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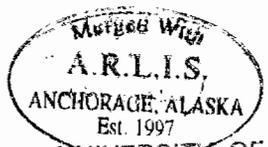
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CHAPTER 6: REVIEW DRAFT

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Anchorage, Alaska

Edited by:  
Christopher C. Estes  
and  
Douglas S. Vincent-Lang



Prepared for:  
ALASKA POWER AUTHORITY  
334 W. FIFTH AVE.  
ANCHORAGE, ALASKA 99501

UNIVERSITY OF ALASKA  
ARCTIC ENVIRONMENTAL INFORMATION  
AND DATA CENTER  
707 A STREET  
ANCHORAGE, AK 99501

AN EVALUATION OF PASSAGE CONDITIONS FOR ADULT SALMON  
IN SLOUGHS AND SIDE CHANNELS OF THE MIDDLE SUSITNA RIVER

1984 Report, Chapter 6

By:

Joseph S. Sautner  
and  
Leonard J. Vining

Alaska Department of Fish and Game  
Susitna Hydro Aquatic Studies  
2207 Spenard Road  
Anchorage, Alaska 99503

and

Larry A. Rundquist  
Woodward-Clyde Consultants

ABSTRACT

Twelve slough and side channel sites were selected to evaluate salmon passage conditions for adult Pacific salmon into and within habitats most directly affected by mainstem Susitna River discharges. These sites account for the majority of chum, sockeye and pink salmon which spawn in sloughs and side channels in the middle Susitna River. The evaluation of salmon passage conditions at each site included the effects of mainstem breaching flows and backwater staging, and slough flows (local flows) derived from local water sources (e.g., upwelling, tributaries, precipitation). Timing and distribution patterns of salmon were briefly evaluated in relation to passage conditions and flow patterns in the Susitna River system.

Daily catch data at three fishwheel sites on the mainstem river were compared to mean daily discharge levels. These data indicate that as discharge levels increase in the mainstem, salmon migrational activity decreases. Survey counts of peak numbers of live and dead salmon in sloughs and side channels indicate that the period from 20 August to 20 September is a critical period for providing passage into and within slough and side channel sites. All analyses of passage were therefore restricted to this period.

Reaches which were restrictive to salmon passage (passage reaches) were identified at each site on the basis of salmon passage requirements for depth of water. Depth requirements for successful passage increased with increasing length of reach. The analyses of breaching, backwater and local flow effects on passage reaches were conducted independently and their relative importance is reported on a site by site basis. In general, breaching flows affect all passage reaches within a site simultaneously, whereas backwater flows usually affect only one or two passage reaches in the lower portion of a site. Local flow requirements may affect all passage reaches, but vary among sites and among passage reaches. These variations in local flow requirements are due to spatial variations in sources of local flow.

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## 1.0 INTRODUCTION

This chapter presents an evaluation of selected hydrological characteristics which influence passage conditions for adult chum (Oncorhynchus keta), sockeye (O. nerka) and pink (O. gorbuscha) salmon into and within selected slough and side channel habitats of the Susitna River from Talkeetna (RM 98.0) to Devil Canyon (RM 152.0) (Figure 6-1). This report also examines the influence of discharge on the timing of upstream migration of salmon in the mainstem Susitna River and the distribution of spawning salmon within the selected slough and side channel sites. Salmon timing and distribution patterns are addressed briefly to the extent that they relate to, or affect, passage at slough and side channel habitats. Passage conditions into selected tributaries within the Talkeetna to Devil Canyon reach of the Susitna River have been evaluated in previous studies (Trihey 1983) and are not repeated here.

### 1.1 Background

Five species of Pacific Salmon [chum, sockeye, pink, coho (O. kisutch) and king (O. tshawytscha)] presently spawn in various habitats of the Talkeetna to Devil Canyon reach of the Susitna River. These habitats include mainstem, side channel, slough, and tributary sites. Utilization of these habitats by salmon varies between species (Figure 6-2). Tributaries are used primarily by chinook, coho, chum, and pink salmon, whereas sloughs are used primarily by chum and sockeye salmon and to a lesser extent by pink salmon. Various mainstem and side channel sites are also used, to a lesser extent, by chum, coho and sockeye salmon.

The distribution of spawning salmon in the Susitna River system is influenced by various physical and chemical conditions that affect salmon timing and passage events. Proper timing of the upstream migration of salmon is important to ensure that they will arrive at spawning areas when environmental conditions (flows, water depths, etc.) are suitable for passage into and within these habitats. Alteration of these environmental conditions may affect the timing, passage, and resultant distribution of salmon in the Susitna River system.

Field observations of passage conditions at several sloughs and side channels within the study area (ADF&G 1983a, 1983b: Appendix B) indicate that it is unlikely that hydraulic velocity barriers would exist at these or other spawning locations under present or future projected flow regimes. Therefore, the ability for salmon to enter and traverse slough and side channel habitats from the mainstem Susitna River is primarily a function of the depth and length of critical reaches which are restrictive to salmon passage (passage reaches) (ADF&G 1983b: Appendix B, Trihey 1982). When passage is prevented at a particular passage reach, spawning habitat above the impasse becomes unavailable for use by adult salmon. Under these conditions, the overall distribution of spawning salmon is restricted and the density of spawning adults in remaining available spawning areas may be excessive. If these conditions persist, it will result in a reduction in the number of salmon originating from and returning to the affected habitats.

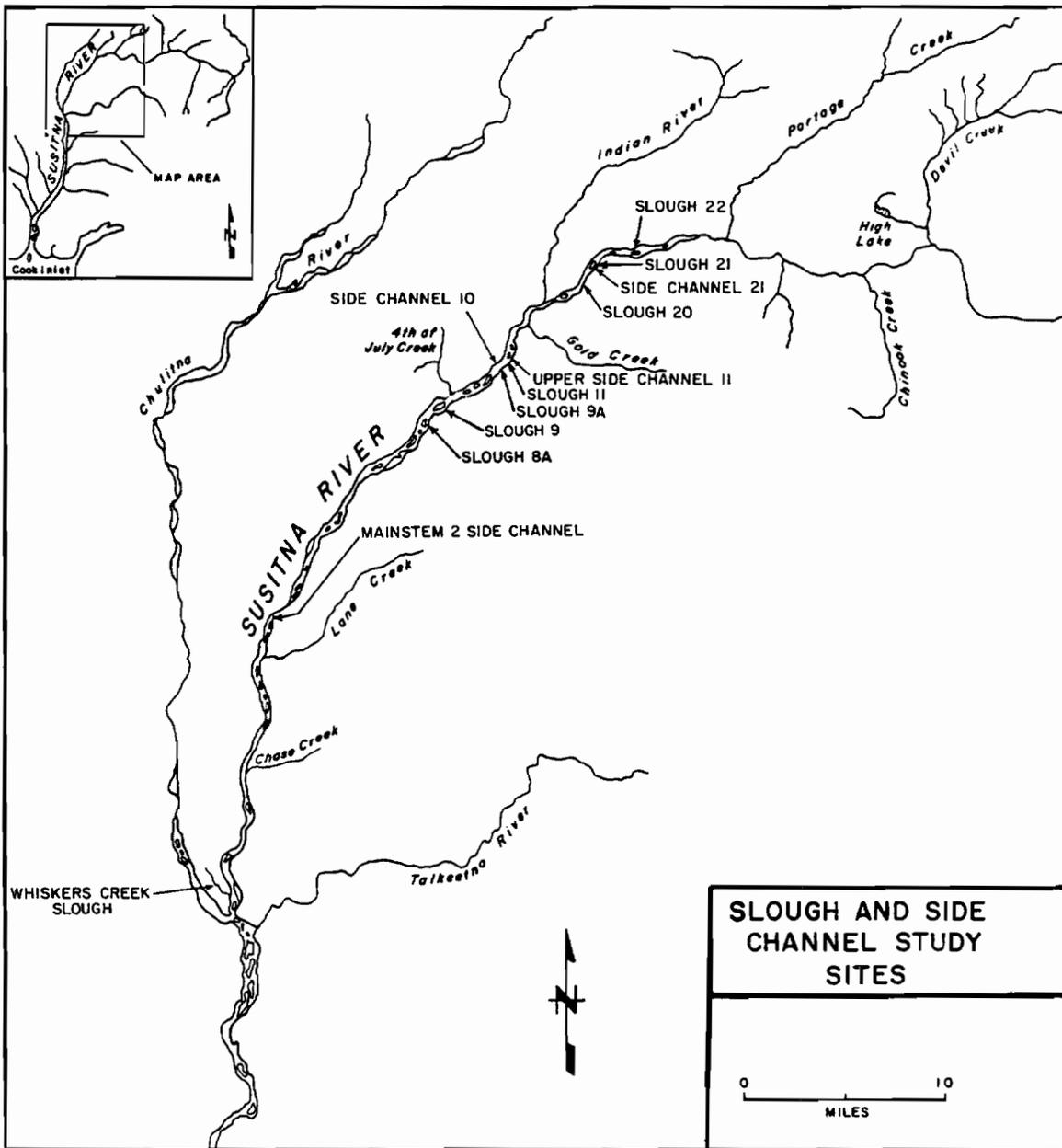


Figure 6-1 Slough and side channel study sites selected for passage evaluation, 1983.

# SPAWNING HABITAT PREFERENCE

- MS - MAINSTEM
- SC - SIDE CHANNEL
- SL - UPLAND and SIDE SLOUGHS
- T - TRIBUTARIES
-  - PRIMARY SPAWNING HABITAT
-  - SECONDARY SPAWNING HABITAT
-  - INCIDENTAL SPAWNING HABITAT

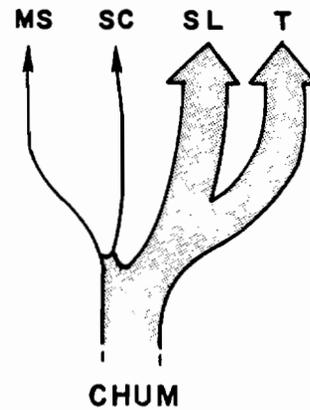
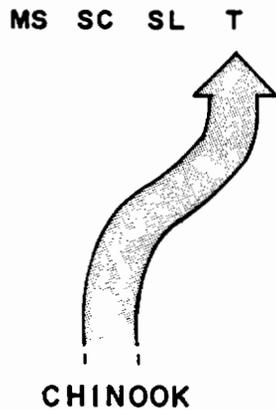
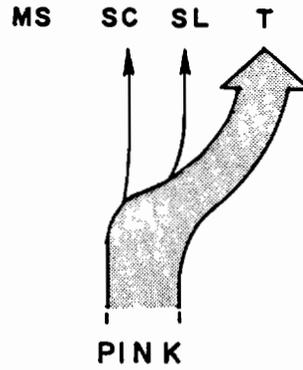
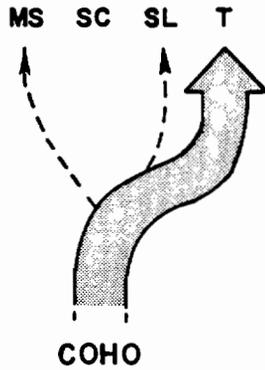
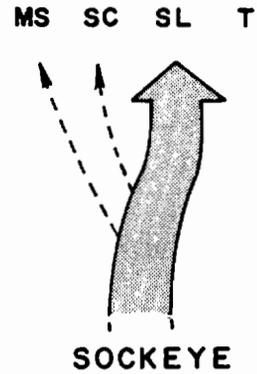


Figure 6-2 General spawning habitat preference of the five species of salmon utilizing the Susitna River Basin.

Mainstem discharge levels influence backwater and breaching conditions in slough and side channel habitats and consequently affect fish passage into and within these habitats (ADF&G 1983a, 1983b: Appendix B). At low mainstem discharges (unbreached conditions), the backwater area formed at the mouth of sloughs and side channels may not have sufficient depths to allow successful passage. As mainstem discharge increases, the backwater area normally increases in depth and extends its length upstream, thus increasing depths within those critical passage reaches affected by the backwater. This elimination of passage restrictions within a reach by inundation would continue in the upstream direction with increasing mainstem discharge, until controlling breaching discharge levels occur, at which time depths become adequate for passage at all passage reaches in most slough and side channel habitats.

During breached conditions, slough flow (local flow) normally constitutes a negligible contribution to the overall flow of the system. However, during unbreached conditions, changes in local flow alone can result in significant changes in passage conditions within critical passage reaches.

Naturally occurring discharge levels and local flows ensure that suitable depths and velocities will occur during most years to provide successful passage conditions for adult salmon into traditional slough and side channel spawning sites. These naturally occurring discharges in the Susitna River (as recorded at the USGS gaging station at Gold Creek) commonly range between 20,000 and 30,000 cfs during June, July and August (Scully, et al., 1978), when adult salmon are migrating upstream in the mainstem and 15,000-20,000 cfs during the peak spawning period (20 August - 20 September).

The proposed Susitna Hydroelectric Project would alter existing discharge levels of the mainstem Susitna River. Discharges would be reduced during the summer and increased during the winter (Acres 1982). Average monthly post-project discharges at Gold Creek are projected to range from 7,000 to 11,000 cfs during June, July and early August, with a proposed controlled discharge of no less than 12,000 cfs from mid-August to mid-September (Acres 1982). These projected discharges would alter the breaching and backwater influence of mainstem discharge on many of the sloughs and side channels within the Talkeetna to Devil Canyon reach of the Susitna River. This will likely alter passage conditions for salmon into and within these habitats. Water levels within these habitats would be primarily dependent upon flow from small tributaries, surface runoff, and upwelling groundwater (ADF&G 1981a, 1982, 1983a, 1983b: Appendix B).

