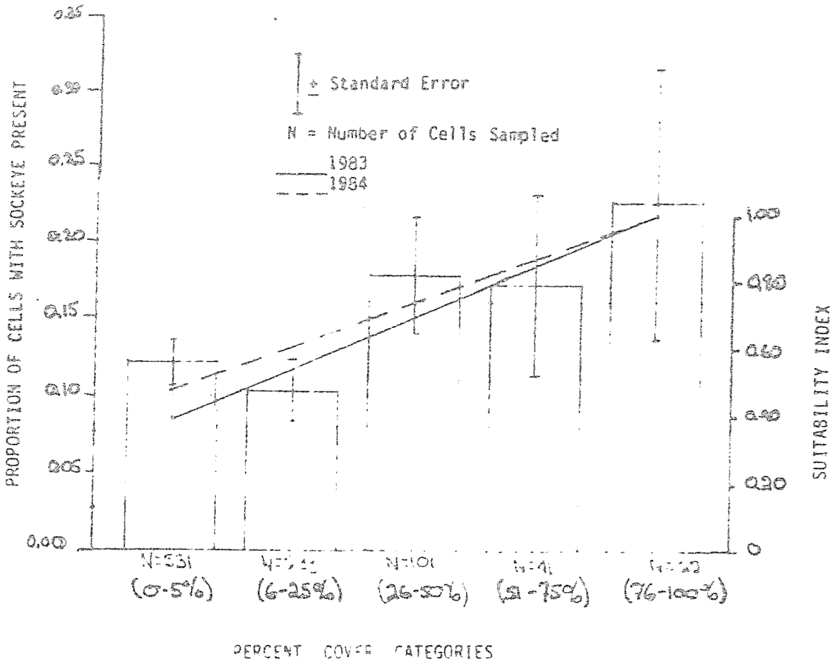
Appendix Table A-6. Kendall correlation coefficients between habitat variables and sockeye catch by cell (N = 922).

	Percent Cover	Cover Type	Velocity	Depth
Percent Cover	1.00			
Cover Type	0.30**	1.00		
Velocity	-0.18**	0.65**	1.00	
Depth	0.05*	-0.01	0.07**	1.00
Sockeye	0.04	-0.06*	-0.21**	0.02

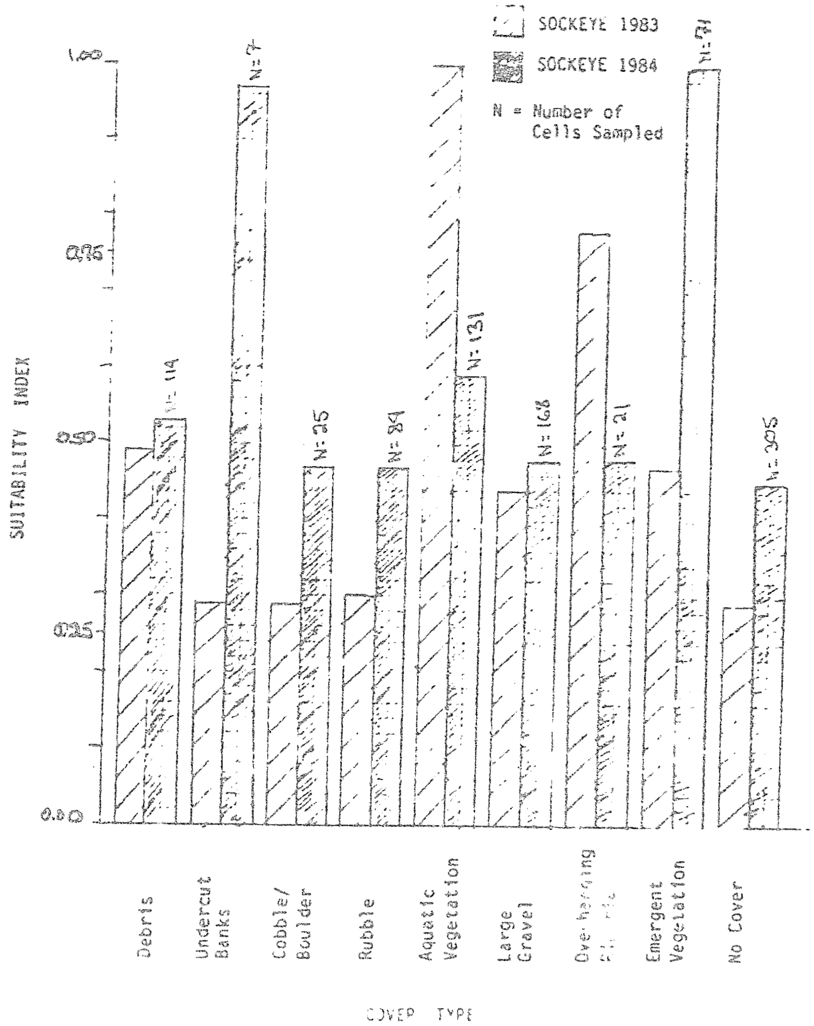
* Significantly different from 0 at $p<0.05$.
** Significantly different from 0 at $p<0.01$.



Appendix Figure A-18. Proportion of cells with juvenile sockeye salmon present by velocity intervals (bars) in the lower Susitna River, 1984 and fitted suitability index (line) developed for the middle Susitna River, 1983 and revised in 1984 for the lower river using professional judgement.



Appendix Figure A-19. Proportion of cells with juvenile sockeye salmon present by percent cover category (bars) in the lower Susitna River, 1984 and comparison of fitted suitability indices (lines) calculated in 1984 and for the middle Susitna River, 1983.



Appendix Figure A-20. Comparison of cover type suitability indices for juvenile sockeye salmon calculated from 1984 lower Susitna River distribution data and 1983 middle Susitna River distribution data.

No trend was noted in the 1984 depth distribution data and therefore no suitability criteria were fit to these data (Appendix Figure A-21). Of the 20 cells sampled with 0.1 ft depth, fish were sampled in 2 suggesting that this depth does have value. Therefore any depth will be assumed to have a suitability of 1.

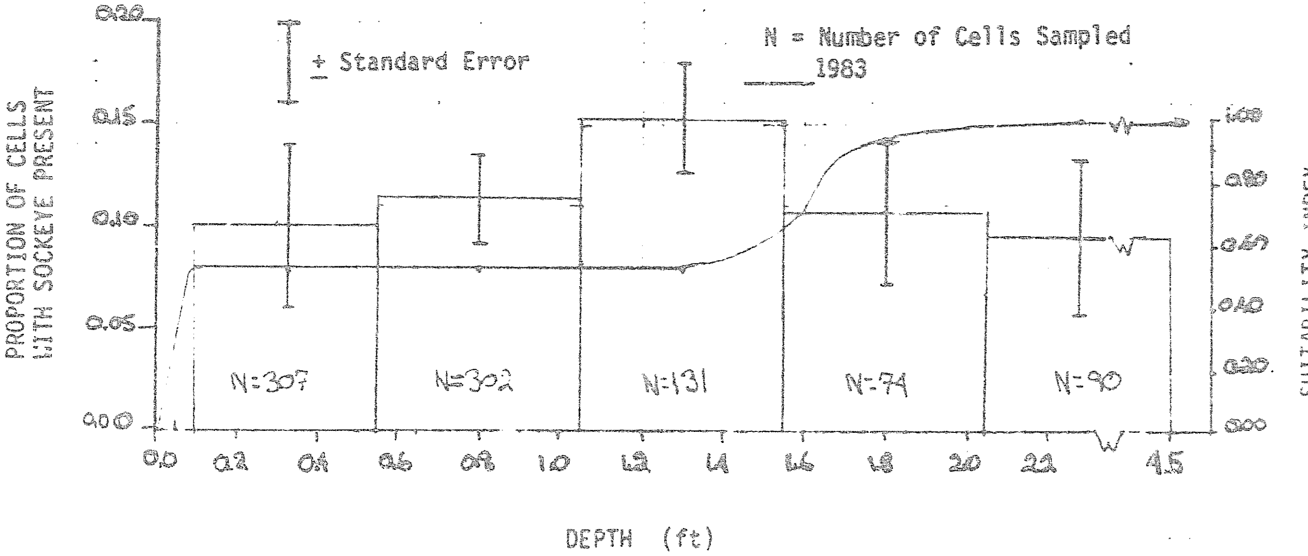
Composite weighting factor intervals calculated by multiplying cover and velocity suitabilities together were associated with proportional presence of sockeye salmon (Appendix Table A-7).

Appendix Table A-7. Proportional presence of sockeye salmon associated with the composite weighting factor calculated by multiplying velocity and cover suitabilities together.

Composite Weighting Factor Interval	Total Number of Cells	Proportion With Fish Present	Chi-Square
0 - 0.06	244	0.02	$\chi^2 = 55.3$
0.07 - 0.11	213	0.08	
0.12 - 0.19	228	0.17	$p < 0.001$
0.20 - 1.00	241	0.23	

Chum Salmon

Juvenile chum salmon suitability criteria were developed by pooling data over gear type and turbidity in 1983. Abundance and distribution data indicate that chum salmon use of lower river side channels is limited by high turbidities (Figure 15). Cells with turbidities greater than 200 NTU were eliminated from suitability criteria development. Also, since



Appendix Figure A-21. Proportion of cells with juvenile sockeye salmon present by depth intervals (bars) in the lower Susitna River, 1984 and fitted suitability index (line) developed for the middle Susitna River, 1983.

most chum salmon outmigrate before July 16, only data collected before this date were retained for suitability criteria analysis.

The number of cells available for analysis of chum distribution totaled 249 after elimination of the cells outlined above. Chum salmon were captured in 98 (39.4%) of these cells. Correlations among the habitat variables and chum fry catch ranged to 0.32 in absolute value (Appendix Table A-8). Partial habitat data were collected at two additional cells.

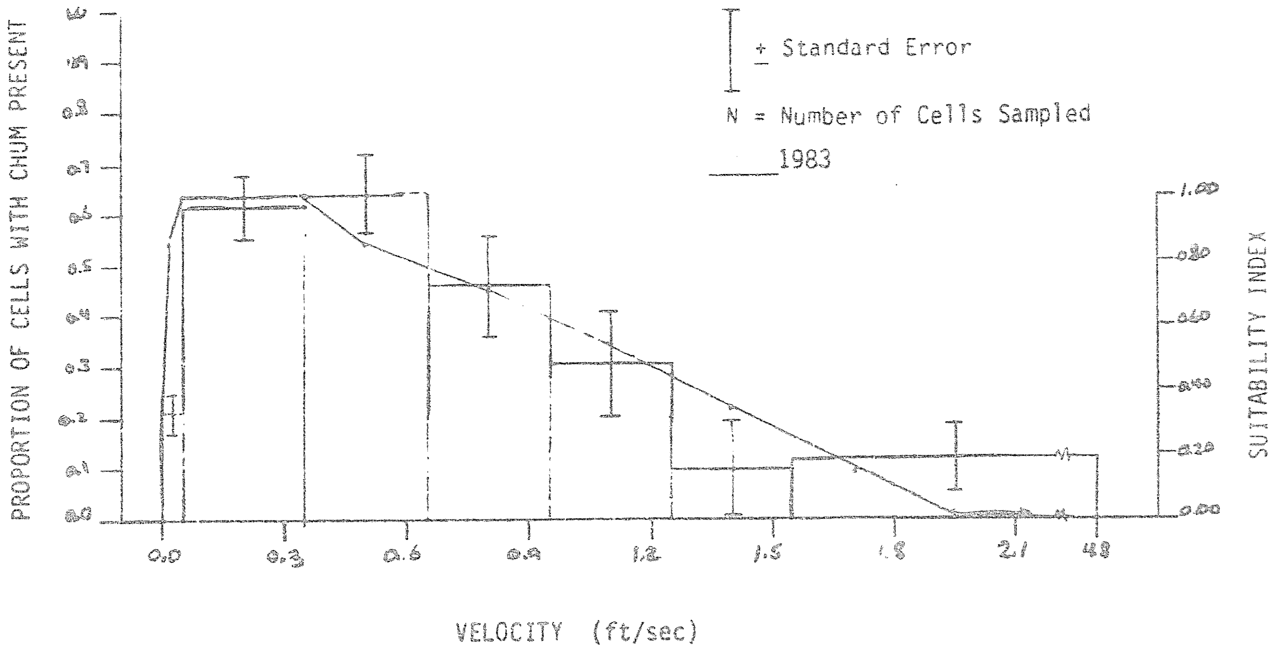
The chum salmon distribution by velocity interval in 1984 was very similar to that found in 1983 (Appendix Figure A-22). Therefore, the suitability criteria for chum salmon developed in 1983 was selected for use in 1984.

In 1983, the relationship of chum salmon use to both percent cover and cover type was the weakest of any of the four species. In 1984, the 0-5% cover category and the "no cover" type had the highest proportional presence within their respective distributions (Appendix Figures A-23 and A-24). These data indicate that chum salmon fry do not orient to cover during rearing. Even if velocity suitability is adjusted for, no real trends in percent cover and cover type utilization were noted, although large gravel and rubble were used slightly more than was the "no cover" type. Since there were no trends, cover type and percent cover will not be used in the 1984 analysis of chum habitat use.

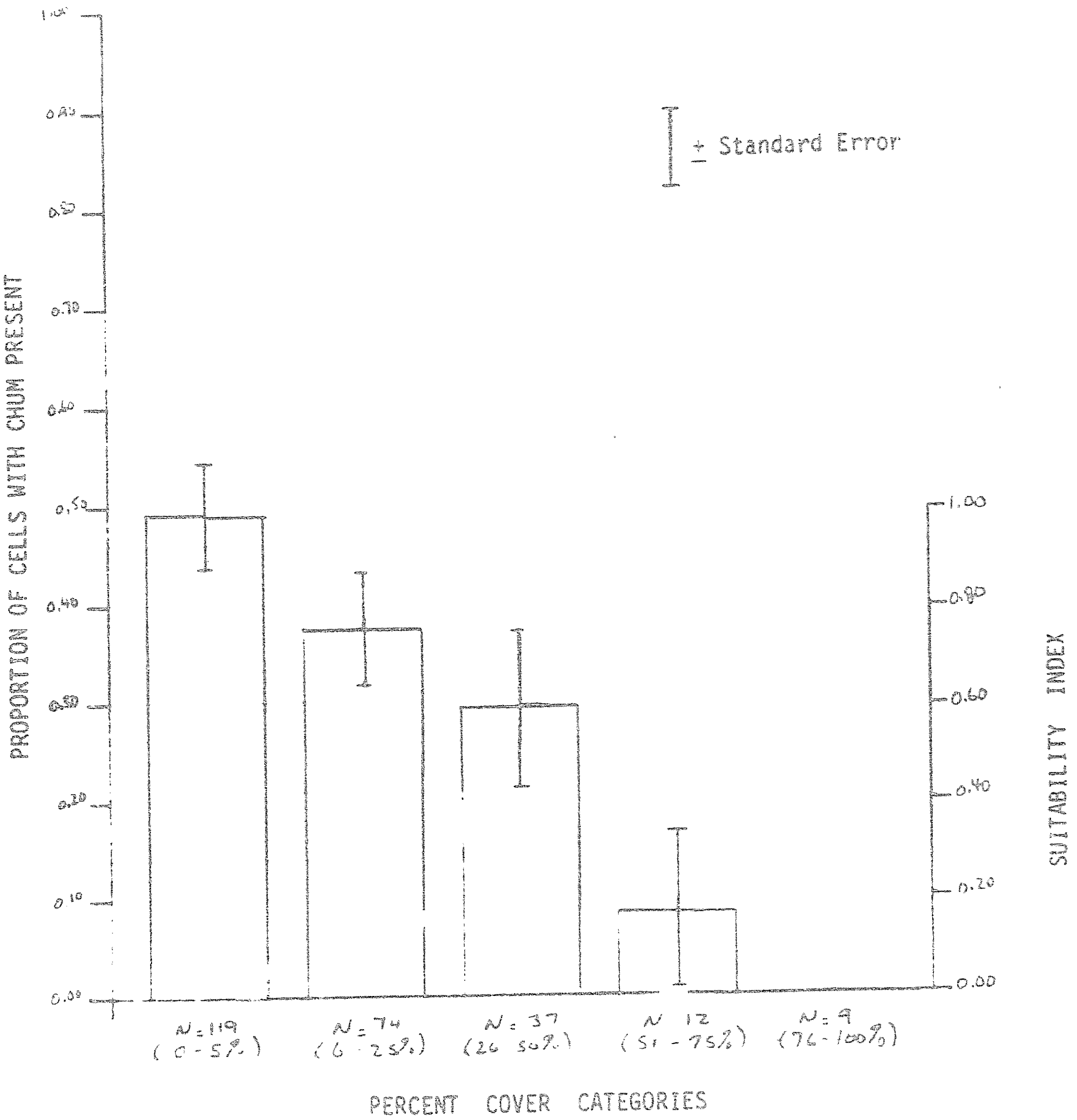
Appendix Table A-8. Kendall correlation coefficients between habitat variables and chum catch by cell (N=249) for all gear types, turbidity below 200 NTU.

	Percent Cover	Cover Type	Velocity	Depth	Chum
Percent Cover	1.00				
Cover Type	0.13**	1.00			
Velocity	-0.25**	0.15**	1.00		
Depth	-0.05	-0.03	0.07	1.00	
Chum	-0.20**	-0.07	-0.04	-0.32**	1.00

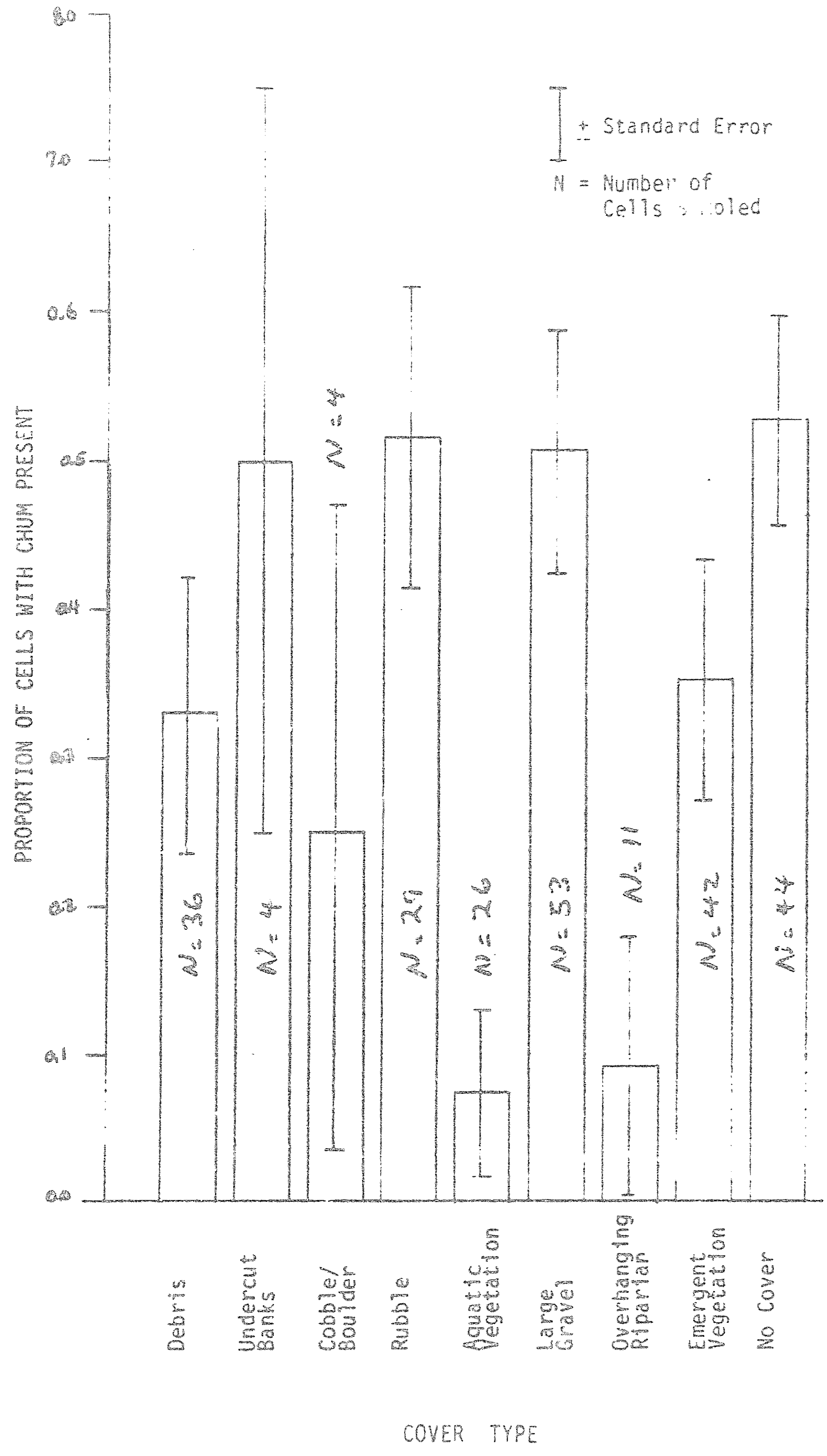
* Significantly different from 0 at $p < 0.05$.
** Significantly different from 0 at $p < 0.01$.



Appendix Figure A-22. Proportion of cells with juvenile chum salmon present by velocity intervals (bars) in the lower Susitna River, 1984 and fitted suitability index (line) developed for the middle Susitna River, 1983.



Appendix Figure A-23. Proportion of cells with juvenile chum salmon present by percent cover category (bars) in the lower Susitna River, 1984 and fitted suitability index (line) calculated for the middle Susitna River, 1983.



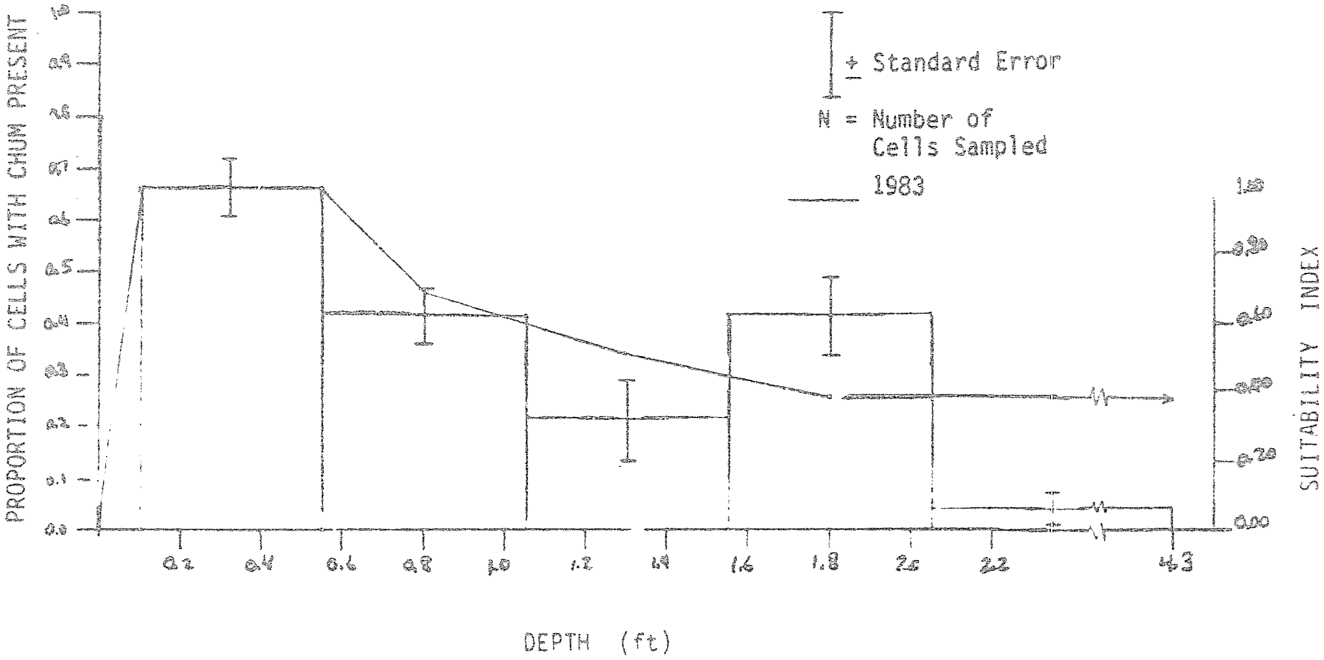
Appendix Figure A-24. Proportion of cells with juvenile chum salmon present by cover type (bars) in the lower Susitna River, 1984.

The distribution of chum proportional presence by depth intervals in 1984 was similar to that found in the 1983 studies (Appendix Figure A-25). Since the distributions were similar, the criteria fit in 1983 was used to test for the value of depth in increasing the associations with chum catch. Therefore velocity was first used alone and then with depth to form categories which were associated with chum proportional presence.

Although composite weighting factors calculated by velocity alone and velocity and depth together were both significantly associated with chum proportional presence, the composite weighting factor calculated by depth and velocity together seemed to fit better (Appendix Table A-9). Therefore both velocity and depth suitabilities will be used to model chum salmon habitat.

Summary

A summary table of revisions of the middle river suitability criteria for use in the lower river reveals that about half the criteria were not changed or changed only slightly (Appendix Table A-10). The velocity and percent cover relationships were often not changed while the depth and cover type criteria have often been modified greatly. Point specific values for all the suitability criteria developed for use in the lower river are presented in Appendix Table A-11.



Appendix Figure A-25. Proportion of cells with juvenile chum salmon present by depth intervals (bars) in the lower Susitna River, 1984 and fitted suitability index (line) developed for the middle Susitna River, 1983.

Appendix Table A-9. Proportional presence of chum salmon fry associated with several composite weighting factors.

Composite Weighting Factor Calculation	Composite Weighting Factor Interval	Total Number of Cells	Proportion With Fish Present	Chi-Square
Velocity	0 - 0.55	49	0.20	$\chi^2 = 34.3$
	0.60 - 0.81	51	0.49	$p < 0.001$
	0.86	82	0.24	
	0.93 - 1.00	69	0.64	
Velocity*Depth	0 - 0.32	71	0.10	
	0.34 - 0.49	54	0.43	$\chi^2 = 46.8$
	0.50 - 0.73	60	0.42	$p < 0.001$
	0.76 - 1.00	66	0.67	

Appendix Table A-10. Summary of revisions of 1983 middle river juvenile salmon criteria for use in the lower Susitna River, 1984.

Species	Velocity	Percent Cover	Cover Type	Depth
Chinook (clear)	Turbid chinook criteria developed in 1983 used	Same as 1983	Modified	Modified
Chinook (turbid)	Same as 1983	Same as 1983	Modified	Modified
Coho	Same as 1983	Same as 1983	Modified	Same as 1983
Sockeye	Modified Slightly	Same as 1983	Modified Slightly	Modified Slightly
Chum	Same as 1983	Modified (Set to 1.0)	Modified (Set to 1.0)	Modified

Appendix Table A-11. Suitability indices for juvenile salmon for velocity, depth, and cover in the lower Susitna River, 1984.

VELOCITY

Chinook		Coho		Sockeye		Chum	
Velocity (ft/sec)	Suitability	Velocity (ft/sec)	Suitability	Velocity (ft/sec)	Suitability	Velocity (ft/sec)	Suitability
0.00	0.42	0.00	0.29	0.00	1.00	0.00	0.86
0.05	1.00	0.05	1.00	0.05	1.00	0.05	1.00
0.35	1.00	0.35	1.00	0.20	0.71	0.35	1.00
0.50	0.80	0.50	0.88	0.50	0.48	0.50	0.87
0.80	0.38	0.80	0.55	0.80	0.35	0.80	0.70
1.10	0.25	1.10	0.32	1.10	0.14	1.10	0.56
1.40	0.15	1.40	0.12	1.30	0.00	1.40	0.37
1.70	0.07	1.70	0.04			1.70	0.15
2.00	0.02	2.00	0.01			2.00	0.03
2.30	0.01	2.10	0.00			2.10	0.00
2.60	0.00						

DEPTH

Chinook (turbid)		Chinook (clear)		Coho		Sockeye		Chum	
Depth (ft)	Suitability	Depth (ft)	Suitability	Depth (ft)	Suitability	Depth (ft)	Suitability	Depth (ft)	Suitability
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.10	0.29	0.15	0.00	0.14	0.00	0.10	1.00	0.10	1.00
0.30	1.00	0.20	0.25	0.15	1.00	10.00	1.00	0.50	1.00
1.50	1.00	1.50	0.25	10.00	1.00			0.80	0.68
1.80	0.33	1.80	0.80					1.30	0.50
10.00	0.33	2.10	1.00					1.80	0.38
		10.00	1.00					10.00	0.38

Appendix Table A-11 (Continued)

Cover Type	Percent Cover	Chinook (turbid)	Chinook (clear)	Coho	Sockeye	Chum
No cover	0-5%	0.15	0.01	0.00	0.18	1.00
Emergent Vegetation	0-5%	0.23	0.11	0.05	0.39	1.00
	6-25%	0.30	0.33	0.14	0.54	1.00
	26-50%	0.33	0.55	0.24	0.70	1.00
	51-75%	0.39	0.78	0.33	0.85	1.00
	76-100%	0.40	1.00	0.42	1.00	1.00
Aquatic Vegetation	0-5%	0.23	0.10	0.04	0.23	1.00
	6-25%	0.30	0.32	0.13	0.32	1.00
	26-50%	0.33	0.53	0.21	0.41	1.00
	51-75%	0.39	0.76	0.30	0.50	1.00
	76-100%	0.40	0.97	0.38	0.59	1.00
Debris or Deadfall	0-5%	0.15	0.05	0.08	0.21	1.00
	6-25%	0.20	0.17	0.24	0.29	1.00
	26-50%	0.20	0.28	0.39	0.37	1.00
	51-75%	0.20	0.39	0.55	0.45	1.00
	76-100%	0.20	0.50	0.70	0.53	1.00
Overhanging Riparian Vegetation	0-5%	0.15	0.04	0.07	0.25	1.00
	6-25%	0.20	0.13	0.20	0.34	1.00
	26-50%	0.20	0.21	0.33	0.44	1.00
	51-75%	0.20	0.30	0.46	0.54	1.00
	76-100%	0.20	0.38	0.59	0.63	1.00
Undercut Banks	0-5%	0.23	0.11	0.12	0.25	1.00
	6-25%	0.30	0.33	0.34	0.34	1.00
	26-50%	0.33	0.55	0.56	0.44	1.00
	51-75%	0.39	0.78	0.78	0.54	1.00
	76-100%	0.40	1.00	1.00	0.63	1.00

Appendix Table A-11 (Continued)

Cover Type	Percent Cover	Chinook (turbid)	Chinook (clear)	Coho	Sockeye	Chum
Large Gravel (1-3")	0-5%	0.15	0.02	0.02	0.18	1.00
	6-25%	0.20	0.08	0.06	0.24	1.00
	26-50%	0.20	0.13	0.10	0.32	1.00
	51-75%	0.20	0.18	0.14	0.38	1.00
	76-100%	0.20	0.23	0.18	0.45	1.00
Rubble (3-5")	0-5%	0.15	0.03	0.02	0.18	1.00
	6-25%	0.20	0.10	0.06	0.24	1.00
	26-50%	0.20	0.17	0.10	0.32	1.00
	51-75%	0.20	0.23	0.14	0.38	1.00
	76-100%	0.20	0.30	0.18	0.45	1.00
Cobble or Boulder (>5")	0-5%	0.15	0.03	0.02	0.18	1.00
	6-25%	0.20	0.11	0.06	0.24	1.00
	26-50%	0.20	0.18	0.10	0.32	1.00
	51-75%	0.20	0.25	0.14	0.38	1.00
	76-100%	0.20	0.32	0.18	0.45	1.00

DISCUSSION

Chinook Salmon

The turbid water velocity criteria developed in 1983 were used for both clear and turbid chinook distributions in the lower river in 1984. The reason that there was no shift in velocity optimum from clear to turbid water may be due to several factors. In the middle river, substrate is much larger and therefore, on the average, chinooks may find higher velocities as suitable as there is always some substrate cover to hide under or behind. In the lower river, however, very little substrate cover is present and therefore chinook use lower velocity water much more.

In the lower river, cover suitabilities were also found to be somewhat different. Part of this difference may be due to the actual cover in cover type categories being of a different type. For instance, the aquatic vegetation in Caswell Creek which harbored large numbers of chinook fry was not present in any of the sampled streams in the middle river. Also the debris cover type in the lower river was often much more silted in than in the middle river and therefore less suitable. The primary cover type is associated with a variety of secondary cover types and it is likely that, on the average, secondary cover types associated with a primary cover type in the lower river are different than the secondary cover types most common in the middle river. If these secondary cover types are more suitable for fish then they might raise the suitability of the primary cover type.

Most notable in the analysis of chinook suitability criteria was the effect of depth upon the distribution of chinook salmon. In clear water in the lower river, chinook salmon found deep water much more suitable (Appendix Figure A-7). This is probably due to the tributaries in the lower river having a turbidity of approximately 10 to 20 NTU and therefore depth might have a cover value in deeper waters. In the upper river much of the data was collected in Portage Creek and Indian River and other areas where the turbidity was usually less than 5 NTU and depth would not provide cover at depths which can be sampled. Sometimes juvenile salmon thought to be chinook fry could be seen feeding on the surface in tributary mouths such as Rolly Creek where depths were greater than 5.0 ft.

In turbid water, on the other hand, depths greater than 1.5 ft were less suitable than shallower cells (Appendix Figure A-11). This trend was also found in 1983 although discounted at the time. This difference may be due to fish reacting to high suspended solid concentrations by staying near the surface (Wallen 1951 as cited in Beauchamp et al. 1983). It also could be due to fish not being able to feed at depths where there is very little light, whereas in shallower water a small amount of light may enable fish to feed.

Coho Salmon

The suitability criteria developed for coho salmon juveniles in the middle river were modified only slightly in cover suitability for use in the lower reach. The fit of the data to the composite weighting factor was not very high (r=0.33) however, which suggests that coho respond to other factors than those studied. These factors might include food supply or seasonal movements.

Sockeye Salmon

Since sockeye normally rear in lakes, it is not surprising that velocity is one of the most important variables affecting their distribution. In both the lower and upper river, no sockeye have been captured in cells with velocities greater than 1.2 ft/sec. The highest catches of sockeye were made at Beaver Dam Slough, which is always a backwater with minimal velocity.

Instream cover does have some importance in juvenile sockeye salmon distribution and it appears they also use turbidity as cover (Section 3.2.4). Cover type suitabilities were somewhat different in the lower reach than in the middle reach, perhaps due to differences in the primary or secondary cover type within the categories between the two reaches.

Chum Salmon

Chum salmon, in contrast to the other species, did not show any positive response to the presence of cover. The response shown, which is a negative one, is probably partly a function of gear efficiency. They did respond to velocity and depth, however. The lack of relationship with cover may partly be a function of schooling behavior which reduces the need for cover. It is also possible that since chum fry rear in fresh water for only a short period they usually are searching for food instead of hiding in cover.

The heavier use of shallower depths by chum juveniles found in both years is due to unknown factors. This could be due to a use of shallow depths and low velocities in side channels where some of the suspended solids may settle out. Perhaps these areas also are somewhat warmer than adjacent areas as the sunlight strikes the substrate and is absorbed heating the water above.

LITERATURE CITED

Beauchamp, D.A., M.F. Sheperd, and G.B. Pauley. 1983. Species profiles: Life histories and environmental requirements (Pacific Northwest) chinook salmon. U.S. Department of the Interior, Fish and Wildlife Service. FWS/OBS-83/1.

Bovee, K.D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Instream Flow Information Paper. No. 12. U.S. Fish and Wildlife Service. FWS/035-82/26.

E. Woody Trihey and Associates and Woodward-Clyde Consultants. 1985. Instream flow relationships report. Vol. I. Working Draft. Alaska Power Authority Susitna Hydroelectric Project. Report for Harza-Ebasco Susitna Joint Venture, Anchorage, AK. 1 vol.

Hale, S.S., P.M. Suchanek, and D.C. Schmidt. 1984. Modelling of juvenile salmon and resident fish habitat. Part 7 in Schmidt, D.C., S.S. Hale, D.L. Crawford, and P.M. Suchanek (eds.). 1984. Resident and juvenile anadromous fish investigations (May - October 1983). Susitna Hydro Aquatic Studies. Report No. 2. Alaska Department of Fish and Game. Anchorage, Alaska.

Marshall, R.P., P.M. Suchanek, and D.C. Schmidt. 1984. Juvenile salmon rearing habitat models. Part 4 in Schmidt, D.C., S.S. Hale, D.L. Crawford, and P.M. Suchanek, (eds.). 1984. Resident and juvenile anadromous fish investigations (May - October 1983). Susitna Hydro Aquatic Studies. Report No. 2. Alaska Department of Fish and Game. Anchorage, Alaska.

Nie, N.H., C.H. Hull, J.G. Jenkins, K. Steinbrenner, and D.H. Bent. 1975. Statistical package for the social sciences. 2nd ed. McGraw-Hill Book Co., New York, USA.

Suchanek, P.M., R.P. Marshall, S.S. Hale, and D.C. Schmidt. 1984. Juvenile salmon rearing suitability criteria. Part 3 in Schmidt, D.C., S.S. Hale, D.L. Crawford, and P.M. Suchanek (eds.). 1984. Resident and juvenile anadromous fish investigations (May - October 1983). Susitna Hydro Aquatic Studies. Report No. 2. Alaska Department of Fish and Game. Anchorage, Alaska.

Wallen, I.E. 1951. The direct effect of turbidity on fishes. Doctoral dissertation. University of Michigan, Ann Arbor, Michigan, USA.

APPENDIX B

MODELLED SITE TURBIDITIES, JUVENILE SALMON CATCHES, AREAS, SIDE CHANNEL FLOWS, WEIGHTED USABLE AREAS, AND HABITAT INDICES

This appendix is a compilation of data arranged into a number of graphs and tables. The first three tables (Appendix Tables B-1, B-2, and B-3) present: modelled side channel turbidities; modelled site catches and CPUE's of juvenile salmon; and lengths of RJHAB model sites; respectively. Appendix Table B-4 presents modelled side channel flows as a function of mainstem discharge at 3,000 cfs increments.

Next weighted usable areas and habitat indices are presented by species in the following order:

Chinook Salmon

Tabulation of weighted usable areas and habitat indices for 18 sites (Appendix Table B-5).

Graphs of weighted usable area versus mainstem discharge for sites not presented in Section 3.3:

Caswell Creek Mouth	(Appendix Figure B-1)
Beaver Dam Slough	(Appendix Figure B-1)
Hooligan Side Channel	(Appendix Figure B-2)
Bearbait Side Channel	(Appendix Figure B-2)
Last Chance Side Channel	(Appendix Figure B-3)
Rustic Wilderness Side Channel	(Appendix Figure B-3)
Island Side Channel	(Appendix Figure B-4)
Mainstem West Bank	(Appendix Figure B-4)
Goose 2 Side Channel	(Appendix Figure B-5)

Circular Side Channel	(Appendix Figure B-5)
Sauna Side Channel	(Appendix Figure B-6)
Bearbait Side Channel	(Appendix Figure B-6)
Sunset Side Channel	(Appendix Figure B-7)
Sunrise Side Channel	(Appendix Figure B-7)
Trapper Creek Side Channel	(Appendix Figure B-8)

Coho Salmon

Tabulation of weighted usable areas and habitat indices for three sites (Appendix Table B-6).

Chum Salmon

Tabulation of weighted usable areas and habitat indices for 15 sites (Appendix Table B-7).

Graphs of weighted usable area versus mainstem discharge for sites not presented in Section 3.3:

Hooligan Side Channel	(Appendix Figure B-9)
Kroto Slough Head	(Appendix Figure B-9)
Bearbait Side Channel	(Appendix Figure B-10)
Island Side Channel	(Appendix Figure B-10)
Mainstem West Bank	(Appendix Figure B-11)
Goose 2 Side Channel	(Appendix Figure B-11)
Circular Side Channel	(Appendix Figure B-12)

Sauna Side Channel	(Appendix Figure B-12)
Sucker Side Channel	(Appendix Figure B-13)
Beaver Dam Side Channel	(Appendix Figure B-13)
Sunrise Side Channel	(Appendix Figure B-14)

Sockeye Salmon

Tabulation of weighted usable areas and habitat indices for seven sites (Appendix Table B-8).

Graphs of weighted usable area versus mainstem discharge for sites not presented in Section 3.3:

Caswell Creek Mouth	(Appendix Figure B-15)
Beaver Dam Slough	(Appendix Figure B-15)

Appendix Table B-1. Turbidities within modelled side channels of the lower Susitna River, June through August, 1984. Values within parentheses were calculated by inputting the overall mean for all the side channels during a given two week period.

Site	June 1-15	June 16-30	July 1-15	July 16-30	Aug 1-15	Aug 16-30	Mean
West Bank Side Channels							
Kroto Side Channel	(64)	394	(369)	272,704	784	126	388
Bear Bait Side Channel	(64)	392	284	312	328	142	254
Mainstem West Bank	(64)	(227)	(369)	368	324	324	279
Sauna Side Channel	120	(227)	496	364	244	156,256	266
Trapper Side Channel	96	576	940	470	306	608	499
Middle Side Channels							
Hooligan Side Channel	(64)	365	288	296	704	544	377
Last Chance Side Channel	(64)	(227)	296	672	352	576	365
Island Side Channel	55	126	334	336	228	(209)	215
Circular Side Channel	89	122	592	288	216	78,304	241
Sucker Side Channel	26	64	276	118	292	44,163	140
Sunrise Side Channel	18	112	180	88	280	44,124	121
East Bank Side Channel							
Rustic Wilderness Side Channel	(64)	120	130	160	196	38	118
Goose Side Channel	41	140	384	300	188	64,244	194
Sunset Side Channel	(64)	(227)	(369)	114	100	41,146	152
Beaver Dam Side Channel	(64)	90	224	134	170	150	139
OVERALL MEAN	64	227	369	312	314	209	

Appendix Table B-2. Catch and catch per cell (CPUE) of juvenile salmon within lower Susitna River sampling sites, 1984. Cells have been standardized to an area of 300 ft^2.

Site	No. of cells sampled	Chinook catch	Coho catch	Chum catch	Sockeye catch	Chinook CPUE	Coho CPUE	Chum CPUE	Sockeye CPUE
Hooligan Side Channel	77	21	0	78	3	0.27	0.00	1.01	0.04
Eagles Nest Side Channel	30	5	0	0	0	0.17	0.00	0.00	0.00
Kroto Slough Head	56.5	4	0	1	2	0.07	0.00	0.02	0.04
Rolly Creek Mouth	91	53	39	2	87	0.58	0.43	0.02	0.96
Bearbait Side Channel	49.4	4	0	3	0	0.08	0.00	0.06	0.00
Last Chance Side Channel	50	0	0	1	0	0.00	0.00	0.02	0.00
Rustic Wilderness Side Channel	65	55	1	11	0	0.85	0.02	0.17	0.00
Caswell Creek Mouth	74	419	245	0	21	5.66	3.31	0.00	0.28
Island Side Channel	82	39	1	74	2	0.48	0.01	0.90	0.02
Mainstem West Bank	45	7	0	0	1	0.16	0.00	0.00	0.02
Goose 2 Side Channel	82	74	1	30	2	0.90	0.01	0.37	0.02
Circular Side Channel	88	28	0	114	6	0.32	0.00	1.30	0.07
Sauna Side Channel	44	3	0	41	5	0.07	0.00	0.93	0.11
Sucker Side Channel	77.1	23	0	112	15	0.30	0.00	1.45	0.19
Beaver Dam Slough	83	14	67	0	101	0.17	0.81	0.00	1.22
Beaver Dam Side Channel	102	153	9	23	71	1.50	0.09	0.23	0.70
Sunset Side Channel	73.5	121	0	0	12	1.65	0.00	0.00	0.16
Sunrise Side Channel	73	120	1	43	8	1.64	0.01	0.59	0.11
Birch Creek Slough	96	23	71	45	29	0.24	0.74	0.47	0.30
Trapper Creek Side Channel	96	43	2	20	4	0.45	0.02	0.21	0.04
SUBTOTAL	1434.5	1209	437	598	369	0.84	0.30	0.42	0.26
Opportunistic sites	163.7	249	5	10	43	1.52	0.03	0.06	0.26
TOTAL	1598.2	1458	442	608	412	0.91	0.28	0.38	0.26

Appendix Table B-3. Lengths of RJHAB model sites in the lower Susitna River, 1984.

Site	Length (feet)
Hooligan Side Channel	1377
Eagle's Nest Side Channel	490
Kroto Slough Head	748
Rolly Creek Mouth	1437
Bearbait Side Channel	496
Last Chance Side Channel	961
Rustic Wilderness Side Channel	1169
Caswell Creek Mouth	712
Island Side Channel	769
Goose 2 Side Channel	1030
Sucker Side Channel	658
Beaver Dam Slough	436
Beaver Dam Side Channel	608
Sunrise Side Channel	1003
Birch Creek Slough	841
Trapper Creek Side Channel	968

Appendix Table B-4. Side channel flows at the 15 modelled side channels in the lower Susitna River as a function of mainstem discharge, 1984. Flows calculated from rating curves presented in Quane et al. (1985). Flows marked with an asterisk were not reliably modelled according to hydraulic criteria (Appendix D). Discharges for which NA is presented for flow are "not available" because rating curves were not developed at these discharges.

	HOOLIGAN S. C.		KROTO SLOUGH HEAD		BEARBAIT SIDE CHANNEL		LAST CHANCE S. C.		RUSTIC WILDERNESS S. C.	
MAINSTEM DISCHARGE	SITE AREA	FLOW	SITE AREA	FLOW	SITE AREA	FLOW	SITE AREA	FLOW	SITE AREA	FLOW
12000	63400	0	48200	0	3100	0	17500	0	4800	0
15000	63400	0	48200	0	3100	0	17500	0	4800	0
18000	63400	0	48200	0	3100	0	17500	0	4800	0
21000	63400	0	48200	0	3100	0	17500	0	31900	54
24000	79600	50	48200	0	3100	0	17500	1	49500	76
27000	86900	72	48200	0	3100	0	31700	3	60700	103
30000	90800	100	48200	0	3100	0	50600	5	69700	134
33000	96500	135	48500	0	3100	0	63900	8	76800	171
36000	104800	178	57900	0	5700	33	73200	13	83300	213
39000	113700	229	67900	74	10800	48	80000	21	89900	261
42000	122900	288	77500	98	14600	67	85900	31	97000	315
45000	131300	356	86800	128	17900	93	90600	46	104000	375
48000	141200	439	95.00	163	21100	125	94000	67	109000	442
51000	152000	531	102200	206	23800	166	96300	95	114000	516
54000	163000	636	106700	255	26400	217	98500	131	117400	596
57000	174100	753	110200	314	29000	279	100200	178	119200	684
60000	186800	885	113500	381	31500	354	101800	238	120700	779
63000	200800	1032	116600	459	33900	445	103200	314	121700	NA
66000	213300	1194	119000	547	36300	552	104400	408	122200	NA
69000	226000	1373	120100	646	38300	NA	105500	526	122700	NA
72000	239000	1570	121000	761	40000	NA	106300	669	123000	NA
75000	250900	1785	121400	889	41500	NA	107000	844	123500	NA

Appendix Table B-4. Continued.

	ISLAND SIDE CHANNEL		MAINSTEM WEST BANK		GOOSE 2 SIDE CHANNEL		CIRCULAR SIDE CHANNEL		SAUNA SIDE CHANNEL	
MAINSTEM DISCHARGE	SITE AREA	FLOW	SITE AREA	FLOW	SITE AREA	FLOW	SITE AREA	FLOW	SITE AREA	FLOW
12000	31500	6	61603	6	0	0	59464	6	42093	5
15000	31500	6	61603	6	0	0	59464	6	42093	5
18000	31500	6	61603	6	0	0	59464	6	42093	5
21000	31500	6	73426	19	0	0	59464	6	42093	5
24000	31500	6	80904	53	0	0	59464	6	42093	5
27000	31500	6	93353	134	0	0	59464	6	42093	5
30000	31500	6	108613	307	9600	0	59464	6	42093	5
33000	31500	6	114738	470	21500	24	59464	6	47611	14
36000	44600	67	117696	559	34300	32	71590	27	48790	19
39000	48100	94	120505	657	47800	41	76534	38	49127	21
42000	53200	126	123397	762	61400	52	80557	54	49758	25
45000	58900	166	129211	874	72000	65	85140	73	50289	29
48000	65500	[illegible]	133649	995	81400	81	92944	98	50889	34
51000	72000	273	136885	1123 *	87800	98	102530	129	51451	39
54000	79400	342	140761	1260 *	93200	118	113323	167	52011	44
57000	86700	424	144269	1404 *	97100	141	125753	213	52678	50
60000	93100	520	147899	1555 *	99900	166	134218	268	53294	56
63000	99800	631	151842	1715 *	102000	195	143575	334	54275	63
66000	106200	758	154205	1882 *	103200	226	150869	412 *	55184	70
69000	111900	904	156425	2057 *	104200	261	154657	503 *	56053	77
72000	118200	1070 *	158522	2241 *	104800	300	157074	610 *	57142	85
75000	123300	1256 *	160818	2431 *	105100	342	159211	733 *	61018	93

Appendix Table B-4. Continued.

	SUCKER SIDE CHANNEL		BEAVER DAM SIDE CHANNEL		SUNSET SIDE CHANNEL		SUNRISE SIDE CHANNEL		TRAPPER CREEK S. C.	
MAINSTEM DISCHARGE	SITE AREA	FLOW	SITE AREA	FLOW	SITE AREA	FLOW	SITE AREA	FLOW	SITE AREA	FLOW
12000	0	0	18900	<1	49562	5	0	0	73300	14
15000	0	0	18900	<1	49562	5	0	0	73300	14
18000	0	0	18900	<1	49562	5	0	0	73300	14
21000	0	0	18900	<1	49562	5	0	0	73300	14
24000	0	0	18900	<1	49562	5	0	0	73300	14
27000	1600	0	18900	<1	64118	15 *	0	0	73300	14
30000	8500	13	18900	<1	69129	25 *	0	0	73300	14
33000	14900	18	18900	<1	78498	47	0	0	73300	14
36000	16900	24	18900	<1	89472	68	19000	19	75600	26
39000	19400	31	18900	<1	97943	96	53900	25	85100	28
42000	23600	39	18900	<1	106320	132	78500	41	97100	30
45000	29600	48	19900	<1	122338	178	97100	58	108700	39
48000	37100	59	22400	7	135476	235	115400	79	119100	72
51000	46600	71	28000	11	149248	305	131100	106	128900	129
54000	57900	86	32600	18	165990	390	146900	139	137400	221
57000	66900	101	35700	29	173483	492	160600	181	143300	370
60000	71300	119	38000	45	188419	614	175600	233	148800	564
63000	73900	139	39600	68	194419	757	192000	295	154800	683
66000	75900	161	40800	101	203000	925	207300	370	160700	819
69000	77300	185	41500	148	206972	1179 *	221400	459	166100	975 *
72000	78100	211	41900	213	210728	1345 *	229000	564	169800	1151 *
75000	78300	240	42100	302	215861	1603 *	233300	686	172600	1351 *

Appendix Table B-5. Weighted usable areas and habitat indices for juvenile chinook salmon in lower Susitna River model sites, 1984.

ROLLY CREEK MOUTH

MAINSTEM DISCHARGE	SITE AREA	CHINOOK WUA	CHINOOK H. I.
12000	84900	3900	0.05
15000	84900	3900	0.05
18000	84900	3900	0.05
21000	84900	3900	0.05
24000	85300	3900	0.05
27000	88300	3900	0.04
30000	93200	3900	0.04
33000	99800	4100	0.04
36000	108900	4200	0.04
39000	121000	4300	0.04
42000	135000	4400	0.03
45000	152600	4500	0.03
48000	178500	7300	0.04
51000	198800	14100	0.07
54000	213000	20100	0.09
57000	223200	23400	0.10
60000	229800	25800	0.11
63000	235000	28000	0.12
66000	238700	30000	0.13
69000	241600	31500	0.13
72000	243200	32800	0.13
75000	243600	33500	0.14

CASWELL CREEK MOUTH

MAINSTEM DISCHARGE	SITE AREA	CHINOOK WUA	CHINOOK H. I.
12000	16200	800	0.05
15000	16200	800	0.05
18000	16200	800	0.05
21000	16200	800	0.05
24000	16200	800	0.05
27000	16300	800	0.05
30000	16700	1100	0.07
33000	17300	1600	0.09
36000	18000	2200	0.12
39000	18900	2700	0.14
42000	19800	3200	0.16
45000	21000	3700	0.18
48000	21800	4200	0.19
51000	22700	4700	0.21
54000	23700	5200	0.22
57000	24600	5700	0.23
60000	25500	6200	0.24
63000	26300	6700	0.25
66000	27200	7200	0.26
69000	27900	7600	0.27
72000	28900	8000	0.28
75000	29700	8400	0.28

BEAVER DAM SLOUGH

MAINSTEM DISCHARGE	SITE AREA	CHINOOK WUA	CHINOOK H. I.
12000	11600	1300	0.11
15000	11600	1300	0.11
18000	11600	1300	0.11
21000	11700	1300	0.11
24000	11900	1300	0.11
27000	12200	1300	0.11
30000	12500	1300	0.10
33000	13000	1300	0.10
36000	13400	1300	0.10
39000	13900	1400	0.10
42000	14400	1500	0.10
45000	15000	1800	0.12
48000	15700	2100	0.13
51000	16300	2600	0.16
54000	16800	3000	0.18
57000	17600	3700	0.21
60000	18500	4200	0.23
63000	19700	4600	0.23
66000	20800	4800	0.23
69000	21600	5000	0.23
72000	22100	5100	0.23
75000	22600	5200	0.23

HOOLIGAN SIDE CHANNEL

MAINSTEM DISCHARGE	SITE AREA	CHINOOK WUA	CHINOOK H. I.
12000	63400	500	0.01
15000	63400	500	0.01
18000	63400	500	0.01
21000	63400	500	0.01
24000	79800	7600	0.10
27000	86900	7200	0.08
30000	90800	6700	0.07
33000	96500	6100	0.06
36000	104800	5500	0.05
39000	113700	4900	0.04
42000	122900	4200	0.03
45000	131300	3600	0.03
48000	141200	2900	0.02
51000	152000	2300	0.01
54000	163000	2000	0.01
57000	174100	2000	0.01
60000	186800	1900	0.01
63000	200800	1800	0.01
66000	213300	1800	0.01
69000	226000	1800	0.01
72000	239000	1800	0.01
75000	250900	1800	0.01

KROTO SLOUGH HEAD

MAINSTEM DISCHARGE	SITE AREA	CHINOOK WUA	CHINOOK H. I.
12000	48200	100	.00
15000	48200	100	.00
18000	48200	100	.00
21000	48200	100	.00
24000	48200	100	.00
27000	48200	100	.00
30000	48200	100	.00
33000	48500	100	.00
36000	57900	2700	0.05
39000	67900	4900	0.07
42000	77500	6200	0.08
45000	86800	7300	0.08
48000	95100	8100	0.09
51000	102200	7900	0.08
54000	106700	6900	0.06
57000	110200	6000	0.05
60000	113500	5100	0.04
63000	116500	4300	0.04
66000	119000	3400	0.03
69000	120100	2900	0.02
72000	121000	2500	0.02
75000	121400	2200	0.02

BEARBAIT SIDE CHANNEL

MAINSTEM DISCHARGE	SITE AREA	CHINOOK WUA	CHINOOK H. I.
12000	3100	20	0.01
15000	3100	20	0.01
18000	3100	20	0.01
21000	3100	20	0.01
24000	3100	20	0.01
27000	3100	20	0.01
30000	3100	20	0.01
33000	3100	20	0.01
36000	5700	200	0.04
39000	10800	350	0.03
42000	14600	530	0.04
45000	17900	650	0.04
48000	21100	720	0.03
51000	23800	790	0.03
54000	26400	800	0.03
57000	29000	750	0.03
60000	31500	700	0.02
63000	33900	650	0.02
66000	36300	610	0.02
69000	38300	590	0.02
72000	40000	570	0.01
75000	41500	560	0.01

Appendix Table B-5. Continued.

LAST CHANCE S. C.

MAINSTEM DISCHARGE	SITE AREA	CHINOOK WUA	CHINOOK H. I.
12000	17500	110	0.01
15000	17500	110	0.01
18000	17500	110	0.01
21000	17500	110	0.01
24000	17500	110	0.01
27000	31700	200	0.01
30000	50600	370	0.01
33000	63900	540	0.01
36000	73200	700	0.01
39000	80000	900	0.01
42000	85900	1030	0.01
45000	90600	1220	0.01
48000	94000	1520	0.02
51000	96300	1990	0.02
54000	98500	2560	0.03
57000	100200	2620	0.03
60000	101800	2540	0.02
63000	103200	2460	0.02
66000	104400	2350	0.02
69000	105500	2240	0.02
72000	106300	2100	0.02
75000	107000	1900	0.02

RUSTIC WILDERNESS S. C.

MAINSTEM DISCHARGE	SITE AREA	CHINOOK WUA	CHINOOK H. I.
12000	4800	30	0.01
15000	4800	30	0.01
18000	4800	30	0.01
21000	31900	4800	0.15
24000	49500	5100	0.10
27000	60700	4300	0.07
30000	69700	3700	0.05
33000	76800	30[illegible]	0.04
36000	83300	2400	0.03
39000	89900	1900	0.02
42000	97000	1500	0.02
45000	104000	1200	0.01
48000	109000	900	0.01
51000	114000	700	0.01
54000	117400	500	.00
57000	119200	500	.00
60000	120700	600	.00
63000	121700	600	.00
66000	122200	600	.00
69000	122700	700	0.01
72000	123000	700	0.01
75000	123500	800	0.01

ISLAND SIDE CHANNEL

MAINSTEM DISCHARGE	SITE AREA	CHINOOK WUA	CHINOOK H. I.
12000	31500	400	0.01
15000	31500	400	0.01
18000	31500	400	0.01
21000	31500	400	0.01
24000	31500	400	0.01
27000	31500	400	0.01
30000	31500	400	0.01
33000	31500	500	0.02
36000	44600	3500	0.08
39000	48100	4800	0.10
42000	53200	4100	0.08
45000	58900	3400	0.06
48000	65500	2900	0.04
51000	72000	2400	0.03
54000	79400	2100	0.03
57000	86700	1800	0.02
60000	93100	1700	0.02
63000	99800	1800	0.02
66000	106200	2100	0.02
69000	111900	2400	0.02
72000	118200	2600	0.02
75000	123300	2700	0.02

MAINSTEM WEST BANK

MAINSTEM DISCHARGE	SITE AREA	CHINOOK WUA	CHINOOK H. I.
12000	61603	1082	0.02
15000	61603	1082	0.02
18000	61603	1082	0.02
21000	73426	10041	0.14
24000	80904	8325	0.10
27000	93353	5224	0.06
30000	108613	4045	0.04
33000	114738	3959	0.03
36000	117696	3861	0.03
39000	120505	3775	0.03
42000	123397	3855	0.03
45000	129211	4113	0.03
48000	133649	4630	0.03
51000	136885	508[illegible]	0.04
54000	140761	5554	0.04
57000	144269	6217	0.04
60000	147899	6720	0.05
63000	151842	7092	0.05
66000	154205	7598	0.05
69000	156425	7913	0.05
72000	158522	8079	0.05
75000	160818	8438	0.05

GOOSE 2 SIDE CHANNEL

MAINSTEM DISCHARGE	SITE AREA	CHINOOK WUA	CHINOOK H. I.
12000	0	0	0.00
15000	0	0	0.00
18000	0	0	0.00
21000	0	0	0.00
24000	0	0	0.00
27000	0	0	0.00
30000	9600	1500	0.16
33000	21500	2900	0.13
36000	34300	4000	0.12
39000	47800	5100	0.11
42000	61400	6100	0.10
45000	72000	6900	0.10
48000	81400	7000	0.09
51000	87800	6700	0.08
54000	93200	6000	0.06
57000	97100	4600	0.05
60000	99900	3100	0.03
63000	102000	2700	0.03
66000	103200	2400	0.02
69000	104200	2100	0.02
72000	104800	1800	0.02
75000	105100	1600	0.02

CIRCULAR SIDE CHANNEL

MAINSTEM DISCHARGE	SITE AREA	CHINOOK WUA	CHINOOK H. I.
12000	59464	747	0.01
15000	59464	747	0.01
18000	59464	747	0.01
21000	59464	747	0.01
24000	59464	747	0.01
27000	59464	747	0.01
30000	59464	747	0.01
33000	59464	747	0.01
36000	71590	8717	0.12
39000	76534	8404	0.11
42000	80557	8013	0.10
45000	85140	7472	0.09
48000	92944	7077	0.08
51000	102530	6998	0.07
54000	113323	6999	0.06
57000	125753	6634	0.05
60000	134218	6516	0.05
63000	143575	6906	0.05
66000	15086[illegible]	7926	0.05
69000	154657	8561	0.06
72000	157074	8840	0.06
75000	159211	8854	0.06

Appendix Table B-5. Continued.

SAUNA SIDE CHANNEL

MAINSTEM DISCHARGE	SITE AREA	CHINOOK WUA	CHINOOK H. I.
12000	42093	165	.00
15000	42093	165	.00
18000	42093	165	.00
21000	42093	165	.00
24000	42093	165	.00
27000	42093	165	.00
30000	42093	165	.00
33000	47611	5470	0.11
36000	48790	5713	0.12
39000	49127	5759	0.12
42000	49758	5740	0.12
45000	50289	5503	0.11
48000	50889	4980	0.10
51000	51451	4470	0.09
54000	52011	4046	0.08
57000	52678	3645	0.07
60000	53294	3365	0.06
63000	54275	3116	0.06
66000	55184	2947	0.05
69000	56053	2757	0.05
72000	57142	2678	0.05
75000	61018	2714	0.04

SUCKER SIDE CHANNEL

MAINSTEM DISCHARGE	SITE AREA	CHINOOK WUA	CHINOOK H. I.
12000	0	0	0.00
15000	0	0	0.00
18000	0	0	0.00
21000	0	0	0.00
24000	0	0	0.00
27000	1600	0	0.00
30000	8500	1060	0.12
33000	14900	1600	0.11
36000	16900	1570	0.09
39000	19400	1510	0.08
42000	23600	1450	0.06
45000	29600	1550	0.05
48000	37100	2070	0.06
51000	46600	2940	0.06
54000	57900	4230	0.07
57000	66900	4680	0.07
60000	71300	4490	0.06
63000	73900	4230	0.06
66000	75900	3940	0.05
69000	77300	3610	0.05
72000	78100	3270	0.04
75000	78300	3010	0.04

BEAVER DAM SIDE CHANNEL

MAINSTEM DISCHARGE	SITE AREA	CHINOOK WUA	CHINOOK H. I.
12000	18900	50	.00
15000	18900	50	.00
18000	18900	50	.00
21000	18900	50	.00
24000	18900	50	.00
27000	18900	50	.00
30000	18900	50	.00
33000	18900	50	.00
36000	18900	50	.00
39000	18900	50	.00
42000	18900	50	.00
45000	19900	50	.00
48000	22400	820	0.04
51000	28000	2370	0.08
54000	32600	3560	0.11
57000	35700	3840	0.11
60000	38000	3570	0.09
63000	39600	3060	0.08
66000	40800	2510	0.06
69000	41500	2260	0.05
72000	41900	2100	0.05
75000	42100	2000	0.05

SUNSET SIDE CHANNEL

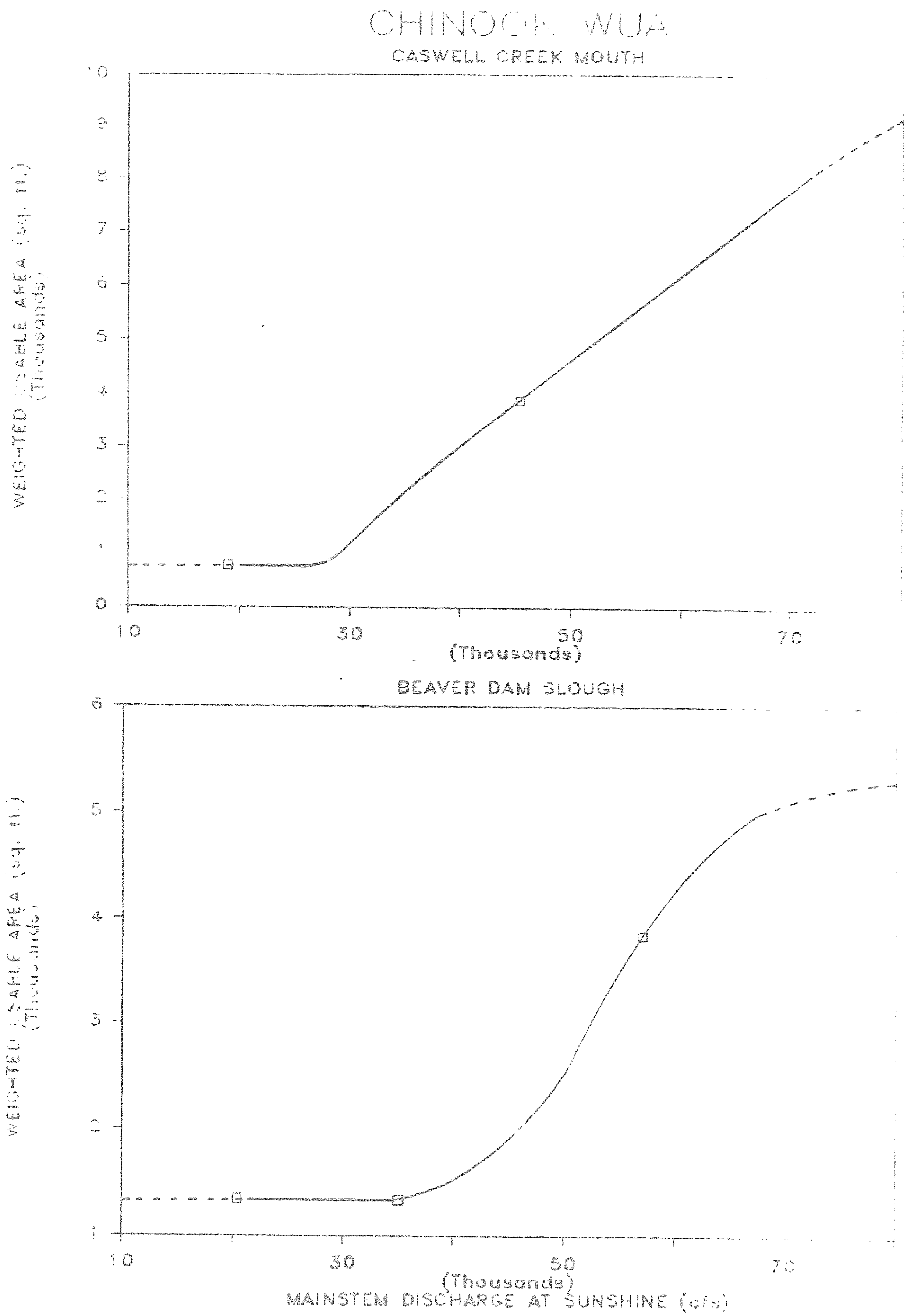
MAINSTEM DISCHARGE	SITE AREA	CHINOOK WUA	CHINOOK H. I.
12000	49562	568	0.01
15000	49562	568	0.01
18000	49562	568	0.01
21000	49562	568	0.01
24000	49562	568	0.01
27000	64118	3920	0.06
30000	69129	4091	0.06
33000	78488	4378	0.06
36000	89472	4420	0.05
39000	97943	4630	0.05
42000	106320	4984	0.05
45000	122338	5436	0.04
48000	135476	5846	0.04
51000	149248	5868	0.04
54000	165990	5768	0.03
57000	173483	5487	0.03
60000	188419	5931	0.03
63000	194419	6060	0.03
66000	203000	6231	0.03
69000	206972	6263	0.03
72000	210728	6157	0.03
75000	215861	5848	0.03

SUNRISE SIDE CHANNEL

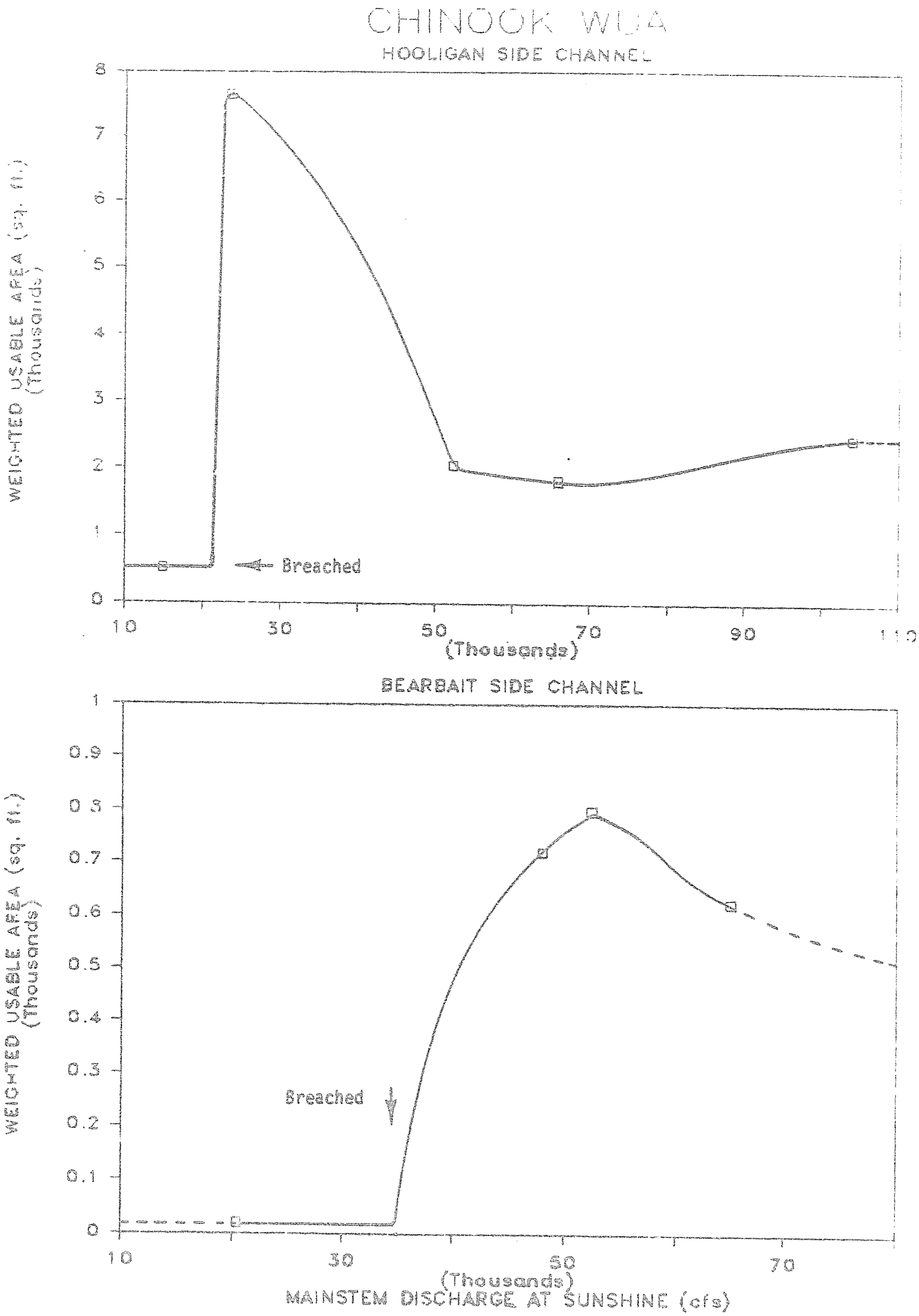
MAINSTEM DISCHARGE	SITE AREA	CHINOOK WUA	CHINOOK H. I.
12000	0	0	0.00
15000	0	0	0.00
18000	0	0	0.00
21000	0	0	0.00
24000	0	0	0.00
27000	0	0	0.00
30000	0	0	0.00
33000	0	0	0.00
36000	19000	610	0.03
39000	53900	3250	0.06
42000	78500	5660	0.07
45000	97100	6090	0.06
48000	115400	4270	0.04
51000	131100	3820	0.03
54000	146900	3540	0.02
57000	160600	3250	0.02
60000	175600	3180	0.02
63000	192000	3460	0.02
66000	207300	3760	0.02
69000	221400	4080	0.02
72000	229000	4190	0.02
75000	233300	4210	0.02

TRAPPER CREEK S. C.

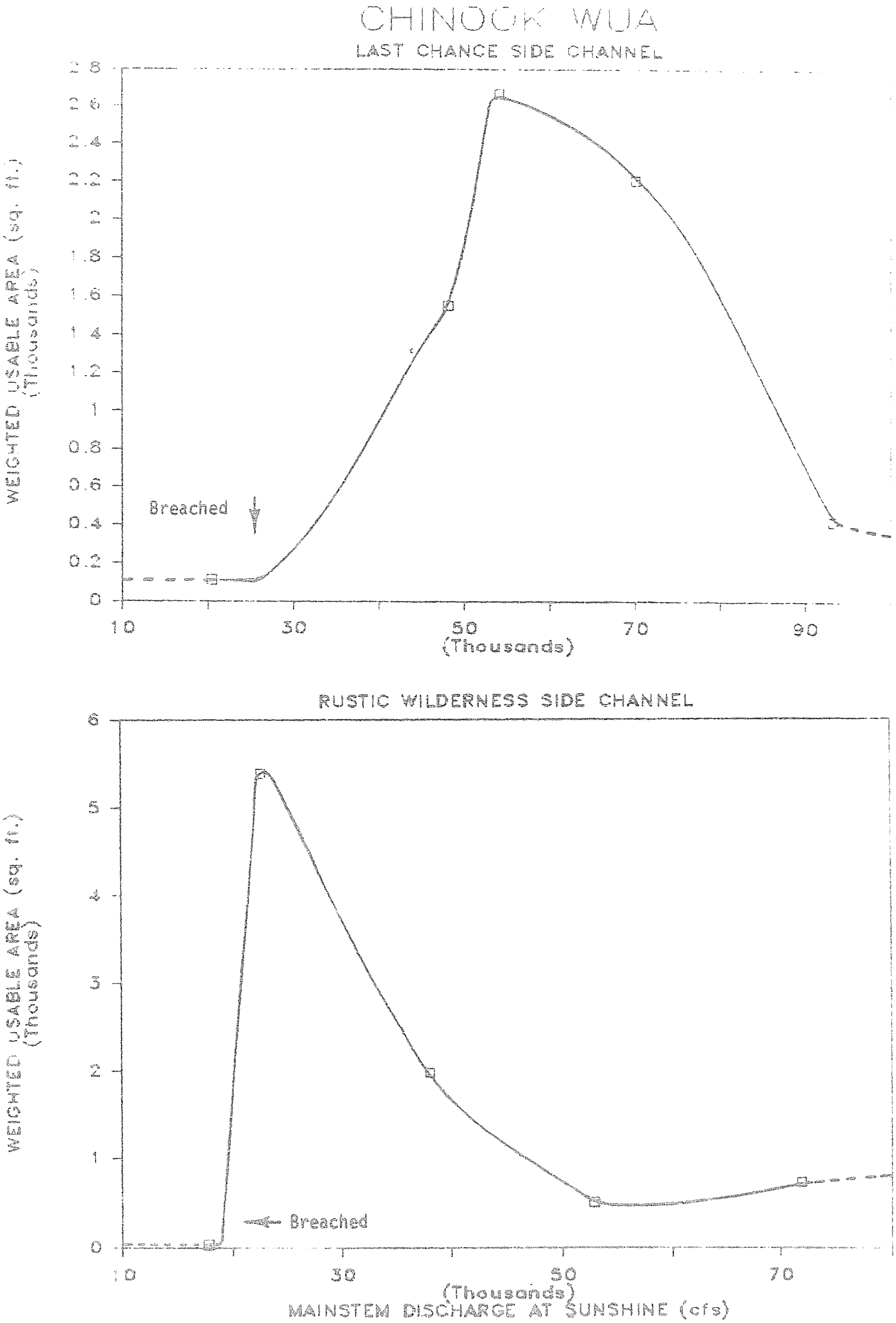
MAINSTEM DISCHARGE	SITE AREA	CHINOOK WUA	CHINOOK H. I.
12000	73300	1100	0.02
15000	73300	1100	0.02
18000	73300	1100	0.02
21000	73300	1100	0.02
24000	73300	1100	0.02
27000	73300	1100	0.02
30000	73300	1100	0.02
33000	73300	1100	0.02
36000	75600	2000	0.03
39000	85100	9100	0.11
42000	97100	8300	0.09
45000	108700	7100	0.07
48000	119100	5700	0.05
51000	128900	4000	0.03
54000	137400	2700	0.02
57000	143300	1800	0.01
60000	148800	1300	0.01
63000	154800	1300	0.01
66000	160700	1300	0.01
69000	166100	1300	0.01
72000	169800	1300	0.01
75000	172600	1300	0.01



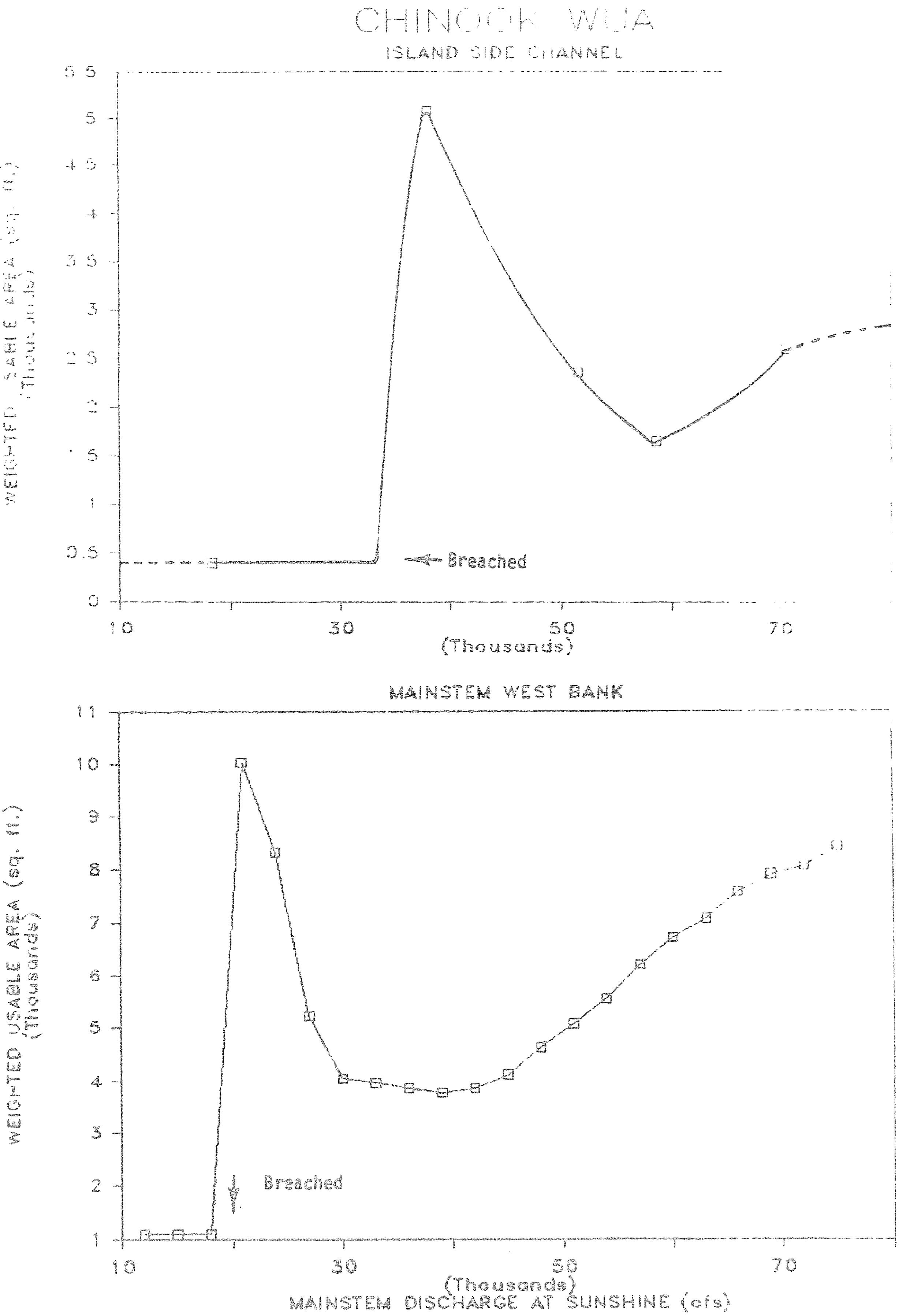
Appendix Figure B-1. Weighted usable area for juvenile chinook salmon at the Caswell Creek and Beaver Dam tributary study sites as a function of mainstem discharge.



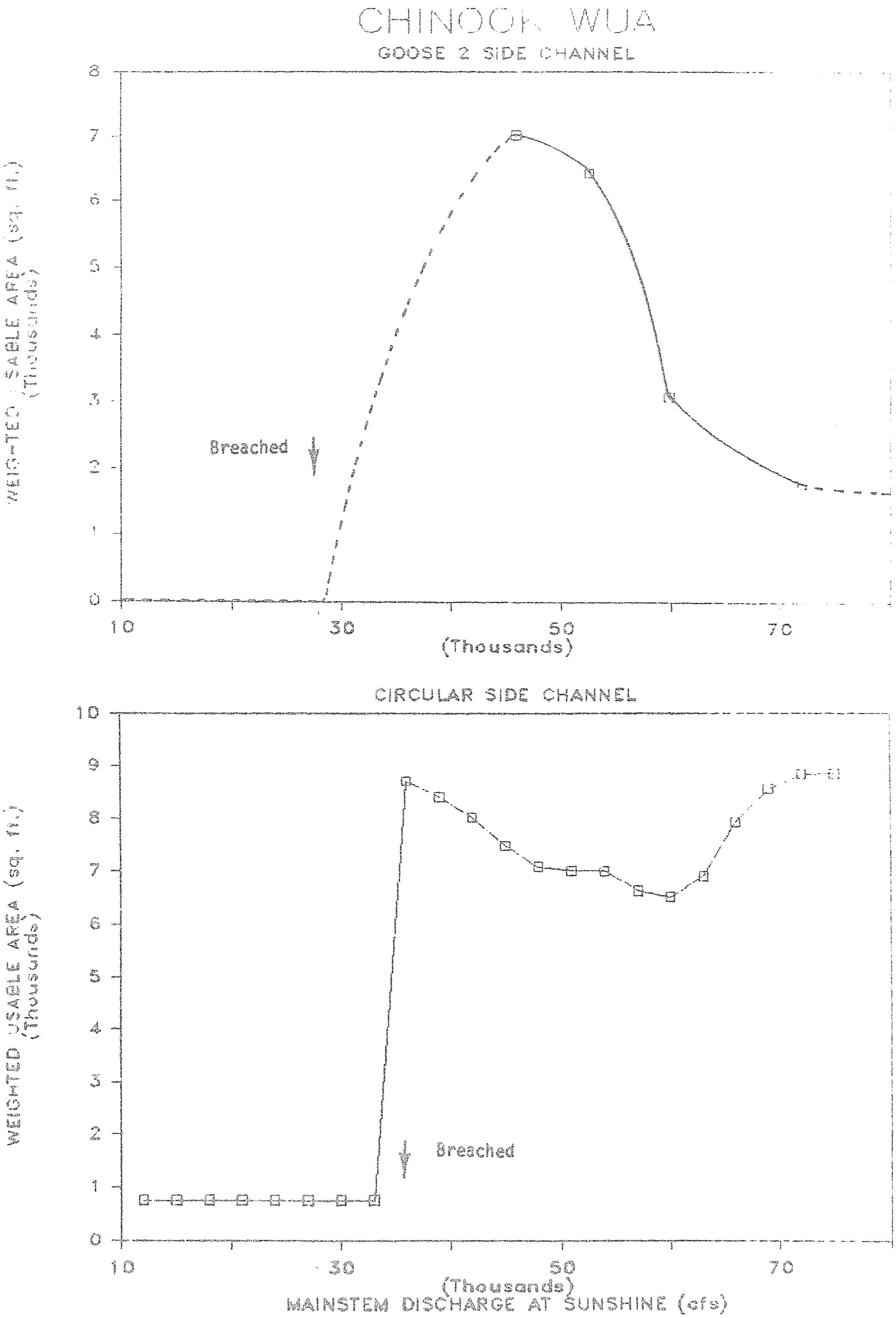
Appendix Figure B-2. Weighted usable area for juvenile chinook salmon at the Hooligan and Bearbait Side Channel study sites as a function of mainstem discharge.



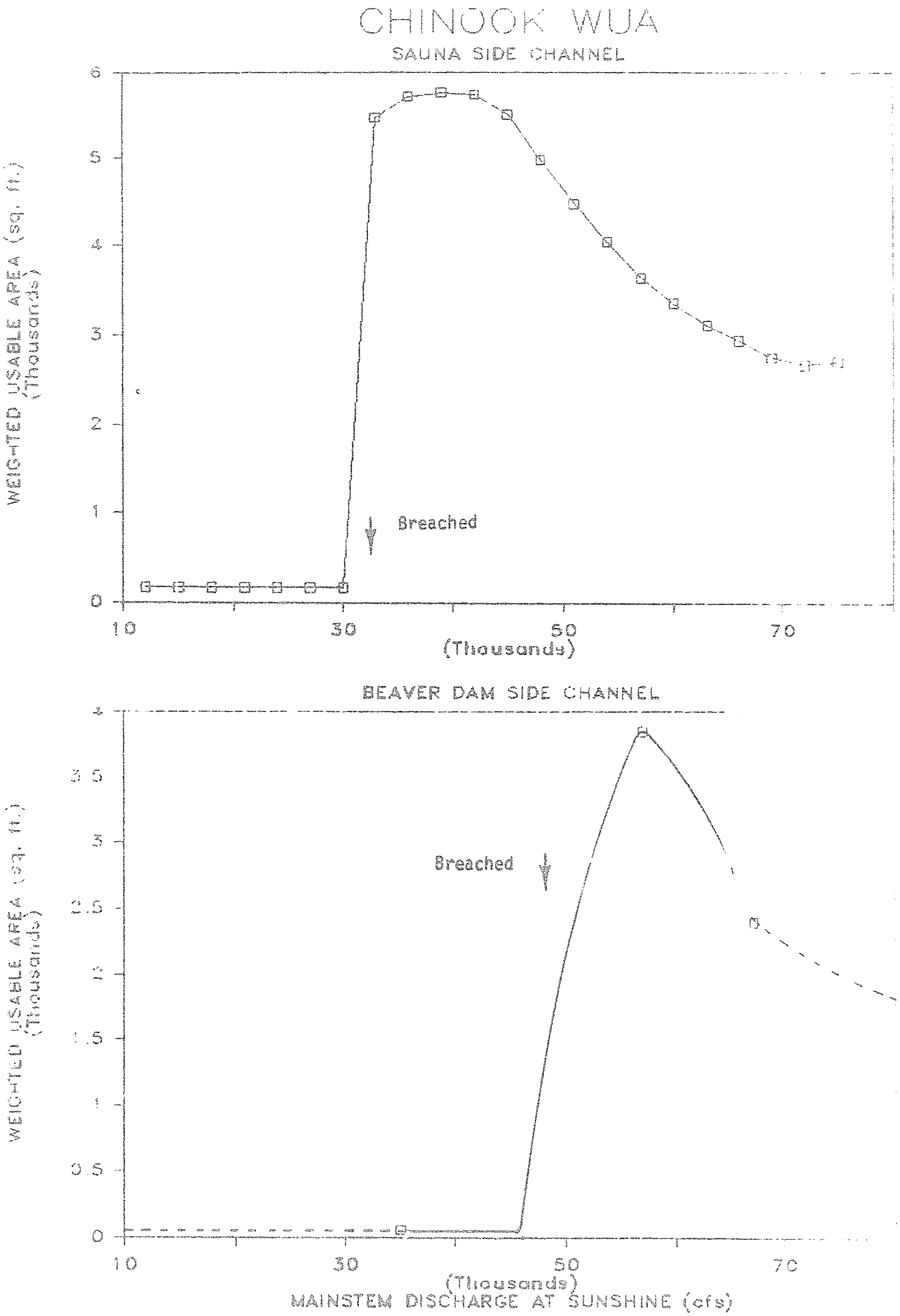
Appendix Figure B-3. Weighted usable area for juvenile chinook salmon at the Last Chance and Rustic Wilderness Side Channel study sites as a function of mainstem discharge.



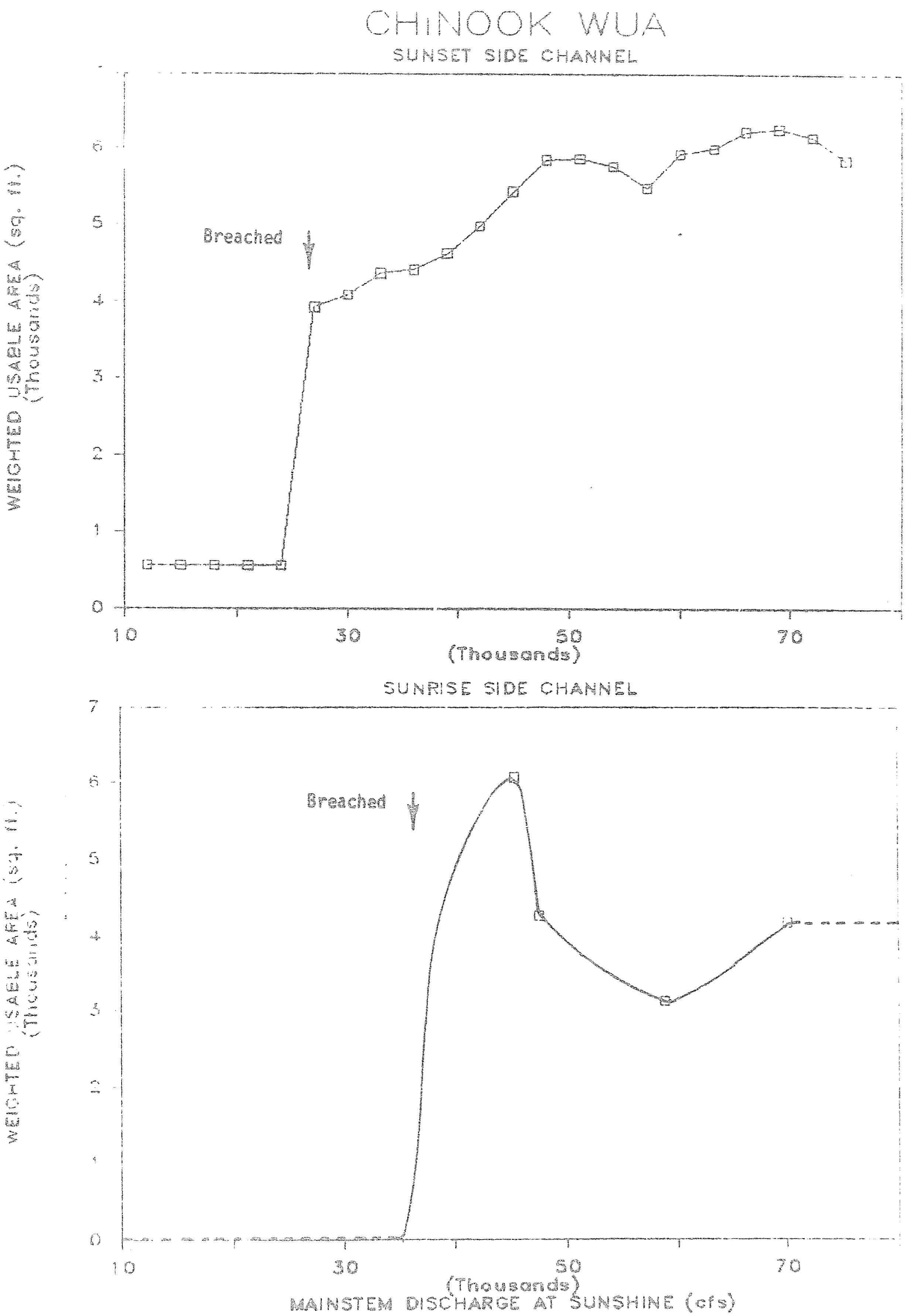
Appendix Figure B-4. Weighted usable area for juvenile chinook salmon at the Island Side Channel and Mainstem West Bank study sites as a function of mainstem discharge.