Therefore, an evaluation of timing of the adult salmon migration to slough and side channel spawning sites, and the passage conditions available at various mainstem discharges is important in determining their role on the overall distribution of spawning salmon in these Susitna River habitats. This information, when combined with the evaluation of other life phases (e.g., spawning, incubation and rearing), is also necessary for evaluating the effects of regulated discharges of the proposed hydroelectric project upon these habitats and to assist in developing appropriate mitigative options.

## 1.2 Objective

This study was designed to fulfill one primary objective: to evaluate the influence of mainstem discharge and/or local flows on passage conditions for adult salmon into and within selected slough and side channel habitats of the Susitna River. In support of this objective, timing and distribution patterns of spawning adult salmon in selected slough and side channel habitats were analyzed to the extent that they relate to passage conditions.

Previous investigations have evaluated the influence of mainstem discharge on salmon passage conditions in selected tributary (Trihey 1983) and slough habitats [Trihey 1982, ADF&G 1983b (Appendix B)] of the middle Susitna River. However, these studies were not sufficient to provide a complete analysis of passage conditions for all mainstem affected salmon spawning habitats in this reach of river because of the relatively small number of sites investigated. The present study is designed to expand the number of study sites (including relevant side channel sites) and to refine the methods previously employed to provide a more comprehensive and precise evaluation of salmon passage conditions in the middle Susitna River.

The primary objective of this report focuses on chum salmon due to their more restrictive passage requirements (Scott and Crossman 1973) and their wide distribution among slough and side channel habitats in comparison with other salmon species in the Susitna River. Since chum salmon are more restricted in their ability to surmount obstacles it is assumed that passage criteria set for this species can be applied to other species. The limited available information on sockeye and pink salmon are also included to present a more comprehensive overview of salmon utilization and potential passage problems within Susitna River slough and side channel habitats.

*note -  
they are  
chum  
runners only.*

## 2.0 METHODS

### 2.1 Site Selection

A total of 12 slough and side channel sites were considered in the passage evaluation studies (Figure 6-1). These study sites represent the major slough and side channel spawning areas and range of habitat characteristics for chum, sockeye and pink salmon, in the middle reach of the Susitna River. Sloughs 8A, 9, 11 and 21 were are primary spawning areas for chum salmon. Mainstem 2 Side Channel, Upper Side Channel 11, Side Channel 21, Whiskers Creek Slough and Sloughs 9A, 20 and 22, support lesser concentrations of spawning chum salmon. Side Channel 10 was selected because of its potential as a mitigation evaluation site for future studies. It was not evaluated in the local flow analysis. Detailed descriptions of study sites are presented in Appendix 6-A and site maps are present in Appendix 6-D.

### 2.2 Timing and Distribution of Salmon

The Alaska Department of Fish and Game (ADF&G) Su Hydro Aquatic Study Team has been collecting timing and distribution data on adult salmon since 1981. This chapter presents a compilation and comparison of timing and distribution data presented in previous ADF&G reports [ADF&G 1981b; 1982; 1983b (Appendix B); 1983c; Barrett, et al., 1984].

#### 2.2.1 Mainstem Sites

Timing of the upstream migration of adult salmon in the mainstem Susitna River was related to mainstem discharge for the 1981, 1982, and 1983 open water field seasons. For each year, numbers of salmon or catch per unit effort data were compared to mainstem discharge by plotting both variables over time. Adult salmon were counted during each of these years at fishwheels located at three mainstem sites on the Susitna River: Sunshine Station (RM 80.0), Talkeetna Station (RM 103.0) and Curry Station (RM 120.0). More specific methods for fishwheel operations are presented in ADF&G (1983c) and Barrett, et al., (1984).

Discharge data from two United States Geological Survey (USGS) gaging stations were used to construct the timing plots. Discharge data used in association with the Sunshine Station fishwheel site were recorded at the USGS gaging station at Sunshine (USGS gage #15292780), RM 89.3. Discharge data for the Talkeetna and Curry Station fishwheels were recorded at the USGS gaging station at Gold Creek (USGS gage #15292000), RM 136.7. *wrong*

Numbers of adult salmon enumerated at each fishwheel site on a daily basis were plotted with mean daily Susitna River discharge data for the years 1982 and 1983. Flood events prevented continuous fishwheel operations during 1981. Therefore, fishwheel catch data are plotted as catch per unit effort rather than numbers of salmon during this year. The timing of salmon migration was compared with discharge data for all three years to detect trends that may not be evident by evaluating data from a single year.

### 2.2.2 Slough and Side Channel Sites

Adult salmon survey data reported for slough and side channel habitats in 1981, 1982 and 1983 (ADF&G 1981b; ADF&G 1983c; Barrett et al., 1984, respectively) were analyzed to determine timing and distribution patterns of salmon at these sites. ADF&G field personnel surveyed selected slough and side channel habitats in their entirety for adult salmon between RM 98.6 and RM 161.0. The surveys were generally conducted weekly from July through October during each of these years. Beginning and ending dates of surveys varied each year depending on factors such as weather and timing of fish migration patterns. All survey data are based upon visual counts with visibility conditions rated as poor, fair, good or excellent. Visibility conditions were affected primarily by turbidity levels but were also affected at times by other factors such as sun glare and wind. For those surveys with fair, good or excellent visibility conditions, the total number of liv salmon, by species, were recorded. Surveys conducted during periods o poor visibility conditions were not used for this analysis. A more detailed discussion of survey methods is included in ADF&G (1981b, 1983c, 1983d) and Barrett et al., 1984.

*When was they? → see previous page  
(1981b, 1983c, 1983d)*

Timing plots were developed for slough and side channel sites by plotting numbers of fish over time. The plots include only the time period of August through September because the peak occurrence of salmon within these habitats occurred during these two months. For periods of poor or fair survey conditions, where no usable data were available, the data points were interpolated. In some cases, surveys were limited to the lower portion of a slough or side channel because upstream areas appeared to be inaccessible to salmon and salmon were not sighted in the area immediately above the impasse. In such cases, the data were used as if 100% of the slough or side channel was surveyed because it was assumed that these counts represented all of the salmon at that site.

Timing plots were constructed for all slough and side channel study sites with the exceptions of Side Channel 10, Mainstem 2 Side Channel, Upper Side Channel 11 and Slough 21 Complex. The reasons for excluding these sites are given below.

- 1) Side Channel 10 and Mainstem 2 Side Channel were excluded because there were insufficient data to construct a meaningful plot.
- 2) Numbers of fish counted in Upper Side Channel 11 were not differentiated from those in Slough 11. Data were combined for those sites and the resultant plot is referred to as the Slough 11 Complex. Likewise, data from Slough 21 and Side Channel 21 were presented in a single plot referred to as the Slough 21 Complex.

Maps illustrating the distribution of spawning chum, sockeye and pink salmon were developed for each site (see Appendix D). These maps were primarily used to determine the areas traditionally used for spawning in each site and how the distribution of salmon relates to passage reaches.

### 2.3 Passage of Salmon

The methods presented below focus on the 1983 field and 1984 analytical methods used to evaluate the influence of mainstem discharge and/or local flows on passage conditions into and within selected slough and side channel habitats. Many of these methods are refinements of methods used in previous years. For more detailed information on methods previously used, the reader should refer to ADF&G (1983a, 1983b: Appendix B) and Trihey (1982).

Physical and hydraulic conditions influencing passage of adult chum salmon into and within slough and side channel habitats were evaluated by first identifying potential passage reaches and then by comparing passage reach characteristics (i.e., channel morphology, substrate composition, water depths and lengths) at various mainstem discharges to chum salmon passage requirements. The methods employed to evaluate passage reach conditions are presented in Figure 6-3.

#### 2.3.1 Field Methods

##### 2.3.1.1 Thalweg Surveys

Thalwegs were surveyed along the entire length of each slough and side channel study site at low water conditions during October of 1982 and 1983. Thalweg data were collected using a surveying level, standard surveying rod, and rod level. Standard surveying techniques of differential leveling were used (Bovee and Milhous 1978; Trihey and Wegner 1981). At the beginning of each survey, a temporary bench mark (TBM) was established that was later surveyed to a known elevation.

Surveying the thalweg in a slough involved two steps. First, points of significant change of the slough bed elevation along a longitudinal gradient were determined by visual assessment (i.e., upper and lower ends of riffles, lower ends of pools, etc.). Next, a transect perpendicular to the channel was visually established at each point. The point of greatest water depth was identified along this transect. These points of greatest depth were defined as thalweg points. The line connecting these points was defined as the thalweg. Distances between thalweg points were measured to the nearest foot by: 1) using fiberglass surveying tape; 2) reading stadia and computing distances or; 3) measuring angles and distances, and computing distances between thalweg points utilizing trigonometric functions (triangulation). When survey data (i.e., cross sections at study sites, staff gage sites or the mouth or head of a slough) were available from previous work which met the requirements for developing a thalweg profile, these data were used in conjunction with or in addition to other thalweg survey work.

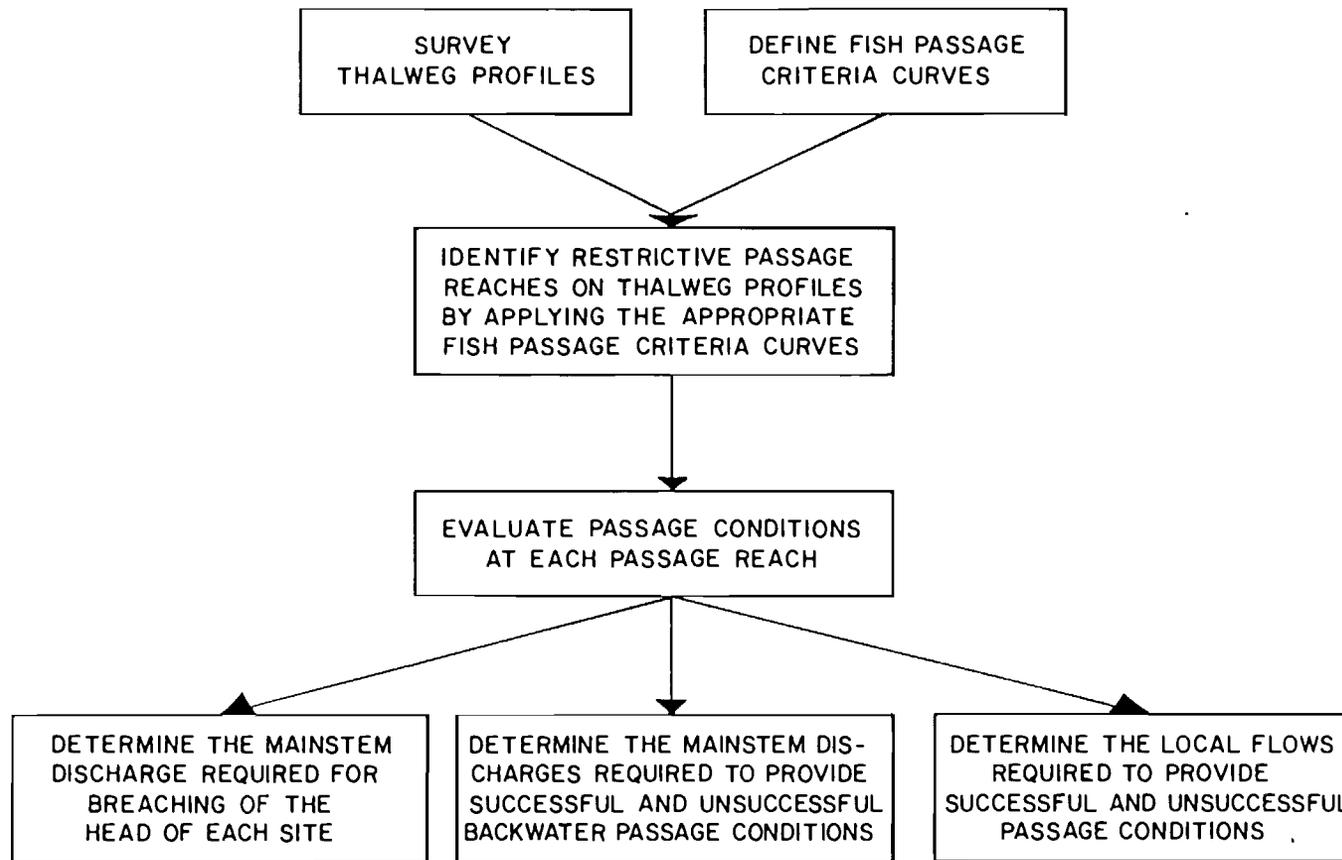


Figure 6-3 Flow chart of methods employed to evaluate passage reach conditions.

7

### 2.3.1.2 Cross Sectional Profiles

Cross sectional profiles were obtained by surveying selected passage reaches of slough and side channel sites to provide a more accurate representation of water depth in the shallowest areas in the passage reach. Each cross section was located on a riffle that was above the mainstem backwater (on the day sampled), but below the uppermost limit of reported spawning in 1981, 1982, and 1983.

Cross sectional profiles were obtained by surveying points of significant changes in gradient along a temporary transect established across the shallowest part in the passage reach perpendicular to the flow. At each transect, the end points were defined by placing temporary headpins on the left and right banks. Stationing along each passage reach cross section was determined by either measuring the distance with a surveyors tape or from stadia readings taken while surveying. All surveying was conducted according to standard surveying techniques of differential leveling (Bovee and Milhous 1978; Trihey and Wegner 1981).

### 2.3.1.3 Staff Gage Readings

Stage data were collected over a range of local flows or local plus mainstem breaching discharges. The flow values were measured at the staff gage location using techniques described in ADF&G (1983d). Staff gages were installed at the mouth, within, and at the head of each study site. Generally, gage readings at the mouth and the head (and some gages within sloughs) were correlated to mainstem discharge to evaluate backwater and breaching effects, respectively. Selected gages located within the slough were used to evaluate local flow effects by correlating staff gage readings with measured local flow. All staff gages were surveyed to a known elevation using basic survey techniques of differential leveling (Bovee and Milhous 1978, Trihey and Wegner 1981, ADF&G 1983c) so that resultant stage readings could be converted to true water surface elevations (WSEL). Table 6-1 provides a list of all study sites and their corresponding staff gage numbers and locations.

In general, stage data correlated to mainstem discharges, were collected over a range of high, medium and low discharges. However, at some sites, insufficient data were collected to evaluate the entire range of discharges. All discharge values related to these gages are referenced from the USGS gaging station at Gold Creek [USGS 1983 (gage #15292000, RM 136.7)] unless otherwise indicated.

### 2.3.2 Analytical Methods

The conceptual approach for analyzing salmon passage reaches in sloughs and side channels was based on a procedure involving three steps.

Table 6-1. List of staff gage numbers and locations used in evaluating passage reach conditions at slough and side channel study sites in the middle Susitna River, 1983.

<u>Study Site</u>	<u>Staff Gage #</u>	<u>Staff Gage Location<sup>a</sup></u>
Whiskers Creek Slough	101.2W1	200 ft upstream of mouth
	101.2S3	400 ft upstream of confluences with Whiskers Creek
Mainstem II Side Channel	114.4W6	at mouth
	114.4S9	850 ft upstream of mouth
	114.4S7	1200 ft upstream of mouth
Slough 8A	125.3W5	mouth of slough
	125.3S6	1000 ft upstream of mouth
	125.3S4	1200 ft upstream of mouth
	125.3S8	7150 ft upstream of mouth
	125.3H7	head of slough
Slough 9	128.3W3	mouth of slough
	128.3S1	2300 ft upstream of mouth (ADF&G Q site)
	128.3H2	head of slough
Slough 9A	No staff gages	No access determination possible
Slough 10	133.8W5	mouth of slough
	134.1S1 (R&M)	R&M Q site
Side Channel 10	133.8S7B	25 ft upstream of mouth
	133.8S1B	750 ft upstream of mouth
	133.8S21B	1000 ft upstream of mouth
Slough 11	135.3W1	mouth of slough
	135.3S6	1000 ft upstream of mouth (ADF&G Q site)
	136.3H3	head of slough
Upper Side Channel 11	136.2W3	at mouth
	136.2S4	225 ft upstream of mouth
	136.2S5	450 ft upstream of mouth
	136.2S1	1050 ft upstream of mouth

(Continued)

Table 6-1 (Continued).

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<u>Study Site</u>	<u>Staff Gage #</u>	<u>Staff Gage Location</u>
Slough 20	140.1W4 140.1S5	275 ft upstream of mouth 1150 ft upstream of mouth (ADF&G Q site)
Slough 21 Complex (Side Channel 21)	140.6W1 140.6S4	mouth of side channel in modeling site Q site
(Slough 21)	140.6S2 140.6S7 142.0W5 142.0S6	1500 ft downstream of mouth 400 ft downstream of mouth mouth of slough 900 ft upstream of mouth (ADF&G Q site)
	142.0H3 142.0H1	NW head NE head
Slough 22	144.3W3 144.3S4 144.3S6	at mouth of slough 1100 ft upstream of mouth 2100 ft upstream of mouth

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<sup>a</sup> Q site refers to a site where discharge measurements were obtained.

1st  
2nd  
3rd  
4th  
5th  
6th  
7th  
8th  
9th  
10th  
11th  
12th  
13th  
14th  
15th  
16th  
17th  
18th  
19th  
20th  
21st  
22nd  
23rd  
24th  
25th  
26th  
27th  
28th  
29th  
30th  
31st

- 1) Define the necessary requirements for successful and unsuccessful salmon passage (passage criteria).
- 2) Based upon the passage criteria established in step number one, identify all reaches within the selected study sites that do not meet the criteria for successful salmon passage (at low flow conditions).
- 3) Evaluate each passage reach in terms of its hydraulic characteristics, and determine the amount of local flow and/or mainstem discharge required to provide passage conditions that satisfy the requirements identified in step number one.

### 2.3.2.1 Definitions of Fish Passage Criteria

Two sets of fish passage criteria curves were developed from the results of previous work conducted by the ADF&G (ADF&G 1983b: Appendix B), work of other researchers (Thompson 1972) field observations, and the professional judgement of members of Woodward-Clyde Consultants, E. W. Trihey and Associates, and the ADF&G Su Hydro Aquatic Studies group. One set of curves was developed for reaches having small substrate ( $\leq 3.0$  inches), and a uniform, straight channel (Figure 6-4). The other set of curves was developed for reaches characterized by large substrates ( $> 3.0$  inches), and non-uniform and/or braided channels (Figure 6-5). Velocities at all slough and side channel sites were assumed to be less than two feet per second. Other variables such as gradient and temperature were assumed to be "normal" and were not considered likely to affect passage conditions in slough and side channel habitats. The curves were also limited to a maximum reach length of 200 feet because it was assumed that water depths at which passage becomes successful at a reach length of 200 feet would be adequate for passage for longer reach lengths in a slough or side channel. The depth which is used in Figures 6-4 and 6-5 is the passage depth which is defined as the average of the mean depth and maximum depth at a transect.

The curves are divided into three areas to represent varying levels of fish passage success. These three areas are referred to as (1) successful passage, (2) successful passage with difficulty and exposure and (3) unsuccessful passage. Detailed definitions of these three terms can be found in the glossary. Points above line A on the curves are considered successful. Points between lines A and B are considered successful with difficulty and exposure. Points below line B are in the unsuccessful category.

reference  
Figure 6-4  
6-5

### 2.3.2.2 Identification of Passage Reaches

Thalweg and surveyed water surface elevation (WSEL) data were plotted against streambed station to obtain a profile of the slough or side channel. The location and length of passage reaches within each study site were identified from the thalweg profiles. All passage reaches were sequentially numbered in ascending order beginning at the downstream end of each site. Specific steps in the process of identification are as follows.

# CURVE I

Substrate  $\leq 3$  inches  
 Uniform, unobstructed channel  
 Water Velocity  $< 2.0$  ft/sec

A		B	
Coordinates		Coordinates	
X	Y	X	Y
0	0.411	0	0.298
10	0.411	10	0.298
20	0.485	20	0.351
100	0.485	100	0.355
200	0.537	200	0.411

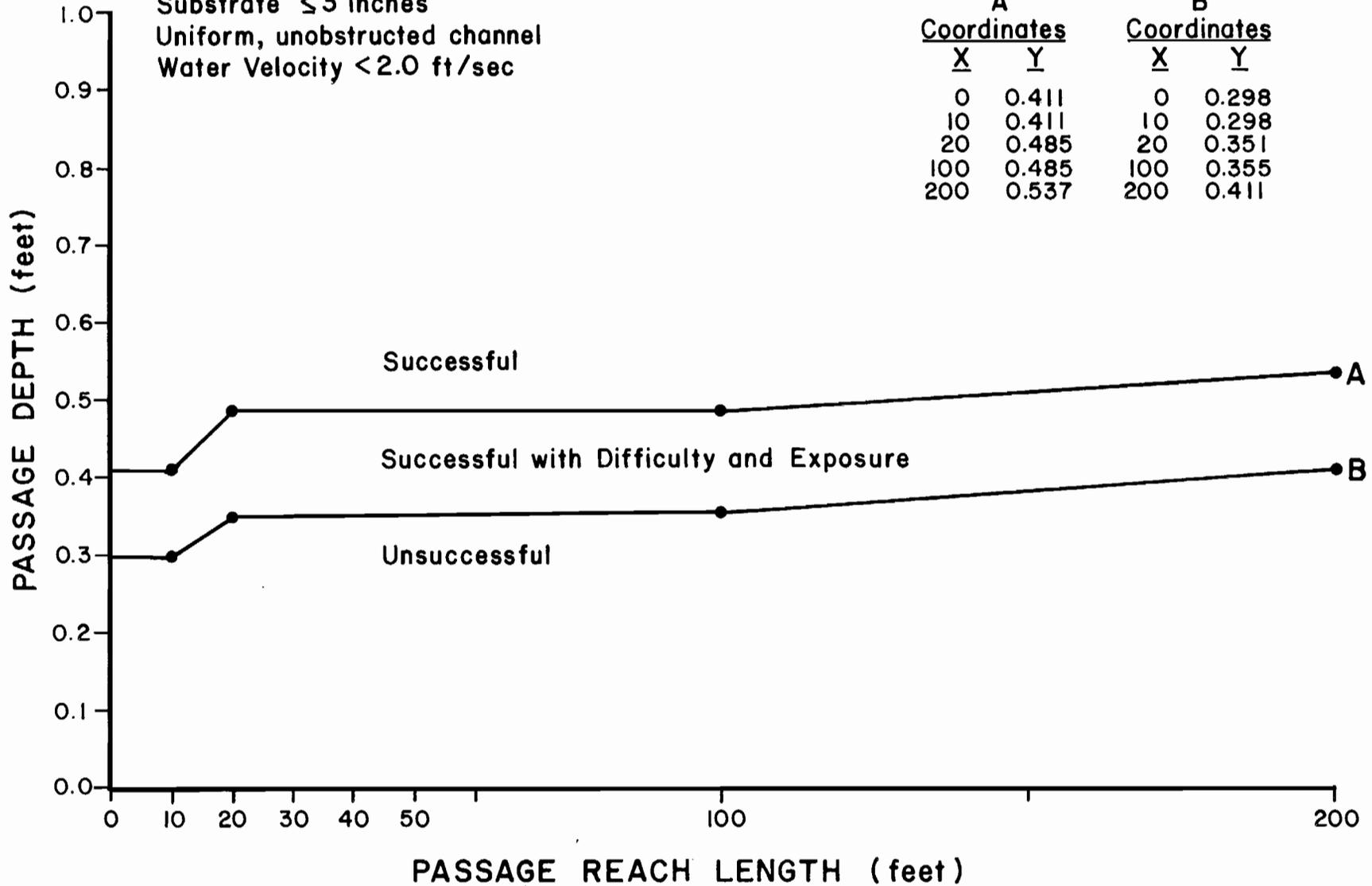


Figure 6-4 Passage depth requirements for chum salmon as a function of passage reach length within sloughs and side channels having substrates less than 3.0 inches in diameter, uniform morphology and water velocities less than 2.0 ft/sec.

**CURVE II**

Substrate >3 inches  
 Non-uniform, braided and obstructed channels  
 Velocities <2.0 ft/sec

A		B	
Coordinates		Coordinates	
X	Y	X	Y
0	0.298	0	0.179
10	0.298	10	0.179
20	0.351	20	0.239
100	0.355	100	0.259
200	0.411	200	0.317