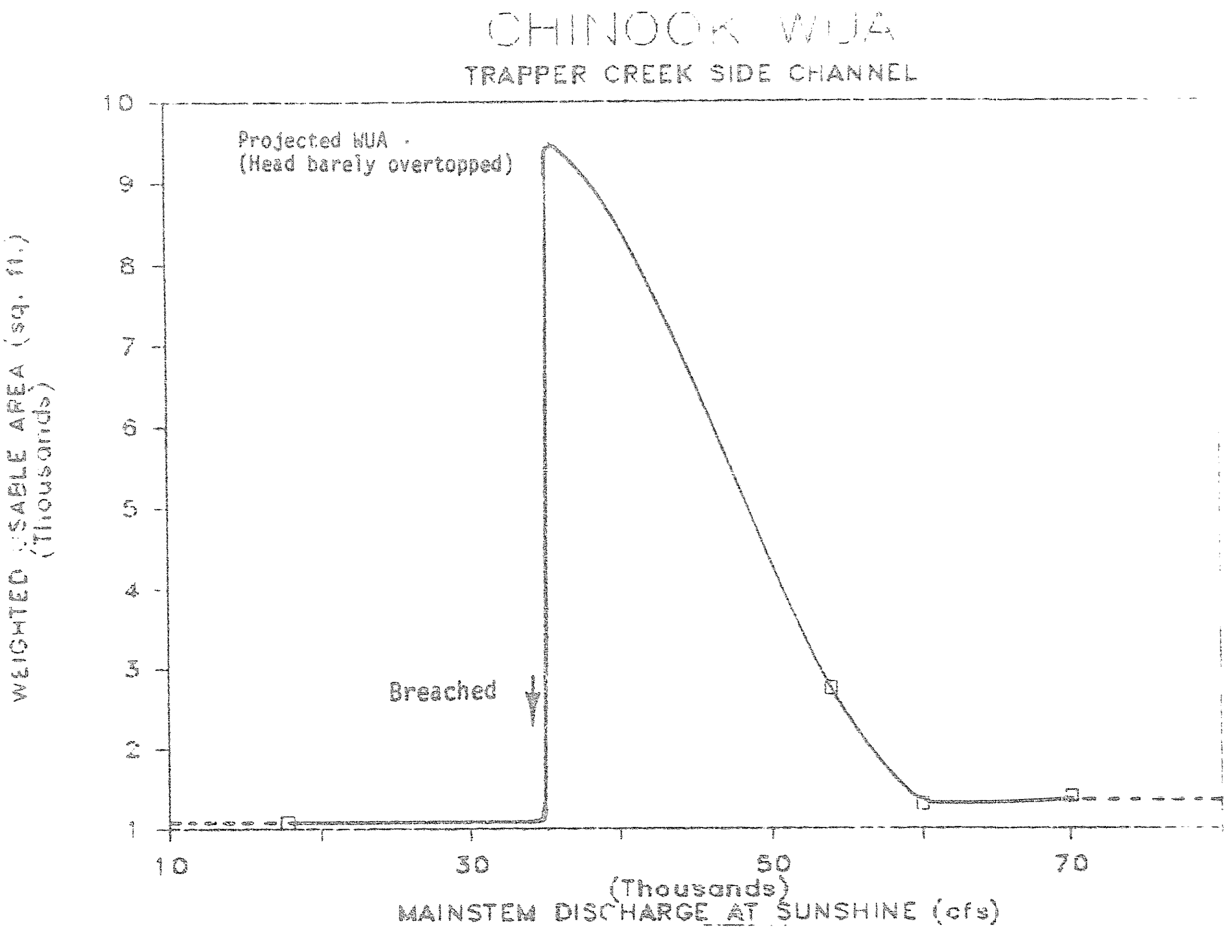
Appendix Figure B-5. Weighted usable area for juvenile chinook salmon at the Goose 2 and Circular Side Channel study sites as a function of mainstem discharge.



Appendix Figure B-6. Weighted usable area for juvenile chinook salmon at the Sauna and Beaver Dam Side Channel study sites as a function of mainstem discharge.



Appendix Figure B-7. Weighted usable area for juvenile chinook salmon at the Sunset and Sunrise Side Channel study sites as a function of mainstem discharge.



Appendix Figure B-8. Weighted usable area for juvenile chinook salmon at the Trapper Creek Side Channel study site as a function of mainstem discharge.

Appendix Table B-6. Weighted usable areas and habitat indices for juvenile coho salmon in lower Susitna River model sites, 1984.

ROLLY CREEK MOUTH			
MAINSTEM DISCHARGE	SITE AREA	COHO WUA	COHO H. I.
12000	84900	7900	0.09
15000	84900	7900	0.09
18000	84900	7900	0.09
21000	84900	7900	0.09
24000	85300	7900	0.09
27000	88300	7700	0.09
30000	93200	7500	0.08
33000	99800	7100	0.07
36000	108900	6800	0.06
39000	121000	6400	0.05
42000	135000	5900	0.04
45000	152600	5500	0.04
48000	178500	5600	0.03
51000	198800	7300	0.04
54000	213000	9200	0.04
57000	223200	10100	0.05
60000	229800	10700	0.05
63000	235000	11200	0.05
66000	238700	11700	0.05
69000	241600	12000	0.05
72000	243200	12300	0.05
75000	243600	12500	0.05

CASWELL CREEK MOUTH			
MAINSTEM DISCHARGE	SITE AREA	COHO WUA	COHO H. I.
12000	16200	1350	0.08
15000	16200	1350	0.08
18000	16200	1350	0.08
21000	16200	1350	0.08
24000	16200	1350	0.08
27000	16300	1500	0.09
30000	16700	1700	0.10
33000	17300	2000	0.12
36000	18000	2300	0.13
39000	18900	2500	0.13
42000	19800	2800	0.14
45000	21000	3000	0.14
48000	21800	3200	0.15
51000	22700	3400	0.15
54000	23700	3600	0.15
57000	24600	3800	0.15
60000	25500	4000	0.16
63000	26300	4300	0.16
66000	27200	4400	0.16
69000	27900	4700	0.17
72000	28900	4900	0.17
75000	29700	5100	0.17

BEAVER DAM SLOUGH			
MAINSTEM DISCHARGE	SITE AREA	COHO WUA	COHO H. I.
12000	11600	1700	0.15
15000	11600	1700	0.15
18000	11600	1700	0.15
21000	11700	1700	0.15
24000	11900	1700	0.14
27000	12200	1700	0.14
30000	12500	1700	0.14
33000	13000	1700	0.13
36000	13400	1700	0.13
39000	13900	1700	0.12
42000	14400	1670	0.12
45000	15000	1650	0.11
48000	15700	1610	0.10
51000	16300	1540	0.09
54000	16800	1480	0.09
57000	17600	1430	0.08
60000	18500	1480	0.08
63000	19700	1540	0.08
66000	20800	1630	0.08
69000	21600	1740	0.08
72000	22100	1780	0.08
75000	22600	1810	0.08

Appendix Table B-7. Weighted usable areas and habitat indices for juvenile chum salmon in lower Susitna River model sites, 1984.

HOOLIGAN SIDE CHANNEL			
MAINSTEM DISCHARGE	SITE AREA	CHUM WUA	CHUM H. I.
12000	63400	28500	0.45
15000	63400	28500	0.45
18000	63400	28500	0.45
21000	63400	28500	0.45
24000	79800	47900	0.60
27000	86900	46700	0.54
30000	90800	44000	0.48
33000	96500	41700	0.43
36000	104800	38400	0.37
39000	113700	34700	0.31
42000	122900	30300	0.25
45000	131300	26100	0.20
48000	141200	21900	0.16
51000	152000	18900	0.12
54000	163000	18100	0.11
57000	174100	17400	0.10
60000	186800	17200	0.09
63000	200800	16900	0.08
66000	213300	16700	0.08
69000	226000	16400	0.07
72000	239000	16100	0.07
75000	250900	15800	0.06

KROTO SLOUGH HEAD			
MAINSTEM DISCHARGE	SITE AREA	CHUM WUA	CHUM H. I.
12000	48200	39600	0.82
15000	48200	39600	0.82
18000	48200	39600	0.82
21000	48200	39600	0.82
24000	48200	39600	0.82
27000	48200	39600	0.82
30000	48200	39600	0.82
33000	48500	39600	0.82
36000	57900	41000	0.71
39000	67900	42800	0.63
42000	77500	44500	0.57
45000	86800	46100	0.53
48000	95100	47600	0.50
51000	102200	46500	0.45
54000	106700	42300	0.40
57000	110200	38300	0.35
60000	113500	34400	0.30
63000	116600	29700	0.25
66000	119000	24100	0.20
69000	120100	19800	0.16
72000	121000	17800	0.15
75000	121400	15200	0.13

BEARBAIT SIDE CHANNEL			
MAINSTEM DISCHARGE	SITE AREA	CHUM WUA	CHUM H. I.
12000	3100	1300	0.42
15000	3100	1300	0.42
18000	3100	1300	0.42
21000	3100	1300	0.42
24000	3100	1300	0.42
27000	3100	1300	0.42
30000	3100	1300	0.42
33000	3100	1300	0.42
36000	5700	1400	0.25
39000	10300	1900	0.18
42000	14600	2600	0.18
45000	17900	3300	0.18
48000	21100	4100	0.19
51000	23800	5300	0.22
54000	26400	5700	0.22
57000	29000	5500	0.19
60000	31500	5100	0.16
63000	33900	4700	0.14
66000	36300	4400	0.12
69000	38300	4200	0.11
72000	40000	4100	0.10
75000	41500	4000	0.10

Appendix Table B-7. Continued.

LAST CHANCE S. C.

MAINSTEM DISCHARGE	SITE AREA	CHUM WUA	CHUM H. I.
12000	17500	11500	0.66
15000	17500	11500	0.66
18000	17500	11500	0.66
21000	17500	11500	0.66
24000	17500	11500	0.66
27000	31700	11500	0.36
30000	50600	11500	0.23
33000	63900	11500	0.18
36000	73200	11500	0.16
39000	80000	11500	0.14
42000	85900	11500	0.13
45000	90600	11500	0.13
48000	94000	11700	0.12
51000	96300	15100	0.16
54000	98500	20200	0.21
57000	100200	19500	0.19
60000	101800	18000	0.18
63000	103200	16200	0.16
66000	104400	13600	0.13
69000	105500	10500	0.10
72000	106300	8800	0.08
75000	107000	7600	0.07

RUSTIC WILDERNESS S. C.

MAINSTEM DISCHARGE	SITE AREA	CHUM WUA	CHUM H. I.
12000	4800	3600	0.75
15000	4800	3600	0.75
18000	4800	3600	0.75
21000	31900	30800	0.97
24000	49500	32500	0.66
27000	60700	27600	0.45
30000	69700	22700	0.33
33000	76800	18100	0.24
36000	83300	13700	0.16
39000	89900	10600	0.12
42000	97000	8800	0.09
45000	104000	7400	0.07
48000	109000	5800	0.05
51000	114000	4200	0.04
54000	117400	3300	0.03
57000	119200	3000	0.03
60000	120700	3000	0.02
63000	121700	3000	0.02
66000	122200	3000	0.02
69000	122700	3000	0.02
72000	123000	3000	0.02
75000	123500	3000	0.02

ISLAND SIDE CHANNEL

MAINSTEM DISCHARGE	SITE AREA	CHUM WUA	CHUM H. I.
12000	31500	19300	0.61
15000	31500	19300	0.61
18000	31500	19300	0.61
21000	31500	19300	0.61
24000	31500	19300	0.61
27000	31500	19300	0.61
30000	31500	19300	0.61
33000	31500	19800	0.63
36000	44600	28100	0.63
39000	48100	28800	0.60
42000	53200	25800	0.49
45000	58900	22700	0.39
48000	65500	19700	0.30
51000	72000	17400	0.24
54000	79400	15100	0.19
57000	86700	13200	0.15
60000	93100	12400	0.13
63000	99800	12700	0.13
66000	106200	13000	0.12
69000	111900	13300	0.12
72000	118200	13600	0.12
75000	123300	13600	0.11

MAINSTEM WEST BANK

MAINSTEM DISCHARGE	SITE AREA	CHUM WUA	CHUM H. I.
12000	61603	47090	0.76
15000	61603	47090	0.76
18000	61603	47090	0.76
21000	73426	53955	0.73
24000	80904	43289	0.54
27000	93353	31606	0.34
30000	108613	27151	0.25
33000	114738	23420	0.20
36000	117696	21782	0.19
39000	120505	21096	0.18
42000	123397	21218	0.17
45000	129211	22389	0.17
48000	133649	26770	0.20
51000	136885	27661	0.20
54000	140761	30382	0.22
57000	144269	31815	0.22
60000	147899	33950	0.23
63000	151842	35953	0.24
66000	154205	36489	0.24
69000	156425	36211	0.23
72000	158522	37029	0.23
75000	160818	36809	0.23

GOOSE 2 SIDE CHANNEL

MAINSTEM DISCHARGE	SITE AREA	CHUM WUA	CHUM H. I.
12000	0	0	0.00
15000	0	0	0.00
18000	0	0	0.00
21000	0	0	0.00
24000	0	0	0.00
27000	0	0	0.00
30000	9600	4900	0.51
33000	21500	11000	0.51
36000	34300	17400	0.51
39000	47800	25500	0.53
42000	61400	31800	0.52
45000	72000	37900	0.53
48000	81400	41600	0.51
51000	87800	42600	0.49
54000	93200	40700	0.44
57000	97100	33400	0.34
60000	99900	24000	0.24
63000	102000	18000	0.18
66000	103200	13800	0.13
69000	104200	10400	0.10
72000	104900	8300	0.08
75000	105100	7400	0.07

CIRCULAR SIDE CHANNEL

MAINSTEM DISCHARGE	SITE AREA	CHUM WUA	CHUM H. I.
12000	59464	46109	0.78
15000	59464	46109	0.78
18000	59464	46109	0.78
21000	59464	46109	0.78
24000	59464	46109	0.78
27000	59464	46109	0.78
30000	59464	46109	0.78
33000	59464	46109	0.78
36000	71590	44495	0.62
39000	76534	44606	0.58
42000	80557	42269	0.52
45000	85140	42176	0.50
48000	92944	43074	0.46
51000	102530	45026	0.44
54000	113323	50073	0.44
57000	125753	50248	0.40
60000	134218	46305	0.34
63000	143575	49339	0.34
66000	150849	49565	0.33
69000	154657	50346	0.33
72000	157074	48491	0.31
75000	159211	46797	0.29

Appendix Table B-7. Continued.

SAUNA SIDE CHANNEL

MAINSTEM DISCHARGE	SITE AREA	CHUM WUA	CHUM H. I.
12000	42093	31754	0.75
15000	42093	31754	0.75
18000	42093	31754	0.75
21000	42093	31754	0.75
24000	42093	31754	0.75
27000	42093	31754	0.75
30000	42093	31754	0.75
33000	47611	28574	0.60
36000	48790	27855	0.57
39000	49127	27307	0.56
42000	49758	26413	0.53
45000	50289	25204	0.50
48000	50889	23670	0.47
51000	51451	22565	0.44
54000	52011	21836	0.42
57000	52678	21381	0.41
60000	53294	20990	0.39
63000	54275	20669	0.38
66000	55184	20938	0.38
69000	56053	21017	0.37
72000	57.42	21153	0.37
75000	61018	23075	0.38

SUCKER SIDE CHANNEL

MAINSTEM DISCHARGE	SITE AREA	CHUM WUA	CHUM H. I.
12000	0	0	0.00
15000	0	0	0.00
18000	0	0	0.00
21000	0	0	0.00
24000	0	0	0.00
27000	1600	0	0.00
30000	8500	7300	0.86
33000	14900	11800	0.79
36000	16900	12700	0.75
39000	19400	13200	0.68
47000	23600	13400	0.57
45000	29600	14300	0.48
48000	37100	19900	0.54
51000	46600	27700	0.59
54000	57900	33700	0.58
57000	66900	34400	0.51
60000	71300	32900	0.46
63000	73900	30800	0.42
66000	75900	28200	0.37
69000	77300	25000	0.32
72000	78100	21800	0.28
75000	78300	19200	0.25

BEAVER DAM SIDE CHANNEL

MAINSTEM DISCHARGE	SITE AREA	CHUM WUA	CHUM H. I.
12000	18900	11900	0.63
15000	18900	11900	0.63
18000	18900	11900	0.63
21000	18900	11900	0.63
24000	18900	11900	0.63
27000	18900	11900	0.63
30000	18900	11900	0.63
33000	18900	11900	0.63
36000	18900	11900	0.63
39000	18900	11900	0.63
42000	18900	11900	0.63
45000	19900	11900	0.60
48000	22400	13200	0.59
51000	28000	15700	0.56
54000	32600	17500	0.54
57000	35700	18800	0.53
60000	38000	18200	0.48
63000	39600	16400	0.41
66000	40800	14000	0.34
69000	41500	12100	0.29
72000	41900	11300	0.27
75000	42100	10700	0.25

SUNSET SIDE CHANNEL

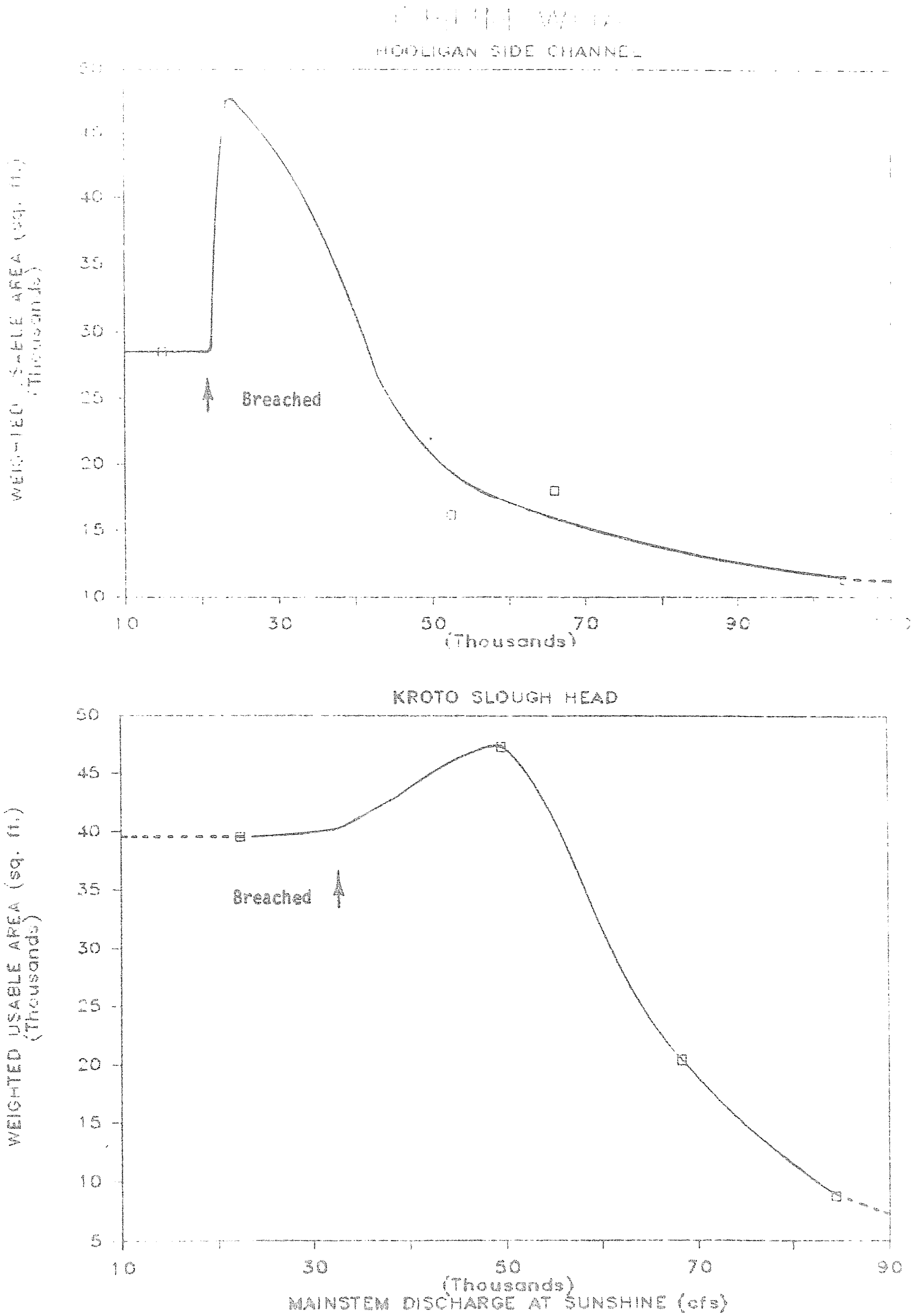
MAINSTEM DISCHARGE	SITE AREA	CHUM WUA	CHUM H. I.
12000	49562	27135	0.55
15000	49562	27135	0.55
18000	49562	27135	0.55
21000	49562	27135	0.55
24000	49562	27135	0.55
27000	64118	30457	0.48
30000	69129	32580	0.47
33000	78408	34059	0.43
36000	89472	34808	0.39
39000	97943	37649	0.38
42000	106320	39888	0.38
45000	122338	46376	0.38
48000	135476	51185	0.38
51000	149248	52671	0.35
54000	165990	53786	0.32
57000	173483	48410	0.28
60000	188419	50093	0.27
63000	194419	43299	0.22
66000	203000	41715	0.21
69000	206972	37100	0.18
72000	210728	33481	0.16
75000	215861	32949	0.15

SUNRISE SIDE CHANNEL

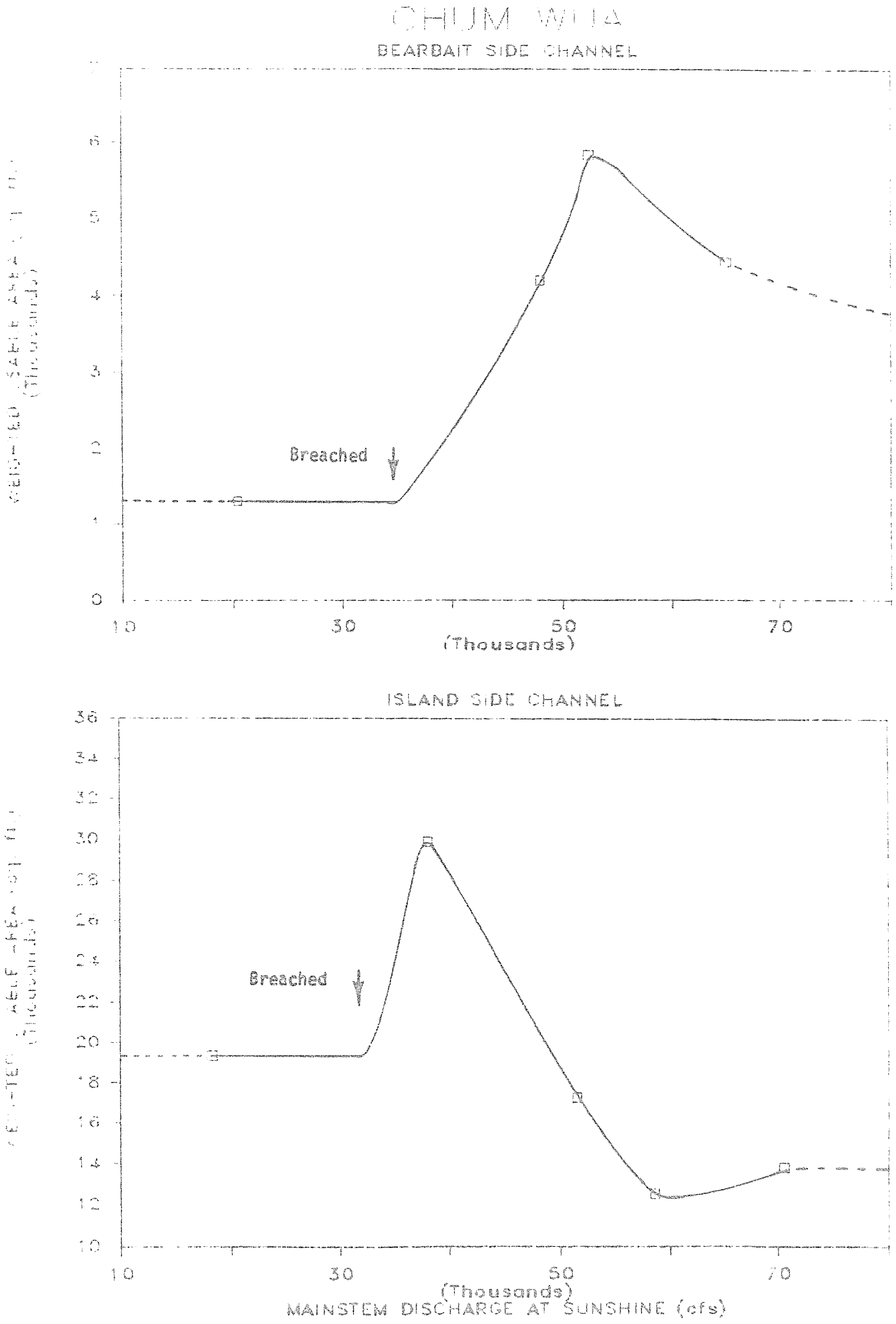
MAINSTEM DISCHARGE	SITE AREA	CHUM WUA	CHUM H. I.
12000	0	0	0.00
15000	0	0	0.00
18000	0	0	0.00
21000	0	0	0.00
24000	0	0	0.00
27000	0	0	0.00
30000	0	0	0.00
33000	0	0	0.00
36000	19000	6200	0.33
39000	53900	32400	0.60
42000	78500	46400	0.59
45000	97100	49700	0.51
48000	115400	44500	0.39
51000	131100	37500	0.29
54000	146900	31100	0.21
57000	160600	26600	0.17
60000	175600	25200	0.14
63000	192000	25300	0.13
66000	207300	26200	0.13
69000	221400	27700	0.13
72000	229000	28500	0.12
75000	233300	29000	0.12

TRAPPER CREEK S. C.

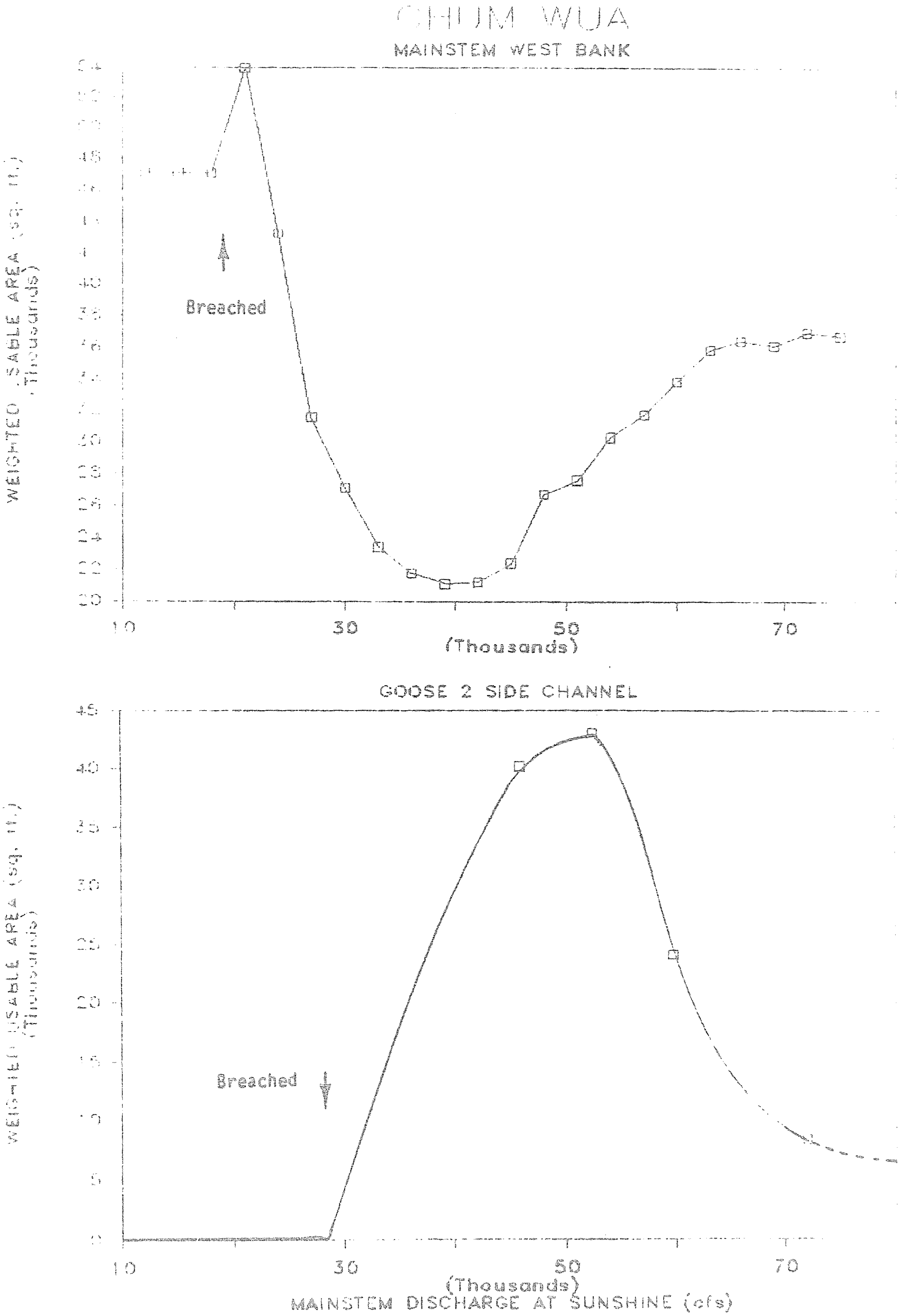
MAINSTEM DISCHARGE	SITE AREA	CHUM WUA	CHUM H. I.
12000	73300	45400	0.62
15000	73300	45400	0.62
18000	73300	45400	0.62
21000	73300	45400	0.62
24000	73300	45400	0.62
27000	73300	45400	0.62
30000	73300	45400	0.62
33000	73300	45400	0.62
36000	75600	44700	0.59
39000	85100	43200	0.51
42000	97100	40500	0.42
45000	108700	36900	0.34
48000	119100	32100	0.27
51000	128900	25700	0.20
54000	137400	19400	0.14
57000	143300	13800	0.10
60000	148800	10600	0.07
63000	154800	10100	0.07
66000	160700	9700	0.06
69000	166100	9500	0.06
72000	169800	9400	0.06
75000	172600	9400	0.05



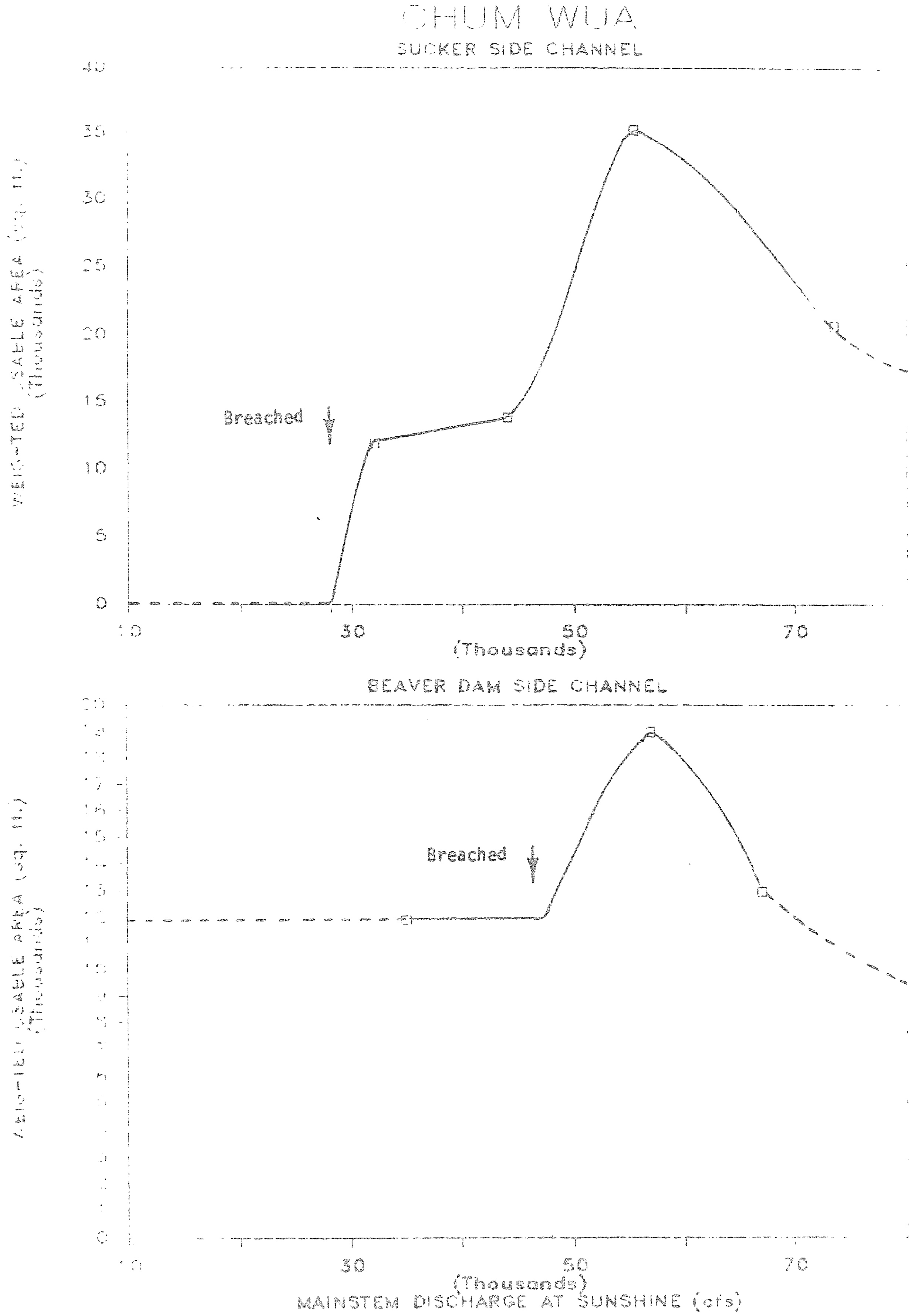
Appendix Figure B-9. Weighted usable area for juvenile chum salmon at the Hooligan Side Channel and Kroto Slough Head study sites as a function of mainstem discharge.



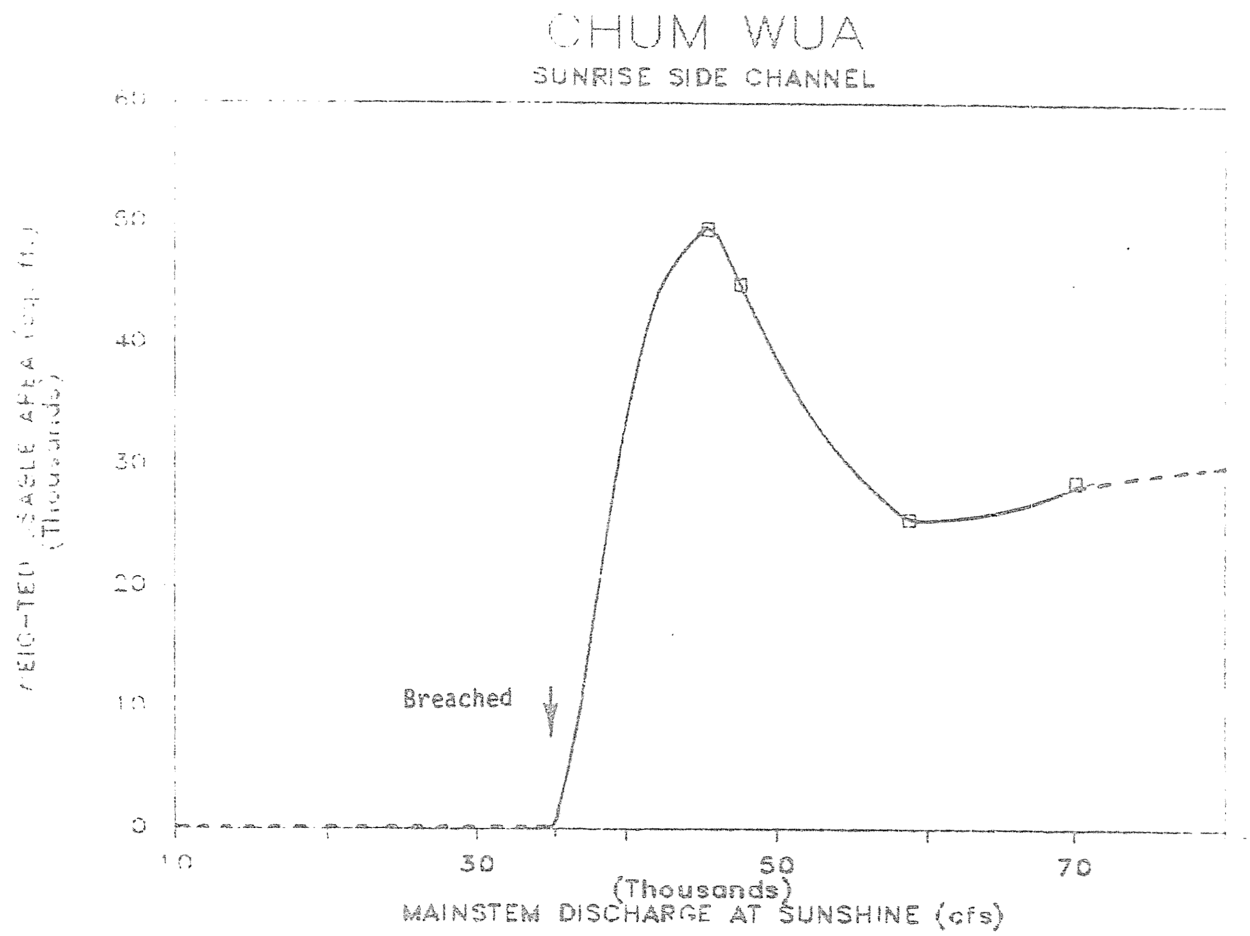
Appendix Figure B-10. Weighted usable area for juvenile chum salmon at the Bearbait and Island Side Channel study sites as a function of mainstem discharge.



Appendix Figure B-11. Weighted usable area for juvenile chum salmon at the Mainstem West Bank and Goose 2 Side Channel study sites as a function of mainstem discharge.



Appendix Figure B-13. Weighted usable area for juvenile chum salmon at the Sucker and Beaver Dam Side Channel study sites as a function of mainstem discharge.



Appendix Figure B-14. Weighted usable area for juvenile chum salmon at the Sunrise Side Channel study site as a function of mainstem discharge.

Appendix Table B-8. Weighted usable areas and habitat indices for juvenile sockeye salmon in lower Susitna River model sites, 1984.

ROLLY CREEK MOUTH

MAINSTEM DISCHARGE	SITE AREA	SOCKEYE WUA	SOCKEYE H. I.
12000	84900	10600	0.12
15000	84900	10600	0.12
18000	84900	10600	0.12
21000	84900	10600	0.12
24000	85300	10600	0.12
27000	88300	11000	0.12
30000	93200	13400	0.14
33000	99800	17600	0.18
36000	108900	22800	0.21
39000	121000	28900	0.24
42000	135000	35500	0.26
45000	152600	43400	0.28
48000	178500	52100	0.29
51000	198800	64400	0.32
54000	213000	75300	0.35
57000	223200	82800	0.37
60000	229800	88200	0.38
63000	235000	93000	0.40
66000	238700	97200	0.41
69000	241600	99900	0.41
72000	243200	100700	0.41
75000	243600	101500	0.42

CASWELL CREEK MOUTH

MAINSTEM DISCHARGE	SITE AREA	SOCKEYE WUA	SOCKEYE H. I.
12000	16200	1350	0.08
15000	16200	1350	0.08
18000	16200	1350	0.08
21000	16200	1350	0.08
24000	16200	1600	0.10
27000	16300	1700	0.10
30000	16700	1900	0.11
33000	17300	2300	0.13
36000	18000	2600	0.14
39000	18900	3100	0.16
42000	19800	3700	0.19
45000	21000	4300	0.20
48000	21800	5000	0.23
51000	22700	5700	0.25
54000	23700	6400	0.27
57000	24600	7200	0.29
60000	25500	7900	0.31
63000	26300	8600	0.33
66000	27200	9200	0.34
69000	27900	10000	0.36
72000	28900	10600	0.37
75000	29700	11400	0.38

BEAVER DAM SLOUGH

MAINSTEM DISCHARGE	SITE AREA	SOCKEYE WUA	SOCKEYE H. I.
12000	11600	6200	0.53
15000	11600	6200	0.53
18000	11600	6200	0.53
21000	11700	6200	0.53
24000	11900	6200	0.52
27000	12200	6400	0.52
30000	12500	6600	0.53
33000	13000	6700	0.52
36000	13400	7000	0.52
39000	13900	7100	0.51
42000	14400	7300	0.51
45000	15000	7500	0.50
48000	15700	7700	0.49
51000	16300	8000	0.49
54000	16800	8200	0.49
57000	17600	8600	0.49
60000	18500	8900	0.48
63000	19700	9400	0.48
66000	20800	10200	0.49
69000	21600	10800	0.50
72000	22100	11000	0.50
75000	22600	11000	0.49

SUCKER SIDE CHANNEL

MAINSTEM DISCHARGE	SITE AREA	SOCKEYE WUA	SOCKEYE H. I.
12000	0	0	0.00
15000	0	0	0.00
18000	0	0	0.00
21000	0	0	0.00
24000	0	0	0.00
27000	1600	0	0.00
30000	8500	1200	0.14
33000	14900	1800	0.12
36000	16900	1700	0.10
39000	19400	1500	0.08
42000	23600	1200	0.05
45000	29600	1200	0.04
48000	37100	2600	0.07
51000	46600	4000	0.09
54000	57900	5000	0.09
57000	66900	5300	0.08
60000	71300	5400	0.08
63000	73900	5500	0.07
66000	75900	5600	0.07
69000	77300	5600	0.07
72000	78100	5600	0.07
75000	78300	5600	0.07

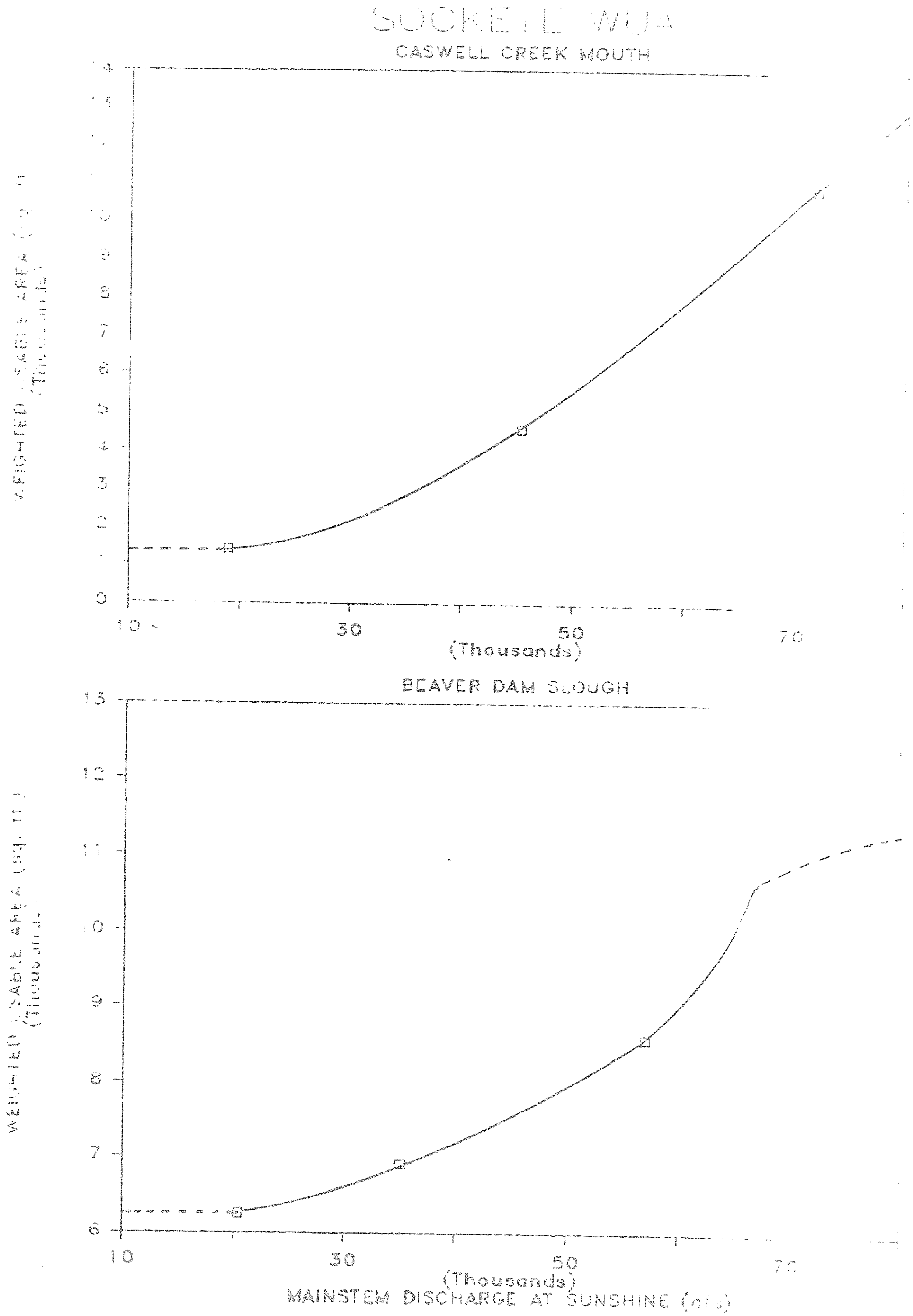
BEAVER DAM SIDE CHANNEL

MAINSTEM DISCHARGE	SITE AREA	SOCKEYE WUA	SOCKEYE H. I.
12000	18900	3000	0.16
15000	18900	3000	0.16
18000	18900	3000	0.16
21000	18900	3000	0.16
24000	18900	3000	0.16
27000	18900	3000	0.16
30000	18900	3000	0.16
33000	18900	3000	0.16
36000	18900	3000	0.16
39000	18900	3000	0.16
42000	18900	3000	0.16
45000	19900	3000	0.15
48000	22400	3200	0.14
51000	28000	3700	0.13
54000	32600	4100	0.13
57000	35700	4300	0.12
60000	38000	4200	0.11
63000	39600	3900	0.10
66000	40800	3600	0.09
69000	41500	3200	0.08
72000	41900	3000	0.07
75000	42100	2800	0.07

Appendix Table B-8. Continued.

SUNRISE SIDE CHANNEL			
MAINSTEM DISCHARGE	SITE AREA	SOCKEYE WUA	SOCKEYE H. I.
12000	0	0	0.00
15000	0	0	0.00
18000	0	0	0.00
21000	0	0	0.00
24000	0	0	0.00
27000	0	0	0.00
30000	0	0	0.00
33000	0	0	0.00
36000	19000	400	0.02
39000	53900	4700	0.09
42000	78500	5800	0.07
45000	97100	5800	0.06
48000	115400	3400	0.03
51000	131100	3200	0.02
54000	146900	3100	0.02
57000	160600	3000	0.02
60000	175600	3000	0.02
63000	192000	3100	0.02
66000	207300	3100	0.01
69000	221400	3200	0.01
72000	229000	3200	0.01
75000	233300	3200	0.01

SUNSET SIDE CHANNEL			
MAINSTEM DISCHARGE	SITE AREA	SOCKEYE WUA	SOCKEYE H. I.
12000	49562	7182	0.14
15000	49562	7182	0.14
18000	49562	7182	0.14
21000	49562	7182	0.14
24000	49562	7182	0.14
27000	64118	7213	0.11
30000	69129	7129	0.10
33000	78488	6738	0.09
36000	89472	6493	0.07
39000	97943	6639	0.07
42000	106320	6828	0.06
45000	122338	7412	0.06
48000	135476	7529	0.06
51000	149248	7108	0.05
54000	165990	6643	0.04
57000	173483	6006	0.03
60000	188419	6682	0.04
63000	194419	6275	0.03
66000	203000	6740	0.03
69000	206972	6850	0.03
72000	210728	7124	0.03
75000	215861	7861	0.04



Appendix Figure B-15. Weighted usable area for juvenile sockeye salmon at the Caswell Creek and Beaver Dam tributary study sites as a function of mainstem discharge.

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APPENDIX C

COMPARISON OF THE IFIM AND RJHAB MODELLING TECHNIQUES AT TWO SELECTED SITES

DRAFT

INTRODUCTION

In 1983, two techniques were used to model the effects of mainstem discharge on juvenile salmon habitat within the middle Susitna River. The Instream Flow Incremental Methodology (IFIM) (Bovee 1982) was used at seven sites (Hale et al. 1984) while the RJHAB habitat model developed in Marshall et al. (1984) was used to model six other sites. Since studies of the effects of mainstem discharge on juvenile salmon habitat within the lower Susitna River were begun in 1984, it was desirable to compare these two modelling methods. Both methods were used, therefore, at the same transects within two sites to compare results from the two techniques.

METHODS

Trapper Creek Side Channel (RM 91.6) and Island Side Channel (RM 63.2) were selected as sampling sites for this comparative study because they represent two different channel types of the lower Susitna River. Trapper Creek Side Channel is a simple straight channel. Island Side Channel is a more complex, winding channel. Further descriptions and photos of these two sites are contained in Quane et al. (1985).

Descriptions of the two modelling techniques will not be presented here. Detailed descriptions of the IFIM are presented in Appendix D of this report and Bovee (1982), and summarized in Section 2.0 of this report. The original RJHAB model was first developed and described in Marshall et al. (1984) and modifications were described in Section 2.0 of this report.

Both techniques entail taking depth, velocity and cover or substrate measurements spaced at intervals across transects running at right angles to the channel. Far fewer measurements are taken for the RJHAB model than for the IFIM models. A hydraulic model is developed with the IFIM and the model is run on a main frame computer. No hydraulic model is developed by the RJHAB and the model runs on a spreadsheet with a microcomputer. The IFIM model can generate estimates of equivalent optimum habitat called weighted usable areas (WUA's) with any flow within its calibration range, while the RJHAB model only calculates WUA's at discharges for which measurements are taken. Therefore, it is necessary to interpolate between point measurements generated by the RJHAB model. The RJHAB model does have the advantage of being able to run in areas heavily influenced by mainstem backwater or sloughs with flows less than 5 cfs. The measurements and data analysis for the RJHAB model were taken by different investigators than those who took the IFIM measurements and analyzed them.

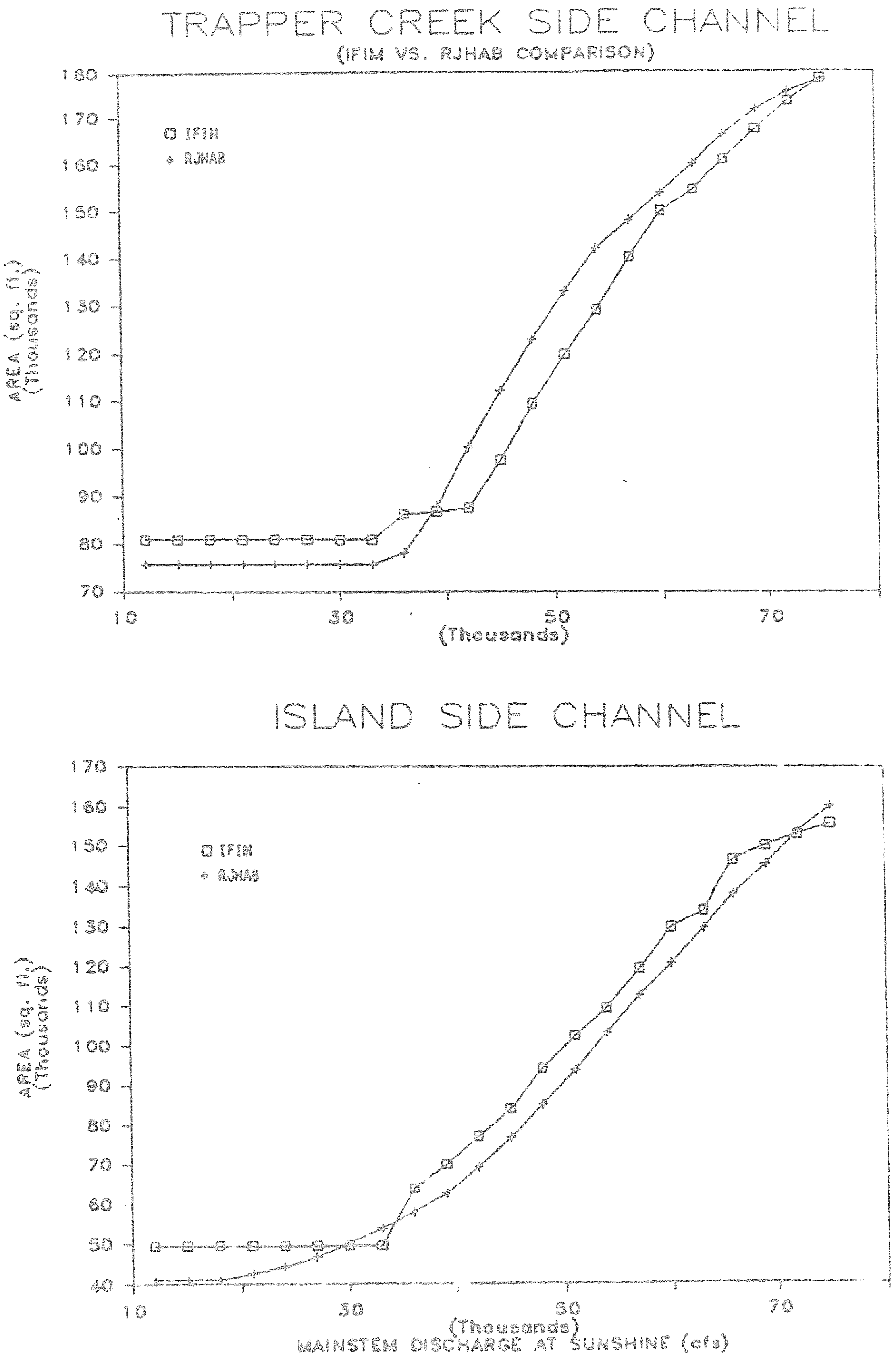
The RJHAB model uses measurements at an additional upper transect within each of the sites. This upper area was very similar to lower sections of the site, and therefore would not change comparability of the two methods. The IFIM presents results of the analysis on the basis of a 1000 foot reach, while the RJHAB model presents WUA's for the site. Therefore, the length of each site as used in the RJHAB model was calculated and WUA's were adjusted to the basis of a 1000 foot reach.

At Island Side Channel, two additional partial transects were put in for IFIM analysis of the site, and no RJHAB measurements were taken at these transects. A trial run which minimized the effect of these two additional transects showed only very minor changes in WUA.

RESULTS

An IFG-2 IFIM model was run at Island Side Channel and hydraulic data were collected at a side channel flow of 338 cfs (Appendix D). At Trapper Creek Side Channel, hydraulic data for an IFG-4 IFIM model were collected at flows of 16, 32, and 389 cfs. Habitat data for the RJHAB model were collected four times at Trapper Creek Side Channel and five times at Island Side Channel and the RJHAB models at both sites were evaluated as "good" (Table 6).

The modelled response of area at the Trapper Creek and Island side channel sites to changes in discharge was almost identical for both the IFIM and RJHAB modelling techniques (Appendix Figure C-1). Differences in areas below the overtopping flow at Island Side Channel are probably due to the IFIM not being able to model flows below 5 cfs while the RJHAB WUA was measured at a flow of less than one cfs. Other differences are readily attributable to sampling error. Since juvenile chinook and chum salmon are the two salmon species which make the heaviest use of side channels for rearing, only WUA results from these two species will be presented here.

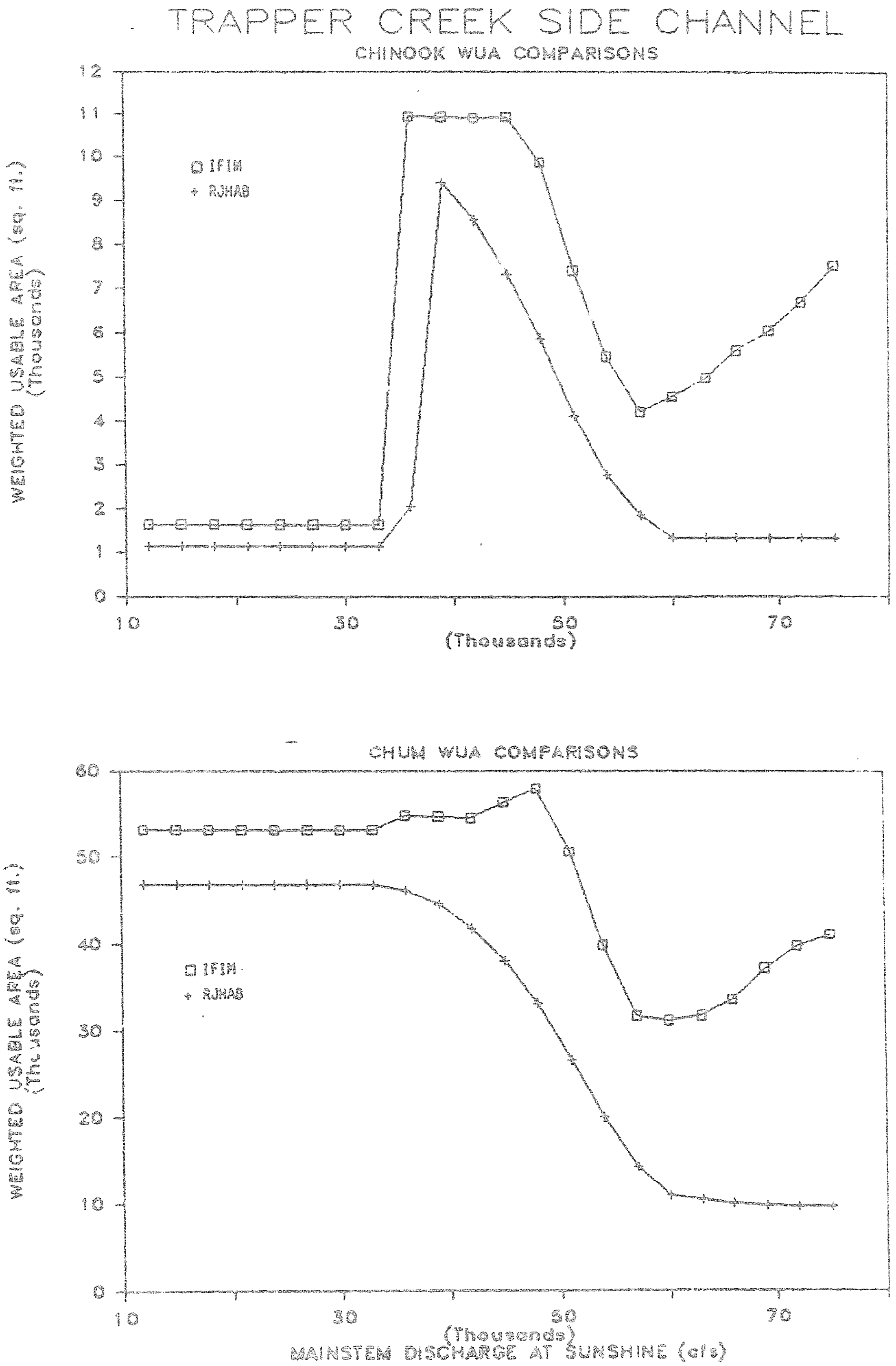


Appendix Figure C-1. Comparison of site areas calculated with the RJHAB and IFIM modelling techniques for the Trapper Creek and Island Side Channel study sites.

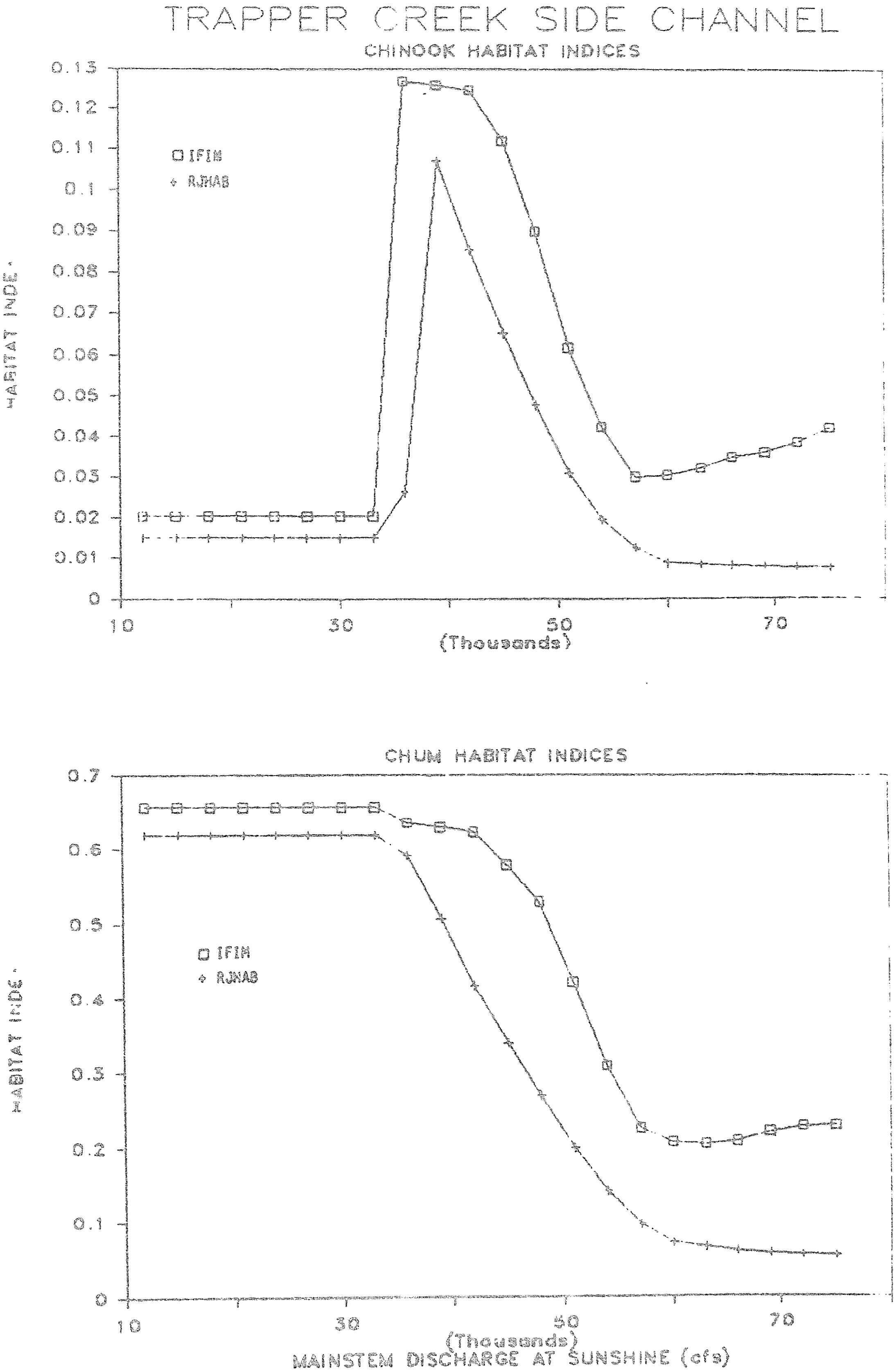
At Trapper Creek Side Channel, the shape of the WUA curves for both species were basically the same for both modelling methods (Appendix Figure C-2). The RJHAB model appears to consistently underestimate the amount of WUA in comparison to the IFIM model. The underestimation of WUA by the RJHAB model leads to smaller habitat indices although the shapes of the habitat index curves are similar for both techniques (Appendix Figure C-3).

At Island Side Channel, on the other hand, WUAs from the two modelling methods do not compare closely (Appendix Figure C-4). The chinook and chum WUA response curves look more similar to each other than do the modelling techniques. Peaks in WUA for the RJHAB model occur at approximately 40,000 cfs while the IFIM model predicts a peak WUA at approximately 60,000 cfs. The IFIM model does predict a chinook salmon WUA of 6,230 ft^2 to 6,600 ft^2 at side channel flows of 6 to 11 cfs which corresponds to the peak in the RJHAB model where a measurement was taken at a side channel flow of approximately 10 cfs.

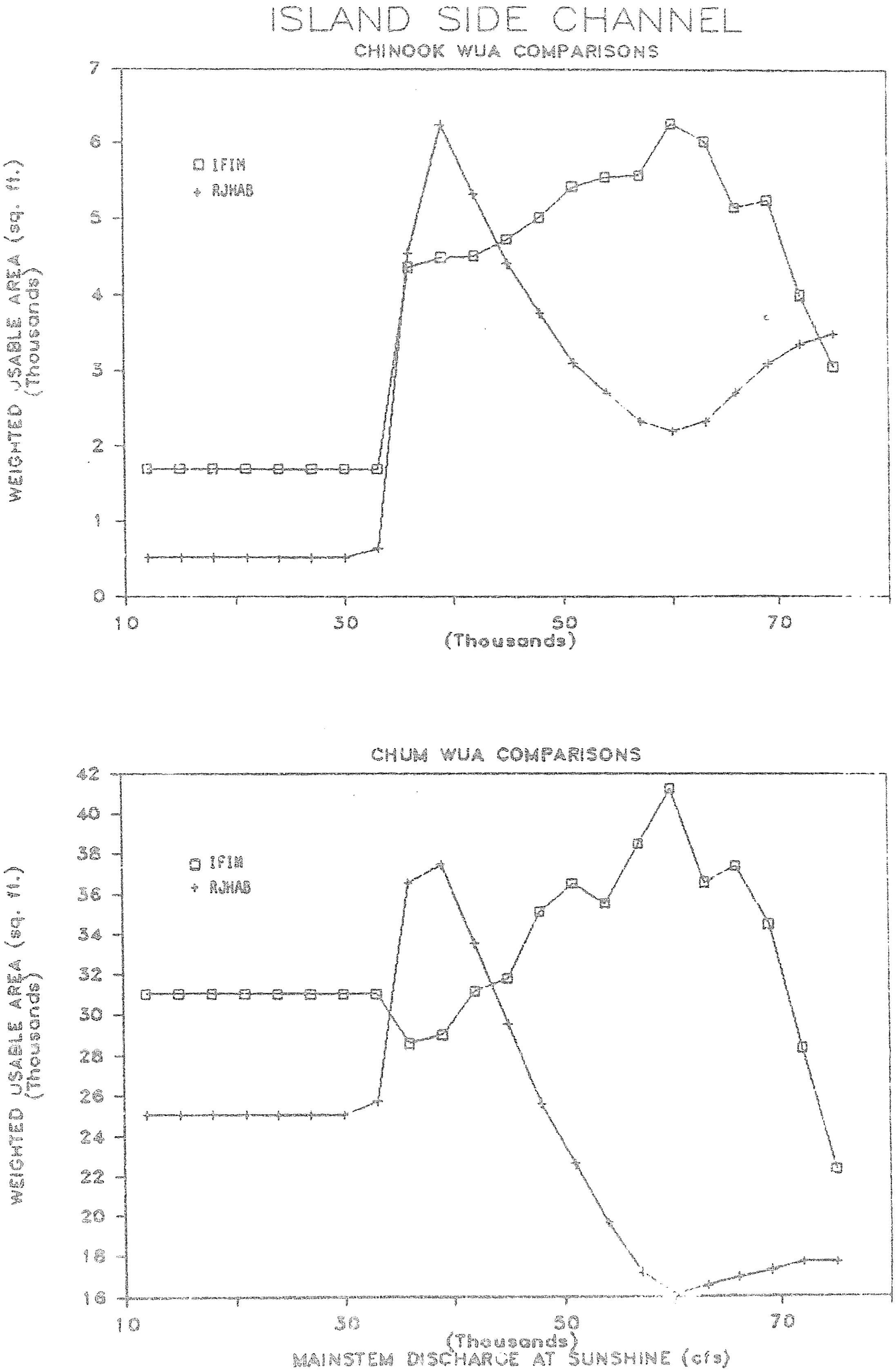
When habitat indices are calculated for both methods at Island Side Channel, differences between the two techniques appear smaller (Appendix Figure C-5). The RJHAB model shows a peak habitat index for chinook salmon at approximately 39,000 cfs which the IFIM model would also show at side channel flows of 6 to 11 cfs. Chum habitat indices for both techniques decrease after overtopping although the RJHAB habitat indices drop off more steeply.



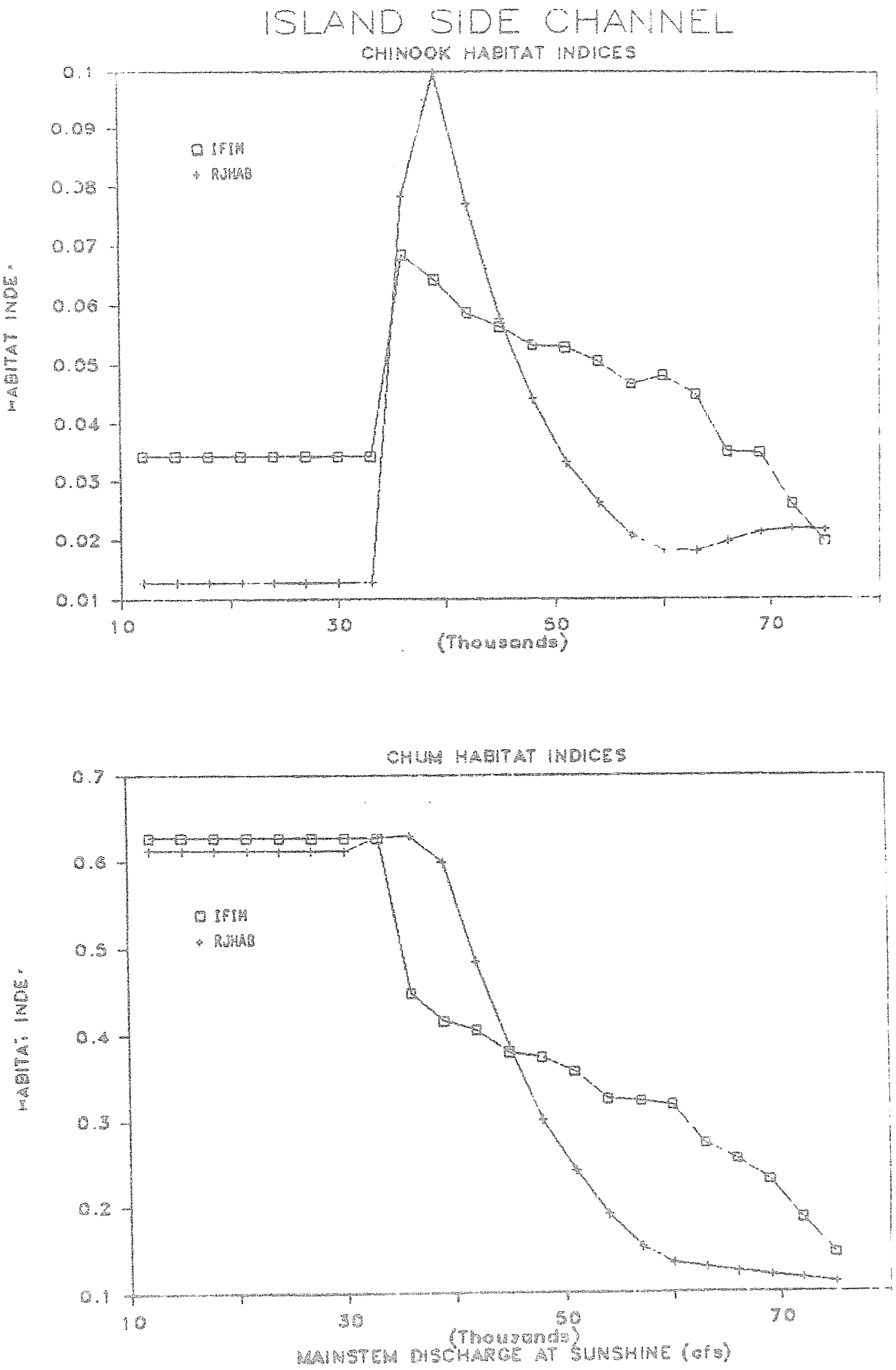
Appendix Figure C-2. Comparison of weighted usable areas calculated with the RJHAB and IFIM modelling techniques for juvenile chinook and chum salmon at Trapper Creek Side Channel, 1984.



Appendix Figure C-3. Comparison of habitat indices calculated with the RJHAB and IFIM modelling techniques for juvenile chinook salmon at Trapper Creek Side Channel, 1984.



Appendix Figure C-4. Comparison of weighted usable areas calculated with the RJHAB and IFIM modelling techniques for juvenile chinook and chum salmon at Island Side Channel, 1984.



Appendix Figure C-5. Comparison of habitat indices calculated with the RJHAB and IFIM modelling techniques for juvenile chinook and chum salmon at Island Side Channel, 1984.

DISCUSSION

The two modelling methods compared very favorably at calculating areas within the two sites. The shape of the chum and chinook WUA and habitat index responses at Trapper Creek Side Channel were very similar. The RJHAB model consistently underestimated WUA in comparison to the IFIM model. This is probably due to the RJHAB model not taking into account the area between the shoreline cell and the cell located one-third of the way across the channel. This area is often marginal habitat with barely suitable velocities.

At Island Side Channel, large differences in WUA can also be attributed, in part, to the RJHAB model not taking into account peripheral marginal habitat more than six feet from shore. This difference is also reflected in the habitat indices where the proportion of usable area drops off more quickly for the RJHAB model. The differences in WUA below the overtopping flow can be attributed to the fact that the IFIM model does not run at flows less than five cfs while actual flows at discharges below the overtopping one are less than one cfs (Quane et al. 1985).

Other sources of differences between the two methods may be attributed to errors in the rating curves between side channel flow and mainstem discharge. For example, the rating curves calculated a side channel flow of 49 cfs at a mainstem discharge of 33,000 cfs for Island Side Channel. Small changes in mainstem discharge near the overtopping flow lead to big changes in WUA which chopped off the top of the chinook salmon WUA peak for the IFIM method.

The effects of sampling errors in data collection on WUA estimates from both the RJHAB and IFIM techniques are unknown. Since many more measurements are taken for the IFIM, it should be less susceptible to sampling errors. Because only one IFIM measurement was taken at Island Side Channel at a flow of 338 cfs, however, the reliability of modelling flows as small as 5 cfs is unknown. It seems reasonable to assume that an IFG-4 model at Island Side Channel would have given somewhat different results than did the IFG-2 model. The RJHAB model works well in situations where the primary effect of discharge is due to backwater and the IFIM model cannot be used or works poorly.

In summary, the RJHAB model generally gives lower WUA estimates than does the IFIM methodology. Also peaks in WUA are often narrower for the RJHAB model. Both models show the same general trends in the habitat indices for chum and chinook salmon although the RJHAB model is more sensitive to increases in velocity and depth which decrease the habitat indices more quickly. Since the habitat indices for both sites calculated using both techniques are not appreciably different, analysis of trends and optimal flows by use of habitat indices would lead to similar conclusions using both methods. Comparisons of the IFIM with other instream flow methodologies have also shown differences in output, and no one method has yet been proven best (Annear and Conder 1984).

LITERATURE CITED

Annear, T.C., and A.L. Conder. 1984. Relative bias of several fisheries instream flow methods. North American Journal of Fisheries Management 4:531-539.

Bovee, K.D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Instream Flow Information Paper. No. 12. U.S. Fish and Wildlife Service. FWS/035-82/26.

Hale, S.S., P.M. Suchanek, and D.C. Schmidt. 1984. Modelling of juvenile salmon and resident fish habitat. Part 7 in Schmidt. D.C., S.S. Hale, D.L. Crawford, and P.M. Suchanek (eds.). 1984. Resident and juvenile anadromous fish investigations (May - October 1983). Susitna Hydro Aquatic Studies. Report No. 2. Alaska Department of Fish and Game. Anchorage, Alaska.

Marshall, R.P., P.M. Suchanek, and D.C. Schmidt. 1984. Juvenile salmon rearing habitat models. Part 4 in Schmidt, D.C., S.S. Hale, D.L. Crawford, and P.M. Suchanek (eds.). 1984. Resident and juvenile anadromous fish investigations (May - October 1983). Susitna Hydro Aquatic Studies. Report No. 2. Alaska Department of Fish and Game. Anchorage, Alaska.

Quane, T., P. Morrow, I. Queral, T. Keklak, and T. Withrow. 1985. Technical memorandum in support of Task 14 (Lower River Resident and Juvenile Anadromous Fish Studies) Alaska Department of Fish and Game, Susitna Aquatic Studies. Anchorage, Alaska.

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APPENDIX D

HYDRAULIC MODELS FOR USE IN ASSESSING THE REARING HABITAT OF JUVENILE SALMON IN SIX SIDE CHANNELS OF THE LOWER SUSITNA RIVER

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ABSTRACT

Six side channels (Island, Mainstem West Bank, Circular, Sauna, Sunset, and Trapper Creek) in the lower reach of the Susitna River were evaluated using an Instream Flow Incremental Methodology (IFIM) physical habitat simulation (PHABSIM) modelling approach to evaluate the effects that site flow and mainstem discharge have on rearing juvenile salmon habitat. These sites were thought to contain potential habitat conditions for rearing juvenile salmon and were chosen to range greatly in size, shape, and overtopping discharge.

Six hydraulic simulation models (either IFG-2 or IFG-4) were calibrated to simulate depths and velocities associated with a range of site-specific flows at these six modelling study sites. Comparisons between

corresponding sites of simulated and measured depths and velocities indicate that the calibrated models provide reliable estimates of depths and velocities within their recommended calibration ranges.

The recommended calibration ranges over which these models can hydraulically simulate the habitat of rearing juvenile salmon is: Island Side Channel from 35,000 to 70,000 cfs mainstem discharge; Mainstem West Bank Side Channel from 18,000 to 48,000 cfs; Circular Side Channel from 36,000 to 63,000 cfs; Sauna Side Channel from 44,000 to 63,000 cfs; Sunset Side Channel from 32,000 to 67,000 cfs; and Trapper Creek Side Channel from 20,000 to 66,000 cfs.

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INTRODUCTION

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About 40% of the annual discharge of the lower Susitna River at Park's Highway bridge originates from the mainstem Susitna River above the confluence of the Talkeetna and Chulitna Rivers. Thus, operation of the proposed hydroelectric project will alter the natural flow regime of this lower river reach beyond the normal weekly variations in flow which occur naturally during the open water season.

One of the predominate aquatic habitat types in this lower river reach which maybe affected by such flow alternations are side channels. Side channel areas in this river reach currently provide habitat for rearing juvenile salmon. The quantity and quality of juvenile salmonid rearing habitat in side channels in this river reach is dependent on a multitude of interrelated habitat variables, including water depth and velocity, which are intimately related to mainstem discharge.

This appendix presents results of the physical habitat modelling simulation efforts that Alaska Department of Fish and Game (ADFG) Su Hydro personnel conducted in the open water season of 1984. The objective of the study was to provide calibrated hydraulic simulation models for selected Task 14 lower river juvenile salmon habitat modelling study sites. The approach of the study was to apply a methodology which utilizes water depth and velocity as the dominant hydraulic variables to quantify the responses of rearing habitat to changes in site flow and mainstem discharge. The methodology used was the system developed by the U.S. Fish and Wildlife Service (USF&WS) Instream Flow Group (IFG) using the Instream Flow Incremental Methodology (IFIM) Physical Habitat

Simulation (PHABSIM) modelling system (IFG 1980, Bovee 1982). The calibrated hydraulic simulation models will be utilized to assess how site flows and mainstem discharge affect juvenile salmon rearing habitat in side channel habitats of the lower Susitna River reach.

METHODS

Analytical Approach

The current most accepted methodology used for assessing habitat responses to flow variations is the USFWS, IFIM, PHABSIM modelling system. The IFIM, PHABSIM modelling system is a collection of computer programs used to simulate both the available hydraulic conditions and usable habitat at a study site for a particular species/life phase as a function of flow. It is based on the theory that changes in riverine habitat conditions can be estimated from a sufficient hydraulic and biologic field data base. It is intended for use in those situations where flow regime and channel structure are the major factors influencing river habitat conditions.

The modelling system is based on a three step approach. The first step uses field data to calibrate hydraulic simulation models to forecast anticipated changes in physical habitat variables important for the species/life phase under study as a function of flow. The second step involves the collection and analysis of biological data to determine the behavioral responses of a particular species/life phase to selected physical habitat variables important for the species/life phase under study. This information is used to develop weighted behavioral response criteria curves (e.g., utilization curves, preference curves, or suitability curves). The third step combines information gained in the first two steps to calculate weighted usable area (WUA) indices of habitat usability as a function of flow for the species/life phase under study.

Hydraulic modelling is of central importance to the PHABSIM system. The primary purpose of incorporating hydraulic modelling into the analytical approach is to make the most efficient use of limited field observations to forecast hydraulic attributes of riverine habitat (depths and velocities) under a broad range of unobserved streamflow conditions.

The IFG specifically developed two hydraulic models (IFG-2 and IFG-4) during the late 1970's to assist fisheries biologists in making quantitative evaluations of effects of streamflow alterations on fish habitat. The IFG-2 hydraulic model is a water surface profile program that is based on open channel flow theory and formulae. The IFG-2 model can be used to predict the horizontal distribution of depths and mean column velocities at 100 points along a cross section for a range of streamflows with only one set of field data. The IFG-4 model provides the same type of hydraulic predictions as the IFG-2 model, but it is more strongly based on field observations and empiricism than hydraulic theory and formulae. Although a minimum of two data sets are required for calibrating the IFG-4 model, three are recommended. Either model can be used to forecast depths and velocities occurring in a stream channel over a broad range of streamflow conditions.

The IFG-4 model, which is based upon a greater number of observed sets of field data (i.e. flow levels), generally can be used to model a greater range of flow conditions than the IFG-2 model. Additionally, since the IFG-4 model is more dependent upon observed depths and velocities than the IFG-2 model, predicted depths and velocities can be directly compared with the observed values. This comparison is a useful tool for verifying the models.

Both models are most applicable to streams of moderate size and are based on the assumption that steady flow conditions exist within a rigid stream channel. A stream channel is rigid if it meets the following two criteria: (1) it must not change shape during the period of time over which the calibration data are collected, and (2) it must not change shape while conveying streamflows within the range of those that are to be simulated. Thus a channel may be "rigid" by the above definition, even though it periodically (perhaps seasonally) changes course. Streamflow is defined as "steady" if the depth of flow at a given location in the channel remains constant during the time interval under consideration (Trihey 1980).

In this analysis, all streamflow rates were referenced to the average daily discharge of the Susitna River at the U.S. Geological Survey (USGS) stream gage at Sunshine, Alaska (station number 15292780). This location was selected as the index station primarily because it is the gage located near the center of the river segment that is of greatest interest in this particular analysis. The target mainstem discharge range for data collection was from 12,000 to 75,000 cfs.

species-specific life history requirements. Criteria for application of the representative concept are less restrictive, enabling this concept to be used when only limited biological information is available or when critical habitat conditions cannot be identified with any degree of certainty.

In the critical concept, a study area is selected because one or more of the physical or chemical attributes of the habitat are known to be of critical importance to the fish resource. That is, recognizable physical or chemical characteristics of the watershed hydrology, instream hydraulics, or water quality are known to control species distribution or relative abundance within the study area. Because of this, an evaluation of critical areas will provide a meaningful index of species response in the overall critical study area.

The representative concept acknowledges the importance of physical habitat variables throughout the entire study stream for sustaining fish populations. Thus, under the representative concept approach, study areas are selected for the purpose of quantifying relationships between streamflow and physical habitat conditions important for species/life phase under study at selected key locations (representative reaches) that collectively exemplify the general habitat characteristics of the entire river segment inhabited by the species/life phase under study.

For this study, an adaptation of the representative concept was the approach used to assess how mainstem discharges affect the rearing habitat of juvenile salmon in the side channel habitat of the Kashwitna to Talkeetna reach of the Susitna River. The six specific sites modelled in this study were chosen by ADF&G Su Hydro Resident and Juvenile Anadromous (RJ) project personnel in conjunction with ADF&G Su Hydro Aquatic Habitat and Instream Flow Study (AH) project and E. Woody Trihey and Associates (EWTA) personnel from lower river side channels which met the following basic criteria:

1. The sites were chosen to range greatly in size, shape, and overtopping discharge;

2. The sites were thought to contain potential habitat conditions for rearing juvenile salmon;

3. The sites were judged by AH project and EWTA personnel to be readily modelled using IFG methods;

4. The sites were accessible by boat at normal mainstem discharges during the open-water season; and,

5. The sites were above Kashwitna landing and therefore much easier to sample for logistical purposes.

The six sites chosen for modelling complemented other sites modelled using the RJHAB method. All were side channels as the majority of potential habitat in the lower river is composed of side channel habitat, and much of the other habitat is affected primarily by mainstem backwater which is difficult to model with the IFG model.

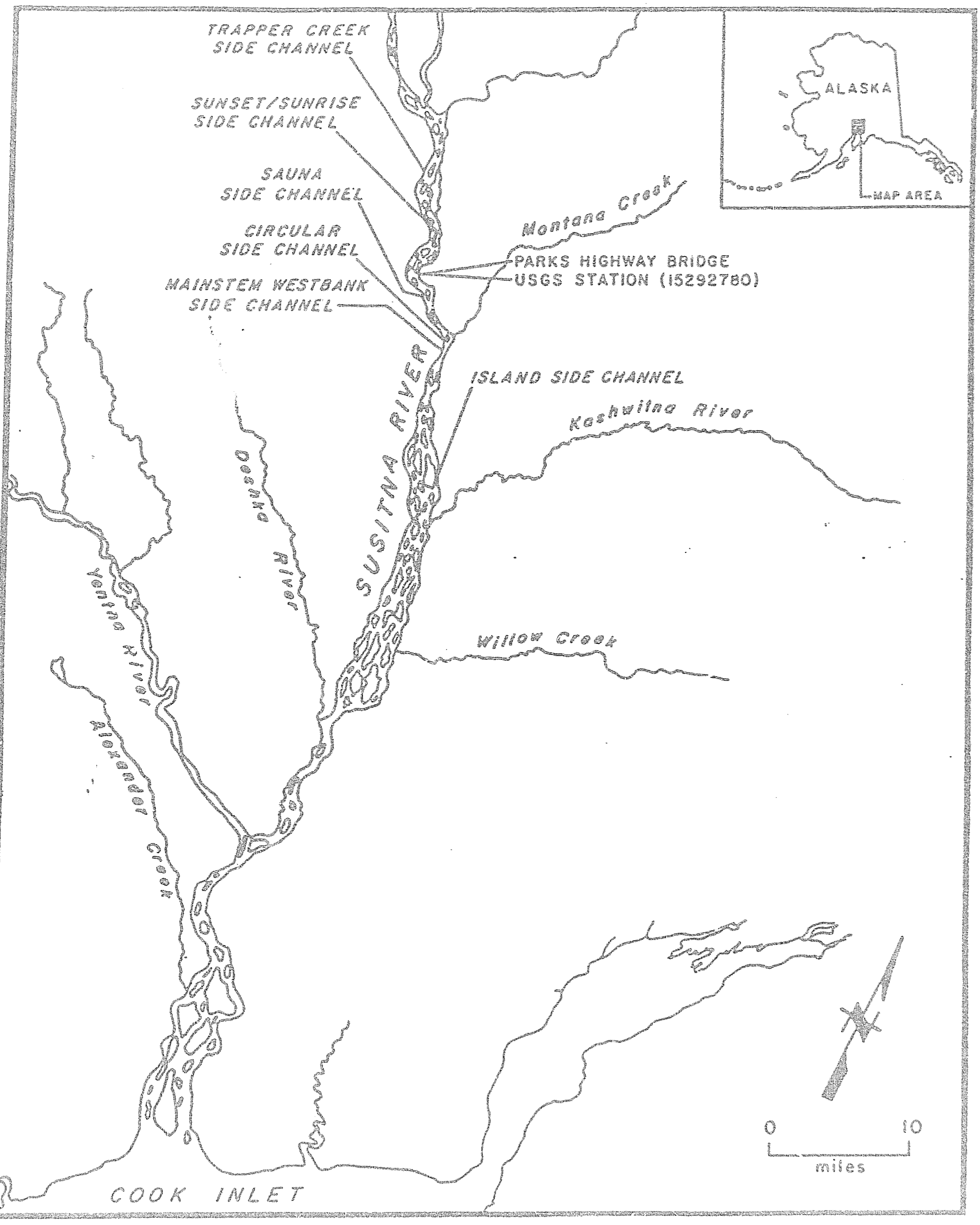
Appendix Figure D-1 shows the location of each of these six study sites selected for study based on the above criteria. The river mile location of each of the six sites is presented in Table D-1.

General Techniques for Data Collection

A study reach was selected for detailed evaluation in each of the six side channel sites. The length of the reach was determined by placing enough transects within the area to adequately represent the major macrohabitat types of the particular side channel area.

Cross sections were located within each study reach following field methods described in Bovee and Milhous (1978) and Trihey and Wegner (1981). Cross sections were located to facilitate collection of hydraulic and channel geometry measurements of importance in evaluating flow effects on salmon rearing habitat. Field data were obtained to describe a representative spectrum of water depth and velocity patterns, cover, and substrate composition at each side channel reach.

The number of cross sections established at the study reaches varied from four to eight. The end points of each cross sections were marked with 30-inch steel rods (headpins) driven approximately 28 inches into the ground. The elevation of each headpin was determined by differential leveling using temporary benchmarks set at assumed elevations of 100.00 feet.



Appendix Figure D-1. Location of the six IFG hydraulic modelling sites in the lower Susitna River.

Appendix Table D-1. The six lower river IFG modelling sites with corresponding river mile location.

Side Channel Site	River Mile
Island Side Channel	63.2
Mainstem West Bank Side Channel	74.4
Circular Side Channel	75.3
Sauna Side Channel	79.8
Sunset Side Channel	86.9
Trapper Creek Side Channel	91.6

Cross section profiles were measured with a level, survey rod, and fiberglass tape. Horizontal distances were recorded to the nearest 1.0 foot and streambed elevations to the nearest 0.1 foot. Water surface elevations at each cross section in the study site were determined to the nearest 0.01 feet by differential leveling or reading staff gages located on the cross section.

Streambed elevations used in the hydraulic models were determined by making a comparison between the surveyed cross section profile and the cross section profiles derived by subtracting the flow depth measurements at each cross section from the surveyed water surface elevation at each calibration flow (Trihey 1980).

A longitudinal streambed profile (thalweg profile) was surveyed and plotted to scale for each modeling site (Quane et al. 1985).