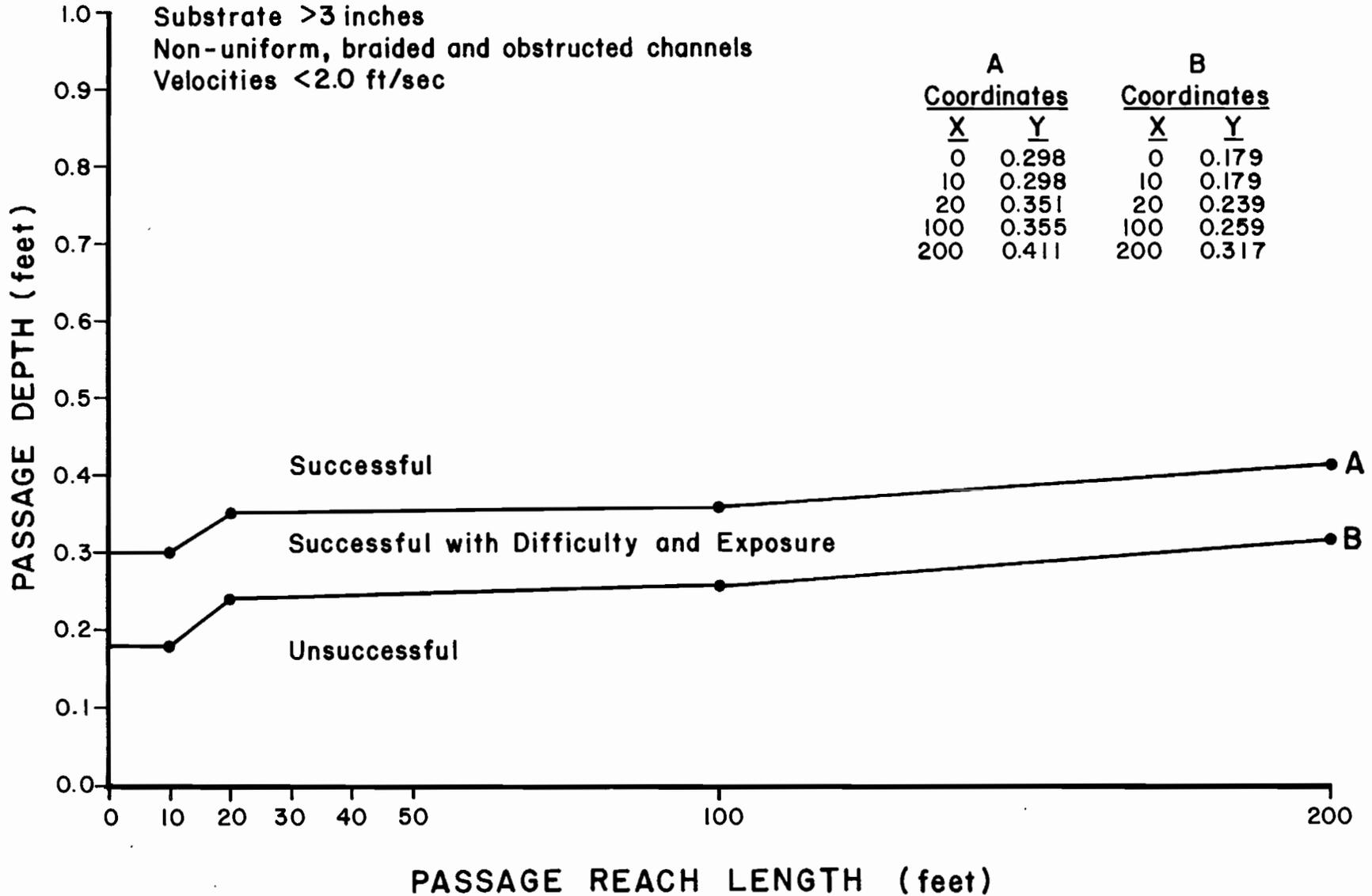


Figure 6-5

Passage depth requirements for chum salmon as a function of passage reach length within sloughs and side channels having substrates greater than 3.0 inches in diameter, non-uniform, braided and obstructed channels and velocities less than 2.0 ft/sec.

- 1) Depth criteria for passage reach identification - the threshold water depth for which salmon passage is considered successful for a reach length of 200 feet:

<u>Condition</u>	<u>Passage Depth</u>	<u>Criteria Curves</u>	<u>Figure Number</u>
Substrate $\leq$ 3.0 inches uniform, unobstructed channel	.41 ft	I	6-4
Substrate $>$ 3.0 inches non-uniform, braided channel	.54 ft	II	6-5

- 2) Initial selection of passage reaches - passage reaches were identified at base flow conditions (i.e., lowest flow conditions available during the field season) by locating all portions of the thalweg having water depths less than the appropriate criteria depth identified in step 1 above. The upstream limit of the analysis was the first passage reach beyond the upstream limit of utilization by spawning salmon during the years 1981, 1982, and 1983;
- 3) The length of each passage reach was calculated as the distance along the thalweg from the point where the depth of water first became less than the criteria depth (defined in step 1) to the point where the depth exceeded the criteria depth;
- 4) Minimum passage depth - the minimum passage depth was the shallowest depth within each passage reach; and
- 5) Passage reaches eliminated from analysis - those reaches for which passage reach lengths and minimum passage depth plot above the successful curve at the lowest mainstem discharge (for which data were available) were not considered as passage problem areas and were eliminated from further consideration.

### 2.3.2.3 Evaluation of Passage Reaches

Three types of analyses were used to evaluate passage reaches: breaching, backwater and local flow. Breaching and backwater analyses were used to evaluate all passage reaches, whereas, the local flow analysis was used to evaluate a subset of passage reaches. The subset which was analyzed includes the majority of passage reaches which are most problematic for salmon passage. However, it is anticipated that the local flow analysis will be conducted on the complete set of passage reaches based on ongoing field studies intended to supplement this study.

In each of the three analyses, length and depth of passage reaches were used as the primary criteria to evaluate salmon passage conditions. Based on these criteria, three categories of passage conditions were recognized: successful, successful with difficulty and exposure, or unsuccessful (Figures 6-4 and 6-5). In each analysis, the flow requirements are defined for conditions that fulfill threshold passage conditions for successful and unsuccessful passage (i.e., for points on the lines in Figures 6-4 and 6-5). By defining these upper and lower boundaries the middle condition of "successful with difficulty and exposure" is also defined. A flow duration curve was developed for the period between 20 August and 20 September based on mainstem discharge data at Gold Creek collected over a 32 year period (Figure 6-6). This curve was used to evaluate the percentage of time that the flow requirements for passage are equalled or exceeded. Although a flow duration curve for local flows would also be desired, the available data are insufficient to develop such a curve. Specific methods employed in each of the three types of analyses are presented separately in following sections.

#### 2.3.2.3.1 Breaching

The breaching analysis was applied to an entire study site rather than to individual passage reaches within each site. Two breaching conditions were defined: initial breaching discharge and controlling discharge. Initial breaching occurs when water first overtops the head of the slough or side channel. The controlling discharge is a higher discharge that directly governs hydraulic characteristics within a slough or side channel. Passage reach conditions within a site are considered to be successful under controlling breaching discharge conditions. Methods used in determining these discharges can be found in ADF&G (1984: Chapter 1).

#### 2.3.2.3.2 Backwater

The backwater analysis included the evaluation of increasing mainstem discharge at all passage reaches which were physically located in areas directly influenced by the rising stage in the mouth of each site. This analysis disregarded the effects of local flow for two reasons: (1) local base flow was presumed to be a relatively insignificant factor relative to the effect of the mainstem, and (2) local flow varies greatly in space (i.e., from site to site) and time (i.e., dependent on temporal weather patterns). The present data base is insufficient to define this variation.

Six steps involved in the backwater analysis of each passage reach are as follows:

- 1) Locate the passage reach on the thalweg and identify the streambed station that corresponds to the point of shallowest depth within the passage reach (this point is referred to as the index station);

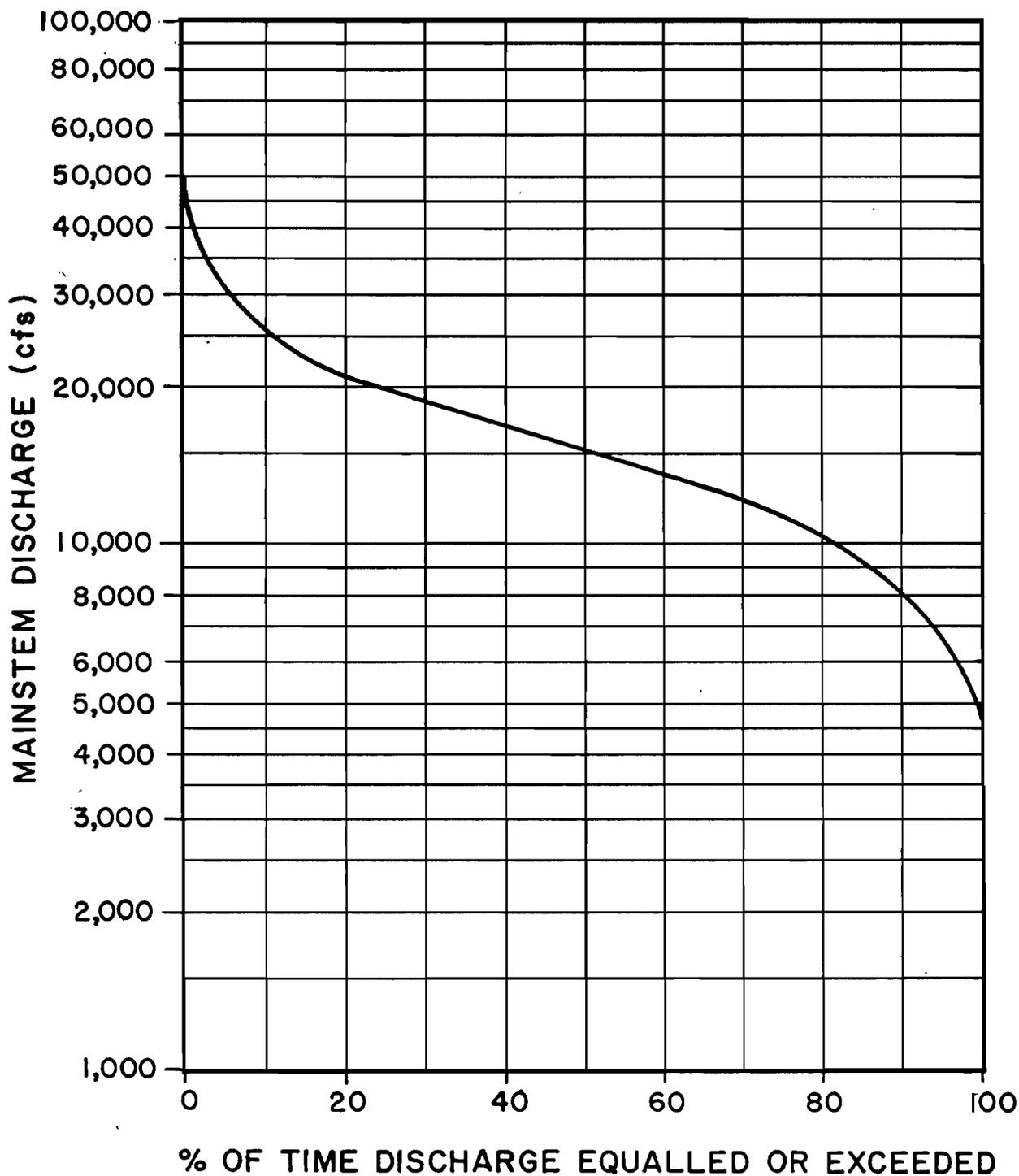


Figure 6-6 Flow duration curve depicting Susitna River discharge at Gold Creek for the salmon migrational period (20 August to 20 September). Data obtained for years 1950-1981 at gage number 15292000 of the United States Geological Survey.

- 2) From the thalweg survey data for the study site identify three streambed stations and corresponding elevations that include the index station (identified in step 1) and the nearest point upstream and downstream of the index station;
- 3) Add the depths required for successful and unsuccessful passage for a zero reach length to the index station elevation to obtain the two water surface elevations (WSEL's) required for successful and unsuccessful passage over that point;
- 4) Calculate the bed elevation along the thalweg which defines two points separated by 20 feet that fall on both sides of the index station. This calculation uses linear interpolation of thalweg survey data to define intermediate thalweg points with equal elevations; those points whose stations are 20 feet apart define the thalweg elevation of interest. Add the depths required for successful and unsuccessful passage to this bed elevation to get the WSEL's corresponding to the 20-foot passage reach length;

*Difficult  
to understand*

Determine the required WSEL's for both successful and unsuccessful passage by comparing the corresponding WSEL's from steps 3 and 4 and selecting the larger value; and

- 6) Use the WSEL's derived in step 5 to obtain a corresponding mainstem discharges. The mainstem discharge is calculated from a rating curve equation representing the hydraulic relationship in the mouth of the study site. These two mainstem discharge values represent the minimum discharge required to meet the threshold passage conditions of successful and unsuccessful salmon passage defined in the criteria curves.

#### 2.3.2.3.3 Local Flow

The local flow analysis evaluated the amount of local flow required in each passage reach to provide adequate depth of flow for passage independent of the influence of mainstem discharge. Although the data base varied for each slough the general approach follows the four steps outlined below and shown schematically in Figure 6-7.

- 1) Select required depths for successful and unsuccessful passage for each passage reach from the appropriate criteria curve given the initial passage length, size of substrate, degree of channel uniformity and water velocity in the passage reach;
- 2) Obtain a surveyed cross section for each passage reach. If a surveyed cross section is not available, use the Aerial Photographic Method described in Appendix B and go to Step 4;
- 3) Obtain a rating curve for each cross section. If the cross section does not have a rating curve, use the Manning Equation Method described in Appendix B; and

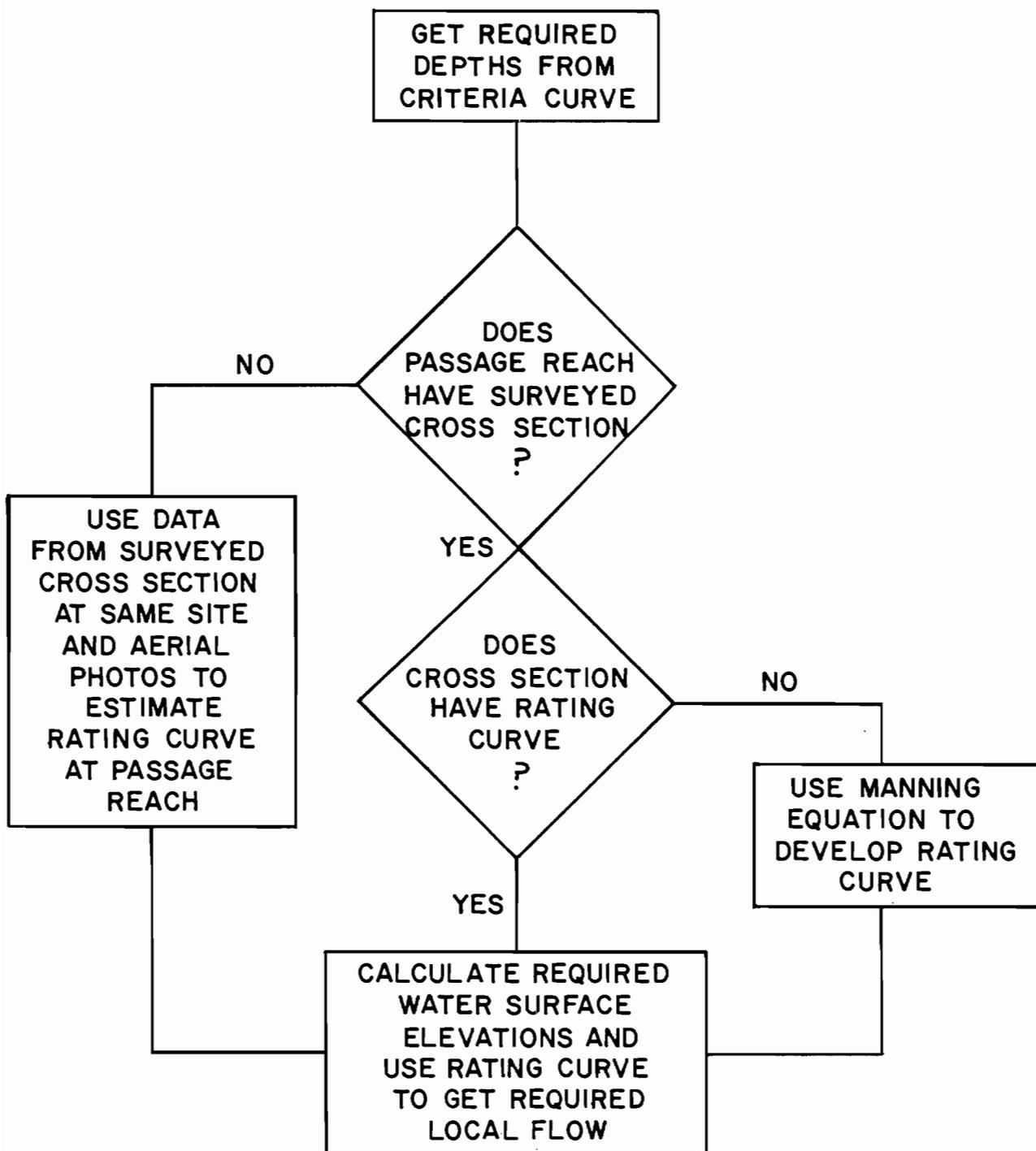


Figure 6-7 Flow diagram depicting the process for selecting methods employed in the local flow analysis.

- 4) Calculate the required water surface elevations (WSEL's) for successful and unsuccessful passage at each reach by adding the required depths from Step 1 to the elevation of the shallowest point within the passage reach. Use the rating curve to match the required WSELs to the local flows necessary for successful and unsuccessful passage.

The data base for each passage reach studied and the methods used to estimate the required local flows for passage are listed in Table 6-2. The passage reaches which were not analyzed for local flow, as explained in Section 2.3.2.3 (Evaluation of Passage Reaches) are identified.

If data indicated the presence of inflow or outflow along the site, the known local flow at one location at the site required adjustment in order to obtain passage reach flows elsewhere in the site. Adjustments which were made to the local flow for inflow or outflow are indicated in Table 6-2 if they were included in the flow calculations at the specified passage reach.

For certain sloughs, no useable data were available. Field observations by E. W. Trihey and Associates provided estimates of the local flows required for successful and unsuccessful passage.

Table 6-2. A summary of data sources and methods used in the analysis of local flow requirements for salmon passage.

Site	Data Base at Passage Reach			Adjustment To Local Flow For Inflow/ Outflow	Method Used				Local Flows Not Calculated
	Passage Reach	Surveyed Cross Section	Rating Curve		General Approach	Aerial Photo- graphic	Mannings Equation	Field Observations	
Whiskers Creek	I			x		x			
	II			x		x			
	III							x	
Mainstem 2	I							x	
	II							x	
	III L							x	
	III R							x	
	IV R						x		
	V R						x		
	VI R						x		
	VII R						x		
VIII R						x			
Slough 8A	I	x	x		x				
	II							x	
	III	x	x		x				
	IV							x	
	V	x	x		x				
	VI							x	
	VII							x	
	VIII	x	x		x				
	IX	x	x		x				
Slough 9	I	x	x		x				
	II	x	x		x				
	III	x	x		x				
	IV							x	
	V	x	x		x				

(Continued)

Table 6-2 (Continued).

Site	Data Base at Passage Reach			Adjustment To Local Flow For Inflow/ Outflow	Method Used				Local Flows Not Calculated
	Passage Reach	Surveyed Cross Section	Rating Curve		General Approach	Aerial Photo- graphic	Mannings Equation	Field Observations	
Slough 9A	I	x		x			x		
	II			x	x	x			
	III	x		x			x		
	IV			x	x	x			
	V							x	
	VI							x	
	VII							x	
	VIII							x	
	IX	x		x			x		
	X			x	x	x			
Side Channel 10	I							x	
	II							x	
	III							x	
	IV							x	
	V							x	
	VI							x	
	VII							x	
Slough 11	I						x		
	II						x		
	III						x		
	IV						x		
	V						x		
Upper Side Channel 11	I	x	x		x				
	II	x	x		x				
	III							x	
Slough 20	I					x			
	II					x			
	III					x			
	IV							x	
	V							x	
	VI							x	

(Continued)

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Table 6-2 (Continued).

Site	Data Base at Passage Reach			Adjustment To Local Flow For Inflow/ Outflow	Method Used				Local Flows Not Calculated
	Passage Reach	Surveyed Cross Section	Rating Curve		General Approach	Aerial Photo- graphic	Mannings Equation	Field Observations	
Slough 21	I							x	
	II L							x	
	II R							x	
Side Channel 21	I							x	
	II					x			
	III							x	
	IV					x			
	V	x		x	x				
	VI							x	
	VII							x	
	VIII							x	
	IX	x		x	x				
	X								x
Slough 22	I	x		x	x				
	II							x	
	III							x	
	IV					x			

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### 3.0 RESULTS

#### 3.1 Timing and Distribution of Salmon

##### 3.1.1 Mainstem Sites

Timing and distribution information on the upstream migration of adult salmon in relation to Susitna River discharge for the years 1981, 1982, and 1983 is presented in Figures 6-8 and 6-10. These plots show that peak migration periods for chum salmon occurred between late July and the middle of August during all three years at each of the sampling locations. Peak periods for pink and sockeye salmon also occurred within this same general time period, although, migrations for both these species slightly preceded those of chum salmon.

Mainstem discharges during the salmon migration period for the years 1981, 1982, and 1983 ranged from 27,000 to 150,000 cfs at the Sunshine fishwheel (USGS Sunshine gaging station) and from 12,000 to 60,800 cfs at the Talkeetna and Curry fishwheels (Gold Creek gaging station). The plots show that peak numbers of salmon were generally recorded during periods of stable or decreasing discharges. Catch records for all three years shows that fishwheel catches declined during periods of high discharge (ADF&G 1983c). Although this could be in part attributed to the inefficiency of the sampling gear at high discharges, examination of sonar count records during periods of high discharge also show a decrease in numbers of migrating salmon (ADF&G 1983c).

##### 3.1.2 Slough and Side Channel Sites

Timing information on the seasonal occurrence of chum and sockeye salmon in slough and side channel habitats for the years 1981, 1982, and 1983 is presented in Figures 6-11 and 6-12, respectively. Sufficient data to evaluate timing of pink salmon for all three years were not available. Tables 6-3 and 6-4 present more detailed information on the timing and peak numbers of each species at each site. Timing plots for each site for the months of August and September for chum, sockeye and pink salmon are presented by site in Appendix C of this report.

These data show that peak occurrences of chum and sockeye salmon within these habitats fall between August 18 and September 20 over the three year period. Chum salmon are more prevalent in late July and early August while larger numbers of sockeye appear in late August through September.

Maps which display salmon spawning distribution for the years 1981, 1982 and 1983 are presented in Appendix D of this report.

#### 3.2 Passage of Salmon

Salmon passage conditions were evaluated at individual passage reaches at each study site. Individual passage reaches were identified on the

1981

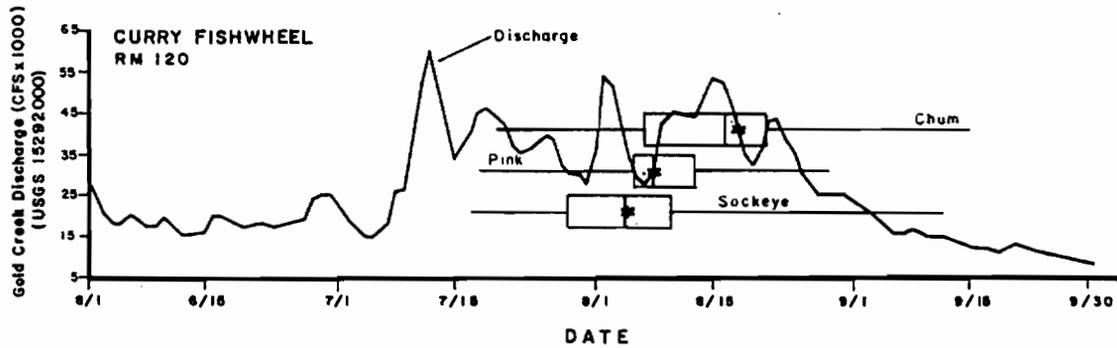
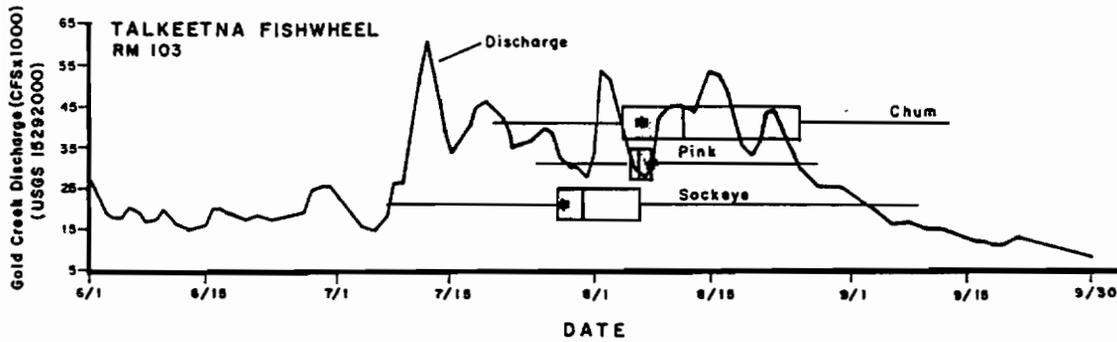
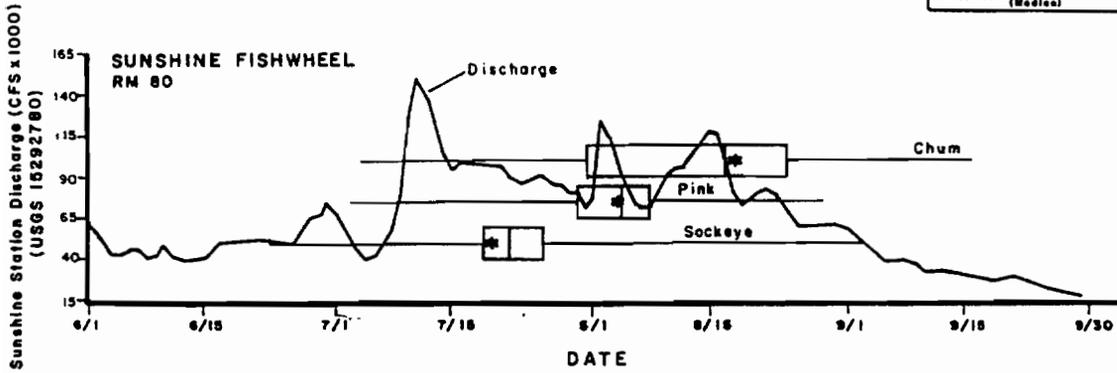
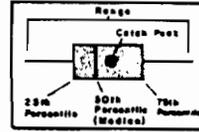


Figure 6-8 Timing plots showing peak occurrence of chum, pink and sockeye salmon migration at mainstem Susitna River fishwheel sites, 1981.