The water surface elevation at which no flow occurs (stage of zero flow) at each cross section in the study site was determined from the streambed profile. If the cross section was not located on a hydraulic control, then the stage of zero flow was assumed equal to that of the control immediately downstream of the cross section.

Discharge measurements were made using a Marsh-McBirney or Price AA velocity meter, topsetting wading rod, and fiberglass tape. Discharge measurements were made using standard field techniques (Buchanan and Somers 1969; Bovee and Milhous 1978; Trihey and Wegner 1981). Depth and velocity measurements at each calibration flow were recorded for the same respective points along the cross sections by referencing all horizontal measurements to the left bank headpin.

Cover and substrate values were also determined for each cell along modelling transects. Methods described in Schmidt et al. (1984) were used to code cover (Appendix Table 2). Substrate categories were classified by visual observation employing the substrate classifications presented in Appendix Table 3. The distribution of various substrate types was indicated on field maps. Substrates were classified using a single or dual code. In those instances that a dual code was used, the first code references the most predominant (i.e., 70% rubble/30% cobble = RU/CO).

General Techniques for Calibration

The calibration procedure for each of the hydraulic models was preceded by field data collection, data reduction, and refining the input data. The field data collection entailed establishing cross sections along which hydraulic data (water surface elevations, depths, and velocities) were obtained at each of the different calibration flows. The data reduction entails determining the streambed and water surface elevations, velocity distribution and stage of zero flow for each cross section; and, determining a mean discharge for all the cross sections in the study site. Refining the input data entailed adjusting the water surface elevations and velocities so that the forecasted data agreed more closely to the observed. A model was considered calibrated when: 1) the majority of predicted water surface profiles were within ±0.05 ft

Table D-2. Percent cover and cover type categories.

Substrate	Code	% Cover	Code
silt, sand (no cover)	1	0-5	.1
emergent vegetation	2	6-25	.2
aquatic vegetation	3	26-50	.3
1-3" gravel	4	51-75	.4
3-5" rubble	5	76-100	.5
5" cobble, boulder	6		
debris	7		
overhanging riparian vegetation	8		
undercut bank	9		

Appendix Table D-3. Substrate classifications.

Substrate	Particle Size	Classification
Silt	Silt	1
		2
Sand	Sand	3
		4
Small Gravel	1/8-1"	5
		6
Large Gravel	1-3"	7
		8
Rubble	3-5"	9
		10
Cobble	5-10"	11
		12
Boulder	10"	13

of the observed elevations and 2) the majority of predicted velocities were within ±0.10 ft/sec of the measured velocities. A calibrated IFG-4 model gives velocity adjustment factors in the range of 0.9 to 1.1, and relatively few velocity prediction errors. The velocity adjustment factor is the ratio of the computed (observed) discharge to the predicted discharge.

An IFG-2 model does not have velocity adjustment factors and must be reviewed with the observed data before its considered calibrated.

General Techniques for Verification

The verification of how well each of these six hydraulic models simulated their respective site flows was performed by hydraulic engineers of EWT&A. The approach they used to assess the quality of each model was based on two levels of criteria. The first was qualitative evaluation of four separate sub-criteria. These sub-criteria were:

1. How well does the model conform to the established IFG and EWT&A guidelines?

2. How well does the extrapolation range of the model conform to the desired range?

3. Are the models appropriate for the species and life stage being considered?

4. How well do the ranges of depth and velocities of the forecasted data conform to the ranges of depth and velocity of the suitability criteria curves being considered based on a "visual" evaluation?

After the first level of qualitative evaluation was performed, an overall rating was given to the various segments of each model. The ratings given were excellent, good, acceptable, and unacceptable. Figures depicting these rating are presented for each site in the results section. The second level in the verification process required a statistical analytical evaluation of the models calibration. It was only performed when the forecast capabilities of either the IFG-2 and IFG-4 model were not given an excellent rating in the level one evaluation. For a detailed explanation of the verification analysis see Appendix Attachment 1.

RESULTS

The results of the physical habitat simulation modelling studies are presented below by study site. The six lower river side channel IFG modelling sites with type of hydraulic model used, dates calibration flows were measured, and corresponding site specific flows and mainstem discharges for the open water period in 1984 are presented in Appendix Table D-4. For each study site, a general site description, a summary of data collected at the study sites, a description of the model calibration procedures used to calibrate the model for the study site, the verification of the model at the study site, and the recommended application of the model for the study site are presented.

Appendix Table D-4. The six lower river side channel IFG modelling sites with type of hydraulic model used, dates calibration flows measured, and corresponding site specific flows and mainstem discharges for the open water period in 1984.

Side Channel Site (RM)	Type of Hydraulic Model	Date Calibration Flow Measured	Site Specific Flow (cfs)	Mainstem Discharge at Sunshine (cfs)
Island Side Channel (63.2)	IFG-2	July 25	338	56,100
Mainstem West Bank (74.4)	IFG-4	September 2	450	32,000
		September 20	310	30,500
		September 25	6	
Circular Side Channel (75.3)	IFG-4	July 24	204	55,200
		August 17	50	42,500
Sauna Side Channel (79.8)	IFG-2	July 23	52	52,000
Sunset Side Channel (86.9)	IFG-4	July 22	496	57,800
		August 17	127	42,500
Trapper Creek Side Channel (91.6)	IFG-4	September 18	16	20,900
		August 16	32	44,000
		July 21	389	57,700

Island Side Channel (RM 63.2)

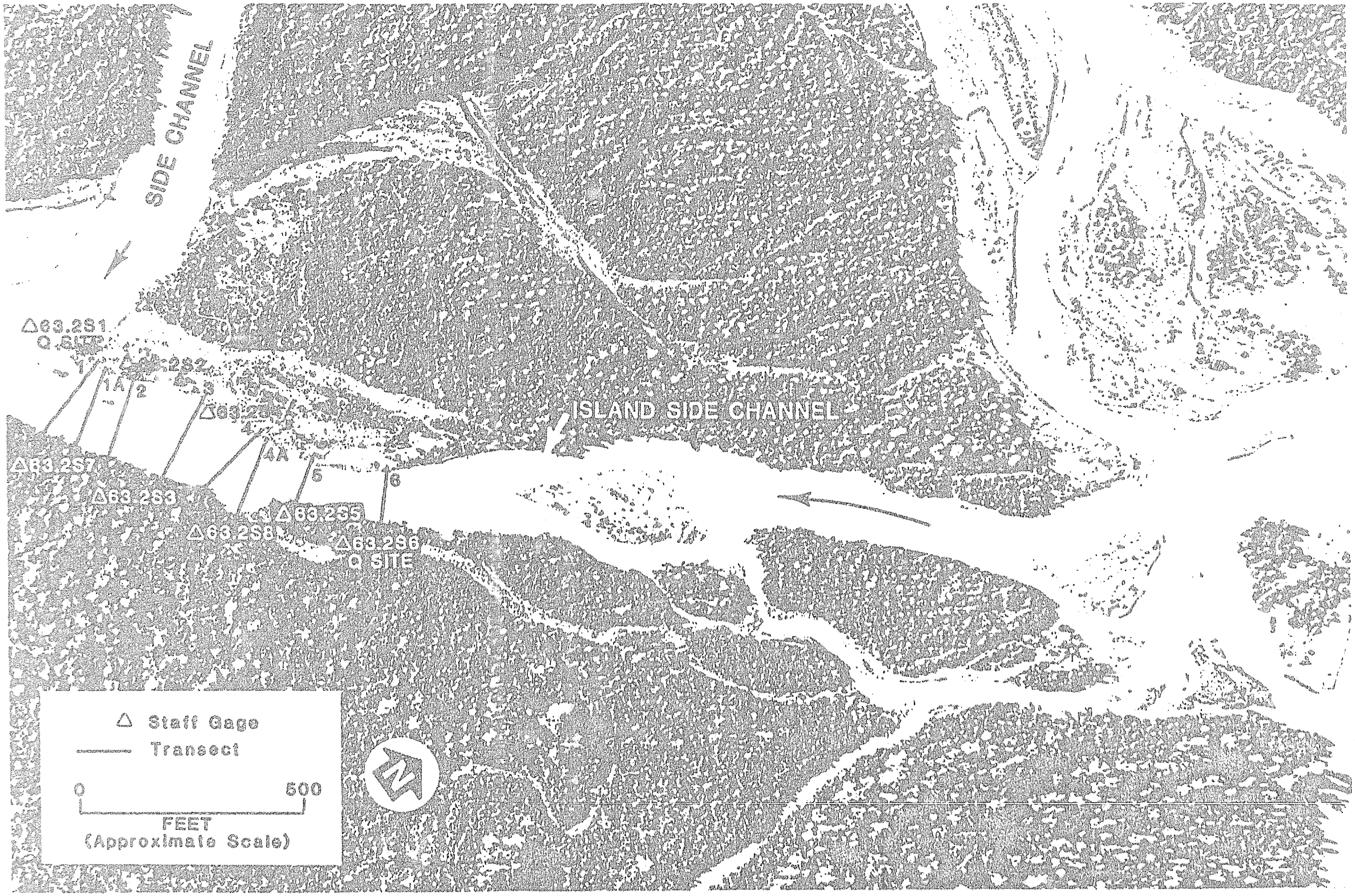
Site Description

Island Side Channel is located on the east bank of the main channel of the Susitna River at river mile (RM) 63.2 (Appendix Figure D-2). This side channel is located downstream of a braided, vegetated floodplain and is not directly connected to the main channel Susitna River. It is approximately 0.7 miles in length with both the mouth and head portions adjoining side channel networks. Breaching flows in this side channel result from overtopping of the head by an adjoining larger side channel. Prior to breaching, flow in the side channel is greatly reduced with a series of pools remaining (Quane et al. 1985).

The IFG modelling site selected for Island Side Channel during the 1984 open water field season, was 735 feet in length and was located in the lower portion of the side channel (Appendix Figure D-3). The site generally consists of a pool-riffle-pool sequence. Based on assessments by Quane et al. (1985), an area of backwater extends through the study site to a point at least 1,100 feet upstream from the mouth of the side channel at a non-breaching mainstem discharge of 35,000 cfs. During mainstem discharges of 38,000 to 66,700 cfs, the area of backwater extends throughout the study site.

The right bank of the study site is steep, being approximately five feet high, and results from erosional effects. The primary riparian vegetation along this bank is alder. There are also two side pocket areas,

Appendix Figure D-2. Overview of Island Side Channel (RM 63.2).



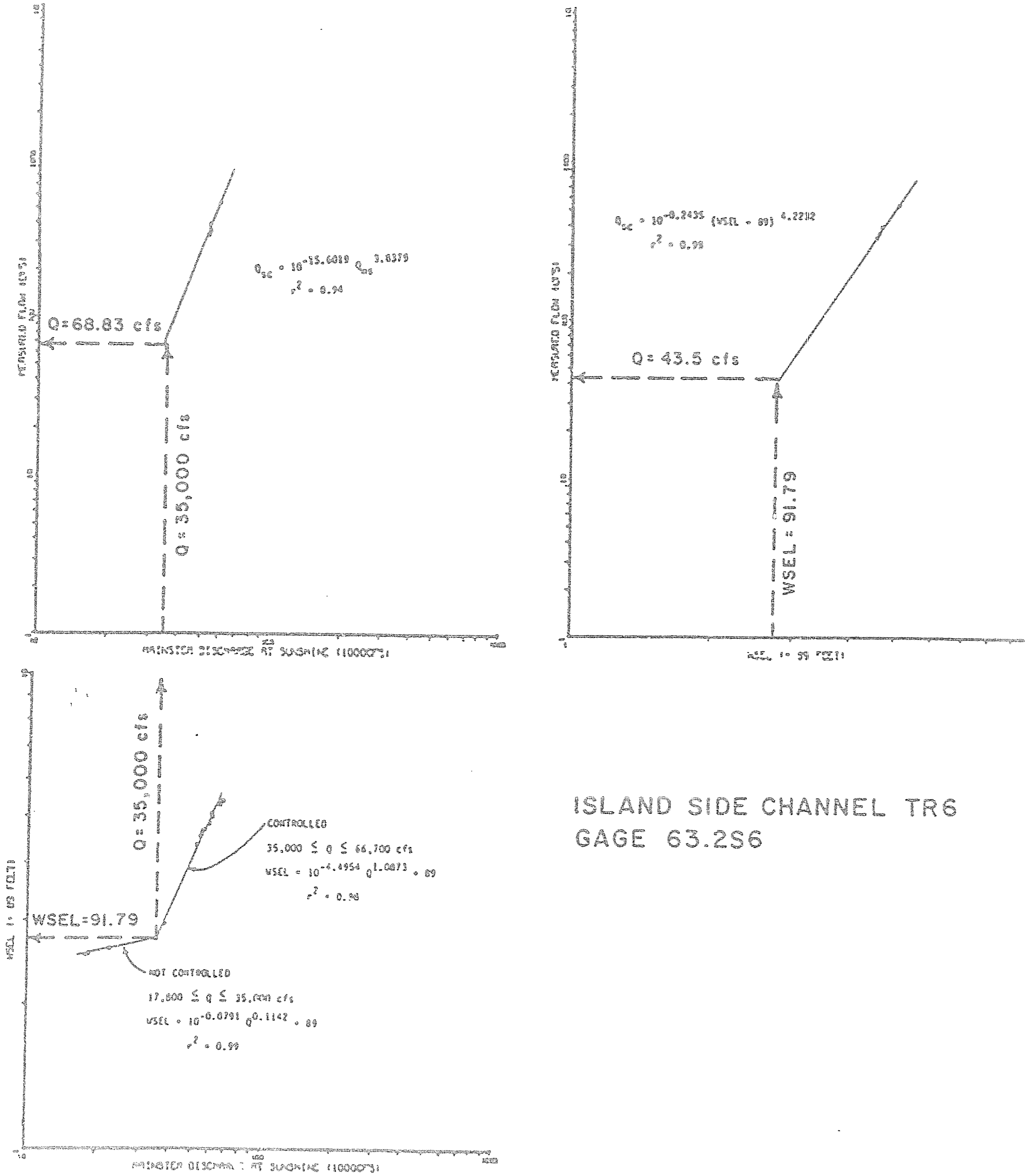
Appendix Figure D-3. Location of Island Side Channel study site (RM 63.2).

along this bank, which during higher site flows (about 400 cfs), become slow velocity slack water areas. In contrast, the left bank of the study site consists largely of a gently sloping depositional bank. The riparian vegetation on this bank is sparse and consists primarily of shrub willow.

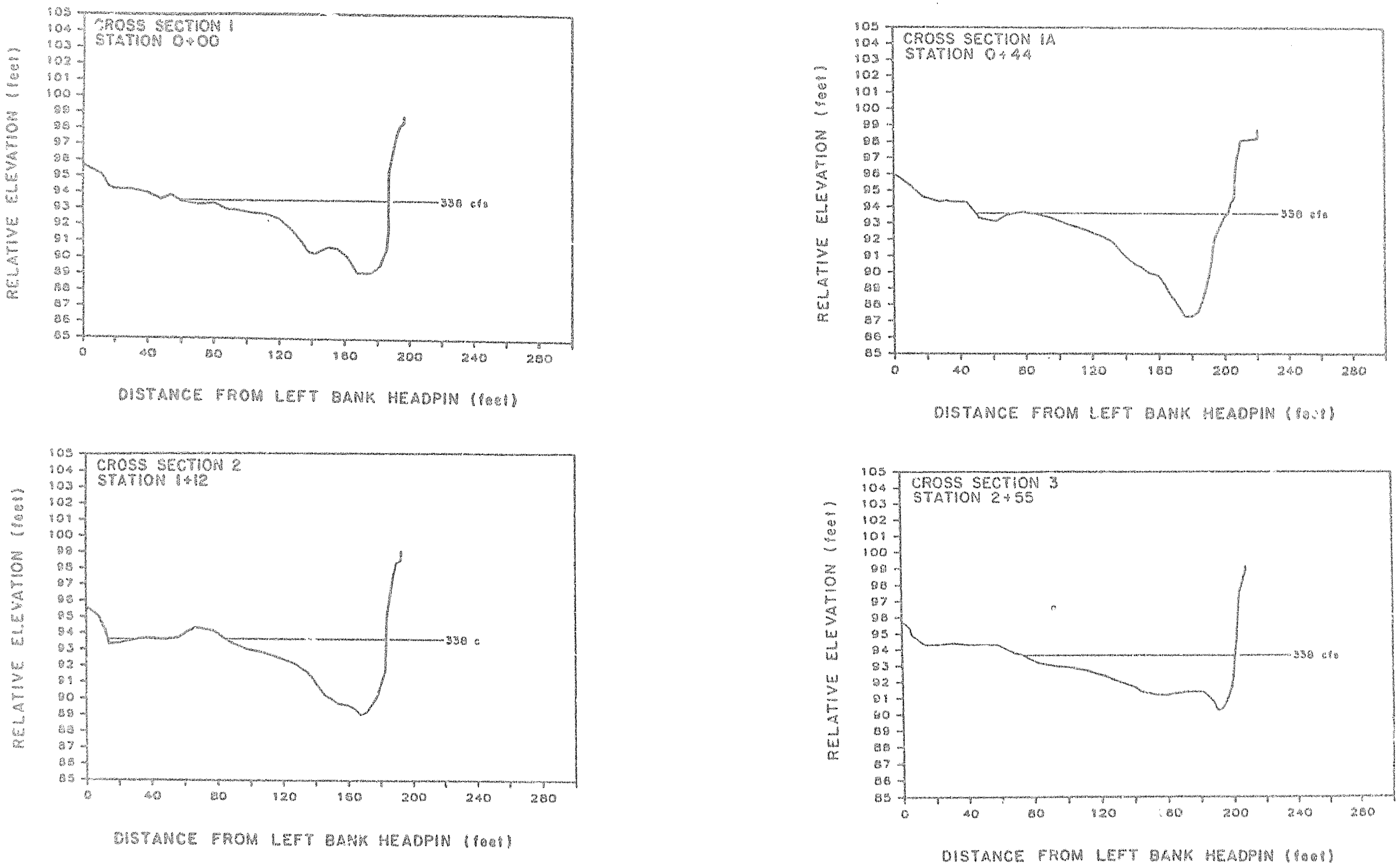
Substrate at the study site consists primarily of gravels, cobbles, and rubbles, with substrate changing to sand and silt in slackwater areas. The thalweg gradient of the side channel is 15.6 ft/mile (Quane et al. 1985). Breaching of Island Side Channel is the result of overtopping of the head by an adjoining side channel. From an evaluation of field observations, aerial photography and the stage/discharge relationship developed for this side channel, an initial breaching discharge has been estimated to occur at 34,000 cfs (Quane et al. 1985).

Based on a review of available rating curves (Appendix Figure D-4) it has been determined that at mainstem discharges exceeding 35,000 cfs, the hydraulics within this side channel become directly controlled by mainstem discharge (Quane et al. 1985). A side channel streamflow estimate of 43.5 cfs has been estimated to occur at a mainstem discharge of 35,000 cfs (Quane et al. 1985).

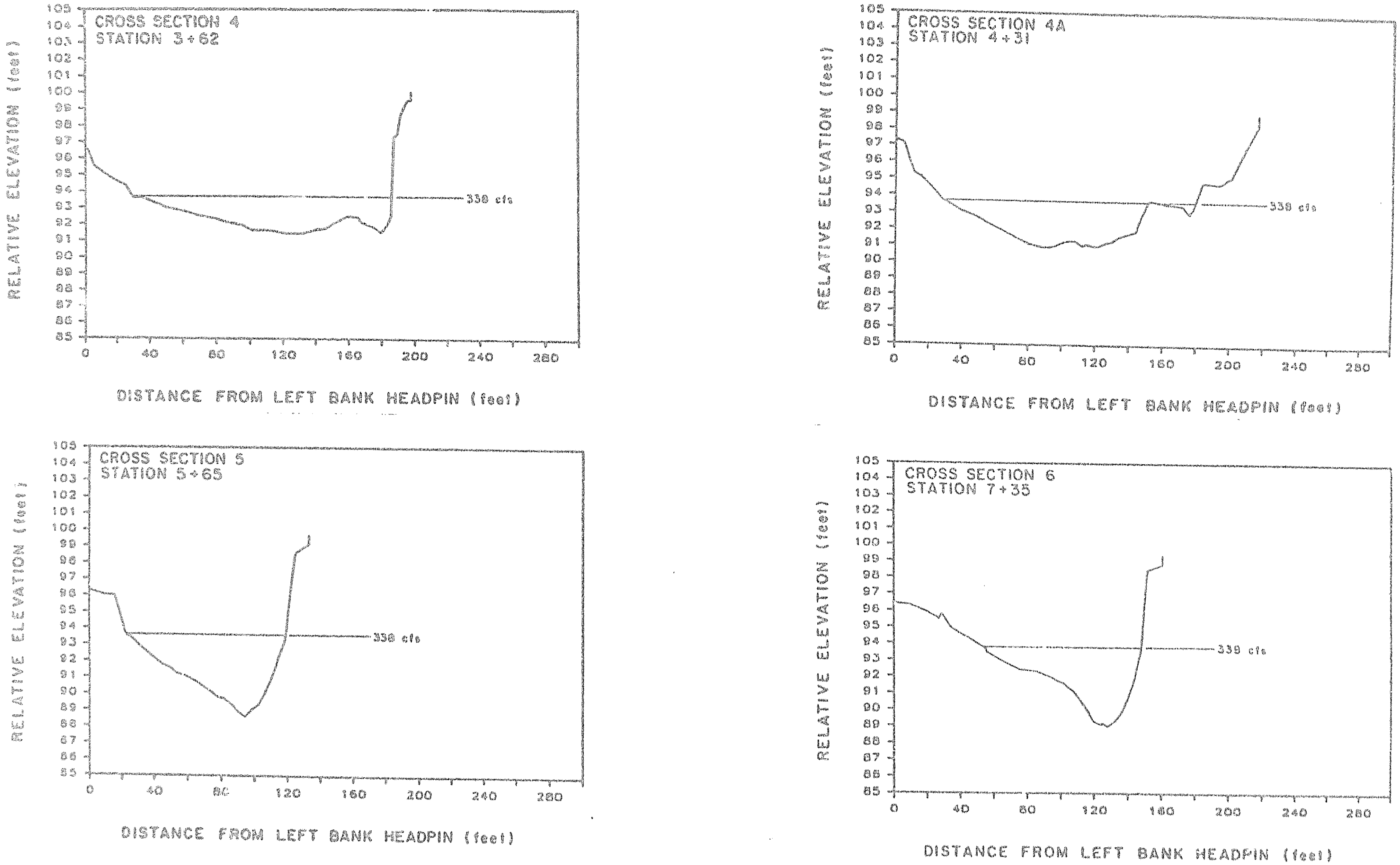
Eight cross sections were surveyed within this site during 1984 to define channel geometry (Appendix Figures D-5 & 6). The upper two transects (5 and 6) were located in primarily pool habitat. Transects 4A and 4 represent primarily riffle habitat in the main portion of the channel. Transect 4A was placed as a partial transect originating from the right hand bank. It represents the larger of the two slack water



Appendix Figure D-4. Comparison of rating curves for Island Side Channel transect 6(Q site) (from Quane et. al. 1985).



Appendix Figure D-5. Cross section of transects 1,1A, 2, and 3 at Island Side Channel (adapted from Quane et. al. 1985).



Appendix Figure D-6. Cross section of transects 4,4A,5, and 6 at Island Side Channel (adapted from Quane et. al. 1985).

areas in this reach. The four downstream most transects are primarily in pool type habitat. Transect 1A was also a partial transect, representing the smaller slack water area along the right bank.

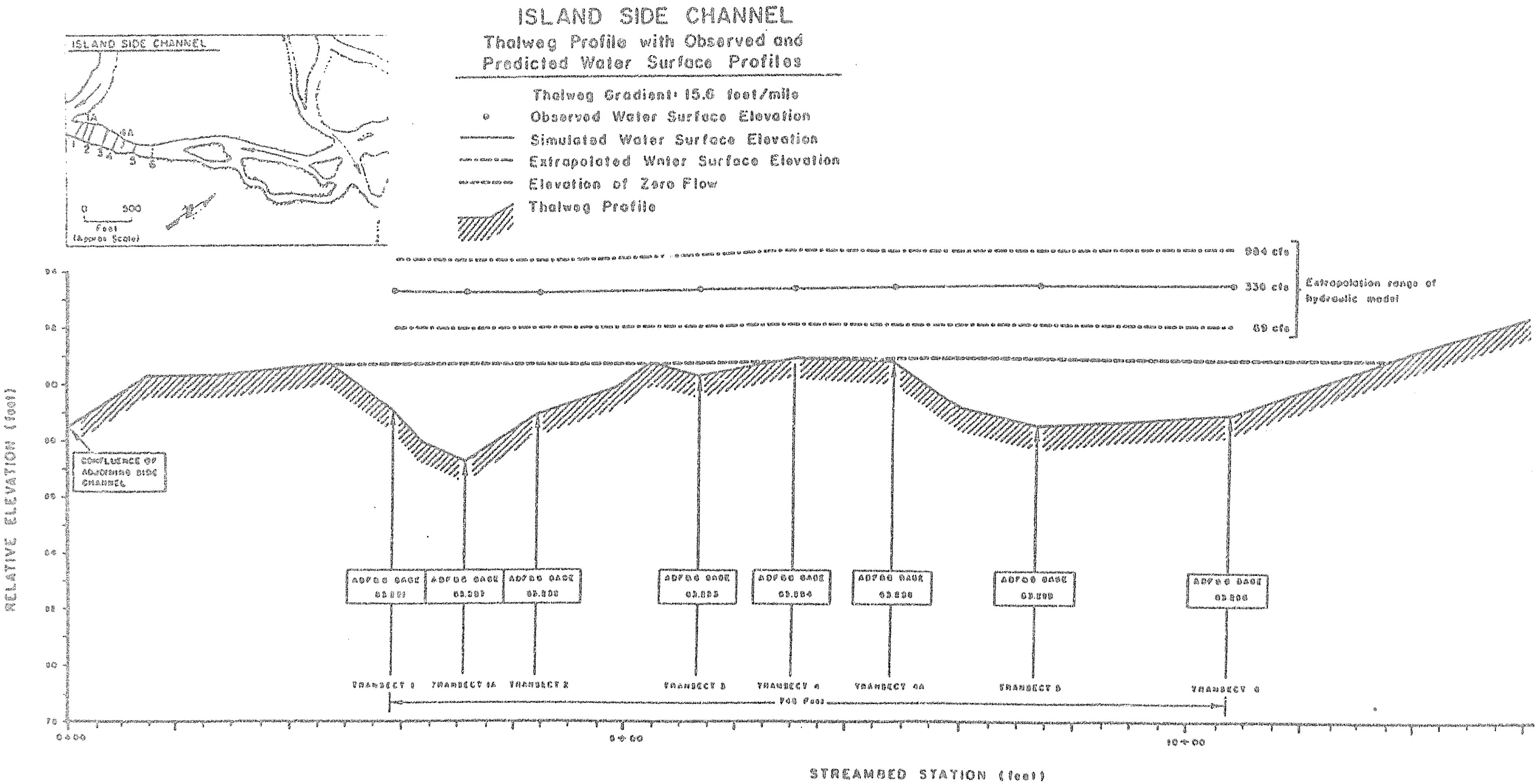
Data Collected

Hydraulic data were collected at a site flow of 338 cfs (Appendix Table D-4). The mean daily discharge for the Susitna River on the date the calibration data were collected at the study site was 56,100 cfs as determined from provisional USGS streamflow data.

Calibration

Calibration data available at the close of 1984 field season was limited to that obtained for a side channel flow of 338 cfs (56,100 cfs mainstem discharge). As a result, an IFG-2 model was used to forecast instream hydraulics based on this single calibration flow. The streambed profile, stages of zero flow, and observed and predicted water surface elevations for this study reach are plotted to scale in Appendix Figure D-7.

The original field water surface elevations (WSEL's) were compared to the model predicted WSEL's for the calibration flow of 338 cfs (Appendix Table D-5). At transect 1A, the original field WSEL was surveyed at 93.46 feet. In examining the WSEL's of transects 1 and 2 (93.33 and 93.41 feet in elevation respectively), it was felt that an error in



Appendix Figure D-7. Comparison of observed and predicted water surface profiles from calibrated model and surveyed thalweg profile at Island Side Channel (adapted from Quane et. al. 1985).

Appendix Table D-5. Comparison of field measured and model predicted water surface elevations at the calibration flow of 338 cfs for Island Side Channel.

Transect	Water Surface Elevation (ft) Field	Model Predicted	Difference
1	93.33	93.33	--
1A	93.46[A]	93.36	0.00
2	93.41	93.36	0.05
3	93.44	93.40	0.04
4	93.48	93.46	0.02
4A	93.52	93.50	0.02
5	93.56	93.53	0.03
6	93.55	93.56	0.01

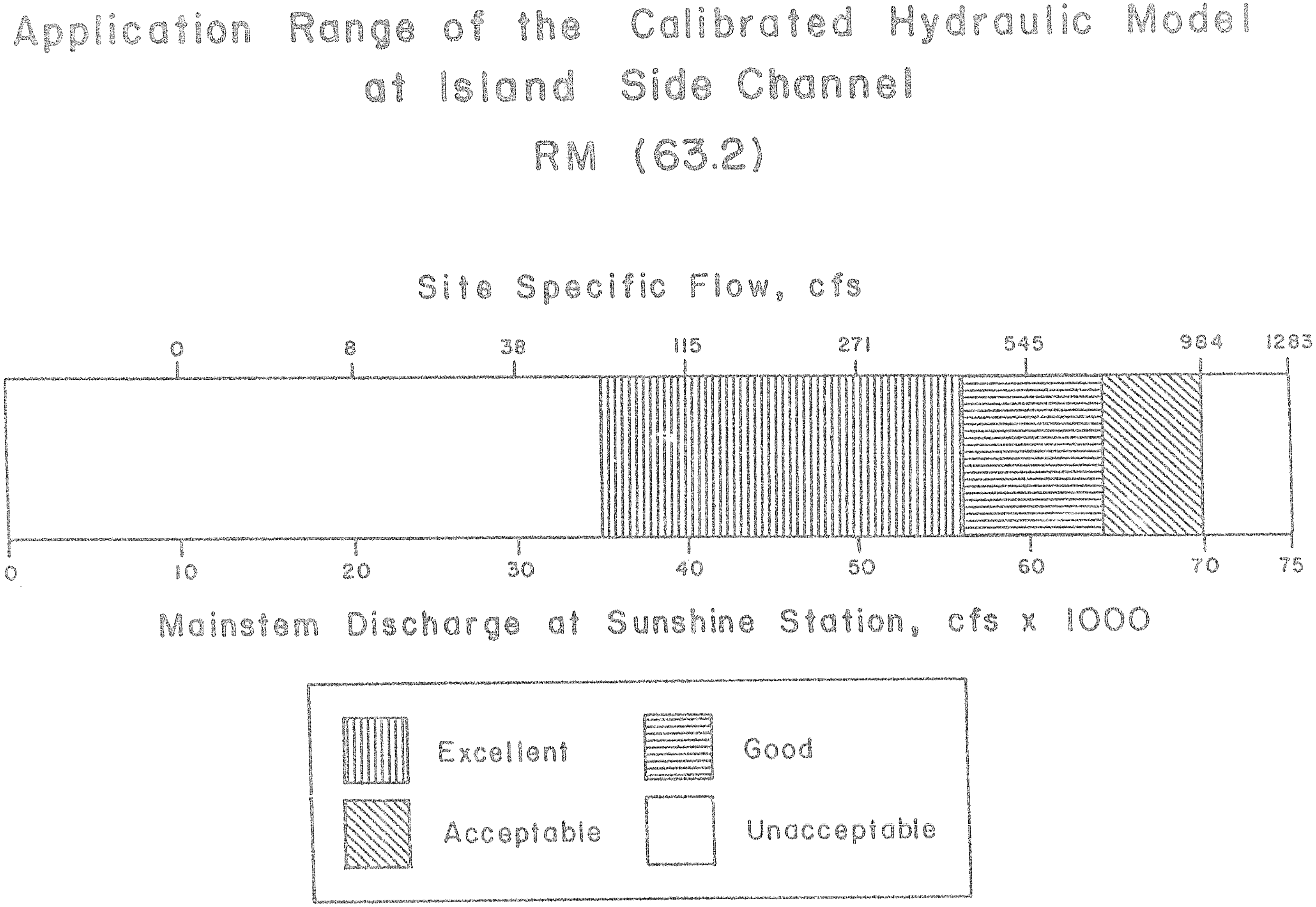
[A] Water surface elevation reduced by 0.1 feet to 93.36 feet.

surveying occurred at transect 1A. As a result, the WSEL for this transect was lowered by 0.1 feet to 93.36 feet. For all other transects, the difference between the field WSEL's and the model predicted WSEL's for the calibration flow were 0.05 ft. or less.

The two partial transects (1A and 4A) which represent slackwater habitat were extended out to the principal velocity filament. In order to complete the data sets for these two partial transects for use in the model, the associated data from transects 1 and 4 were used. At partial transect 1A, the velocities were all negative. In order to use this information in the model, these velocities were treated as positive, as it was felt that the direction of the current would not influence the utilization of this area by juvenile salmon. With respect to the amount of water flowing through this section, it amounted to only 6.5 cfs or about 2% of the flow.

Verification

Based on the first level of verification conducted by EWT&A, the model does an excellent job of simulating hydraulics between 35,000 and 56,000 cfs mainstem discharge (69 and 416 cfs site flow). Above 56,000 cfs, however, the simulated depth and velocity distributions begin to deteriorate in quality. As a result, the model simulations were rated good between 56,000 and 64,000 cfs (416 and 692 cfs site flow), acceptable between 64,000 and 70,000 cfs (692 and 984 cfs site flow), and unacceptable above 70,000 cfs mainstem. Below 35,000 cfs mainstem, insufficient



Appendix Figure D-8. Application range of the calibrated hydraulic model at Island Side Channel.

data was available to evaluate the performance of the model. These ratings are depicted graphically in Appendix Figure D-8.

The second level of the verification has not been performed as of this time.

Application

For habitat simulation modelling purposes, the hydraulic simulation model developed for Island Side Channel can simulate channel flows in the mainstem discharge range of 35,000 to 70,000 cfs.

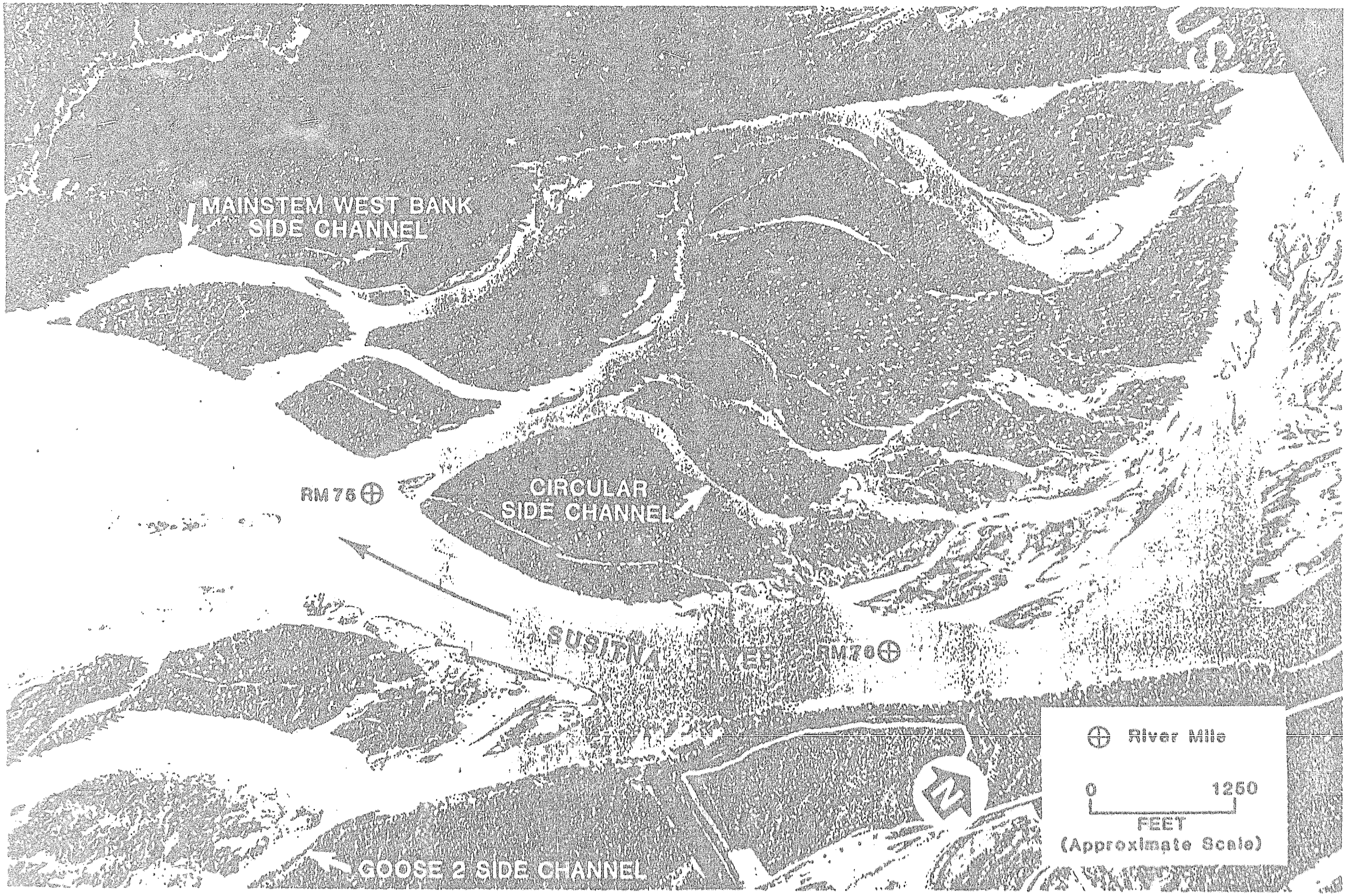
Mainstem West Bank Side Channel (RM 74.4)

Site Description

Mainstem West Bank Side Channel is located on the west bank of the main channel Susitna River at river mile 74.4 (Appendix Figure D-9). It is approximately 2.2 miles in length. Both the mouth and head of the side channel directly connect to the Susitna River. Two heads, both located approximately 1.5 miles upstream of the study site, connect this side channel to the mainstem (Quane et al. 1985).

The IFG modelling site within this side channel during the 1984 open water field season was 930 feet in length and was located in the lower portion of the side channel (Appendix Figure D-9). The side channel within the study site is confined on the west by a steep bank and on the east by a well vegetated island which separates it from the mainstem. The upper portion of the side channel upstream of the study site is separated from the mainstem by a network of side channels and well vegetated islands. A minor channel is located within the study site on the east bank of the side channel. During nonbreached conditions, the side channel primarily consists of a series of pools and small riffles. Groundwater provides the major contribution of flow prior to breaching of the head (Quane et al 1985).

Breaching of Mainstem West Bank Side Channel occurs as the result of overtopping by the mainstem of at least one of the two side channel heads located approximately 1.5 miles upstream of the study site. The



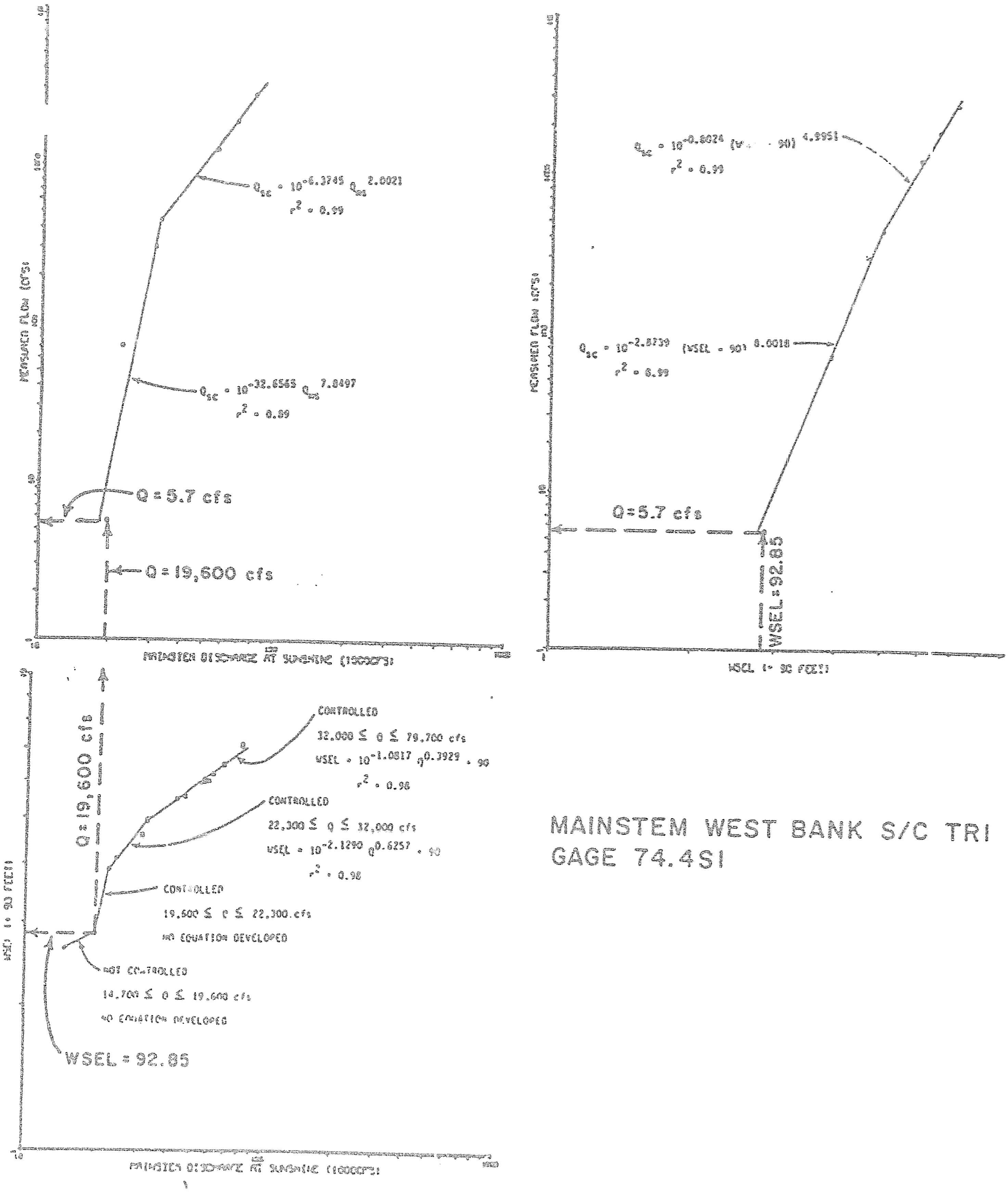
Appendix Figure D-9. Overview of Mainstem West Bank Side Channel (RM 74.4).

side channel has been estimated to be initially breached at a mainstem discharge of 19,000 cfs (Quane et al. 1985).

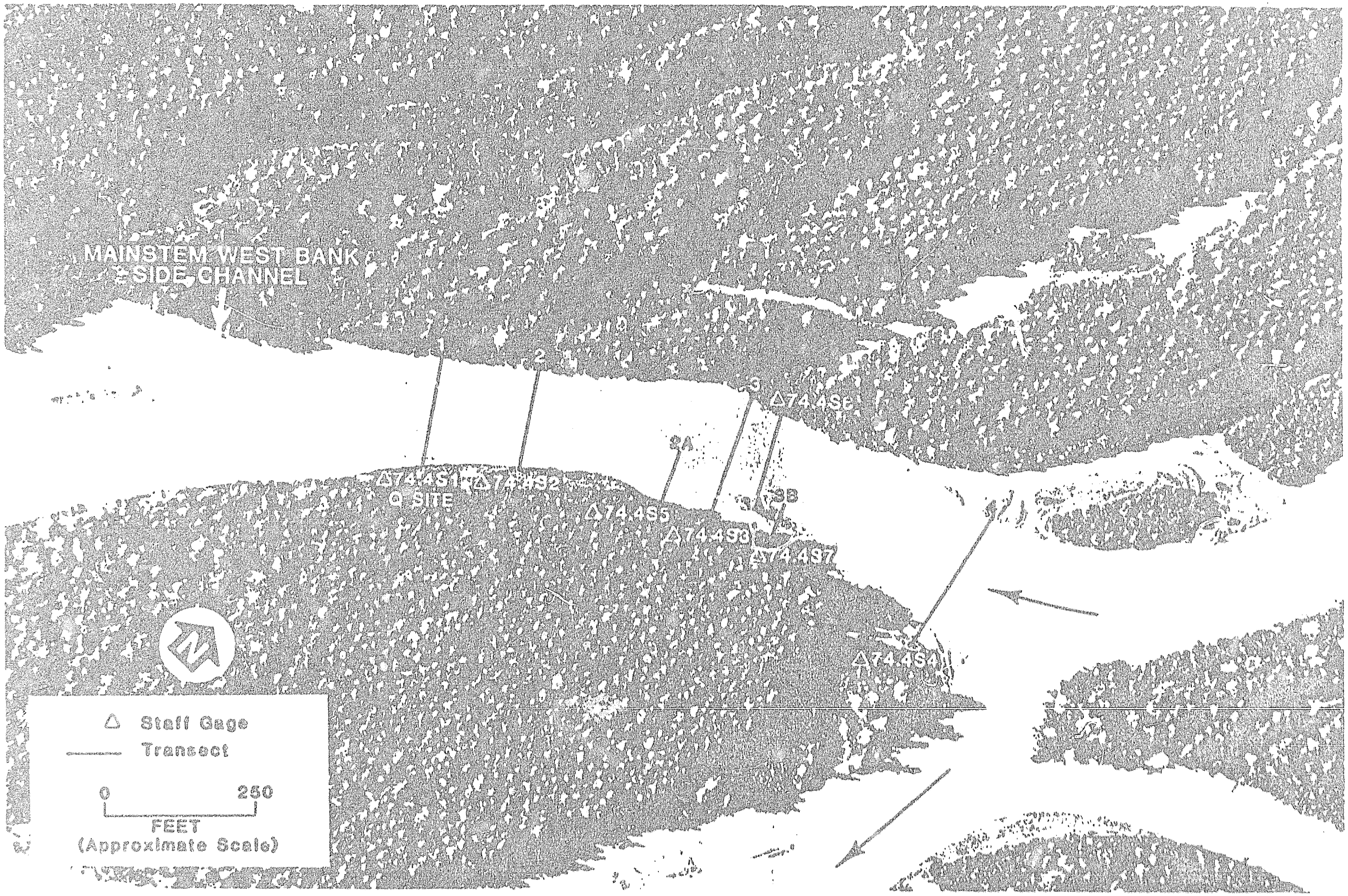
Based on a review by Quane et al. (1985) of the stage versus mainstem discharge rating curve (Appendix Figure D-10), it has been determined that at mainstem discharges greater than 19,600 cfs, the hydraulics within this side channel are directly controlled by mainstem discharge. The site flow that occurs at 19,600 cfs was measured to be 5.7 cfs.

Located within this study site were five transects (1, 2, 3, 3A, 4) in the main channel and three transects (2A, 3 in part, 3B) in a minor side channel from which hydraulic information was gathered (Appendix Figure D-11). The corresponding cross sections are presented in Appendix Figure D-12 & 13.

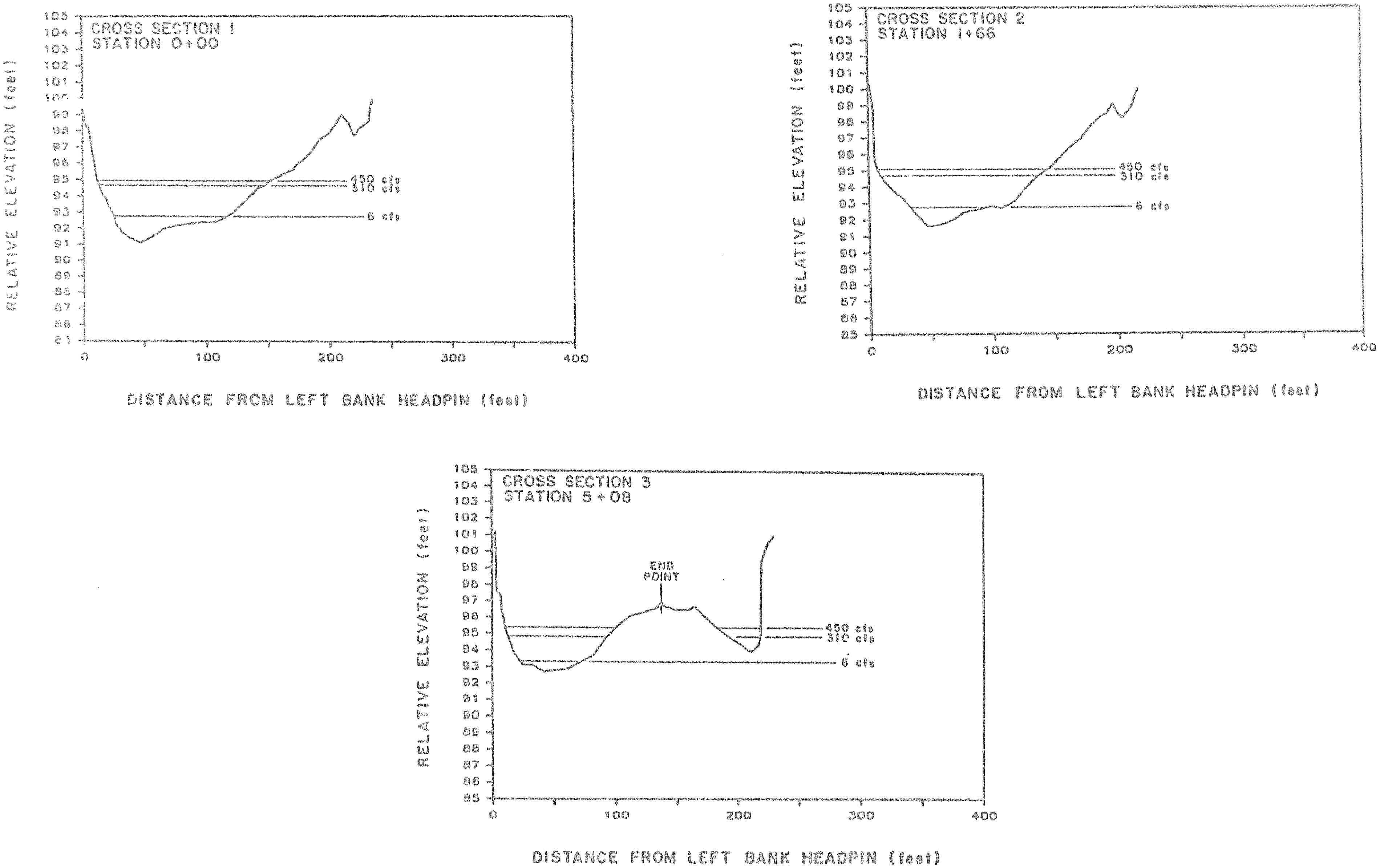
The lower two transects (1 & 2) bisect primarily pool-run type habitat where the banks are gently sloping on both sides. On the upper three transects (3, 3A, & 4) the left bank consisted of an erosional bank and was primarily bordered by alder. For modelling purposes, transects 3 and 3A were ended on a finger-like gravel bar on the right bank which longitudinally bisected the site with the main channel on the left and a minor channel on the right which was free flowing at high flows, backwater at median flows, and dry at low flows. This bar began downstream from transect 4 and ended between transects 2 and 3. Transect 3A was placed in order to obtain a better representation of the slow water debris-strewn habitat along the left hand bank. The main



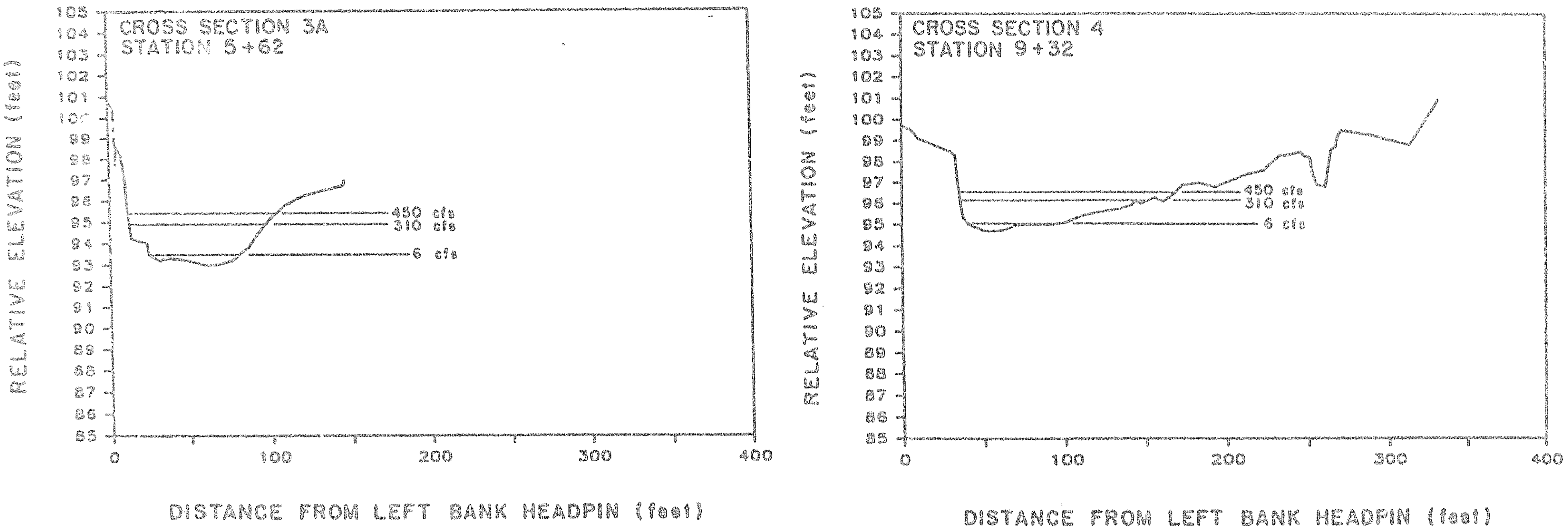
Appendix Figure D-10. Comparison of rating curves for Mainstem West Bank Side Channel transect 1(Q site) (from Quane et. al. 1985).



Appendix Figure D-11. Location of Mainstem West Bank Side Channel study site (RM 74.4).



Appendix Figure D-12. Cross section of transects 1,2,and 3 at Mainstem West Bank Side Channel (adapted from Quane et. al. 1985).



Appendix Figure D-13. Cross section of transects 3A and 4 at Mainstem West Bank Side Channel (adapted from Quane et. al. 1985).

channel habitat of these three transects (3, 3A, & 4) consisted of run-riffle type habitat.

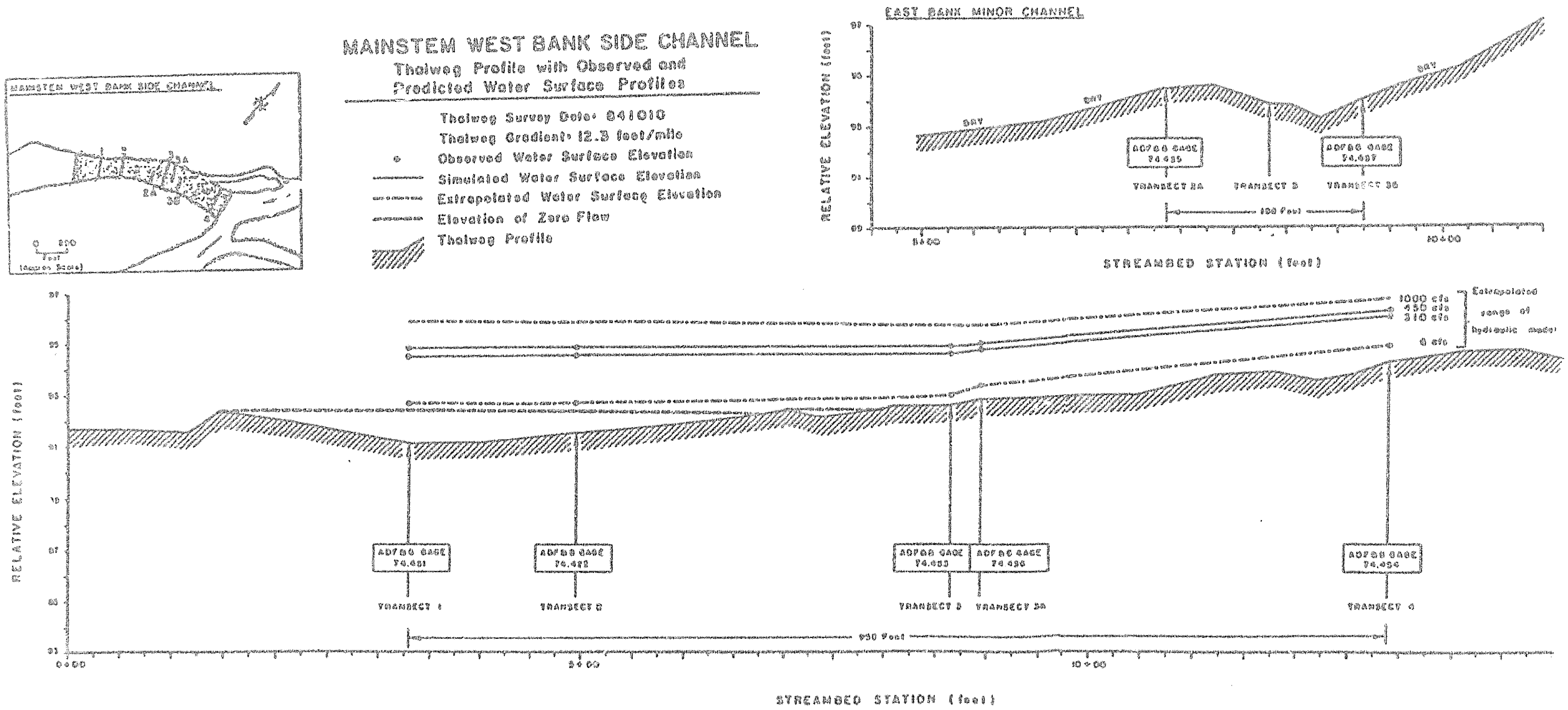
Substrate at this site primarily consisted of rubble and cobble. The thalweg gradient of the side channel is approximately 12.3 ft/mile (Quane et al. 1985).

Data Collected

Hydraulic data were collected for model calibration at three discharges: 6, 310, and 450 cfs (Appendix Table D-4). Mean daily discharges for the Susitna River on the dates that calibration data were collected of this study site were 19,600; 30,500, and 32,000 cfs, representively as determined from provisional USGS streamflow data.

Calibration

Calibration data available at the close of the 1984 field season included data collected for side channel flows of 6, 310, and 450 cfs. Based on these data, an IFG-4 model was used to forecast instream hydraulics. The streambed profile, stage of zero flow, and observed and predicted water surface elevations for the study reach are plotted to scale in Appendix Figure D-14. All three data sets were used to predict hydraulic information for side channel flows of 6 to 2,431 cfs (mainstem discharges of 18,000 to 75,000 cfs).



Appendix Figure D-14. Comparison of observed and predicted water surface profiles from calibrated model and surveyed thalweg at Mainstem West Bank Side Channel (adapted from Quane et. al. 1985).

To evaluate the performance of the hydraulic model, observed and predicted water surface elevations, discharges, and velocity adjustment factors were compared (Appendix Table D-6). The 15 sets of observed and predicted WSEL's for the five transects of the 3 calibration flows were all within ± 0.02 ft. of each other except for 2 sets which were within ± 0.10 feet of each other. All the observed and predicted discharges were within 10% of each other and all velocity adjustment factors were within the good range of 0.9 to 1.1. Additionally, the stage information of the model was compared to available rating curves (Appendix Figure D-10).

To represent the slackwater debris area along the left bank of the upper portion of this study site, a partial transect (3A) was placed about 60 feet upstream from transect 3. In order to complete this data set for transect 3A for use in the model, the velocity information from transect 3 for the two site flows of 310 and 450 cfs were incorporated into transect 3A cross sectional area and water surface elevations. After incorporating this information into transect 3A, the discharge for the 310 cfs site flow, however, did not fall within 10% of the respective discharge that was calculated at the discharge transect. As a result, velocities for the 310 cfs site flow were adjusted upward by 17%.

At the low flow measurement of 6 cfs, the velocity measurements were made completely across transect 3A. The discharge calculated at this site was 18% higher than calculated at the discharge transect. The velocities at this transect were therefore reduced by 15%.

Appendix Table D-6. Comparison between observed and predicted water surface elevations, discharges, and velocities for 1984 Mainstem West Bank side channel hydraulic model.

Streambed Station (ft)	Water Surface Elevation Observed (ft)	Water Surface Elevation Predicted (ft)	Discharge Observed (cfs)	Discharge Predicted (cfs)	Velocity Adjustment Factor
0+00	92.85	92.86	6.0	6.3	1.005
1+66	92.86	92.87	6.9	7.2	.991
5+08	93.25	93.26	6.9	7.2	1.004
5+62	93.51	93.52	5.8	6.1	.996
9+32	95.06	95.06	5.1	5.4	1.013
			Qo = 6.0	Qp = 6.0	
0+00	94.62	94.61	312.8	315.7	1.030
1+66	94.64	94.64	301.3	307.5	1.024
5+08	94.85	94.86	306.4	318.2	1.007
5+62	94.93	94.99	292.8	288.6	.993
			Qo = 301.0	Qp = 308.0	
0+00	94.97	94.98	460.4	457.0	.974
1+66	95.00	95.00	446.1	438.2	.975
5+08	95.19	95.18	470.6	455.2	.994
5+62	95.29	95.23	409.6	415.3	1.001
9+32	96.54	96.45	473.9	451.9	.969
			Qo = 452.0	Qp = 444.0	

Qo is the mean observed calibration discharge.

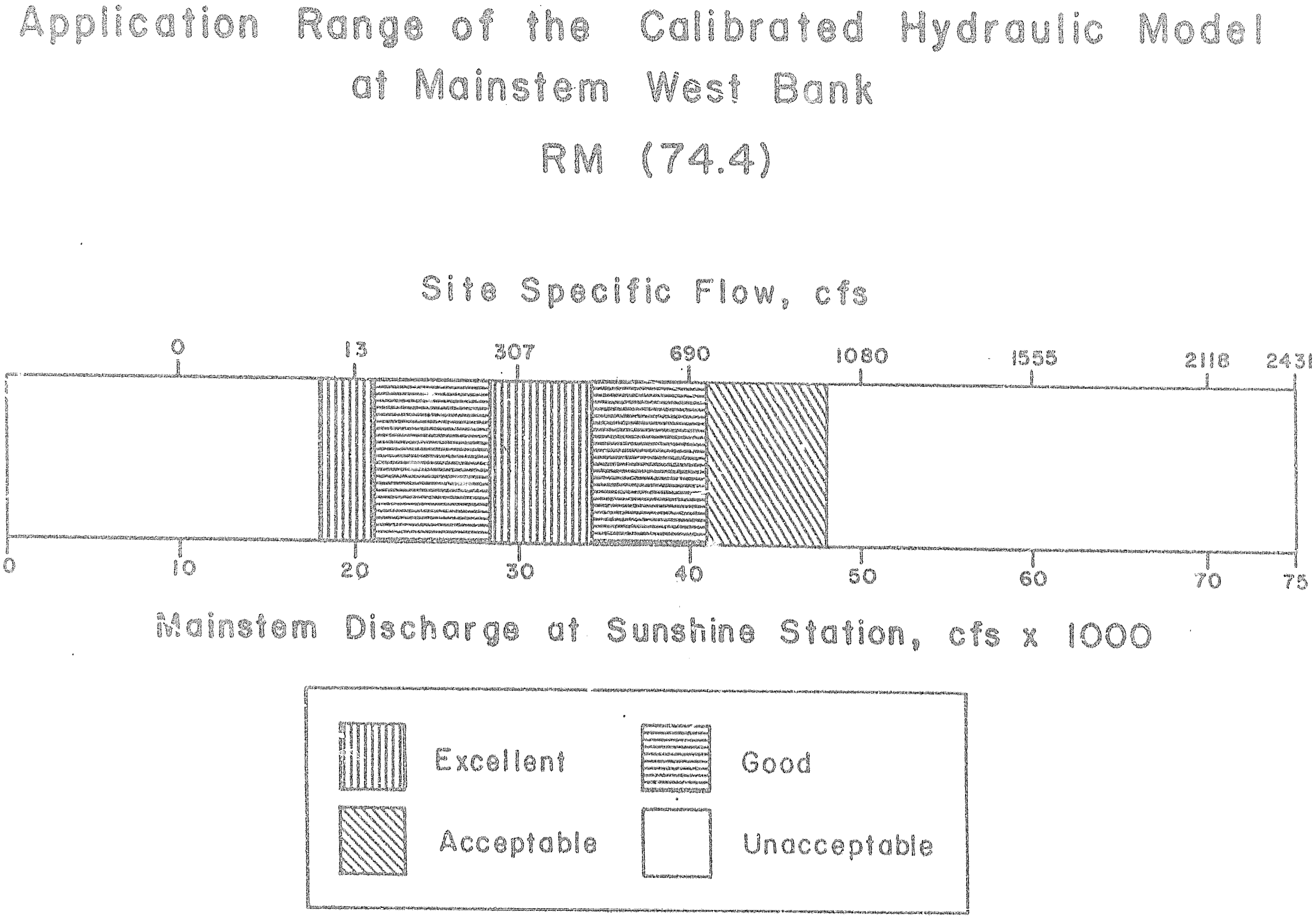
Qp is the mean predicted calibration discharge.

At transect 4 the water surface elevations were not similar across the transect at the 6 cfs flow measurement. Therefore, a weighted average water surface elevation was calculated for this transect.

At higher site flows several small low velocity side channel/backwater areas existed. It was felt that this habitat, which was not represented in the IFG-4 analysis, would be an important area to assess. Because of this, three transects were placed across one of these minor side channels. These transects were to be used to hand calculate the habitat in this area. However, because this side channel area is so small compared to the total area being modelled using the IFG-4, it was felt that including this area in the total weighted usable area calculations would not truly reflect the value of this habitat. For this reason, hand calculations of these areas were not done.

Verification

Based on the first level of verification by EWT&A, the model does an excellent job of simulating channel hydraulics between 18,000 and 21,000 cfs mainstem discharge (6 and 20 cfs site flow) (Appendix Figure D-15). Above 21,000 cfs, simulated water surface profiles deviate somewhat from field observations. As a result, the model was rated good between 21,000 and 28,000 cfs mainstem discharge (20 and 200 cfs site flow), and between 28,000 and 34,000 cfs mainstem discharge (200 and 500 cfs site flow) the model again was rated excellent. Two calibration data sets were collected within this range. Above 34,000 cfs, the quality of the



Appendix Figure D-15. Application range of the calibrated hydraulic model at Mainstem West Bank Side Channel.

hydraulic simulations begins to deteriorate as the slope of the site flow versus WSEL relationship flattens as a result of channel geometry. The deviation between the regression line developed within the model and that of the rating curve developed independently for the site increases with discharge until the model simulations are no longer acceptable. The model simulations were rated good between 34,000 and 41,000 cfs (500 and 727 cfs site flow), acceptable between 41,000 and 48,000 cfs (727 and 1000 cfs site flow), and unacceptable above 48,000 cfs mainstem discharge.

Overall, the model simulations were rated excellent between 18,000 and 21,000 cfs (6 and 20 cfs) and 28,000 and 34,000 cfs (200 and 500 cfs), good between 21,000 and 28,000 cfs (20 and 200 cfs) and 34,000 and 41,000 (500 and 727 cfs). They were acceptable between 41,000 and 48,000 cfs (727 and 1,000 cfs) and unacceptable over 48,000 cfs.

As of this time, the second level of the verification has not been performed.

Application

For habitat simulation modelling purposes, the hydraulic simulation model developed for Mainstem West Bank Side Channel can simulate channel flows in the mainstem discharge range of 18,000 to 48,000 cfs.

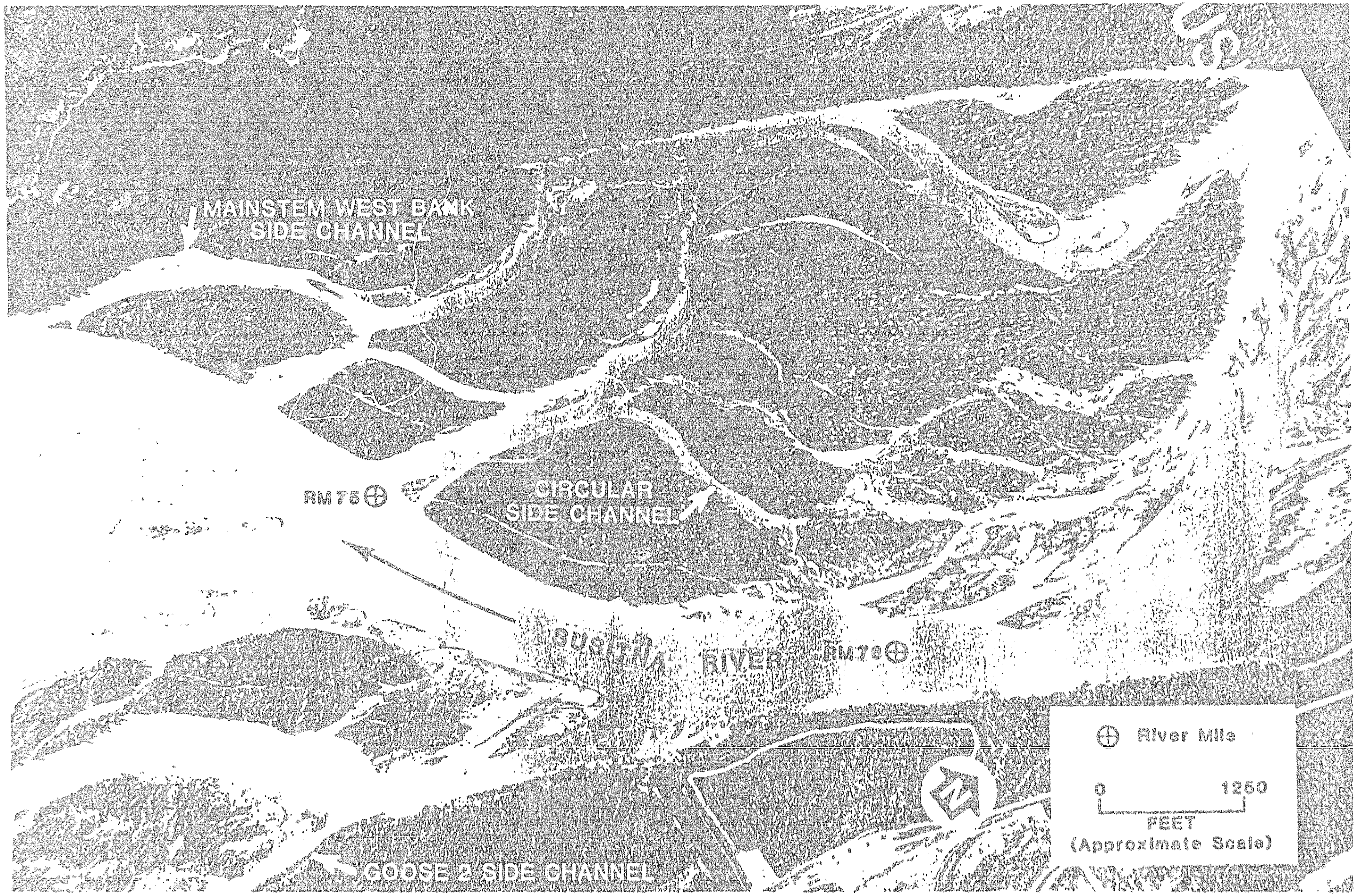
Circular Side Channel (RM 75.3)

Site Description

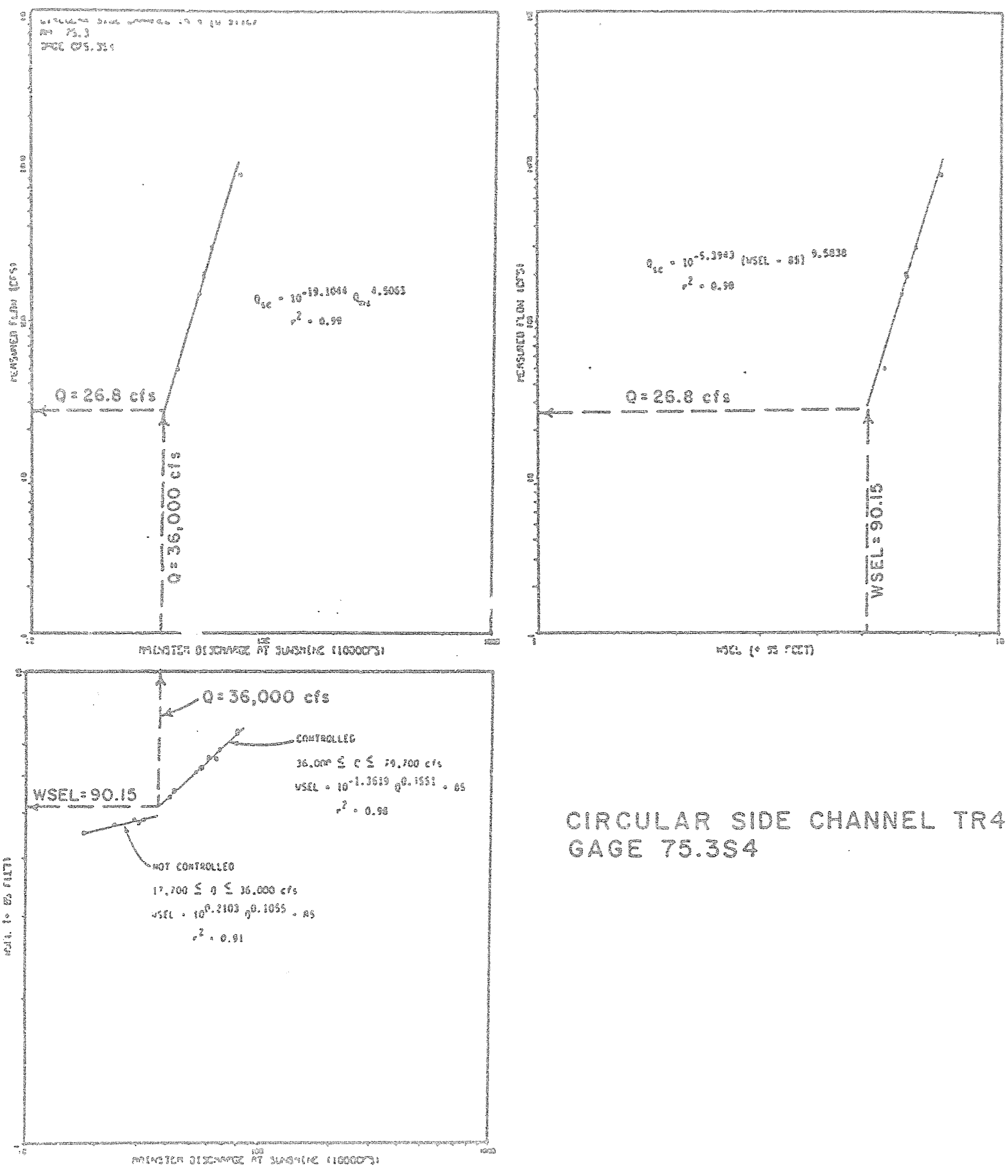
Circular Side Channel is located on the west bank of the Susitna River at river mile 75.3 (Appendix Figure D-16). It is approximately 0.9 miles long and is separated from the mainstem by a large well vegetated island. Both the mouth and head of this side channel are connected to the mainstem Susitna River. An extensive backwater area has been observed to occur in the lower portion of the study site. A network of small channels at the head provide mainstem flow into the site after breaching. Prior to breaching, flow is greatly reduced and the channel is composed of large pools connected by small riffles (Quane et al. 1985).

Breaching of Circular Side Channel is the result of direct overtopping of the head by the mainstem Susitna River, and has been estimated to be initially breached at a mainstem discharge of 36,000 cfs (Quane et al. 1985). It has been determined that the hydraulics within this side channel become governed by mainstem discharge at mean daily mainstem discharge exceeding 36,000 cfs. The site flow that occurs at this mainstem discharge has been estimated to be 26.8 cfs (Appendix Figure D-17) (Quane et al. 1985).

Based on assessments by Quane et al. (1985), backwater has not been observed to occur during non-breaching mainstem discharges. At breaching mainstem discharges of 55,200 to 66,700 cfs, however, an area of



Appendix Figure D-16. Overview of Circular Side Channel (RM 75.3).



Appendix Figure D-17. Comparison of rating curves for Circular Side Channel transect 4 (from Quane et. al. 1985).

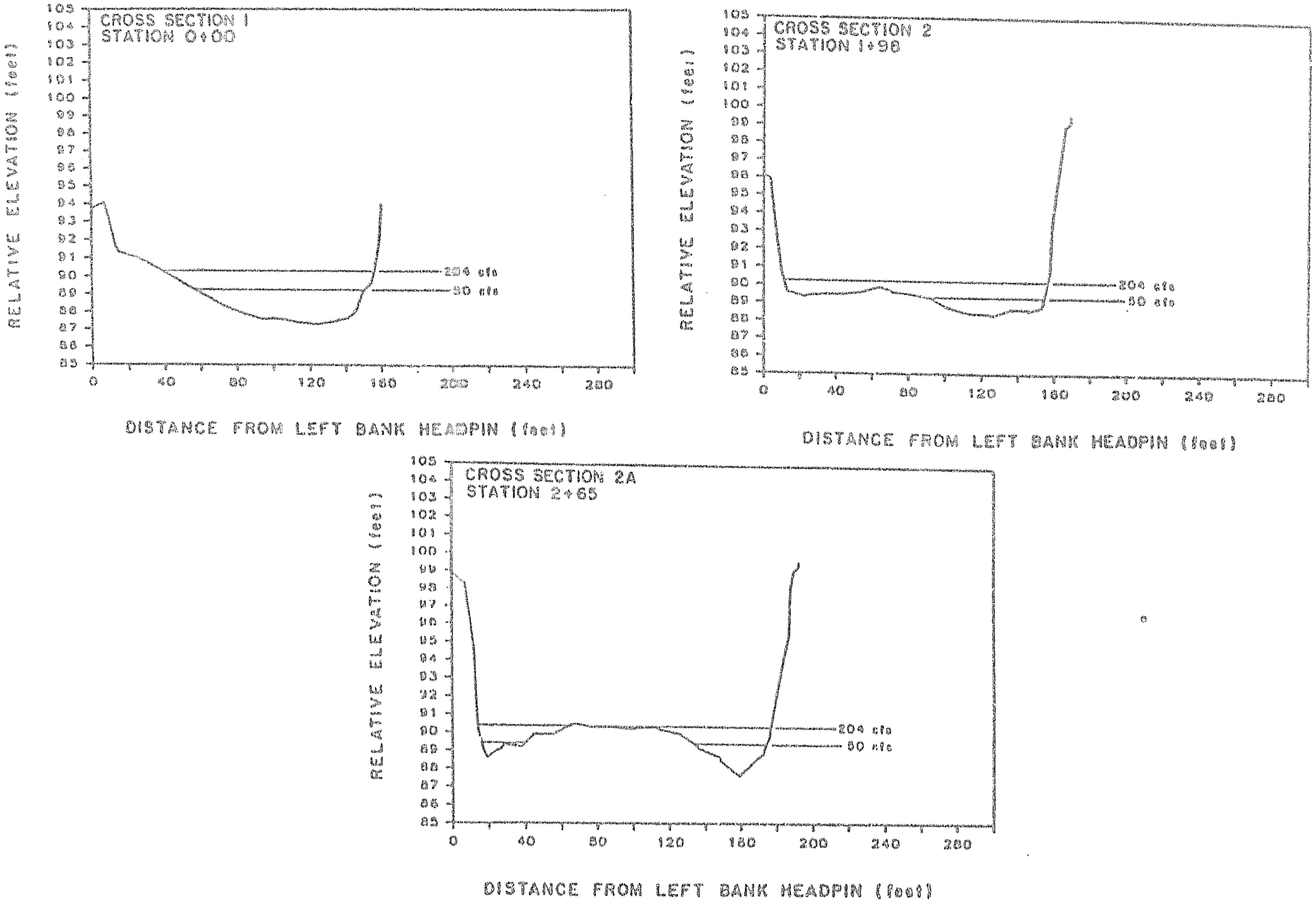
backwater was found to occur upstream to a point approximately 90 feet above transect 2A. At a mainstem discharge of 42,500 cfs, backwater has been determined to extend slightly past transect 2.

The IFG modelling study site within Circular Side Channel was 820 feet in length and was located in the upper half of the side channel (Appendix Figure D-18). The thalweg gradient of this study site is 14.3 ft/mile (Quane et al. 1985). Riparian vegetation along both banks of this study site consists mostly of alder and cottonwood. Substrate within the lower reaches of the study site consisted predominately of silts, sands, and gravels changing to rubbles at the upper reaches. Six transects from which hydraulic information was gathered for the model were located within this study site (Appendix D-18). The channel is relatively straight and the cross sections are generally box shaped in configuration (Appendix Figures 19 & 20). Transects 1 and 2 were located in shallow pool habitat, created by the backwater. Transect 2A was located in transitional habitat which became run-like habitat at higher flows. Transect 3 was located in riffle habitat. Transect 4 was located in a run area at the end of a pool area which transect 5 also bisects.

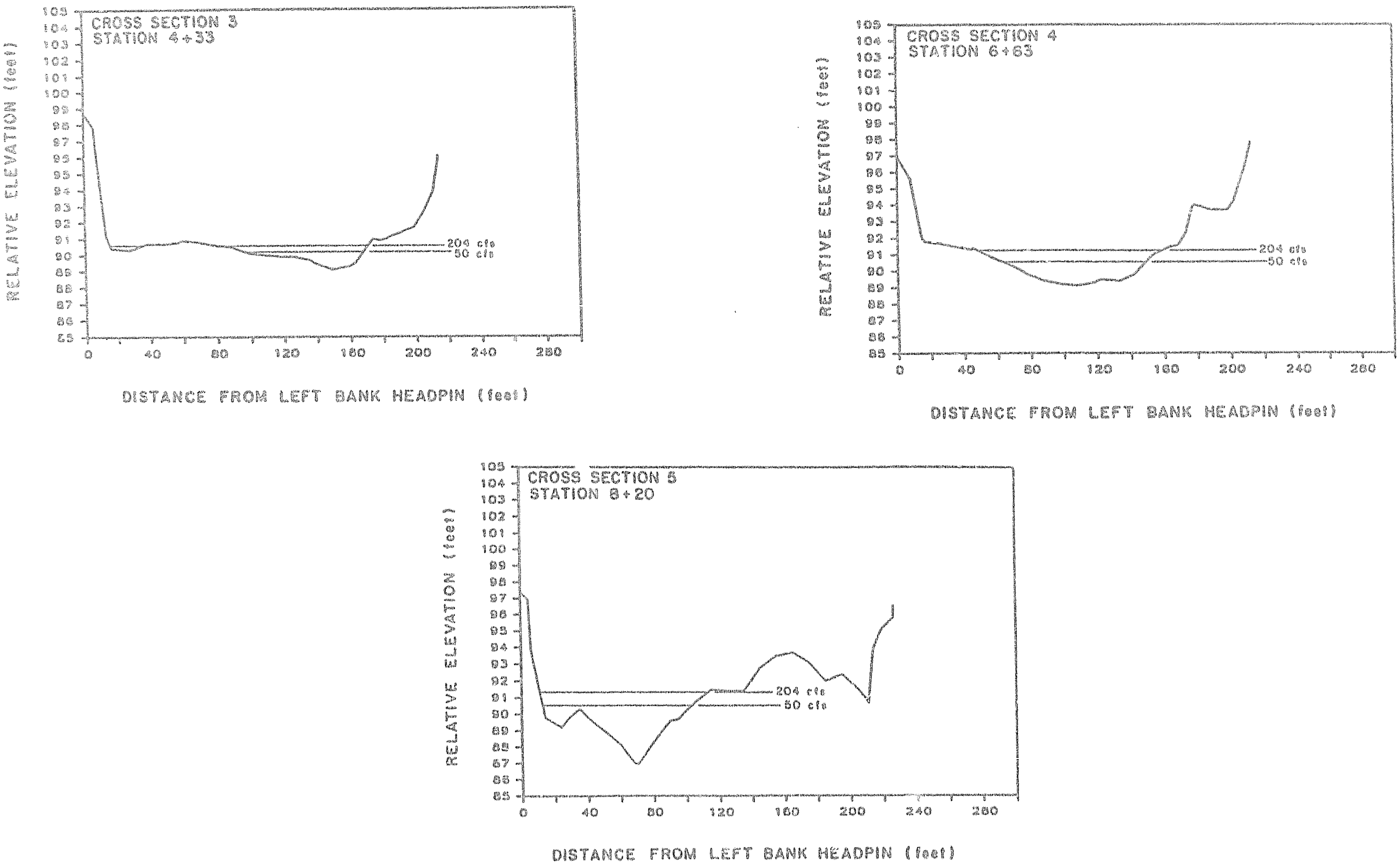
Data Collected

Hydraulic data were collected at two calibration discharges: 50 and 204 cfs (Appendix Table D-4). Mean daily discharges for the Susitna River on the dates that calibration data were collected at the Circular

Appendix Figure D-18. Location of Circular Side Channel study site (RM 75.3).



Appendix Figure D-19. Cross section of transects 1,2, and 2A at Circular Side Channel (adapted from Quane et. al. 1985).



Appendix Figure D-20. Cross section of transects 3,4, and 5 at Circular Side Channel.

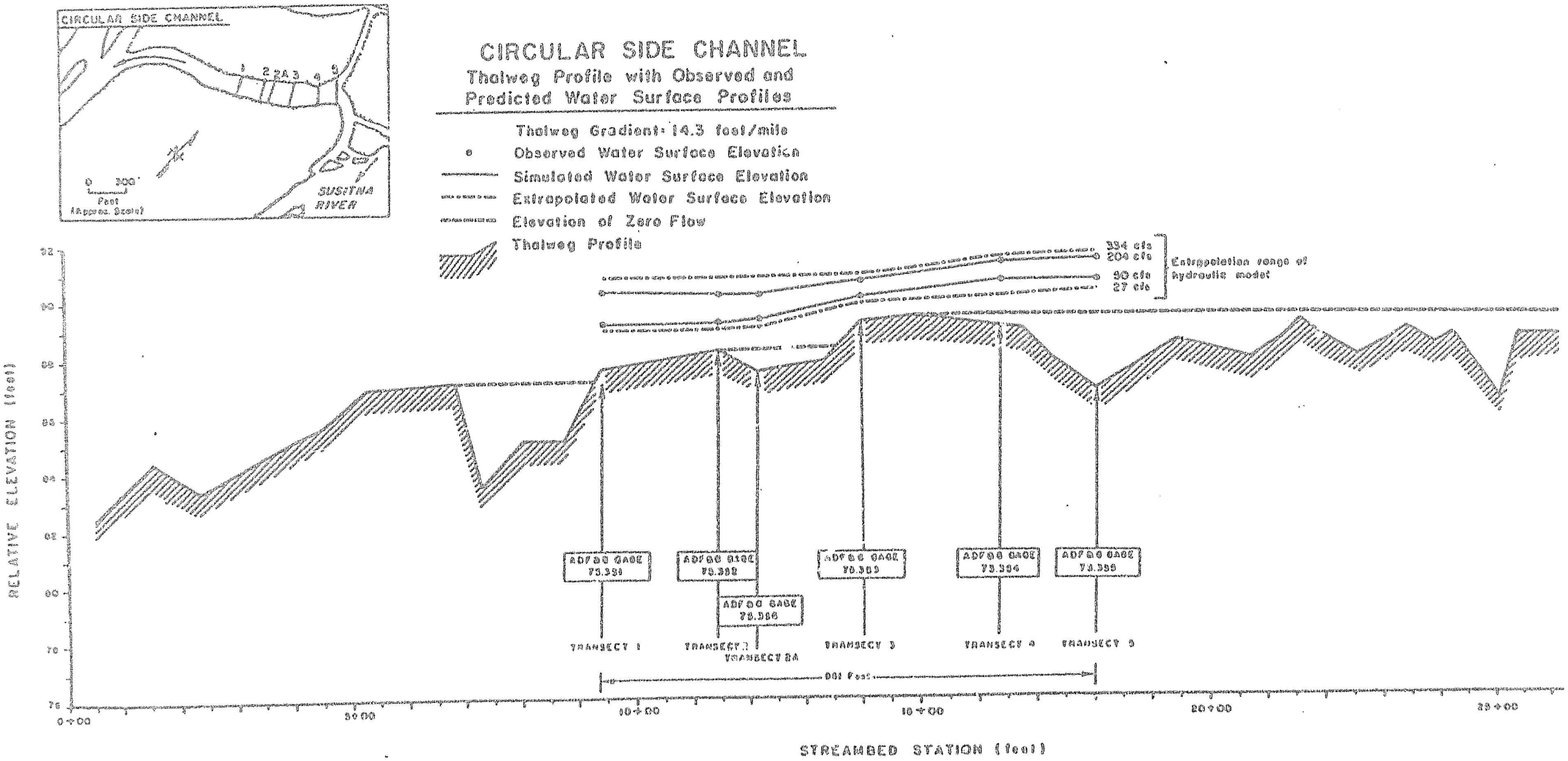
Side Channel study site were 42,500 and 55,200 cfs as determined from provisional USGS streamflow data.

Calibration

Calibration data were available at the close of the 1984 field season for side channel flows of 50 and 204 cfs. An IFG-4 model was used to forecast instream hydraulics based on these two calibration flows. The streambed profile, stages of zero flow, and observed and predicted water surface elevations for the study reach are plotted to scale in Appendix Figure D-21. The two data sets were used to predict hydraulic information from side channel flows of 6 to 733 cfs (mainstem discharges of 25,500 to 75,000 cfs).

To evaluate the performance of the hydraulic model, observed and predicted water surface elevations, discharges, and velocity adjustment factors were compared (Appendix Table D-7). Because of the 2 calibration flows only a 2 point rating curve was formulated. In evaluating the performance of the model, observed and predicted WSEL's and discharges were the same because of this rating curve. Velocity adjustment factors were all within the good range of 0.9 to 1.1. Additionally, the stage information of the model was compared to the rating curves established by Quane et al. 1985 (Appendix Figure D-17).

At the high flow measurement of 204 cfs, the original field measured discharge at transect 2 was 34% lower than that calculated at the discharge transect. In order to use this information in the model, the



Appendix Figure D-21. Comparison of observed and predicted water surface profiles from calibrated model and surveyed thalweg profile at Circular Side Channel (adapted from Quane et. al. 1985).

Appendix Table D-7. Comparison between observed and predicted water surface elevations, discharges, and velocities for 1984 Circular Side Channel hydraulic model.

Streambed Station (ft)	Water Surface Elevation Observed (ft)	Water Surface Elevation Predicted (ft)	Discharge Observed (cfs)	Discharge Predicted (cfs)	Velocity Adjustment Factor
0+00	89.28	89.28	44.4	44.4	1.000
1+98	89.30	89.30	47.9	47.9	.998
2+65	89.41	89.41	56.0	56.0	1.000
4+33	90.20	90.20	43.7	43.7	1.000
6+63	90.60	90.60	50.9	50.9	.997
8+20	90.62	90.63	53.6	53.6	1.000
			Qo = 49.0	Qp = 49.0	
0+00	90.29	90.29	202.8	202.8	.998
1+98	90.27	90.27	203.1	203.1	.987
2+65	90.31	90.31	198.4	198.4	.999
4+33	90.66	90.66	176.9	176.9	.998
6+63	91.29	91.29	199.9	199.9	1.000
8+20	91.32	91.32	194.2	194.2	1.000
			Qo = 196.0	Qp = 196.0	

Qo is the mean observed calibration discharge.