1982

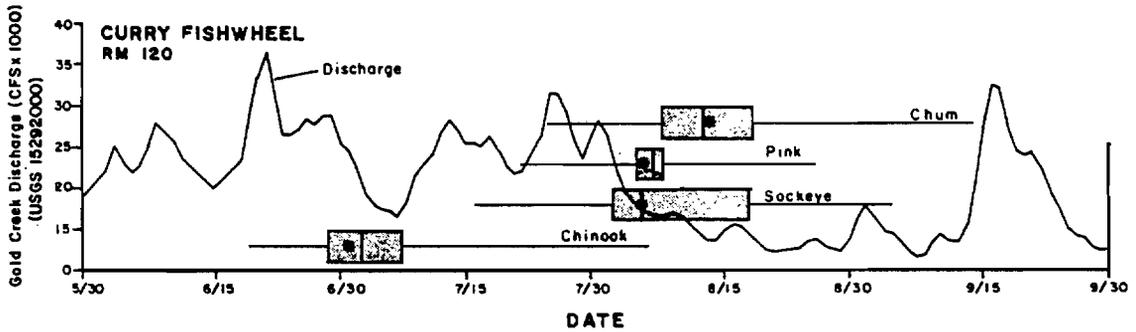
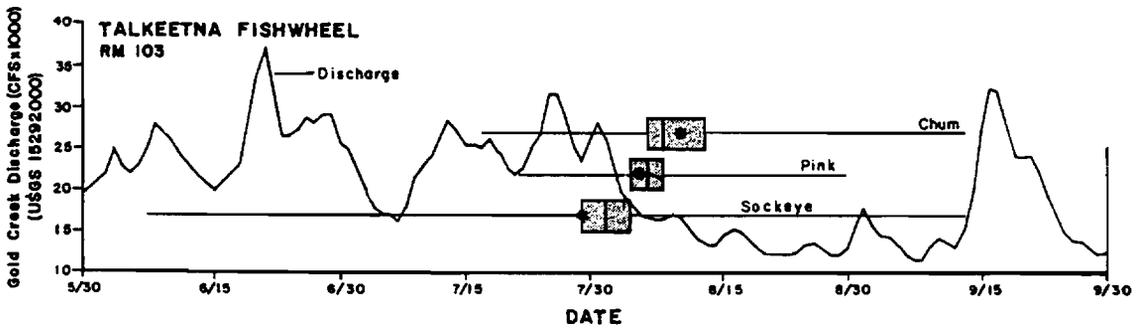
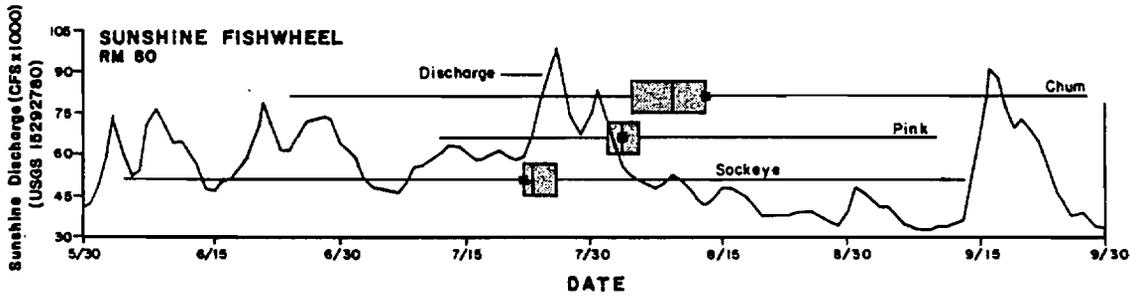
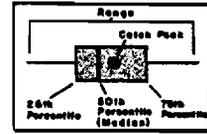
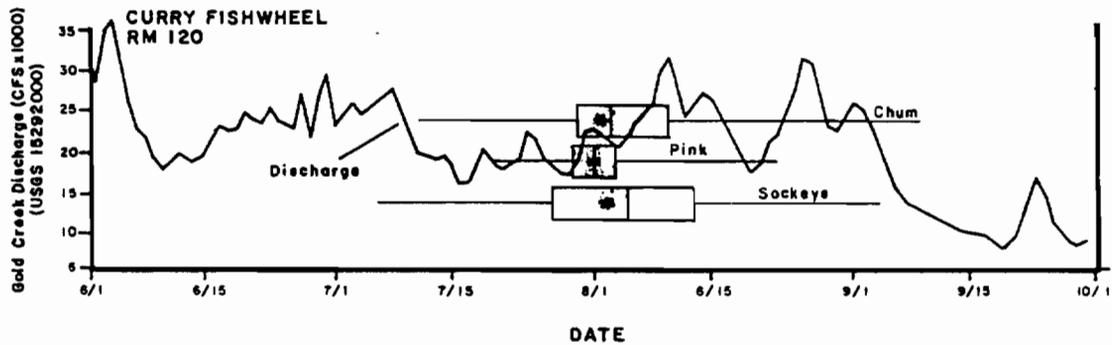
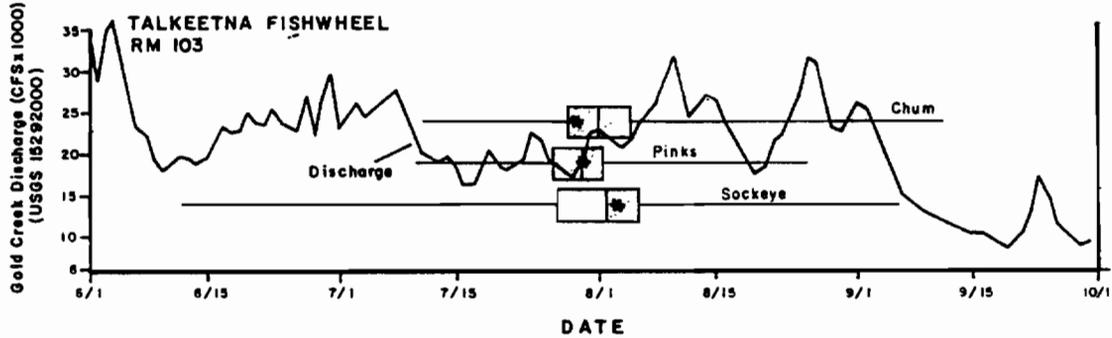
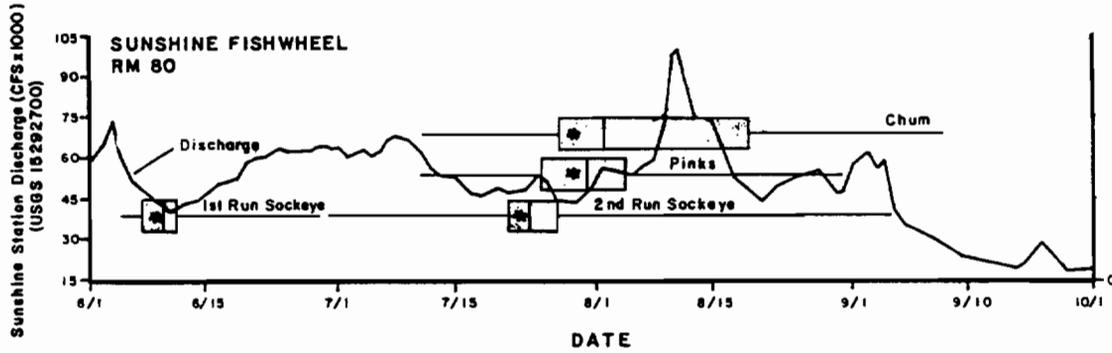
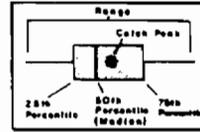


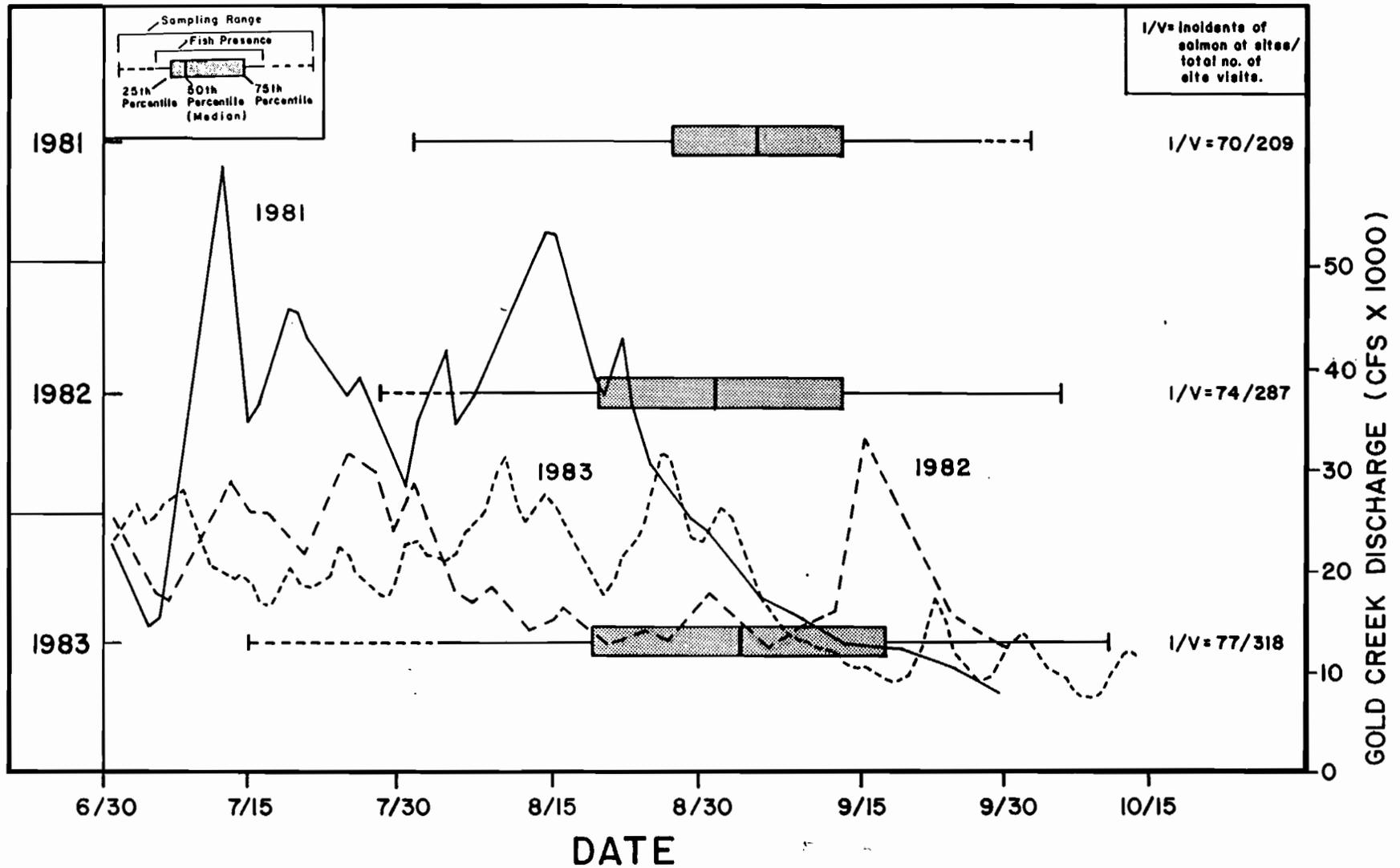
Figure 6-9 Timing plots showing peak occurrence of chum, pink and sockeye salmon migration at mainstem Susitna River fishwheel sites, 1982.

1983



4 Figure 6-10 Timing plots showing peak occurrence of chum, pink and sockeye salmon migration at mainstem Susitna River fishwheel sites, 1983.

# CHUM



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Figure 6-11. Peak periods of chum salmon presence in relation to mainstem Susitna River discharge in slough and side channel study sites, 1981, 1982, 1983.

# SOCKEYE

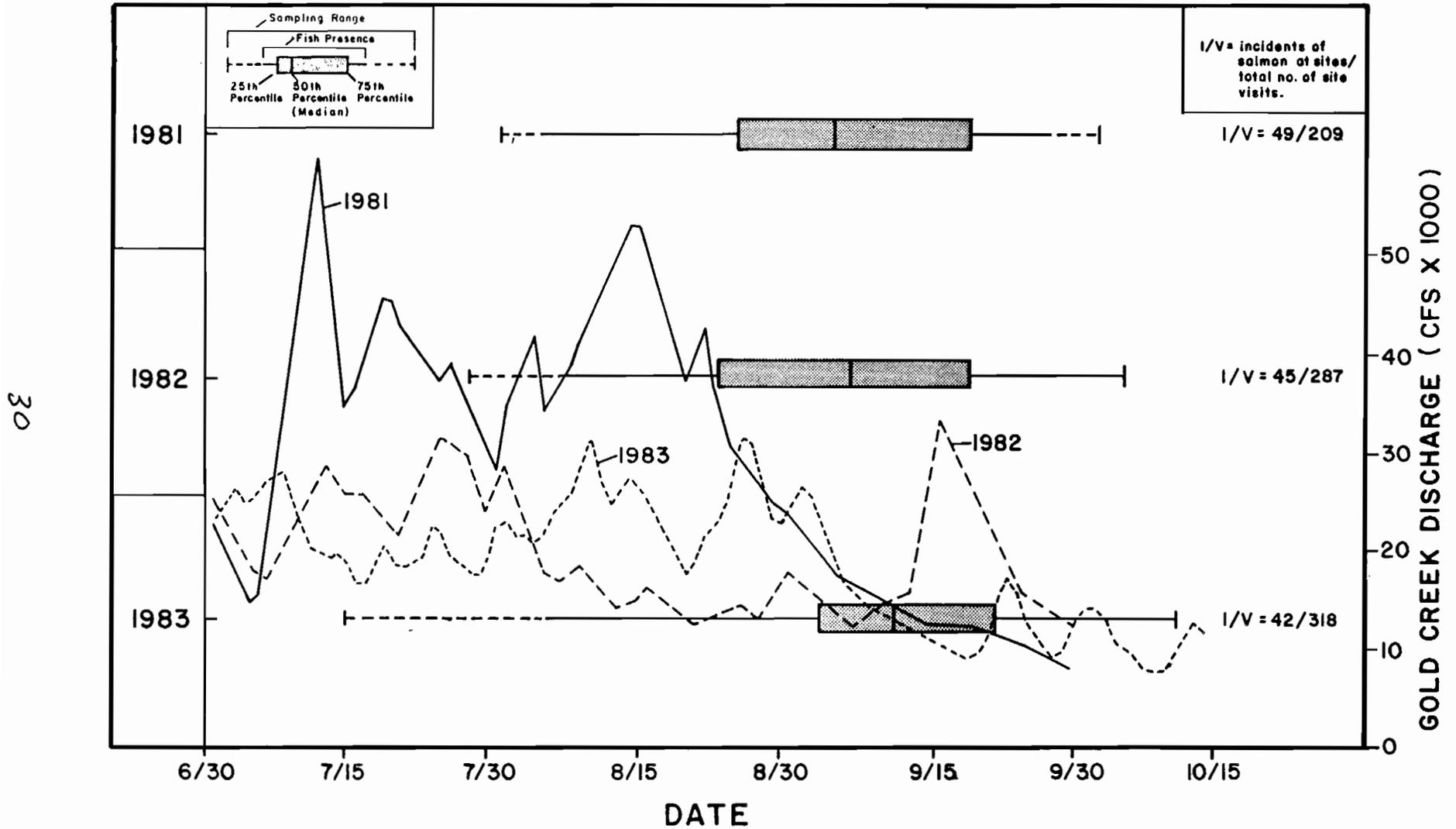


Figure 6-12. Peak periods of sockeye salmon presence in relation to mainstem Susitna River discharge in slough and side channel study sites, 1981, 1982, 1983.

Table 6-3. Dates and counts of peak escapement of chum and sockeye salmon observed in selected sloughs and side channels in the middle Susitna River during 1981, 1982 and 1983. Data based on survey conducted on 35 sloughs in the middle Susitna River, Barrett et al., 1984.

Site	River Mile	Chum Salmon						Sockeye Salmon					
		1981		1982		1983		1981		1982		1983	
		Date/No. Fish	Date/No. Fish	Date/No. Fish	Date/No. Fish	Date/No. Fish							
Whiskers Creek Slough	101.2	--	--	--	--	--	--	--	--	--	--	--	
Mainstem 2 Side Channel	114.5	--	--	--	--	--	--	--	--	--	--	--	
Slough 8A	125.3	9/4 (330)	8/23 (307)	8/30 (34)	9/4 (170)	8/12 (28)	9/11 (63)						
Slough 9	128.3	9/4 (212)	9/5 (242)	9/5 (121)	9/4 (10)	9/13 (3)	9/7 (2)						
Slough 9A	133.2	9/20 (136)	9/6 (107)	9/11 (93)	9/12 (2)	9/19 (1)	9/11 (1)						
Side Channel 10	133.8	--	--	--	--	--	--						
Slough 11 Complex <sup>b</sup>	135.3	8/27 (403)	8/30 (395)	9/9 (214)	9/11 (710)	8/30 (455)	9/11 (237)						
Slough 20	140.1	9/3 (12)	9/4 (23)	8/18 (57)	8/26 (2)	--	--						
Slough 21 Complex <sup>c</sup>	141.8	9/3 (270)	9/4 (615)	9/9 (149)	9/11 (38)	9/4 (43)	9/9 (180)						
Slough 22	144.2	--	--	8/18 (109)	--	--	--						

<sup>a</sup> Includes fish from Slough 11 and Upper Side Channel 11.

<sup>b</sup> Includes fish from Slough 21 and Side Channel 21.

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Table 6-4. Percent of total number of chum, sockeye and pink salmon in selected sloughs in 1981-1983. Percents were based on peak counts of live and dead fish. Averages are weighed. Table was derived from tables presented in Barrett et al., 1984.

Location	River Mile	Percent Distribution									Average		
		1981			1982			1983			Chum	Sockeye	Pink
		Chum	Sockeye	Pink	Chum	Sockeye	Pink	Chum	Sockeye	Pink	Chum	Sockeye	Pink
Slough 8A	125.9	23.9	14.3	0.0	15.0	11.2	5.5	2.5	11.9	14.2	15.1	13.0	5.2
Slough 9	128.3	10.0	0.8	0.0	13.4	0.8	2.4	11.5	0.3	0.0	11.1	0.7	2.1
Slough 9A	133.6	7.0	0.1	0.0	5.3	0.2	0.0	7.2	0.2	0.0	6.2	0.1	0.0
Slough 10	133.8	0.0	0.0	0.0	0.1	0.0	0.0	b	0.2	0.0	a	0.0	0.0
Slough 11	135.3	15.8	72.0	0.0	20.5	75.2	25.8	16.2	44.7	33.3	16.9	66.3	24.1
Slough 20	140.1	0.6	0.1	0.0	1.3	0.0	12.6	4.3	0.0	33.3	1.7	0.1	12.6
Slough 21	141.8	10.6	3.1	0.0	32.8	8.7	12.6	21.8	35.5	4.8	20.2	12.0	11.5
Slough 22	144.2	a	a	0.0	0.0	a	a	7.8	0.0	0.0	5.2	0.0	0.0

a = Insufficient data.

b = Less than 0.1% of total numbers of fish.

appropriate thalweg profile (Appendix E), and selected physical characteristics of each reach were summarized in Table 6-5. Based on physical characteristics present at each passage reach, passage conditions were evaluated according to one of two sets of fish passage criteria curves (refer to Figures 6-4 and 6-5).

2  
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### 3.2.1 Breaching and Backwater

Mainstem discharges and corresponding percent exceedence values that are required to provide successful and unsuccessful salmon passage conditions at selected spawning sites, are provided in Table 6-6. In this table, all mainstem discharges are paired with a corresponding percent exceedence that represents the percent of time that the indicated flow was equalled or exceeded during the critical salmon spawning period (20 August - 20 September) based on a 32 year flow record (USGS gage #15292000). All exceedence values were derived from the resultant flow duration curve previously provided in Figure 6-6.

### 3.2.2 Local Flow

Local flow estimates corresponding to successful and unsuccessful passage conditions at selected passage reaches are provided in Table 6-7. The estimates provide an indication of how much local flow is required for passage in the absence of mainstem discharge effects.

*I don't understand Tables 6-5 & 6-6 -  
I feel they are important but what exactly  
do they mean? (MBK)*

*Agree from*

*Passage reaches were ~~evaluated~~<sup>identified</sup>  
(p. 16) using Figures 6-4 & 6-5  
at low flows ('base flow  
conditions') Is this the  
flow used? (on tables  
6-5 + 6-6)*

Table 6-5. A summary list of all passage reaches and selected physical characteristics pertinent to backwater and/or local flow analyses.

*is the "low water" or "open flow"?*

Location (River Mile)	Passage Reach	Initial Conditions		Shallowest Depth		Length (ft)	Criteria Curve Used
		Mainstem Discharge (cfs)	Passage Condition	Thalweg (ft)	Passage (ft)		
Whiskers Creek Slough (101.2)	I	8440	unsuccessful	0.10	0.10	270	II
	II	-	unsuccessful	0.15	0.14	120	II
	III	-	unsuccessful	0.10	0.10	100	II
Mainstem 2 Side Channel (114.4)	I	9080	unsuccessful	0.30	0.26	105	I
	II	-	unsuccessful	0.35	0.30	170	I
	III L	-	unsuccessful	0.30	0.26	360	II
	III R	-	unsuccessful	0.30	0.26	165	II
	IV R	-	unsuccessful	0.25	0.22	25	I
	V R	-	unsuccessful	0.10	0.10	295	II
	VI R	-	unsuccessful	0.00	0.00	85	II
	VII R	-	unsuccessful	0.00	0.00	355	II
VIII R	-	unsuccessful	0.10	0.10	390	II	
Slough 8A (125.9)	I	6750	unsuccessful	0.20	0.18	170	I
	II	-	unsuccessful	0.15	0.14	265	I
	III	-	unsuccessful	0.20	0.18	510	I
	IV	-	unsuccessful	0.30	0.26	260	I
	V	-	unsuccessful	0.20	0.18	190	I
	VI	-	successful/difficult	0.40	0.34	80	I
	VII	-	successful/difficult	0.40	0.34	75	I
	VIII	-	unsuccessful	0.20	0.18	435	I
	IX	-	unsuccessful	0.10	0.10	475	I
Slough 9 (128.3)	I	10,700	unsuccessful	0.30	0.26	200	I
	II	-	unsuccessful	0.20	0.18	520	I
	III	-	unsuccessful	0.20	0.18	275	I
	IV	-	successful/difficult	0.40	0.34	30	I
	V	-	unsuccessful	0.00	0.00	3140	II
Slough 9A (133.6)	I	9,400	unsuccessful	0.30	0.26	115	II
	II	-	unsuccessful	0.30	0.26	145	II
	III	-	unsuccessful	0.15	0.14	320	II
	IV	-	unsuccessful	0.20	0.18	30	II
	V	-	successful/difficult	0.45	0.37	20	II
	VI	-	successful/difficult	0.50	0.41	205	II
	VII	-	successful/difficult	0.50	0.41	20	II
	VIII	-	unsuccessful	0.40	0.34	40	II
	IX	-	unsuccessful	0.20	0.18	310	II
	X	-	unsuccessful	0.00	0.00	255	II

(Continued)

Table 6-5 (Continued).

Location (River Mile)	Passage Reach	Initial Conditions		Shallowest Depth		Length (ft)	Criteria Curve Used
		Mainstem Discharge (cfs)	Passage Condition	Thalweg (ft)	Passage (ft)		
Side Channel 10 (133.8)	I	13,200	unsuccessful	0.00	0.00	340	I
	II	-	unsuccessful	0.00	0.00	365	I
	III	-	unsuccessful	0.00	0.00	40	I
	IV	-	unsuccessful	0.00	0.00	40	I
	V	-	successful/difficult	0.30	0.26	10	I
	VI	-	unsuccessful	0.00	0.00	200	I
	VII	-	unsuccessful	0.00	0.00	265	I
Slough 11 (135.3)	I	6,600	unsuccessful	0.30	0.26	250	I
	II	-	unsuccessful	0.30	0.26	745	I
	III	-	unsuccessful	0.30	0.26	115	I
	IV	-	unsuccessful	0.15	0.14	480	II
	V	-	unsuccessful	0.20	0.18	2,640	II
Upper Side Channel 11 (136.1)	I	-	unsuccessful	0.20	0.18	105	I
	II	-	unsuccessful	0.05	0.41	735	II
	III	-	unsuccessful	0.00	0.00	935	II
Slough 20 (140.1)	I	8,480	unsuccessful	0.15	0.14	170	II
	II	-	unsuccessful	0.15	0.14	300	II
	III	-	unsuccessful	0.25	0.22	170	II
	IV	-	successful/difficult	0.50	0.41	100	II
	V	-	unsuccessful	0.30	0.26	50	II
	VI	-	unsuccessful	0.05	0.41	660	II
Side Channel 21 (140.6)	I	7,800	unsuccessful	0.20	0.18	45	II
	II	-	unsuccessful	0.30	0.26	155	II
	III	-	successful/difficult	0.50	0.41	135	II
	IV	-	unsuccessful	0.20	0.18	35	II
	V	-	unsuccessful	0.40	0.34	505	II
	VI	-	unsuccessful	0.30	0.26	160	II
	VII	-	unsuccessful	0.40	0.34	360	II
	VIII	-	unsuccessful	0.25	0.22	105	II
	IX	-	unsuccessful	0.30	0.26	940	II
	X	-	unsuccessful	0.30	0.26	600	II
Slough 21 (141.8)	I	7,800	successful/difficult	0.50	0.41	30	II
	II L	-	unsuccessful	0.25	0.22	1,260	II
	II R	-	unsuccessful	0.00	0.00	2,030	II

(Continued)

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Table 6-5 (Continued).

Location (River Mile)	Passage Reach	Initial Conditions		Shallowest Depth		Length (ft)	Criteria Curve Used
		Mainstem Discharge (cfs)	Passage Condition	Thalweg (ft)	Passage (ft)		
Slough 22 (144.2)	I	16,500	unsuccessful	0.25	0.22	350	II
	II	-	successful/difficult	0.40	0.34	35	I
	III	-	successful/difficult	0.40	0.34	30	I
	IV	-	unsuccessful	0.10	0.10	295	I

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Table 6-6. Summary of mainstem discharges required to provide successful and unsuccessful salmon passage conditions at selected spawning sites in the Talkeetna to Devil Canyon reach of the Susitna River, Alaska, 1983.