Qp is the mean predicted calibration discharage.

individual velocity measurements were all adjusted upwards by 52%. Why there was such a large discrepancy between flows at this particular transect when the four other transect flow measurements were within 9% of the discharge transect measurement is unknown.

At transect 5 there was a change in the channel cross section from when the actual cross section survey was done and when the two calibration flows were made. Between the cross section survey of September 5, 1985, and the two calibration flow measurements July 24 and August 17, 1984, a flood event occurred on August 26, 1984. After this flood, the right side of the channel at transect 5 was scoured out. In order to avoid violating one of the underlying assumptions of the model, (i.e.,that a rigid stream channel exists) the cross section determined from the two calibration flows was used in the model.

During the 50 cfs calibration flow measurement a water surface elevation was not surveyed for transect 5. In order to obtain a water surface elevation for the model, a value was calculated from the average of the depth measurements added to the corresponding cross section elevations of the 50 cfs flow measurement.

Verification

Based on the first level of verification by EWT&A, the model does an excellent job of simulating channel hydraulics between 39,000 and 57,000 cfs, mainstem discharge (38 and 213 cfs site flow) (Appendix Figure

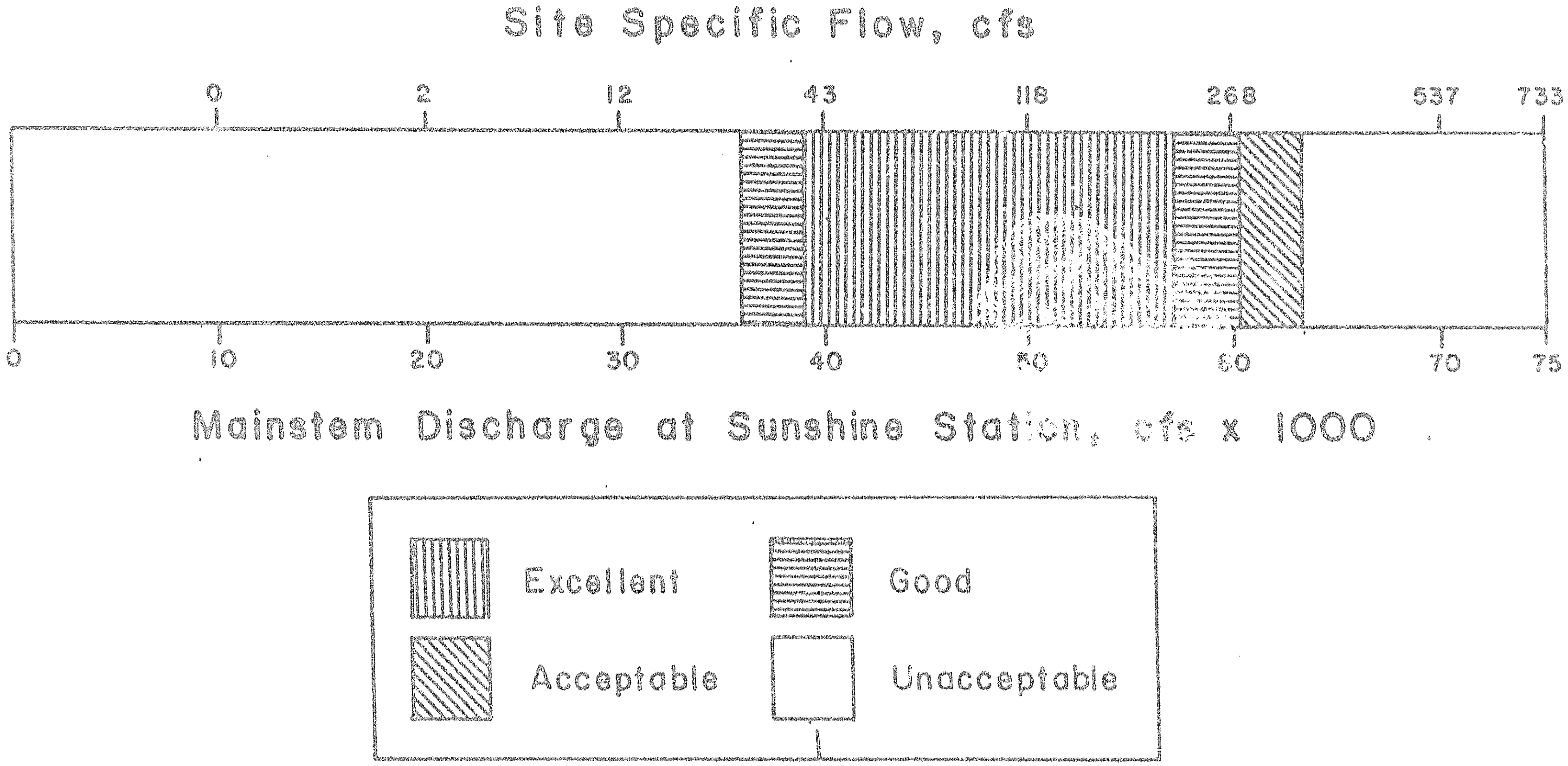
D-22). Above 57,000 cfs, the simulated depth and velocity distributions begin to deteriorate in quality. The model simulations were therefore rated good between 57,000 and 60,000 cfs (213 and 268 cfs site flow), acceptable between 60,000 and 63,000 cfs (268 and 334 cfs site flow), and unacceptable above 63,000 cfs mainstem discharge (Appendix Figure D-22). Below 39,000 cfs, the model simulations were also rated less than excellent as forecasted velocity and depth distributions deteriorated in quality. The model simulations were rated good between 36,000 and 39,000 cfs mainstem discharge (27 and 38 cfs site flow) (Appendix Figure D-22). Below 36,000 cfs mainstem (controlling discharge), insufficient information is available to evaluate the model.

The second level of the verification has not been performed as of this time.

Application

For habitat simulation modelling purposes, the hydraulic simulation model developed for Circular Side Channel can simulate channel flows in the mainstem discharge range of 36,000 to 63,000 cfs.

Application Range of the Calibrated Hydraulic Model at Circular Side Channel RM (75.3)



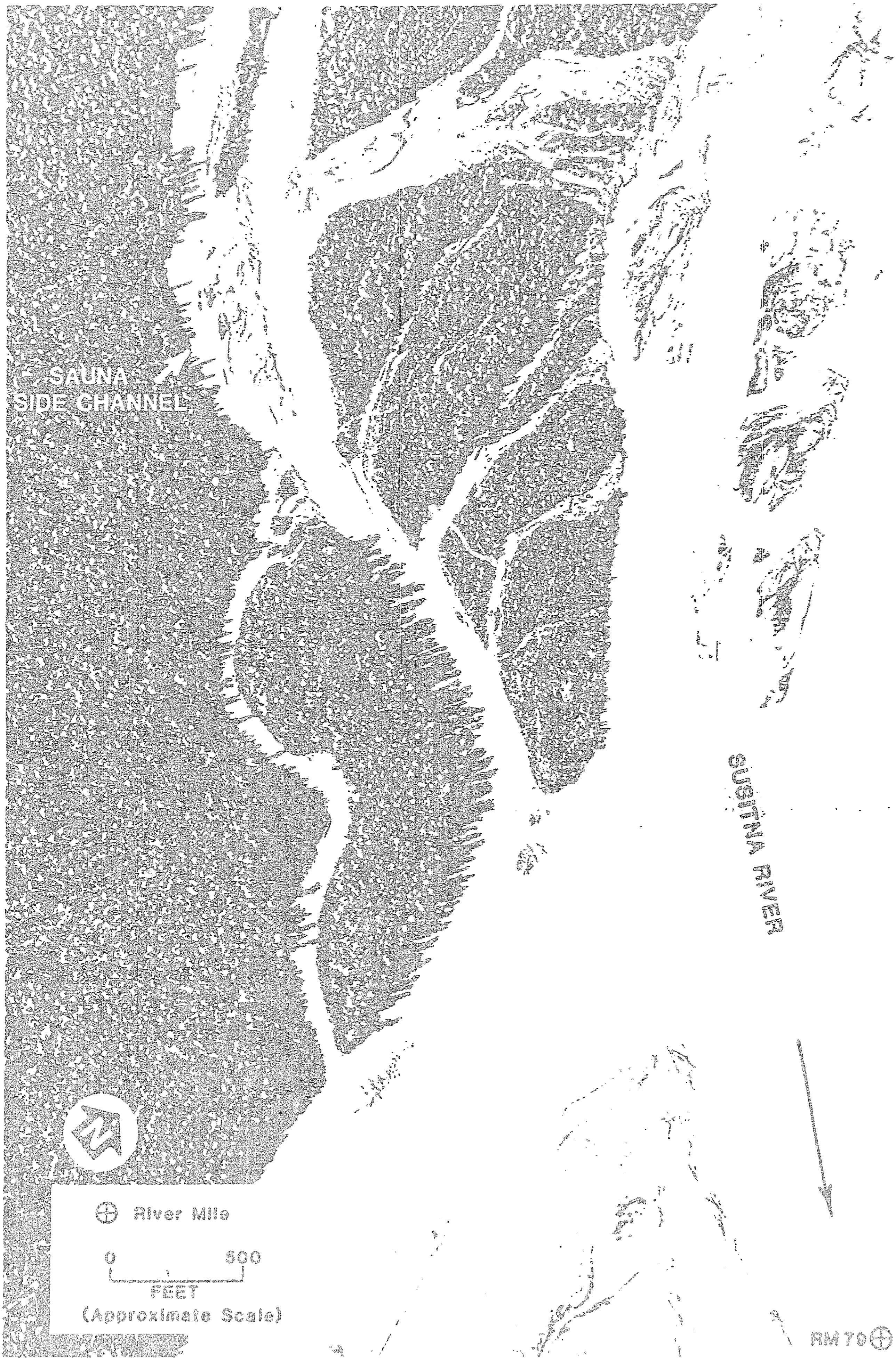
Appendix Figure D-22. Application range of the calibrated hydraulic model at Circular Side Channel.

Sauna Side Channel (RM 79.8)

Site Description

Sauna Side Channel is located on the west bank of the Susitna River at river mile 79.8 (Appendix Figure D-23). It is approximately 0.2 miles long. Both the mouth and head of the side channel are connected to a larger side channel of the mainstem Susitna River. For the most part, the side channel is confined on the west side by a high bank and on the east by a large sparsely vegetated gravel bar. A smaller side channel enters just below the head of Sauna Side Channel on its west bank. This side channel conducts flow to the study site during high mainstem discharges, but dewaters before the head of Sauna Side Channel becomes unbreached. Breaching flows result from overtopping of the side channel that adjoins the head on the east bank of Sauna Side Channel. Prior to breaching, the channel is composed of two large interconnected pools whose water levels are maintained from ground water seepage originating from the vicinity of the head. An extensive log jam exists at the head of Sauna Side Channel that likely influences the flow into this side channel.

Based on assessments by Quane et al. 1985 breaching of Sauna Side Channel is the result of overtopping of the head of the side channel by the adjoining side channel. Based on field observations and stage/discharge relationships, the mainstem discharge estimated to initially breach Sauna Side Channel was 37,000 cfs. A controlling discharge of 38,000 cfs was determined for this side channel also based



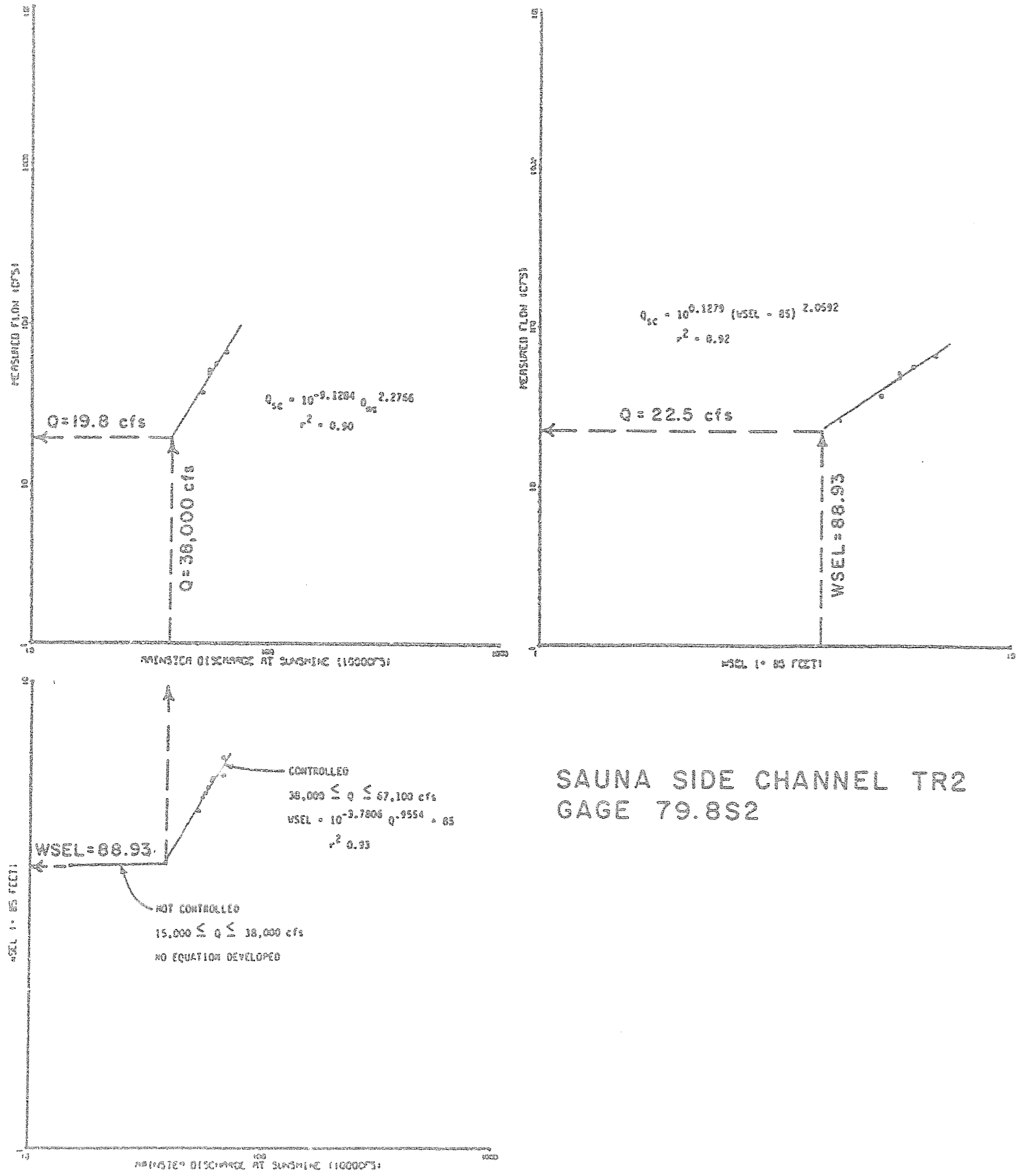
Appendix Figure D-23. Overview of Sauna Side Channel (RM 79.8).

on this stage/discharge relationship. A side channel flow of 22.5 cfs has been estimated to occur at the 38,000 cfs mainstem discharge as derived from the stage versus streamflow rating curve (Appendix Figure D-24). Based on a review of the 1984 stage data and thalweg elevations by Quane et al (1985), it has been determined that backwater does not occur in Sauna Side Channel during non-breaching mainstem discharges. During breaching discharges of 54,600 to 56,700 cfs, however, the area of backwater was observed to occur throughout the Sauna Side Channel study site. The IFG modelling site within this side channel during the 1984 open water field season was 480 feet in length and located approximately 2,000 feet from the mouth of the side channel (Appendix Figures D-23 & 25). The thalweg gradient at this site is 10.4 ft/mile (Quane et al. 1985) with substrates throughout this site consisting primarily of sands and silts. The water is slow moving with velocities usually less than 1.0 ft/sec. The left bank at this site is a erosional bank with a height exceeding five feet. Riparian vegetation along this bank consists of alder and birch, in contrast, the left bank is a depositional bank with no riparian vegetation.

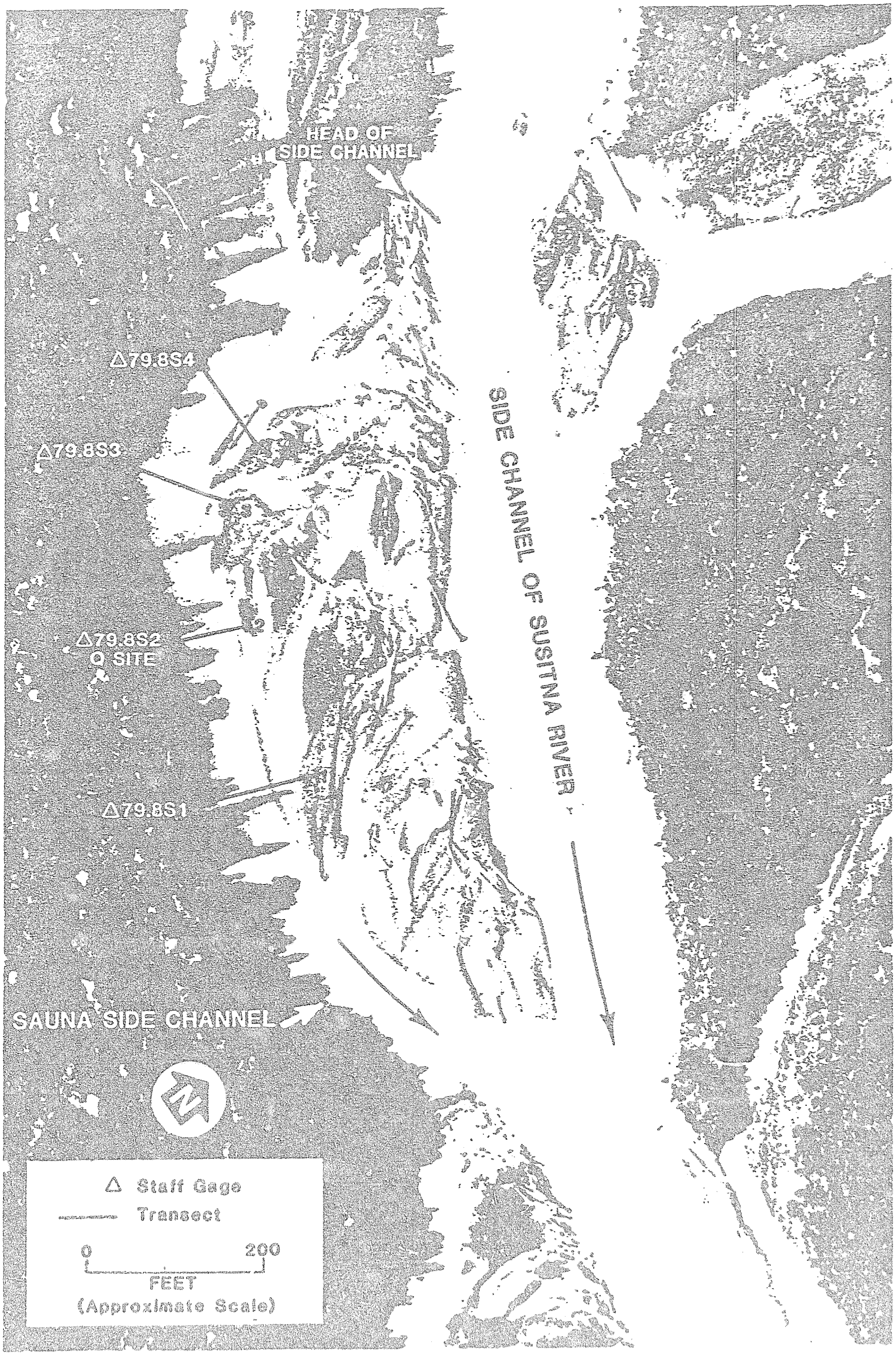
Four transects were located within this study site (Appendix Figure D-26) . Transects 1 and 2 were located in shallow pool habitat whereas transects 3 and 4 were located in deeper pools.

Data Collected

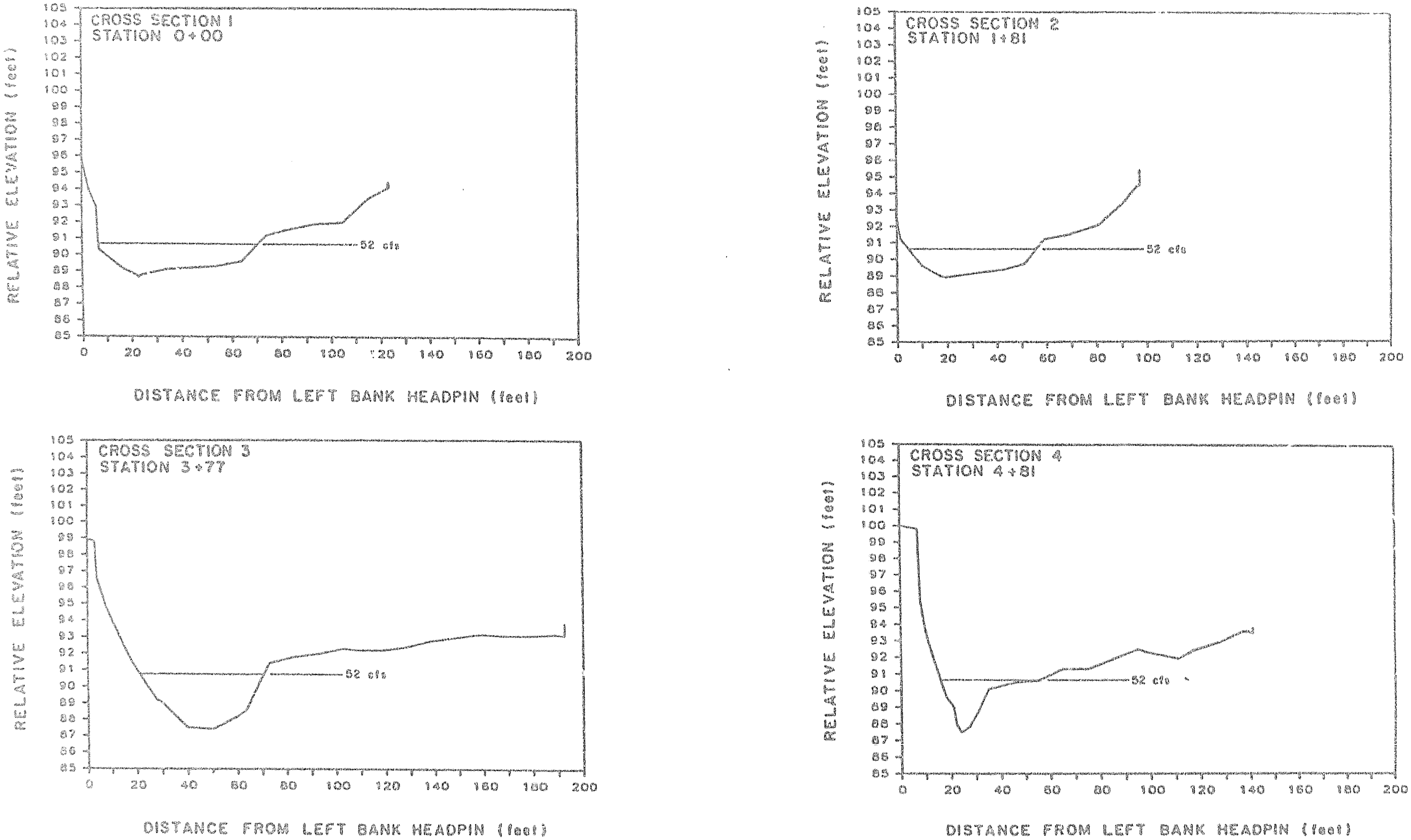
Hydraulic data were collected at a calibration discharge of 52 cfs (Appendix Table D-4). The mean daily discharge for the Susitna River on



Appendix Figure D-24. Comparison of rating curves from Sauna Side Channel transect 2 (from Quane et. al. 1985).



Appendix Figure D-25. Location of Sauna Side Channel study site (RM 79.8).



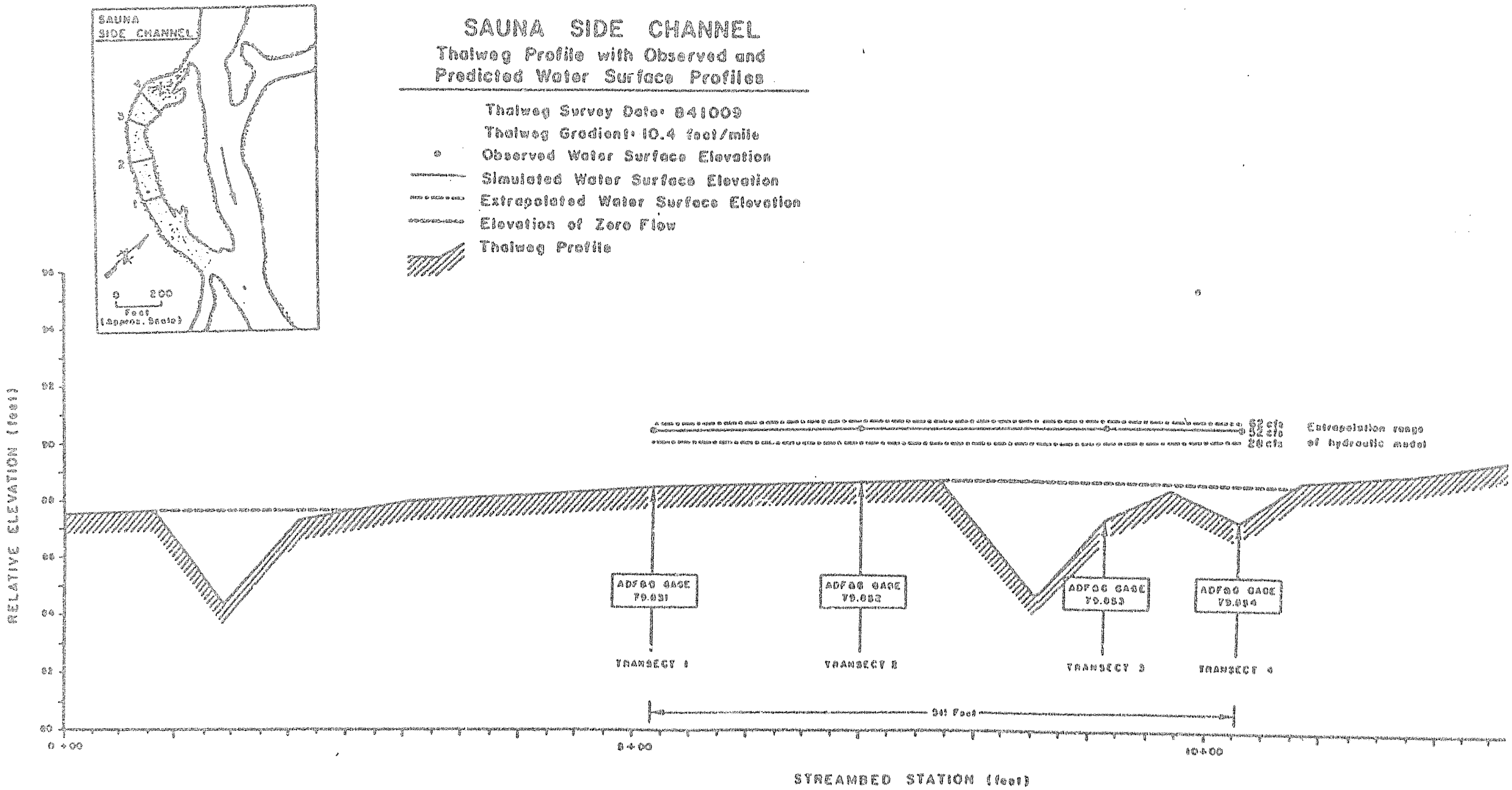
Appendix Figure D-26. Cross section of transects 1,2,3,and 4 at Sauna Side Channel (adapted from Quane et. al. 1985).

the date that the calibration data were collected at the Sauna Side Channel study site was determined to be 52,000 cfs, based on provisional USGS streamflow data.

Calibration

Calibration data available at the close of the 1984 field season consisted of that for a side channel flow of 52 cfs. Based on this calibration flow, an IFG-2 model was used to forecast instream hydraulics of this study site. The streambed profile, stage of zero flow, and observed and predicted water surface elevations for the study reach are plotted to scale in Appendix Figure D-27. This data set was used to predict hydraulic information from side channel flows of 5 to 93 cfs (mainstem discharges of 21,000 to 75,000 cfs). To evaluate the performance of the hydraulic model field observed and model predicted water surface elevations were compared (Appendix Table D-8). Additionally, the stage information of the model was compared to the rating curves established by Quane et al. (1985) (Appendix Figure D-24).

It was difficult to hydraulically calibrate this site as only very limited field data were available. A site flow WSEL rating curve could only be developed for transect 2 (Appendix Figure D-24). The IFG-2 model is essentially a water surface profile model and a critical variable for calibrating it, is the water surface elevations of simulated flows. Data, however, is only available for transect 2 and not for any of the other three transects. The actual velocity measurements from other measured field flows at the discharge transect, however, can be



Appendix Figure D-27. Comparison of observed and predicted water surface profiles from calibrated model and surveyed thalweg profile at Sauna Side Channel (adapted from Quane et. al. 1985).

Appendix Table D-8. Comparison of field measured and model predicted water surface elevations at the calibration flow of 52 cfs for Sauna Side Channel.

	Water Surface Elevation (ft)		
Transect	Original Field	Modified Field*	Model Predicted
1	90.70	90.60	90.61
2	90.7[illegible]	90.61	90.62
3	90.72	90.62	90.63
4	90.69	90.59	90.63

* Field water surface elevations were reduced by 0.1 feet.

used to compare to the model predicted velocities for those same flows. At the discharge measurement for transect 2, however, there were only two flows that were far enough away from the 52 cfs measurement to be able to do this (38 and 68 cfs). Thus, the information available to hydraulically calibrate the IFG-2 model for this site consists of the water surface elevations and velocity measurements for all four transects at the calibrating flow of 52 cfs and water surface elevations and velocities for the two other site flows of 38 and 68 cfs at transect 2.

Overall, the site is hydraulically quite homogenous being influenced to a great deal by backwater (i.e., all predicted velocities were less than 1.0 ft/sec). The effects of the backwater seem more pronounced at the 68 cfs flow. From the field data, the observed top width is greater by 20 feet, the water surface elevation is 0.93 feet higher and the average velocity is 0.20 ft/sec slower than predicted by the model (Appendix Table D-9). At the 38 cfs flow the effect seems to have reversed, with the observed widths being similar, the WSEL 0.08 feet lower, and the average velocity 0.09 ft/sec faster than predicted by the model (Appendix Table D-9).

In the calibration process, the original field WSEL was reduced by 0.1 feet. This adjustment was made in order to obtain water surface elevations that agreed more closely at the lower site flows. It was felt that this adjustment would make the model, in terms of predictability, more sensitive at the lower site flows. By reducing the WSEL of transect 1 by 0.1 feet, the difference between the WSEL of the field

Appendix Table D-9. The effects of the backwater at Sauna Side Channel, information obtained from transect 2.

Site Flow (cfs)	Original WSEL (ft)		Modified WSEL (ft)		Top Width (ft)		Average Velocity (ft/sec)	
	Field	Model	Field	Model	Field	Model	Field	Model
68	91.85	91.06	91.85	90.92	77.0	55.0	0.32	0.52
52[A]	90.71[B]	90.74	90.61[C]	90.62	53.5	53.0	0.53	0.49
38	90.24	90.42	90.24	90.32	50.5	52.0	0.51	0.42

[A] Calibration flow

[B] Original field WSEL input into model

[C] Field WSEL reduced by 0.1 ft

and the model at the 38 cfs site flow was reduced from 0.18 feet, when the calibration discharge WSEL was 90.71, to 0.08 feet, when the calibration discharge WSEL was 90.61 feet (Appendix Table D-9).

As a result of a flood on August 26, sediments were deposited in the study site resulting in changes in all the cross sections derived from the calibration flow on July 23. As a result, the cross sections obtained during the September 15 survey were used in the model until the water's edge of the calibration flow was reached when then the cross section from the calibration flow was used.

When measuring the velocities and depths at each of the transects, the discharge calculated at transect 4 was 16% lower than the 52 cfs site flow calculated at the discharge transect. In order to utilize this information in the model, the velocities were adjusted upwards by 16%.

There was not a stage-site flow rating curve developed for transect 1. When inputting other flows into the model, the IFG-2 requires either the associated WSEL for this flow or the slope. Because the WSEL could not be obtained for these other flows at this transect, a slope value of 0.00005 was input instead. This value was generated by the model from transect 1 at the calibration flow of 52 cfs.

Verification

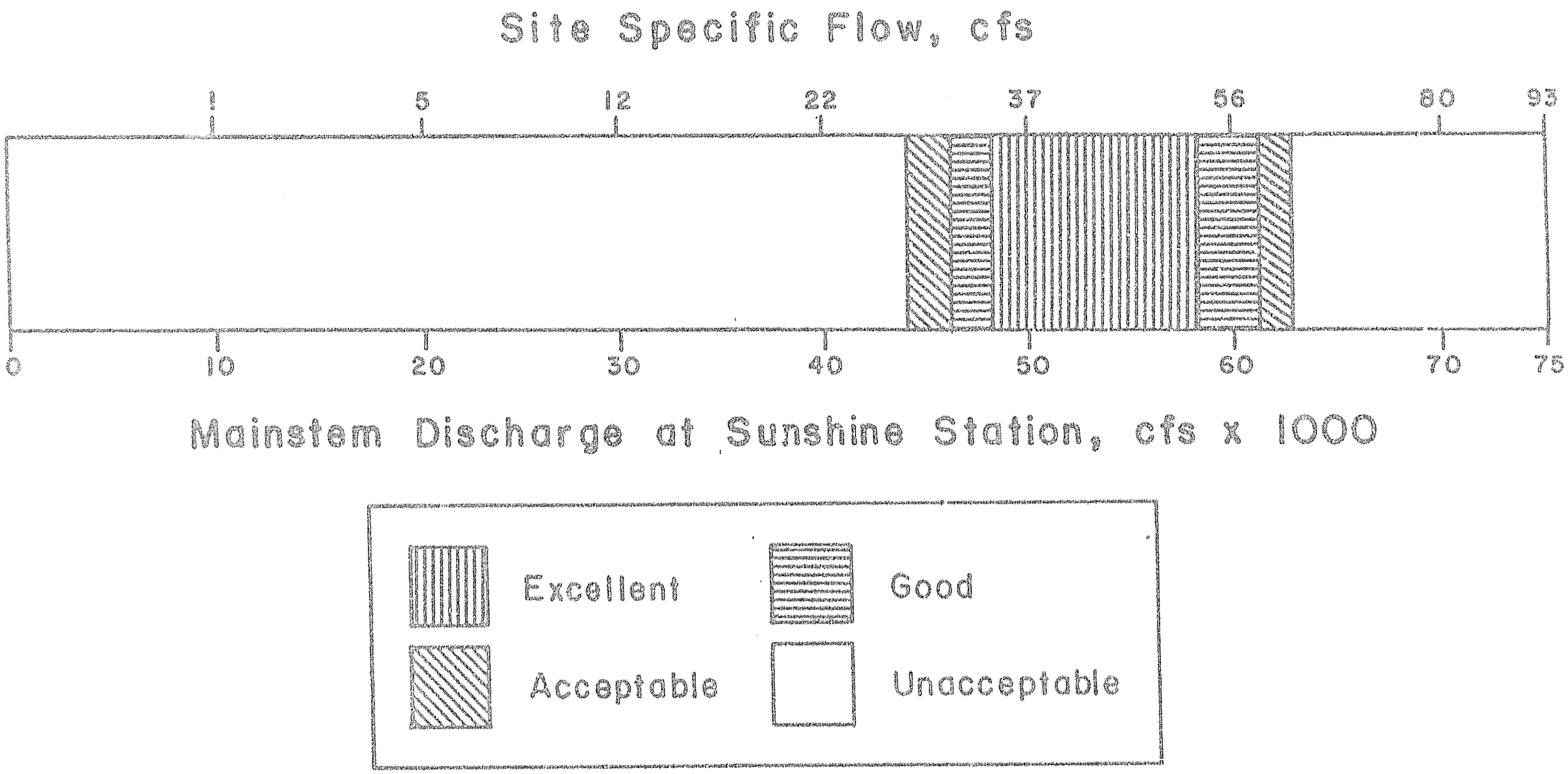
The dominant influence of backwater on channel hydraulics makes the site a poor candidate for application of IFG-2 modeling techniques. However, because only one data set was collected, application of the IFG-4 hydraulic model was not an option.

Based on the first level of verification by EWT&A, the IFG-2 model for this site does an excellent job of simulating channel hydraulics between 48,000 cfs and 58,000 cfs mainstem discharge (34 to 52 cfs site flow) (Appendix Figure D-28). Within this range, predicted WSEL's, depths, and velocities are in close agreement with field information (evaluated at 38 cfs by discharge measurement made by Quane et al (1985). The predictive capability of the model within this range provides evidence that the backwater influence within the study site is lessening with decreasing discharge.

Below 48,000 cfs mainstem, there is increasing disagreement between the WSEL's predicted by the model and those extrapolated from the rating curve. At 23 cfs site flow, the difference in predicted WSEL between model and rating curve equation has increased to approximately one foot at transects 1 and 2. Although there is evidence that suggests that the model may be a more accurate predictor of WSEL's than the rating curve equations below 48,000 cfs mainstem, insufficient information exists to resolve the difference with confidence. Since depths become shallow within this range, predictive errors in WSEL can result in significant errors in predicted depths and velocities. For this reason, the recommended extrapolation range is limited below 48,000 cfs.

Above 48,000 cfs mainstem, there is increasing, disagreement between the WSEL's predicted by the model and those observed in the field. One of

Application Range of the Calibrated Hydraulic Model
at Sauna Side Channel
RM (79.8)



Appendix Figure D-28. Application range of the calibrated hydraulic model at Sauna Side Channel.

the premises of the hydraulic theory that is the basis of the IFG-2 model is that the water surface profile of the study reach is controlled by its slope. This premise is violated when the water surface profile is influenced by mainstem backwater. From examination of discharge measurements made at 48 and 68 cfs it is apparent that the influence of backwater is increasing with stage above 58,000 cfs mainstem.

Overall, the recommended extrapolation range is limited above 58,000 cfs. The model simulations were rated excellent between 48,000 and 58,000 mainstem discharge (34 to 52 cfs site flow). Good between 46,000 and 48,000 (31 to 34 cfs) and from 58,000 to 60,000 cfs (52 to 58 cfs). Acceptable between 44,000 and 46,000 cfs (28 to 31 cfs) and 60,000 to 63,000 cfs (58 to 62 cfs). The model was rated unacceptable below 44,000 cfs and above 63,000 cfs mainstem discharge (Appendix Figure D-28).

The second level of the verification procedure has not been performed as of this time.

Application

For habitat simulation modelling purposes the hydraulic simulation model developed for Sauna Side Channel can simulate channel flows in the mainstem discharge range of 44,000 to 63,000 cfs.

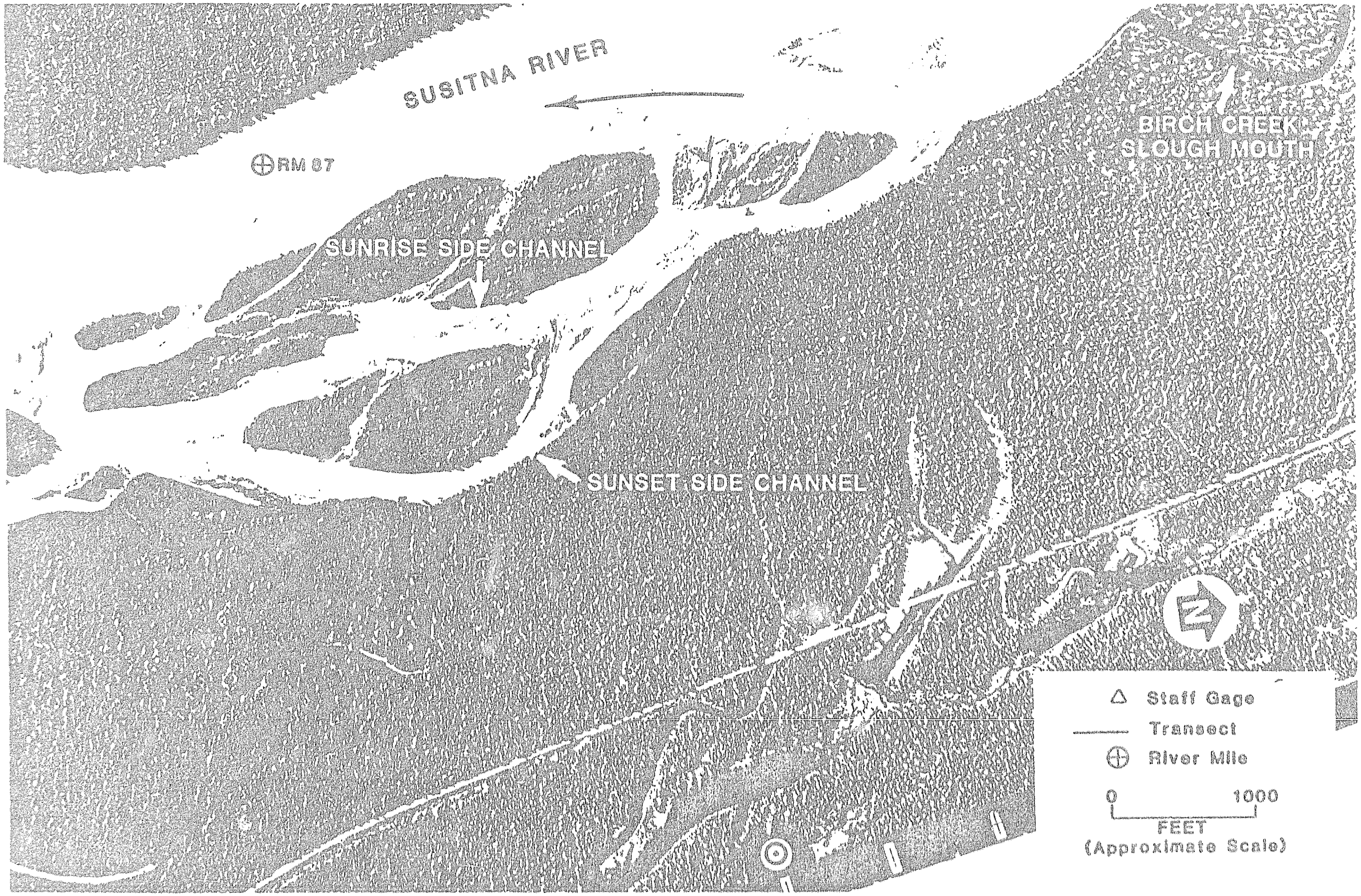
Sunset Side Channel (RM 86.9)

Site Description

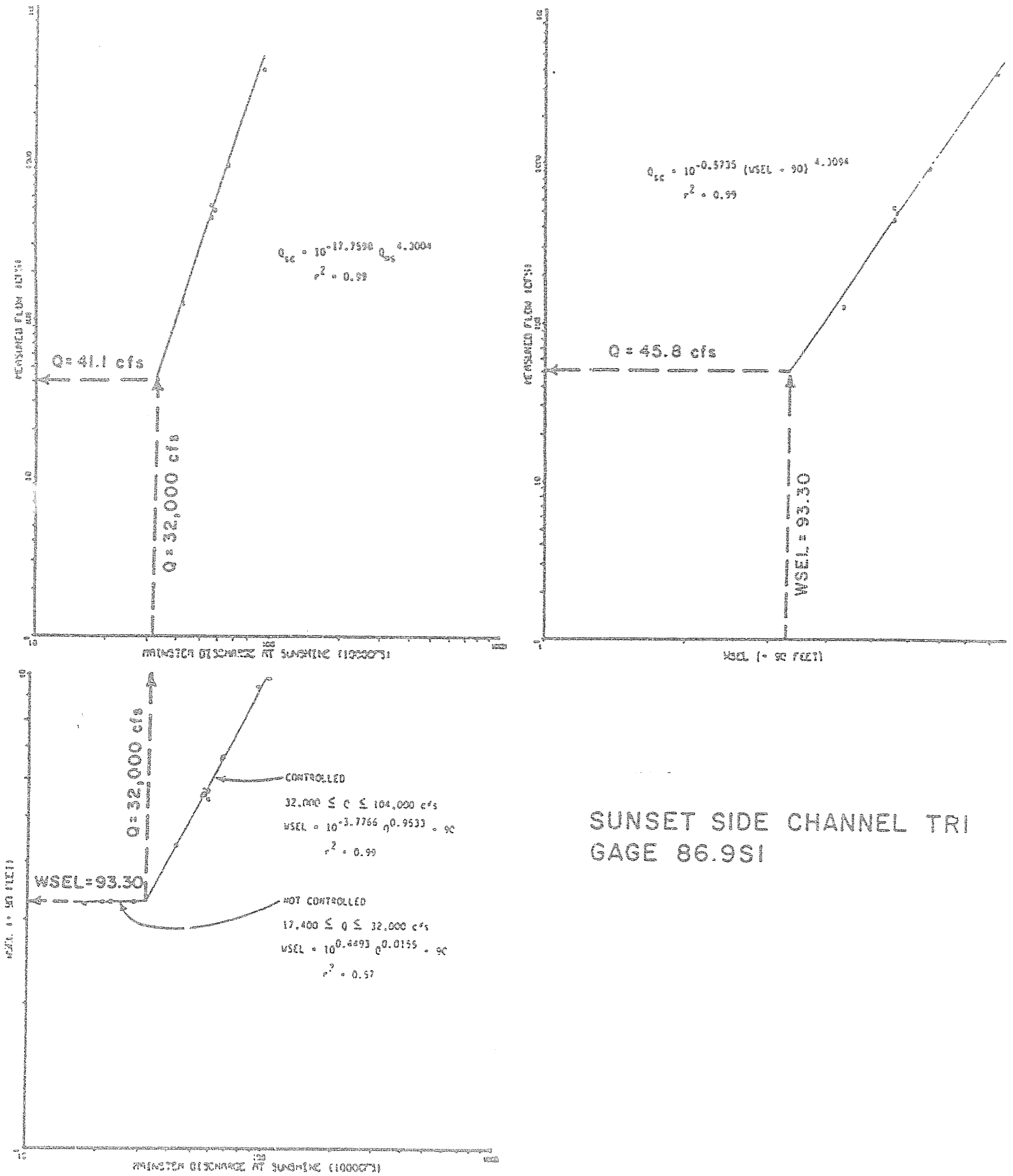
Sunset Side Channel is located on the east bank of the Susitna River at river mile 86.9 (Appendix Figure D-29). It is approximately 1.1 miles in length and is separated from the main channel Susitna River on the west by a network of vegetated islands and side channels. The channel is confined on the east by a high cut bank. Prior to breaching, the side channel is composed of a sequence of pools and riffles. During this period, flow is maintained in the main channel by groundwater seepage and upwelling. Subsequent to breaching, flows up to 3,900 cfs have been measured (Quane et al 1985).

Breaching of Sunset Side Channel results from the direct overtopping of the head of the side channel by the mainstem Susitna River. Based on assessments by Quane et al. 1985 the side channel has been estimated to be initially breached at 31,000 cfs and controlled at a mainstem discharge of 32,000 cfs. The associated site flow has been estimated to be 45.8 cfs (Appendix Figure D-30). This compares to an estimated flow of 41.1 cfs derived from the flow versus mainstem discharge rating curve presented in Appendix Figure D-30 (Quane et al. 1985).

Based on assessments by Quane et al. (1985) a backwater area does not occur in this side channel during unbreached conditions. But at breaching mainstem discharges ranging from 56,000-66,700 cfs, an area of



Appendix Figure D-29. Overview of Sunset Side Channel (RM 86.4).

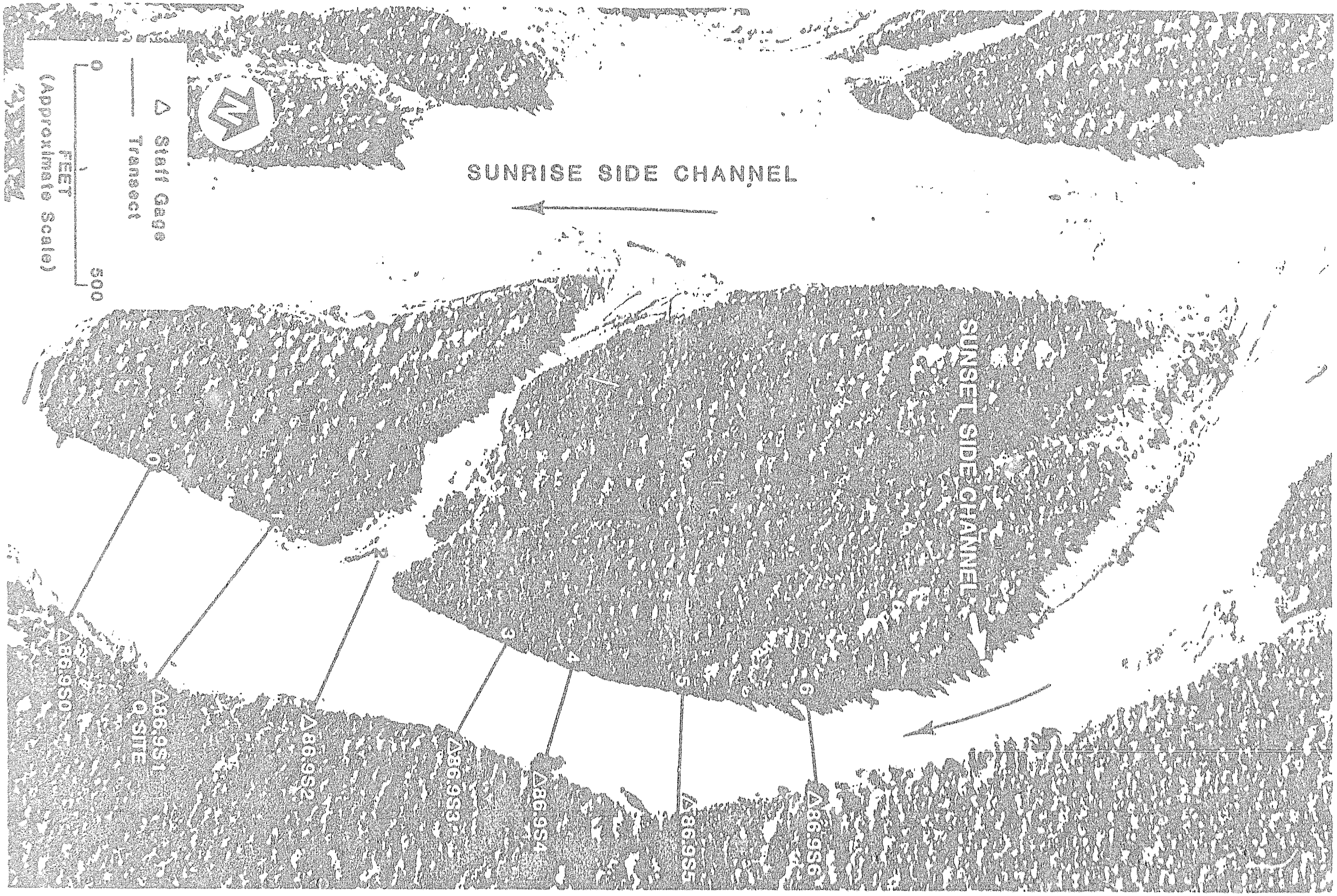


Appendix Figur D-30. Comparison of rating curves from Sunset Side Channel at transect 1 (from Quane et. al. 1985).

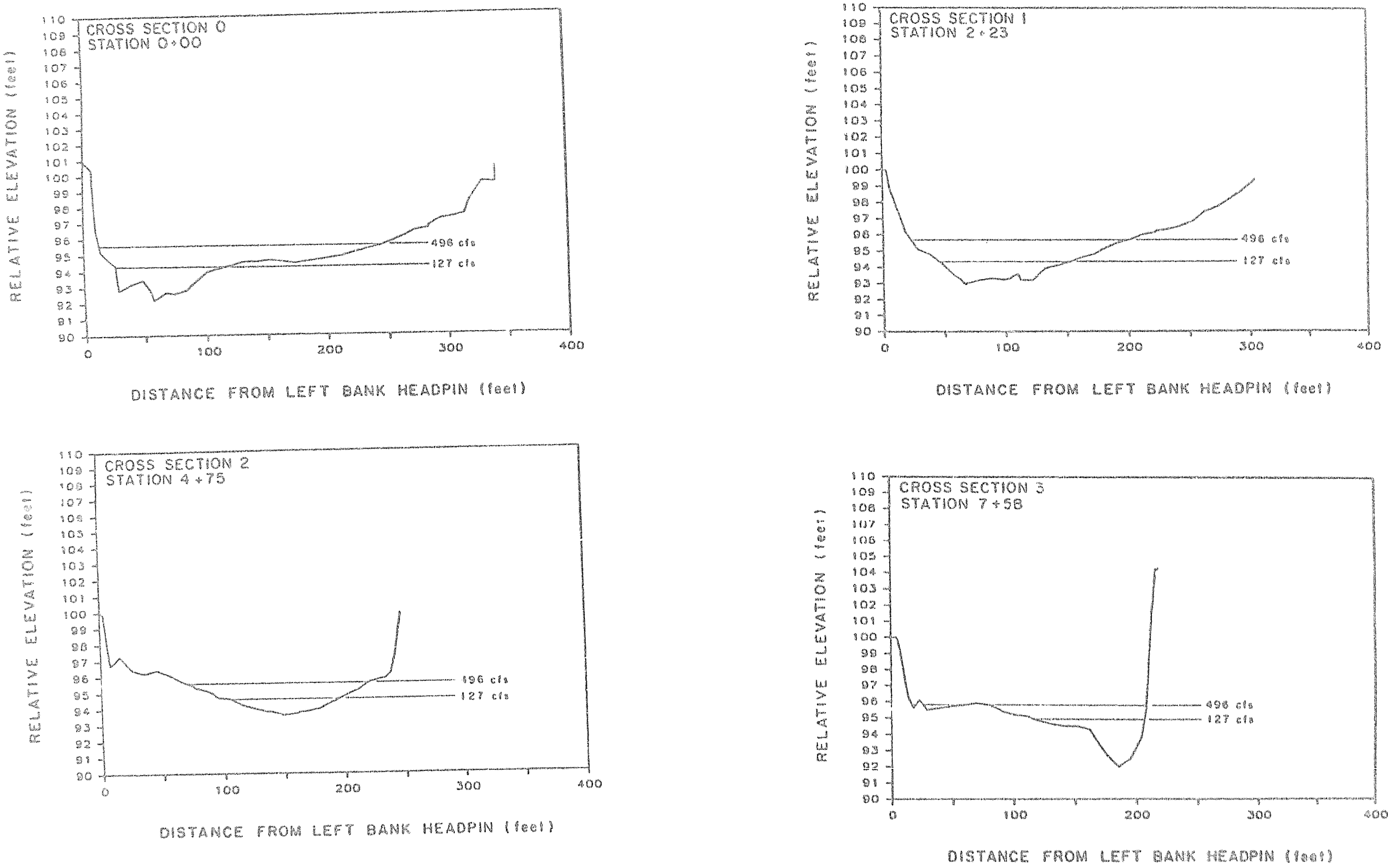
backwater was observed to extend upstream approximately 1,100 feet to a point between transects 1 and 2.

The IFG modelling site within Sunset Side Channel during the 1984 open water field season was located in the lower portion of the side channel and was 1410 feet in length (Appendix Figures D-29 & 31). Seven transects from which hydraulic information was collected were located within this study site (Appendix Figures D-32 & 33). The channel within the study site has a gradual bend. The right bank from transects 2 to 6 is erosional in nature becoming less steep and depositional in nature at transects 0 and 1. On the left bank from transects 2 to 6 is primarily depositional in nature becoming steep and erosional in the areas of transects 0 and 1. At the transect 2 on the left bank a small side channel area enters through which water was never observed running (Appendix Figure D-31). The thalweg gradient within the study site is 9.5 ft/mile (Quane et al. 1985). Riparian vegetation along the right bank is primary birch and spruce whereas on the left bank it is alder.

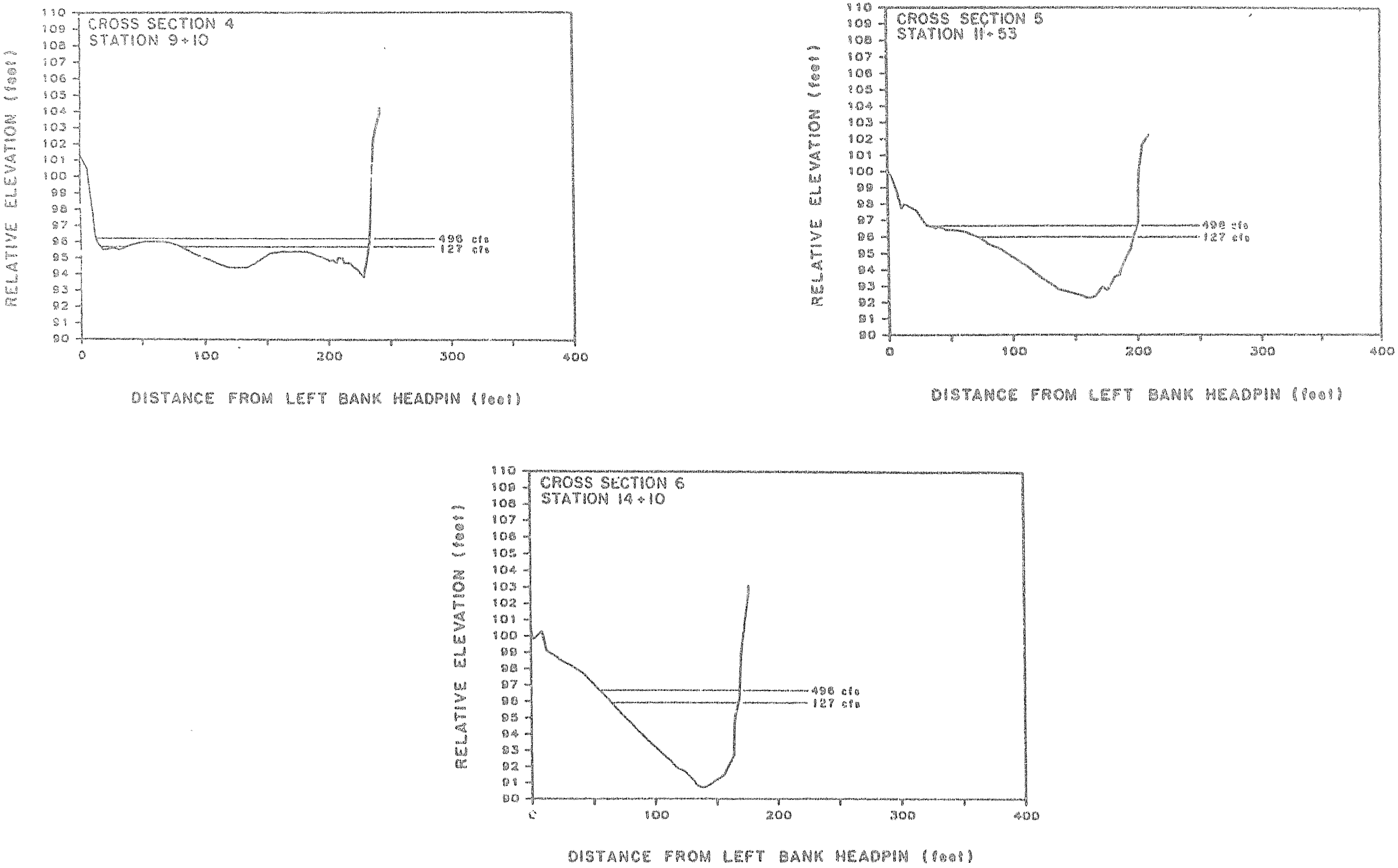
Transect 0 is located in shallow pool type habitat and has substrates of sand and small gravels. At transects 1 (the discharge site) and 2, the primary habitat type is run, and the substrate is small gravel. At transect 3, the habitat changes to run- shallow pool habitat, with the predominate substrates being small and large gravels. The hydraulic control for transects 5 and 6 is transect 4. This transect represents riffle habitat, with substrates composed mostly of small and large gravels. Transects 5 and 6 are located in deep pool habitat, with substrates being composed of mostly small and large gravels.



Appendix Figure D-31. Location of Sunset Side Channel study site (RM 86.9).



Appendix Figure D-32. Cross section of transects 0,1,2, and 3 at Sunset Side Channel (adapted from Quane et. al. 1985).



Appendix Figure D-33. Cross section of transects 4,5, and 6 at Sunset Side Channel (adapted from Quane et. al. 1985).

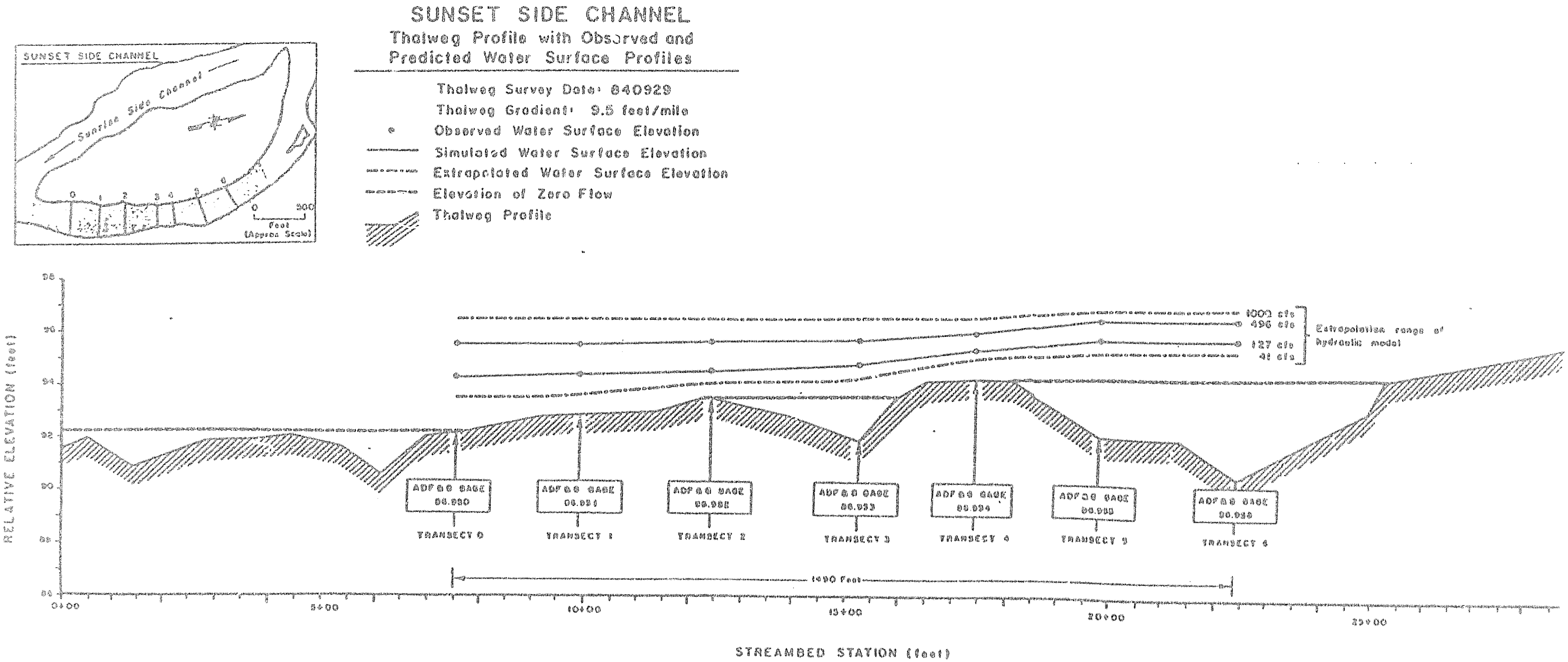
Data Collected

Hydraulic data were collected at two calibration discharges: 127 and 496 cfs (Appendix Table D-4). Mean daily discharges for the Susitna River on the dates that calibration data were collected at the Sunset Site Channel study site were 42,500 and 57,800 cfs, respectively as determined from provisional USGS streamflow data.

Calibration

Calibration data were available at the close of the 1984 field season for side channel flows of 127 and 496 cfs. Based on these two calibration flows, an IFG-4 model was used to forecast instream hydraulics at this study site. The streambed profile, stage of zero flow, and observed and predicted water surface elevations for the study reach are plotted to scale in Appendix Figure D-34. Both calibration data sets were used to predict hydraulic information from side channel flows of 7 to 1,603 cfs (mainstem discharges of 21,000 to 75,000 cfs).

To evaluate the performance of the hydraulic model, observed and predicted water surface elevations, discharges, and velocity adjustment factors were compared (Appendix Table D-10). The hydraulic model at Sunset Side Channel is similar to Circular Side Channel. Because of the 2 calibration flows, only a 2 point rating curve was formulated. In evaluating the performance of the model, observed and predicted WSEL's and discharges were the same because of this rating curve. Velocity



Appendix Figure D-34. Comparison of observed and predicted water surface profiles from calibrated model and surveyed thalweg profile at Sunset Side Channel (adapted from Quane et. al. 1985).

Appendix Table D-10. Comparison between observed and predicted water surface elevations, discharges, and velocities for 1984 Sunset Side Channel hydraulic model.

Streambed Station (ft)	Water Surface Elevation Observed (ft)	Water Surface Elevation Predicted (ft)	Discharge Observed (cfs)	Discharge Predicted (cfs)	Velocity Adjustment Factor
0+00	94.27	94.27	132.7	132.4	1.000
2+23	94.34	94.34	131.7	131.3	.999
4+75	94.69	94.69	133.6	133.3	1.000
7+58	94.97	94.97	127.2	126.9	.998
9+10	95.54	95.54	136.4	136.3	1.000
11+53	95.98	95.98	125.5	125.2	.999
14+10	95.97	95.97	129.9	129.6	
			Qo = 131.0	Qp = 131.0	
0+00	95.62	95.62	462.3	462.3	1.000
2+23	95.67	95.67	500.0	500.0	.999
4+75	95.75	95.75	504.6	504.6	1.000
7+58	95.87	95.87	438.1	438.1	1.000
9+10	96.18	96.18	507.2	507.2	.993
11+53	96.64	96.64	469.9	469.9	.999
14+10	96.63	96.63	492.0	492.0	1.000
			Qo = 482.0	Qp = 482.0	

Qo is the mean observed calibration discharge.

Qp is the mean predicted calibration discharge.

adjustment factors were all within the good range of 0.9 to 1.1. Additionally, the stage information of the model was compared to the rating curves established by Quane et al. (1985) (Appendix Figure D-30).

In the model, the stages of zero flow are not the same as those determined from the thalweg survey by Quane et al. 1985 (Appendix Table D-11). The stage of zero flow values, input into the model, were derived from the thalweg points of the model input cross sections of transects 0, 1, 2, and 4. The reason for this change in thalweg elevations is likely the result of the flood event. All the points used in the model were from measurements made before the flood, whereas the Quane et al. (1985) thalweg survey was done after the flood event.

At transect 6, the velocities at the high calibration flow measurement (496 cfs) were adjusted upwards by 15% and at the low calibration flow measurement (127 cfs) adjusted downwards by 21%. Because this transect bisects a deep pool with eddies, it is difficult to obtain an accurate discharge measurement. The eddy effect was much more pronounced at the high calibration flow measurement, as there was a section of about 40 feet in which the velocities were negative. Because of its depth and slow velocities this area was considered as valuable habitat for rearing juvenile salmon. In order to facilitate using these negative velocity values in the model these measurements were treated as positive.

At transect 3 there was a difference in WSEL's at the 127 cfs calibration flow. WSEL at the left bank was 95.03 feet whereas at the right bank it was 94.90 feet. As the staff gage WSEL was 94.93 feet and the

Appendix Table D-11. Differences between stages of zero flow input into the model and Quane et al. (1985) thalweg survey at Sunset Side Channel.

Transect	Stage of Zero Flow (ft)	
	Model Input	Thalweg Survey
0	92.30	92.50
1	92.60	93.00
2	93.40	93.60
3	93.40	93.60
4	94.20	94.40
5	94.20	94.40
6	94.20	94.40

majority of flow occurred along this right side a WSEL of 94.93 feet was used in the model.

At transect 4 there was a large discrepancy (0.54 ft) in WSEL's across the transect at the calibration flow of 127 cfs. This was because the section of the channel where a majority of the flow occurred was higher in elevation and separated by a gravel berm from a lower elevation minor channel where the staff gage was located. In order to utilize this cross section in the model, the channel cross section of the minor channel was elevated upwards by 0.6 feet.

At a section of transect 3 the individual velocity measurements for the 127 cfs site flow were greater than the corresponding velocity measurements at the higher 496 cfs site flow. If these original values were to be used in the model, the simulated velocities would decrease with increasing site flows. This realistically does not occur. In order to amend this situation, the velocities were adjusted such that the relationship would simulate a positive increase in velocities with corresponding increases in site flow.

Verification

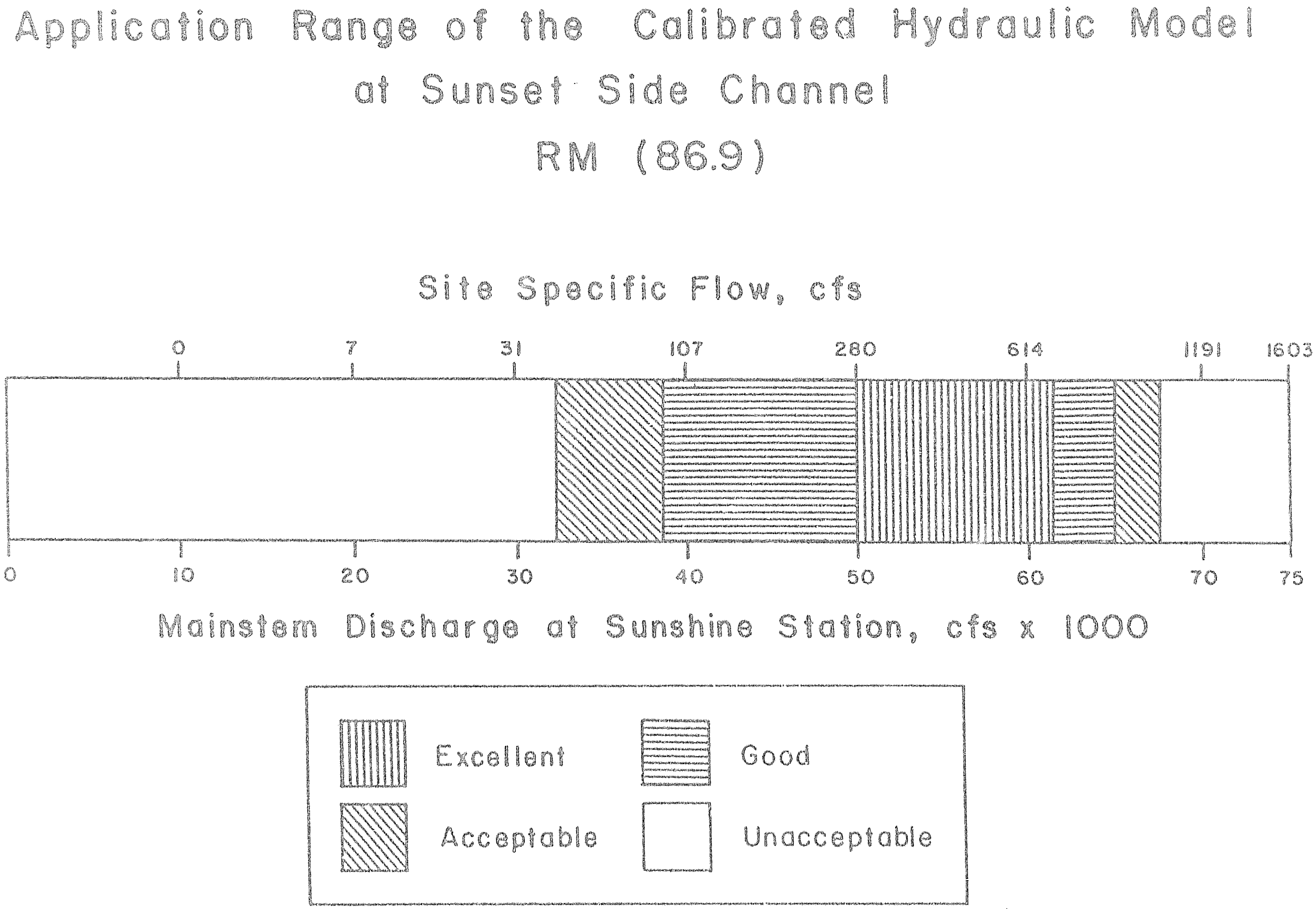
Based on the first level of verification by EWT&A, the model does an excellent job of simulating channel hydraulics between 50,000 and 61,000 cfs, mainstem discharge(275 and 649 cfs site flow) (Appendix Figure 35). Above 61,000 cfs, the simulated depth and velocity distributions begin to deteriorate in quality. The model simulations were rated good between 61,000 and 64,500 cfs (649 and 850 cfs site flow), acceptable between 64,500 and 67,000 cfs (850 and 1,000 cfs site flow), and unacceptable above 67,000 cfs mainstem discharge (Appendix Figure D-35). Below 50,000 cfs, the model simulations were also rated less than excellent, primarily because of reduced effectiveness in predicting water surface profiles as compared to field observations. The model simulations were rated good between 38,000 and 50,000 cfs (89 and 275 cfs site flow), acceptable between 32,000 and 38,000 cfs (41 and 89 cfs site flow), and unacceptable below 32,000 cfs mainstem discharge (Appendix Figure D-35).

Overall, the model simulations were rated excellent between 50,000 and 61,000 cfs (275 and 649 cfs) and good from 38,000 to 50,000 cfs (89 to 275 cfs) and from 61,000 to 64,500 cfs (649 to 850 cfs). They were acceptable between 32,000 and 38,000 cfs (41 and 89 cfs) and between 64,500 and 67,000 cfs (850 and 1,000 cfs), and became unacceptable at mainstem discharges below 32,000 cfs and above 67,000 cfs.

The second level of verification has not been performed as of this time.

Application

For habitat simulation modelling purposes the hydraulic simulation model developed for Sunset Side Channel can simulate channel flows in the mainstem discharge range of 32,000 to 67,000 cfs.



Appendix Figure D-35. Application range of calibrated hydraulic model at Sunset Side Channel.

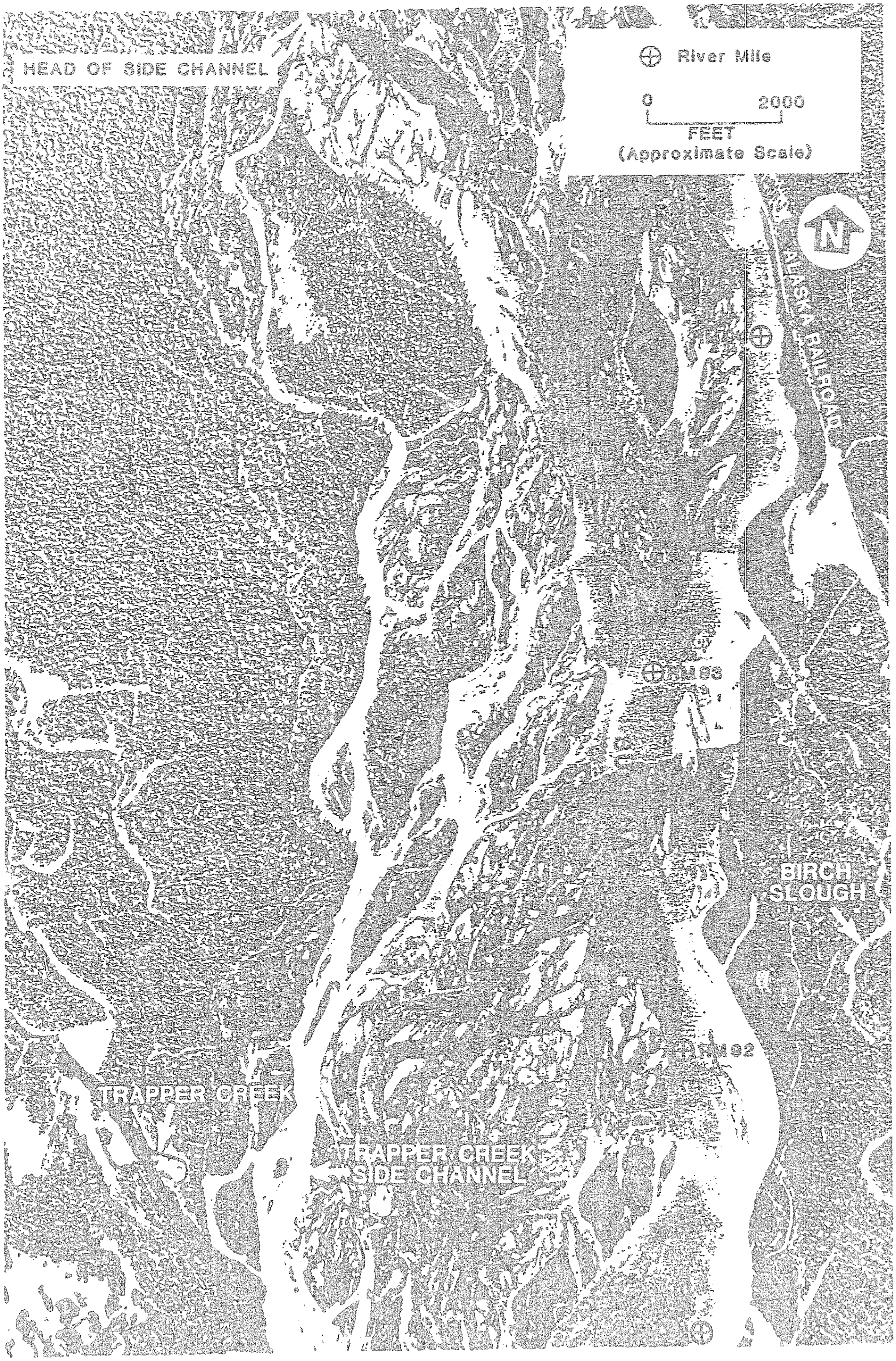
Trapper Creek Side Channel (RM 91.6)

Site Description

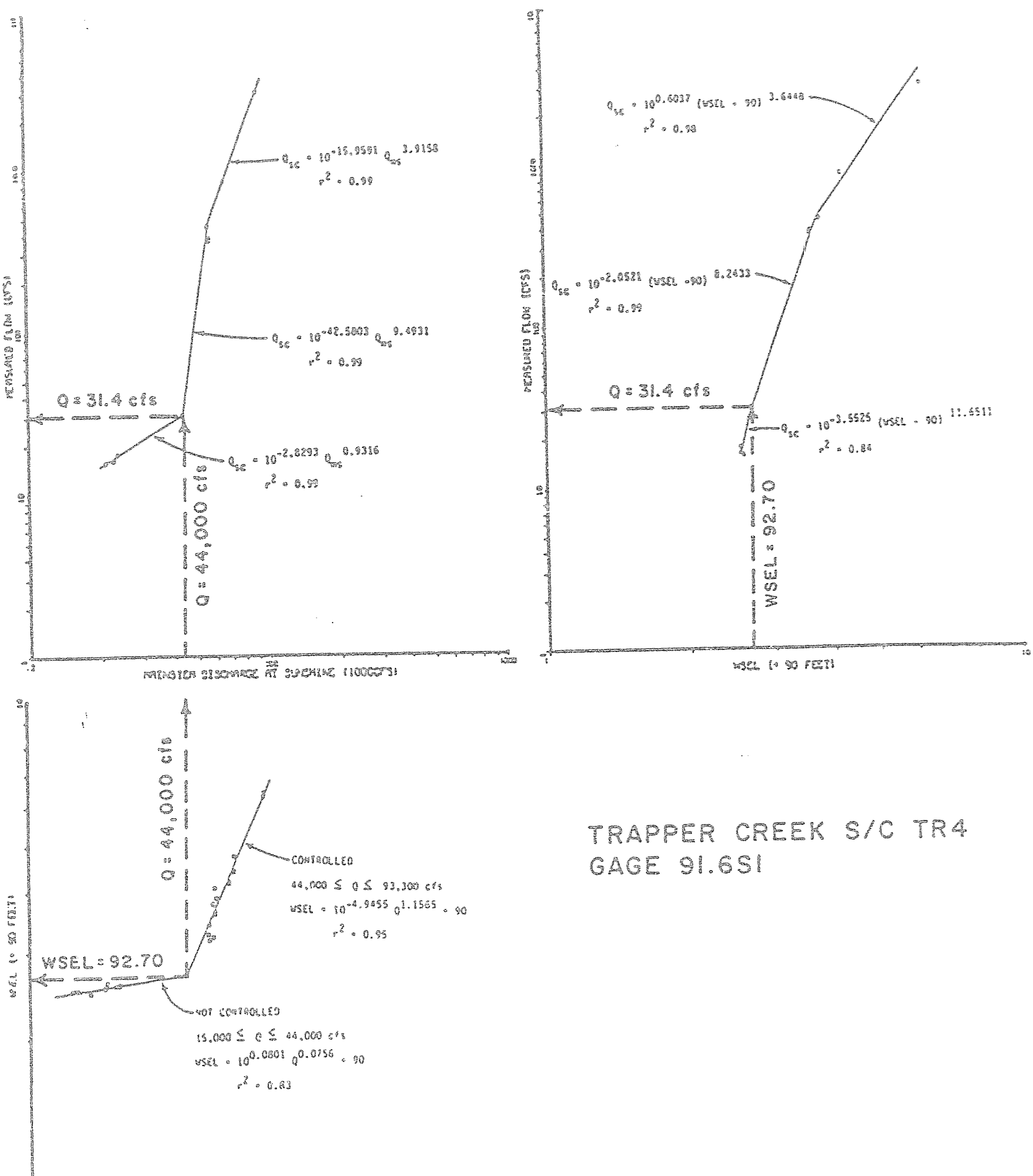
Trapper Creek Side Channel is located on the west bank of the Susitna River and is approximately 5.0 miles in length (Appendix Figure D-36). It has a relatively uniform, broad, and flat bottomed alluvial channel which is fed by multiple heads. It is separated from the mainstem Susitna River by a complex of sand bars, small channels, and vegetated islands. The head portion of this side channel is located in a complex of small channels and vegetated islands making it difficult to identify the origin of breaching flows (Quane et al. 1985).

During unbreached conditions flows in Trapper Creek Side Channel are principally due to Cache Creek and groundwater occurring in the upper reaches of the side channel. Breaching of Trapper Creek Side Channel is the result of the direct overtopping of the multiple heads of the side channel by the mainstem Susitna River. Based on assessments by Quane et al. (1985), the channel is estimated to be initially breached at a mainstem discharge of 43,000 cfs. Based on the comparison of the stage versus mainstem discharge rating curve for transect 4 (Appendix Figure D-37) by Quane et al. 1985, a discharge of 44,000 cfs was selected as the controlling breaching discharge. This mainstem discharge corresponds to a streamflow measurement of 31.4 cfs.

Based on assessments of backwater by Quane et al. (1985), an area of backwater has not been observed during other breaching and nonbreaching



Appendix Figure D-36. Overview of Trapper Creek Side Channel (RM 91.5).



Appendix Figure D-37. Comparison of rating curves from Trapper Creek Side Channel transect 4 (from Quane et. al. 1985).

mainstem discharges. But at mainstem discharges ranging from 15,700 to 22,700 cfs, pooling was observed at transects 1, 2, and 3 which resulted from the control located about 370 feet downstream from transect 1.

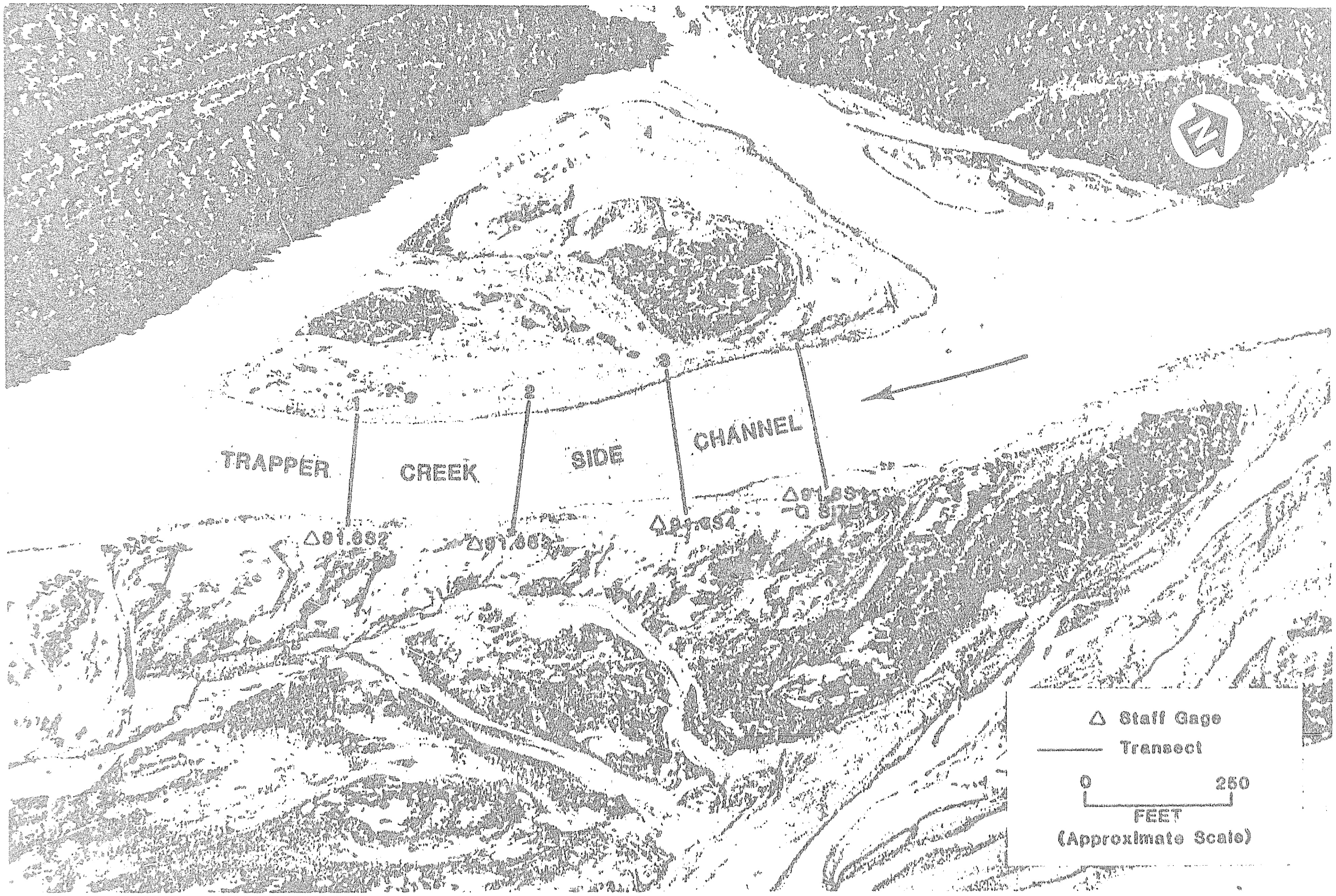
The IFG modelling site selected for Trapper Creek Side Channel during the 1984 open water field season was 790 feet in length and was located in the lower portion of the side channel in a broad open channel area (Appendix Figures D-36 and D-38). Four cross sections were surveyed within this area to define channel geometry (Appendix Figure D-39). The upper two transects were situated in a run, whereas the lower two transects were in a backwater pool influenced by a downstream control. Substrate within the study consisted primarily of cobbles and gravels with some sand at the first transect. The thalweg gradient of the side channel is 12.1 ft/mile (Quane et al. 1985).

Data Collected

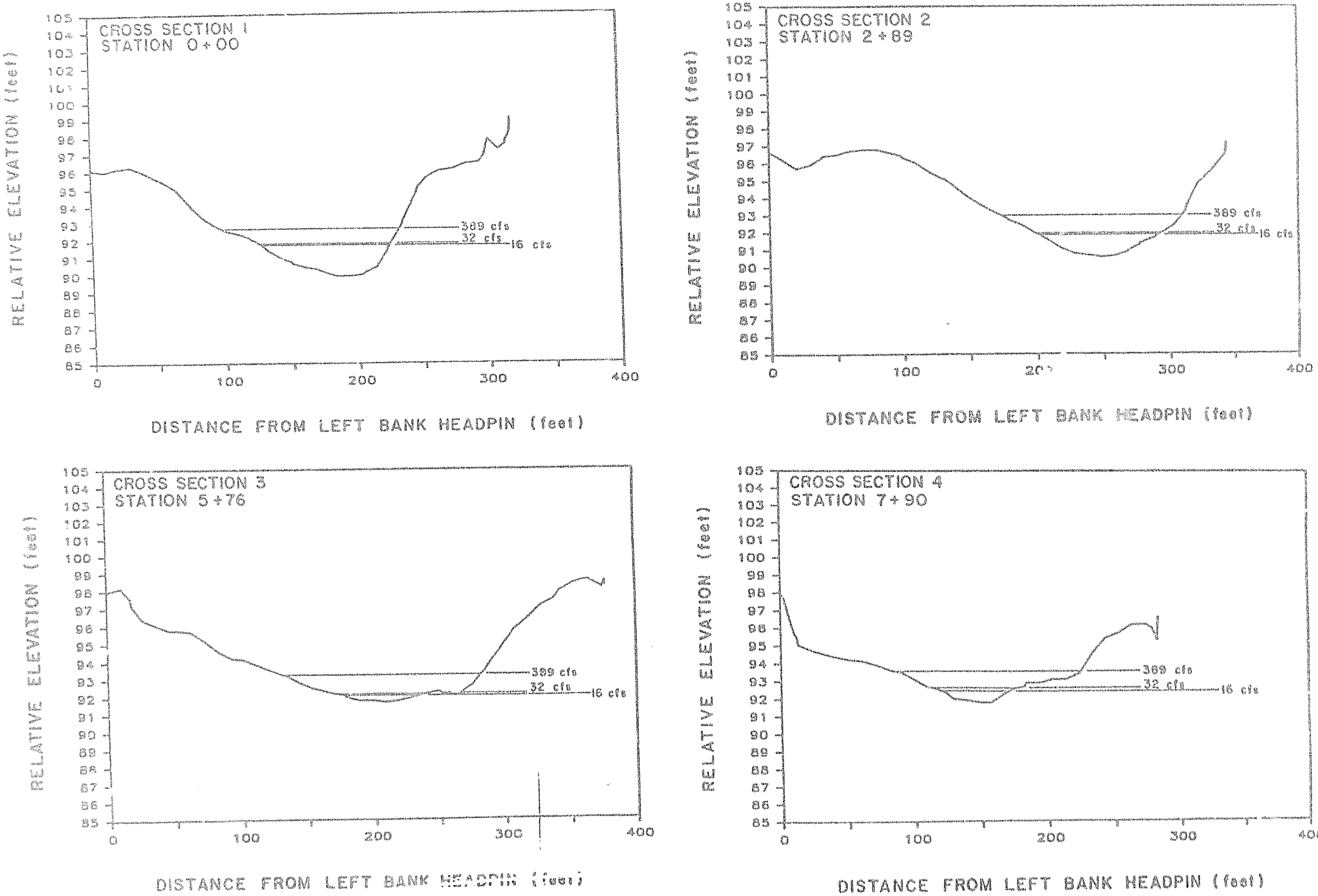
Hydraulic data were collected at three calibration discharges: 16, 32, and 389 cfs (Appendix Table D-4). Mean daily discharges for the Susitna River on the dates that calibration data were collected at the Trapper Creek study site were 20,900; 44,000; and 57,700 cfs respectively as determined from provisional USGS streamflow data.

Calibration

Calibration data were available at the close of the 1984 field season for side channel flows of 16, 32, and 389 cfs. Based on these



Appendix Figure D-38. Location of Trapper Creek Side Channel study site (RM 91.6).

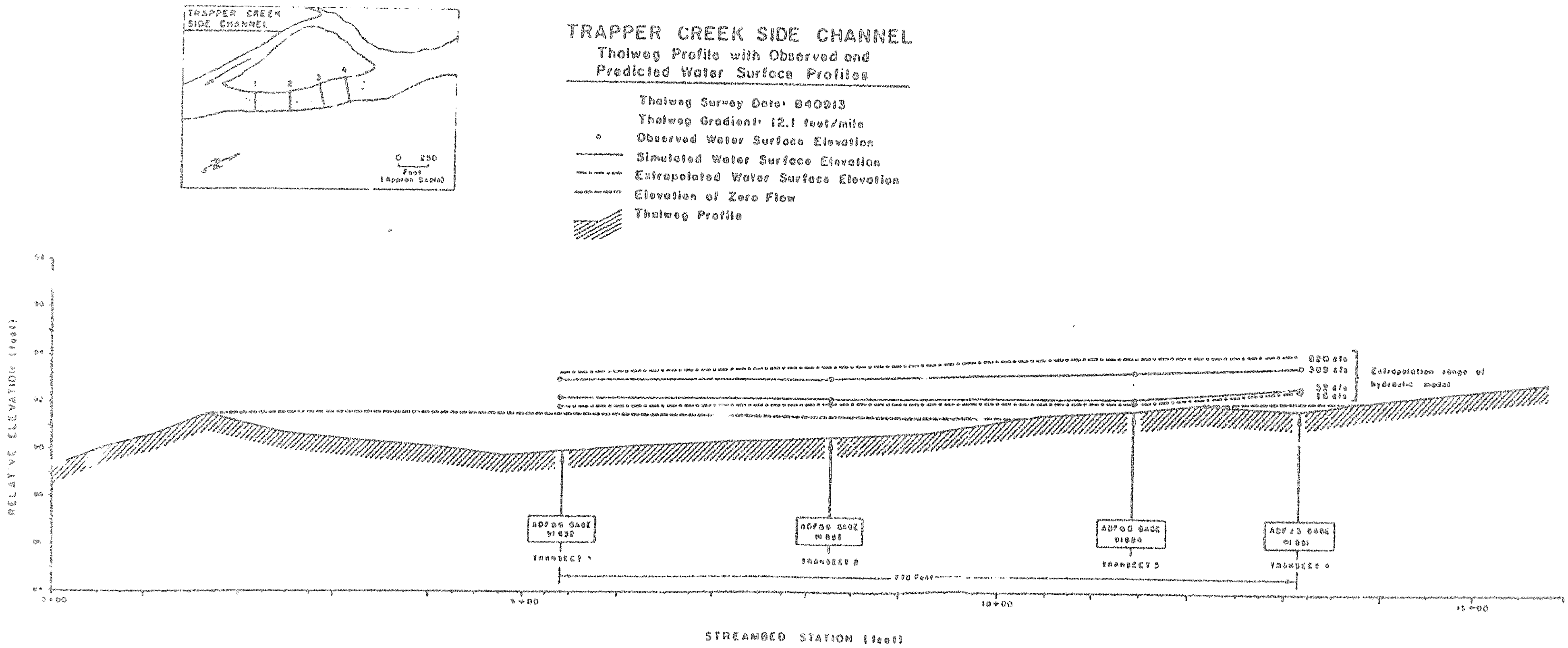


Appendix Figure D-39. Cross section of transects 1,2,3, and 4 at Trapper Creek Side Channel (adapted from Quane et al. 1985).

calibration flows an IFG-4 model was used to forecast instream hydraulics for this study site. The streambed profile, stages of zero flow, and observed and predicted water surface elevations for the study reach are plotted to scale in Appendix Figure D-40. All three data sets were used to predict hydraulic information for side channel flows from 9 to 1,351 cfs (mainstem discharges of 12,000 to 75,000 cfs).

To evaluate the performance of the hydraulic model, observed and predicted water surface elevations, discharges, and velocity adjustment factors were compared (Appendix Table D-12). Of the 12 sets of observed and predicted WSEL's, six sets were within ±0.02 feet of each other and the other six sets were within ±0.05 feet of each other. All the observed and predicted discharges were within 10% of each other except for one set in which there was an 11% difference. All velocity adjustment factors were within the good range of 0.9 to 1.1. Additionally, the stage information of the model was compared to the rating curves established by Quane et al. (1985) (Appendix Figure D-37).

Between the time period when the first two calibration flows (389 and 32 cfs) were made and the last calibration flow of 16 cfs was made the channel cross section at transect 1 was scoured by a flood event. In order to utilize this information in the model the cross section determined from the survey and the 16 cfs flow measurement were used, the WSEL's of the two calibration flows (389 and 32 cfs) were then reduced by 0.37 feet.



Appendix Figure D-40. Comparison of observed and predicted water surface profiles from calibrated model and surveyed thalweg profile for Trapper Creek Side Channel (adapted from Quane et. al. 1985).

Appendix Table D-12. Comparison between observed and predicted water surface elevations, discharges, and velocities for 1984 Trapper Creek Side Channel hydraulic model.

Streambed Station (ft)	Water Surface Elevation Observed (ft)	Water Surface Elevation Predicted (ft)	Discharge Observed (cfs)	Discharge Predicted (cfs)	Velocity Adjustment Factor
0+00	91.94	91.90	15.4	15.1	.985
2+89	91.94	91.91	15.5	14.1	.962
5+76	92.18	92.14	16.7	15.6	.995
7+90	92.56	92.56	15.1	15.1	.976
			Qo = 16.0	Qp = 15.0	
0+00	91.97	92.92	30.1	30.8	1.041
2+89	92.00	92.04	26.0	28.9	1.033
5+76	92.24	92.29	29.6	31.8	1.043
7+90	92.70	92.70	30.2	30.2	1.042
			Qo = 29.0	Qp = 30.0	
0+00	92.75	92.74	397.8	397.3	.980
2+89	93.00	92.99	392.3	387.9	.995
5+76	93.32	93.31	413.4	410.7	.994
7+90	93.58	83.58	367.2	367.2	.997
			Qo = 393.0	Qp = 391.00	

Qo is the mean observed calibration discharge.

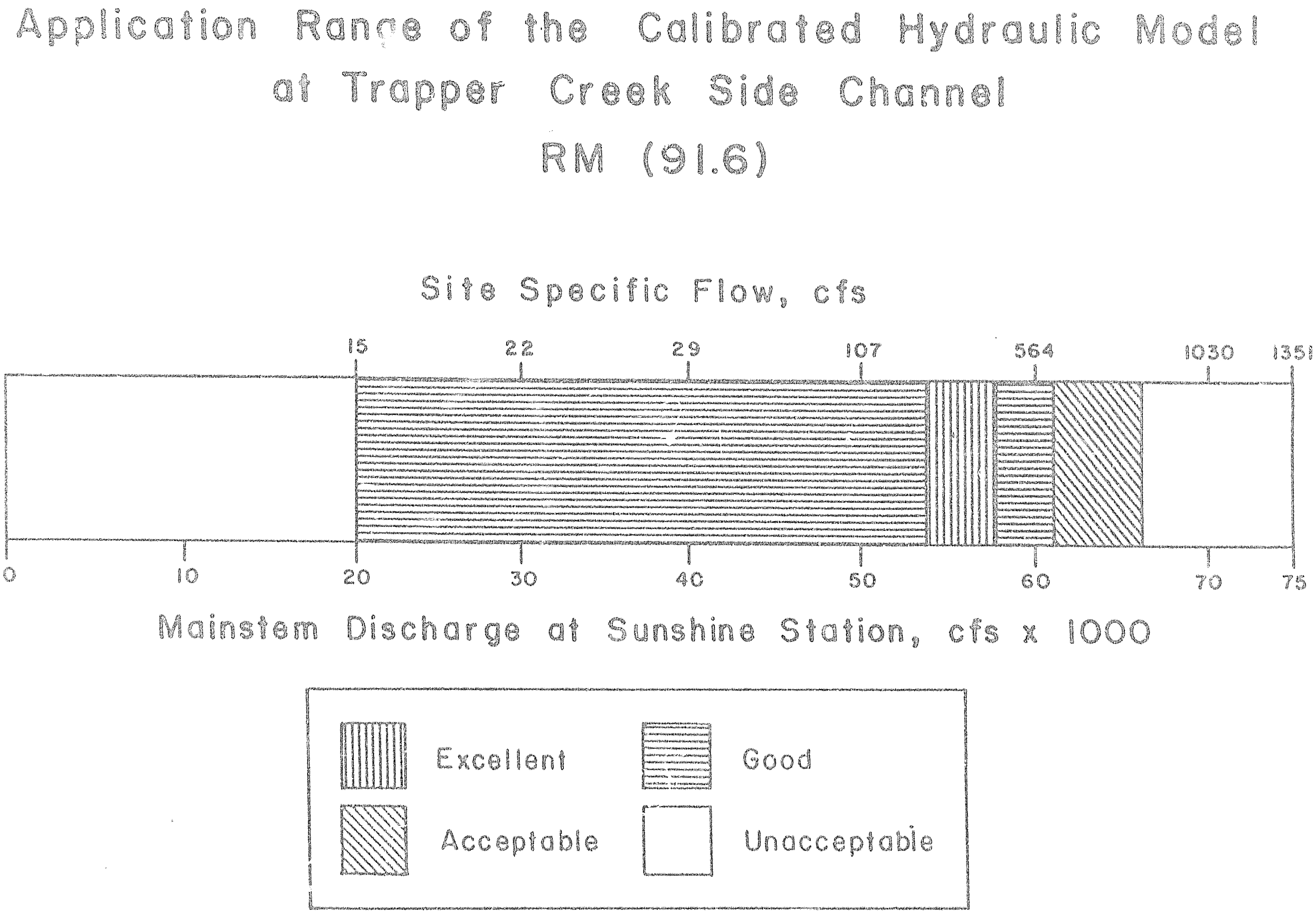
Qp is the mean predicted calibration discharge.

Transect 1 was determined to be a poor site for measuring discharge as it was a pool area affected by a downstream control. The velocities for the 32 cfs calibration flow were therefore adjusted upwards by 27% and for the 16 cfs calibration flow by 20%.

Verification

Based on the first level of verification by EWT&A the model does a good job of simulating channel hydraulics between 20,000 cfs and 54,000 cfs mainstem discharge (15 and 220 cfs site flow) (Appendix Figure D-41). There are sufficient deviations in water surface elevation and discharge between predicted and observed values within this range to preclude attainment of the excellent rating. This is because the model is approximating a portion of the rating curve described by two adjoining linear relationships with a single line.

Between 54,000 cfs and 58,000 cfs mainstem (220 and 460 cfs site flow) the model does an excellent job of simulating channel hydraulics. Beyond 58,000 cfs mainstem, the quality of the simulations begins to deteriorate as the slope of the stage/discharge relationship for the site flattens with a change in channel geometry. The deviation between the regression line developed within the model and that of the rating curve increases with discharge until the model simulations are no longer acceptable. The model simulations were rated good between 58,000 cfs and 61,000 cfs (460 and 600 cfs site flow), acceptable between 61,000 cfs and 66,000 cfs (600 and 820 cfs site flow), and unacceptable above 66,000 cfs mainstem (Appendix Figure D-41).



Appendix Figure D-41. Application range of the calibrated hydraulic model at Trapper Creek Side Channel.

#2-97

The second level of the verification has not been performed as of this time.

Overall, the model simulations were rated excellent from 54,000 to 58,000 cfs (220 to 460 cfs) and good from 20,000 to 54,000 (15 to 220 cfs) and from 58,000 to 61,000 cfs (460 to 600 cfs). They were acceptable from 61,000 to 66,000 cfs (600 to 820 cfs), the simulations became unacceptable below 20,000 cfs and above 66,000 cfs.

Application

For habitat simulation modelling purposes the hydraulic simulation model developed for Trapper Creek Side Channel can simulate channel flows in the mainstem discharge range of 20,000 to 66,000 cfs.

SUMMARY

Island Side Channel (RM 63.2)

An IFG-2 hydraulic model was used to hydraulically simulate site flows of this study site based on one field measured flow of 338 cfs was. The calibrated IFG-2 model simulated site flows excellently in the mainstem discharge range of 35,000 to 56,000 cfs and good in the range of 56,000 to 64,000 cfs. The acceptable range was from 64,000 to 70,000 cfs. For habitat simulation modelling purposes the Island Side Channel hydraulic model can simulate channel flows in the mainstem discharge range of 35,000 to 70,000 cfs.

Mainstem West Bank Side Channel (RM 74.4)

An IFG-4 hydraulic model was used to hydraulically simulate site flows at this study site based on field measured flows of 6, 310, and 450 cfs from which simulated flows were based. The IFG-4 model developed for this site simulated site flows excellently in the mainstem discharge range of 18,000 to 21,000 cfs and from 28,000 to 34,000 cfs. It predicted good in the range of 21,000 to 28,000 cfs and from 34,000 to 41,000 cfs. The acceptable range was from 41,000 to 48,000 cfs. For habitat simulation modelling purposes the Mainstem West Bank Side Channel hydraulic model can simulate channel flows in the mainstem discharge range of 18,000 to 48,000 cfs.

Circular Side Channel (RM 75.3)

An IFG-4 hydraulic model was used to hydraulically simulate site flows at this study site based on field measured flows of 50 and 204 cfs from which simulated flows were based. The IFG-4 model simulated site flows excellently in the mainstem discharge range of 39,000 to 57,000 cfs. It predicted good in the range of 36,000 to 39,000 cfs and from 57,000 to 60,000 cfs. The acceptable range was from 60,000 to 63,000 cfs. For habitat simulation modelling purposes the Circular Side Channel hydraulic model can simulate channel flows in the mainstem discharge range of 36,000 to 63,000 cfs.

Sauna Side Channel (RM 79.8)

An IFG-2 hydraulic model was used to hydraulically simulate site flows at this study site based on one field measured flow of 52 cfs from which simulated flows were based. The IFG-2 model simulated site flows excellently in the mainstem discharge range of 48,000 to 58,000 cfs and good in the range of 46,000 to 48,000 cfs and from 58,000 to 61,000 cfs. The acceptable range was from 44,000 to 46,000 cfs and from 61,000 to 63,000 cfs. For habitat simulation modelling purposes the Sauna Side Channel hydraulic model can simulate channel flows in the mainstem discharge range of 44,000 to 63,000 cfs.

Sunset Side Channel (RM 87.0)

An IFG-4 hydraulic model was used to hydraulically simulate channel flows at this study site based on field measured flows of 127 and 496 cfs from which simulated site flows were based on. The IFG-4 model simulated site flows excellently in the mainstem discharge range of 50,000 to 61,000 cfs. It predicted good in the range of 38,000 to 50,000 cfs and from 61,000 to 64,500 cfs. The acceptable range was from 32,000 to 38,000 cfs and from 64,500 to 67,000 cfs. For habitat simulation modelling purposes the Sunset Side Channel hydraulic model can simulate channel flows in the mainstem discharge range of 32,000 to 67,000 cfs.

Trapper Creek Side Channel (RM 91.6)

An IFG-4 hydraulic model was used to hydraulically simulate channel flows at this study site based on field measured flows of 16, 32, and 389 cfs from which simulated flows were based. The IFG-4 model simulated site flows excellently in the mainstem discharge range of 54,000 to 58,000 cfs. It predicted good in the range of 20,000 to 54,000 cfs and from 58,000 to 61,000 cfs. The acceptable range was from 61,000 to 66,000 cfs. For habitat simulation modelling purposes the Trapper Creek Side Channel hydraulic model can simulate channel flows in the mainstem discharge range of 20,000 to 66,000 cfs.

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-- To E.W. Trihey and Associates particularly Bob Aaserude and Diane Hilliard for the valuable expertise in the collection of data, the calibration, and the verification of the hydraulic models. It is felt that Bob Aaserude's involvement in the preparing of this appendix deserves an authorship.

LITERATURE CITED

Bovee, K.D., and R. Milhous. 1978. Hydraulic simulation in instream flow studies: theory and techniques. Instream Flow Information Paper No. 5. Instream Flow Service Group. USFWS. Ft. Collins, Colorado.

______. 1982. A guide to stream habitat and analysis using instream flow incremental methodology. Instream Flow Information paper No. 12. Coop. Instream Flow Service Group. USFWS. Colorado.

Buchanan, T.J., and W.P. Somers. 1969. Techniques of water resources investigations of the United States Geological Survey. Chapter A8. Discharge measurements at gaging stations. USGS. Washington DC.

Estes, C.C., D.S. Vincent-Lang, (eds) 1984. Aquatic Habitat and Instream Flow Investigations. Alaska Department of Fish and Game. Su Hydro Aquatic Studies Report Series No. 3. Alaska Department of Fish and Game. Anchorage, Alaska.

Quane, T., P. Morrow, and I. Queral. 1985. Hydrological Investigations at Selected Lower Susitna River Study Sites. Alaska Department of Fish and Game. Su Hydro Aquatic Studies Task 36 Support Technical Report. Alaska Department of Fish and Game. Anchorage, Alaska.

Schmidt, D.C., S.S. Hale, and D.L. Crawford (eds.). 1984. Resident and Juvenile Anadromous Fish Investigations (May - October 1983). Alaska Department of Fish and Game. Su Hydro Aquatic Studies Report Series No. 2. Alaska Department of Fish and Game. Anchorage, Alaska.

Trihey, E.W. 1979. The IFG incremental methodology. In G.L. Smith, ed. Proceedings of the Instream Flow Criteria and Modeling Workshop. Colorado Water Resources Research Institute, Colorado State University. Pages 24-44. Information Series No. 40. Fort Collins, Colorado.

______. 1980. Field data reduction and coding procedures for use with the IFG-2 and IFG-4 hydraulic simulation models. Instream Flow Service Group, USFWS. Fort Collins, Colorado.

______. and D.L. Wegner. 1981. Field data collection procedures for use with the physical habitat simulation system of the Instream Flow Group. Instream Flow Service Group. USFWS. Fort collins, Colorado.

Appendix Attachment 1

Technical Memorandum
Extrapolation Limits of the 1984 Middle River IFG Models

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Technical Memorandum

Extrapolation Limits of the 1984 Middle River IFG Models

by

N. Diane Hilliard

E. Woody Trihey and Associates

April 8, 1985

The 1984 middle river IFC hydraulic models have been calibrated and their extrapolation ranges evaluated. The IFG-4 models were calibrated using both the IFG and EWT&A guidelines. The IFG-2 models were calibrated using a variable Manning's n approach. With an increase in the depth of flow, there is a corresponding decrease in Manning's n values. The depth and velocity information collected at each site was classified as either calibration or shoreline data. The calibration data was collected across the entire cross section. Shoreline data were collected from each bank out into the channel until either the depth or velocity was limiting to field personnel. Site-specific flow values, as determined by either the water surface elevation versus site flow or site flow versus mainstem discharge relationships are presented for mainstem discharges from 5,000 to 35,000 cfs. Within this range of mainstem discharges, several study sites transform from clear water side sloughs to turbid water side channels to mainstem channels. Baseline flows have been estimated for the sites when they are not controlled by the mainstem.

The quality of each model was based on two levels of criteria. The level one criteria is a qualitative evaluation of four separate criteria. The models were given a numeric rating of compliance for each criteria whenever possible. When it was not possible to routinely assign a numeric rating through a comparison of model performance with criteria, a numeric rating was assigned based on professional judgment. Application of professional judgment requires: an understanding of open channel hydraulics, familiarity with the study site, experience with the models, and knowledge of how the model will be used in the habitat analysis.

Numeric ratings for each of the four criteria are 2, 1, or 0. The models received a rating depending on how well they met the criteria. By summing the individual ratings, an overall rating was calculated for each model. Using the overall rating, models were evaluated according to the following scale:

Excellent	8
Good	7
Acceptable	5-6
Unacceptable	<5; or zero for any evaluation category

The level two criteria are based on analytical approach and will only be made when a model is not considered excellent in the level one evaluation.

LEVEL ONE EVALUATION FOR IFG MODELS

1. How well does the model conform to the IFG and EWT&A calibration guidelines?

Compare predicted depths and velocities for calibration flows with observed field data.

Are the velocity profiles realistic?

Are there more than a few outliers for the extrapolated flows?

Do the predicted discharges agree with the discharges measured in the field (IFG-4 model only) for each transect?

Are the predicted water surface elevations for a broad range of discharges coincident with the rating curves for each site?

Plot the water surface profiles, stage of zero flow, and thalweg. Are they reasonable? To be reasonable, the water must flow downhill; an increase in discharge should cause the pool riffle sequence to drown out and the water surface profile to become more uniform in gradient; a decrease in discharge should cause the water surface profile to more acutely reflect changes in stream bed gradient and riffle pool profiles.

2 = A model that can forecast both water surface elevations and velocities accurately.

1 = A model that can define water surface elevations and velocities accurately at the calibration flows but may not be able to reliably define both WSEL and velocities for the extrapolated flows.

0 = A model that can not reproduce depths or velocities accurately at the calibration flow or throughout the extrapolation range.

2. How well does the extrapolation range of the model conform to the desired range?

The first assumption made in this evaluation is that the rating curves (site flow versus mainstem discharge and water surface elevations versus mainstem discharge for the site are accurate. The ability to evaluate the forecasting capabilities improve with an increase in number of transects which have well-defined rating curves. By reviewing aerial photography and incorporating field experience, determine if there are dramatic changes in the channel geometry or local flow patterns (such as other channels becoming overtopped at higher mainstem discharges) that may cause a significant change in the site flow versus mainstem discharge relationship above the range of available data. The number of hydraulic models required to describe the full spectrum of hydraulics in the site can be determined from this analysis (one for each straight-line portion of the site flow versus mainstem discharge plot). Low flow models should be able to describe the baseline flow conditions. High flow models describe the breached conditions and can be checked by comparing the water surface profiles and velocities with observed data.

2 = A model that can accurately define both water surface elevations and velocities accurately.

1 = A model that can describe either velocities or water surface profiles accurately.

0 = The model can't describe depth and velocity for the defined range.

3. Are the models appropriate for the species and life stage being considered?

Cross sections should be located to accurately define cover, substrate, or other habitat parameters which are of importance to the species and/or life stage of interest. Study sites set up for a particular species or life stage may not accurately represent the habitat conditions for a second species or life stage.

Hydraulic models for juveniles should accurately define low velocity areas (<0.8 ft/sec), but need not be as accurate when velocities exceed 2 fps. Depth needs only to be approximate above 0.15 feet, and is of little consequence in steep-sided channels where an error will not cause a notable change in top width.

Hydraulic models for adults should accurately define velocities up to 2 ft/sec, and depths up to 1.0 feet.

2 = A model that provides sufficient precision in hydraulic forecasts to be applied to evaluation of adult and juvenile life phases with an equal level of confidence.

1 = The model provides a higher level of precision for evaluation of either adult or juvenile life phase. The greatest accuracy of the model is for the life phase for which it was originally established but resulting hydraulic forecasts are sufficiently accurate to be acceptable for other life phases. Had the study site been laid out differently, additional data collected or a separate hydraulic model calibrated, an excellent rating would have been possible.

0 = Insufficient data were collected to calibrate the model in the flow range of interest for the species/life stages to be evaluated.

4. How well do the ranges of depth and velocities of the forecasted data conform to the ranges of depth and velocity of the suitability criteria curves being considered based on a "visual" evaluation?

Do the predicted hydraulic variables associated with a high percent error fall within the a, b, or c limits of the suitability curves?

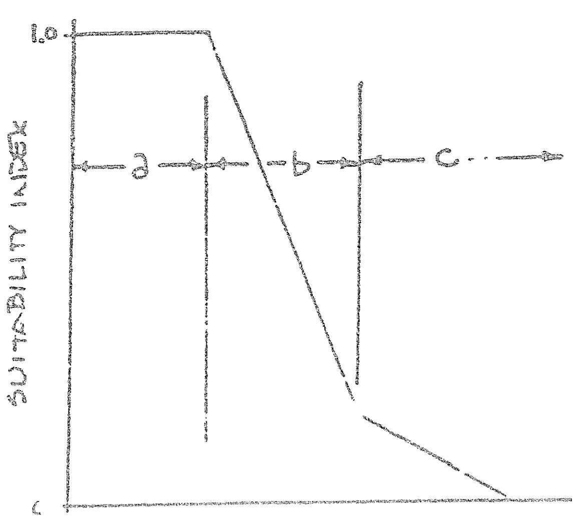


FIGURE 1.

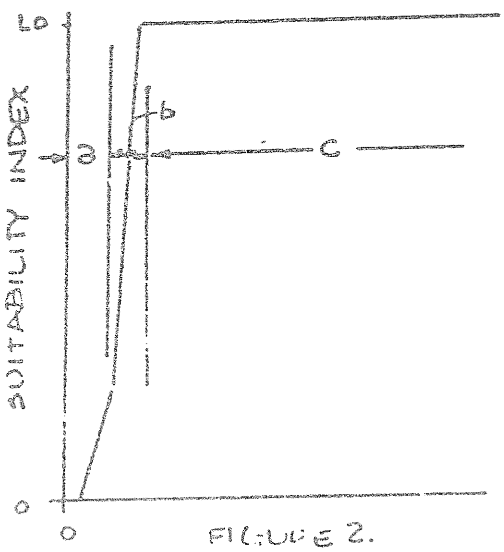
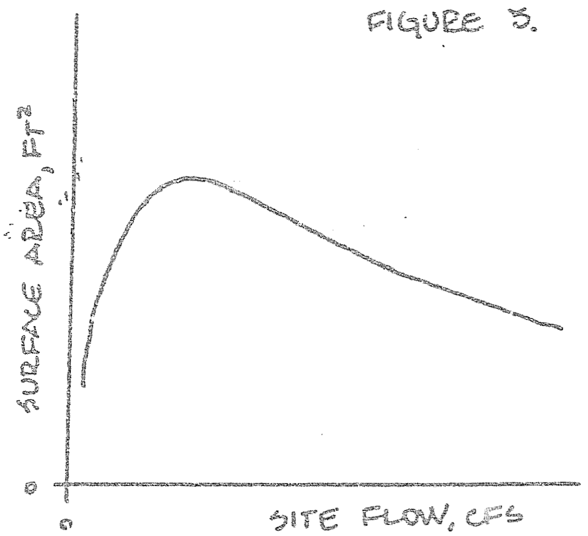


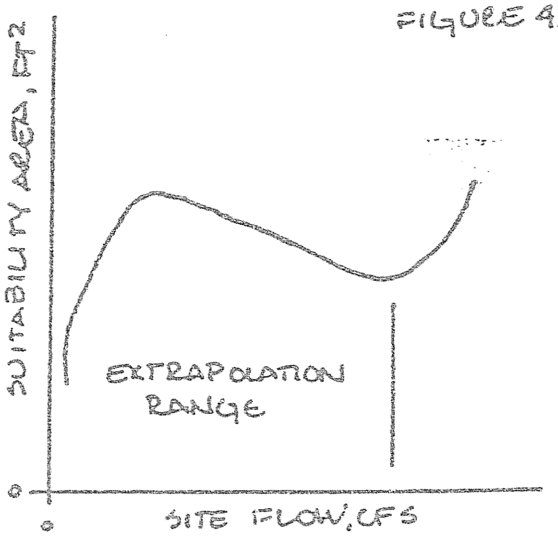
FIGURE 2.

Even though the model is not accurately reproducing depths or velocities from a hydraulic viewpoint, the predicted suitability indices could fall within a range that is not sensitive to errors in one of these indices.

The calibrated model is linked with the habitat model and weighted usable area versus site flow plots are developed. Are the WUA projections continuing on the same trend beyond the extrapolation range or is the e a change in the trend?

When there is a change in the WUA versus site flow relationship similar to Figure 4, an upper limit should be established at the low point in the curve.





2 = An accurate description of all ranges of depths and velocities present in the study site.

1 = Forecasting capabilities of the model are adequate when it accurately describes two of the three ranges of the suitability curve.

0 = When one or no ranges of the suitability curve are described accurately.

LEVEL TWO EVALUATION FOR IFG MODELS

Use of the level two criteria requires an analytical approach and should be applied when the forecast capabilities of either the IFG-2 and IFG-4 model are not given an excellent rating in the level one evaluation. These techniques can be incorporated as an additional step in the calbration procedure for future studies. The best method of evaluating the predictive capabilities of the hydraulic models is to collect an additional data set at each cross section that is not used in the calibration procedure and compare it to the model predictions. The test could not be applied, however, because of the limited field data that were available. All data sets that were collected were used to calibrate the models.

The analytical procedure presented has been suggested for use in geographic models which face similar problems in evaluating the differences between observed and predicted data. To date, this is the most appropriate method to use in place of collecting an additional data set.

A visual comparison is made between scatter plots of the observed and predicted depths and velocities at all cross sections for each calibration flow. The standard USGS discharge measurement procedure requires at least 20 - 25 verticals where depth and velocity data are collected. For a particular channel the verticals at higher flows are spaced further apart than at low flows. Because a cell-by-cell comparison is made for the IFG-4 model, velocities must be assigned to the same cells at the same flows. The velocities are interpolated between adjacent cells for the high flows and used as input for the model. The IFG-4 model with two or more flows generally has a larger number of verticals than the IFG-2 model suggesting this method of evaluation is more appropriate for the IFG-4 model. Scatterplot evaluations provide a qualitative assessment of the forecas. capabilities of the model. A quantitative assessment can be made by computing several statistics which describe the differences between observed and predicted values (Willmott 1981). Pearson's Product-Moment Correlation Coefficient (r), Coefficient of Determination (r2), the slope (b) and intercept (a) of a least squares regression between observed and predicted values are reported as the reliable measures of a model's predictive capabilities. Willmott has suggested computing additional statistics to better evaluate the predictive capability of the model. These variables include the systematic and unsystematic components of the root mean square error

$$RMSE_S = [N^{-1}\sum_{i=1}^{N}((a + bO_i) - O_i)^2]^{0.5}$$

and

$$RMSE_U = [N^{-1}\sum_{i=1}^{N}(P_i - (a + bO_i))^2]^{0.5}$$

as well as the total root mean square error

$$RMSE = [N^{-1}\sum_{i=1}^{N}(P_i - O_i)^2]^{0.5}$$

where:

$i = 1,2,........n$ (sample size of the number of predicted cells)

O = Observed or field measured data

P = Model predicted data.

An index of agreement (d) may also be calculated to determine the degree to which a model's predictions are error free. The index of agreement is computed by

$$d = 1 - \frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum_{i=1}^{N}[P_i - O + O_i - O]^2}$$

The value of d varies between 0.0 and 1.0 where a computed value of 1.0 indicates perfect agreement between the observed and predicted observations, and 0.0 denotes complete disagreement.

A visual comparison can be made of the observed and predicted velocity distribution plots for the IFG-2 models, where much of the data is along the shorelines only. In general, the cells in the IFG-2 model do not coincide with verticals where field measurements were made, but rather with distinct changes in channel geometry, roughness, or habitat suitability. A representative velocity distribution "shape" was developed for each cross section, using the calibration flow data, which typically extended the full width of the channel. Where only shoreline data was available, the shape of the velocity profile was modeled after either a similar cross section at the site where a complete data set was available, or by simply developing a shape based on the channel geometry (i.e., the highest velocities should correspond to the deepest portion of the channel). This is a reliable method, since cross-sectional area and discharge are fixed and therefore the average channel velocity is defined.

Operating the IFG-2 model at discharges other than the calibration flow produces velocity profiles similar in shape to that of the calibration flow. When inconsistencies between field data and predicted velocities occurred at high flows, a second model was developed. Generally, the high flow model predicts velocity profiles that are steeper near the water's edge than the corresponding low flow models.

The level two analyses are nearly complete and will be included in the draft report. Each of the models were evaluated and rated using chinook juvenile rearing criteria. A separate evaluation using the chum spawning criteria will be discussed in a later memorandum after upwelling information is collected. A summary of the application ranges of the calibrated models with their associated ratings is presented in Figure 1. The hydraulic relationships used in the calibration effort are listed in the Appendix tables and should be used in the habitat modeling and flow duration analysis.

SITE-SPECIFIC EVALUATIONS

The specific evaluations of the middle river sites are not given because they are not applicable to the lower river study.

DRAFT

PART 3

Resident Fish Distribution and Population Dynamics in the Susitna River below Devil Canyon

DRAFT

RESIDENT FISH DISTRIBUTION AND POPULATION DYNAMICS IN THE SUSITNA RIVER BELOW DEVIL CANYON

Report No. 7, Part 3

by Richard L. Sundet and Stuart D. Pechek

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ABSTRACT

Studies of resident fish were conducted in both the lower and middle Susitna River in 1984. Primary emphasis in the middle river was to determine the seasonal distribution, timing of spawning, and spawning areas of rainbow trout, and to monitor 13 index sites as part of the long term monitoring effort. Most of the rainbow trout data was collected by use of radio telemetry. Results showed that rainbow trout are relatively few in numbers and that spawning occurs at selected areas which are influenced by lakes. Much of the rainbow trout population in the middle river probably originates in lakes which outlet to middle river tributaries. Lakes where rainbow trout are abundant and which probably contribute heavily to middle river populations wer at the headwaters of Fourth of July Creek and in the upper reaches of Portage Creek. Rainbow trout were also found to use Portage Creek more extensively than previously thought. Spawning occurred during the first week of June. All rainbow trout move out of tributaries by early October

(probably triggered by low fall discharges), and most overwinter in the mainstem Susitna River slightly downstream (0.1-4.0 miles) of the tributary where they were captured. Other middle river studies suggest Arctic grayling overwinter in the mainstem Susitna then ascend and spawn in tributaries in late May. Arctic grayling also outmigrate from tributaries at the same time as rainbow trout. Catch data at middle river index sites in 1984 was similar to 1982 and 1983 findings. Studies in the lower river reinforces the belief that some humpback whitefish are anadromous, and rainbow trout and Arctic grayling outmigrate from most east side tributaries in September. Lower river studies also found that burbot move into the Deshka River in mid-September.

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1.0 INTRODUCTION

Since November 1980, Resident Fish Studies have been conducted in the Susitna River drainage to more accurately determine the distribution and relative abundance of resident fish. In 1982, resident fish abundance were compared at mainstem, slough, and tributary mouth macrohabitats (ADF&G 1983d). In 1983, studies focused more on the middle reach of river because construction of the proposed hydroelectric dams would affect this reach of river most. Microhabitat suitability criterias and population estimates were developed for rainbow trout (Salmo gairdneri Richardson) and burbot (Lota lota Linnaeus) in selected areas during 1983 (Suchanek et al. 1984; Sundet and Wenger 1984). Rainbow trout and burbot movements were more clearly defined using radio telemetry in 1982 and 1983 (ADF&G 1983c; Sundet and Wenger 1984). Data from these studies and catch data has shown burbot most often reside in the mainstem in summer and in both mainstem and some tributaries in winter. These data also show rainbow trout migrate between tributaries and the mainstem during summer and all reside in the mainstem overwinter. During 1982 and 1983, information collected on spawning fish suggests that burbot and round whitefish (Prosopium cylindraceum Pallus) are mainstem spawners.

This report primarily addresses resident fish studies conducted during the 1984 open-water season. However, radio telemetry results also present fish movements from December 1, 1983 to the open-water season (for winter monitoring of 1983 radio tagged fish) and after the open-water season to December 1, 1984 (to show movement patterns of summer

1984 tagged fish during the transition period from open-water to winter conditions). Although sampling primarily occurred in the mainstem Susitna River between Cook Inlet and Devil Canyon, sampling also occurred at several tributaries in this reach of river.

The primary emphasis of Resident Fish Studies in 1984 was to further determine the seasonal distribution, timing of spawning, and locations of spawning for rainbow trout above Talkeetna using radio telemetry. Studies in 1984 also furthered our knowledge of resident fish distribution in the Susitna River below Talkeetna.

The radio telemetry program in the Susitna River below Talkeetna in 1984 monitored rainbow trout and burbot movements. Fish below Talkeetna as well as several fish in the middle river were radio tagged after August 1984. This report will include radio tagged fish monitoring data from December 1983 to December 1984. Since data from fish radio tagged after August is limited, these data will be presented in a report to be published in November 1985 covering winter 1984-85 studies.

In addition to radio telemetry studies, 13 resident fish index areas between Talkeetna and Devil Canyon were sampled regularly during 1984 to evaluate trends in abundance of resident fish. These 13 index areas, which have been sampled each year since 1982, encompass three macro-habitats (tributary mouths, sloughs, and mainstem). By annual monitoring these sites where larger concentrations of resident fish have traditionally been found in comparison to other sites, the effects of the proposed hydroelectric dams to resident fish populations can be assessed by habitat type. These post-project effects result from changes in water temperature, flow, turbidity, and other water quality parameters.

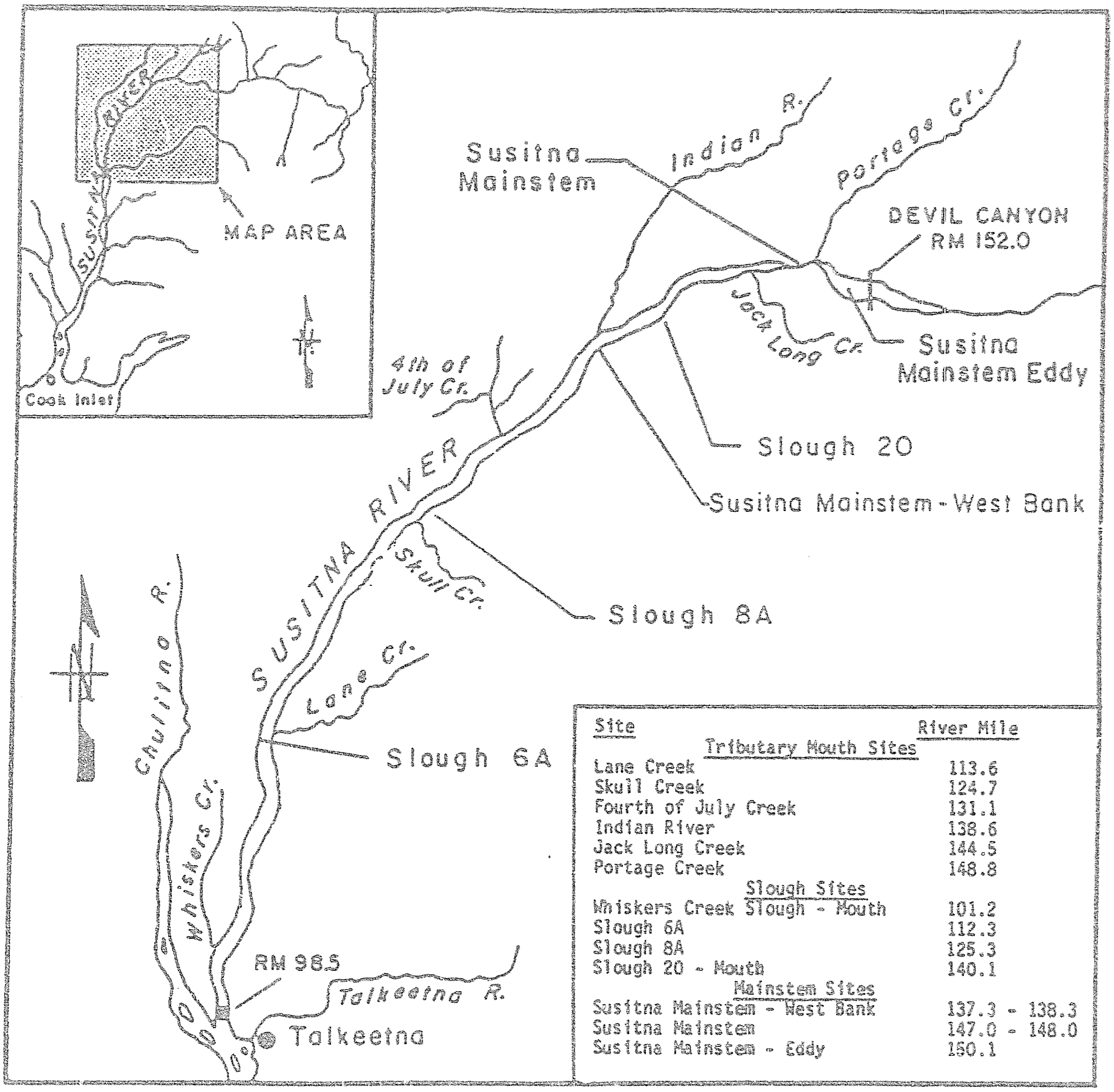
2.0 METHODS

2.1 Study Locations

2.1.1 Relative abundance measurements

Thirteen index sites between Talkeetna and Devil Canyon were sampled twice per month by boat electrofishing to monitor seasonal trends in relative abundance of resident fish (Figure 1). Site descriptions of Skull Creek (RM 124.7), Susitna Mainstem - West Bank (RM's 137.3-138.3), Susitna Mainstem (RM's 147.0-148.0), and Susitna Mainstem - Eddy (RM 150.1) are provided in Appendix E, while the remaining nine site descriptions are presented in Appendix F of Aquatic Instream Flow Studies, 1982 (ADF&G 1983f). In addition, other mainstem, side channel, slough, and tributary sites on the Susitna River between Cook Inlet and Devil Canyon were sampled intermittently.

Several tributaries in the middle reach of the Susitna River were sampled during 1984 to determine the extent of rainbow trout and Arctic grayling (*Thymallus arcticus* Pallus) spawning and rearing in these tributaries (Table 1). These tributaries were selected because of their size, their proximity to Devil Canyon, or due to their relatively high abundance of these fish species.



Site	River Mile
Tributary Mouth Sites	
Lane Creek	113.6
Skull Creek	124.7
Fourth of July Creek	131.1
Indian River	138.6
Jack Long Creek	144.5
Portage Creek	148.8
Slough Sites	
Whiskers Creek Slough - Mouth	101.2
Slough 6A	112.3
Slough 8A	125.3
Slough 20 - Mouth	140.1
Mainstem Sites	
Susitna Mainstem - West Bank	137.3 - 138.3
Susitna Mainstem	147.0 - 148.0
Susitna Mainstem - Eddy	150.1

Figure 1. Resident fish study sites on the Susitna River between the Chulitna River confluence and Devil Canyon, 1984.

Table 1. Resident fish sampling schedule at tributaries in the middle reach of the Susitna River, 1984.

	RM	TRM	May	Jun	Aug	Oct
Whiskers Creek	101.4	7.0		X		
Fourth of July Creek	131.1	0.1 - 3.5		X	X	X
Indian River	138.6	0.1 - 9.0	X	X		
Portage Creek	148.8	0.1 - 11.6	X	X		

In the lower Susitna river, the upper reaches of Kashwitna River (RM 61.0), Sheep Creek (RM 66.1), Goose Creek (RM 72.0), and Montana Creek (RM 77.0) were sampled during early September to determine the extent of rainbow trout and Arctic grayling rearing in these tributaries. Attempts were made to radio tag fish in these tributaries to determine the timing of their fall outmigration. Radio telemetry results from fish tagged in these areas will be presented in a later report.

Six lakes with outlets to the middle Susitna River were surveyed in 1984. These surveys were done to determine if rainbow trout populations existed in these lakes and if these fish migrate to or from the mainstem Susitna River. Surveys were conducted at four lakes at the headwaters of Fourth of July Creek [Lakes A, B, C, and D (Figure 2)], Miami Lake which outlets into Indian River at TRM 4.5, and an unnamed lake which outlets into Portage Creek at TRM 2.3 (Figure 3).

Resident fish catches recorded at five fishwheel sites, two outmigrant trap sites, a fyke net weir site, and 20 juvenile salmon rearing study sites (JAHS) were also examined to evaluate trends in relative abundance

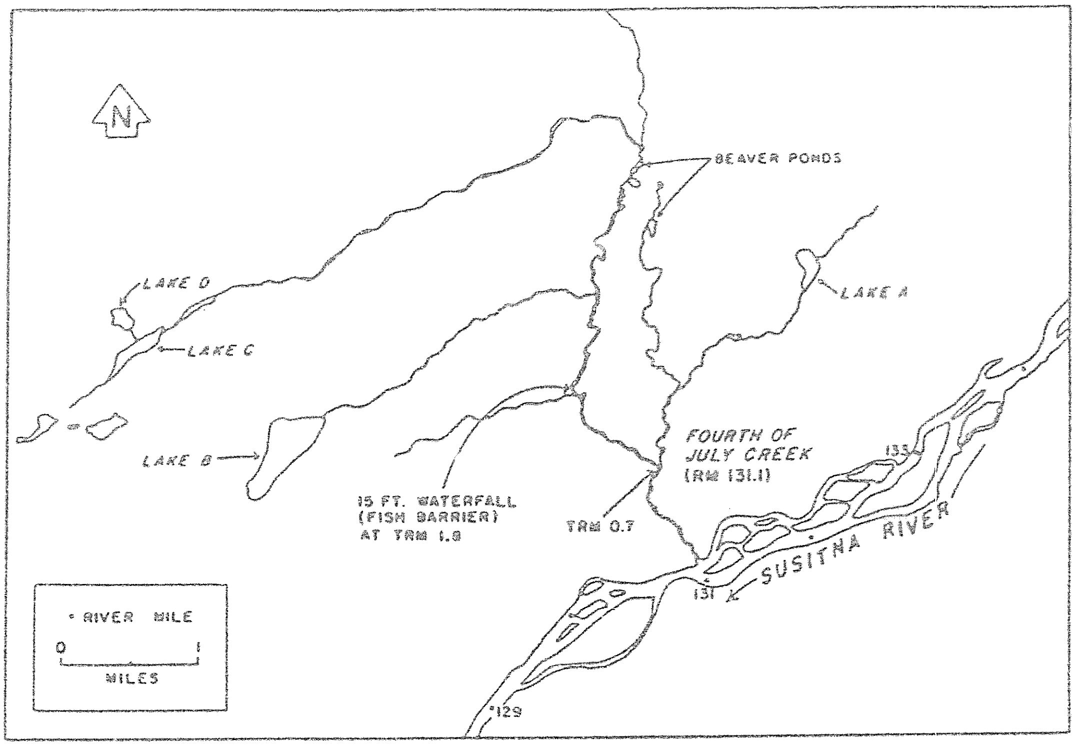


Figure 2. Fourth of July Creek drainage.

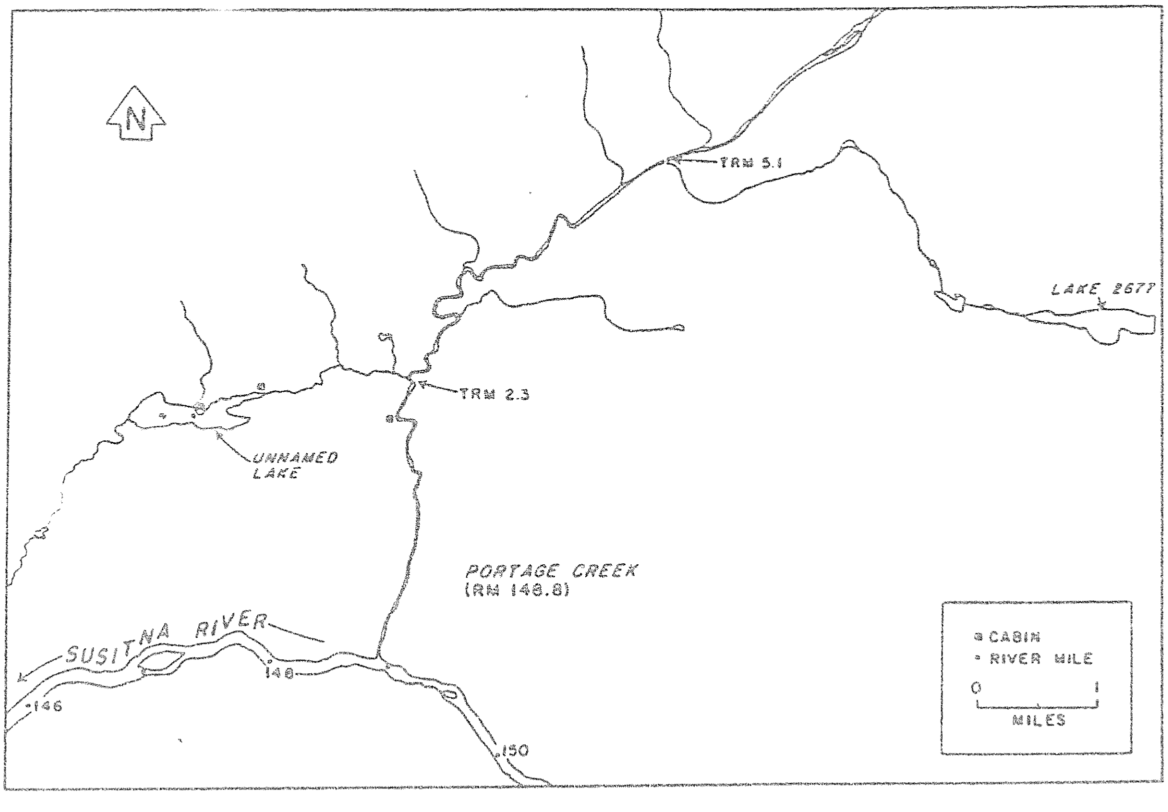


Figure 3. Lower Portage Creek drainage.

and seasonal movements. In addition, several east side tributaries such as Kashwitna River were monitored in April and May to determine timing of immigration of resident fish from the mainstem Susitna River.

2.1.2 Population estimates

Population esimates were made using multi-year data (1981-84) for four resident fish species tagged in the middle river (see Appendix D).

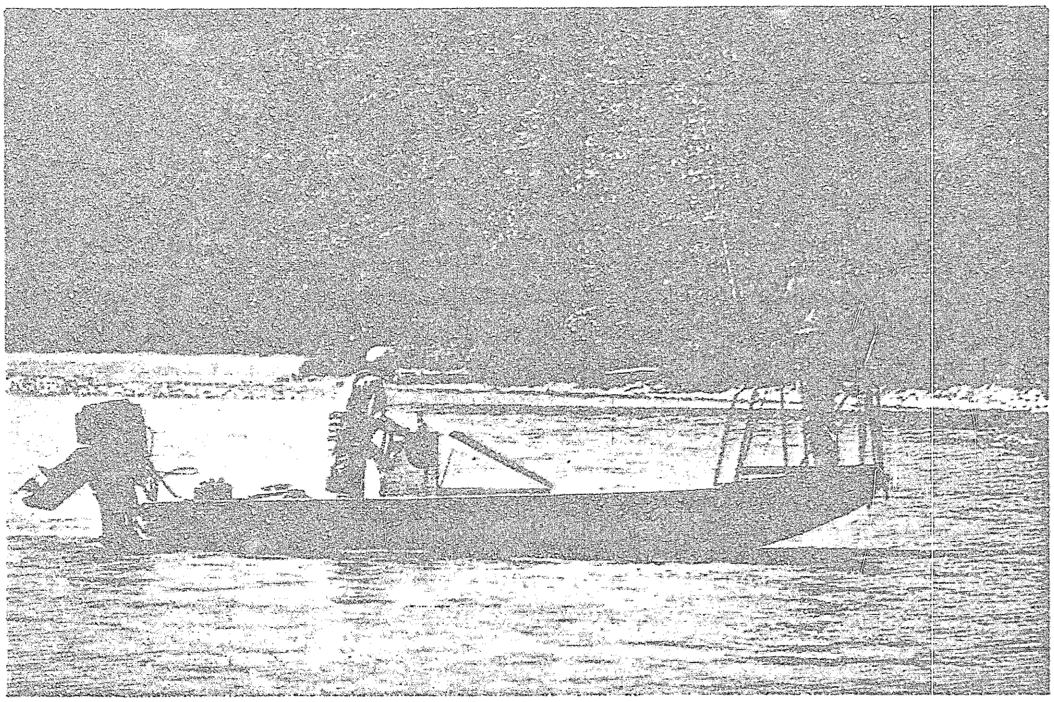
2.1.3 Radio telemetry

Selection of radio tagging sites in the mainstem Susitna between the Chulitna River confluence and Devil Canyon were based on resident fish distribution data collected during the 1981, 1982, and 1983 open water field seasons (ADF&G 1981b, 1983b; Sundet and Wenger 1984). Primary efforts to capture and radio tag rainbow trout and Arctic grayling in the mainstem were focused at the mouths of Whiskers Creek, Lane Creek (RM 113.6), Fourth of July Creek, Indian River, and Portage Creek. Fish were also caught and radio tagged in the upper reaches of Fourth of July Creek, Indian River and Portage Creek at the same time the spawning studies were done.

2.2 Data Collection

2.2.1 Relative abundance

Resident fish were collected at mainstem and tributary sites primarily with a boat mounted electrofishing unit (Plate 1). A Coffelt Model



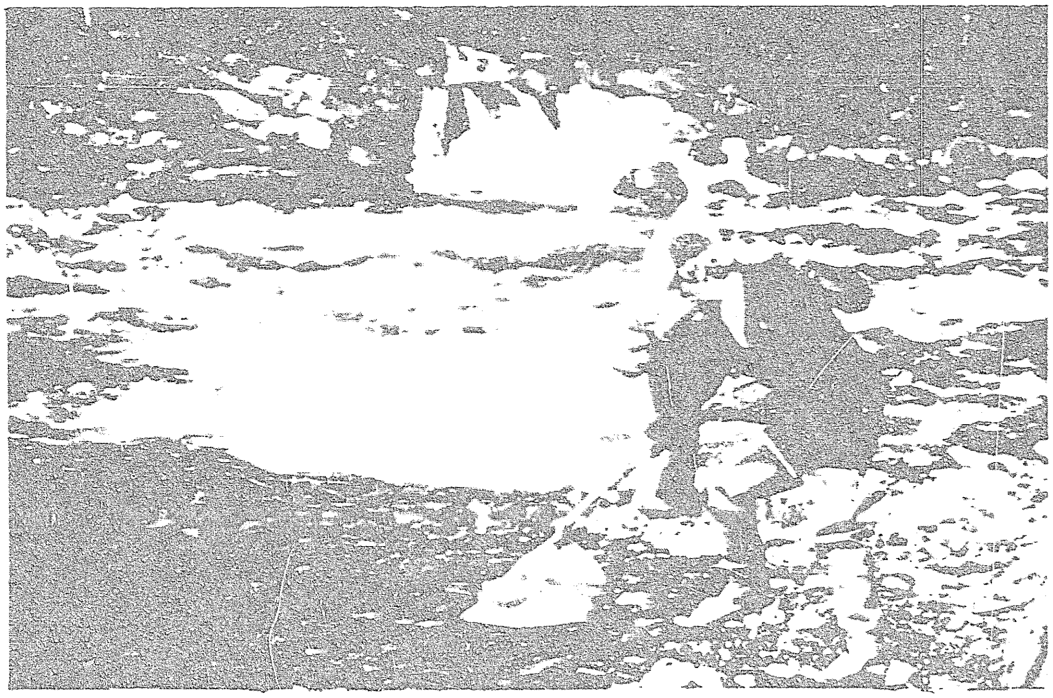


Plate 1. Boat electrofishing in the mainstem Susitna River at RM 147.8 and angling at TRM 2.3 of Portage Creek, June 1984.

VVP-3E boat electrofishing unit powered by a 2,500 watt Onan generator was used for boat electrofishing and using techniques described in ADF&G (1983a). Secondary gear types used included outmigrant traps at RM 22.4 and at RM 103.0, a fyke net weir at TRM 2.5 of the Deshka River, backpack electrofishing units, gill nets, hook and line, hoop nets, and trotlines.

Biological data (age, length, sex, and sexual maturity) were collected as outlined in ADF&G (1983a). Scales for age determination were taken from a representative sample of rainbow trout captured above the Chulitna River confluence. Scales were also taken from spawning Arctic grayling and round whitefish to determine ages of spawners for these species.

Survival rates were calculated for rainbow trout above the Chulitna River confluence in 1984 using catch and age data and methods presented in Everhart et al. (1975).

Habitat parameters were measured at locations where spawning rainbow trout were found. These parameters included water velocity, water depths, substrate type, and general water quality. Specific habitat data collection methodology are summarized in ADF&G (1983a).

Habitat parameters were also measured at radio tagged fish relocation sites during winter 1983-84. During ground surveys in January and February, some radio tagged fish were located to within a four-foot-radius and habitat measurements were made as close to the signal as possible (Plate 2). Habitat parameters measured included those taken at fish spawning sites as well as ice thickness and the presence or absence of slush ice. In January and February the fate of each radio tagged fish surveyed was also determined.

A tag-and-recapture program was continued in 1984 to monitor the seasonal movements of adult resident fish. Floy anchor tags were used to tag seven species of adult resident fish: rainbow trout, Arctic grayling, humpback whitefish (Coregonus pidschian Gmelin), round whitefish, burbot, longnose suckers (Catostomus catostomus Forster), and Dolly Varden (Salvelinus malma Walbaum). All resident fish that appeared healthy after capture and were large enough to accommodate a tag were tagged. Burbot with a total length (TL) greater than 225 millimeters (mm) were tagged and other resident species with fork lengths (FL) greater than 225 mm were tagged.

Tag recoveries were made by the resident fish study group, the adult salmon fishwheel crews, and the angling public.

2.2.2 Population estimates

Population estimates were made for adult (≳ 200 mm) rainbow trout, Arctic grayling, round whitefish, and longnose suckers in the middle river using the multiple year (1981-84) tagging and recapture data (see Appendix D).

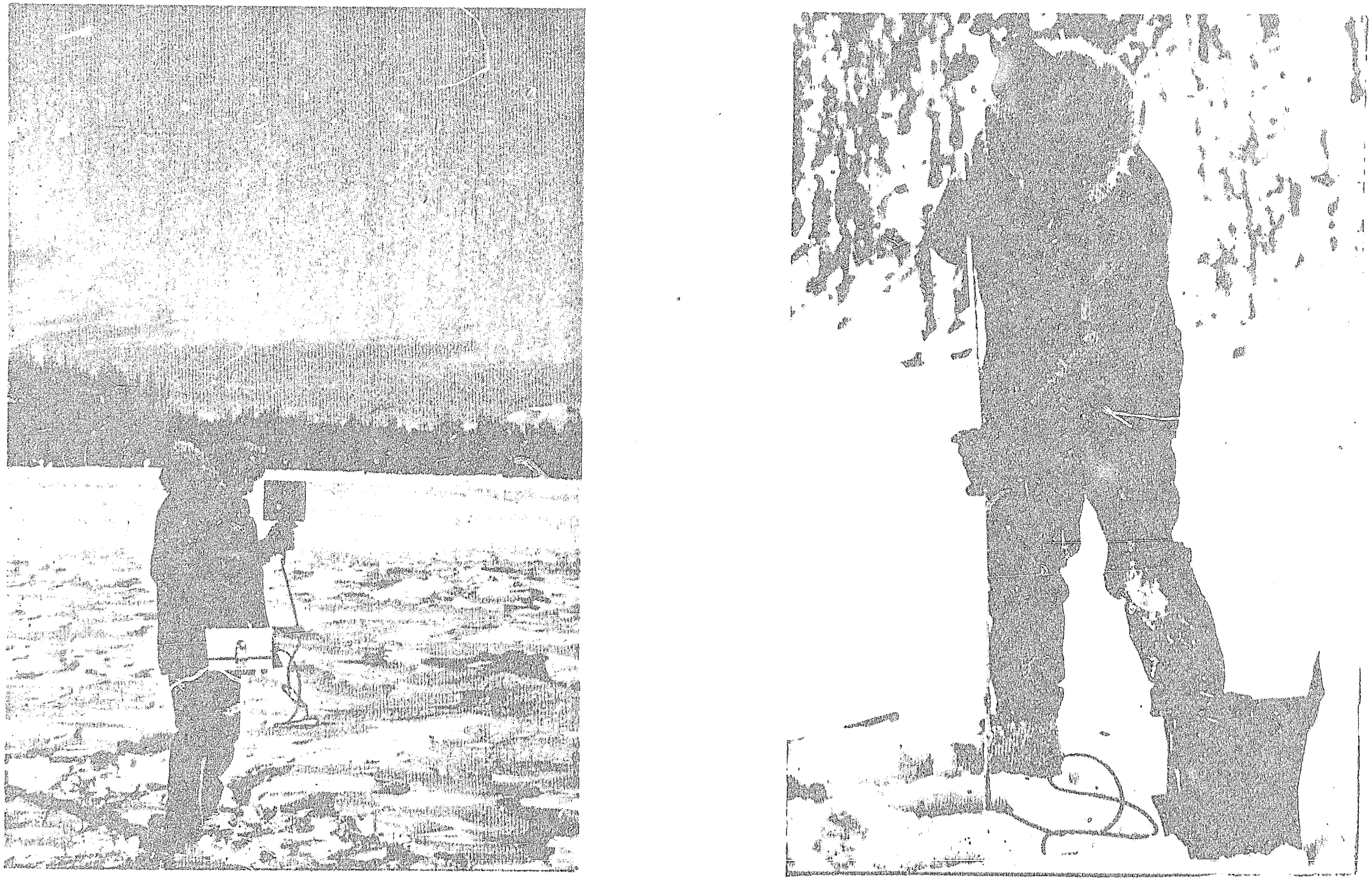


Plate 2. Locating a radio tagged rainbow trout in the mainstem at RM 111.4 and measuring water velocities at this location, February 1984.

2.2.3 Radio telemetry

Most fish which were radio tagged were captured by boat electrofishing or by hook and line (Plate 1).

Equipment

Radio telemetry receiving equipment used in this study was developed by Smith-Root Incorporated in Vancouver, Washington. Receiving equipment consisted of a low frequency (40 MHz) radio tracking receiver (Model RF-40) and scanner (Model SR-40), and a loop antenna (Model LA-40).

Radio transmitters used in 1984 were manufactured by Advanced Telemetry Systems (ATS) of Bethel, Minnesota. Two types of radio tags were used: internal and external. Internal radio tags with 6-11 month life expectancies were implanted in rainbow trout. External radio tags were attached to several pre-spawning rainbow trout and one Arctic grayling. External tags were used on several pre-spawning rainbow trout since it was believed the condition of some of these fish would be unacceptable for internal implants. An external radio tag was used on the Arctic grayling since past efforts to internally radio tag this species have failed (ADF&G 1983c).

Radio tags used in rainbow trout and burbot tagged in 1983 and monitored during 1984 were somewhat different. Refer to Suchanek et al (1984) and

Sundet and Wenger (1984) for methods of tagging, transmitter types, biological characteristics, and summer movement of fish tagged in 1983.

Advanced Telemetry Systems' internal transmitters (Model 10-35) used in 1984 were identical to those used in 1983 studies except pulse rates were slightly higher [1.0 and 2.5 pulses per second (pps)].

Advanced Telemetry Systems' external radio tags (Model RM 625) are rectangularly shaped, encapsulated in epoxy, and have slightly flexible 24.0 centimeter (cm) external antennas. The external transmitters are 0.9 cm high, 1.5 cm wide, 3.0 cm long, and have a dry weight of approximately 9.5 grams. The power source for the transmitters is a 1.4 volt mercury battery providing life expectancies of 90 days. The pulse rates for these tags are 2.4 pps.

The same transmitter frequencies (40.600-40.770 MHz) were used in 1984 as in 1983 studies. All radio tags were immersed in cold water (1.5°C) for 48 hours to ensure they were transmitting properly before they were implanted in fish.

Transmitter implantation

Based on personal communications with Carl Burger (USFWS) and experience gathered from the previous three years of radio telemetry studies, the minimum fork lengths of rainbow trout and Arctic grayling radio tagged was set at 380 mm (ADF&G 1983b, 1983c; Sundet and Wenger 1984).

Internal radio tags were implanted using the same procedures described in Ziebell (1973). Before surgery, fish were anesthetized with MS-222 (tricaine methane-sulfonate).

Prior to attaching external tags to fish, two Peterson disc needles were epoxied to one side of each radio tag so the needles were perpendicular to the length of the tag. Fish to be externally radio tagged were anesthetized and then the external tag was attached just below the dorsal fin (Plate 3). This method was similar as attaching Peterson disc needles described in the adult anadromous section of the 1983 procedures manual (ADF&G 1983a). This was accomplished by using pliers to push the two Peterson needles through the dorsal portion of the fish. After the needles were through the fish, one Peterson disc was attached to each needle. The radio tag and Peterson discs were then pushed tightly next to the fish and excess needle (over 1.0 cm past the discs) were cut off with pliers. The remaining needles were then rolled with the tip of the pliers to tighten and secure the tag in place.

After radio tagging, the fish were placed into a live box and held upright until they regained their equilibrium. The fish were then held overnight whenever possible for observation. The following day the sutures were checked and the transmitter's signal was tested before releasing each radio tagged fish near their point of capture.

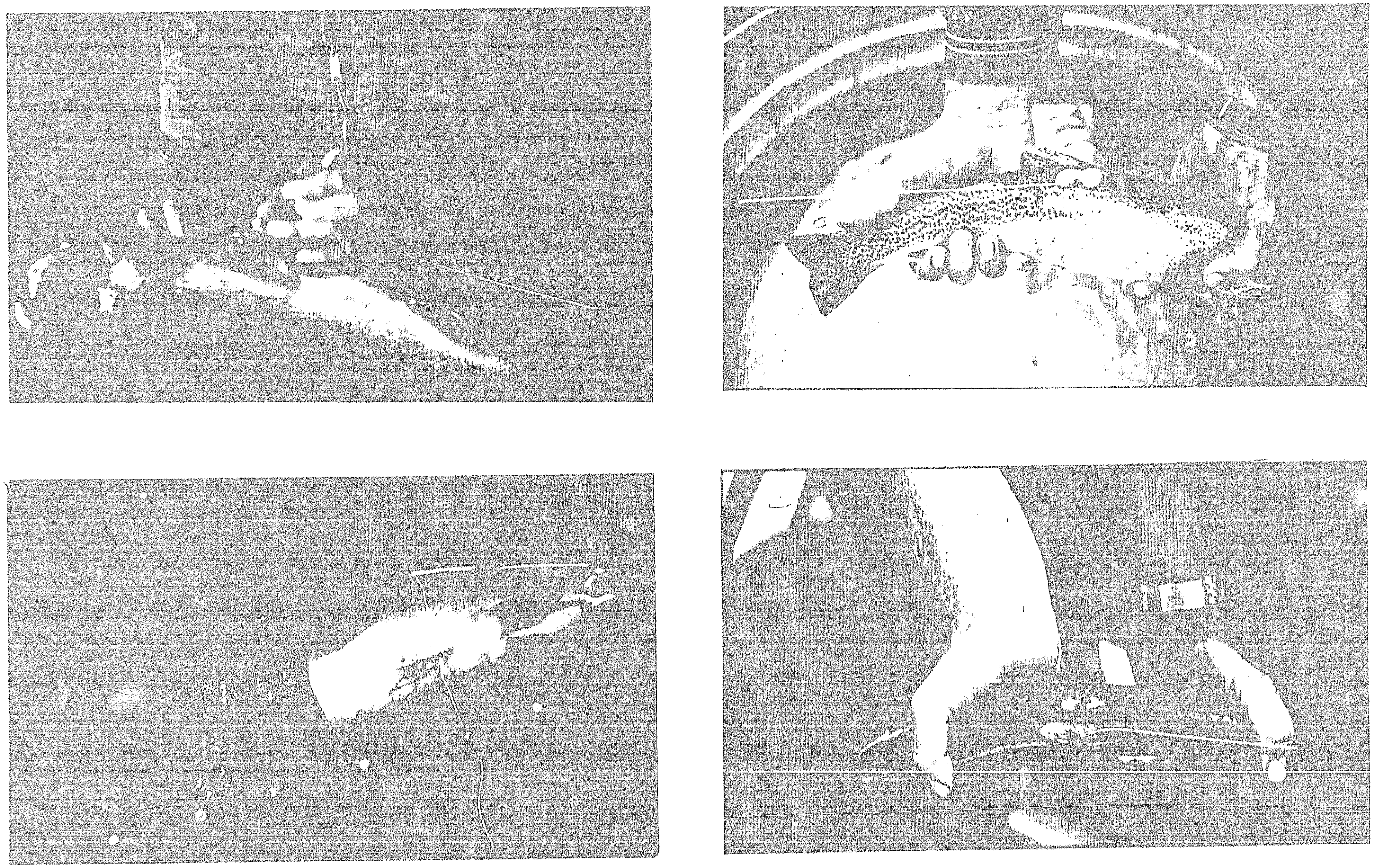


Plate 3. Implanting a radio tag into the abdomen of a rainbow trout (on left) and externally radio tagging a rainbow trout (on right).

Tracking

Biologists radio tracked fish primarily by fixed wing aircraft and boat. Aerial radio tracking was done using methods described in Adult Anadromous Investigations 1981 (ADF&G 1981c). Radio tracking was conducted over the mainstem Susitna by fixed wing from December 1983 to December 1984. Between December 1, 1983 and May 1, 1984, radio tracking was done between RM 40.6 and RM 152.0 approximately every 20 days. From May 1 to August 30, 1984 radio tracking flights were made every 10-14 days between RM 97.0 (Talkeetna) and RM 152.0. From September 1 to December 1, 1984 radio tracking was conducted between RM 0.0 and RM 152.0 every 14 days. Fixed wing tracking was also done over various tributaries such as Fourth of July Creek and Portage Creek from May 1 to December 1, 1984.

Aerial tracking by helicopters was also done occasionally during winter 1983-84 and in May and June 1984. During the summer, radio tracking was also done by boat during each field trip to pinpoint radio tagged fish.

3.0 RESULTS

3.1 Distribution and Relative Abundance of Resident Fish on the Lower Susitna River

3.1.1 Rainbow trout

Rainbow trout were first recorded captured on May 6 at the Deshka River. Other early immigration of rainbow trout were reported by sport fishermen at Kashwitna River between May 16-19 (David James, pers. comm.). During this time, water temperatures were 6.0°C (on May 6) at the Deshka River and 8.2°C (on May 10) at Kashwitna River (TRM 1.5).

A total of 155 rainbow trout were captured by all methods in 1984. The highest rainbow trout catches (62 fish) were at the Deshka River. Relatively high catches were made during boat electrofishing sampling in the mainstem Susitna River between RM 30.0 and RM 98.5 in early September (31 fish) and at the mouth of Little Willow Creek (RM 50.3, 14 fish) during late September. Only nine rainbow trout were captured in upper reaches of east side tributaries during early September.

In 1984, 73 rainbow trout were Floy anchor tagged in the lower river and four fish were recaptured. All four fish were tagged and recovered in the Deshka River in 1984 and moved a maximum of 3.5 miles.

3.1.2 Burbot

A total of 334 burbot were captured in 1984. Of these, the 282 adult burbot (≥200 mm) were caught at the Deshka River between TRM's 0.0 and 6.0. Adult catches at the Deshka River were high in May, September and October, however, little sampling was done between these time periods.

Few juvenile burbot (< 200 mm) were captured. Twenty-one juveniles were captured at JAHS and the Deshka River weir sites, while none were captured by outmigrant traps at RM 22.4.

In 1984, 197 burbot were Floy anchor tagged in the lower river. Most of these burbot (178) were captured at the Deshka River between TRM 0.0 and TRM 6.0. Twenty-five recoveries were made in 1984 from 23 different fish. All 25 recoveries were made in the Deshka River between TRM 0.0 and TRM 6.0. Nearly all (23) of these recoveries were from burbot tagged in this reach of the Deshka River in September or October 1984. Another recovered burbot was tagged in the Deshka River in May. The remaining recovery was from a burbot tagged at Anderson Creek (RM 23.8) on June 22, 1981 and recaptured on October 15, 1984 at the mouth of the Deshka River (RM 40.6). During the interim, it grew from 488 mm to 581 mm (TL).

3.1.3 Arctic grayling

In 1984, Arctic grayling immigration from the mainstem Susitna River were first reported by local fishermen at Grey's Creek (RM 59.5) on

April 28, and Rabideux Creek (RM 83.1) on May 1. Peak catches for Arctic grayling were reported at Grey's Creek on May 7 - 8 and at Kashwitna River (RM 61.0) from May 16-19 (David James pers. comm.).

A total of 271 Arctic grayling were captured in 1984. Most (60%) of the fish were captured during September and early October boat electrofishing efforts. The maximum catch during these efforts was 69 fish at mainstem sites between RM 60.1 and RM 98.5. Only two Arctic grayling were captured in upper reaches of east side tributaries during early September.

Ninety-nine Arctic grayling were Floy anchor tagged in the lower river and no recaptures were made in 1984.

3.1.4 Round whitefish

A total of 1,195 round whitefish were captured in 1984. Round whitefish were most abundant at JAHS sites. Eight hundred three juvenile ($<$ 200 mm) and one adult round whitefish ($\geq$200 mm) were captured at 20 regularly sampled sites and several opportunistic sites. Catches over 100 round whitefish were recorded at four side channel sites: Sucker (RM 84.5), Beaver Dam (RM 86.3), Sunset (RM 86.9), and Sunrise (87.0). Adult catches were made mostly by boat electrofishing in the mainstem between river miles 60.1 and 98.5 where 72 fish were captured.

In October, 19 sexually ripe round whitefish were captured at six sites. Most spawning fish (8) were found in the mainstem at RM 70.0. Several individual or pairs of spawning fish were also caught in the mainstem between RM 50.5 and RM 84.0.

In 1984, 113 round whitefish were tagged in the lower river and four round whitefish were recovered. Three of the fish (one tagged each year in 1981, 1982, and 1984) were recaptured less than 5.0 miles from their tagging site. The remaining fish moved from Montana Creek (RM 77.0) to TRM 1.5 of the Kashwitna River (RM 61.0) in two years.

3.1.5 Humpback whitefish

Six hundred eighty-seven humpback whitefish were captured in 1984. Most (94.2%) of the fish were captured by fishwheels or by outmigrant traps. Outmigrant traps located at Flathorn Station (RM 22.4) captured 71 juvenile humpback whitefish with 26.8% of the catch occurring in early September. No adult humpback whitefish ($\geq$ 200 mm) were captured at the outmigrant trap site.

Fishwheel catches of humpback whitefish were the greatest at Flathorn Station (RM 22.4) where 369 adults were captured. Fishwheels at Sunshine (RM 79.0) and Yentna (RM 28.5, TRM 4.0) stations also captured over 70 humpback whitefish. The maximum seasonal catch at all fishwheel sites was during late August with relatively high catches also in early July to early August.

Boat electrofishing humpback whitefish catches were the highest (16 of 27 fish) at mainstem sites between RM 30.0 and RM 98.5. No catches were made at JAHS sites, but some round whitefish catches may have been misidentified and were actually humpback whitefish (Paul Suchanek, pers. comm.).

In 1984, 261 humpback whitefish were tagged in the lower river and three were subsequently recaptured by fishwheels. All three recaptures were tagged at Flathorn Station (RM 22.4). One fish was recovered at Flathorn Station eight days later. The other two were recovered at Yentna Station (RM 28.5, TRM 4.0). The time between tagging and recovery of these two fish was 2 and 30 days.

3.1.6 Longnose suckers

Eight hundred sixty-two longnose suckers were captured in 1984. Most longnose sucker catches (326 fish) were made at JAHS sites and all but a few were juveniles (≤200 mm). Catches at JAHS sites were the highest at Sunrise Side Channel (RM 87.0, 53 fish). Catches over 40 fish were also made at Hooligan (RM 35.2) and Sucker (84.5) side channels.

Higher boat electrofishing catches (145 of 191 fish) were recorded at mainstem sites between RM's 30.0 and 60.0 compared to other boat electrofishing sites. Relatively high catches were also made at the Deshka River and fishwheel sites (226 and 76 fish, respectively). Most (50%) fishwheel catches occurred during early July or late August and most (87%) Deshka River catches were in May or September. Thirty-five juvenile longnose suckers were also captured by outmigrant traps at RM 22.4.

During 1984, 283 longnose suckers were tagged in the lower river and one longnose sucker was recaptured. In five months at large it was recovered only 0.7 miles from where it was tagged in the Deshka River (RM 40.6, TRM 1.0).

3.1.7 Other Species

Dolly Varden

Thirty-one Dolly Varden were captured in the Susitna River during 1984 with the highest catch at fishwheel sites (15 fish).

Concentrations of Dolly Varden were found at the mouth of the Talkeetna River and some at Kashwitna River (TRM 1.2) between April 30 and May 6. After this time, sport fishermen's catches sharply declined indicating that the fish had moved elsewhere. Sport fishermen reported Dolly Varden catches at Clear Creek (TRM 6.0 of Talkeetna River) increased near May 6. Dolly Varden were the first observed resident species to immigrate the Kashwitna River and Talkeetna River in 1984. At this time, both of the summer glacial rivers were still clear and much shelf ice was present. Mid-day water temperatures at Talkeetna River on May 2 was 3.5°C and on May 8 was 4.5°C, while at Kashwitna River on May 6 was 6.5°C.

During 1984, five Dolly Varden were tagged in the lower river and none were recovered.

Northern pike

In 1984, three northern pike (Esox lucius Linnaeus) were captured with all three being caught at Flathorn Station (RM 22.4). Two adult fish (≥200 mm) were captured in late August, one by a fishwheel and one by an outmigrant trap. The other fish was a juvenile (< 200 mm) captured by an outmigrant trap in mid-August.

Threespine stickleback

A total of 8,775 threespine stickleback (Gasterosterus aculeatus Linnaeus) were captured during 1984. Outmigrant traps at Flathorn Station captured 7,765 threespine stickleback. The highest seasonal outmigrant trap catches (37.1%) occurred during early August. Juvenile salmon crews (JAHS) captured the remaining fish. At JAHS sites, the maximum catch (915 of 1,010) of threespine stickleback was recorded at Beaver Dam Slough (RM 86.3). Over 95 percent of the catch at all sites were young of the year stickleback (20-40mm).

Ninespine stickleback

In 1984, 50 ninespine sticklebacks (Pungitius pungitius Linnaeus) were captured by a Juvenile Anadromous Habitat Study crew sampling at an opportunistic site and another ten by outmigrant traps at RM 22.4. Fish caught by the JAHS crew were captured by beach seining at an unnamed upland slough on the west side of the Susitna River at RM 57.2. No lengths were taken but two age classes were observed. One age class was approximately 25 mm, while the other was approximately 50 mm in total length. Table 2 lists the habitat parameters and corresponding measurements taken where the sticklebacks were captured.

Table 2. Habitat data collected at RM 57.2 where 50 ninespine stickleback were captured, August 5, 1984.

Water Measurements:	
Velocity	0.1 fps
Depth	3.5 ft
pH	6.6
Temperature	7.5°C
DO	6.5 mg/l
Conductivity	160 uhos/cm
Substrate Composition	Mud
Cover Characteristics:	
Type	emergent vegetation
% cover	96-100%

Arctic lamprey

A total of 425 Arctic lamprey (Lampetra japonica Martens) were captured in 1984. A fyke net weir on the Deshka River (RM 40.6, TRM 2.5) captured most Arctic lamprey (336 fish). Five of these fish were adults (310-600 mm) and the remainder juveniles (< 200 mm). Arctic lamprey were caught at the Deshka River from late May to mid-August with most being captured during mid-May (32.7%) or late July (66.9%).

Outmigrant traps at RM 22.4 captured 22 Arctic lamprey. The remaining Arctic lamprey were captured at JAHS sites, with nearly all (55 of 57) the catch being at Birch Creek Slough (RM 88.4), or in the Deshka River by hoop nets.

3.2 Resident Fish Index Site Monitoring on Middle Susitna River

A total of 1,409 resident fish were captured by boat electrofishing at 13 index sites in 1984. Seven species of fish were captured: rainbow trout, burbot, Arctic grayling, round whitefish, humpback whitefish, longnose suckers, and Dolly Varden. Most of these fish (56.6%) were captured at tributary sites. Mainstem sites and slough sites accounted for 35.3% and 8.2% of the catch, respectively. Relatively high catches at the combined sites were recorded for rainbow trout, Arctic grayling, round whitefish, and longnose suckers. Catch data for these four species are presented by site in Appendix Table E-1 and by macrohabitat type in Table 3. Less than 20 fish of each of the other resident fish species were captured at index sites. Because catches of these species were so small, no further catch data of these species will be presented.

3.2.1 Tributary mouth sites

Round whitefish and Arctic grayling were captured more frequently at tributary mouth sites (83.5%) in 1984 than rainbow trout or longnose suckers (Table 3). Round whitefish were captured in greatest numbers at Indian River (136 fish) (Appendix Table E-1). Arctic grayling were

Table 3. Boat electrofishing catch and catch per unit effort (CPUE) of four resident fish species in the middle Susitna River by three macrohabitat types. CPUE is in parenth sis, and the units are catch per minute.

SPECIES	MAY 16-31	JUN 1-15	JUN 16-30	JUL 1-15	JUL 16-31	AUG 1-15	AUG 16-31	SEP 1-15	SEP 16-30	OCT 1-15	TOTAL
MACROHABITAT TYPE											
Tributary Mouths											
RAINBOW TROUT	15(.07)	3(.08)	3(.06)	---(----)	4(.12)	---(----)	2(.06)	17(.25)	8(.16)	1(.04)	53(.11)
ROUND WHITEFISH	63(.31)	27(.70)	89(1.91)	---(----)	25(.74)	---(----)	18(.54)	46(.67)	83(1.64)	20(.74)	371(.74)
ARCTIC GRAYLING	61(.30)	14(.36)	27(.58)	---(----)	30(.88)	---(----)	31(.93)	75(1.09)	36(.71)	9(.33)	283(.56)
LONGNOSE SUCKER	0(0.00)	2(.05)	3(.06)	---(----)	31(.91)	---(----)	21(.63)	16(.23)	2(.04)	1(.04)	76(.15)
TOTAL	139(.68)	46(1.19)	122(2.62)	---(----)	90(2.65)	---(----)	72(2.15)	154(2.23)	129(2.55)	31(1.15)	783(1.55)
Sloughs											
RAINBOW TROUT	10(.20)	0(0.00)	0(0.00)	---(----)	1(.08)	---(----)	0(0.00)	2(.12)	1(.14)	---(----)	14(.11)
ROUND WHITEFISH	6(.12)	4(1.00)	5(.20)	---(----)	0(0.00)	---(----)	3(.21)	5(.30)	0(0.00)	---(----)	23(.18)
ARCTIC GRAYLING	42(.85)	2(.50)	0(0.00)	---(----)	1(.08)	---(----)	2(.14)	7(.42)	0(0.00)	---(----)	54(.42)
LONGNOSE SUCKER	2(.04)	1(.25)	5(.20)	---(----)	1(.08)	---(----)	6(.41)	5(.30)	0(0.00)	---(----)	20(.16)
TOTAL	50(1.21)	7(1.75)	10(.41)	---(----)	3(.25)	---(----)	11(.76)	19(1.15)	1(.14)	---(----)	111(.87)
Mainstem											
RAINBOW TROUT	3(.04)	0(0.00)	0(0.00)	---(----)	0(0.00)	---(----)	0(0.00)	5(.09)	11(.18)	5(.10)	24(.07)
ROUND WHITEFISH	36(.53)	65(1.49)	16(.82)	---(----)	3(.18)	---(----)	8(.50)	60(1.09)	64(1.08)	25(.49)	277(.84)
ARCTIC GRAYLING	27(.40)	20(.46)	24(1.23)	---(----)	21(1.24)	---(----)	6(.38)	40(.73)	14(.24)	4(.08)	156(.47)
LONGNOSE SUCKER	0(0.00)	3(.07)	5(.26)	---(----)	6(.35)	---(----)	0(0.00)	9(.16)	5(.08)	2(.04)	30(.09)
TOTAL	66(.98)	88(2.02)	45(2.31)	---(----)	30(1.76)	---(----)	14(.88)	114(2.07)	94(1.58)	36(.70)	487(1.48)

- - - = No effort.

captured mostly at Indian River (104 fish) or Portage Creek (104 fish). Most rainbow trout and longnose suckers were captured at Indian River (26 fish) and Jack Long Creek (21 fish), respectively.

3.2.2 Slough Sites

~~Table 3 shows~~ In 1984, Arctic grayling (48.7%) were found more often at slough sites ~~in 1984~~ than other species: rainbow trout (12.6%), round whitefish (20.7%), and longnose suckers (18.0%) (Table 3). Thirty-eight of 41 Arctic grayling captured were caught at Whiskers Creek Slough in late May (Appendix Table E-1).

3.2.3 Mainstem sites

Round whitefish (56.9%) and Arctic grayling (32.0%) were captured more often at mainstem sites than rainbow trout or longnose suckers (Table 3). Most round whitefish (178 fish) were captured between RM 147.3 and RM 147.4, while most (72 fish) Arctic grayling were captured between RM 137.3 and 138.3. Rainbow trout and longnose suckers were both captured in the highest numbers at RM 150.1 where 19 and 34 fish were captured, respectively.

3.3 Radio Telemetry Studies of Selected Resident Fish of the Middle Susitna River

3.3.1 Rainbow trout

Eighteen of 26 radio tagged rainbow trout tagged in 1983 were monitored during the winter of 1983-84 until their batteries expired. The remaining eight fish died or their batteries expired between July and early December 1983. Biological data, tagging data, and monitoring data collected between May and early December 1983 is presented in Suchanek et al. (1984) and Sundet and Wenger (1984).

Movements of the 1983 tagged fish from mid-December through late April were minimal with most (13 of 18 fish) moving less than 2.0 miles from where they were found in early December (Figures 4 and 5). The maximum winter movement was shown by rainbow trout 729-1.0 which moved 46.5 miles in 23 days. Because it moved downstream much more rapidly than the others, it was believed to have died between early January and early February. The remaining four fish moved from 2.8-8.1 miles between mid-December and late April. The maximum upstream movement of radio tagged rainbow trout during this time was 2.8 miles.

On January 11 and 12, fourteen of 17 fish whose transmitters were still functioning were located by helicopter in open-water areas of the mainstem Susitna. The open water prevented sampling and biologists were unable to determine the fate of these fish.

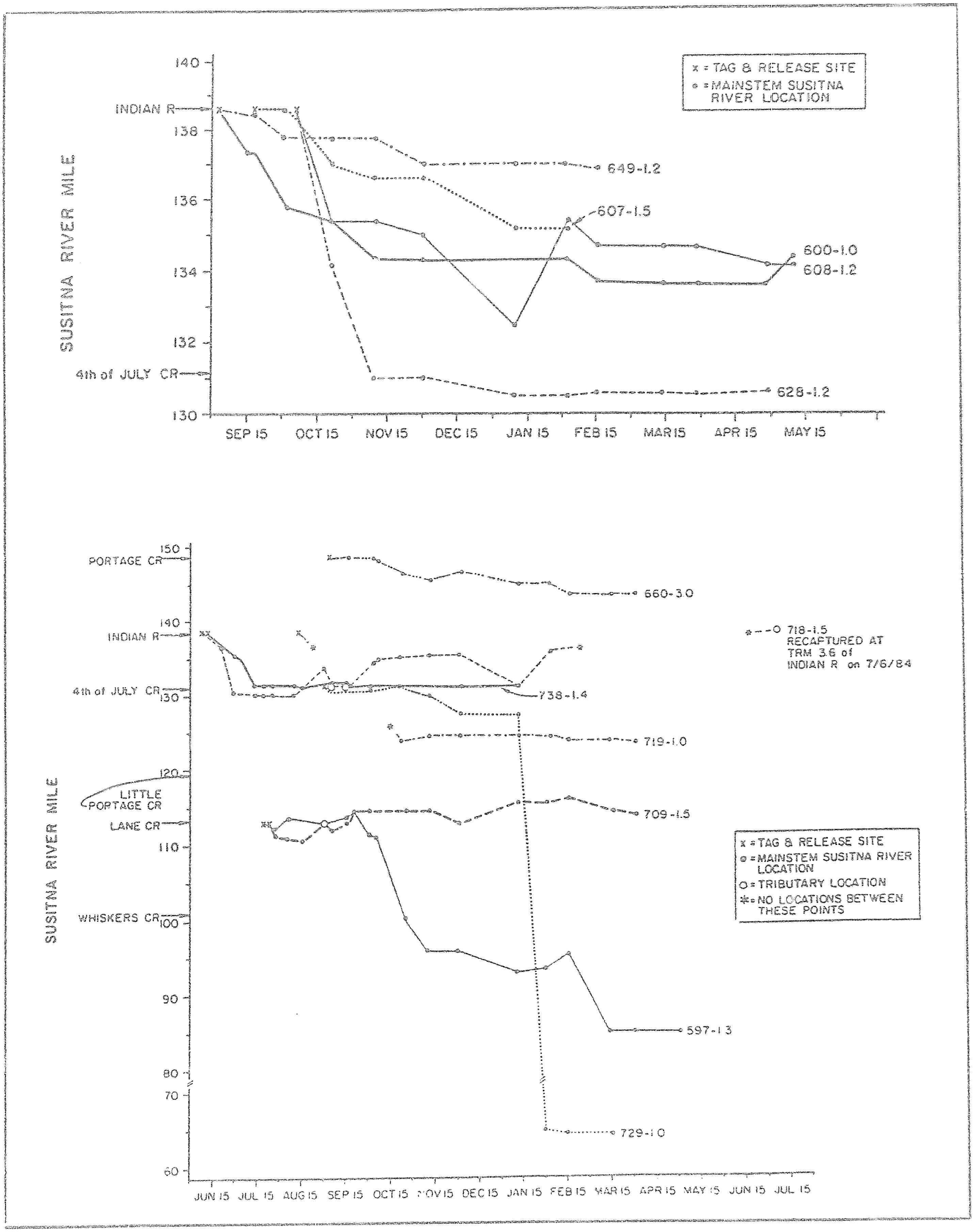


Figure 4. Movement of 12 radio tagged rainbow trout in the Susitna River below Devil Canyon, June 1983 to May 1984.

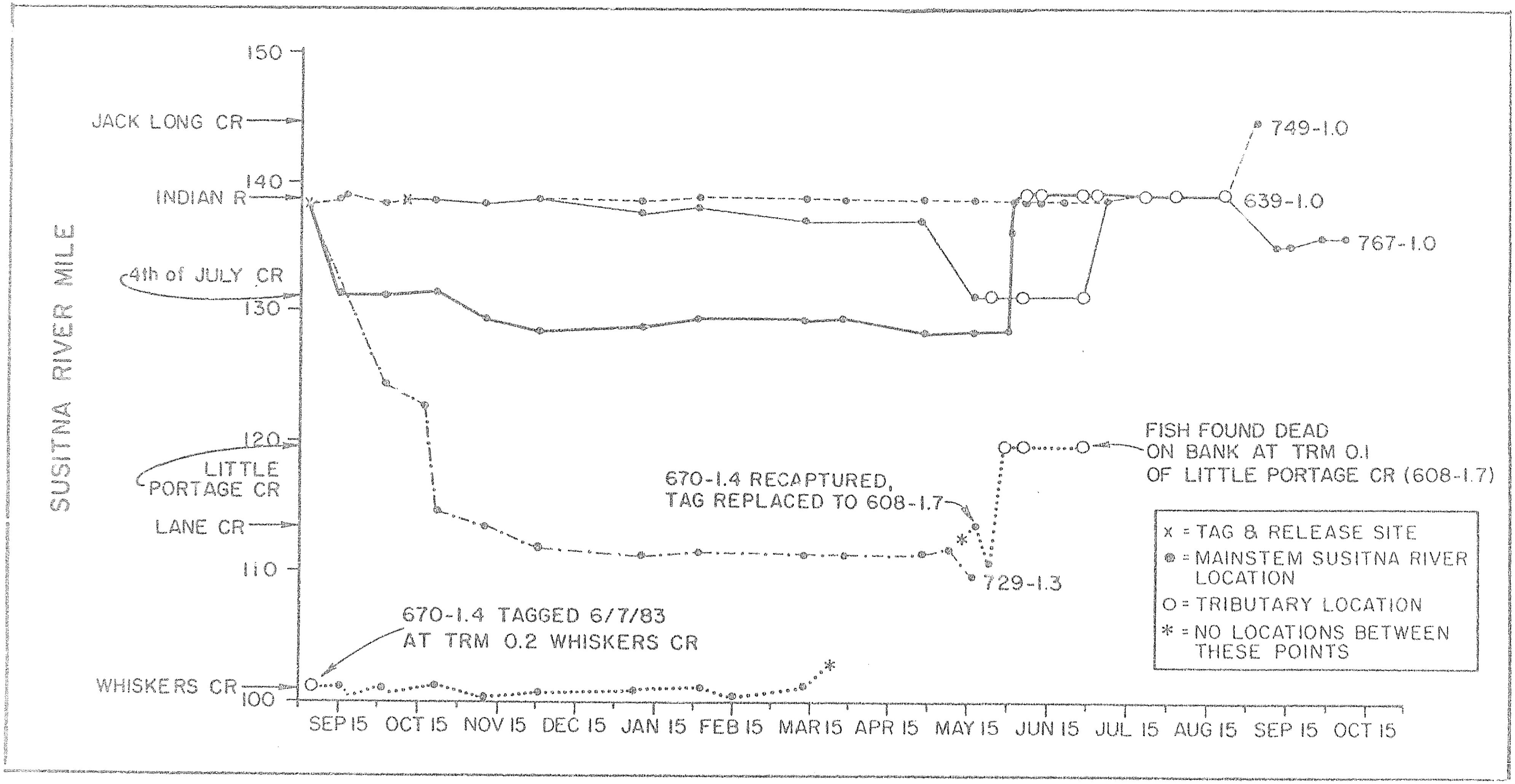


Figure 5. Movement of five radio tagged rainbow trout in the Susitna River below Devil Canyon, September 1983 to October 1984.

The other three rainbow trout were initially located by helicopter then pinpointed during ground surveys in areas of the mainstem covered by ice. Rainbow trout 670-1.4 was pinpointed at RM 101.1, this fish had stayed within a 0.5 mile radius during 1983-84 monitoring. It was in 2.5 feet of slush free water with an estimated velocity of 1 to 2 feet per second (Appendix Table B-1). Rainbow trout 767-1.5 was pinpointed at RM 114.8, it had ranged 1.2 miles from its tagging location. Rainbow trout 767-1.5 was located in one foot of water with six inches of slush ice over the water. The fate of both of these fish (670-1.4 and 767-1.5) was not determined since no movement was detected after ice augering in the areas where their transmitted signals were the strongest. The fate of the remaining rainbow trout (597-1.3) located during the ground survey was not determined. This was due to a peculiar null from its signal which prevented pinpointing the fish.

Surveys on February 15-17 found 15 fish whose transmitters were still functioning. All but five fish were found in areas of open water. Three (670-1.4, 709-1.5, and 729-1.3) of the five fish found under ice cover moved from 10-200 feet after drilling with an ice auger over them. These three fish were found in water depths averaging 6.2 feet and flows averaging 2.2 fps. Appendix Table B-1 lists habitat measurements taken at the three locations.

The other two fish found during ground surveys in mid-February were believed to be dead. No movement was detected for either rainbow trout 767-1.5 or 729-1.0. Rainbow trout 767-1.5 was found in only one foot of water and 729-1.0 in 1.5 feet of water. Water velocities near these two fish were less than 0.5 fps.

All ten fish found in open water during mid-February were in areas with no anchor ice. Three of these fish were in pools and the others were in riffles.

Six 1983 radio tagged rainbow trout were found after April but batteries from transmitters of three of these fish expired by mid-May. The remaining three fish (639-1.0, 749-1.0 and 767-1.0) were monitored until August or September 1984 (Figure 5). One of these fish (767-1.0) moved into Fourth of July Creek on May 24, then moved up and into Indian River in early July (Figure 6 and 7). The other two fish also moved into Indian River during the summer (Figure 7).

Two rainbow trout tagged in 1983 were recovered in 1984. Transmitters in both fish had been dead for over one month. Rainbow trout 718-1.5 was recaptured at TRM 3.6 of Indian River by a sport fisherman on July 6 and rainbow trout 670-1.4 was recaptured at Lane Creek on May 18 by a boat electrofishing crew. At this time, the transmitter was replaced with tag 608-1.7. On May 31, the fish was located at the mouth of Little Portage Creek (RM 119.0). On June 27 the tag was found along the bank at TRM 0.1 of the creek and the fish was suspected to have been eaten by a predator.

In 1984, 23 rainbow trout were radio tagged in the middle river between May 17 and July 23 with 82.6% being tagged by June 10. Fourteen of the

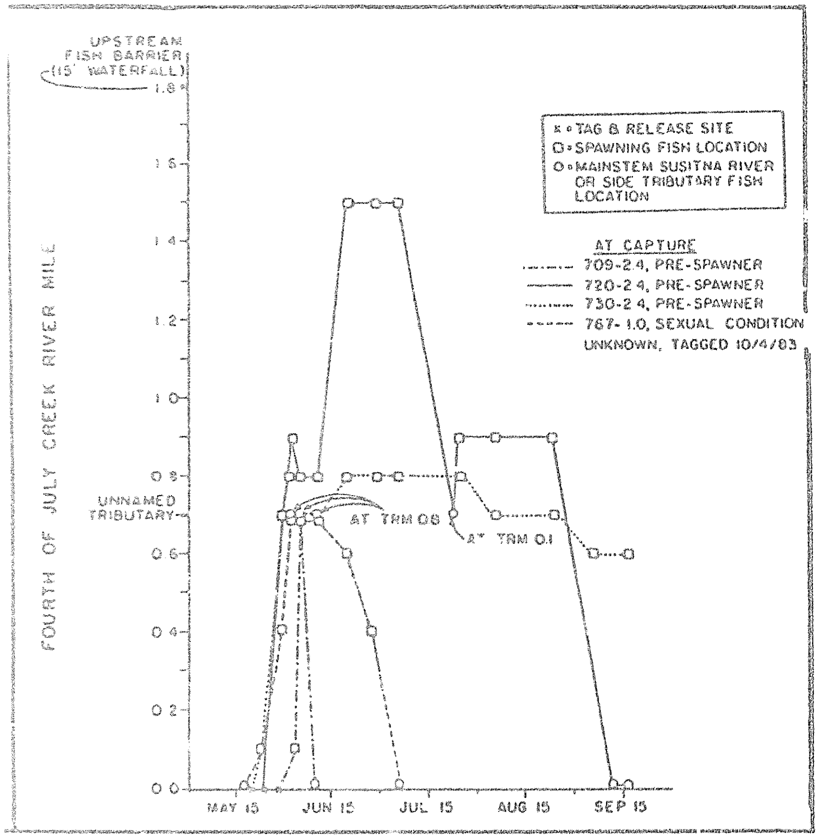


Figure 6. Movement of four radio tagged rainbow trout in Fourth of July Creek, May to October 1984.

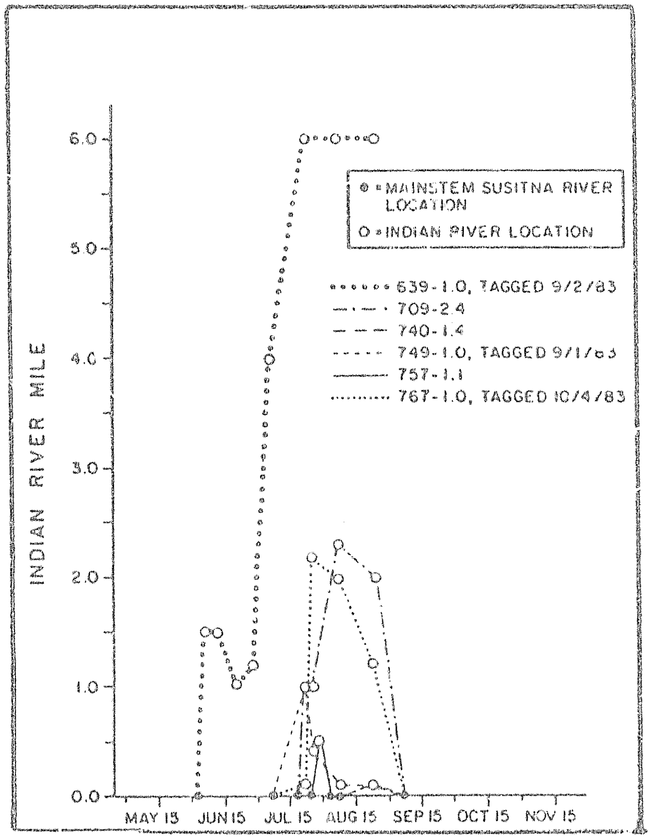


Figure 7. Movement of six radio tagged rainbow trout in Indian River, May to October 1984.

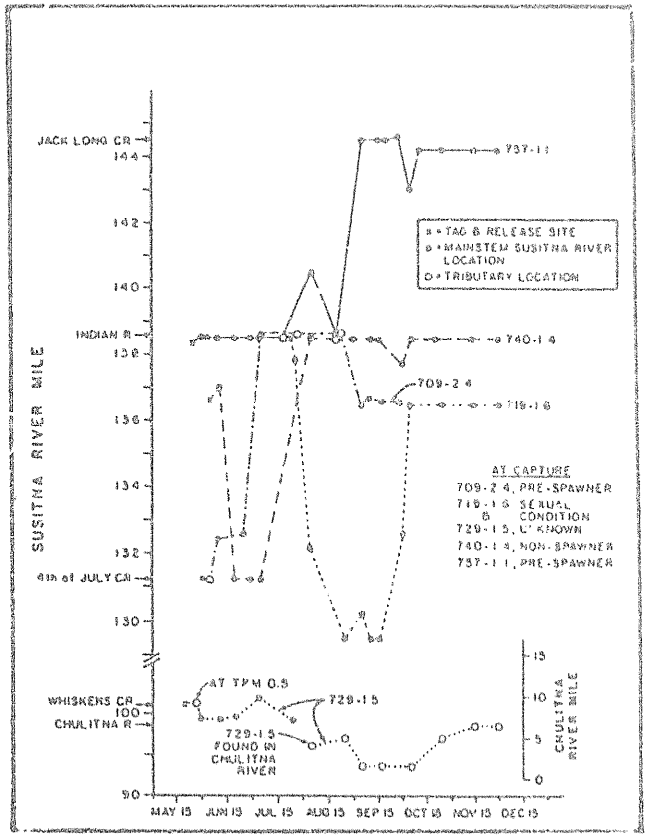


Figure 8. Movements of five radio tagged rainbow trout in the Susitna River, May to December 1984.

fish radio tagged were pre-spawners. All but two of the fish were captured in tributaries or at tributary mouths with most being in Fourth of July Creek (9), Portage Creek (8), and Indian River (4). No tracking data is provided for one fish tagged at Fourth of July Creek because it apparently died after tagging. Appendix Table B-2 presents a summary of capture and biological data for the other 22 radio tagged fish. Individual fish movements of the 22 radio tagged rainbow trout from time of tagging to November 30, 1984 are presented in Figures 6 to 11. Most (21 of 25) radio tagged fish monitored during the summer appear in two or more figures since they moved in the mainstem as well as in tributaries such as Portage Creek or between tributaries. Most (16) of the 1984 tagged fish showed large summer movements between 5.0-15.0 miles from where they were tagged. All but one fish showed an upstream movement over 1.0 mile. The maximum movement was shown by rainbow trout 598-1.6 which moved 101.2 miles (Figure 8). Because it moved so much and so rapidly after August 13, it was believed to have died close to this time. Another fish (670-1.2) was believed to have died because of spawning (Figure 9).

Only one of the 25 monitored radio tagged rainbow trout was not found in a tributary during the summer of 1984. Ten fish ascended Portage Creek, six ascended Fourth of July Creek, four ascended Indian River, two ascended both Fourth of July Creek and Indian River, one fish ascended Little Portage Creek, and one ascended Whiskers Creek. The fish which moved into Whiskers Creek, later moved into the Chulitna River (Figure 8). In 1984, 434 locations of 39 different radio tagged rainbow

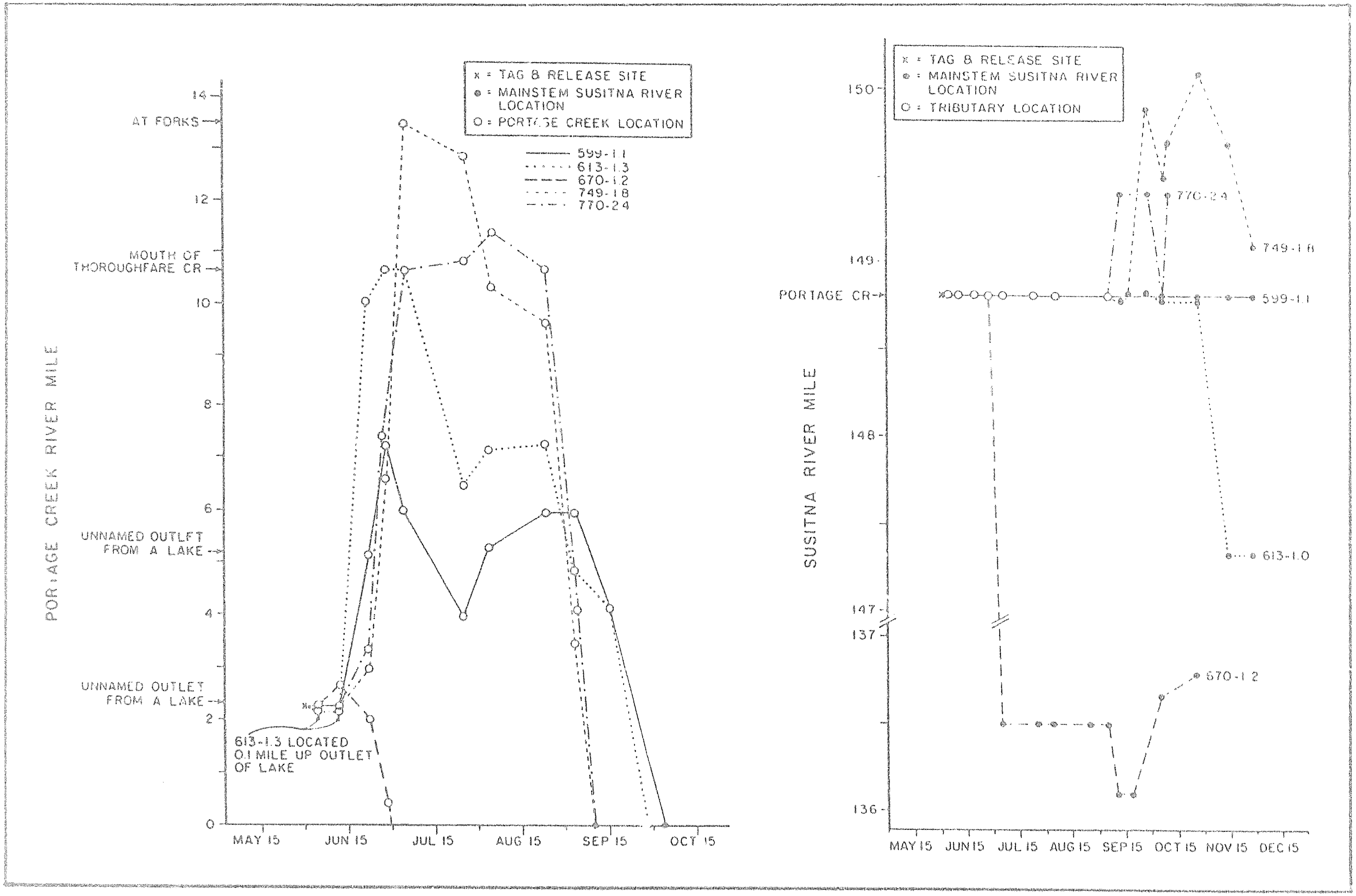


Figure 9. Movement of five spawning rainbow trout, tagged at TRM 2.3 Portage Creek, in Portage Creek and then in the mainstem Susitna River, May to December 1984. At capture, all five fish were pre-spawners.

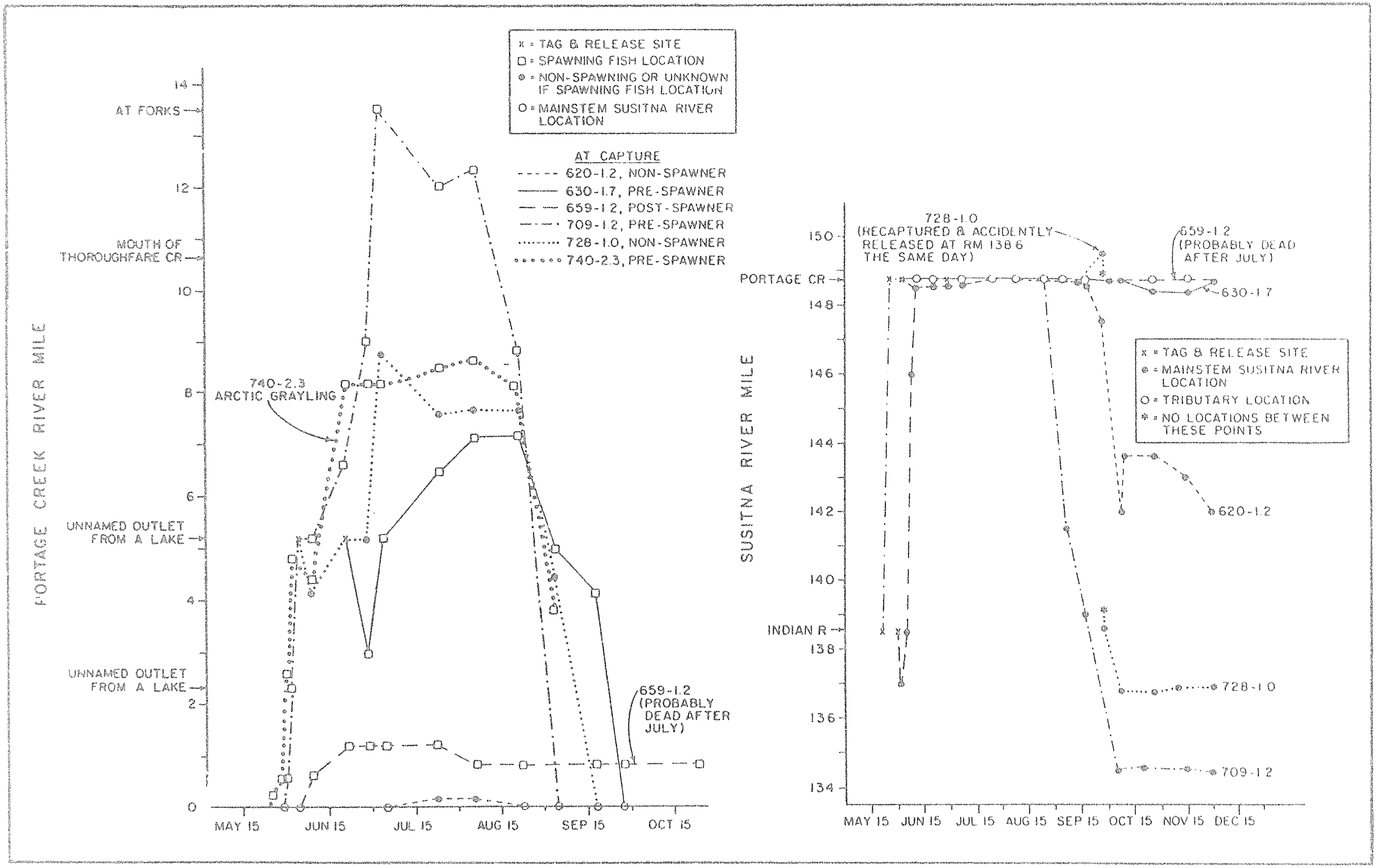


Figure 10. Movement of five rainbow trout and one Arctic grayling in Portage Creek and then in the mainstem Susitna River, May to December 1984.

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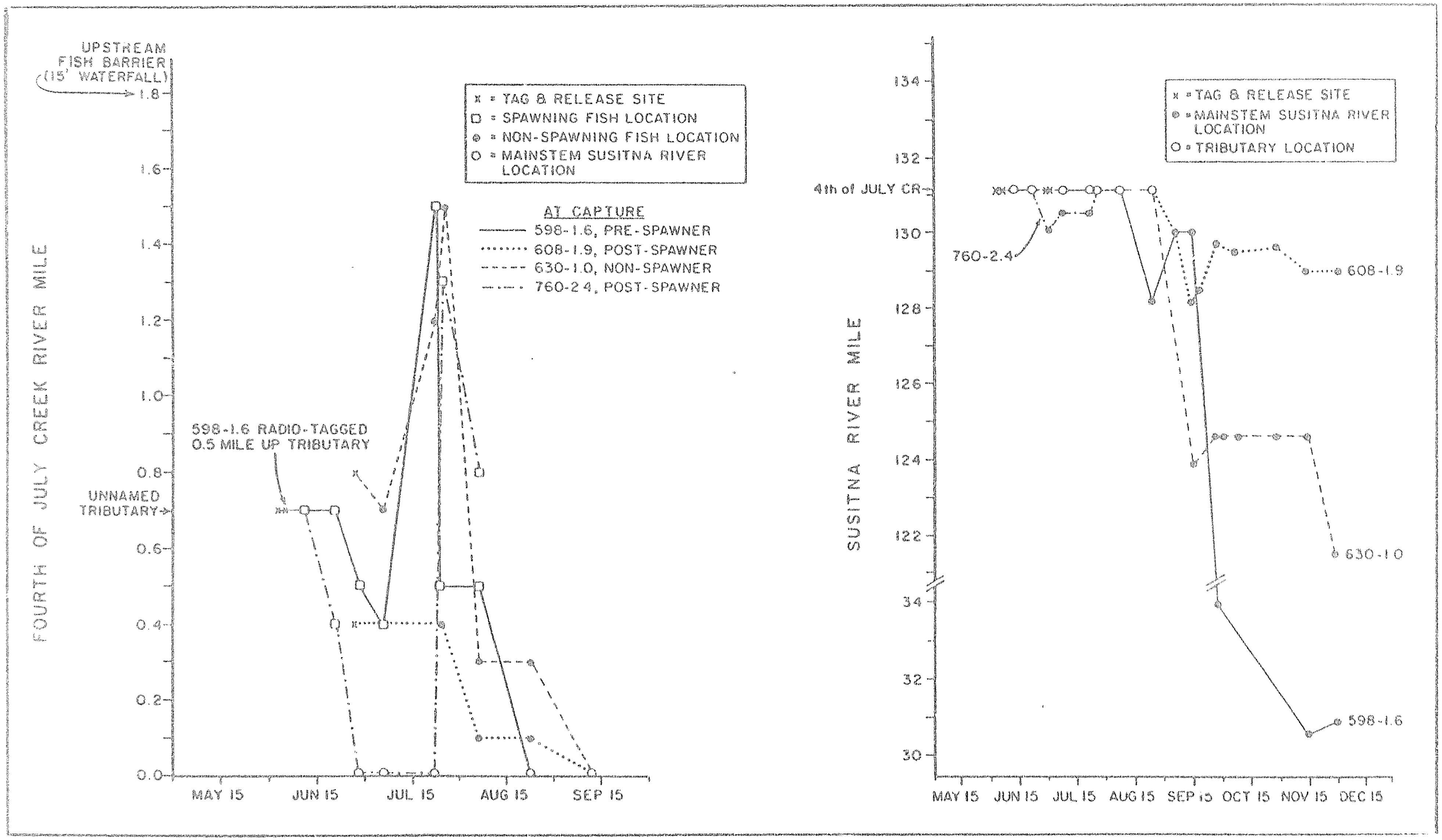

Figure 11. Movement of four radio tagged rainbow trout in Fourth of July Creek and then into the mainstem Susitna River, May to December 1984.

trout were made. Movements of the 1984 monitored radio tagged rainbow trout can be placed into four major categories based on their annual life history: (1) those associated with overwintering (December - April), (2) those associated with spawning (May and June), (3) those associated with summer rearing (July - September), and (4) those associated with the transition period between fall and winter (October and November). The distribution of 1984 monitored fish changed by macrohabitat as the season changed. Between December and April, nearly all (90.7%) rainbow trout were found in the mainstem (Figure 12). During May and June, 62.2 percent of the radio tagged rainbow trout locations were in tributaries. The majority (58.9%) of fish locations from July to September were also in tributaries.

By October 6, all but one radio tagged rainbow trout had outmigrated tributaries to their mouths or the mainstem. The one fish (659-1.2) that remained in a tributary after September was believed dead since it had not moved recently (Figure 9). In October and November, 72.1% of the fish locations were associated with the mainstem with the remaining locations being at tributary mouths.

3.3.2 Burbot

Two sampling trips made in mid-January and mid-February 1984 to locate and determine the fate of burbot radio tagged in summer 1983 yielded limited data. In January, only one burbot was pinpointed during ground surveys. Two more radio tagged burbot were located in open-water areas

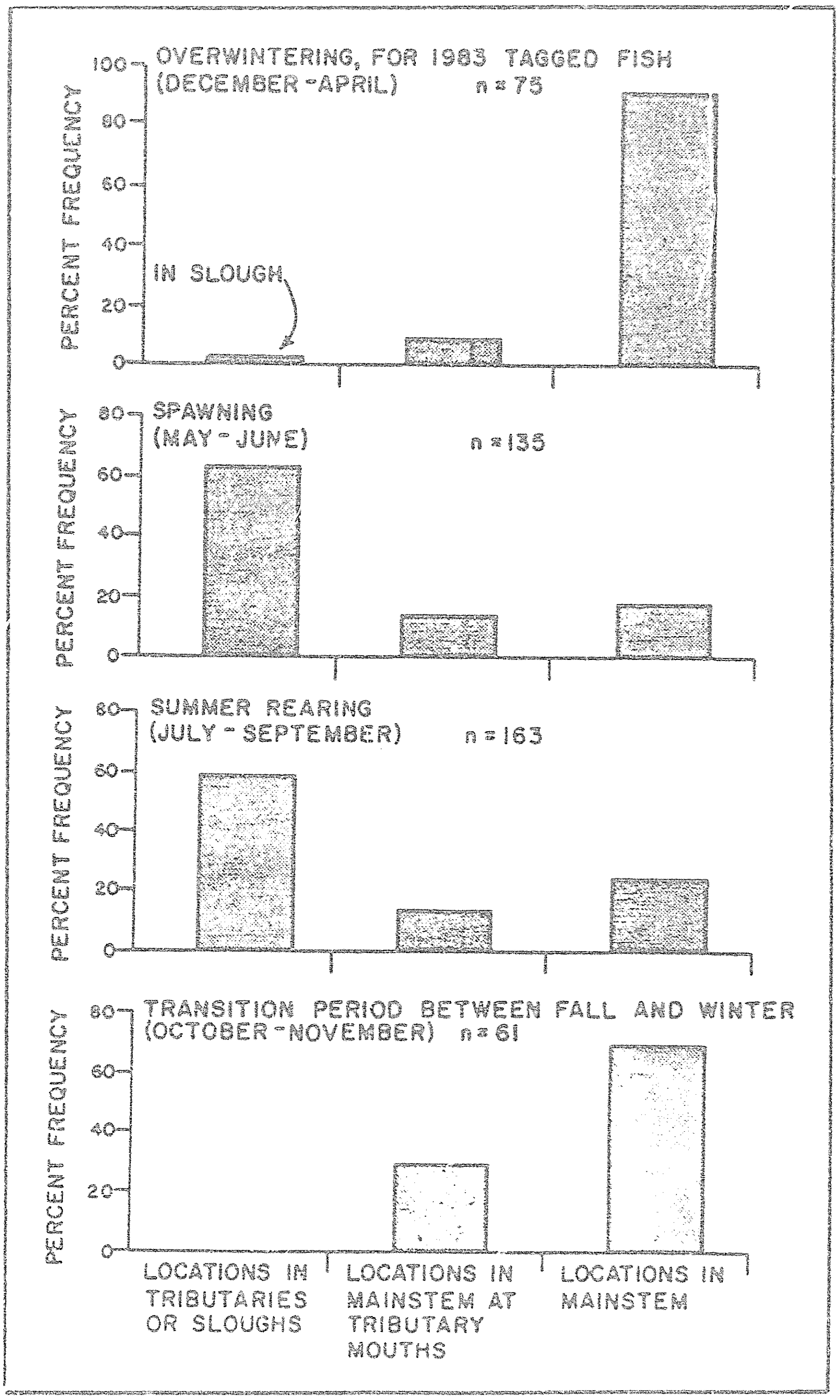

Figure 12. Frequency distribution of radio tagged rainbow trout locations in tributaries, at tributary mouths, and in the mainstem Susitna River during 1984.

of the mainstem during January. In February, only one radio tag was still functioning.

Burbot 670-3 was located in the mainstem at RM 87.0 in January. Biologists measured six inches of water with zero velocity and two feet of slush ice between the water and the ice at this location. This burbot did not move when ice augering was done in the vicinity of its strongest radio tag signal and therefore its fate was not determined. Two burbot sets made in the area overnight failed to catch any fish. Both this fish and the other two fish (639-3.0 and 720-3.0) located in mid-January were found to have moved downriver less than 1.0 mile from where they were found on December 1, 1983. Burbot 639-3.0 was located at RM 131.1 in waters approximately 4.0 feet deep and velocities of 1-2 fps. Habitat measurements taken near burbot 639-3.0 showed a water temperature of 0.2°C, conductivity of 247 umhos, pH of 7.9, and DO of 13.6 mg/l. In February, burbot 720-3.0 was found 0.2 miles downriver where it was pinpointed in January in an open-water channel off Slough 10 (RM 133.8) in water approximately 4.0 feet deep. Burbot 720-3.0 was last found on March 13, at RM 133.7.

3.3.3 Arctic grayling

One radio tagged Arctic grayling was monitored between May and September 1984. This fish was captured by boat electrofishing, tagged and released at RM 150.1 on May 22. At capture, it was found to be a prespawning male, 410 mm (FL) long and 10 years old. Two days after tagging, it moved into Portage Creek (RM 148.8) for the summer (Figure 10). The maximum recorded upstream location of this fish was TRM 8.7 on August 6. Shortly thereafter, the fish began to move out of Portage Creek. This fish was last found on September 6 at TRM 3.8 of Portage Creek.

3.4 Other Resident Fish Studies on the Middle River

Table 4 provides catch data of resident fish captured in the middle river in 1984 at sites other than the 13 boat electrofishing index sites. Population estimates were made using provisional data; numbers used and population estimates made are provided in Appendix D.

Four sites were located in 1984 where rainbow trout probably spawned. These sites were at Portage Creek TRM 2.3 and TRM 5.1, at Fourth of July Creek TRM 0.7 and at TRM 0.5 of an unnamed side tributary outletting at TRM 0.7 of Fourth of July Creek. Appendix Table E-2 provides habitat measurements taken at these sites as well as general comments about each site.

3.4.1 Lake surveys

A total of 390 resident fish were captured in six lakes surveyed in 1984 (Table 4). Most (86.1%) fish captured were rainbow trout. Lake B was the only lake surveyed where no rainbow trout were captured. Effort was similar in all lakes except at the lake outletting at TRM 2.3 of Portage

Table 4. Catch data of resident fish species in the middle river at opportunistic and lake sites, May to October 1984.

Species	Catch Data at Middle River Sites (Excluding Lakes): Fishwheel Sites	Outmigrant Traps	Boat Electro-shocking Opportunistic Sites	Other Gear at Mainstem Influenced Opportunistic Sites	Indian River TRM 0.1-TRM 9.0	Portage Creek TRM 0.1-TRM 11.6	Fourth of July Creek TRM 0.1-TRM 1.8	Total Catch	Middle River Lake Catch Data: Lakes at Headwaters of Fourth of July Creek A	B	C	D	Miami Lake	Lake Outletting at 2.3 of Portage Creek	Total Catch
Rainbow trout	9	50	12	39	1	13	54	178	64	0	192	59	11	10	336
Burbot	2	8	0	4	0	0	0	14	0	0	0	0	0	0	0
Arctic grayling	8	88	13	112	0	40	0	261	0	0	0	0	0	0	0
Round whitefish	16	2,173	31	32	0	0	0	2,252	0	0	0	0	0	0	0
Humpback whitefish	27	277	1	7	0	0	0	312	0	0	0	0	0	0	0
Longnose suckers	17	316	5	71	0	0	0	409	0	0	0	0	0	0	0
Dolly Varden	1	5	1	4	0	0	1	12	0	19	0	0	0	0	19
Lake trout (*Salvelinus namaycush* Walbaum)	0	0	0	0	0	0	0	0	-	33	0	0	2	0	35
Threespine stickleback	-	5,080	0	-	-	-	-	5,080	0	0	0	0	0	0	0
Arctic lamprey	-	93	0	-	-	-	-	93	0	0	0	0	0	0	0
TOTAL CATCH	80	8,090	63	270	1	53	55	8,611	64	52	192	59	13	10	390

- = Not applicable for this species.

Creek. Much less effort was expended in this lake compared to the other five lakes.

3.4.2 Tag-and-recapture studies

Rainbow trout

In 1984, 153 rainbow trout were Floy anchor tagged and 30 recoveries were made from rainbow trout tagged in the middle river. Seven recoveries were made at the tagging sites and 15 rainbow trout were recovered within 5.0 miles of their tagging sites. The remaining eight fish moved an average of 27.4 miles from where they were tagged. Most (63%) recoveries were from fish tagged in 1983. Eighty-seven percent of the recoveries were made in or at the mouths of tributaries such as Fourth of July Creek (14, RM 131.1), Indian River (6, RM 138.6), and Portage Creek (3, RM 148.8). The longest move recorded for a Floy anchor tagged rainbow trout in the Susitna River is 55.7 miles. This fish was tagged in Fourth of July Creek in 1983 and recovered in an unnamed tributary of the Chulitna River (TRM 23.1) during 1984.

Burbot

In 1984, six burbot were Floy anchor tagged in the middle Susitna River and there were no recaptures.

Arctic grayling

During 1984, 425 Arctic grayling were tagged and 44 recoveries of 43 different fish were made from fish tagged in the middle river. This included one fish tagged at Cheechako Creek (RM 152.4) in August 1982 and recovered in May 1984 at Portage Creek (RM 148.8). The 44 recaptured fish ranged 0.0 to 95.8 miles from the time they were tagged. Eight fish were recaptured at their tagging sites. Twenty-one Arctic grayling recaptured were caught within 5.0 miles of their tagging site. The remaining 15 fish moved an average of 20.0 miles. The maximum movement for an Arctic grayling to date is 95.8 miles. This fish w tagged in Portage Creek (RM 148.8, TRM 6.0) in 1983 and recovered in Kashwitna River (RM 61.0, TRM 2.0) in 1984. Most (61.4%) recoveries were made from fish tagged in 1983. Twenty-one of the recoveries were made in tributaries or at tributary mouths with another 17 recaptured in the mainstem.

In addition to these recoveries, one Arctic grayling was recaptured at Portage Creek which had been tagged at Tsusena Creek (RM 181.3) in 1982.

Round whitefish

In 1984, 481 round whitefish were tagged and 76 recoveries of 72 different fish were made from fish tagged in the middle river. Most of the recoveries were made near the tagging sites with 25 at the tagging sites and 35 recoveries made within 5.0 miles of the tagging sites. The remaining 16 fish moved an average of 16.0 miles with a maximum movement of 55.7 miles. Sixty-one percent of the recoveries were made from fish tagged in 1983. Forty-two of the recoveries were made at tributary mouths and 32 recoveries were made in the mainstem.

Humpback whitefish

In 1984, a total of 25 humpback whitefish were tagged in the middle Susitna River. No humpback whitefish were recaptured in 1984.

Longnose suckers

A total of 158 longnose suckers were tagged in 1984. Thirteen longnose suckers were recaptured in 1984 of which all were tagged in the middle river. Four fish were recaptured at their tagging sites, another four were recaptured within five miles of their tagging sites, and the remaining five fish moved an average of 16.5 miles. Most of the fish recaptured were tagged in 1982 (five fish) or in 1983 (six fish).

Dolly Varden

During 1984, eight Dolly Varden were tagged in the middle river. Three recoveries of two different fish were made in 1984 with both fish being tagged in 1984. One fish was tagged at RM 139.4 and recaptured one month later at RM 136.7 and again three months later at Indian River (RM 138.6). The other fish was tagged and recaptured, 12 days later, at Indian River.

4.0 DISCUSSION

4.1 Lower Susitna River

4.1.1 Rainbow trout

Studies done in 1984 show rainbow trout immigrate lower river tributaries up to 10 days earlier than middle river tributaries. Water temperatures taken at Deshka River and Kashwitna River in 1984 shows the immigration occurs at similar temperatures (6.0°C and 8.2°C, respectively) as Fourth of July Creek (7.7°C) in the middle river. Catch data from 1981 also shows rainbow trout immigrate lower river tributaries early in May (ADF&G 1981b).

After rearing in tributaries during summer, rainbow trout are believed to move out of most east side tributaries in September or October and overwinter in the mainstem Susitna River. The fall outmigration is probably triggered by discharge and/or temperature. In 1984, the primary cause of the outmigration was probably a flood in late August (refer to part 4.2.1 and Figure 14). Surveys conducted in the upper reaches of several of these tributaries in early September found very few rainbow trout. Sport fishermen have reported summer rainbow trout populations in these tributaries such as the North Fork of the Kashwitna River and Montana Creek to be high (Dave Watsjold, pers. comm.).

Radio tagging data from winter 1981-82 support the hypothesis that some rainbow trout overwinter in the lower mainstem Susitna River (ADF&G

1983b). Recoveries of Floy anchor tagged fish show some Talkeetna River rainbow trout also overwinter in the mainstem Susitna River (Sundet and Wenger 1984). Because few adult rainbow trout were captured in early spring or late fall in the Deshka River in 1981 or 1984, adult rainbow trout may overwinter in the upper reaches of the Deshka River. Likewise, because catch rates were relatively high for juvenile rainbow trout during these times on the Deshka River, it appears some upper Deshka River juveniles outmigrate to the mainstem or the lower Deshka River for overwintering.

4.1.2 Burbot

Susitna River burbot reside mostly in mainstem influenced areas (ADF&G 1981b, 1983b, 1983c, 1983d). This relationship is probably due to high turbidities or low light penetration in the mainstem which the light sensitive burbot prefers (ADF&G 1983e; Suchanek et al. 1984). Studies (1981-84) have shown that burbot are found in much higher concentrations below Talkeetna than above it (ADF&G 1981b, 1983b). This is probably due to a greater frequency of preferred habitat. Captured burbot and radio tagged burbot have been found most often in backwater areas of varying depths (ADF&G 1983c, 1983e, Suchanek et al. 1984).

Our data indicates that burbot readily use mainstem influenced areas in the lower river for spawning. Capture rates have been reported by sport fishermen to be high at the mouths of the Deshka River (RM 40.6) and Alexander River (RM 10.1) during mid-December to early February (ADF&G 1983b, 1983c). Radio tagged burbot data has also shown that all

11 burbot monitored during January and February 1982 and 1983 have remained in the mainstem between RM's 26.0 to 89.6. Since approximately 85% of burbot over 400 mm total length are spawners for a given year (ADF&G 1983c), it is likely several of the radio tagged fish spawned in the mainstem Susitna.

Burbot spawning in mainstem influenced areas is of particular importance. One post-project effect of hydroelectric dams is power peaking which rapidly fluctuates water levels. Because burbot are demersal spawners, this effect could substantially decrease burbot populations in mainstem influenced areas of the Susitna River by desiccating eggs. Eggs of other species such as salmon could possible survive this effect if redds are in areas of groundwater.

Burbot most likely use the Deshka River and Alexander River for spawning. The pre-spawning movement into these tributaries has been reported to begin in November, but from studies done in 1984 this movement appears to begin slightly earlier (ADF&G 1981b; 1983b). During 1984, burbot were captured by hoop nets between TRM's 0.0-6.0 on the Deshka River with catch rates increasing substantially from mid-September to mid-October. The highest burbot catch rates during May, September and October 1984 sampling were between October 11-15 which were the last days of the open-water field season. Local residents on the Deshka River reported that slush ice flowed from October 16 to November 11 and on November 11 the river froze over (Leon Dick, pers. comm.).

While few burbot were captured at the farthest upriver Deshka River sites (between TRM's 5.0 to 6.0) in early September, by mid-September the catch and catch rates were much higher. This also suggests that Susitna burbot may spawn in the Deshka River further upriver than thought. Data from one burbot tagged and recovered in 1984 and catch data from 1981 also supports this this hypothesis. The recaptured fish was tagged at TRM 1.5 on September 13 and recovered at TRM 6.0 on October 13. Catch data in 1981 at TRM 4.5 (site C) showed no adult burbot until late August (ADF&G 1981b). Between then and mid-October catch rates increased.

Young-of-the-year burbot have been seldom captured; however, during mid-June 1984 several thousand approximately 15 mm (TL) burbot were observed along the shoals of the Deshka River at TRM 1.9. A similar timing of hatching was reported in 1982 at Slough 9 (RM 129.2) where several dozen of the same size fish were captured (ADF&G 1983b).

4.1.3 Arctic grayling

Arctic grayling spring movements into lower river tributaries usually begins in early May or up to 20 days earlier than in most middle river tributaries such as Portage Creek. The earlier immigration in tributaries below RM 98.5 than above is probably due to warmer water temperatures. Daytime surface water temperatures in 1984 was 8.2°C at Kashwitna River on May 10 and 0.8°C at Portage Creek on May 9.

After rearing in tributaries during the summer, Arctic grayling apparently move out of most east side tributaries into the mainstem to overwinter. In larger west side tributaries such as the Deshka River, most adult Arctic grayling are suspected to overwinter in the upper reaches of those tributaries. Catch rates were only slightly higher in early spring and late fall compared to other times at the Deshka River (TRM's 1.5-6.0) in both 1981 and 1984. Two recaptures in 1981 indicate that some Arctic grayling in the lower river may overwinter far downriver in the mainstem from their summer rearing tributaries. These fish were tagged in May 1981 and were later recovered 9.9 and 32.5 miles upriver (ADF&G 1981b).

4.1.4 Round whitefish

Boat electrofishing in the lower river was resumed in 1984. Data collected in this area showed round whitefish distribution in 1984 was similar to 1982 findings (ADF&G 1983b). Because a number of sexually ripe round whitefish have been found in the mainstem in October, round whitefish are thought to use this habitat for spawning at this time.

4.1.5 Humpback whitefish

Two stocks of humpback whitefish appear to be in the Susitna River below Devil Canyon. One stock is anadromous while the other remains in the river all year. Scale analysis of fish captured in 1983 at Yentna River fishwheels showed that many (19.2%) exhibited periods of high growth compared to most (4.9%) fish captured above the Chulitna River confluence. This suggests that a high percentage of humpback whitefish in the lower river overwinter in the estuary. Relatively high juvenile humpback whitefish catches at outmigrant traps at RM 22.4 in 1984 also lends support to this hypothesis.

Fishwheel catch data shows adult humpback whitefish begin their spawning run in June and it continues through September. With the addition of fishwheels at Flathorn Station (RM 22.4) in 1984 more knowledge was gathered on the timing and behavior of humpback whitefish during the spawning migration. As the season progressed, humpback whitefish catches similiarly progressed up the river. Catches were high at Flathorn station from early July to late August, at Yentna Station (RM 28.5, TRM 4.0) from early July to early September, and at Sunshine Station (RM 79.0) in late August and early September. During this time, fishwheel effort was approximately the same at all stations except during spring. Comparison of catches between the three sites suggests many humpback whitefish migrate up the Yentna River and into areas between these stations to spawn. One of the suspected spawning areas between stations is Anderson Creek (RM 23.8). Large numbers of humpback whitefish were gill netted in this tributary in 1981 (ADF&G 1981b).

Tag-and-recapture data also support evidence of the spawning run originating from or near the estuary. In 1984, two fish were recovered at Yentna Station in late August and early September which had been tagged two and 30 days earlier at Flathorn Station.

Exact spawning locations for humpback whitefish have not been found, but it is highly suspected that they nearly exclusively spawn in tributaries. Support for this hypothesis is provided by the few numbers of humpback whitefish captured in mainstem influenced areas in either 1982 or 1984. Large numbers of pre-spawners have been captured, however, at Anderson Creek. Spawning is presumed to occur from mid to late October.

4.1.6 Longnose Suckers

Longnose suckers are distributed widely throughout the Susitna River. Boat electrofishing catch data from 1982 and 1984 show they are the most abundant resident fish species (except sculpins and sticklebacks) in the lower river (ADF&G 1983b).

Recapture data from 1981 to 1984 suggests most adult longnose suckers move little in the summer. Only one of 12 suckers recaptured from 1981 to 1984 moved over 5.0 miles from their tagging sites (ADF&G 1981b, 1983b).

Late May spawning occurs for longnose suckers in tributaries as well as in the mainstem Susitna River (ADF&G 1983b). Although Morrow (1980) reports longnose suckers are only spring spawners, high numbers of male and several female pre-spawners have been captured in the mainstem Susitna River during September and October. These fish have been captured throughout the lower river above RM 35.4 but are most numerous between RM 35.4 and RM 60.0. These data suggest that there may be two spawning periods of longnose suckers in the Susitna River with one in late May and the other in October or November. Because no practical sampling occurs during freeze-up (between mid-October to December) this hypothesis will be difficult to prove.

4.1.7 Other Species

Dolly Varden

Dolly Varden are widely distributed in the Susitna River but few have been captured. They have been captured most frequently near the mouths of the Kashwitna River and Talkeetna River.

In tributaries which have sizable populations of Dolly Varden, studies done in 1984 show that this species is the first resident species to immigrate from the mainstem during spring. Limited data from 1984 suggests that this migration occurs at colder temperatures than for other species.

Northern pike

Northern pike are scarce in the Susitna River with only five fish being captured since 1981.[1] Since all of the fish have been captured between RM's 22.4 and 36.3, including Yentna fishwheels (RM 28.5, TRM 4.0), it is most probable that these fish have emigrated from the Yentna River

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1 The reference to the Susitna River includes only where fish have been collected for the past four years. Studies have been conducted at TRM 4.0 Yentna River but no further upriver than that

drainage. Northern pike populations in the Yentna River system, particularly around Skwentna, has increased dramatically in the last decade (Kelly Hepler, pers. comm.). These fish are believed to have been originally illegally stocked (Stan Kubik, pers. comm.).

Threespine stickleback

Populations of threespine stickleback appear to be very variable in the Susitna River. In 1981, large numbers of Age 3 stickleback were captured throughout the lower reach above RM 10.1. Although limited sampling was done in 1982, relatively few threespine sticklebacks (mostly Age I) were captured. Prior to the 1984 season, we theorized that catches would be high for threespine stickleback if the offspring of the 1981 spawners returned in 1984 as Age 3 fish. However, there was no large increase in Age 3 stickleback catches in 1984. Over 95% of the 1984 catch was Age I fish. It is not known what has caused the decrease in threespine stickleback numbers.

Capture data in both 1981 and 1982 suggests that threespine stickleback are anadromous and an upriver spring migration begins from the estuary in late May (ADF&G 1981b, 1983b).

Ninespine stickleback

Catch data from 1981-84 reflects the scarcity of this species in the lower river. In 1984, a small concentration of ninespine sticklebacks were captured in a low oxygen and heavily vegetated slough in the lower

Susitna at RM 57.2. In 1981, only two fish were captured with both captures occurring in the Deshka River (unpublished data).

Arctic lamprey

Arctic lamprey have been found to be much more abundant in the lower river than the middle river. Most Arctic lampreys have been captured in muskeg or shallow lake draining tributaries such as Birch Creek or Deshka River.

Arctic lamprey populations can be anadromous or resident (Morrow 1980). Both forms have been reported to be parasitic, but the more blunt teeth found in the freshwater form suggests that it is nonparasitic. McPhail and Lindsey (1970) report that while the largest Alaskan Arctic lamprey found is 411 mm, most adults of the nonparasitic form rarely exceeds 180 mm. In four years, only 16 adults over 180 mm have been captured. One fish captured in 1984 at the Deshka River may have been a Pacific lamprey. It measured approximately 60.0 centimeters (cm) in length and 9.0 cm in diameter. Other adults captured have been smaller in length and much less in diameter.

4.2 Middle Susitna River

4.2.1 Rainbow trout

In 1984, our knowledge of the seasonal distribution of rainbow trout in the middle river was greatly increased. Primary sampling emphasis was placed on radio tagging fish earlier in the year, May-June, to learn more about the timing and locations of spawning. Emphasis was also placed on tagging fish from the upper section of the middle river: Portage Creek, Indian River and Fourth of July Creek. Previously few rainbow trout have been captured early in the season, however, 18 fish were successfully tagged in 1984 before June 16 of which 14 were pre-spawners. Several pre-spawners from a school of 30 probable spawners were captured in Portage Creek a river which was previously believed to harbor few rainbow trout (Sundet and Wenger 1984). Previous success at capturing rainbow trout in Portage Creek may have failed because most of the adults move up into the creek before sampling normally occurs (after ice-out in the mainstem). Since sampling was done during this time from TRM 0.0 to TRM 11.6 and only these fish were observed or captured, it is highly possible that these fish represented the majority of spawning rainbow trout in Portage Creek. Four tagged fish apparently spawned at TRM 2.3 and another 0.5 miles up the small side tributary which enters at TRM 2.3 during early June 1984 (Figures 9). Movements of other pre-spawning radio tagged fish shows spawning also occurs at TRM 5.1 and at the same time (Figure 10).

Other pre-spawning radio tagged rainbow trout show that a similar timing of spawning occurs in Fourth of July Creek at TRM 0.7 and TRM 0.8 in a side tributary which enters at TRM 0.7 of Fourth of July Creek and probably at Little Portage Creek during the same period as those in Portage Creek (Figure 6; Sundet and Wenger 1984; Figures 11 and 5).

Water surface temperatures correlated to movement of four radio tagged rainbow trout into Fourth of July Creek in 1984 shows spawning rainbow trout move into that tributary in late May when temperatures are 6.7°C to 8.5°C (Figure 13). Slightly cooler temperatures (2.8°C) in this tributary was observed in 1983 during the immigration (Mark Wenger, pers. comm.).

Both TRM 4.3 and TRM 5.1 of Portage Creek, and TRM 0.7 of Fourth of July Creek are similar in all three have an outlet from a lake flowing into it. It is suspected that rainbows in both Portage Creek and Fourth of July Creek use the confluences of the lake outlets to spawn at because of the outlets warmer water temperatures. During the first week of June 1984, the mainstem of both Fourth of July Creek and Portage Creek were approximately 8°C, while the outlets at TRM 0.7 of Fourth of July and TRM 2.3 of Portage Creek were 12°C. Little Portage Creek is also influenced by lakes, however, no temperatures have been taken at this creek in June.

Follow-up studies in 1984 on the lakes which flow into Fourth of July Creek (Figure 2) and Portage Creek at TRM 2.3 (Figure 3) showed that they were abundant with rainbow trout. Since few juvenile (≤200mm) rainbow trout have been captured in Portage Creek over the past four years, it is suspected that the lake which flows into Portage Creek at TRM 2.3 acts as a nursery. No sampling was done in the lakes which outlet at TRM 5.1, but a similar phenomenon probably occurs there.

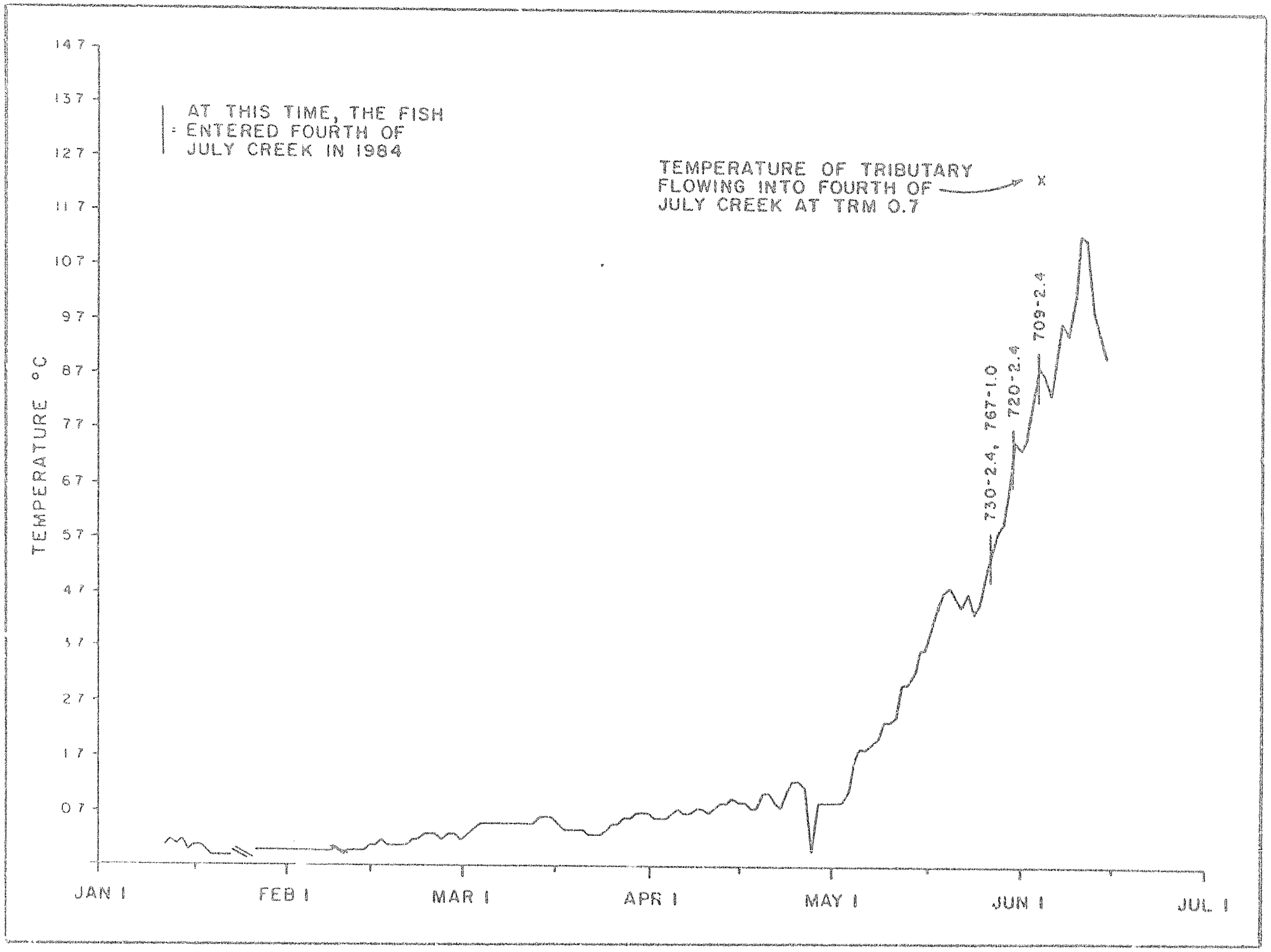

Figure 13. Mean surface water temperatures in Fourth of July Creek correlated to four spawning radio tagged rainbow trout's movement from the Susitna River into Fourth of July Creek, 1984.

Although many juveniles have been captured in Fourth of July Creek, it is suspected that the lakes which outlet to this tributary contribute heavily to the rainbow trout population in Fourth of July Creek below TRM 1.8. Support for this hypothesis is provided by: (1) little spawning gravel has been found in Fourth of July Creek between TRM 0.0 and TRM 1.8, (2) several small adult rainbow trout were gill netted above the barrier at TRM 3.5 in 1984 and (3) better scale analysis of rainbow trout in 1984 showed that many fish captured below TRM 1.8 of Fourth of July Creek had the same stunting scale patterns as those captured in lakes at its headwaters. Scale analysis of mainstem Fourth of July Creek fish also showed they were usually the smaller sized fish in each age class compared to other middle river stocks. For example, of 39 Age 5 fish, five fish from Fourth of July Creek were the smallest.

While spawning has been found to occur in both Fourth of July Creek and Portage Creek, little spawning evidence has been documented in Indian River. Only one pre-spawning radio tagged rainbow is believed to have spawned in Indian River (Fish 757-1.1 in Figure 8). Other pre-spawners captured at Indian River have moved elsewhere to spawn. A juvenile salmon crew captured over 30,000 juvenile salmon in Indian River during the open-water season of 1984 and only one juvenile rainbow trout. The apparent low success of rainbow trout spawning in Indian River may be due to no acceptable passage for rainbow trout from Miami Lake or other lakes draining into Indian River.

The overall low number of juveniles found in the middle river infers that either egg or juvenile survival is extremely low. One reason for this low survival may be the cold temperatures of these tributaries.

After spawning in early to mid-June, fish in different systems have been found to act differently for the rest of the summer. In Fourth of July Creek most fish stay between TRM 0.4 and TRM 1.8. However, a number of fish have been found to move out and into other areas as the mouth, nearby sloughs or into Indian River (Figure 7, Sundet and Wenger 1984). In Portage Creek, most radio tagged rainbow trout move further upriver in that tributary after spawning (Figures 9 and 10).

Fish tagged in 1984 showed a similar summer association with spawning salmon as did fish tagged in 1983, many of which were found close to spawning chum and pink salmon (Sundet and Wenger 1984). More fish were tagged earlier in 1984 than in 1983 and their movement coincides with the earlier adult chinook salmon movement. This movement was most evident at Indian River and Portage Creek which have the greatest number of spawning chinook salmon above Talkeetna; escapement in 1984 was over 1,500 chinook salmon in each river (Barrett et al. 1985). As in 1983, this close association with spawning salmon is probably due to rainbow trout utilizing salmon eggs as a primary summer food source. This was substantiated during a late June 1984 helicopter survey. At this time, fish were pinpointed to an exact location in a pool or riffle and in all cases, radio tagged fish were within 100 feet of adult chinook salmon. Most rainbow trout found in Portage Creek and Indian River, remain in the tributaries through peak salmon spawning periods Peak chinook spawning is in late July and peak pink and chum spawning is in late August. Apparently, however, rainbow trout do not rely on coho salmon eggs as a food source because most fish have moved out before coho peak spawning. Peak coho spawning is in late September.

By October 6 in both 1983 and 1984, all radio tagged fish outmigrated tributaries. Ground surveys conducted in early October 1984 between TRM's 0.1 and 1.0 of Fourth of July Creek also support radio tagged fish outmigration findings. At this time, no rainbow trout were captured and only one was observed.

Water surface temperatures and relative depths were correlated to the outmigration of seven radio tagged rainbow trout from Portage Creek to the mainstem in 1984. Water depths appeared to influence the outmigration more than temperature. A late season flood between August 20 and August 30 apparently triggered the final outmigration of six fish (Figure 14). Downstream movements had begun much earlier for most of the fish with the maximum upriver locations for four fish being on July 6. The slower downriver movement between then and late August is probably due to other reasons such as food supply more than temperature or water depths.

Winter monitoring movement of radio tagged fish over three years show nearly all rainbow trout move slightly downstream (0.1-4.0 miles) after October before holding (ADF&G 1983b, 1983c; Sundet and Wenger 1984; Figures 4 and 5). This downstream movement is believed to occur because they are searching for acceptable overwintering areas. During all three years, however, several rainbow trout have remained all winter near the tributary at which they were tagged. From 1984 taggings, it appears

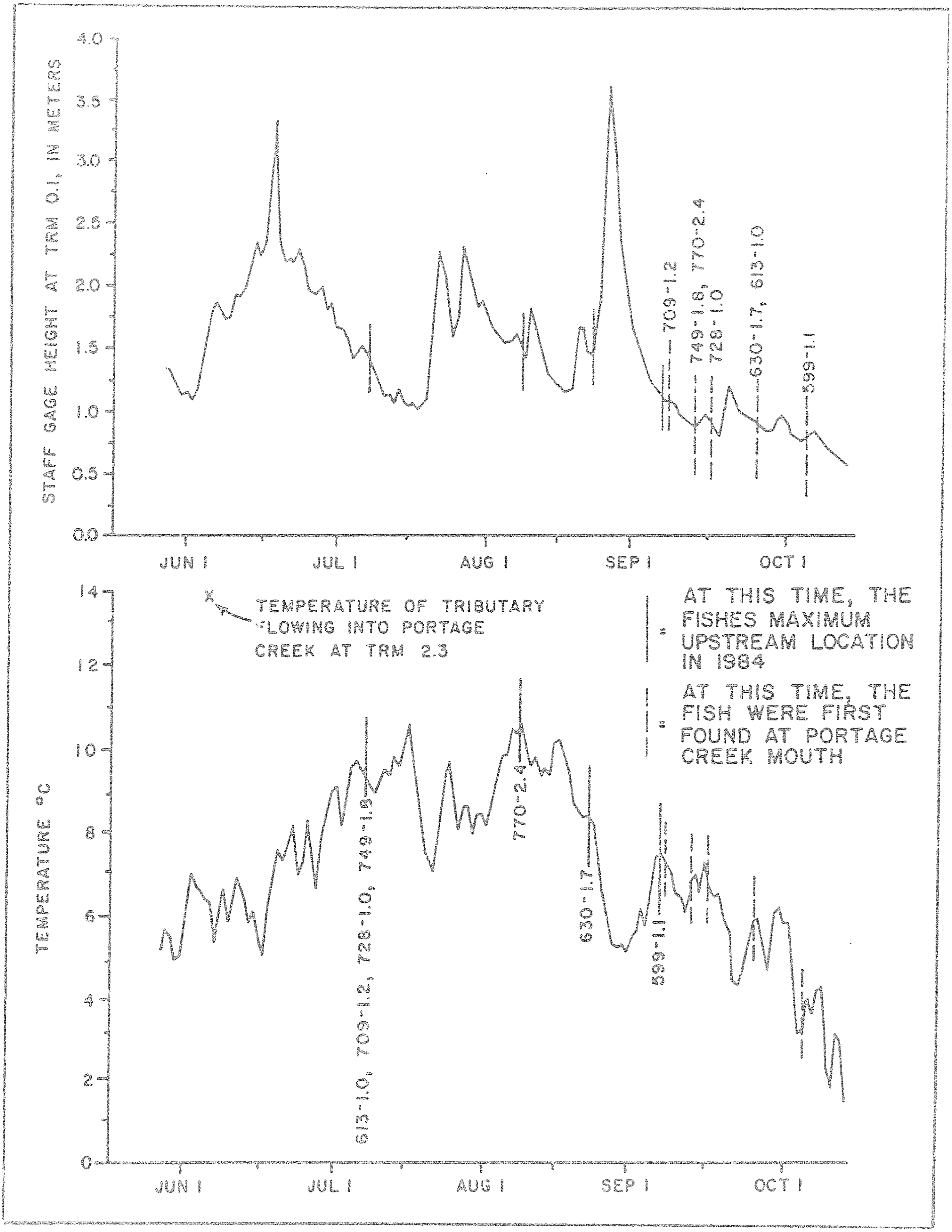

Figure 14. Mean surface water temperatures and relative depths in Portage Creek correlated to seven radio tagged rainbow trout's maximum movement and their outmigration into the mainstem Susitna River, 1984.

that fish from Portage Creek may overwinter near that tributary mouth.

During winter sampling in the lower river in 1981-82, although none of the radio tagged fish were captured, a high catch per unit effort was recorded for other rainbow trout in the vicinities of the tagged fish (ADF&G 1983b). Due to this reason, it is suspected that rainbow trout concentrate in small numbers and use specific areas of the lower mainstem Susitna for overwintering. A similiar phenomenon probably occurs in the middle river.

Winter sampling at radio tagged fish relocations have provided little information to characterize rainbow trout overwintering areas. This is mostly due to the difficulty in winter sampling. In winter 1983-84 most of the river was open where radio tagged fish were found. Habitat data collected at these areas has varied except for conductivity. In all cases where radio tagged fish have been found in winter, the conductivity was relatively high (above 125.0 uhos/cm) indicating that the areas they seek out are influenced by groundwater. Radio tagged rainbow trout also appear to prefer areas of moderate water velocities. Limited data from winter 1982-83 shows similar conclusions (ADF&G 1983c).

Several radio tagged rainbow trout known to be alive in September and October, have been found dead when sampling in January or February. This supports the theory that there is a heavy overwintering mortality. Needham and Jones (1959) and Needham and Slater (1945) report that overwintering mortalities are often high due to physical catastrophes such as dewatering, collapsed snow banks, and anchor ice formation.

Radio tagged fish data reflects the high mortality rate for rainbow trout. In 1983, middle river rainbow trout mortality rate was only 33.3% and in 1984 was 42.7%.[1] In three years, sport fishermen have reported catching two radio tagged fish, three have been found eaten by predators, and one died after being trapped in a side channel which dewatered during fall. Other mortalities include one attributable to post-spawning die-off and three to overwintering.

4.2.2 Burbot

Catch data from 1981-83 shows burbot are much less abundant in the middle river than the lower river (ADF&G 1981b, 1983b, 1983c). Although food and rearing habitat could possibly be limiting factors in the numbers of burbot found between the Chulitna River confluence and Devil Canyon, biologists observed in winter 1983-84 another reason why there may be is less burbot in this reach. During aerial tracking surveys for radio tagged fish in January, a large section of the river from RM 123.0 to RM 150.0 was noticed to have remained open. It was observed that approximately half of the area that was open had anchor ice on the substrate and occasionally the anchor ice would free itself and float to the top. Since burbot spawn from mid-January to early February in the Susitna River, the formation and movement of anchor ice could disrupt the success of spawning. With several poor years of spawning and given the fact most radio tagged burbot have not migrated far or frequently, no new individuals would be recruited to the existing population in

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[1] The higher survival rate is somewhat biased because in 1984 we sought out more large adults to radio tag. Therefore the survival rate is probably closer to 1983 findings.

this area.

Although spawning is probably limited in the middle river, one radio tagged fish monitored overwinter in 1983-84 stayed near Slough 10 indicating that some spawning may occur there. The capture of juveniles near Slough 9 in 1982, suggests spawning may also occur there (ADF&G 1983b).

4.2.3 Arctic grayling

The general distribution and abundance of Arctic grayling in the middle Susitna River in 1984 was found to be similar to 1981-83 findings. Population estimates using multiple-year data show Arctic grayling are the third most abundant resident fish species in the middle river (other than sculpins and sticklebacks). During all four years, Arctic grayling have been found most numerous at Indian River (RM 138.6) and Portage Creek (RM 148.8). High catches at Whiskers Creek Slough (RM 101.2), Lane Creek (RM 113.6), Fourth of July Creek (RM 131.1), and a mainstem site at RM 150.1 are recorded only in May, June or September. Catches at all sites over all four years have generally been the highest in the spring and fall.

Until 1984, our knowledge of Arctic grayling immigration and outmigration from tributaries to the mainstem was based on tag-and-recapture and catch per unit effort data. These data show Arctic grayling move into tributaries in May and early June to spawn, then begin to outmigrate in mid-September (ADF&G 1981b, 1983b; Sundet and Wenger 1984). In 1984, the monitoring of only one pre-spawning radio tagged fish added considerably to our knowledge of Arctic grayling movement and spawning. This fish ascended Portage Creek two days after being tagged in the mainstem on May 22. Other studies done in 1984 also shows the spring immigration to Portage Creek occurs at this time. No fish were observed or captured between TRM 1.5 and TRM 3.2 from May 9 to 25, but surveys conducted later in the upper reaches of Portage Creek showed Arctic grayling were found upriver to TRM 11.6. During early to mid-June, catch rates became higher in the upper reaches indicating Arctic grayling were ascending Portage Creek.

The radio tagged fish apparently spawned at TRM 0.4 between May 22 and 30. A similar timing of spawning was shown by 82 other Arctic grayling in 1984 which were captured and examined for sexual conditions above RM 125.0. Other fish examined in 1984 below RM 125.0 shows timing of spawning there is about seven to ten days earlier than above RM 125.0 (Appendix Figure C-7). The difference in timing of spawning between these sections is probably due to tributaries warmer water temperatures below RM 125.0 than above. A similar timing of spawning occurred in 1983 (Sundet and Wenger 1984).

Mean surface water temperatures in Portage Creek during late May 1984 when Arctic grayling began to immigrate and spawn were slightly higher than those reported elsewhere in Alaska. Portage Creek water temperatures were 5.1°C on May 26 while Tack (1980, 1973) reports the spawning run begins when water temperatures are 1°C and spawning occurs at 4°C in Interior Alaska.

Catch and recapture data from 1981-84 as well as the radio tagged fish movement data, shows most large adult Arctic grayling remain in tributaries through early September. Smaller adults and juvenile Arctic grayling have been captured at tributary mouths during the summer, probably because they were displaced in the upper reaches as a result of territorialism (ADF&G 1983b). Floy anchor recaptures of tagged fish shows adults move little during the summer.

It was speculated in 1983 that some adult Arctic grayling may overwinter in Portage Creek, however, evidence from the radio tagged fish suggests that hypothesis is not true. After early August, the fish began to move rapidly downstream along with radio tagged rainbow trout. Unfortunately, the tag's battery expired before the Arctic grayling reached the mainstem. Radio tagged rainbow trout which were outmigrating at the same time were all found to be out of Portage Creek and in the mainstem by October 6. The outmigration of the radio tagged Arctic grayling, as well as radio tagged rainbow trout, was apparently triggered by a late season flood between August 20 to 30 (Figure 14).

Little information except what can be speculated from tag recapture data has been obtained on the winter distribution of Arctic grayling in the mainstem. Several tag recoveries in 1983 and 1984 from fish tagged during those years suggest some Arctic grayling may overwinter far downriver in the mainstem from their summer rearing tributaries. Several fish tagged at Portage Creek in late May to July have been recovered 10 to 20 miles downriver. Three fish were recovered in late May 1984 25 to 37 miles downriver from where they were tagged in 1982 or

1983. It is possible these three fish were recovered before they returned upriver or that they had simply relocated during the interim. Most fish tagged at Portage Creek or nearby, however, indicate they may overwinter between RM 146.0 to RM 148.0 or at RM 150.1. Boat electrofishing, gill net, and hoop net catch rates were very high at these areas during mid-late May and at RM 146.0 to RM 148.0 in late September 1983 and 1984.

In 1984, two Arctic grayling were recovered which were tagged in or above Devil Canyon. While no recoveries have been made above the canyon from those tagged below, this is the first evidence that fish populations can successfully migrate downriver through Devil Canyon.

4.2.4 Round whitefish

Population estimates made in 1984 using multiple-year data show that round whitefish are the most abundant resident fish species in the middle river. Catch data from 1982-84 show the highest concentrations of round whitefish occurs between RM 132.6 and RM 150.1, and round whitefish are much more abundant in the middle river than in the lower river.

Pooled CPUE rates based on boat electrofishing data from 1982-83 shows that round whitefish CPUE's at tributary or slough sites are much higher than at mainstem sites. Relatively high CPUE's at mainstem sites, however, are in June and September of those years and also overall in 1984. Juvenile round whitefish captured at JAHS sites have been found more often at turbid mainstem and slough sites than at tributary sites (Suchanek et al. 1984). Juvenile round whitefish prefer these areas because of lower water velocities and higher turbidities which they use as cover.

While a definite fall downriver movement was shown by recaptured round whitefish in 1981 and 1982, only a slight downstream movement throughout the summer was shown by recovered fish in 1983 and 1984.

Extremely sexually ripe round whitefish have been captured in the mainstem Susitna or at the mouths of several middle river tributaries each year from 1981-84 during early October. This suggests that round whitefish extensively use mainstem influenced areas for spawning. Peak spawning probably occurs from mid to late October. Several areas have been found since 1981 where round whitefish specifically spawn at such as the mouths of Lane Creek, Indian River, and Portage Creek and in the mainstem at RM 147.0. Other round whitefish close to spawning have also been found scattered throughout the middle river in pairs or small groups.

While it is unknown where adult round whitefish overwinter, early spring catch and recapture data suggests they may overwinter near their summer rearing areas which is primarily in the mainstem above RM 132.0 (ADF&G 1983b; Sundet and Wenger 1984).

4.2.5 Humpback whitefish

Catch data from 1981-84 shows humpback whitefish are relatively scarce in the middle river. Most humpback whitefish in the middle river probably overwinter in that reach. However, increased outmigrant trap catches of humpback whitefish at RM 103.0 in the fall and high growth rates shown in scales of several adults suggests that some humpback whitefish may outmigrate from the middle river to overwinter in the estuary (Sundet and Wenger 1984).

4.2.6 Longnose suckers

Catch data shows little differences in distribution or abundance of longnose suckers between 1982, 1983 and 1984. Recapture data from these years show longnose suckers generally move little in summer, but a spring upriver and a fall downriver migration may occur. Several 1984 recaptured fish also shows some fish move upriver during June through August.

4.2.7 Other species

Dolly Varden

Dolly Varden have been found mostly at Lane Creek, Indian River, and Portage Creek. Catch data suggests Dolly Varden move into tributaries before late June (ADF&G 1983b, 1984b). It is believed that they stay in the tributaries through October at which time they spawn and then outmigrate to overwinter in the mainstem.

Dwarf populations of Dolly Varden are found in the upper reaches of several tributaries (ADF&G 1983b). These populations are believed to remain in these tributaries year-round.

Lake trout

Two populations of lake trout were found in the middle river drainage during lake surveys for rainbow trout in 1984. While Miami Lake had been known to have lake trout in it, no information was known on a lake feeding Fourth of July Creek (Lake B in Figure 2). Although only juveniles were captured, Lake B may harbor a sizeable population of adult lake trout. A steep shoreline and no boat prevented proper setting of gillnets in this lake. No depths were measured, however, the lake was extremely clear and appeared to be over 50 feet deep.

Threespine stickleback

Threespine stickleback are less numerous in the middle reach of the Susitna River than the lower reach. However, they have been caught in relatively large numbers between the Chulitna River confluence and RM 120.0 (ADF&G 1981b).

5.0 CONTRIBUTORS

Data was primarily collected by Richard Sundet and Stuart Pechek. Data were also collected by fishwheel, outmigrant, and JAHS crews.

Dana Schmidt provided the study design and assisted with making population estimates. Drew Crawford edited the draft.

Data processing was done by Allen Bingham, Alice Freeman, Kathrin Zosel, Donna Buchholz, and Dan Sharp.

Drafting was done by Carol Hepler and Roxanne Petersen.

Typing was done by Skeers Word Processing.

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We would like to express our gratitude to all the people and organizations that provided information or assistance to the Resident Fish Study during the past years. We would also like to thank Leon Dick and David James for describing resident fish catch rates on the Deshka River and east side tributaries, respectively.

We are especially grateful to Carl Burger (USFWS) for his technical expertise and advice on radio telemetry investigations. We would also like to thank Carl for providing photographs showing the implantation of radio tags into rainbow trout.

7.0 LITERATURE CITED

Alaska Department of Fish and Game (ADF&G). 1981a. Aquatic studies procedures manual. Phase 1 (1980-81). Subtask 7.10. Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Anchorage, Alaska.

______. 1981b. Phase 1 final draft report. Subtask 7.10. Resident fish investigation on the Lower Susitna River (November 1980-October 1981). Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Anchorage, Alaska.

______. 1981c. Phase 1 final draft report. Subtask 7.10. Adult anadromous fisheries project. Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Anchorage, Alaska.

______. 1983a. Aquatic studies procedures manual. Phase II (1982-83). Subtask 7.10. Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Anchorage, Alaska.

______. 1983b. Susitna Hydro aquatic studies phase II basic data report. Volume 3 (1 of 2). Resident and juvenile anadromous fish studies on the Susitna River below Devil Canyon, 1982. Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Anchorage, Alaska.

______. 1983c. Susitna Hydro aquatic studies phase II data report. Winter aquatic studies (October 1982 - May 1983). Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Anchorage, Alaska.

______. 1983d. Use of major habitat types by juvenile salmon and resident species. Appendix G in Susitna Hydro aquatic studies Phase II report. Synopsis of the 1982 aquatic studies and analysis of fish and habitat relationships (2 of 2: Appendix A-K). Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Anchorage, Alaska.

______. 1983e. Influence of habitat parameters on distribution and relative abundance of juvenile salmon and resident species. Appendix F in Susitna Hydro aquatic studies Phase II report. Synopsis of the 1982 aquatic studies and analysis of fish and habitat relationships (2 parts). Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Anchorage, Alaska.

______. 1983f. Habitat location description and photos. Appendix F in Susitna Hydro aquatic studies phase II basic data report. Volume 4 (3 of 3: Appendices D-J). Aquatic habitat and instream flow studies, 1982. Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Anchorage, Alaska.

______. 1984. Susitna Hydro aquatic studies (May 1983 - June 1984) procedures manual (1 of 2). Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Anchorage, Alaska.

Barrett, B.M., F.M. Thompson, and S.N. Wick. 1985. Adult anadromous fish investigations: May - October 1984. Alaska Department of Fish and Game Susitna Hydro Aquatic studies Report No. 1. Prepared for Alaska Power Authority. Anchorage, Alaska.

Everhart, W.H., A.W. Eupper, and W.D. Youngs. 1975. Principles of fishery science. Cornell University Press. London, United Kingdom.

McPhail, J.D., and C.C. Lindsey. 1970. Freshwater fishes of north-western Canada and Alaska. Bulletin of the Fisheries Research Board of Canada 173:1-381.

Morrow, J.E. 1980. The freshwater fishes of Alaska. Alaska Northwest Publishing Company, Anchorage, Alaska.

Needham, P.R., and D.W. Slater. 1945. Seasonal changes in growth, mortality and condition of rainbow trout following planting. Transactions of the American Fisheries Society. 73:117-124.

Needham, P.R., and A.C. Jones. 1959. Flow, temperature, solar radiation, and ice in relation to activities of fishes in Sagehen Creek, California. Ecology 40(3):465-474.

R&M Consultants. 1982. Tributary stability analysis report. Susitna Hydroelectric Project. Prepared for the Alaska Power Authority. R&M Consultants. Anchorage, Alaska.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada. Bulletin 191. Ottawa, Canada.

Suchanek, P.M., R.L. Sundet, and M.N. Wenger. 1984. Resident fish habitat studies. Part 5 in Schmidt, D.C., S.S. Hale, , D.L. Crawford, and P.M. Suchanek (eds.). 1984. Resident and juvenile anadromous fish investigations (May - October 1983). Susitna Hydro Aquatic Studies. Report No. 2. Alaska Department of Fish and Game. Anchorage, Alaska.

Sundet, R.L., and M.N. Wenger. 1984. Resident fish distribution and population dynamics in the Susitna River below Devil Canyon. Part 5 in Schmidt, D.C., S.S. Hale, D.L. Crawford, and P.M. Suchanek (eds.). 1984. Resident and juvenile anadromous fish investigations (May - October 1983). Susitna Hydro Aquatic Studies. Report No. 2. Alaska Department of Fish and Game. Anchorage, Alaska.

Scott, W.B., and E.J. Crossman. 1973. Freshwater fishes of Canada. Bulletin of the Fisheries Research Board of Canada 184. Ottawa, Canada.

Tack, S.L. 1973. Distribution, abundance, and natural history of the Arctic grayling in the Tanana River drainage. Alaska Dept. of Fish and Game, Federal Aid in Fish Restoration, Annual Report of progress, 1972-1973, Project F-9-5, 14(R-I):34 p.

_____. 1980. Migrations and distribution of Arctic grayling in interior and Arctic Alaska. Alaska Dept. of Fish and Game, Federal Aid in Fish Restoration, Annual Report of Progress, 1979-1980, Project F-9-12, 21(R-I):32 p.

Ziebell, C.D. 1973. Ultrasonic transmitters for tracking channel catfish. The Progressive Fish Culturist. 35(1):28-31.

APPENDIX A

Floy Anchor Tag Retention Rates

METHODS

The external Floy anchor tag (model FD-67) has been used to tag resident fish since January 1981 to determine seasonal and yearly movements. The dimensions of the tag and tagging procedure are explained in the 1981 procedures manual (ADF&G 1981a). Disc dangler tags were used to tag burbot for several months during 1981 and spring 1982.

Floy anchor tag retention rates were evaluated for Arctic grayling, round whitefish, and longnose suckers by comparing the number of fish with tag scars to the total number of fish with tag scars and Floy anchor tags of that species recaptured in 1983.[1] By subtracting this ratio from 1.00, Floy anchor tag retention rates were determined. Tag retention rates for rainbow trout were not determined because the smaller scales of this species regenerate rapidly and make it difficult to detect tag scars. In 1983, no captured longnose suckers showed a tag scar.

RESULTS

The Floy anchor tag retention rate for Arctic grayling during 1984 was 75.9% with 15 of 58 recaptures showing a tag scar. The 1984 tag retention rates for round whitefish and longnose suckers were 83.7% and 92.9% respectively, with 15 of 92 round whitefish and one of 14 longnose suckers showing a tag scar.

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[1] Only those fish recaptured by a resident study crew were used. Other groups such as sport fishermen or fishwheel crews did not look for scarred fish.

DISCUSSION

We believe that improper tag placement has been the primary cause of tag loss in our studies. In 1982, tags were injected into the dorsal musculature. After 1982, tags were anchored at the base of the dorsal fin through the interneural rays. We have noticed increased tag retention rates each year thereafter. Tag retention rates for Arctic grayling increased from 69.4% in 1983 to 75.9% in 1984. Tag retention rates for round whitefish showed similar improvement, increasing from 77.5% in 1983 to 83.7% in 1984.

APPENDIX B

Radio Tagged Fish Capture, Biological,

and Winter Habitat Data

Appendix Table B-1. Summary of tagging data for radio tagged rainbow trout captured on the Susitna River between the Chulitna River confluence and Devil Canyon, May to July 1984.

Radio Frequency/ Fork Lengths (mm)	Type of Implant: Internal or External	Floy Tag Number	Age/ Sex	Spawning Condition	Method Captured	Location Captured and Released	River Mile	Date Captured	Date Released
599-1.1/485	Internal	17457	-/M	pre-spawning	HL	Portage Creek	TRM 2.3	6/1	6/1
598-1.6/410	Internal	---	6/M	pre-spawning	HL	Tributary Mouth at TRM 0.7 of Fourth of July Creek	TRM 0.5	6/5	6/5
613-1.0/475	Internal	17453	8/M	pre-spawning	HL	Portage Creek	TRM 2.3	6/1	6/1
608-1.7/391 (recap was 670-1.4)	Internal	11948	8/F	pre-spawning	EF	Lane Creek	113.6	5/17	5/18
608-1.9/400	Internal	17757	6/F	post-spawned	HL	Fourth of July Cr.	TRM 0.4	6/27	6/27
620-1.2/390	Internal	17492	6/M	non-spawner	EF	Portage Creek	148.8	6/4	6/4
630-1.0/450	Internal	17761	-/-	non-spawner	HL	Fourth of July Cr.	TRM 0.8	6/27	6/27
630-1.7/495	Internal	17753	-/M	pre-spawning	HL	Portage Creek	TRM 5.1	6/20	6/20
659-1.2/435	Internal	12615	7/-	post-spawned	EF	Indian River	138.6	5/26	5/27
670-1.2/450	Internal	17456	-/F	pre-spawning	HL	Portage Creek	TRM 2.3	6/1	6/1
709-1.2/433	Internal	5825	6/F	pre-spawning	EF	Indian River	138.6	5/22	5/24
709-2.4/450	External	17598	-/F	pre-spawning	EF	Fourth of July Cr.	131.1	5/28	5/31
719-1.6/405	Internal	1243	6/-	--	EF	Indian River	138.6	7/23	7/23
720-2.4/400	External	5823	7/F	pre-spawning	HL	Fourth of July Cr.	131.1	5/23	5/24
721-1.0/392	Internal	5091	-/M	non-spawner	HL	Portage Creek	TRM 5.1	6/5	6/5

-- = not sexed or not aged
EF = Electrofishing
HL = Hook and Line
HN = Hoop net
TRM = Tributary River Mile

Appendix Table B-1 (Continued).

Radio Frequency Fork Lengths (mm)	Type of Implant: Internal or External	Floy Tag Number	Age/ Sex	Spawning Condition	Method Captured	Location Captured and Released	River Mile	Date Captured	Date Released
729-1.5/420	Internal	5107	7/-	--	EF	Whiskers Creek Slough	101.2	5/21	5/21
730-2.4/485	External	15464	-/M	pre-spawning	HL	Fourth of July Cr	131.1	5/18	5/18
740-1.4/425	Internal	5867	7/-	non-spawner	HN	Mainstem	136.7	6/5	6/5
749-1.8/418	Internal	5092	7/M	pre-spawning	HL	Portage Creek	2.3	6/5	6/5
757-1.1/424	Internal	5817	7/M	pre-spawning	EF	Indian River	138.6	5/22	5/24
760-2.4/400	External	16066	7/M	post-spawned	HL	Fourth of July Cr.	0.7	6/3	6/3
770-2.4/462	External	17454	8/F	pre-spawning	HL	Portage Creek	2.3	6/1	6/1
Total = 22 Fish									

-- = not sexed or not aged
EF = Electrofishing
HL = Hook and Line
HN = Hoop net
TRM = Tributary River Mile

Appendix Table B-2. Radio tagged rainbow trout habitat measurements taken at their relocations in January and February 1984. Fish were tagged in 1983.

Radio Frequency	Date	RM	Ice Open (0) Covered (c)	Fish Movement (in ft)	Depths (ft) Water	Ice	Slush	Velocity (fps)	Substrate	Water Quality Temp °C	DO mg/l	umhos/cm	pH
670-1.4	1/11	101.1	c	0.0	2.5	2.5	0.0	*1-2	rubble/cobble	--	--	--	--
	2/14	100.7	c	-50.0	5.7	2.5	0.0	2.5	rubble/cobble	+0.1	14.0	236.0	7.6
709-1.5	2/15	116.5	c	-10.0	3.0	2.0	0.0	1.5	rubble/cobble	-0.1	13.1	256.0	7.5
718-1.5	1/11	131.1	0	--	*4.0	0	0	--	rubble/cobble	+0.2	13.6	247.0	7.9
729-1.0[1]	2/16	64.8	c	0	1.5	2.5	3.0	0.0	cobble	--	--	--	--
729-1.3	2/15	111.4	c	-200.0	10.0	2.0	0.0	2.5	cobble	-0.1	13.0	212.0	7.5
767-1.5[1]	1/11	114.8	c	0	1.0	2.0	0.5	0	--	--	--	--	--
	2/15	114.5	c	0	2.0	2.0	0.5	0.5	--	--	--	--	--

[1] Fish believed dead
* Estimated measurement because meter did not work or too deep
-- No movement or no meas rements taken

APPENDIX C

Population and Biological Characteristics

A total of 6,941 resident fish of eleven species were measured for length on the Susitna River from May to October 1984. Appendix Table C-1 presents the range and means of fish measured and Appendix Figures C-1 to C-6 present length frequency compositions of six of these species.

Sexual maturities of four resident fish species were determined in 1984. Appendix Table C-2 presents lengths of fish examined for sexual condition and Appendix Figure C-7 illustrate the timing of spawning for two of these species: rainbow trout and Arctic grayling.

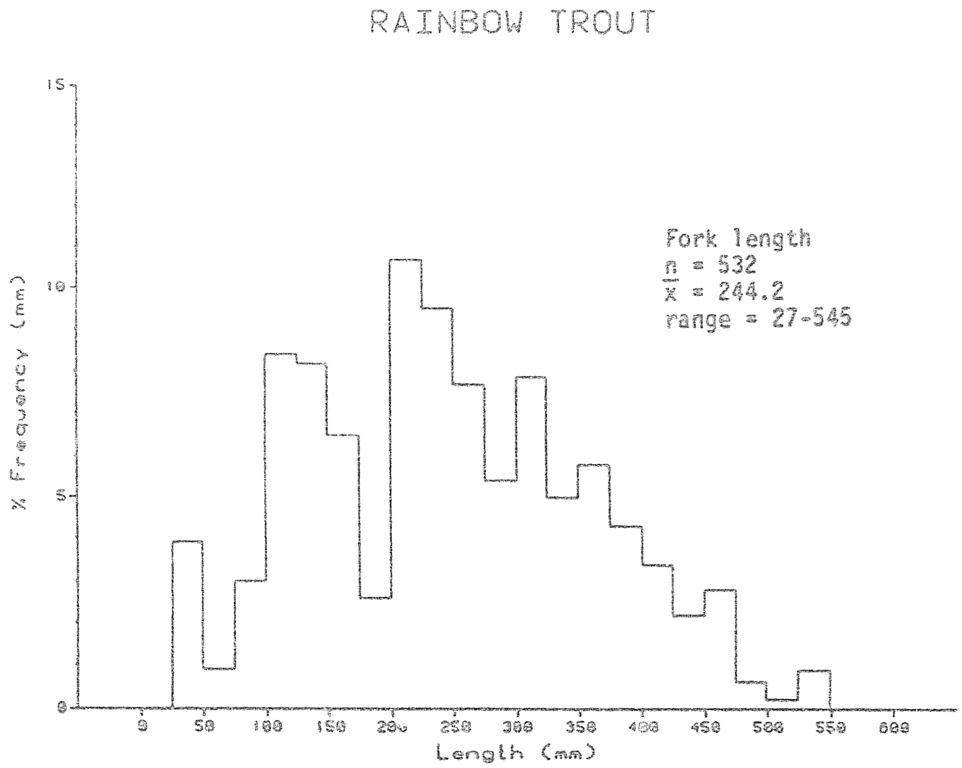
Ages were determined for spawners of three species in 1984 (Appendix Figures C-8 to C-10). Ages were also determined for spawning and non-spawning rainbow trout captured in lakes C and D at the headwaters of Fourth of July Creek (Figure C-11).

The ages of 147 rainbow trout captured on the Susitna River between the Chulitna River confluence and Devil Canyon in 1984 were determined by scale analysis. These rainbow trout ranged in age from Age 1 to Age 9. Ages 4 (17.0%), 5 (26.5%), 6 (23.1%), and 7 (20.4%) were sampled most often (Appendix Table C-3). The ages of thirty-five rainbow trout captured in lakes A, C, and D ranged from Age 2 to Age 7. In these lakes, ages 3 and 4 were sampled more frequently than others. A graphical representation of age-length data shows rainbow trout captured in the mainstem Susitna and its tributaries are approximately 60 mm larger at a given age class than fish captured in Lakes A, C, and D (Appendix Figure C-12).

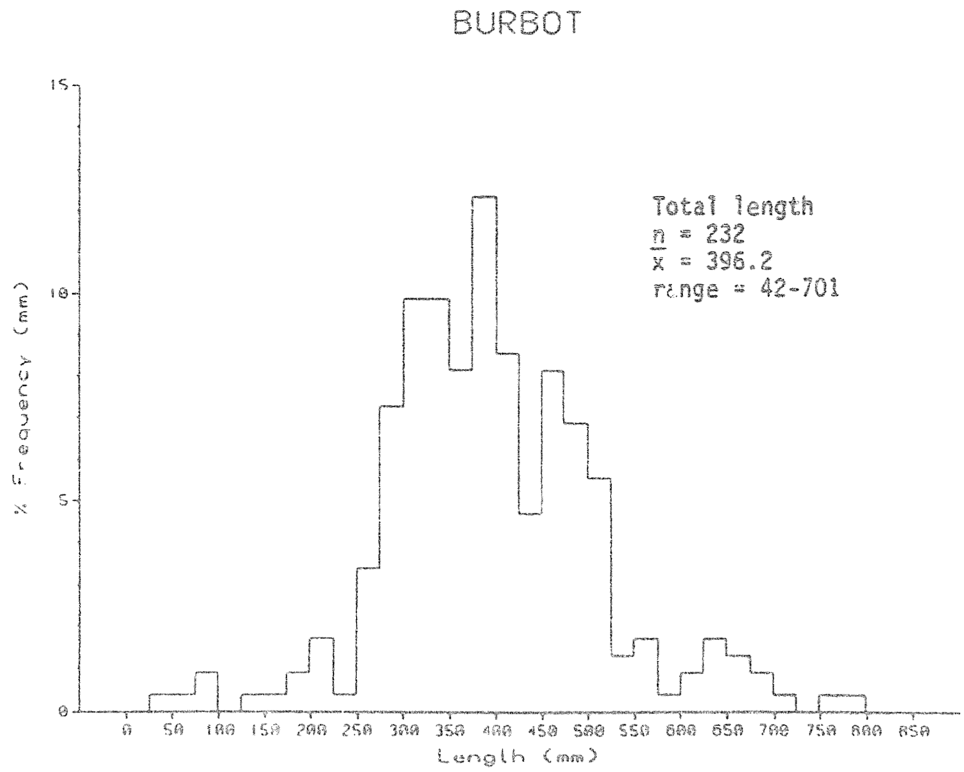
Appendix Table C-1. Length data for resident fish captured on the Susitna River, 1984.

Species	Sampling Period	n	Length (mm) Range	Mean
Rainbow Trout (FL)	Lower Susitna	105	77 - 530	281.9
	Middle Susitna	227	27 - 545	282.7
	Lakes in Middle Susitna	200	70 - 360	180.7
	Combined Total	532	27 - 545	244.2
Burbot (TL)	Lower Susitna	217	209 - 701	406.9
	Middle Susitna	15	42 - 475	241.2
	Combined Total	232	42 - 701	396.2
Arctic Grayling (FL)	Lower Susitna	197	89 - 392	251.2
	Middle Susitna	641	40 - 427	255.4
	Combined Total	838	40 - 427	254.5
Round Whitefish (FL)	Lower Susitna	301	40 - 469	222.8
	Middle Susitna	1729	20 - 410	140.8
	Combined Total	2030	20 - 469	153.0
Humpback Whitefish (FL)	Lower Susitna	348	30 - 510	286.2
	Middle Susitna	298	25 - 410	87.6
	Combined Total	646	25 - 510	194.2
Longnose Suckers (FL)	Lower Susitna	377	30 - 447	297.3
	Middle Susitna	490	24 - 392	148.8
	Combined Total	867	24 - 447	213.4
Dolly Varden (FL)	Lower Susitna	6	163 - 366	247.3
	Middle Susitna	16	119 - 457	249.5
	Lakes in Middle Susitna	20	92 - 190	125.9
	Combined Total	42	92 - 457	190.3
Lake Trout (FL)	Lakes in Middle Susitna	35	60 - 468	109.6
Threespine Stickleback (TL)	Lower Susitna	1271	20 - 90	28.8
	Middle Susitna	337	15 - 74	32.0
	Combined Total	1608	15 - 90	29.5
Northern Pike (FL)	Lower Susitna	3	83 - 713	433.7
Arctic Lamprey (TL)	Lower Susitna	21	113 - 162	134.7
	Middle Susitna	87	74 - 290	126.1
	Combined Total	108	74 - 290	127.8

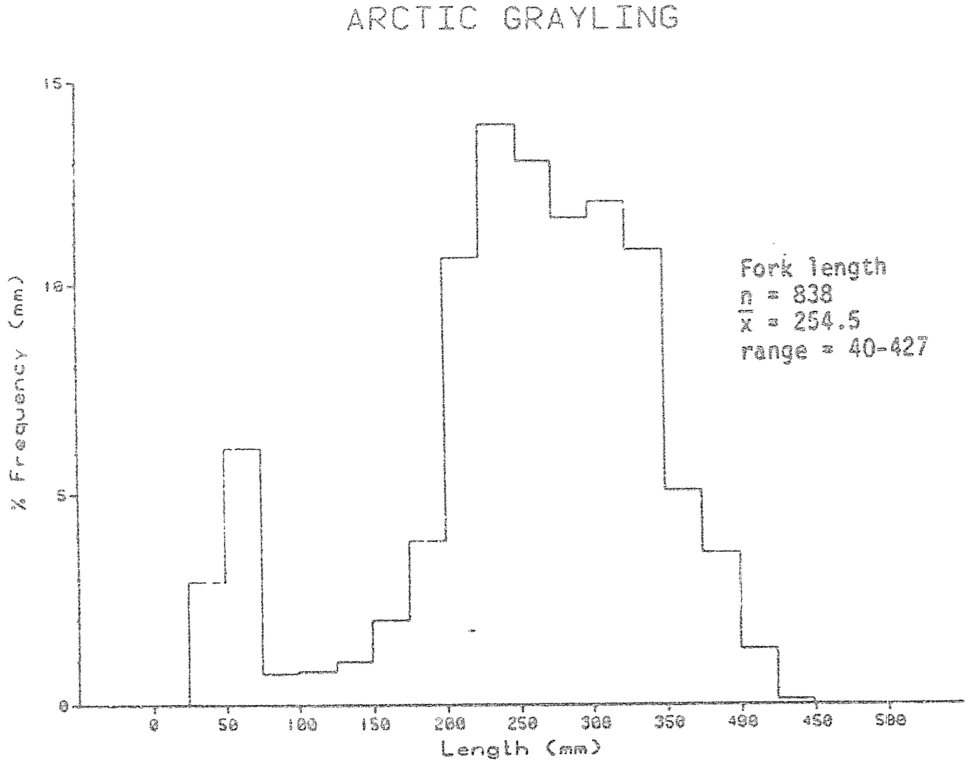
FL = Fork Length
TL = Total Length



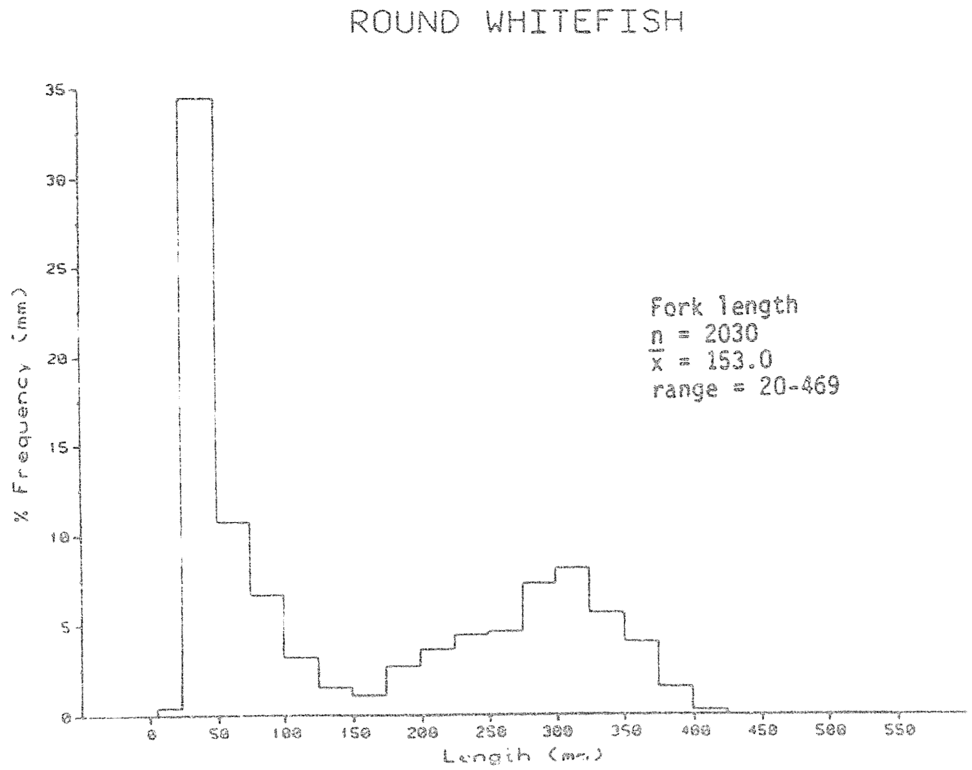
Appendix Figure C-1. Length frequency composition of rainbow trout captured in the Susitna River between Cook Inlet and Devil Canyon by all gear types, May to October 1984.



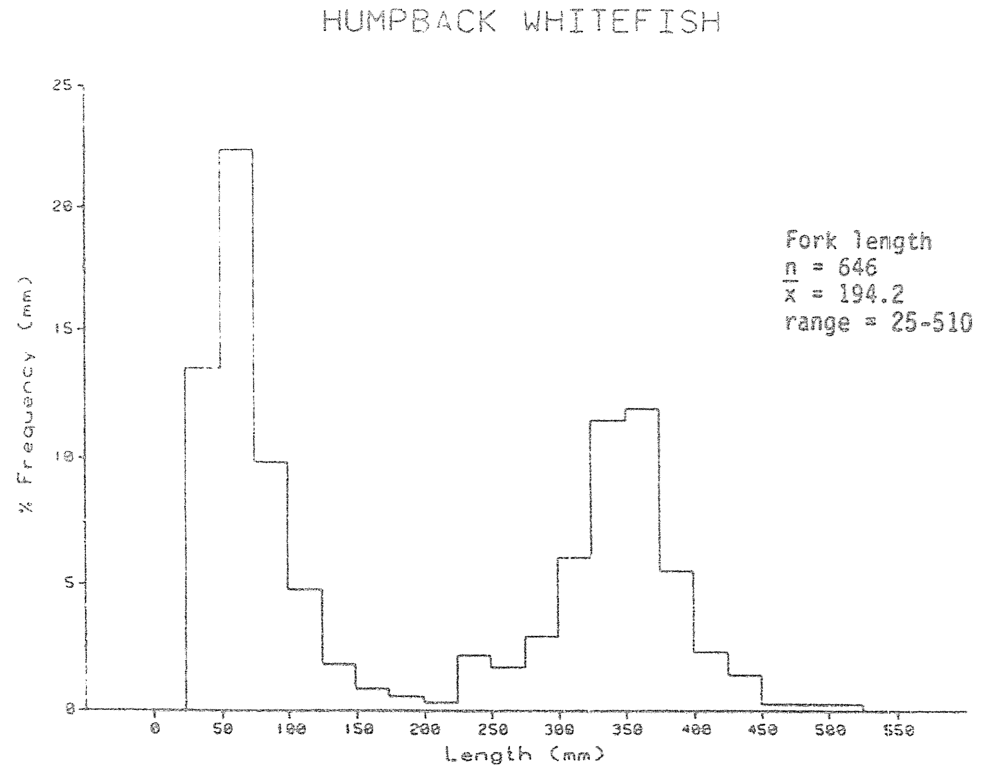
Appendix Figure C-2. Length frequency composition of burbot captured in the Susitna River between Cook Inlet and Devil Canyon by all gear types, May to October 1984.



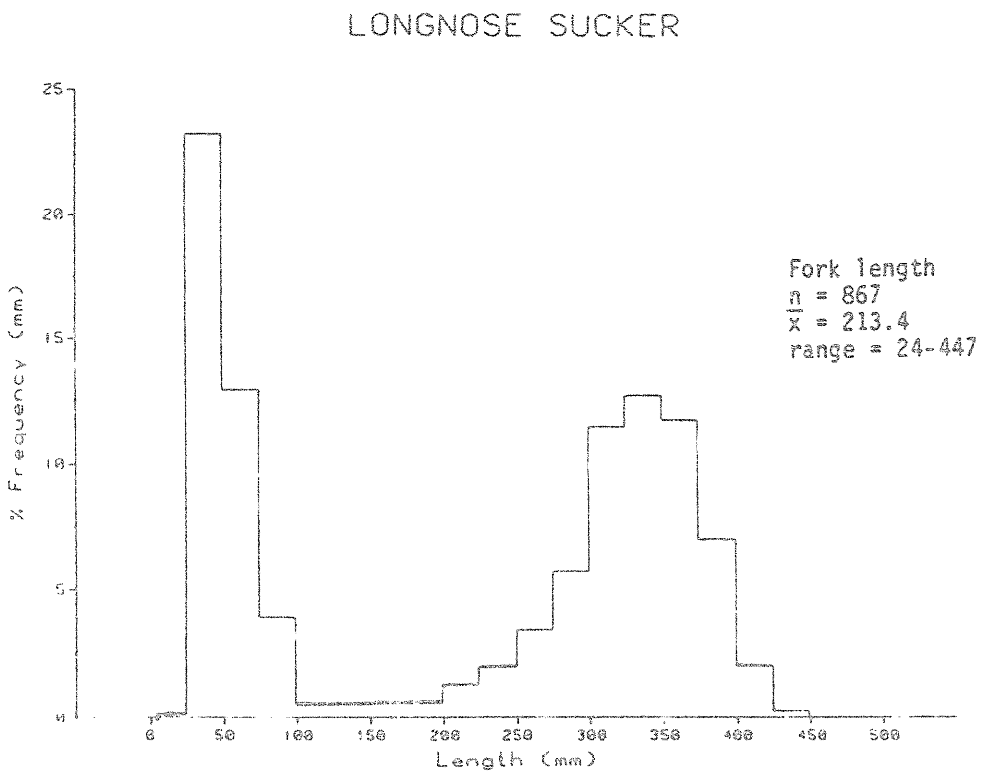
Appendix Figure C-3. Length frequency composition of Arctic grayling captured in the Susitna River between Cook Inlet and Devil Canyon by all gear types, May to October 1984.



Appendix Figure C-4. Length frequency composition of round whitefish captured in the Susitna River between Cook Inlet and Devil Canyon by all gear types, May to October 1984.



Appendix Figure C-5. Length frequency composition of humpback whitefish captured in the Susitna River between Cook Inlet and Devil Canyon by all gear types, May to October 1984.

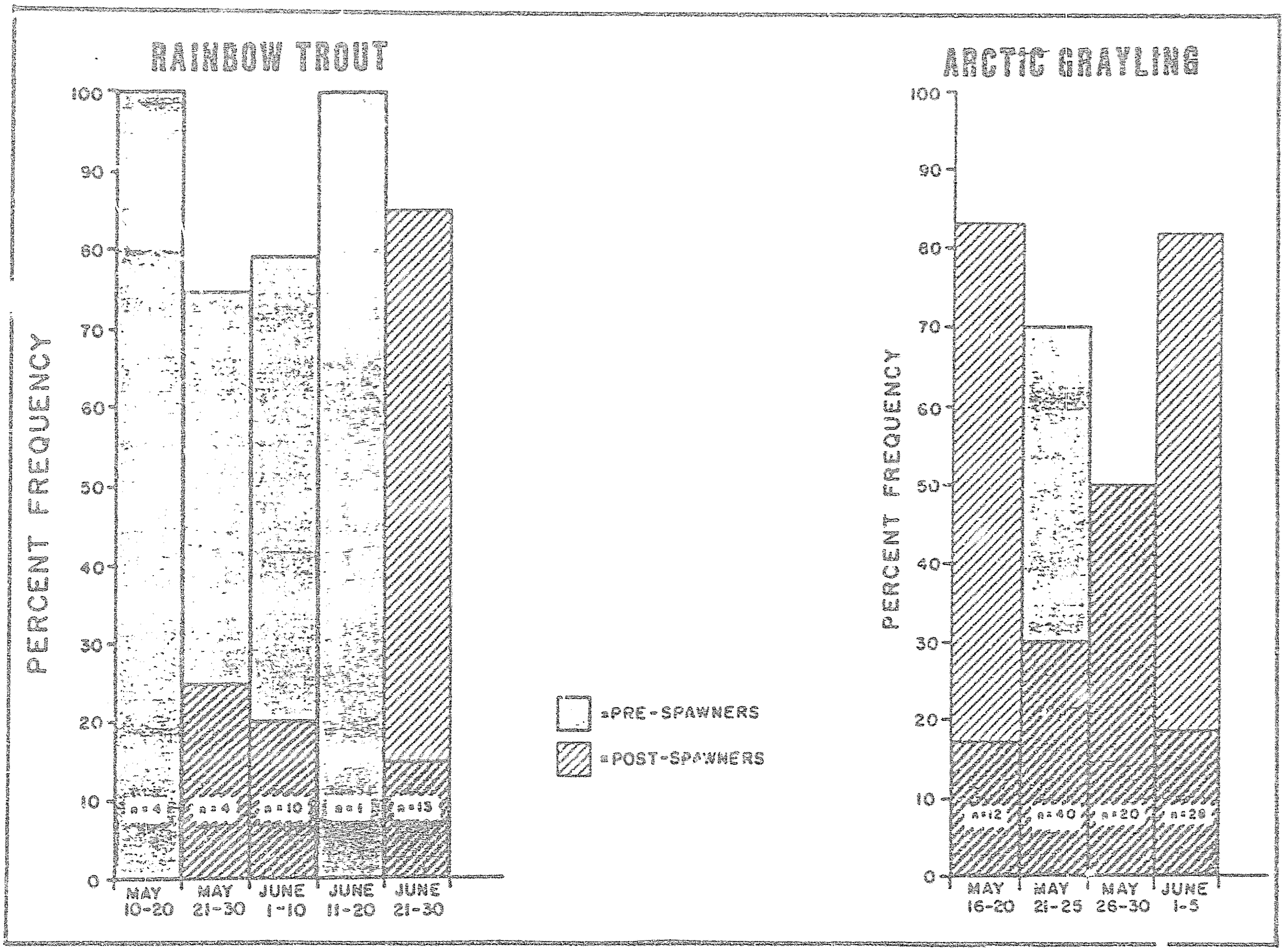


Appendix Figure C-6. Length frequency composition of longnose suckers captured in the Susitna River between Cook Inlet and Devil Canyon by all gear types, May to October 1984.

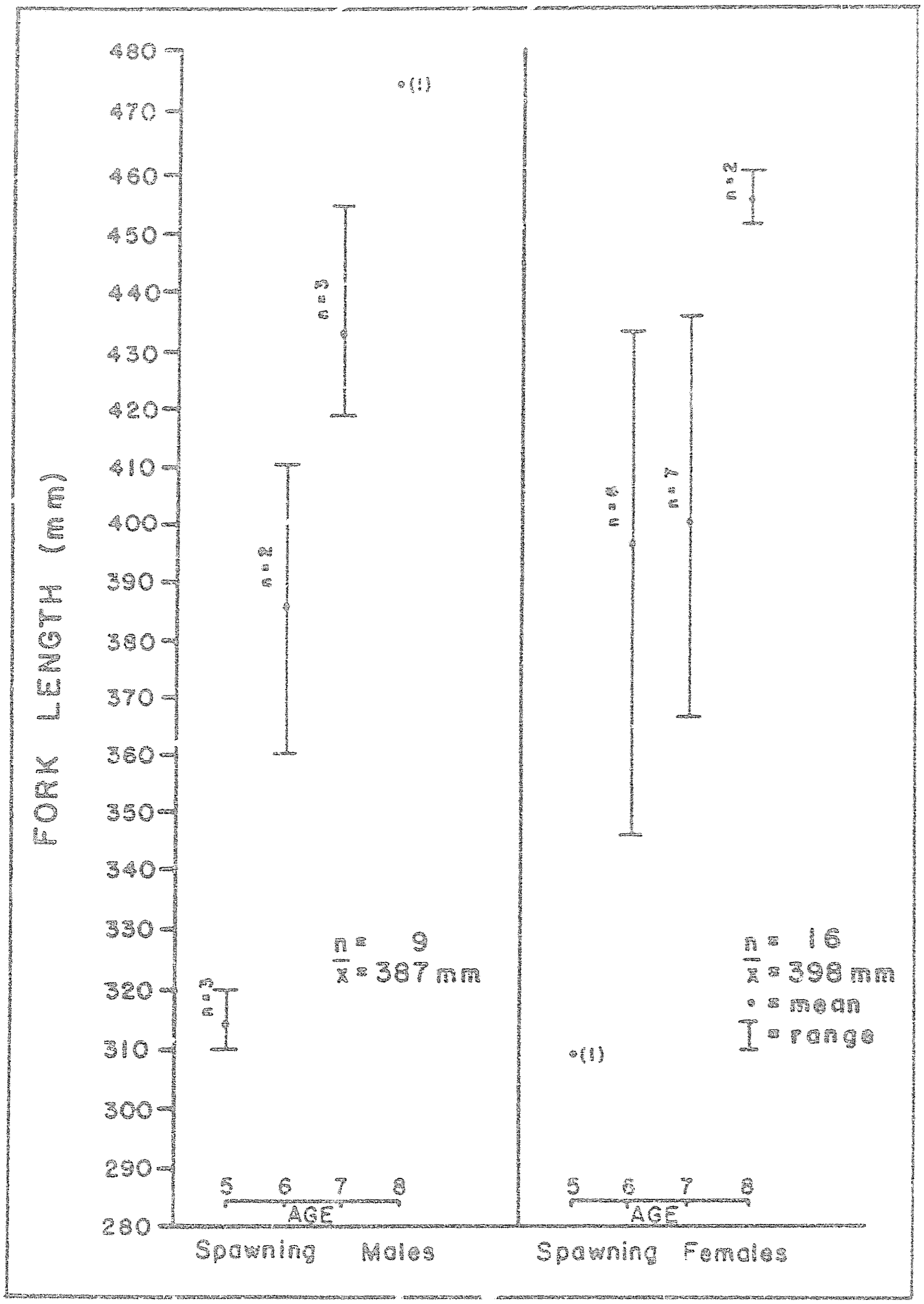
Appendix Table C-2. Fork lengths (mm) of sexually mature and immature resident fish captured on the Susitna River, 1984.

Species	Sampling Area	Dates	Spawning Condition	Males			Females			Combined Sexes		
				n	Range	x	n	Range	x	n	Range	x
Rainbow trout	Middle Susitna reach	5/17-6/27	1	7	320-495	428	11	345-462	406	18	320-495	415
		5/26-6/27	2	5	306-370	332	9	310-450	404	14	306-450	378
		5/17-6/27	3	12	306-495	388	20	310-462	405	32	306-495	399
		6/5-6/28	4	--	--	--	--	--	--	9	255-392	332
	Fourth of July	9/14	1	29	160-310	217	20	173-270	222	49	160-310	219
	Lakes C and D	9/14	4	--	--	--	--	--	--	15	95-240	155
Arctic grayling	Middle Susitna reach	5/17-6/2	1	19	322-417	370	26	265-395	321	45	265-417	341
		5/19-6/28	2	27	302-427	355	29	305-405	352	56	302-427	353
		5/17-6/28	3	46	302-427	361	55	265-405	337	101	265-427	348
		5/27-5/28	4	--	--	--	--	--	--	4	276-290	283
Round whitefish	Combined lower and middle Susitna reaches	9/26-10/15	1	13	244-390	324	20	292-425	334	33	244-425	330
		10/13-10/15	2	--	--	--	4	305-394	349	4	305-394	349
		9/26-10/15	3	13	244-390	324	24	292-425	336	37	244-425	332
Longnose suckers	Combined lower and middle Susitna reaches	5/19-10/15	1	57	273-390	333	1	--	345	58	273-390	333
		6/28-6/29	2	2	322-330	326	--	--	--	2	322-330	326
		5/17-10/15	3	59	273-390	333	1	--	345	60	273-390	333

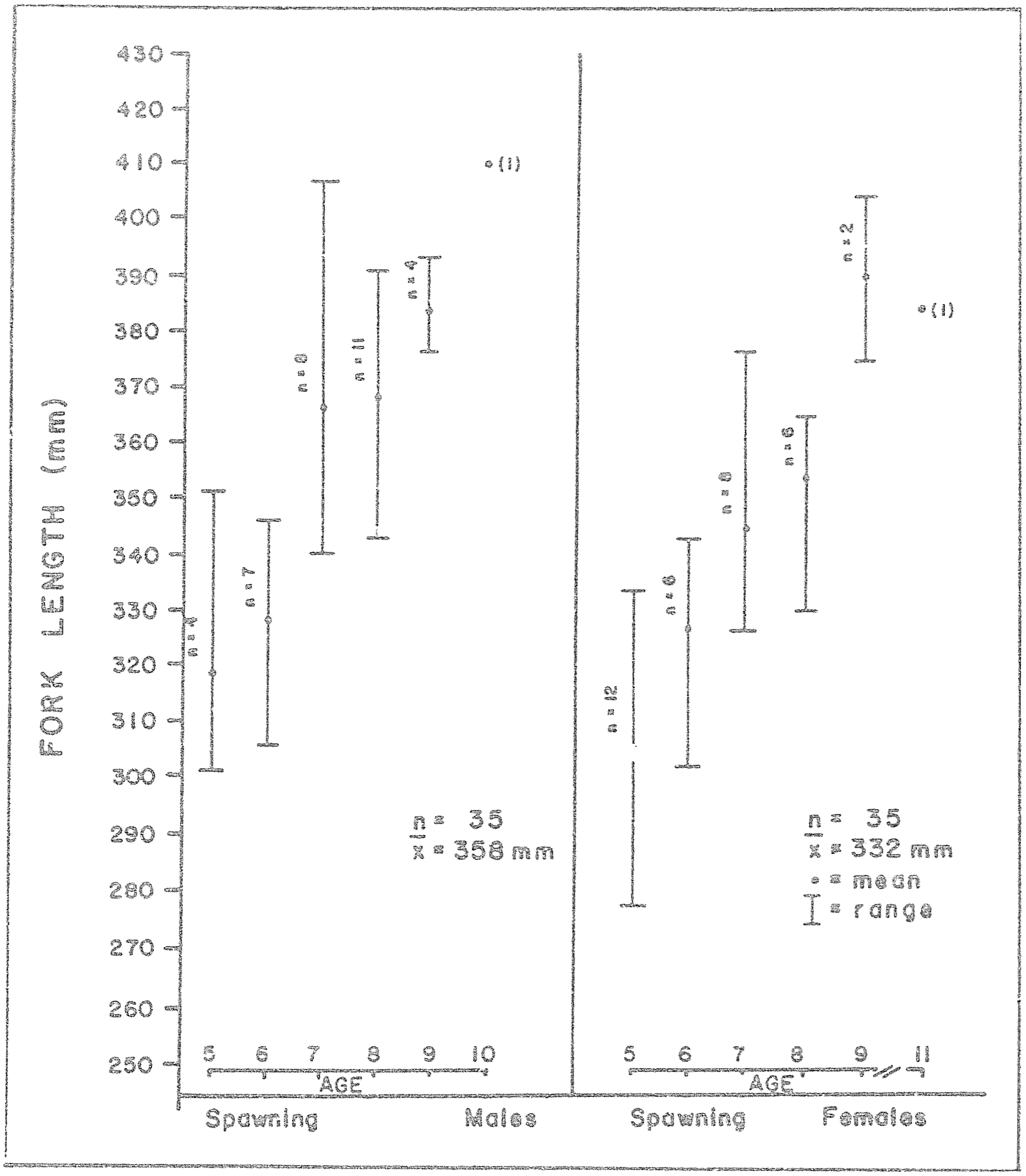
[1] Pre-spawners
[2] Post-spawners
[3] Combined pre- and post-spawners
[4] Non-spawners
-- No sample or sex undetermined



Appendix Figure C-7. Timing of 1984 rainbow trout and Arctic grayling spawning in the middle Susitna River determined by the incidence of pre- to post-spawners.

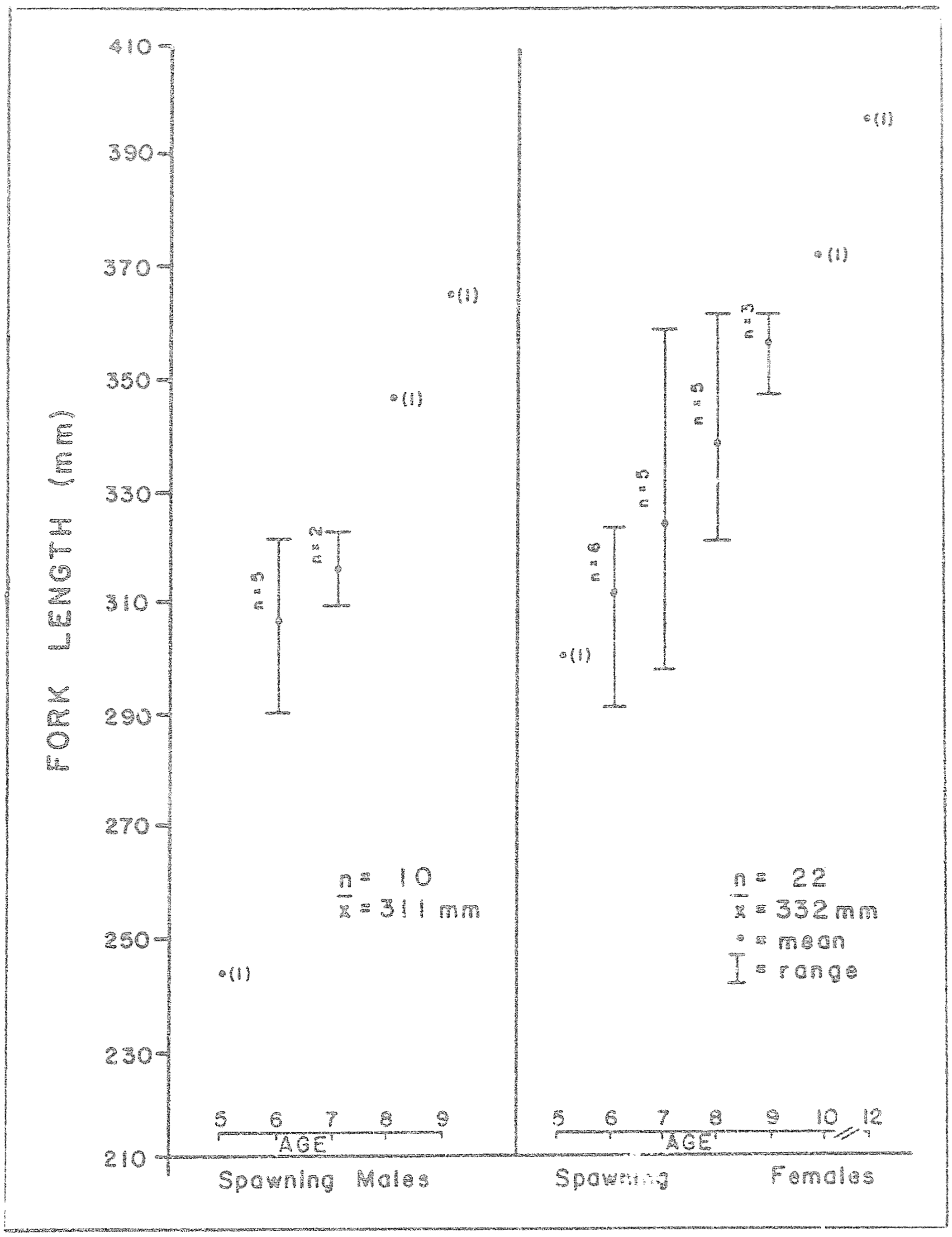


Appendix Figure C-8. Age and length relationship for spawning rainbow trout captured in the Susitna River between the Chulitna River confluence and Devil Canyon. May 17 through June 27, 1984.

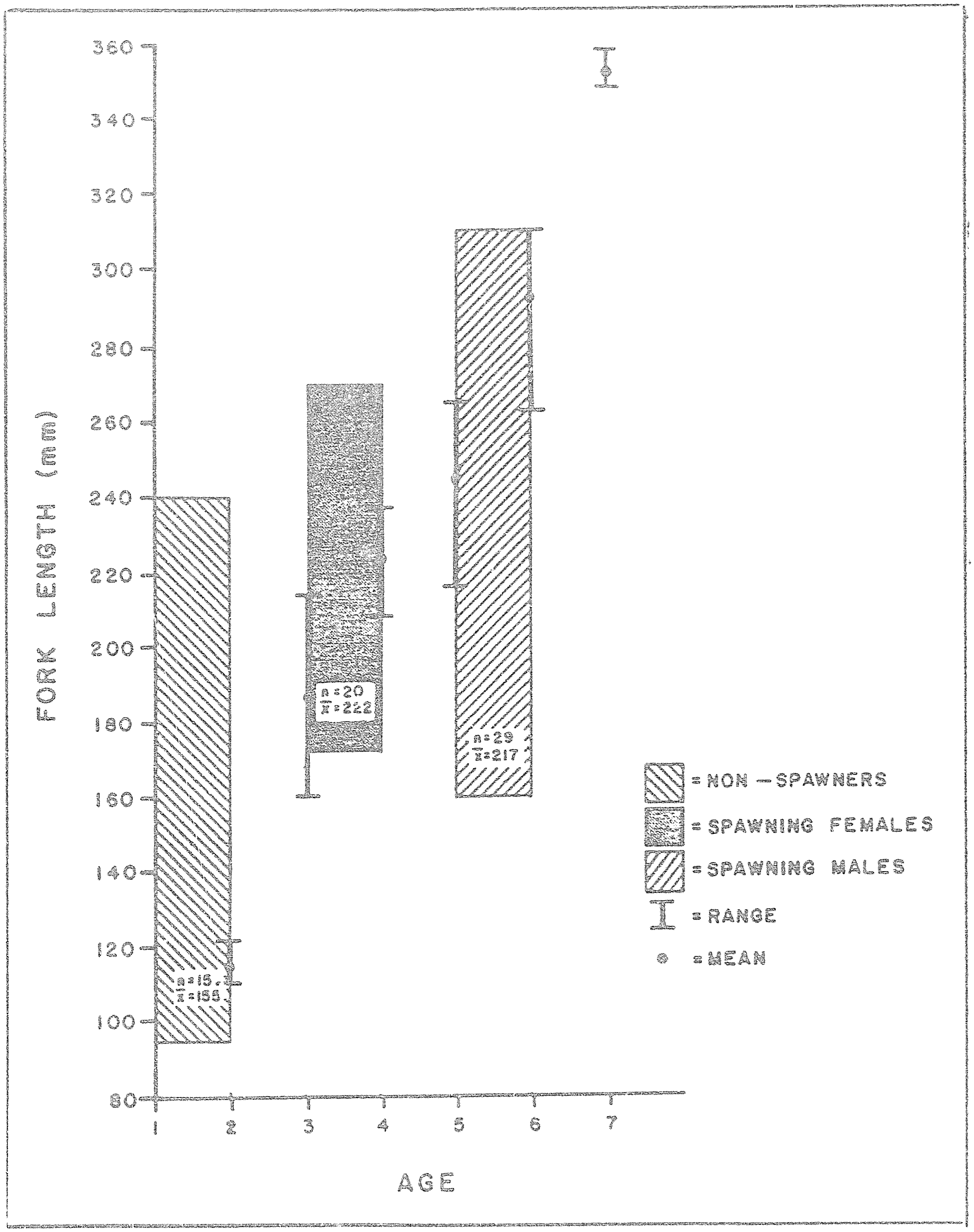


Appendix Figure C-9. Age and length relationships for spawning Arctic grayling captured in the Susitna River between the Chulitna River confluence and Devil Canyon, May 17 through June 5, 1984.

C-9



Appendix Figure 10. Age and length relationships for spawning round whitefish in the Susitna River between Cook Inlet and Devil Canyon, October 9 to to October 15, 1984.



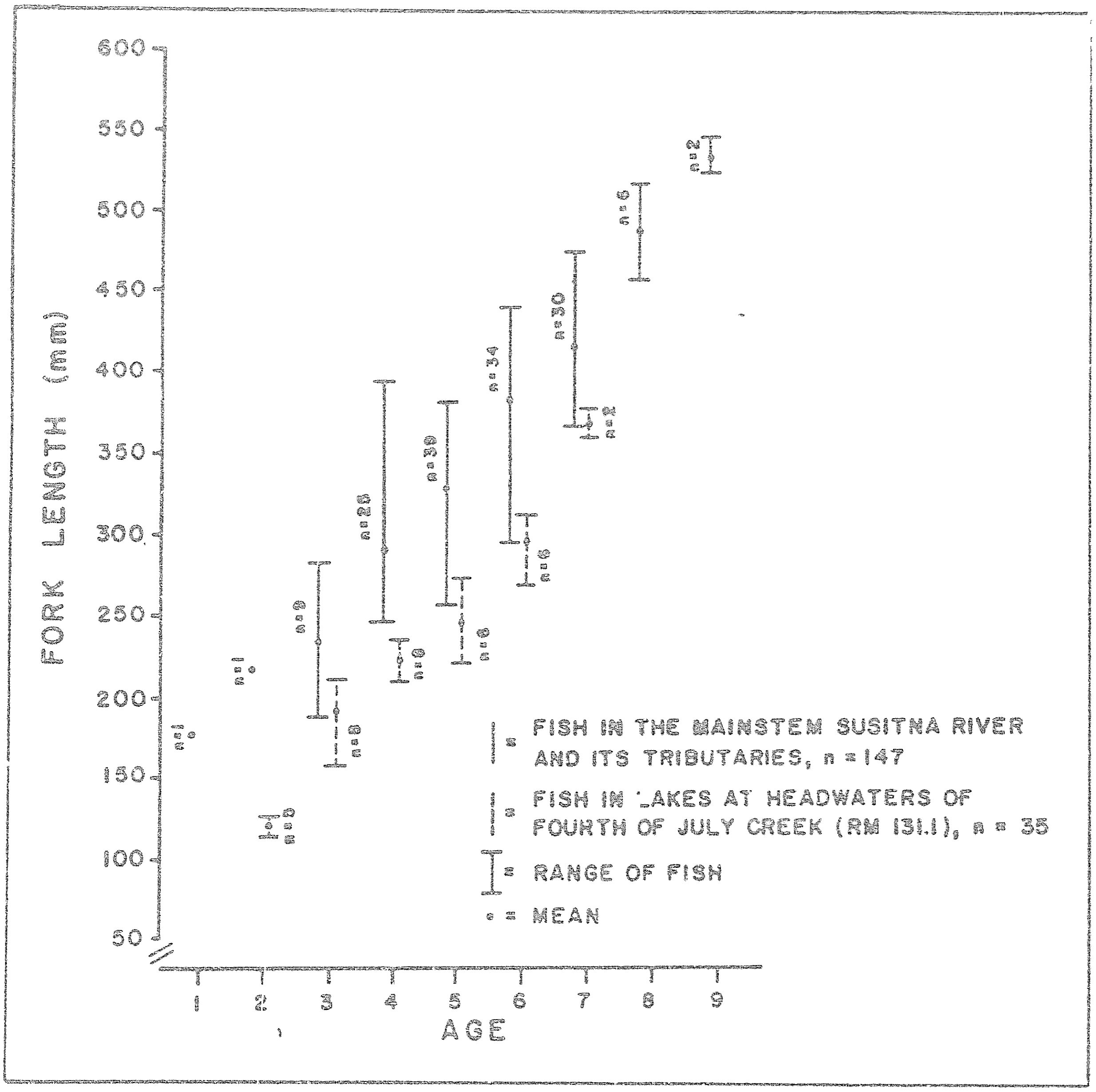
Appendix Figure C-11. Age and length relationships for pre-spawning rainbow trout captured in lakes C and D at the headwaters of Fourth of July Creek, September 14, 1984.

Appendix Table C-3. Rainbow trout age-length relationships on the Susitna River between the Chulitna River confluence and Devil Canyon, May to October 1984. Fish aged were captured by all methods.[1]

Age (Years)	Numbers of Fish Sampled	Length (mm) Mean	Standard Deviation	95% Confidence Intervals	Range
Fish captured in the mainstem Susitna and its tributaries					
1	1	155			
2	1	216			
3	9	232	28.36	210 - 254	186 - 282
4	25	293	33.40	279 - 307	245 - 395
5	39	328	31.80	317 - 338	255 - 375
6	34	380	34.72	368 - 392	291 - 436
7	30	414	31.83	402 - 425	360 - 468
8	6	475	22.26	452 - 498	452 - 517
9	2	538	9.99	450 - 626	531 - 545
TOTAL	147	353			186 - 545
Fish captured in three lakes at the headwaters of Fourth of July Creek (RM 131.1)					
2	5	117	2.88	114 - 120	115 - 121
3	8	185	22.26	166 - 204	160 - 215
4	8	223	8.61	215 - 231	208 - 235
5	6	246	18.54	226 - 266	218 - 265
6	6	294	20.43	276 - 316	263 - 310
7	2	355	7.07	325 - 385	350 - 360
TOTAL	35	223			115 - 360

[1] Methods of capture were by: boat electrofishing, gill net, hoop net, and hook and line.

C-12



Appendix Figure C-12. Age and length relationships for rainbow trout captured in the Susitna River between the Chulitna River confluence and Devil Canyon, May to October 1984.

One hundred forty-three of the 147 rainbow trout aged in the middle river were captured by hook and line or by boat electrofishing.[1] The instantaneous survival rate for rainbow trout in this reach of river captured by these two methods was calculated at 42.7% (Appendix Figure C-13).

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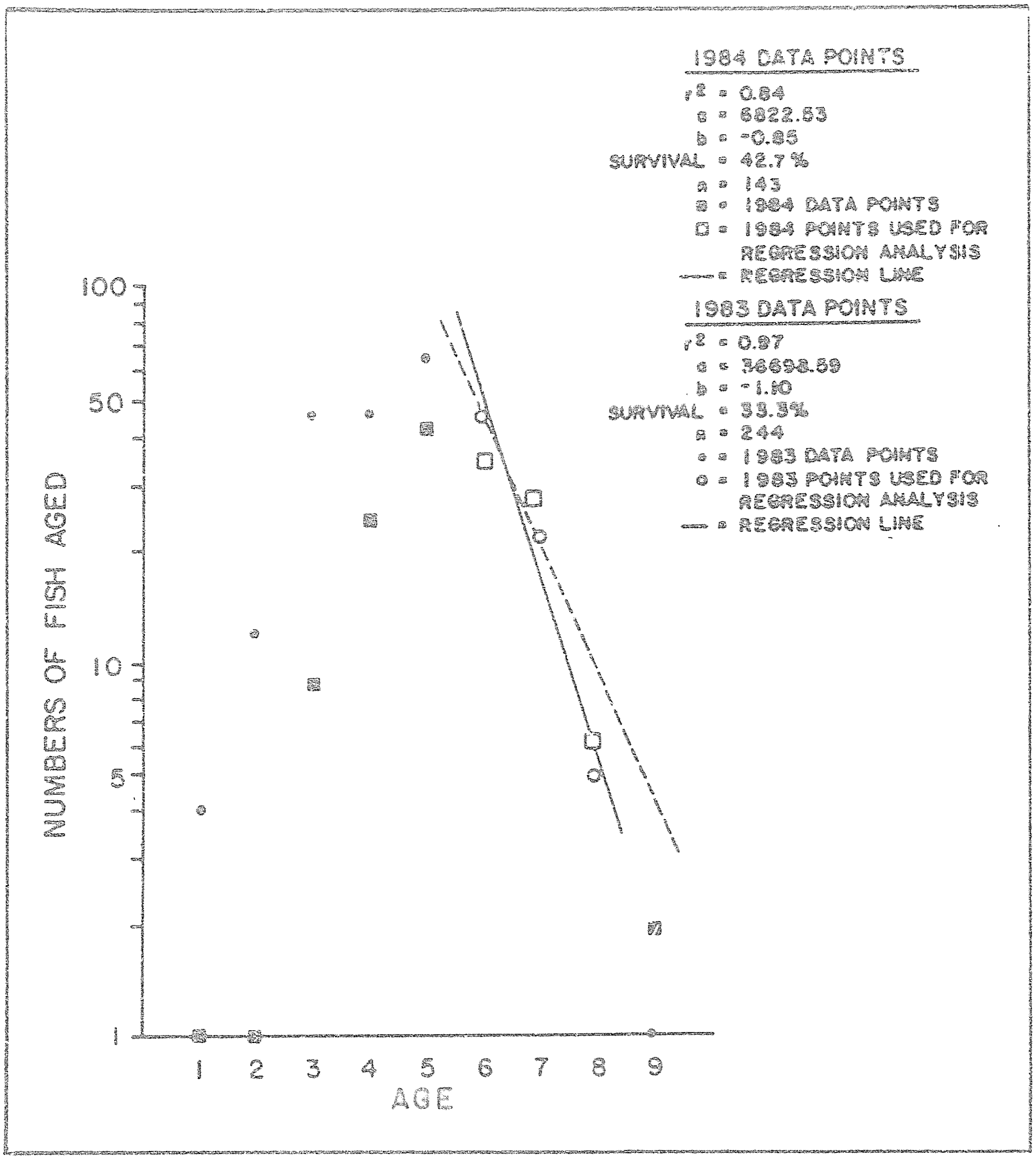
[1] To be consistent with 1983 instantaneous survival rate calculations, one Age 6 and three Age 7 fish were not used in 1984 calculations because they were captured by gear other than boat electrofishing and hook and line. Fish used in 1983 calculations were only used if they were captured by boat electrofishing or by hook and line.



Appendix Figure C-13. Survival rate curves for rainbow trout captured in the Susitna River between the Chulitna River confluence and Devil Canyon, 1983 and 1984.

APPENDIX D

Population Estimates

Methods

Population estimates were made of adult (≧200 mm) rainbow trout, Arctic grayling, round whitefish, and longnose sucker populations in the middle river using the multiple year (1981-1984) tagging and recapture data. Since only adult fish have been tagged, population estimates generated are applicable only for fish above 199 mm fork length. Seber-Jolly and Bailey's methods (Ricker 1975) were set up on a commercial microcomputer spreadsheet program. The number of recaptures of each species was adjusted by the tag retention rate for that species (refer to Appendix A and Recapture Data, below, for tag retention rates).

Results and Discussion

Population estimates from the Seber-Jolly method (Appendix Table D-1) and Bailey's method (Appendix Table D-2) must be considered tentative at this time. The number of recaptures are too low, leading to large confidence intervals on the population estimates using Bailey's method. We are presently working out the confidence intervals for the Seber-Jolly method. For the long term monitoring program, efforts will be redirected so that we can get a higher recapture rate.

Recapture Data

Floy anchor tag retention rates were calculated in 1983 and 1984 for several resident fish species. This was done by comparing the number of

Appendix Table D-1. Seber-Jolly method-population, survival and recruitment from a four-catch or longer experiment. Fish tagged were captured in the middle river from 1981-84.

DATE	Population	Recruits	Fish Newly Marked	Fish checked /Marks	Recaptures of Fish marked at 1981	1982	1983	Total	Ki		
RAINBOW TROUT											
1981	NA		92	NA	NA	NA	NA	NA	NA		
1982	1260	889	144	179	7	NA	NA	7	2		
1983	1036	0	274	312	2	4	NA	6	1	Beta 2	56
1984	0		NA	197	0	1	16	17	NA	Beta 3	23
Total			NA	NA	9	5	16	NA	NA	Survival2	0.12
ARCTIC GRAYLING											
1981	NA		49	NA	NA	NA	NA	NA	NA		
1982	2765	5218	400	410	6	NA	NA	6	4		
1983	6797	0	765	913	3	30	NA	33	10	Beta 2	47
1984	0		NA	583	1	9	34	44	NA	Beta 3	[illegible]
Total			NA	NA	10	39	34	NA	NA	Survival2	0.57
ROUND WHITEFISH											
1981	NA		48	NA	NA	NA	NA	NA	NA		
1982	9093	[illegible]378	720	751	0	NA	NA	0	1		
1983	7264	0	1079	1172	1	50	NA	51	14	Beta 2	12
1984	0		NA	640	0	14	55	69	NA	Beta 3	[illegible]
Total			NA	NA	1	64	55	NA	NA	Survival2	[illegible].44
LONGNOSE SUCKERS											
1981	NA		80	NA	NA	NA	NA	NA	NA		
1982	6555	3516	418	437	2	NA	NA	2	2		
1983	7613	0	434	447	2	14	NA	16	3	Beta 2	45
1984	0		NA	215	0	5	7	12	NA	Beta 3	289
Total			NA	NA	4	19	7	NA	NA	Survival2	0.63

NA = Not applicable.

Appendix Table D-2. Bailey's deterministic method-population, survival and recruitment from a three-catch experiment. Fish tagged were captured in the middle river from 1981-84.

Date	Population	Recruits	Fish Newly Marked	Fish checked /Marks	Recaptures marked at:	
RAINBOW TROUT, 1981-83					1981	1982
1981			92	NA	NA	NA
1982	1296	4.08	144	174	7	NA
1983				312	[illegible]	4
S.D.	1027	2.43				
Survival2	0.94					
S.D	0.85					

Date	Population	Recruits	Fish Newly Marked	Fish checked /Marks	Recaptures marked at:	
RAINBOW TROUT, 1982-84					1982	1983
1982			144	NA	NA	NA
1983	1009	1.27	274	312	4	NA
1984				197	1	10
S.D.	1009	0.90				
Survival2	0.22					
S.D	0.22					

Date	Population	Recruits	Fish Newly Marked	Fish checked /Marks	Recaptures marked at:	
ARCTIC GRAYLING, 1981-83					1981	1982
1981			49	NA	NA	NA
1982	2273	3.34	400	410	6	NA
1983				913	3	30
S.D.	1496	1.93				
Survival2	1.05					
S.D	0.84					

Appendix Table D-2 continued.

Date	Population	Recruits	Fish Newly Marked	Fish checked /Marks	Recaptures marked at:	
ARCTIC GRAYLING, 1982-84					1982	1983
1982			400	NA	NA	NA
1983	5800	1.92	765	913	30	NA
1984				583	9	34
S.D.	2334	0.67				
Survival%	0.55					
S.D	0.30					
ROUND WHITEFISH, 1981-83					1981	1982
1981			48	NA	NA	NA
1982	10616	0.00	720	751	0	NA
1983				1172	1	50
S.D.	10616	0.00				
Survival%	0.59					
S.D	0.59					
ROUND WHITEFISH, 1982-84					1982	1983
1982			720	NA	NA	NA
1983	6204	1.82	1079	1172	50	NA
1984				640	14	56
S.D.	2006	0.52				
Survival%	0.40					
S.D	0.18					

Appendix Table D-2 continued.

<u>LONGNOSE SUCKERS, 1981-83</u>						1981	1982
	1981			80	NA	NA	NA
	1982	8137	0.68	418	437	2	NA
	1983				447	2	14
S.D.		6548	0.54				
Survival2		1.05					
S.D		0.93					

<u>LONGNOSE SUCKERS, 1982-84</u>						1982	1983
	1982			418	NA	NA	NA
	1983	8101	1.13	434	447	14	NA
	1984				215	5	7
S.D.		4667	0.51				
Survival2		0.78					
S.D		0.55					

S.D. = Standard deviation.
NA = Not applicable.

fish recaptured with tags to the total number of fish recaptured (recaptured tagged fish plus those showing a tag scar). Refer to Appendix A for further methods. Tag scars were not recorded for fish captured in 1982 so actual tag retention rates are unavailable for that year. However, since retention rates are known for 1983 and assuming there was little change in retention rates between 1982 and 1983, 1983 retention rates were applied to recaptures made in 1982.

Rainbow trout: 100% tag retention rates for years 1981-1984.

Arctic grayling: 69.4% tag retention rate for year 1982

Year Tagged	Actual No. Recaps	Adjusted No. Recaps
1981	4	6
1982	31	44
Total	35	50

Arctic grayling: 69.4% tag retention rate for year 1983

Year Tagged	Actual No. Recaps	Adjusted No. Recaps
1981	2	3
1982	21	30
1983	14	20
Total	37	53

Arctic grayling: 75.9% tag retention rate for year 1984.

Year Tagged	Actual No. Recaps	Adjusted No. Recaps
1981	1	1
1982	7	9
1983	26	34
1984	8	11
Total	42	55

Round whitefish: 77.5% tag retention rate for year 1982.

Year Tagged	Actual No. Recaps	Adjusted No. Recaps
1981	0	0
1982	32	41
Total	32	41

Round whitefish: 77.5% tag retention rate for year 1983.

Year Tagged	Actual No. Recaps	Adjusted No. Recaps
1981	1	1
1982	39	50
1983	32	42
Total	72	93

Round whitefish: 83% tag retention rate for year 1984

Year Tagged	Actual No. Recaps	Adjusted No. Recaps
1981	0	0
1982	12	14
1983	46	55
1984	18	22
Total	76	91

Longnose suckers: 100.0% tag retention rate for years 1982 and 1983.

Year Tagged	Actual No. Recaps	Adjusted No. Recaps
1981	0	0
1982	5	5
1983	6	7
1984	2	2
Total	13	14

APPENDIX E

Middle River Index Site Catch Data and Descriptions, and Spawning Rainbow Trout Habitat Data

Appendix Table E-1 Boat electrofishing catch and catch per unit effort (CPUE) of four resident fish species at 13 index sites in the midddle reach of the Susitna River in 1984. CPUE is in parentheses, and the units are catch per minute.

Location	River Mile	Species	MAY 16-31	JUN 1-15	JUN 16-30	JUL 1-15	JUL 16-31	AUG 1-15	AUG 16-31	SEP 1-15	SEP 16-30	OCT 1-15	TOTAL CATCH
Tributary Mouth Sites													
Lane Creek	113.6	Rainbow trout	5 (0.2)	0	0	-	0	-	0	1 (0.3)	-	-	6
		Arctic grayling	16 (0.5)	4 (0.7)	3 (0.4)	-	3 (0.8)	-	0	2 (0.6)	-	-	28
		Round whitefish	5 (0.2)	5 (0.8)	2 (0.3)	-	2 (0.5)	-	1 (0.3)	2 (0.6)	-	-	17
		Longnose sucker	0	2 (0.3)	0	-	8 (2.0)	-	9 (3.0)	2 (0.6)	-	-	21
Skull Creek	124.7	Rainbow trout	1 (0.3)	-	0	-	0	-	0	-	-	-	1
		Arrtic grayling	5 (1.4)	-	3 (0.6)	-	2 (0.7)	-	6 (3.0)	-	-	-	16
		Round whitefish	1 (0.3)	-	2 (0.4)	-	0	-	1 (0.5)	-	-	-	4
		Longnose sucker	0	-	0	-	3 (1.0)	-	1 (0.5)	-	-	-	4
Fourth of July Creek	131.1	Rainbow trout	2 (0.1)	1 (0.1)	2 (0.3)	-	1 (0.2)	-	1 (0.2)	1 (0.1)	1 (0.1)	-	9
		Arctic grayling	0	0	1 (0.1)	-	2 (0.4)	-	1 (0.2)	7 (0.5)	1 (0.1)	-	12
		Round whitefish	4 (0.1)	4 (0.5)	6 (0.8)	-	7 (1.3)	-	5 (0.9)	10 (0.8)	1 (0.1)	-	37
		Longnose sucker	0	0	0	-	3 (0.5)		2 (0.4)	11 (0.8)	0	-	16
Indian River	138.6	Rainbow trout	6 (0.1)	1 (0.1)	0	-	3 (0.4)	-	1 (0.1)	9 (0.3)	6 (0.3)	0	26
		Arctic grayling	10 (0.2)	1 (0.1)	7 (0.6)	-	6 (0.8)	-	5 (0.6)	47 (1.4)	28 (1.6)	0	104
		Round whitefish	21 (0.3)	2 (0.3)	33 (3.0)	-	6 (0.8)	-	2 (0.3)	16 (0.5)	45 (2.5)	11 (0.9)	136
		Longnose sucker	0	0	1 (0.1)	-	6 (0.8)	-	4 (0.4)	0	1 (0.1)	1 (0.1)	13
Jack Long Creek	144.5	Rainbow trout	0	0	0	-	0	-	0	0	0	0	0
		Arctic grayling	2 (0.1)	1 (0.2)	5 (1.0)	-	10 (2.9)	-	0	1 (0.1)	0	0	19
		Round whitefish	7 (0.3)	7 (1.3)	25 (5.0)	-	5 (1.4)	-	2 (1.3)	12 (1.6)	18 (3.3)	0	76
		Longnose sucker	0	0	2 (0.4)	-	0	-	0	1 (0.1)	0	0	3
Portage Creek	148.8	Rainbow trout	1 (0.0)	1 (0.1)	1 (0.1)	-	0	-	0	6 (0.5)	1 (0.1)	1 (0.1)	11
		Arctic grayling	28 (0.6)	8 (0.7)	8 (0.8)	-	7 (0.7)	-	19 (1.0)	18 (1.6)	7 (0.4)	9 (0.9)	104
		Round whitefish	25 (0.5)	9 (0.8)	21 (2.1)	-	5 (0.5)	-	7 (0.7)	6 (0.5)	19 (1.0)	9 (0.9)	101
		Longnose sucker	0	0	0	-	11 (1.1)	-	5 (0.5)	2 (0.2)	1 (0.1)	0	19
Slough Sites													
Whiskers Creek Slough Mouth	101.2	Rainbow trout	3 (0.1)	-	0	-	1 (0.3)	-	0	1 (0.2)	-	-	5
		Arctic grayling	38 (1.2)	-	0	-	1 (0.3)	-	1 (0.3)	1 (0.2)	-	-	41
		Round whitefish	3 (0.1)	-	0	-	0	-	1 (0.3)	2 (0.3)	-	-	6
		Longnose sucker	1 (0.0)	-	1 (0.1)	-	1 (0.3)	-	5 (1.4)	0	-	-	8
Slough 6A	112.3	Rainbow trout	0	-	0	-	0	-	0	-	-	-	0
		Arctic grayling	4 (0.3)	-	0	-	0	-	0	-	-	-	4
		Round whitefish	3 (0.2)	-	3 (0.3)	-	0	-	1 (0.2)	-	-	-	7
		Longnose sucker	1 (0.1)	-	3 (0.3)	-	0	-	0	-	-	-	4

Appendix Table E-1 (Continued).

Location	River Mile	Species	MAY 16-31	JUN 1-15	JUN 16-30	JUL 1-15	JUL 16-31	AUG 1-15	AUG 16-31	SEP 1-15	SEP 16-30	OCT 1-15	TOTAL CATCH
Slough 8A	125.3	Rainbow trout	7 (2.0)	-	0	-	0	-	0	1 (0.2)	-	-	8
		Arctic grayling	0	-	0	-	0	-	1 (0.3)	0	-	-	1
		Round whitefish	0	-	0	-	0	-	1 (0.3)	3 (0.5)	-	-	4
		Longnose sucker	0	-	1 (0.2)	-	0	-	0	0	-	-	1
Slough 20 Mouth	140.1	Rainbow trout	-	0	0	-	0	-	0	0	1 (0.1)	-	1
		Arctic grayling	-	2 (0.5)	0	-	0	-	0	6 (1.2)	0	-	8
		Round whitefish	-	4 (1.0)	2 (0.6)	-	0	-	0	0	0	-	6
		Longnose sucker	-	1 (0.3)	0	-	0	-	1 (0.5)	5 (1.0)	0	-	7
Mainstem Sites													
Susitna Mainstem West Bank	137.3-138.3	Rainbow trout	2 (0.2)	0	0	-	0	-	0	0	0	-	2
		Arctic grayling	2 (0.2)	1 (0.1)	22 (1.8)	-	21 (2.0)	-	6 (0.6)	13 (1.2)	7 (0.6)	-	72
		Round whitefish	2 (0.2)	8 (0.7)	7 (0.6)	-	2 (0.2)	-	4 (0.4)	7 (0.6)	17 (1.4)	-	47
		Longnose sucker	0	0	4 (0.3)	-	4 (0.4)	-	0	2 (0.2)	1 (0.1)	-	11
Susitna Mainstem	147.0-148.0	Rainbow trout	0	0	0	-	0	-	0	2 (0.1)	0	1 (0.0)	3
		Arctic grayling	9 (0.2)	17 (0.6)	2 (0.3)	-	0	-	0	23 (0.9)	5 (0.2)	4 (0.1)	60
		Round whitefish	34 (0.9)	56 (2.0)	9 (1.2)	-	1 (0.2)	-	4 (0.8)	33 (1.3)	25 (1.1)	16 (0.5)	178
		Longnose sucker	0	3 (0.1)	1 (0.1)	-	2 (0.3)	-	0	5 (0.2)	4 (0.2)	2 (0.1)	17
Mainstem	150.1	Rainbow trout	1 (0.1)	0	-	-	-	-	-	3 (0.2)	11 (0.5)	4 (0.2)	19
		Arctic grayling	16 (1.0)	2 (0.4)	-	-	-	-	-	4 (0.2)	2 (0.1)	0	24
		Round whitefish	0	1 (0.2)	-	-	-	-	-	20 (1.0)	22 (0.9)	9 (0.5)	52
		Longnose sucker	0	0	-	-	-	-	-	2 (0.1)	0	0	2

0.0 = Trace.

Appendix Table E-2. Habitat characteristics and measurements taken at spawning rainbow trout sites in 1984.

				Water		Water Quality					
Location	RM	TRM	Date	Depth (ft)	Mean Velocity (ft per sec)	Temp °C	pH	DO mg/l	Conductivity umhos/cm	Substrate	Comments
Portage Creek	148.8	2.3	6/2	--	--	4	7.6	12.4	96.0	large gravel 70% small cobble 25% bedrock 5%	Seven spawning fish were captured on June 1 and 5 from a school of approximately 30 adult rainbow trout. Five of these fish were radio tagged. This site is characterized by a pool with a tributary outletting from the west. The pool's maximum depth was estimated at 20 ft. Most spawning probably occurred in the pool near the side tributary's outlet where estimated water velocities were 0.5-1.5 fps and depths 1.5-2.5 ft.
Portage Creek (along the east shore)	148.8	5.1	6/20	4.5	0.2	6.4	7.1	11.8	66.0	large gravel 90% boulders 10%	One spawning fish was captured and radio tagged on June 20. One other spawning radio tagged fish was located at this site during this time. This site is characterized by low velocities due to large boulders and by a small tributary flowing into it. Most spawning probably occurred along the east side versus the west side. Water velocities were much greater along the west side.
Fourth of July Creek	131.1	0.7	6/3	2.8	2.5	9.3	6.8	11.4	21.0	large gravel 10% small cobble 60% large cobble 20%	One post-spawned fish was captured and radio tagged on June 3. Two spawning radio tagged fish were also located at this site during this time. This site is characterized by a side tributary outletting into it on the east side.
Unnamed side tributary outletting at TRM 0.7 of Fourth of July Creek		0.5	6/5	1.4	0.5	12.2	--	--	--	small gravel 60% large gravel 40%	One pair of spawning fish were observed. The male was captured and radio tagged. Other fish were observed but it was unknown if they were spawners. This side tributary was 10-15 feet wide. Limited undercut banks provided primary cover.

-- = No measurements taken.

INDEX SITE DESCRIPTIONS

(the other nine site descriptions are provided in ADF&G 1983f)

Skull Creek - Mouth

Skull Creek is a small clearwater tributary with a summer discharge of approximately 50 cfs which empties into the east side of the Susitna River at RM 124.7 (R&M 1982). The mouth of the creek is characterized by shallow water depths, low water velocities and small cobble substrate. No object cover other than the substrate usually occurs.

Susitna Mainstem - West Bank

The index site Susitna Mainstem - West Bank is along the west bank of the mainstem Susitna River between RM 137.3 and RM 138.3. This site is characterized by low to moderate water depths and velocities, and has large cobble substrate. No object cover other than the substrate usually occurs.

Susitna Mainstem

This mainstem index site is between RM 147.0 and RM 148.0 and includes both sides of a large island. The area along the east and west banks of the mainstem river is characterized by steep banks and moderate water depths and velocities. Along the island, the shorelines are gently sloping and water velocities are low to moderate. The substrate at this site is predominately large cobble which acts as the only object cover.

Susitna Mainstem - Eddy

This site is a back eddy along the east bank of the mainstem Susitna River at RM 150.1. The area is characterized by steep banks, moderate water depths and low velocity. The substrate is sand and rock.

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PART 4

Time Series Analysis of Juvenile Salmon Outmigration, Discharge, and Turbidity in the Susitna River, Alaska

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TIME SERIES ANALYSIS OF JUVENILE SALMON OUTMIGRATION, DISCHARGE, AND TURBIDITY IN THE SUSITNA RIVER, ALASKA

Report No. 7, Part 4

by: Stephen S. Hale

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ABSTRACT

During the three years of study of juvenile salmon outmigration from the middle reach of the Susitna River, a correspondence has been noted between the peaks of river discharge and the peaks of outmigration. Further investigation of the relationship of outmigration to discharge was required because two large hydroelectric dams have been proposed for an area above the rearing area of salmon. These dams will markedly change the downstream discharge and turbidity regimes, factors which influence not only salmon outmigration, but almost all fish species and life stages. Box-Jenkins models were developed for the 1983 and 1984 time series of river discharge, turbidity, and chinook and sockeye salmon fry outmigration rates in order to statistically describe the natural conditions. Bivariate transfer function models were constructed for turbidity and outmigration rate which explain present values of these variables in terms of their own past values as well as past values of discharge. The time series examined were described by relatively simple models, using mostly first-order autoregressive terms. Although the time series plots of discharge and outmigration appeared to be different between the two years, the underlying stochastic processes which generated these series were the same.

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LIST OF FIGURES

1.0 INTRODUCTION

During the course of examining the plots of daily catch rate of outmigrating juvenile salmon at the Talkeetna Station outmigrant traps, it was noted that there was an apparent correspondence between the peaks of the time series of mean daily discharge and the time series of salmon outmigration (ADF&G 1983; Roth et al. 1984; Roth and Stratton 1985). Correlation analysis showed that there was a relatively strong relationship between discharge and the outmigration rates of certain species/age classes of salmon. The term outmigration rate is used here to mean the number of outmigrating fry captured at the traps per hour, not the distance travelled per hour. This relationship is not simply a matter of a greater volume of water being fished at higher discharges. The correlations of catch rate of age 0+ salmon with water velocity at the mouths of the traps were not significantly different from zero (Roth et al. 1984, Appendix A).

Similarly, McDonald (1960) found in the Skeena River in British Columbia that the greater the water velocity (with regard to lateral distribution), the greater the density of sockeye and pink fry per unit volume of water. The correspondence between discharge rate and salmonid outmigration has also been reported by other investigators (Cederholm and Scarlett 1982 - coho salmon; Congleton et al. 1982 - chum and chinook salmon; Godin 1982; Grau 1982; Solomon 1982b). The selective advantages of this behavior, according to Solomon (1982b), include easier passage over long distances or shallow areas and protection from predators provided by increased turbidity and by the large numbers resulting from a coordinated mass migration in response to an environmental cue.

There are probably two mechanisms which account for this relationship in the Susitna River. One is that the fish, which have gradually become physiologically ready for outmigration by growth and in response to photoperiod and temperature, are stimulated by a rise in mainstem discharge to begin that outmigration (Grau 1982). The second mechanism is that high flows physically displace the fish downstream. This latter mechanism may frequently occur for fry rearing in side sloughs, particularly for chum salmon (Oncorhynchus keta) and sockeye salmon (O. nerka). The natal sloughs for many chum and sockeye salmon have berms at the heads which prevent water from the mainstem from entering the site at low levels of discharge. When high flows occur, the slough heads are overtopped and the fry which had been rearing in low velocity water are subjected to a strong current.

Because two large hydroelectric dams have been proposed for the Susitna River in an area upstream of the rearing areas of the juvenile salmon (Fig. 1) and because these dams would markedly alter the natural discharge and turbidity regimes, it is necessary to quantify the relationship between the discharge and turbidity regimes and the outmigration patterns of the juvenile salmon. After the dams begin operation, the annual patterns of river discharge and turbidity level would be smoothed - both would be lower than normal in the summer and higher than normal in the winter. Also, the high frequency (daily) oscillations of these two time series would be dampened; there would be less day to day

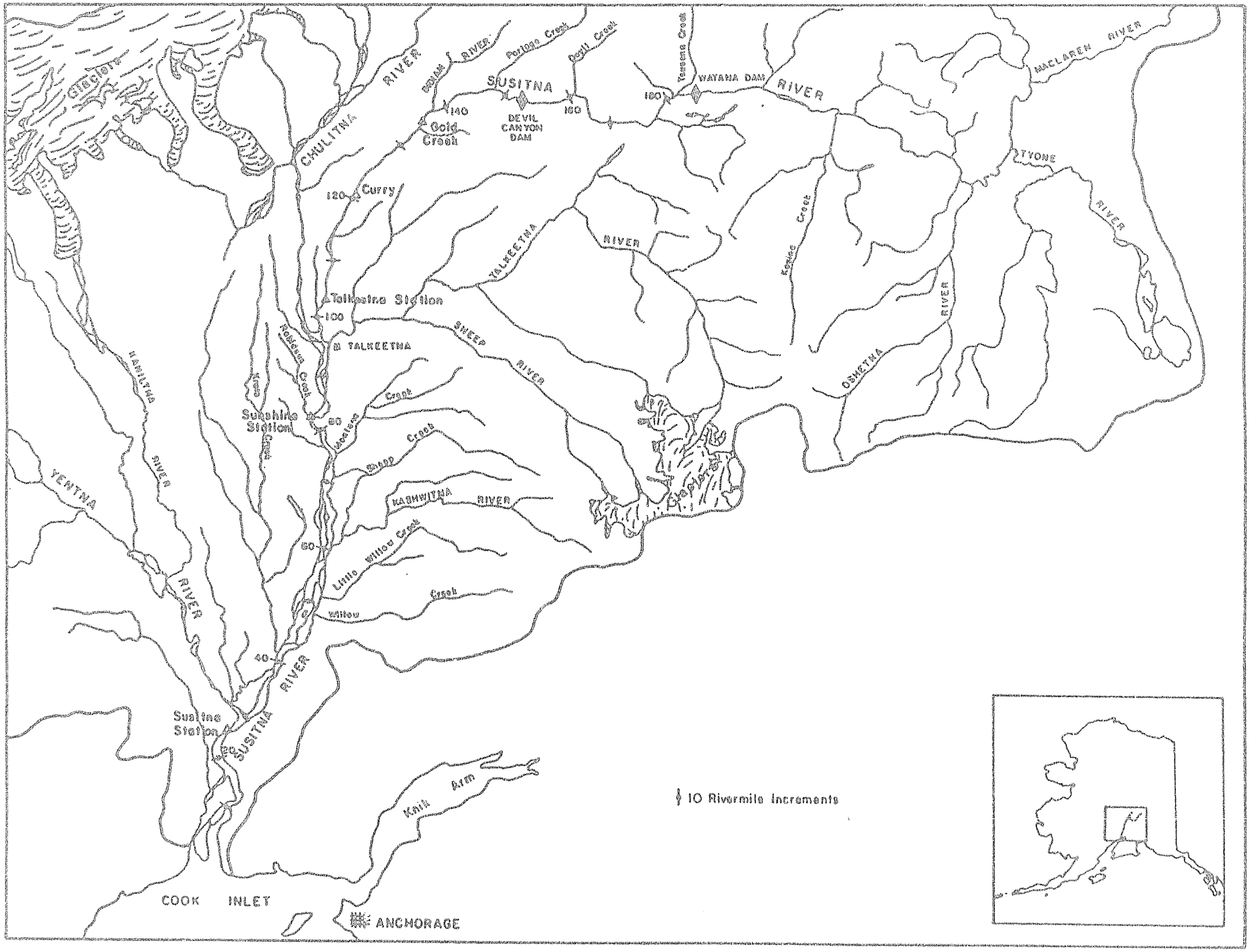


Figure 1. Map of the Susitna basin study region. (Source: Arctic Environmental Information Data Center).

variation. A post-project discharge regime which will have no deleterious effects on salmon outmigration needs to be determined. If such a discharge regime is not feasible, then the effects of a given discharge regime must be known.

There are many factors other than discharge and turbidity which affect the outmigration timing of juvenile salmon including time of year, size of fish, photoperiod, light intensity, and temperature (Brannon and Salo 1982); however, discharge and turbidity bear further investigation because of the changes in these two variables which would be caused by the proposed dams. Potential negative effects of an altered flow regime include accelerated or delayed timing of outmigrations. Changes in outmigration timing may place the fish in their rearing areas at an unfavorable time from the standpoint of food supply, which could cause reduced survival (Hartman et al. 1967). Lower discharge levels can result in a shorter distance covered per day (Raymond 1968). Decreasing mainstem flows can lead to stranding of fish in pools which have been isolated from the mainstem (Solomon 1982a). Lower flows and clearer water than normal may also result in increased predation (Stevens and Miller 1983).

Turbidity level in the Susitna River probably does not have much effect on the daily number of fry which outmigrate or on the initiation of outmigration. In clear water streams, however, an increase in turbidity level can directly increase the number of outmigrating salmon by providing cover from predators (Solomon 1982b). Turbidity level in the Susitna River does change outmigration timing because fry in turbid water outmigrate during the day as well as during the night (Godin 1982; Roth et al. 1984). Clearing of the water could force the fry to shift to a nocturnal outmigration to avoid predators. However, this would be of marginal benefit for fry during the continuous daylight in June and July at 63° N latitude.

To avoid or alleviate the above problems, it is necessary to understand the mechanisms producing the present discharge, turbidity, and outmigration regimes. Knowledge of the discharge - outmigration relationships will be useful in trying to establish a post-project flow regime which will not interfere with the natural outmigration timing.

In addition to the effects of discharge and turbidity level on juvenile salmon outmigration, the effects of these two variables on juvenile salmon rearing and overwintering must be considered because changes in river flow can affect the survival rate of young salmon (Stevens and Miller 1983). The effect of variations in discharge on juvenile salmon habitat of the Susitna River has been modelled (Hale et al. 1984) as has the relationship with turbidity level (Suchanek et al. 1984). The current discharge and turbidity regimes that are driving these models must be statistically described.

1.1 Time Series Analysis

The statistical methods collectively known as time series analysis are a logical choice for analyzing the present discharge, turbidity, and outmigration regimes. A time series is a collection of observations ordered in time such as daily water temperature measurements. Time series are shaped by both deterministic and stochastic (random) events. Future values have a probability distribution which is conditioned by past values. Random events (or "shocks") operating on the time series have a "memory", that is, the effect of these disturbances may be apparent for several time units after the event occurred.

Time series analysis consists of removing deterministic trends from a time series so that the values fluctuate around a mean level. A transformation may be necessary to ensure a constant variance. The random processes that generated the observed series can then be mathematically defined. The residuals left over after this model is fitted should be "white noise" (completely random) if the model is adequate. With a white noise time series, past values provide no linear information about future values.

Time series can be passed through a mathematical filter which changes the form of the input series. A "low pass filter" dampens high frequency perturbations and allows low frequency perturbations to pass unchanged. This is useful in smoothing noisy time series so that the basic pattern may be more readily observed. The low pass von Hann filter was applied to the salmon outmigration time series in Roth and Stratton (1985). High pass filters are used when it is desirable to remove obvious (low frequency) trends in order to focus on the high frequency events.

Time series analysis allows the construction of mathematical models using only the information contained in the time series itself. For example, although the discharge time series results from several independent variables including rainfall, air temperature, and solar insolation on the glaciers, it is not necessary to quantify these inputs in order to model the output (discharge). Information on the effects of all the inputs is already contained in the past history of the discharge record.

Time series analysis includes frequency domain (spectral analysis) and time domain (parametric) problems. Spectral analysis is concerned with transforming a time series with a Fourier transform to a sum of sines and cosines (see Priestley 1981) and is appropriate with periodic series such as the classical example of the Canada lynx/snowshoe hare ten year cycle (Bulmer 1978). Methods for time domain problems (or Box-Jenkins models) are referred to as ARIMA (autoregressive, integrated, moving average) models (Box and Jenkins 1976). ARIMA models have been used extensively in economic forecasting (Nelson 1973; Granger and Newbold 1977).

These models can be extended to what Box and Jenkins (1976) have called transfer function models. This is a model where an output series is a function of one or more independent input series as well as its own past history. Time series models do not require information on input series but if such information is available, then it may be possible to obtain a model with more predictive power.

There are no replicates in time series analysis. An observed series is one realization of all possible time series which could have been generated from a random process. Time series analysis examines the nature of the probablistic process that generated the observed series. The model should have similar properties to the generating mechanisms of the stochastic process (Granger and Newbold 1977). Then, one can form summary statistics about the series and make inferences about the nature of the stochastic process. After a model has been developed, it can be used to test some hypothesis about the generating mechanism of the time series, to forecast future values of the series, or to make decisions on how to control future values of the series (Granger and Newbold 1977).

1.2 Applications of Time Series Analysis

Time series analysis has been extensively used in examining physical data, particularly in oceanography. Salas and Smith (1981) demonstrated that ARIMA models can be used to model the time series of annual flows in streams. Srikanthan et al. (1983) analyzed the time series of annual flows in 156 streams in Australia and found that most of the ones which were non-random could be modeled by an autoregressive model. Time series models have also been used to examine the effect of the Aswan dam on the discharge of the Nile River and the effect of a hydroelectric dam on the discharge regime of the Saskatchewan River (Hipel et al. 1978).

Time series analysis methods have been also been used in examining time series of abundance and catch in marine fisheries (Van Winkle et al. 1979; Botsford et al. 1982; Peterman and Wong 1984; and Taylor and

Prochaska 1984). These methods have been used by Saila et al. 1980; Mendelssohn 1981; Stocker and Hilborn (1981), Kirkley et al. (1982), and Jensen (1985) for forecasting future abundance or catch of marine fish stocks. Mendelssohn (1981) used transfer function models in addition to univariate Box-Jenkins models to forecast fish catch. Botsford et al. (1982) focused on searching for causal mechanisms of observed cycles in salmon fisheries in California rather than on defining models for the fisheries.

Applications to freshwater fish ecology problems are much more limited. Saila et al. (1972) used time series methods to cross correlate upstream migration activity of the alewife to solar radiation and water temperature. O'Heeron and Ellis (1975) considered a time series model for judging the effects of reservoir management on fish. Applications of spectral analysis to ecological problems have been reviewed by Platt and Denman (1975) and time series analysis in ecology was the subject of a symposium proceedings edited by Shugart (1978).

1.3 Objectives

The objective of this paper is to develop mathematical models for the times series of mean daily Susitna River discharge at the Gold Creek gaging station (river mile 136.7), daily turbidity level, and daily outmigration rates of chinook salmon (*Oncorhynchus tshawytscha*) and sockeye salmon (*O. nerka*) at the Talkeetna Station outmigrant traps (river mile 103.0) during the open water seasons of 1983 and 1984. Because time series analysis can provide an efficient summarization of a data set by a few parameters (Hipel et al. 1978), these models will be used to statistically describe the present conditions. The discharge and turbidity information will be useful for examining their relationship with salmon fry outmigration as well as with other species and life history events. In addition, transfer function models for discharge-turbidity, discharge-chinook outmigration and discharge-sockeye outmigration are developed to describe the relationship between these variable and to be used as a possible technique to forecast future values or to examine the probable effects of the proposed dams.

Turbidity was chosen as a variable of interest because of its strong relationship with discharge, because of its importance in determining the distribution of rearing juvenile salmon (Suchanek et al. 1984), and because trapping of suspended sediment from the glaciers in the dam impoundment would create a turbidity regime substantially different from the present regime. Chinook salmon were chosen because this species rears in sloughs and side channels affected by mainstem discharge and because chinook salmon have been selected as the evaluation species of the impact assessment study (EWT&A 1985). The sockeye salmon time series was chosen because mainstem discharge affects sloughs which are both natal and rearing areas for this species. While chinook salmon spawn mainly in tributaries in this system, sockeye salmon spawn mostly in mainstem sloughs.

2.0 METHODS

All of the time series work was done using the BMDP statistical package (Dixon et al. 1981). Univariate models were developed for the four time series: discharge, turbidity, and chinook and sockeye outmigration. Then, transfer function models were constructed for turbidity and the two salmon time series as output with the discharge series as input.

2.1. Time Series Models

Box-Jenkins models can be summarized as follows (Box and Jenkins 1976; McCleary and Hay 1980; Chatfield 1984). Suppose there is a time series y_t , t = 1..N. Then y_t is a moving average process of order q (or an MA(q) process) if

$$y_t = \theta_0 a_t + \theta_1 a_{t-1} + \theta_2 a_{t-2} + \ldots + \theta_q a_{t-q}$$

where θ_i are constants and θ_0 = 1. The term a_t is a white nose process. White noise consists of a series of random shocks, each distributed normally and independently about a zero mean with a constant variance. y_t is an autoregressive process of order p (or an AR(p) process) if

$$y_t = \phi_1 y_{t-1} + \phi_2 y_{t-2} + \ldots + \phi_p y_{t-p} + a_t$$

where ϕ_i are constants. This is similar to a multiple regression model except that y_t is regressed not on independent variables but on past values of itself. A first order autoregressive process, AR(1), has the form:

$$y_t = \phi_1 y_{t-1} + a_t$$

Box and Jenkins (1976) define a backward shift operator B as:

$$B^m(Y_t) = Y_{t-m}$$

For m = 1,

$$BY_t = Y_{t-1}$$ or, the previous value.

Using B, the AR(1) equation can be written:

$$y_t = \frac{a_t}{1 - \phi_1 B}$$

Time series resulting from a mixture of AR and MA processes are called ARMA(p,q) models and have the form:

$$y_t = \phi_1 y_{t-1} + \ldots + \phi_p y_{t-p} + a_t + \theta_1 a_{t-1} + \ldots + \theta_q a_{t-q}$$

Using the backward shift operator B, an ARMA (1,1) may be written as:

$$y_t = (1 - \phi_1 B)^{-1} (1 - \theta_1 B) a_t$$

ARMA (p,q) models are appropriate only when the time series is stationary. Stationary means that there is no systematic change in the mean or the variance over time and that there are no strictly periodic variations (Chatfield 1984); in other words, the mean, variance, and autocovariance are not dependent on time. Time series which are not stationary can sometimes be handled by "differencing" the series. Taking the difference of adjacent values gives a differencing order, d, of one:

$$\nabla^d Y_t = Y_t - Y_{t-1} \quad , \; d = 1$$

Such models are said to be "integrated" and are denoted by ARIMA(p,d,q) where p is the order of the autoregressive component, d is the order of differencing, and q is the order of the moving average component.

Time series with seasonal variations, such as would occur in a multiple year series of daily water temperature measurements, can be made stationary by seasonal differencing. For example, the value for April 15 of one year is subtracted from the value for April 15 of the following year, and so on for all days of the year.

It has been assumed above that the time series had a mean value of zero. With stationary time series which have a non-zero mean (which is the case for all time series discussed in this paper) the mean has to be subtracted from every y_i term. For example, the form of an AR(1) model would be:

$$y_t = \mu + \phi_1 (y_{t-1} - \mu) + a_t$$

The autocorrelation function plays a major role in identifying and building time series models. A regular correlation coefficient measures the correlation between N pairs of observations on two variables. The autocorrelation coefficient is somewhat similar except that it measures the correlation between all observations of the same variable at a given distance apart in time (that is, between Y_t and Y_{t-k} for all values of t). Also, the covariance is estimated only over N-k pairs of observations (McCleary and Hay 1980). Autocorrelation coefficients at different lags indicate the extent to which one value of the series is related to previous values and can be used to evaluate the duration and the degree of the "memory" of the process. The autocorrelation function (ACF) is the set of autocorrelation (AC) coefficients at different lags associated with a time series; a plot of the ACF is called a correlogram (Chatfield 1984).

The ACF is defined as:

$$ACF_k = \frac{\text{covariance}(Y_t, Y_{t+k})}{\text{variance}(Y_t)}$$

and is estimated by:

$$ACF_k = \frac{\sum_{t=1}^{N-k} (Y_t - \bar{Y})(Y_{t+k} - \bar{Y})}{\sum_{t=1}^{N} (Y_t - \bar{Y})^2} \cdot \frac{N}{N-k}$$

A partial autocorrelation (PAC) coefficient measures the excess correlation at lag k which is not accounted for by an autoregressive model of order k-1. The set of PAC's at different lags associated with a time series is called the partial autocorrelation function (PACF).

There are three steps in developing an ARIMA model: model identification, parameter estimation, and diagnostic checking (Box and Jenkins 1976). ARIMA model building is an iterative process. The first thing to do is to look at a plot of the time series. Time series that are not stationary must be made so by trend removal which can be accomplished by either differencing the series or by polynomial regression. Examination of the autocorrelation function (ACF) and the partial autocorrelation function (PACF) of a stationary series helps to identify a possible ARIMA model. The next step is to estimate the parameters of the model and again examine the ACF and PACF plots, this time on the residuals from the model. This process is repeated until the residuals show no significant AC's or PAC's at any lag, which indicates that the residuals are generated by a white noise process.

2.2. The Data

Mean daily discharge values for 1983 and 1984 (Fig. 2, Fig. 3) were obtained from the U.S. Geological Survey gaging station on the Susitna River at Gold Creek, river mile 136.7 (Still et al. 1984; U. S. Geological Survey provisional data, 1984). The time series frame examined was May 18 to August 30 (105 observations). Discharge levels begin to decline in September when glacier melting decreases; hence, a longer series would not be stationary. Throughout this paper, the unit for discharge is one thousand cubic feet per second, except when logarithmic transformation is used - then, the unit is cubic feet per second.

Outmigration rate (Fig. 2, Fig. 3) was measured by two outmigrant traps, one on each bank, located at river mile 103.0 (Roth et al. 1984; Roth and Stratton 1985). The rate is reported as number of fish per trap hour with catch from the two traps combined. Only age 0+ fry were used in the analysis because the traps were not efficient at capturing age 1+ fry and, consequently, the numbers were low. Further, age 1+ chinook and sockeye salmon have essentially completed their outmigration from this reach of river by the end of July so the time series are shorter.

The chinook salmon time series for 1983 runs from May 18 (shortly after ice-out) to August 30 (when outmigration is winding down), a total of 105 observations. The 1983 sockeye salmon data was not examined. There were six days during the 105 day series when the outmigrant traps were

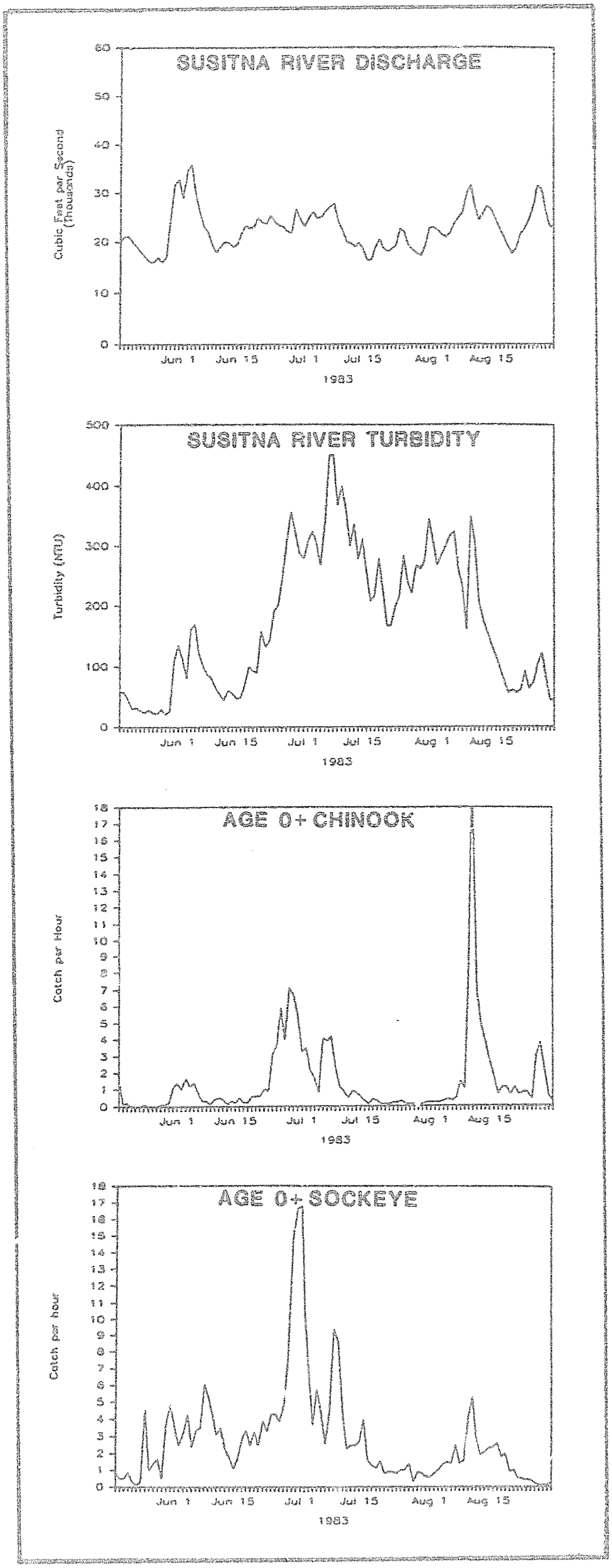


Figure 2. Discharge, turbidity, and chinook and sockeye salmon outmigration rate, 1983.

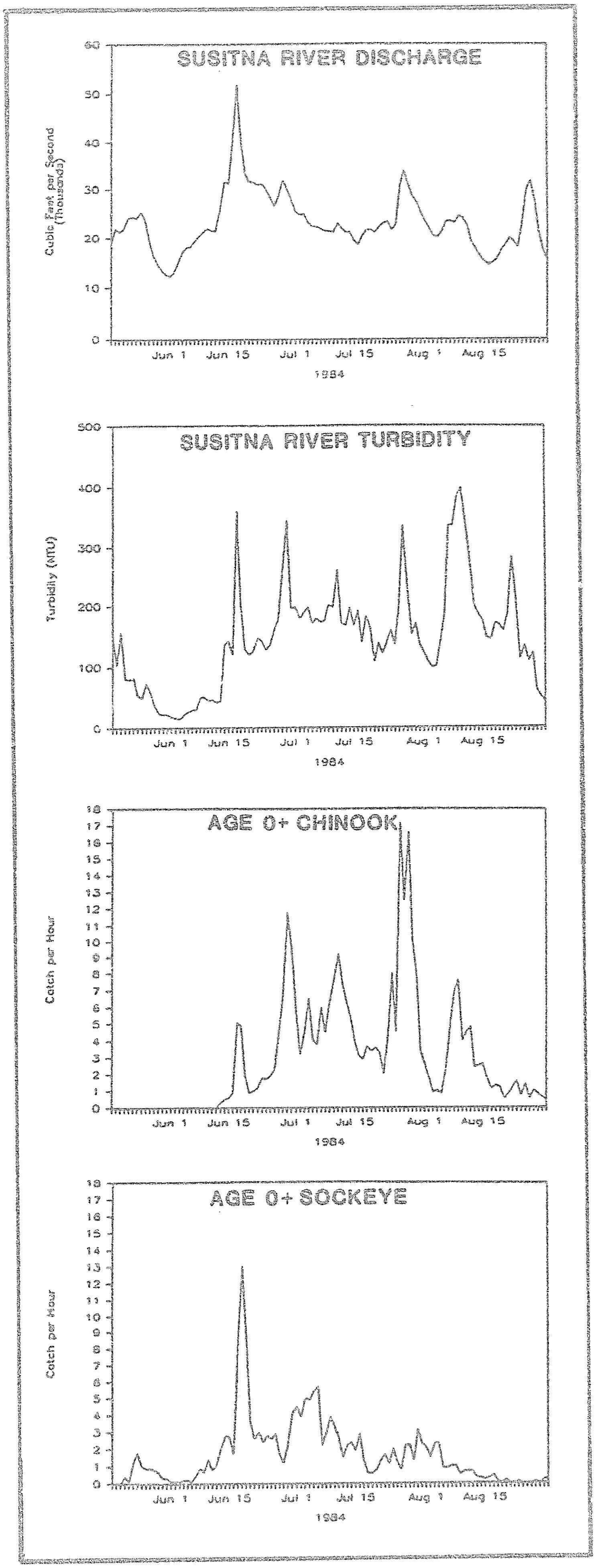


Figure 3. Discharge, turbidity, and chinook and sockeye salmon outmigration rate, 1984.

not fished - a one day, a two day, and a three day period. Although values for gaps in time series can be estimated by a spline method, the gaps in the outmigration series are short enough so that a simple interpolation of values is sufficient (Sturges 1983).

In 1984, the traps were continuously operated from May 14 to October 6. However, the series were cut off at the end of August in order to be comparable to 1983 and to achieve a stationary series. About 98% of the cumulative outmigration of age 0+ chinook and sockeye fry in 1984 had occurred by the end of August (Roth and Stratton 1985).

Daily water samples for turbidity (Fig. 2, Fig. 3) were taken at the outmigrant trap station and measured with an HF Instruments Model No. DRT-15B field turbidometer (Roth et al. 1984; Roth and Stratton 1985). Units are in nephelometric turbidity units (NTU). Only the 1984 turbidity series was examined.

2.3. Identification and Estimation of Time Series Models

The methods described above were applied to the four time series. The AC and PAC plots were examined to help identify possible AR and MA components. A tentative model was developed and the parameters estimated. The BMDP Box-Jenkins program estimates parameters by both the conditional least squares method and the backcasting method. The estimates chosen for this paper were from whichever method gave the lowest residual mean square. Insignificant components were removed from the model.

The residuals were checked to see if there was significant departure from the assumption that they were white noise. If not, the model was adequate.

The time series of mean daily discharge from May 18 to August 30 appeared to be stationary so no differencing was done. A plot of the range of sub-groups of the series against the mean of the sub-groups (as suggested by Hoff (1983)) indicated that a log transformation of the data would be helpful in stabilizing the magnitude of the fluctuations throughout the series; therefore, a model was also developed for the log transformed data. As the turbidity time series was questionably stationary, models were developed for both the original series and for a differenced series.

Models were developed for the chinook and sockeye salmon outmigration rate time series on both the raw data and on data transformed by ln (x + 1). The transformation ln(x + 1) was used to avoid taking logarithms of zero; there was zero catch on some days.

2.4. Transfer Function Models

When there is an independent variable which is also a time series, a transfer function model can be developed. This model consists of the transfer function component from the independent variable as well as the

ARIMA component (or noise component) from the dependent variable (McCleary and Hay 1980) and can be represented as:

$$Y_t = f(X_{t-b}) + N_t$$

where: Y_t is the output time series
X_t is the input time series
$f(X_{t-b})$ is the transfer function component
N_t is the noise or ARIMA component

Transfer function models can be bivariate (when there is one independent variable) or multivariate (more than one independent variable).

The steps to take in developing a transfer function model (Box and Jenkins 1976; McCleary and Hay 1980; Dixon et al. 1981) are: (1) develop an ARIMA model for the input series, obtaining the pre-whitened input (residuals), (2) filter the output series by the model for the input series, (3) cross-correlate the residuals from the first two steps, (4) identify the form of the transfer function component from the cross correlation function, (5) assuming the errors are white noise, estimate the values for the parameters, (6) identify an ARIMA model for the residuals, (7) if the ARIMA component is not white noise, combine the ARIMA component with the transfer function component to form a new model, (8) estimate the parameter values, and (9) examine the ACF and

PACF plots on the residuals from the new model to see if the model is adequate.

Transfer function models were developed in this fashion for discharge/turbidity, discharge/chinook outmigration, and discharge/sockeye outmigration. Only one input (discharge) was used. Multiple input transfer function models (Liu and Hanssens 1980) or multivariate time series models (Mendelssohn 1982) can be developed, but are substantially more complex.

3.0 RESULTS

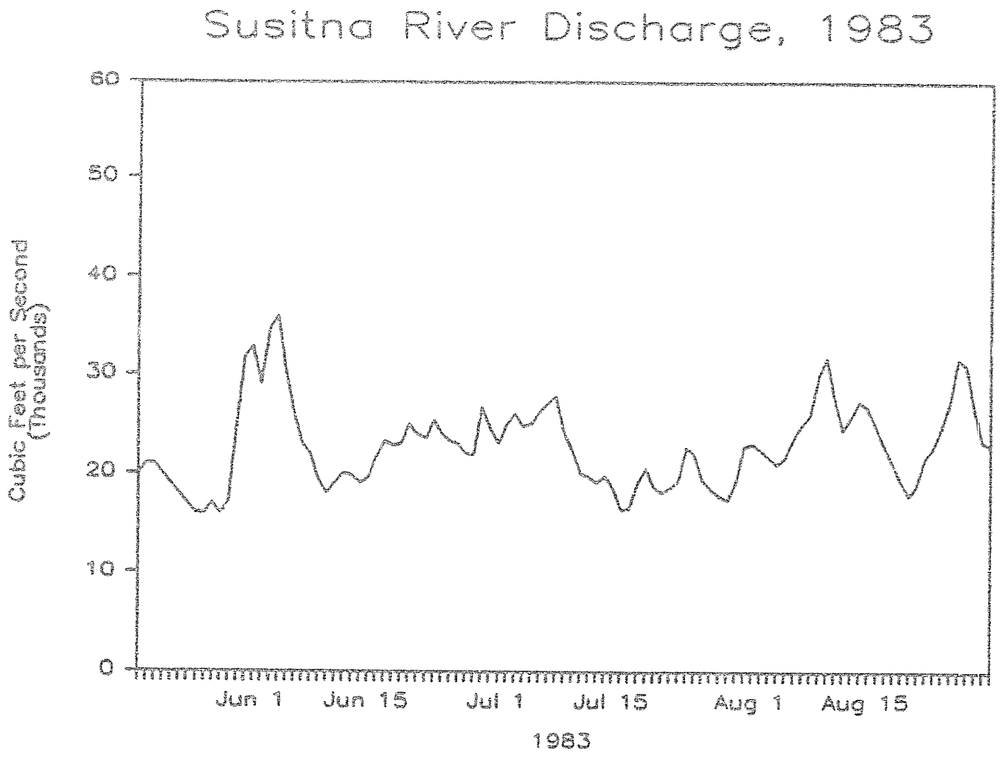
3.1. Univariate Model for Mean Daily Discharge

The time series of mean daily discharge during the summer of 1983 is shown in Fig. 4; the log-transformed data are in Fig. 6. ACF and PACF plots for the raw data are given in Fig. 5 and for the log- transformed data in Fig. 7. In all the ACF and PACF plots, the "+" symbol on either side of the vertical axis indicates the 95% confidence interval. The first order autoregressive component is strong in both the raw and the transformed series. The ACF and PACF plots for the raw data indicate that a moving average component is required. Models containing various combinations of first and second order AR and MA terms were examined. Of the acceptable models identified, the model with the lowest standard errors on the parameter estimates and the least significant residuals was an ARMA(2,2). However, the ARMA(1,1) was nearly as good as the ARMA (2,2) so, in keeping with Box and Jenkins' (1976) advice that a parsimonious model (i.e., the one with the fewest possible parameters) is desirable, the ARMA(1,1) is considered the "best" model for the non-transformed data. Parameter estimates are:

$$\hat{\phi}_1 = .992 \text{ with std. error of } .0135$$
$$\hat{\theta}_1 = -.580 \text{ with std. error of } .0807$$

The model is:

$$y_t = 22.7 + .99(y_{t-1} - 22.7) - .58\, a_{t-1} + a_t$$



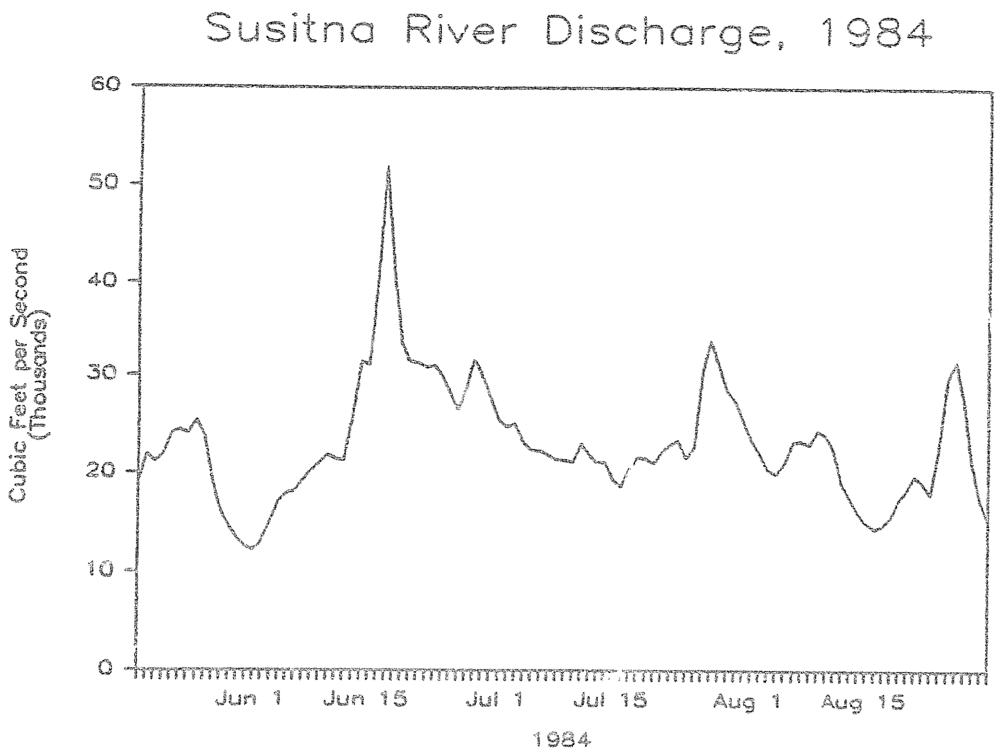


Figure 4. Susitna River discharge time series at the Gold Creek gaging station, 1983 and 1984.

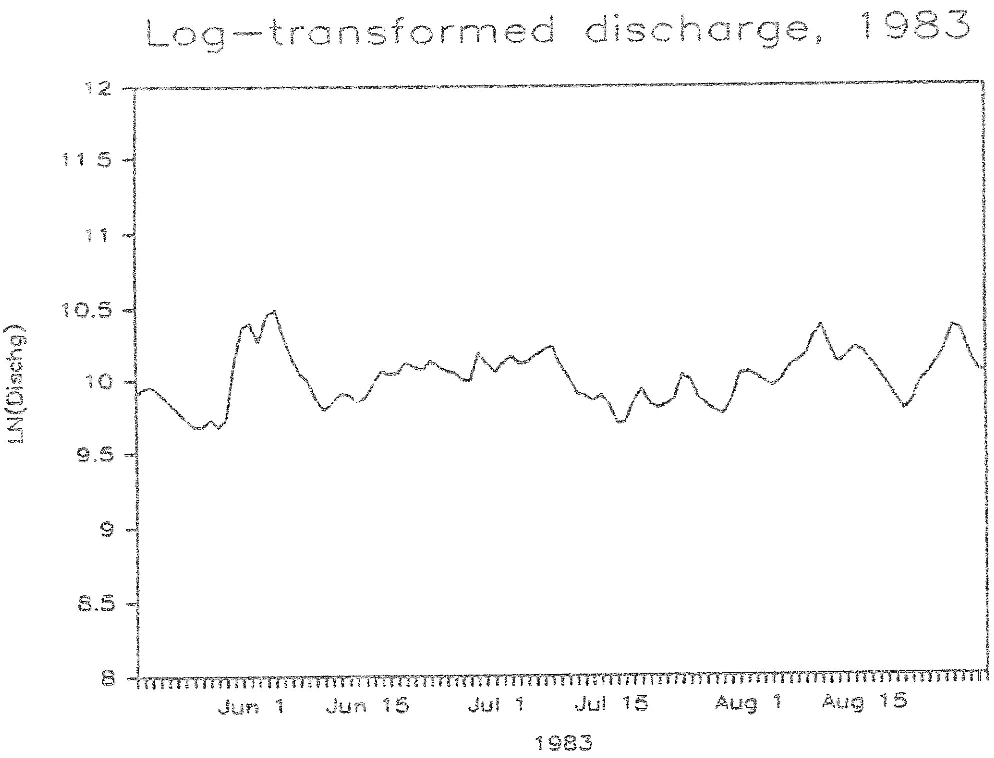
```
PLOT OF AUTOCORRELATIONS

               -1.0  -.8  -.6  -.4  -.2   .0   .2   .4   .6   .8  1.0
LAG   CORR.    +----+----+----+----+----+----+----+----+----+----+
                                          I
  1    .859           +    IXXXX+XXXXXXXXXXXXXXXX
  2    .627        +       IXXXXXXX+XXXXXXX
  3    .444       +        IXXXXXXXX+XX
  4    .266       +        IXXXXXXX +
  5    .057       +        IX       +
  6   -.122       +     XXXI        +
  7   -.230       +  XXXXXXI        +
  8   -.288       + XXXXXXXI        +
  9   -.317      + XXXXXXXXI         +
 10   -.324      + XXXXXXXXI         +
 11   -.281      +  XXXXXXXI         +
 12   -.202      +    XXXXXI         +
 13   -.134      +      XXXI         +
 14   -.077      +       XXI         +
 15    .002      +         I         +
 16    .075      +         IXX       +
 17    .094      +         IXX       +
 18    .055     +          IX         +
 19    .014     +          I          +
 20   -.021     +         XI          +
 21   -.061     +        XXI          +
 22   -.097     +        XXI          +
 23   -.137     +       XXXI          +
 24   -.149     +      XXXXI          +
 25   -.138     +       XXXI          +
 26   -.141     +      XXXXI          +
 27   -.160     +      XXXXI          +
 28   -.135     +       XXXI          +
 29   -.082     +        XXI          +
 30   -.030     +         XI          +
 31    .037     +          IX         +
 32    .118     +          IXXX       +


PLOT OF PARTIAL AUTOCORRELATIONS

               -1.0  -.8  -.6  -.4  -.2   .0   .2   .4   .6   .8  1.0
LAG   CORR.    +----+----+----+----+----+----+----+----+----+----+
                                          I
  1    .859           +    IXXXX+XXXXXXXXXXXXXXXX
  2   -.425     XXXXXX+XXXXI    +
  3    .196           +    IXXXXX
  4   -.325        XXX+XXXXI    +
  5   -.141           +XXXXI    +
  6   -.022           +   XI    +
  7   -.013           +    I    +
  8   -.023           +   XI    +
  9   -.009           +    I    +
 10   -.092           +  XXI    +
 11    .128           +    IXXX +
 12   -.050           +   XI    +
 13   -.031           +   XI    +
 14    .026           +    IX   +
 15    .071           +    IXX  +
 16   -.064           +  XXI    +
 17   -.066           +  XXI    +
 18   -.158           +XXXXI    +
 19    .059           +    IX   +
 20   -.093           +  XXI    +
 21    .067           +    IXX  +
 22   -.015           +    I    +
 23   -.107           + XXXI    +
 24    .029           +    IX   +
 25    .021           +    IX   +
 26   -.203           XXXXXI    +
 27    .036           +    IX   +
 28    .050           +    IX   +
 29   -.048           +   XI    +
 30    .129           +    IXXX +
 31    .040           +    IX   +
 32   -.019           +    I    +
```

Figure 5. Plots of autocorrelations and partial autocorrelations for 1983 discharge time series.



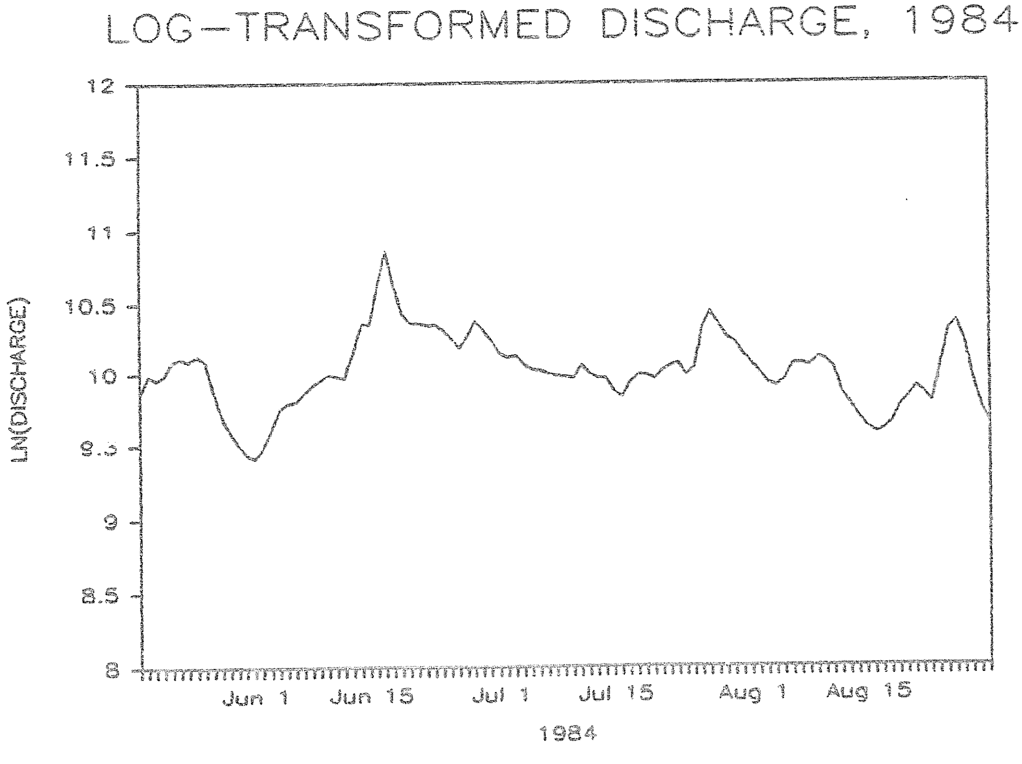


Figure 6. Log-transformed discharge time series, 1983 and 1984.

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PLOT OF AUTOCORRELATIONS

LAG	CORR.
1	.869
2	.644
3	.458
4	.280
5	.081
6	-.094
7	-.208
8	-.276
9	-.310
10	-.315
11	-.268
12	-.184
13	-.113
14	-.059
15	.014
16	.079
17	.090
18	.049
19	.004
20	-.034
21	-.073
22	-.112
23	-.151
24	-.173
25	-.172
26	-.160
27	-.192
28	-.166
29	-.112
30	-.050
31	.023
32	.100

PLOT OF PARTIAL AUTOCORRELATIONS

LAG	CORR.
1	.869
2	-.452
3	.192
4	-.301
5	-.137
6	-.015
7	-.031
8	-.029
9	.013
10	-.072
11	.159
12	-.045
13	-.064
14	.037
15	.070
16	-.097
17	-.049
18	-.141
19	.048
20	-.066
21	.046
22	-.029
23	-.044
24	.012
25	.008
26	-.141
27	.026
28	.034
29	-.017
30	.124
31	.017
32	-.02[illegible]

Figure 7. Plots of autocorrelations and partial autocorrelations for 1983 log-transformed discharge time series.

Neither the mean nor any of the autocorrelations or partial autocorrelations of the residuals was significant; therefore, the model is adequate.

The plots of both the ACF and PACF on the residuals from this model showed a slightly significant spike at a lag of 15 or 16 days. This could indicate that the discharge time series shows a periodicity of about 15 days, or slightly more than two weeks. This possibility was further examined by spectral analysis. The spectrum of discharge (Fig. 8) does in fact indicate a peak at a frequency of .065 (a period of 15 days). It is not known at this time if this periodicity is "real". It may be related to weather patterns in the basin which control solar insolation (cloud cover) and rainfall. A much longer time series of discharge would have to be examined to answer this question. A periodic term could be added to the ARMA(1,1) model (Box and Jenkins 1976) but, given the low significance level of the periodicity, it does not seem appropriate at this stage of model development.

Carrying the idea of parsimony a step further, it can be seen that an ARMA(1,0) model using the log-transformed data is adequate and has the lowest number of parameters. The parameter estimates for this model are:

$$\hat{\phi}_1 = .994 \text{ with std. error of } < .00005$$

giving

$$\ln y_t = 10.0 + .99(\ln y_{t-1} - 10.0) + a_t$$

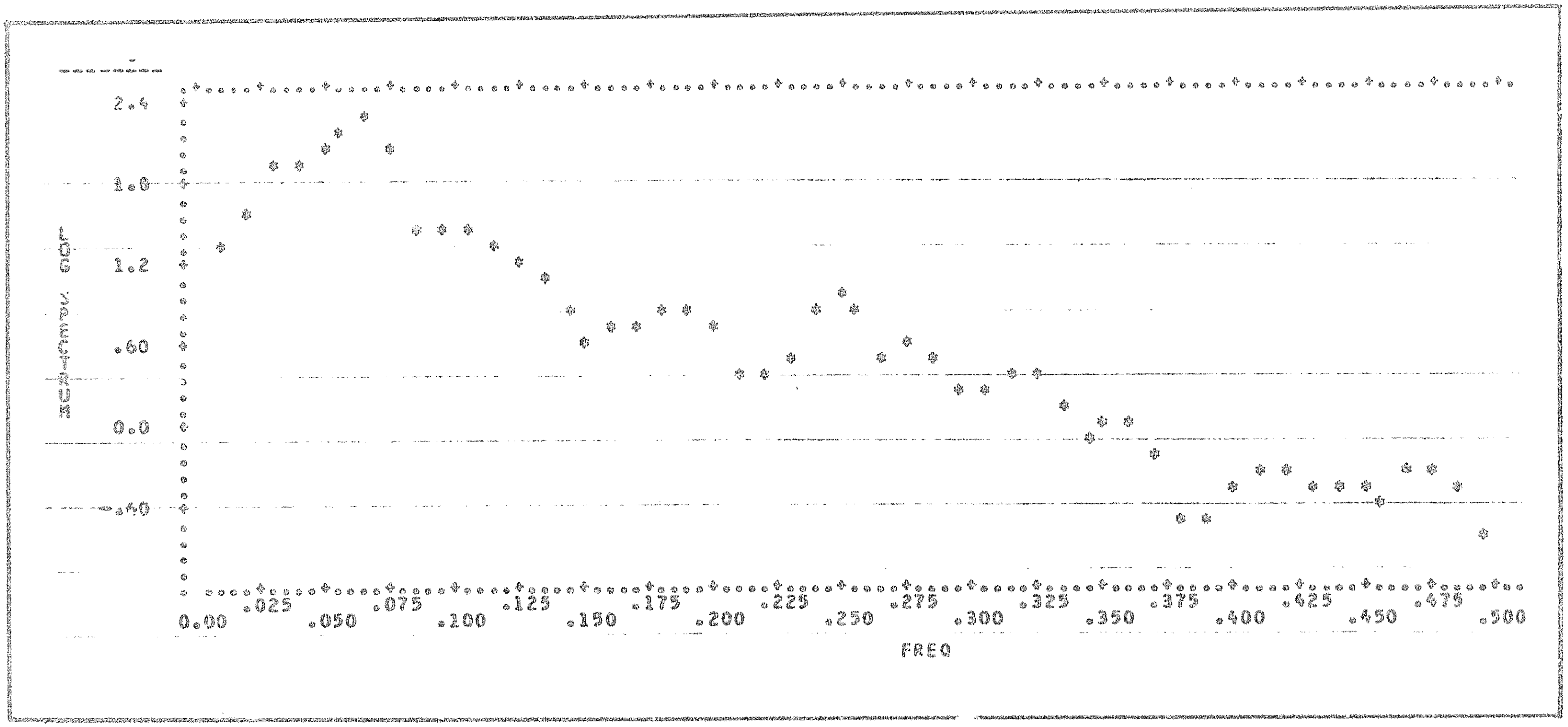

Figure 8. Spectrum of 1983 discharge time series.

The parameter $\hat{\phi}_1$ is very close to unity. If $\hat{\phi}_1$ were equal to 1.000, the model would be reduced to a random walk model (Chatfield 1984). That is, the log of the discharge for today is the same as the log of the discharge for yesterday plus a random error term. When $\hat{\phi}_1$ approaches 1.000 in a model with only one AR term, the series could be non-stationary (Hoff 1983). To test this, the series was differenced. The residuals from an ARIMA(1,1,0) model showed significant spikes, so the differencing did not help; the ARIMA(1,0,0) model is better.

The AC's on the residuals of the ARMA(1,0) model were a little better than those of the ARMA(1,1) on the non-transformed data. However, the mean of the residuals was slightly significant, so the ARMA(1,1) model on the raw data is probably superior to this one.

The 1984 discharge time series is shown in Fig. 4 and Fig. 6. The ACF and PACF plots (Fig. 9) are similar to those of 1983. An ARMA(1,1) model on the 1984 raw data was adequate, as it was in 1983. Parameter estimates are: $\bar{y}$ = 23.2; $\hat{\phi}_1$ = .808 (std. error = .0638); and $\hat{\theta}_1$ = -.692 (std. error = .0750). An AR(1) model on the log-transformed data was also adequate but, again, had a slightly significant mean residual. The ACF and PACF plots, using log-transformed data (Fig. 10), are similar to those of 1983, but perhaps show less indication of a moving average process. The estimate for ϕ_1 is .994 (exactly the same as the 1983 data), with a standard error of 0.0001 and for $\bar{y}$, is 10.0.

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PLOT OF AUTOCORRELATIONS

LAG	CORR.
1	.885
2	.700
3	.556
4	.430
5	.332
6	.268
7	.214
8	.153
9	.097
10	.062
11	.033
12	-.015
13	-.073
14	-.137
15	-.204
16	-.273
17	-.333
18	-.363
19	-.366
20	-.364
21	-.343
22	-.297
23	-.244
24	-.199
25	-.165
26	-.134
27	-.097
28	-.059
29	-.025
30	-.007
31	-.013
32	-.020

PLOT OF PARTIAL AUTOCORRELATIONS

LAG	CORR.
1	.885
2	-.379
3	.195
4	-.163
5	.115
6	-.011
7	-.033
8	-.061
9	-.002
10	.052
11	-.072
12	-.103
13	-.048
14	-.105
15	-.049
16	-.121
17	-.063
18	.041
19	-.034
20	-.043
21	.051
22	.042
23	.032
24	-.029
25	-.008
26	.015
27	.081
28	-.014
29	-.015
30	-.077
31	-.065
32	.001

Figure 9. Plots of autocorrelations and partial autocorrelations for 1984 discharge time series.

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PLOT OF AUTOCORRELATIONS

LAG	CORR.
1	.906
2	.747
3	.601
4	.478
5	.375
6	.292
7	.211
8	.137
9	.088
10	.057
11	.024
12	-.019
13	-.073
14	-.135
15	-.209
16	-.286
17	-.349
18	-.376
19	-.378
20	-.370
21	-.350
22	-.306
23	-.257
24	-.211
25	-.171
26	-.146
27	-.123
28	-.088
29	-.055
30	-.036
31	-.026
32	-.018

PLOT OF PARTIAL AUTOCORRELATIONS

LAG	CORR.
1	.906
2	-.420
3	.140
4	-.071
5	.016
6	-.008
7	-.099
8	.018
9	.060
10	-.033
11	-.062
12	-.077
13	-.073
14	-.073
15	-.155
16	-.069
17	-.023
18	.090
19	-.062
20	-.034
21	.039
22	.090
23	-.060
24	.002
25	-.019
26	-.023
27	.074
28	.019
29	-.058
30	-.030
31	-.023
32	-.047

Figure 10. Plots of autocorrelations and partial autocorrelations for 1984 log-transformed discharge time series.

3.2. Univariate Model for Turbidity

The time series for turbidity in 1983 (Fig. 11) was more complex than that of discharge. The ACF and PACF plots (Fig. 12) indicate a strong AR(1) component. However, AR(1), AR(2), and ARMA(1,1) models were not adequate to explain the series.

The series appears to border on being non-stationary because it increases in the spring as glacier melt increases and then declines in the fall. (This series would certainly be non-stationary over a longer time frame because the turbidity level is very low in the winter). The slow decay of the autocorrelations in the ACF (Fig. 12) also indicates non-stationarity.

Further investigation using the raw data showed that the series has a significant second order MA term, while the first order MA term is not significant. Both first and second order AR terms are significant. This gives the model:

$$y_t = 176.1 + .94\,(y_{t-1} - 176.1) + .06\,(y_{t-2} - 176.1) + .23\,a_{t-2} + a_t$$

with std. errors: on $\hat{\phi}_1$ = .0122

on $\hat{\phi}_2$ = .0234

on $\hat{\theta}_2$ = .0988

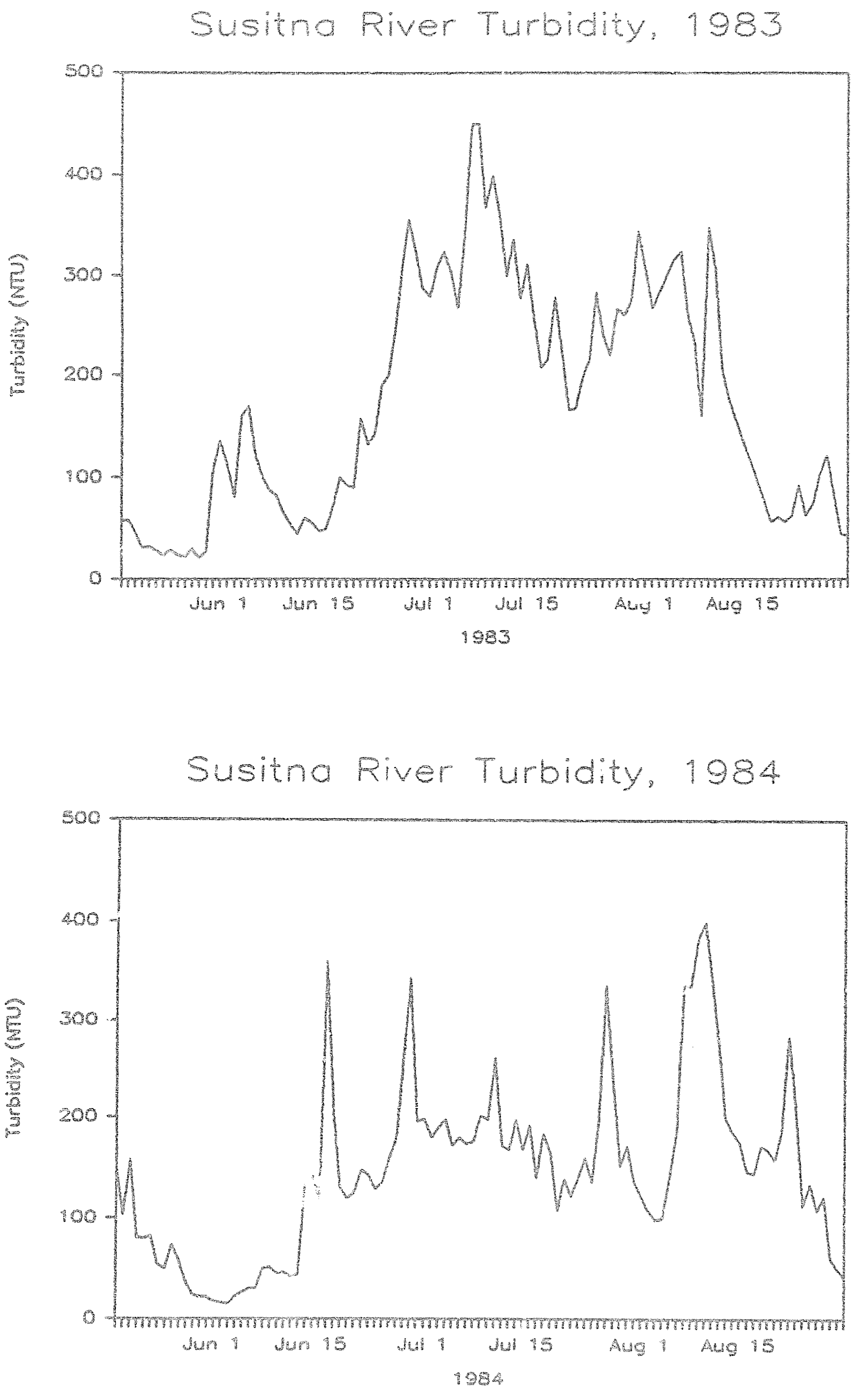

Figure 11. Turbidity time series at Talkeetna Station, 1983 and 1984.

PLOT OF AUTOCORRELATIONS

LAG	CORR.
1	.924
2	.850
3	.814
4	.781
5	.731
6	.666
7	.588
8	.524
9	.470
10	.417
11	.358
12	.302
13	.232
14	.164
15	.138
16	.133
17	.106
18	.069
19	.045
20	.041
21	.056
22	.053
23	.036
24	.015
25	-.001
26	.00[illegible]
27	-.0[illegible]1
28	-.011
29	-.0[illegible]
30	-.075
31	-.082
32	-.097

PLOT OF PARTIAL AUTOCORRELATIONS

LAG	CORR.
1	.924
2	-.025
3	.219
4	.007
5	-.070
6	-.135
7	-.170
8	-.017
9	-.011
10	.014
11	-.018
12	.005
13	-.136
14	-.075
15	.204
16	.155
17	-.013
18	-.021
19	-.017
20	.012
21	.078
22	-.065
23	-.010
24	-.124
25	-.09[illegible]
26	.053
27	-.0[illegible]
28	.0[illegible]
29	-.1[illegible]
30	.0[illegible]7
31	.04[illegible]
32	-.111

Figure 12. Plots of autocorrelations and partial autocorrelations for 1983 turbidity time series.

While this ARMA model is adequate for the time frame examined, in general, an integrated model (i.e., one with a differencing operation) is probably more appropriate. The differenced series (Fig. 13) is clearly stationary with a mean close to zero. The ACF and PACF plots for the differenced series (Fig. 14) verify that the differencing was successful. The differenced series could be adequately modeled with just the second order MA term; the first order autoregression term was not significant in the differenced series. The equation is:

$$Z_t = Z_{t-1} + .23\, a_{t-2} + a_t$$

$$\text{where: } Z_t = y_t - y_{t-1}$$

with std. error on $\hat{\theta}_2$ = .0972 and the mean of the residuals insignificant.

The second order moving average term is likely related to the random "shock" caused by a rising discharge (which is in turn caused by rainfall) which resuspends sediment. It takes a few days after the rainfall is over for this perturbation in turbidity level to drop to the pre-rainfall level.

3.3. <u>Univariate Model for Age 0+ Chinook Salmon Outmigration</u>

The time frame chosen for Age 0+ chinook salmon was the same as that of discharge (Fig. 15). The plots of the ACF and the PACF for 1983 (Fig. 16) show a strong first order autoregresssive component. In fact, an ARMA(1,0) model, abbreviated as AR(1), adequately represents the data.

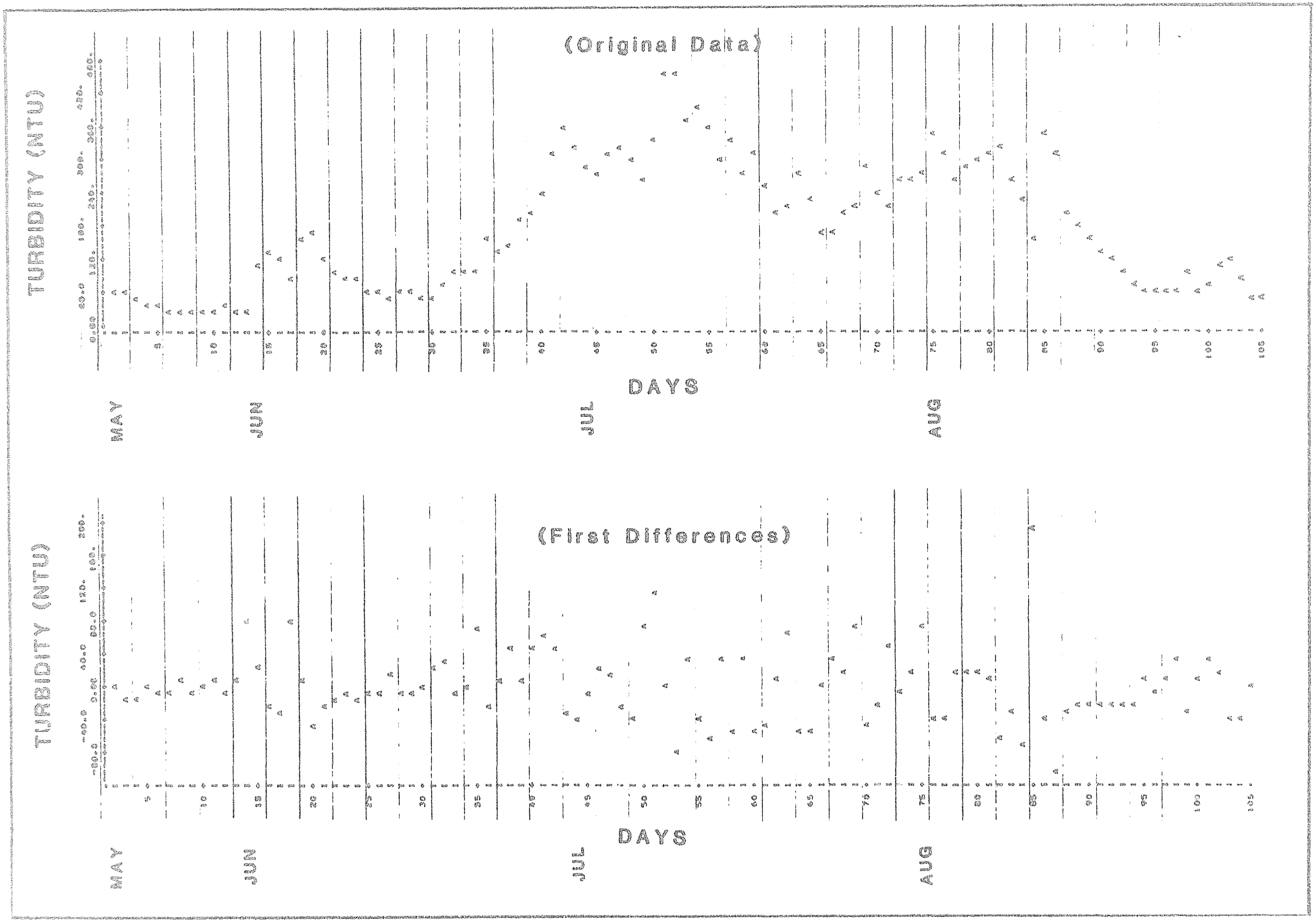

Figure 13. Turbidity time series, 1983. (Day 1 = May 18, Day 105 = August 30).

```
PLOT OF AUTOCORRELATIONS

              -1.0 -.8  -.6  -.4  -.2   .0   .2   .4   .6   .8  1.0
LAG   CORR.  +----+----+----+----+----+----+----+----+----+----+
                                      I
  1   -.015                      +    I    +
  2   -.271                    XX+XXXXI    +
  3   -.005                      +    I    +
  4    .111                      +    IXXX +
  5    .101                      +    IXXX +
  6    .083                      +    IXX  +
  7   -.076                      +  XXI    +
  8   -.110                      + XXXI    +
  9   -.010                      +    I    +
 10    .053                      +    IX   +
 11   -.029                      +   XI    +
 12    .121                      +    IXXX +
 13    .059                      +    IX   +
 14   -.297                    XX+XXXXI    +
 15   -.162                     + XXXXI     +
 16    .167                     +     IXXXX +
 17    .143                     +     IXXXX +
 18   -.068                     +   XXI     +
 19   -.117                     +  XXXI     +
 20   -.126                     +  XXXI     +
 21   -.009                     +     I     +
 22    .153                     +     IXXXX +
 23    .045                     +     IX    +
 24   -.003                     +     I     +
 25   -.154                     + XXXXI     +
 26    .041                     +     IX    +
 27    .047                     +     IX    +
 28    .167                     +     IXXXX +
 29   -.01[illegible]                    +      I      +
 30   -.134                    +   XXXI      +
 31    .034                    +      IX     +
```

```
PLOT OF PARTIAL AUTOCORRELATIONS

              -1.0 -.8  -.6  -.4  -.2   .0   .2   .4   .6   .8  1.0
LAG   CORR.  +----+----+----+----+----+----+----+----+----+----+
                                      I
  1   -.015                      +    I    +
  2   -.271                    XX+XXXXI    +
  3   -.016                      +    I    +
  4    .040                      +    IX   +
  5    .107                      +    IXXX +
  6    .140                      +    IXXX +
  7   -.015                      +    I    +
  8   -.071                      +  XXI    +
  9   -.069                      +  XXI    +
 10   -.031                      +   XI    +
 11   -.065                      +  XXI    +
 12    .165                      +    IXXXX+
 13    .104                      +    IXXX +
 14   -.223                     X+XXXXI    +
 15   -.188                      XXXXXI    +
 16   -.025                      +   XI    +
 17    .065                      +    IXX  +
 18    .025                      +    IX   +
 19    .027                      +    IX   +
 20   -.078                      +  XXI    +
 21   -.104                      + XXXI    +
 22   -.00[illegible]                     +    I    +
 23    .0[illegible]                      +    I    +
 24    .161                      +    IXXXX+
 25   -.10[illegible]                     + XXXI    +
 26    .10[illegible]                      +    IXXX +
 27   -.013                      +    I    +
 28    .10[illegible]                      +    IXXX +
 29   -.117                      + XXXI    +
 30   -.060                      +  XXI    +
 31    .166                      +    IXXXX+
```

Figure 14. Plots of autocorrelations and partial autocorrelations for differenced 1933 turbidity time series.

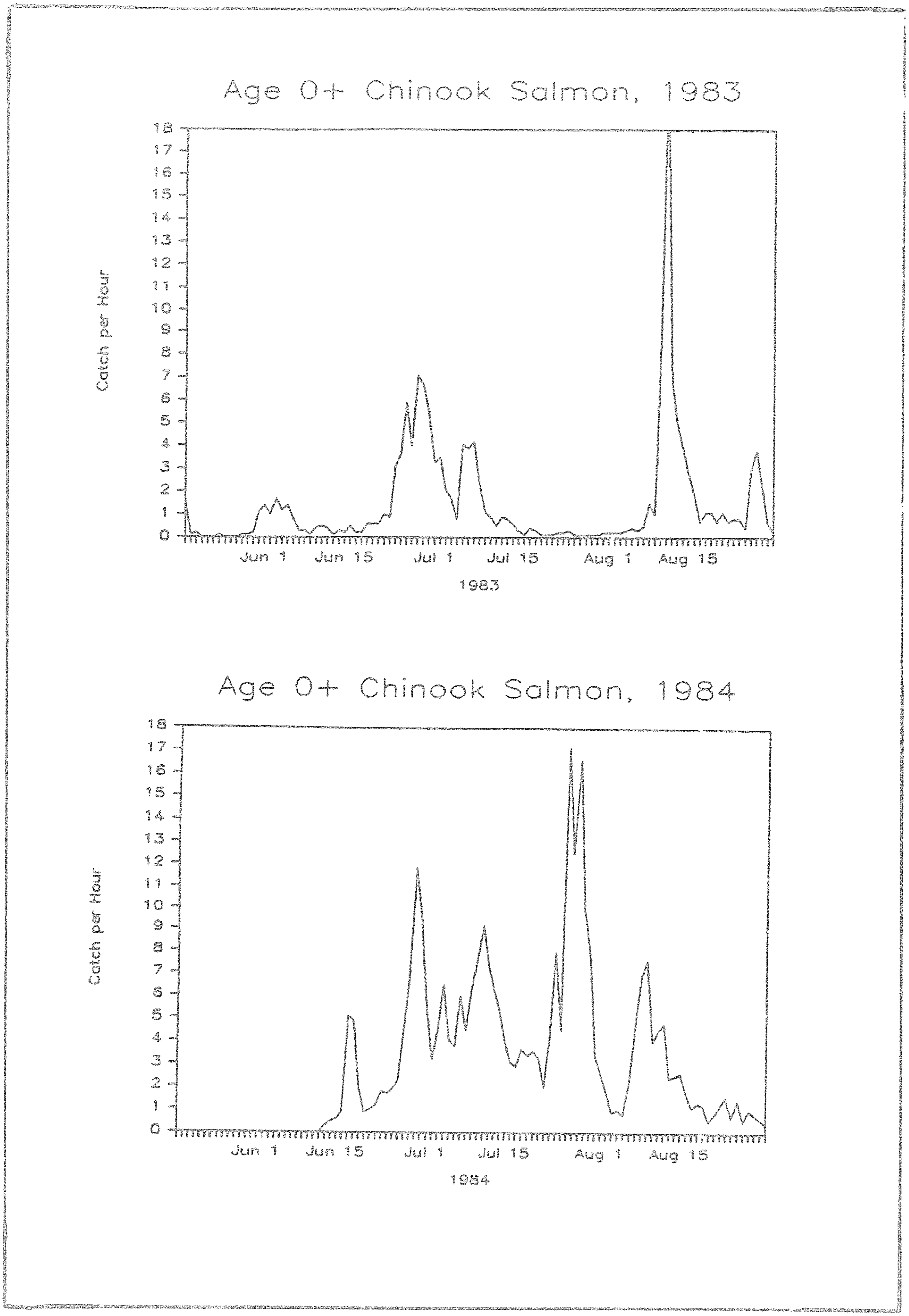

Figure 15. Age 0+ chinook salmon outmigration rate time series, 1983 and 1984.

```
PLOT OF AUTOCORRELATIONS

            -1.0  -.8   -.6   -.4   -.2    .0    .2    .4    .6    .8   1.0
LAG   CORR. +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
                                           I
  1    .657                          +     IXXXX+XXXXXXXXXXX
  2    .398                        +       IXXXXXX+XXX
  3    .284                        +       IXXXXXXX
  4    .182                        +       IXXXXX +
  5    .090                        +       IXX      +
  6    .029                        +       IX       +
  7    .005                        +       I        +
  8   -.001                        +       I        +
  9   -.041                        +      XI        +
 10   -.047                        +      XI        +
 11   -.075                        +     XXI        +
 12   -.087                        +     XXI        +
 13   -.103                        +    XXXI        +
 14   -.119                       +     XXXI         +
 15   -.075                       +      XXI         +
 16   -.052                       +       XI         +
 17   -.099                       +      XXI         +
 18   -.160                       +   XXXXI          +
 19   -.179                       +   XXXXI          +
 20   -.156                       +   XXXXI          +
 21   -.145                       +   XXXXI          +
 22   -.141                       +   XXXXI          +
 23   -.127                       +    XXXI          +
 24   -.123                       +    XXXI          +
 25   -.124                       +    XXXI          +
 26   -.122                       +    XXXI          +
 27   -.117                       +    XXXI          +
 28   -.117                       +    XXXI          +
 29   -.124                       +    XXXI          +
 30   -.137                       +    XXXI          +
 31   -.124                       +    XXXI          +
 32   -.101                       +    XXXI          +


PLOT OF PARTIAL AUTOCORRELATIONS

            -1.0  -.8   -.6   -.4   -.2    .0    .2    .4    .6    .8   1.0
LAG   CORR. +-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
                                           I
  1    .657                          +     IXXXX+XXXXXXXXXXX
  2   -.060                          +    XI   +
  3    .083                          +     IXX +
  4   -.044                          +    XI   +
  5   -.034                          +    XI   +
  6   -.025                          +    XI   +
  7    .009                          +     I   +
  8    .007                          +     I   +
  9   -.062                          +   XXI   +
 10    .016                          +     I   +
 11   -.071                          +   XXI   +
 12   -.001                          +     I   +
 13   -.049                          +    XI   +
 14   -.031                          +    XI   +
 15    .059                          +     IX  +
 16   -.020                          +     I   +
 17   -.099                          +   XXI   +
 18   -.100                          +  XXXI   +
 19   -.036                          +    XI   +
 20    .006                          +     I   +
 21   -.022                          +    XI   +
 22   -.031                          +    XI   +
 23   -.034                          +    XI   +
 24   -.046                          +    XI   +
 25   -.042                          +    XI   +
 26   -.031                          +    XI   +
 27   -.034                          +    XI   +
 28   -.045                          +    XI   +
 29   -.050                          +    XI   +
 30   -.071                          +   XXI   +
 31   -.034                          +    XI   +
 32   -.029                          +    XI   +
```

Figure 16. Plots of autocorrelations and partial autocorrelations for 1983 chinook salmon outmigration time series.

Although the plot of the range of sub-groups against the mean indicated the need for a logarithmic transformation, the residual AC's of an AR(1) model on the log- transformed data (Fig. 17) were slightly larger (but still insignificant) than those of the AR(1) model on the raw data. The standard error on $\hat{\phi}_1$, however, was lower with the log-transformed data. ACF and PACF plots for the log-transformed data are shown in Fig. 18. The AR(1) model for the raw data was:

$$y_t = 1.52 + .66\,(y_{t-1} - 1.52) + a_t$$

with standard error on $\hat{\phi}_1$ = .0743.

The AR(1) model for the log-transformed data was:

$$\ln(y_t + 1) = .67 + .92\,(\ln(y_{t-1} + 1) - .67) + a_t$$

with standard error on $\hat{\phi}_1$ = .0363.

The mean of the residuals was not significant.

The time series plot for age 0+ chinook salmon outmigration in 1984 (Fig. 15) shows a different pattern from that of 1983. The fry did not begin to migrate in 1984 until about June 12. The low level of outmigration early in the season causes a time series which is non-stationary. To avoid this problem, the dates selected to be included in

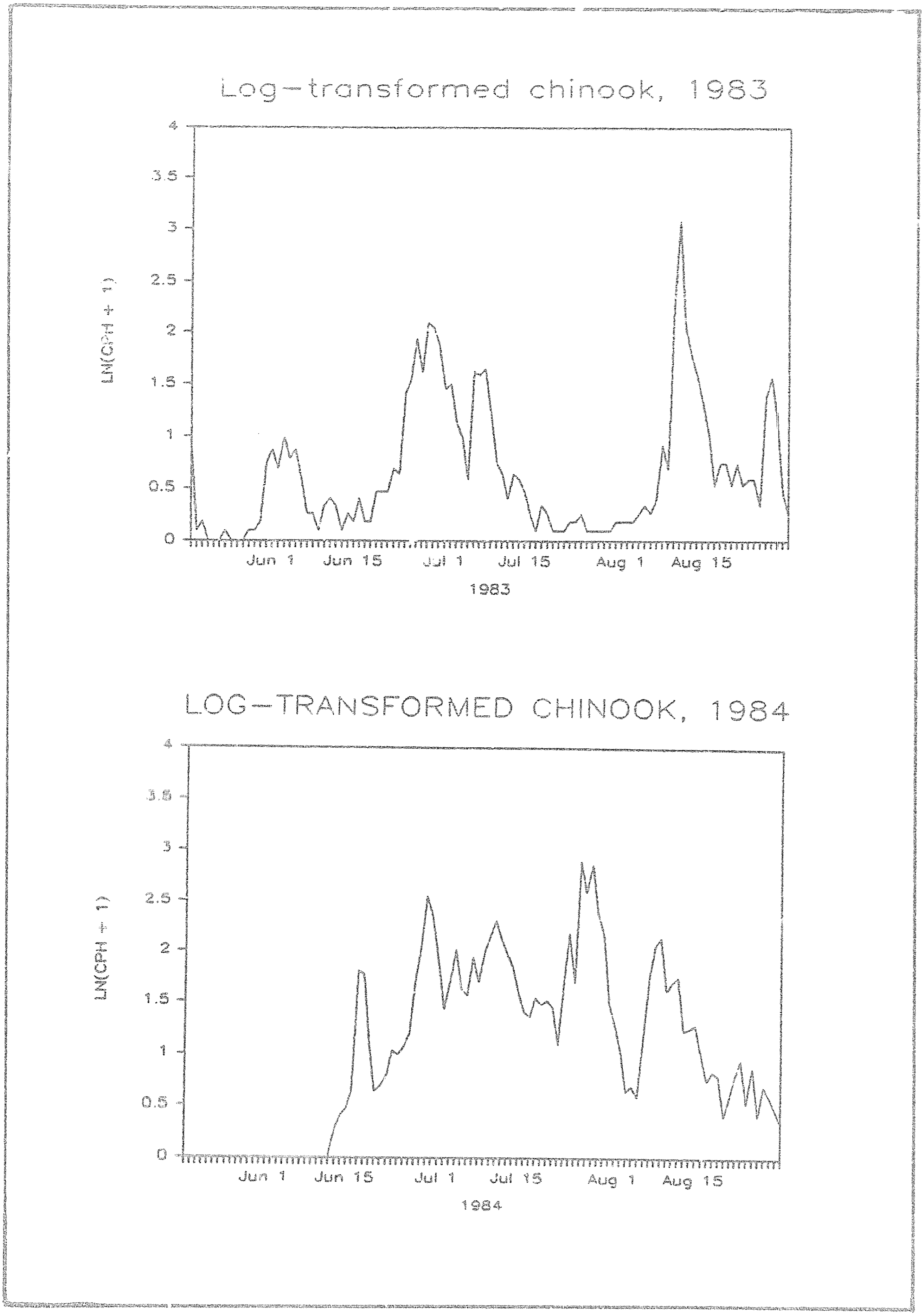

Figure 17. Log-transformed age 0+ chinook salmon outmigration rate, 1983 and 1984.

PLOT OF AUTOCORRELATIONS

LAG	CORR.
1	.847
2	.695
3	.559
4	.445
5	.343
6	.238
7	.165
8	.115
9	.028
10	-.007
11	-.053
12	-.084
13	-.117
14	-.148
15	-.156
16	-.146
17	-.196
18	-.249
19	-.288
20	-.298
21	-.292
22	-.288
23	-.262
24	-.251
25	-.248
26	-.245
27	-.241
28	-.245
29	-.260
30	-.273
31	-.248
32	-.205

PLOT OF PARTIAL AUTOCORRELATIONS

LAG	CORR.
1	.847
2	-.076
3	-.035
4	-.010
5	-.033
6	-.086
7	.037
8	.016
9	-.183
10	.122
11	-.093
12	-.010
13	-.045
14	-.022
15	.003
16	.042
17	-.226
18	-.099
19	.024
20	-.021
21	.015
22	-.024
23	.015
24	-.118
25	.016
26	-.089
27	-.024
28	-.094
29	-.073
30	-.049
31	.041
32	.029

Figure 18. Plots of autocorrelations and partial autocorrelations for log-transformed 1983 chinook salmon outmigration time series.

1984 ran from June 12 to August 31 (79 cases). Analysis of this shorter series is not as strong as that of the longer series in 1983 but the series is long enough from a statistical point of view; Hoff (1983) suggests that about 40 or 50 observations is the minimum necessary for attempting an ARIMA model. Although logarithmic transformation did not appear to be strictly necessary for the 1983 data, it was required (to produce an AR(1) model) with the 1984 data, perhaps because of the shorter time series in 1984.

The ACF plot for 1984 on the log-transformed data (Fig. 19) is similar to that of 1983, although it does decay a little more quickly. The 1984 PACF plot (Fig. 19) is very similar to that of 1983 in indicating a strong AR(1) component. The estimated value of ϕ in 1984 is 0.973 (very close to that of 1983), with a standard error of 0.0265. The 1984 model is:

$$\ln(y_t + 1) = 1.39 + .97(\ln(y_{t-1} + 1) - 1.39) + a_t$$

The mean of the residuals is insignificant. This model does not differ from that of 1983.

3.4. Univariate Model for Age 0+ Sockeye Salmon Outmigration

Age 0+ sockeye salmon outmigration was examined from May 23 through August 31, 1984 (Fig. 20). This time series shows a strong AR(1) component (Fig. 21), similar to that of the chinook salmon time series.

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```
PLOT OF AUTOCORRELATIONS

             -1.0  -.8  -.6  -.4  -.2   .0   .2   .4   .6   .8  1.0
LAG   CORR.    +----+----+----+----+----+----+----+----+----+----+
                                        I
  1      .812                      +    IXXXXX+XXXXXXXXXXXXX
  2      .631                    +      IXXXXXXX+XXXXXXXX
  3      .442                   +       IXXXXXXXXX+X
  4      .285                  +        IXXXXXXX  +
  5      .179                 +         IXXXX     +
  6      .132                 +         IXXX      +
  7      .072                 +         IXX       +
  8      .047                 +         IX        +
  9      .080                 +         IXX       +
 10      .144                 +         IXXXX     +
 11      .200                 +         IXXXXX    +
 12      .226                 +         IXXXXXX   +
 13      .204                 +         IXXXXX    +
 14      .157                 +         IXXXX     +
 15      .110                 +         IXXX      +
 16      .096                 +         IXX       +
 17      .055                 +         IX        +
 18     -.023                 +        XI         +
 19     -.026                 +        XI         +
 20     -.087                 +       XXI         +
 21     -.147                 +     XXXXI         +
 22     -.139                 +      XXXI         +
 23     -.125                 +      XXXI         +
 24     -.112                 +      XXXI         +
 25     -.087                +         XXI          +
 26     -.067                +         XXI          +
 27     -.067                +         XXI          +
 28     -.071                +         XXI          +
 29     -.034                +         XXI          +
 30     -.107                +        XXXI          +
 31     -.168                +       XXXXI          +
 32     -.204                +      XXXXXI          +


PLOT OF PARTIAL AUTOCORRELATIONS

             -1.0  -.8  -.6  -.4  -.2   .0   .2   .4   .6   .8  1.0
LAG   CORR.    +----+----+----+----+----+----+----+----+----+----+
                                        I
  1      .812                     +     IXXXXX+XXXXXXXXXXXXX
  2     -.083                     +   XXI     +
  3     -.134                     +  XXXI     +
  4     -.034                     +    XI     +
  5      .031                     +     IX    +
  6      .079                     +     IXX   +
  7     -.104                     +  XXXI     +
  8      .034                     +     IX    +
  9      .167                     +     IXXXX +
 10      .116                     +     IXXX  +
 11      .011                     +     I     +
 12     -.045                     +    XI     +
 13     -.047                     +    XI     +
 14     -.009                     +     I     +
 15     -.003                     +     I     +
 16      .075                     +     IXX   +
 17     -.083                     +   XXI     +
 18     -.156                     + XXXXI     +
 19      .197                     +     IXXXXX+
 20     -.198                     +XXXXXI     +
 21     -.156                     + XXXXI     +
 22      .126                     +     IXXX  +
 23      .018                     +     I     +
 24     -.001                     +     I     +
 25     -.066                     +   XXI     +
 26      .010                     +     I     +
 27      .012                     +     I     +
 28     -.086                     +   XXI     +
 29     -.033                     +    XI     +
 30      .006                     +     I     +
 31     -.153                     + XXXXI     +
 32      .057                     +     IX    +
```

Figure 19. Plots of autocorrelations and partial autocorrelations for log-transformed 1984 chinook salmon outmigratio time series.

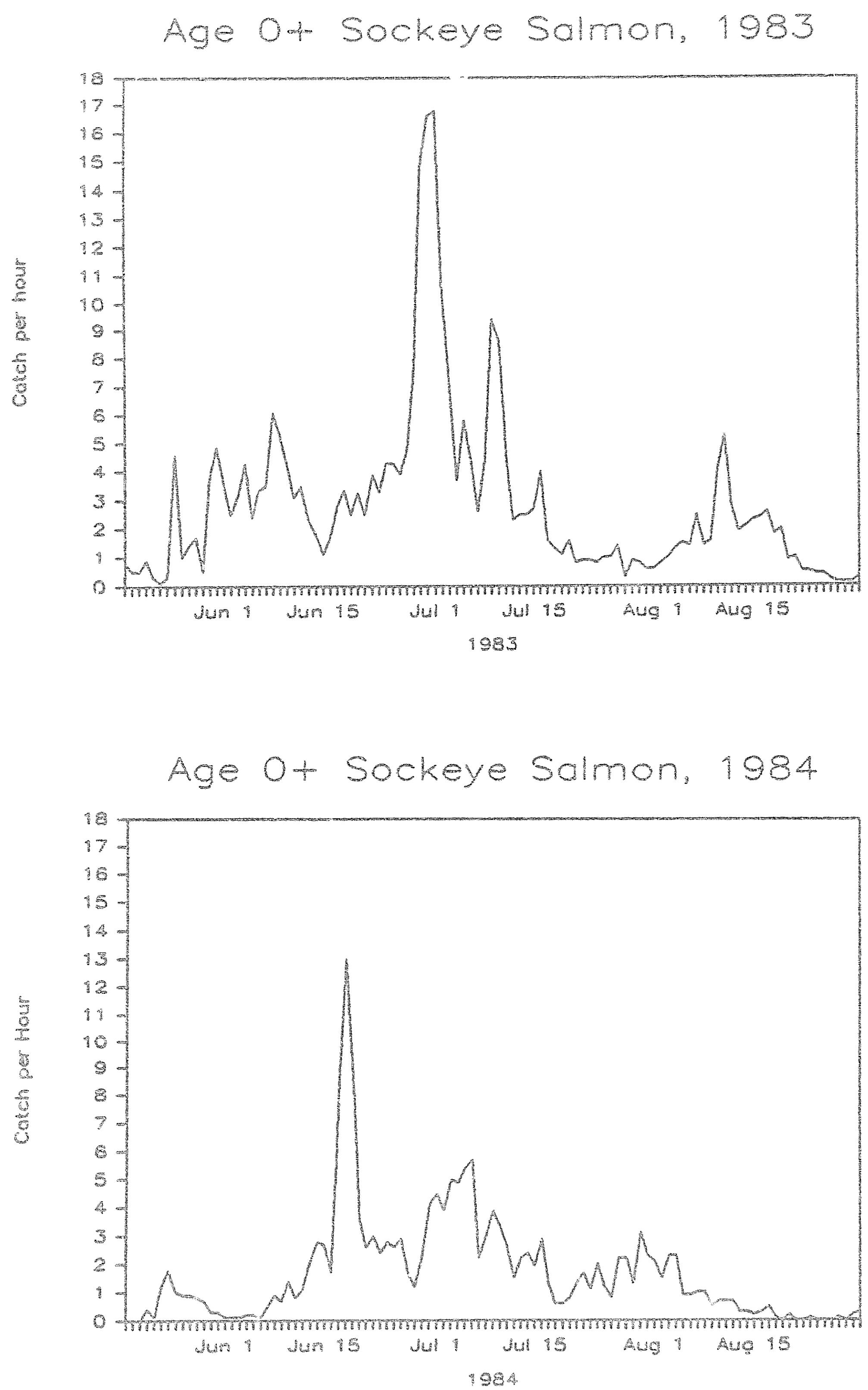

Figure 20. Age 0+ sockeye salmon outmigration rate time series, 1983 and 1984.

PLOT OF AUTOCORRELATIONS

LAG	CORR.
1	.799
2	.543
3	.446
4	.415
5	.361
6	.275
7	.229
8	.190
9	.126
10	.093
11	.101
12	.127
13	.136
14	.126
15	.124
16	.139
17	.132
18	.092
19	.021
20	.003
21	.049
22	.019
23	-.053
24	-.063
25	-.052
26	-.043
27	-.059
28	-.069
29	-.107
30	-.166
31	-.180
32	-.177

PLOT OF PARTIAL AUTOCORRELATIONS

LAG	CORR.
1	.799
2	-.267
3	.329
4	-.044
5	.028
6	-.071
7	.099
8	-.116
9	-.016
10	.059
11	.027
12	.067
13	.015
14	.015
15	.012
16	.055
17	-.071
18	-.042
19	-.134
20	.129
21	.040
22	-.184
23	.048
24	.043
25	-.083
26	.082
27	-.064
28	-.025
29	-.189
30	.047
31	-.030
32	-.065

Figure 21. Plots of autocorrelations and partial autocorrelations for 1984 sockeye salmon outmigration time series.

However, neither an AR(1) model on the raw data or on the log-transformed data was adequate. A MA(1) component was also significant in the raw data, leading to the model:

$$y_t = 1.76 + .78(y_{t-1} - 1.76) - .57\,a_{t-1} + a_t$$

The standard error on $\hat{\phi}_1$ (.775) was .0681 and on $\hat{\theta}_1$ (-.567) was .0883. Although the mean of the residuals was slightly significant, none of the autocorrelations or partial autocorrelations were, so the model is reasonable.

Examination of the autocorrelation coefficients of the four time series presented above at lag = 1 day (adjacent values) gives an idea of the smoothness of the time series. Typically, the coefficient for physical/chemical variables is higher than that of the biological variables and the time series for discharge (Fig. 4) and turbidity (Fig. 11) are less jagged than those for chinook salmon outmigration rate (Fig. 15) and sockeye salmon outmigration rate (Fig. 20). Saila et al. (1972) reported similar results for the autocorrelations of alewife upstream migration activity in relation to incident solar radiation and water temperature.

The square of the autocorrelation coefficient at lag = 1 gives a measure of the percentage of the variance of the value for today which is explained by what was measured yesterday (Murray and Farber 1982). In 1983, $(.86)^2$ = 74% of the variability of discharge for one day was explained by the value for discharge on the previous day. The percentage for turbidity was $(.92)^2 = 85\%$ while, for chinook salmon outmigration rate, it was only $(.66)^2 = 44\%$, and, for sockeye salmon, $(.65)^2 = 42\%$.

3.5. Discharge-Turbidity Transfer Function Model

The cross correlations for the residuals from the discharge series and the turbidity series, both filtered by the ARMA(1,1) model for discharge, had a significant spike at lag = 1 day (Fig. 22). This suggests a candidate model (Box and Jenkins 1976; McCleary and Hay 1980):

$$y_t = \frac{\omega_0 B}{1 - \delta_1 B} x_t + N_t$$

where: y_t is the output series (turbidity)
ω_0 and δ_1 are transfer function parameters
x_t is the input series (discharge)
N_t is the noise component, an ARIMA model

The assumption that the ARIMA component of the model was white noise leads to significant AC's in the residuals series and must be rejected. The ACF and PACF plots on the residuals from this model suggest an AR(1) model for the N component, leading to the full model:

$$y_t = \frac{\omega_0 B}{1 - \delta_1 B} x_t + \frac{a_t}{1 - \phi_1 B}$$

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PLOT OF CROSS CORRELATIONS

               -1.0  -.8  -.6  -.4  -.2   .0   .2   .4   .6   .8  1.0
 LAG    CORR.   +----+----+----+----+----+----+----+----+----+----+
                                         I
 -20    -.023                       +   XI    +
 -19    -.115                       + XXXI    +
 -18    -.022                       +   XI    +
 -17    -.076                       +  XXI    +
 -16     .177                       +    IXXXX+
 -15    -.102                       + XXXI    +
 -14    -.010                       +    I    +
 -13    -.164                       +XXXXI    +
 -12     .062                       +    IXX  +
 -11    -.023                       +   XI    +
 -10    -.112                       + XXXI    +
  -9    -.061                       +  XXI    +
  -8    -.009                       +    I    +
  -7    -.124                       + XXXI    +
  -6    -.009                       +    I    +
  -5    -.050                       +   XI    +
  -4     .021                       +    IX   +
  -3     .037                       +    IX   +
  -2    -.050                       +   XI    +
  -1    -.062                       +  XXI    +
   0     .077                       +    IXX  +
   1     .349                       +    IXXXX+XXXX
   2    -.199                       XXXXXI    +
   3    -.006                       +    I    +
   4     .016                       +    I    +
   5     .138                       +    IXXX +
   6    -.132                       + XXXI    +
   7    -.002                       +    I    +
   8    -.021                       +   XI    +
   9    -.069                       +  XXI    +
  10    -.016                       +    I    +
  11     .005                       +    I    +
  12    -.072                       +  XXI    +
  13    -.029                       +   XI    +
  14    -.026                       +   XI    +
  15    -.146                       +XXXXI    +
  16    -.052                       +   XI    +
  17     .114                       +    IXXX +
  18     .019                       +    I    +
  19    -.235                      X+XXXXI    +
  20     .175                       +    IXXXX+
```

Figure 22. Plot of cross correlations between the residuals of the ARMA (1,1) discharge model and the prewhitened turbidity time series, 1983 data.

Parameter estimates were:

$\hat{\omega}_0$ = 8.349 with std. error of 1.7044

$\hat{\delta}_1$ = -0.559 with std. error of 0.1718

$\hat{\phi}_1$ = 0.993 with std. error of 0.0009

The t statistic for each of these estimates was significant, leading to the conclusion that discharge and turbidity are related by the equation:

$$y_t = \frac{8.35\ B}{1 + .56\ B}\, x_t + \frac{a_t}{1 - .99\ B}$$

The ACF and PACF plots on the residuals from this model showed no significant spikes; therefore, the model is adequate.

This model does not necessarily imply that discharge level is a causal factor for turbidity. These two variables are correlated largely because when glacial melting is high, both discharge and turbidity are high. This phenomenon provides the seasonal trend of the two series; the discharge of clear water tributaries such as Portage Creek and Indian River (which increase discharge but not turbidity) is a noise component. Discharge does have some causal effect of turbidity by resuspending sediments and other particles during a rapid rise in discharge level.

The value of the model is that it allows levels of turbidity for a few days ahead to be predicted from past values of both turbidity and discharge.

3.6. Discharge-Chinook Transfer Function Model

After both the input series (discharge) and the output series (chinook salmon outmigration rate) were filtered by the ARMA(1,1) model for the discharge series and the residuals from both series were cross correlated, there was a significant correlation at lag = 1 day (Fig. 23). This suggests the transfer function model, as given by McCleary and Hay (1980):

$$y_t = \omega_0 x_{t-1} + N_t$$

or, using the backward shift notation of Box and Jenkins (1976):

$$y_t = \omega_0 B x_t + N_t$$

This model implies that the current day's discharge rate has an effect on the next day's outmigration rate. The estimate of ω_0 was 0.02. The residual ACF using this model suggested that the assumption of white noise for the N component was not valid; it appeared that an ARMA(1,0) model would be appropriate. The full model is:

$$y_t = \omega_0 B x_t + \frac{a_t}{1 - \phi_1 B}$$

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```
PLOT OF CROSS CORRELATIONS

                    -1.0 -.8  -.6  -.4  -.2   .0   .2   .4   .6   .8  1.0
LAG    CORR.        +----+----+----+----+----+----+----+----+----+----+
                                             I
-20     .012                            +    I    +
-19    -.040                            +   XI    +
-18    -.032                            +   XI    +
-17    -.045                            +   XI    +
-16     .096                            +    IXX  +
-15     .065                            +    IXX  +
-14    -.048                            +   XI    +
-13     .007                            +    I    +
-12    -.022                            +   XI    +
-11     .025                            +    IX   +
-10    -.044                            +   XI    +
 -9    -.077                            +  XXI    +
 -8     .011                            +    I    +
 -7    -.020                            +    I    +
 -6    -.003                            +    I    +
 -5    -.009                            +    I    +
 -4     .033                            +    IX   +
 -3     .085                            +    IXX  +
 -2    -.062                            +  XXI    +
 -1    -.010                            +    I    +
  0     .017                            +    I    +
  1     .220                            +    IXXXXX+X
  2    -.032                            +   XI    +
  3     .007                            +    I    +
  4    -.004                            +    I    +
  5     .078                            +    IXX  +
  6    -.087                            +  XXI    +
  7     .016                            +    I    +
  8    -.047                            +   XI    +
  9     .062                            +    IXX  +
 10    -.063                            +  XXI    +
 11     .134                            +    IXXX +
 12    -.107                            + XXXI    +
 13     .025                            +    IX   +
 14    -.065                            +  XXI    +
 15    -.024                            +   XI    +
 16    -.045                            +   XI    +
 17     .019                            +    I    +
 18     .119                            +    IXXX +
 19    -.166                            +XXXXI    +
 20     .066                            +    IXX  +
```

Figure 23. Plot of cross correlations between the residuals of the ARMA (1,1) discharge model and the prewhitened chinook salmon outmigration time series, 1983 data.

The parameters for this model were estimated as:

$\hat{\omega}_0$ = .025 with std. error of .0249

$\hat{\phi}_1$ = .667 with std. error of .0751

The t statistic on the estimate for ω_0 was not significant. However, because the practice of prewhitening the output series with the model for the input series tends to underestimate the significance of the results (Botsford et al. 1982) and because there was a significant cross correlation between discharge and outmigration rate at a lag of one day, it seemed best to leave this term in the model. This would have to be verified with more years of data. The model is:

$$y_t = .025\,B\,(x_t) + \frac{a_t}{1 - .67B}$$

The ACF and PACF for the residuals from this model show no significant spikes so we may conclude that the model is adequate.

This model does not imply that the discharge series is a strong predictor for the outmigration series. But adding discharge does result in an expression which has more predictive value than would be obtained by looking at the outmigration series by itself.

3.7. Discharge-Sockeye Transfer Function Model

As with the discharge-chinook relationship, the cross-correlations of the discharge and sockeye series, filtered by an ARMA(1,1) model for discharge, showed a significant spike when the sockeye series was lagged one day behind the discharge series (Fig. 24). This spike was stronger for sockeye than it was for chinook. A candidate model (Box and Jenkins 1976; McCleary and Hay 1980) is:

$$y_t = \frac{\omega_0 B}{1 - \delta_1 B} x_t + N_t$$

The ACF and PACF plots on the residuals from this model suggest an ARMA(1,1) model for the N_t component, leading to the full model:

$$y_t = \frac{\omega_0 B}{1 - \delta_1 B} x_t + \frac{(1 - \theta_1 B)}{(1 - \phi_1 B)} a_t$$

Parameter estimates were:

$\hat{\omega}_0$ = .08 with std. error $< .00005$
$\hat{\delta}_1$ = -.73 with std. error .2205
$\hat{\phi}_1$ = .69 with std. error .0878
$\hat{\theta}_1$ = -.57 with std. error .0957

The t statistic for each of these estimates was significant, giving:

$$y_t = \frac{.08\ B}{1 + .73 B} x_t + \frac{(1 + .57 B)}{(1 - .69 B)} a_t$$

where: x_t = discharge $\times 10^{-3}$

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PLOT OF CROSS CORRELATIONS

LAG	CORR.
-20	-.027
-19	-.099
-18	.059
-17	-.007
-16	-.059
-15	.021
-14	-.047
-13	.020
-12	-.066
-11	.040
-10	.101
-9	-.003
-8	-.102
-7	.034
-6	.020
-5	.012
-4	.009
-3	.035
-2	.106
-1	-.279
0	.096
1	.467
2	-.002
3	-.007
4	.006
5	.126
6	-.168
7	.063
8	.039
9	.054
10	-.052
11	.029
12	-.092
13	.135
14	-.000
15	-.041
16	.050
17	.025
18	-.117
19	.236
20	-.248

Figure 24. Plot of cross correlations between the residuals of the ARMA (1,1) discharge model and the prewhitened sockeye salmon outmigration time series, 1984 data.

The ACF and PACF plots on the residual series from this model showed no significant spikes and the mean of the residuals was barely significant; therefore, the model is adequate.

4.0 DISCUSSION

Time series analysis is a useful method for dealing with time ordered data sets, including ones that do not appear to make much sense at first glance because they are too noisy or because they drift as a result of random events. The modeling effort helps us to understand why the plots look as they do and what factors shape them. It also is useful in trying to understand what effect a change in the controlling factors might produce.

The segments of the time series examined (discharge, turbidity, chinook and sockeye salmon outmigration) were described by relatively simple Box-Jenkins models, using mostly first-order terms. None of the series appeared to require differencing (although turbidity was on the border-line) to achieve stationarity nor did they appear to have a periodic component (discharge being a possible exception) which would require seasonal differencing. All of the series showed a very strong first order autoregressive term, indicating that the value for any one day is strongly influenced by the value for the previous day. Similar results for the flow regimes of several streams in Australia was reported by Srikanthan et al. (1983), who found that most of those streams with a non-random process had a first order autoregressive term.

By building Box-Jenkins models for these time series, a better under-standing of the processes which control these variables was developed in that the structure of the random processes which generate an observed series are now known. It is important to explore the effect on salmon outmigration of a construction project which will change the basic rules, that is, change the underlying physical processes. Whereas the present discharge regime can be described as a mixed first order autoregressive and moving average process, the discharge regime under a post-project scenario could include entirely different terms.

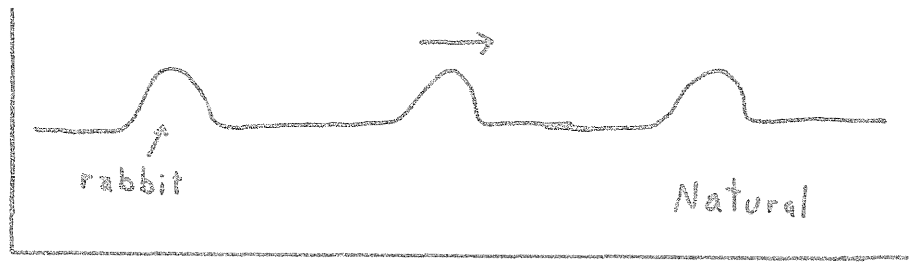
An important point is that the underlying processes (the autoregressive and moving average components) were the same in 1983 and in 1984 even though the actual time series, or "realizations," looked very different between the two years. This was true for both discharge and for chinook salmon outmigration; only a single year of turbidity and sockeye salmon outmigration was examined. Even though the discharge peaks do not match at all well between the two years, the process which generated these peaks in both years was the same and can be described by an ARMA(1,1) model.

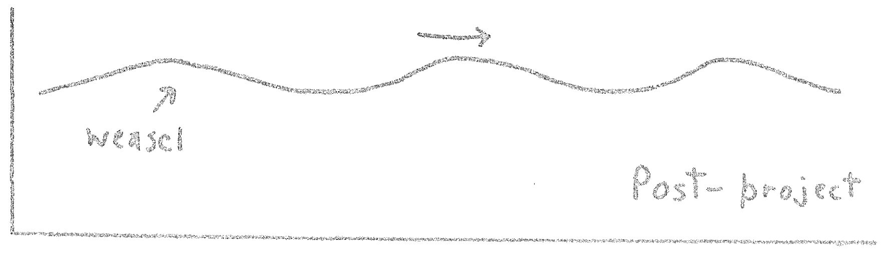
In a sense, the proposed dams would operate like a gigantic low pass filter on the discharge regime, dampening out the high frequency perturbations and letting the low frequency (annual cycle) events pass. However, this is an oversimplification because a new element would be present if the dams are built - namely, power demand. Power demand is not is phase with the natural discharge fluctuations and dam operation to accommodate power demand will change the mechanisms which generate the current discharge regime.

The important question is, how would the outmigration rate be affected if these discharge spikes were not present, as with a dam-regulated discharge regime? Further, what effects would these changes have on the population survival rate? Relatively high levels of discharge, and possibly four or five day peaks, in the late spring and early summer may be necessary to facilitate normal outmigration timing of juvenile salmon. On the other hand, very high discharge levels at this time of year, as do occur naturally, may be harmful to juvenile chinook salmon if these floods displace the fry downstream from what would otherwise be their rearing areas. These questions will be addressed in more detail in future reports.

Time series analysis is a powerful statistical tool which has many applications to the Susitna Aquatic Studies Program. The present paper only begins to use the full potential of the method. It could be useful to build Box-Jenkins models for the 36 year record of discharge at Gold Creek gaging station. Because this information is continuous, it can be digitized as monthly, weekly, daily, or even hourly means. Turbidity, temperature, and dissolved gas time series could also be modeled in this manner. Developing time series models for the proposed post- project discharge regime would be interesting to see whether the post-project discharge regime is also an ARMA(1,1) process. Intervention analysis, which is an extension of Box-Jenkins models concerned with a natural or human caused change to a system, would be an appropriate method to use (Box and Tiao 1975; Hipel et al. 1978; Thompson et al. 1982). One could determine if the intervention (construction of the dams) would have a significant effect on the time series processes. This method has been used to model the effect of the Aswan dam on the Nile River and the Gardiner dam on the South Saskatchewan River in Canada (Hipel et al. 1978). Before and after mean levels can not be compared using normal analysis of variance because the observations are serially correlated.

Some preliminary work was done with the 36 year record of mean weekly discharge. This time series definitely requires differencing to achieve stationarity because a period of discharge "activity" occurs from only about mid-May to mid-September (four months); during the rest of the year, discharge level is low and has relatively little variance. The 1,768 records of mean weekly discharge from 1950 to 1983 are not plotted here, but the reader can picture what the series looks like by imagining a long snake whose practice it is to eat a nice fresh rabbit every third day. The rabbits travel down the length of the snake, undigested in this case. These rabbits come in all shapes - short and skinny, short and fat, tall and skinny, and tall and fat - but they were all from the same litter so the underlying processes which created them is the same. If the dams are built, the parents or even the species will change; the time series would perhaps look as if the snake had swallowed a weasel every third day:





With regard to the Susitna fish data, the work described in this paper on outmigration rates could be expanded to other species, years, and input variables. An excellent use of time series analysis would be to develop forecast models for the annual return of adult salmon or the annual total number of outmigrants. The adult salmon return of a particular year is strongly related to the return of the previous year (that is, when catch is high one year, it tends to be high for several years) and there is probably a periodicity component based on strong age classes. With such a model, one could predict the size of next year's adult salmon return, a piece of information which would be very useful to both fishery and hydroelectric dam managers. However, the time series of adult salmon return to the Susitna River is not long enough (only seven or eight years of data). A minimum of about 40 or 50 observations is necessary (McCleary and Hay 1980; Huff 1983), although the method has been applied by Jensen (1985) to fish catch data with as few as 32 observations. The annual abundance of adult chinook and coho salmon in the California fishery has been examined with time series analysis by Botsford et al. (1982) and Peterman and Wong (1984) have looked at sockeye salmon cycles in British Columbia and Bristol Bay. For the present, analysis of salmon time series in the Susitna River will have to be restricted to daily rates of a single year.

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6.0 LITERATURE CITED

Alaska Department of Fish and Game. 1983. Habitat relationships of juvenile salmon outmigration. Appendix H in Synopsis of the 1982 aquatic studies and analysis of fish and habitat relationships. 1983. Susitna Hydro Aquatic Studies, Alaska Department of Fish and Game, Anchorage, Alaska.

Botsford, L.W., R.D. Methot, Jr., and J.E. Wilen. 1982. Cyclic covariation in the California king salmon, *Oncorhynchus tshawytscha*, silver salmon, *O. kisutch*, and dungeness crab, *Cancer magister*, fisheries. Fishery Bulletin 80:791-801.

Box, G.E.P., and M. Jenkins. 1976. Time series analysis. Forecasting and control. Holden-Day, San Francisco.

Box, G.E.P., and G.C. Tiao. 1975. Intervention analysis with applications to economic and environmental problems. Journal of the American Statistical Association 70:70-79.

Brannon, E.L., and E. O. Salo. (eds.). 1982. Proceedings of the salmon and trout migratory behavior symosium. June 3-5, 1981. University of Washington, Seattle, Washington.

Bulmer, M.G. 1978. The statistical analysis of the ten year cycle. Pages 141-153 in H.H. Shugart, Jr. (ed.). Time Series and Ecological Processes. SIAM-SIMS Conf. Ser. 5. Society for Industrial and Applied Mathematics, Philadelphia.

Cederholm, C. J., and W. J. Scarlett. 1982. Seasonal immigrations of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977 - 1981. Pages 98 - 110 in E.L. Brannon and E.O. Salo (eds.). Proceedings of the salmon and trout migratory behavior symposium. June 3-5, 1981. University of Washington, Seattle, Washington.

Chatfield, C. 1984. The analysis of time series: an introduction. Chapman and Hall. London.

Congleton, J.L., S.K. Davis, and S.R. Foley. 1982. Distribution, abundance and outmigration timing of chum and chinook salmon fry in the Skagit salt marsh. Pages 153 - 163 in E.L. Brannon and E.O. Salo (eds.). Proceedings of the salmon and trout migratory behavior symposium. June 3-5, 1981. University of Washington, Seattle, Washington.

Dixon, W.J., M.B. Brown, L. Engelman, J.W. Frane, M.A. Hill, R.I. Jennrich, and J.D. Toporek. (eds.). 1981. BMDP statistical software. 1981. University of California Press, Berkely, California.

EWT&A. 1985. Instream Flow Relationships Report. Volume No. 1. Prepared for Harza-Ebasco Susitna Joint Venture by E. Woody Trihey and Associates and Woodward-Clyde Consultants, Anchorage, Alaska.

Godin, J-G.Y. 1982. Migrations of salmonid fishes during early life history phases: daily and annual timing. Pages 22-50 in E.L. Brannon and E.O. Salo (eds.). Proceedings of the salmon and trout migratory behavior symposium. June 3-5, 1981. University of Washington, Seattle, Washington.

Granger, C.W.J., and P. Newbold. 1977. Forecasting economic time series. Academic Press, New York.

Grau, E.G. 1982. Is the lunar cycle a factor timing the onset of salmon migration? Pages 184-189 in E.L. Brannon and E.O. Salo (eds.). Proceedings of the salmon and trout migratory behavior symposium. June 3-5, 1981. University of Washington, Seattle, Washington.

Hale, S.S., P.M. Suchanek, and D.C. Schmidt. 1984. Modelling of juvenile salmon and resident fish habitat. Part 7 in D.C. Schmidt, S.S. Hale, D.L. Crawford, and P.M. Suchanek. (eds.). 1984. Resident and juvenile anadromous fish investigations (May - October 1983). Susitna Hydro Aquatic Studies. Report No. 2. Alaska Department of Fish and Game, Anchorage, Alaska.

Hartman, W.L., W.R. Heard, and B. Drucker. 1967. Migratory behavior of sockeye salmon fry and smolts. Journal of the Fisheries Research Board of Canada 24:2069-2099.

Hipel, K.W., D.P. Lettenmaier, and A.I. McLeod. 1978. Assessment of environmental impacts. Part one: intervention analysis. Environmental Management 2: 529-535.

Hoff, C. 1983. A practical guide to Box-Jenkins forecasting. Wadsworth, London.

Jensen, A.L. 1985. Time series analysis and the forecasting of menhoden catch and CPUE. North American Journal of Fisheries Management 5:78-85.

Kirkley, J.E., M. Pennington, and B.E. Brown. 1982. A short-term forecasting approach for analyzing the effects of harvesting quotas: application to the Georges Bank yellowtail flounder (Limanda ferruginea) fishery. J. Cons. int. Explor. Mer. 40:173-175.

Liu, L-M., and D.M. Hanssens. 1980. Identification of multiple-input transfer function models. BMDP statistical software. Technical Report No. 68. Los Angeles.

McCleary, R., and R.A. Hay, Jr. 1980. Applied time series analysis for the social sciences. Sage Publications, Beverly Hills, California.

McDonald, J. 1960. The behaviour of Pacific salmon fry during their downstream migration to fresh water and salt water nursery areas. Journal of the Fishery Research Board of Canada 17:655-676.

Mendelssohn, R. 1981. Using Box-Jenkins models to forecast fishery dynamics: identification, estimation, and checking. Fishery Bulletin 78:887-896.

Mendelssohn, R. 1982. Environmental influences on fish population dynamics: a multivariate time series approach. Paper presented at a meeting of the American Statistical Association. August, 1982. Cincinnati, Ohio.

Murray, L.C., and R.J. Farber. 1982. Time series analysis of an historical visibility data base. Atmospheric Environment 16:2299-2308.

Nelson, R. 1973. Applied time series analysis for managerial forecasting. Holden-Day, San Francisco, California.

O'Heeron, M.K., Jr., and D.B. Ellis. 1975. A comprehensive time series model for studying the effects of reservoir management on fish populations. Transactions of the American Fisheries Society 104:591-595.

Peterman, R.M., and F.Y.C. Wong. 1984. Cross correlations between reconstructed ocean abundances of Bristol Bay and British Columbia sockeye salmon (Oncorhynchus nerka). Canadian Journal of Fisheries and Aquatic Sciences 41:1814-1824.

Platt, T., and K.L. Denman. 1975. Spectral analysis in ecology. Annual Review of Ecology and Systematics 6:189-210.

Priestley, M.B. 1981. Spectral analysis and time series. Vol 1: univariate series, Vol 2: multivariate series, prediction and control. Academic Press, London.

Raymond, H.L. 1968. Migration rates of yearling chinook salmon in relation to flows and impoundments in the Columbia and Snake Rivers. Transactions of the American Fisheries Society 97:356-359.

Roth, K.J., D.C. Gray, and D.C. Schmidt. 1984. The outmigration of juvenile salmon from the Susitna River above the Chulitna River confluence. Part 1 in D.C. Schmidt, S.S. Hale, D.L. Crawford and P.M. Suchanek (eds.). 1984. Resident and juvenile anadromous fish investigations (May - October 1983). Susitna Hydro Aquatic Studies. Report No. 2. Alaska Department of Fish and Game. Anchorage, Alaska.

Roth, K.J., and M.E. Stratton. 1985. The migration and growth of juvenile salmon in the Susitna River. Part 1 in Resident and juvenile salmon fish investigations (May - October 1984). Susitna Aquatic Studies. Report No. 7. Alaska Department of Fish and Game, Anchorage, Alaska.

Saila, S.B., T.T. Polgar, D.J. Sheehy, and J.M. Flowers. 1972. Correlations between alewife activity and environmental variables at a fishway. Transactions of the American Fisheries Society 101:583-594.

Saila, S.B., M. Wigbout, and R.J. Lermit. 1980. Comparison of some time series models for the analysis of fisheries data. J. Cons. int. Explor. Mer. 39:44-52.

Salas, J.D., and R.A. Smith. 1981. Physical basis of stochastic models of annual flows. Water Resources Research. 17:428-430.

Shugart, H.H., Jr. (ed.). 1978. Time series and ecological processes. Proceedings of SIAM-SIMS Conference. Society for Industrial and Applied Mathematics, Philadelphia.

Solomon, D.J. 1982a. Migration and dispersion of juvenile brown and sea trout. Pages 136-145 _in_ E.L. Brannon and E.O. Salo (eds.). Proceedings of the salmon and trout migratory behavior symposium. June 3-5, 1981. University of Washington, Seattle, Washington.

Solomon, D.J. 1982b. Smolt migration in Atlantic salmon (_Salmo salar_ _L._) and sea trout (_Salmo trutta_ _L._). Pages 196-203 _in_ E.L. Brannon and E.O. Salo (eds.). Proceedings of the salmon and trout migratory behavior symposium. June 3-5, 1981. University of Washington, Seattle, Washington.

Srikanthan, R., T.A. McMahon, and J.L. Irish. 1983. Time series analyses of annual flows of Australian streams. Journal of Hydrology. 66:213-226.

Stevens, D.E., and L.W. Miller. 1983. Effects of river flow on abundance of young chinook salmon, American shad, longfin smelt, and delta smelt in the Sacramento-San Joaquin River system. North American Journal of Fisheries Management 3:425-437.

Still, P.J., R.D. Lamke, J.E. Vaill, B.B. Bigelow, and J.L. VanMaanen. 1984. Water resources data. Alaska. Water year 1983. U.S.G.S. Water-Data Report AK-83-1. U.S. Geological Survey, Anchorage, Alaska.

Stocker, M., and R. Hilborn. 1981. Short-term forecasting in marine fish stocks. Canadian Journal of Fisheries and Aquatic Science. 38:1247-1254.

Sturges, W. 1983. On interpolating gappy records for time series analysis. Journal of Geophysical Research. 88:9736-9740.

Suchanek, P.M., R.P. Marshall, S.S. Hale, and D.C. Schmidt. 1984. Juvenile salmon rearing suitability criteria. Part 3 in D.C. Schmidt, S.S. Hale, D.L. Crawford, and P.M. Suchanek (eds.). 1984. Resident and juvenile anadromous fish investigations (May - October 1983). Susitna Hydro Aquatic Studies. Report No. 2. Alaska Department of Fish and Game. Anchorage, Alaska.

Taylor, T.G., and F.J. Prochaska. 1984. Incorporating unobserved cyclical stock movements in fishery catch equations: an application to the Florida blue crab fishery. North American Journal of Fisheries Management 4:67-74.

Thompson, K.W., M.L. Deaton, R.V. Foutz, J. Cairins, Jr., and A.C. Hendricks. 1982. Application of time series intervention analysis to fish ventilatory response data. Canadian Journal of Fisheries and Aquatic Sciences 39:518-521.

Van Winkle, W., B.L. Kirk, and B.W. Rust. 1979. Periodicities in Atlantic Coast striped bass (Morone saxatilis) commercial fisheries data. Journal of the Fisheries Research Board of Canada 36:54-62.