Site (River Mile)	Passage Reach <sup>b</sup>	BREACHING ANALYSIS (CFS)				BACKWATER ANALYSIS <sup>a</sup> (CFS)				Criteria Curve Used	Staff Gage Used
		Initial Breaching Discharge	Exceedence % <sup>c</sup>	Controlling Discharge	Exceedence % <sup>c</sup>	Unsuccess- ful	Exceedence % <sup>c</sup>	Success- ful	Exceedence % <sup>c</sup>		
Whiskers Slough (101.2)	I	22,000	16	23,000	14	22,500	15	d	-	II	101.2W1
	II	22,000	16	23,000	14	d	-	d	-	II	-
	III	22,000	16	23,000	14	d	-	d	-	II	-
Mainstem 2 Side Channel (114.4)	I	12,000	71	16,000	45	11,500	74	12,200	70	I	114.6W6
	II	12,000	71	16,000	45	d	-	d	-	I	-
	III L	12,000	71	16,000	45	d	-	d	-	II	114.6W6
	III R	23,000	14	25,000	10	18,400	32	19,200	28	I	114.4S7
	IV R	23,000	14	25,000	10	d	-	d	-	II	-
	V R	23,000	14	25,000	10	d	-	d	-	II	-
	VI R	23,000	14	25,000	10	d	-	d	-	II	-
	VII R	23,000	14	25,000	10	d	-	d	-	II	-
VIII R	23,000	14	25,000	10	d	-	d	-	II	-	
Slough 8A <sup>e</sup> (125.9)	I	27,000	7	27,000	7	10,600	79	10,600	79	I	125.3W5
	II	27,000	7	27,000	7	14,600	54	15,600	48	I	125.3S6
	III	27,000	7	27,000	7	d	-	d	-	I	-
	IV	33,000	72	33,000	72	d	-	d	-	I	-
	V	33,000	72	33,000	72	d	-	d	-	I	-
	VI	33,000	72	33,000	72	d	-	d	-	I	-
	VII	33,000	72	33,000	72	d	-	d	-	I	-
	VIII	33,000	72	33,000	72	d	-	d	-	I	-
	IX	33,000	72	33,000	72	d	-	d	-	I	-
Slough 9 (128.3)	I	16,000	45	19,000	29	12,000 <sup>f</sup>	71	12,200 <sup>f</sup>	70	I	128.3W3
	II	16,000	45	19,000	29	d	-	d	-	II	-
	III	16,000	45	19,000	29	d	-	d	-	II	-
	IV	16,000	45	19,000	29	d	-	d	-	II	-
	V	16,000	45	19,000	29	d	-	d	-	II	-
Slough 9A (133.6)	I-X	No data		No data		No data		No data		-	-

(Continued)

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Table 6-6 (Continued).

Site (River Mile)	Passage <sup>b</sup> Reach	BREACHING ANALYSIS (CFS)				BACKWATER ANALYSIS <sup>a</sup> (CFS)				Criteria Curve Used	Staff Gage Used
		Initial Breaching Discharge	Exceedence % <sup>c</sup>	Controlling Discharge	Exceedence % <sup>c</sup>	Unsuccess- ful	Exceedence % <sup>c</sup>	Success- ful	Exceedence % <sup>c</sup>		
Side Channel 10 (133.8)	I	19,000	29	19,000	29	17,400	37	18,200	33	I	133.8W5
	II	19,000	29	19,000	29	d	-	d	-	I	-
	III	19,000	29	19,000	29	d	-	d	-	I	-
	IV	19,000	29	19,000	29	d	-	d	-	I	-
	V	19,000	29	19,000	29	d	-	d	-	I	-
	VI	19,000	29	19,000	29	d	-	d	-	I	-
Slough 11 (135.3)	I	42,000	1	42,000	1	15,200	50	16,200	44	I	135.3W1
	II	42,000	1	42,000	1	31,900	3	33,200	2	I	-
	III	42,000	1	42,000	1	38,300	1	39,600	1	I	-
	IV	42,000	1	42,000	1	d	-	d	-	II	-
	V	42,000	1	42,000	1	d	-	d	-	II	-
Upper Side Channel 11 (136.1)	I	13,000	65	16,000	45	11,400	75	12,400	68	I	136.2W3
	II	13,000	65	16,000	45	d	-	d	-	II	-
	III	13,000	65	16,000	45	d	-	d	-	II	-
Slough 20 (140.1)	I	22,000	16	23,000	14	20,800	21	22,100	16	II	140.1W4
	II	22,000	16	23,000	14	22,700	15	d	-	II	-
	III	22,000	16	23,000	14	d	-	d	-	II	-
	IV	22,000	16	23,000	14	d	-	d	-	II	-
	V	22,000	16	23,000	14	d	-	d	-	II	-
	VI	22,000	16	23,000	14	d	-	d	-	II	-
Side Channel 21 (140.6)	I	9,200	85	12,000	71	12,000 <sup>f</sup>	71	12,000 <sup>f</sup>	71	II	No Gage
	II	9,200	85	12,000	71	e	-	e	-	II	-
	III	9,200	85	12,000	71	e	-	e	-	II	-
	IV	9,200	85	12,000	71	e	-	e	-	II	-
	V	9,200	85	12,000	71	e	-	e	-	II	-
	VI	9,200	85	12,000	71	d	-	d	-	II	140.6S4
	VII	9,200	85	12,000	71	d	-	d	-	II	-
	VIII	9,200	85	12,000	71	d	-	d	-	II	-
	IX	9,200	85	12,000	71	d	-	d	-	II	-
	X	18,000	34	24,000	12	d	-	d	-	II	-

(Continued)

Table 6-6 (Continued).

Site (River Mile)	Passage Reach <sup>b</sup>	BREACHING ANALYSIS (CFS)				BACKWATER ANALYSIS <sup>a</sup> (CFS)				Criteria Curve Used	Staff Gage Used
		Initial Breaching Discharge	Exceedence % <sup>c</sup>	Controlling Discharge	Exceedence % <sup>c</sup>	Unsuccess- ful	Exceedence % <sup>c</sup>	Success- ful	Exceedence % <sup>c</sup>		
Slough 21 (141.8)	I	23,000	14	25,000	10	d	-	d	-	II	142.0W5
	II L	23,000	14	25,000	10	d	-	d	-	II	-
	III R	26,000	14	No Data	-	d	-	d	-	II	-
Slough 22 (144.2)	I	20,000	24	23,000	14	23,000 <sup>f</sup>	14	23,000 <sup>f</sup>	14	II	144.3W3
	II	20,000	24	23,000	14	e	-	e	-	I	-
	III	20,000	24	23,000	14	e	-	e	-	I	-
	IV	20,000	24	23,000	14	e	-	e	-	I	-

<sup>a</sup> Assume negligible slough flow.

<sup>b</sup> Left and right channels of sites (facing upstream) are indicated as "L" and "R", respectively.

<sup>c</sup> Percentage of total time for a 32 year flow record, that the indicated flow is equalled or exceeded during the period 20 Aug - 20 Sept. (USGS gage at Gold Creek, gage #15292000).

<sup>d</sup> Influence of backwater was not evaluated since breaching occurs at discharges lower than those required for providing backwater influence.

<sup>e</sup> Influence of backwater based on staff gage reading taken at mainstem discharge of 10,600 cfs; backwater rating curve not adequately defined below 15,000 cfs.

<sup>f</sup> Backwater rating curve not defined below the indicated (or preceding) table value.

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Table 6-7. Required local flows for successful and unsuccessful passage conditions at each passage reach identified in selected slough and side channel habitats in the middle Susitna River, Alaska, 1983.

Site	River Mile	Passage Reach		Successful Conditions		Unsuccessful Conditions	
		Number	Length (ft)	Passage Depth (ft)	Local Flow (cfs)	Passage Depth (ft)	Local Flow (cfs)
Whiskers Creek	101.2	I	270	.54	18	.41	5
		II	120	.49	16	.37	8
		III	120	a	a	a	a
Mainstem 2 <sup>b</sup>	114.4	I	105	a	a	a	a
		II	170	a	a	a	a
		III L	360	a	a	a	a
		III R	165	a	a	a	a
		IV R	25	.35	5	.24	3
		V R	296	.54	5	.41	3
		VI R	83	.48	5	.35	3
		VII R	354	.54	5	.41	3
VIII R	388	.54	5	.41	3		
Slough 8A	125.9	I	170	.40	2	.30	1
		II	265	a	a	a	a
		III	510	.41	4	.32	2
		IV	260	a	a	a	a
		V	190	.41	5	.31	3
		VI	80	a	a	a	a
		VII	75	a	a	a	a
		VIII	435	.41	4	.32	2
		IX	475	.41	4	.32	2
Slough 9	128.3	I	200	.41	2	.32	1
		II	520	.41	1	.32	1
		III	275	.41	6	.32	4
		IV	30	a	a	a	a
		V	3140	a	a	a	a

(Continued)

04

Table 6-7 (Continued).

Site	River Mile	Passage Reach		Successful Conditions		Unsuccessful Conditions	
		Number	Length (ft)	Passage Depth (ft)	Local Flow (cfs)	Passage Depth (ft)	Local Flow (cfs)
Slough 9A	133.6	I	115	.49	1	.36	1
		II	145	.51	3	.38	2
		III	320	.54	3	.41	2
		IV	30	.48	1	.35	0.5
		V	20	a	a	a	a
		VI	205	a	a	a	a
		VII	20	a	a	a	a
		VIII	40	a	a	a	a
		IX	310	.54	2	.41	0.5
		X	255	.54	3	.41	0.5
Side Channel 10	133.8	I	340	a	a	a	a
		II	365	a	a	a	a
		III	40	a	a	a	a
		IV	35	a	a	a	a
		V	10	a	a	a	a
		VI	200	a	a	a	a
		VII	265	a	a	a	a
Slough 11 <sup>b</sup>	135.3	I	250	.41	4	.32	3
		II	745	.41	4	.32	3
		III	115	.36	4	.27	3
		IV	480	.54	8	.41	5
		V	2639	.54	4	.41	3
Upper Side Channel 11	136.1	I	105	.36	6	.26	1
		II	735	.54	12	.41	7
		III	935	a	a	a	a
Slough 20	140.1	I	170	.52	6	.39	3
		II	300	.54	9	.41	4
		III	170	.52	6	.39	3
		IV	100	a	a	a	a
		V	50	a	a	a	a
		VI	660	a	a	a	a

(Continued)

Table 6-7 (Continued).

Site	River Mile	Passage Reach		Successful Conditions		Unsuccessful Conditions	
		Number	Length (ft)	Passage Depth (ft)	Local Flow (cfs)	Passage Depth (ft)	Local Flow (cfs)
Side Channel 21	140.6	I	45	a	a	a	a
		II	155	.51	8	.39	4
		III	135	a	a	a	a
		IV	37	.48	7	.35	2
		V	505	.54	18	.41	10
		VI	160	a	a	a	a
		VII	360	a	a	a	a
		VIII	105	a	a	a	a
		IX	940	.54	20	.41	10
		X	600	a	a	a	a
Slough 21	141.8	I	30	a	a	a	a
		II L	1260	a	a	a	a
		II R	2080	a	a	a	a
Slough 22	144.2	I	350	.54	11	.41	6
		II	35	a	a	a	a
		III	30	a	a	a	a
		IV	295	.41	2	.32	1

<sup>a</sup> Values not determined

<sup>b</sup> Discharge values obtained by observation (personal communication, E.W. Trihey).

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#### 4.0 DISCUSSION

##### 4.1 Assumptions and Limitations of Analyses

In order to develop criteria to evaluate successful and unsuccessful fish passage, several assumptions were made. These five assumptions enable the fish passage criteria to be generalized for application at all sloughs and side channels:

1. All passage reaches can be described as either uniform, straight channels with small substrate or non-uniform, braided channels with large substrate;
2. Successful and unsuccessful passage conditions for a given channel type for chum salmon are dependent only on passage depth and passage reach length;
3. Temperature variation effects are negligible in the development of criteria curves;
4. All velocities in the passage reaches are less than 2 fps and do not limit fish access; and
5. Water depths at which passage becomes successful at a reach length of 200 feet are adequate for passage at longer reach lengths;

All assumptions are justified by field observations by biologists. Most passage reaches conform to one of the two categories described in the first assumption. Those passage reaches which did not conform were classified by field observation. Passage depth and reach length are judged to be the most important factors influencing fish passage. Small ranges in temperature variability and water velocities below 2 fps seem to have little effect on fish passage. Field observations also indicate that at reach lengths exceeding 200 feet, depths required for passage do not increase.

Additional assumptions are made for the evaluation of passage reaches. Some apply to the general application and others relate to the method of analysis. The general assumptions which apply to all analytical methods are listed below.

1. The surveyed cross sections do not change with varying discharge. No erosion or deposition occurs over the study period.
2. Reach length remains constant with variations in local flow.
3. The relationship between passage depth and mean depth and passage depth and thalweg depth which are developed from surveyed transects may be applied at all cross sections.

The first assumption may be justified on two levels: 1) most cross-sections studied typically did not experience significant variations during the period of study; and 2) the analysis attempts to represent a long-term, stable system. Erosion and deposition would be approximately equal in such a system.

The second assumption can be supported through consideration of the small range of depths of interest in the passage reach. Such a small range would not cause a significant change in passage reach length.

The third assumption is based on regime theory in which channel shapes are similar between river systems. Additional data collected during the 1984 field season will provide refinement and verification of this assumption.

The breaching analysis contains one major assumption as follows:

1. When breaching occurs, passage is successful throughout the slough.

This assumption is supported by field observations. When a slough is breached, sufficient volumes of water are present to permit fish access throughout the slough.

The backwater analysis is based on one major assumption:

1. Local base flow is presumed to be a relatively insignificant factor in comparison to the effect of the mainstem and thus is considered negligible in backwater calculations.

The justification for this assumption depends on the small increase in water depth due to the local flow. The passage reach depths will not increase significantly until the backwater directly influences the water depth.

Various assumptions are made specifically for the analysis of the local flow as stated:

1. Slough flow is constant throughout the length of the slough unless data exist to enable estimating the effects of tributaries or groundwater upwelling on local flow;
2. Local unit flow is a function of mean depth and reach gradient;
3. The reach gradient from the thalweg survey corresponds to the energy slope;
4. Uniform flow is assumed; the Manning equation is applicable at passage reaches; and
5. Manning's roughness coefficient as calculated at a gaging site is applicable at a passage reach and is constant for varying depths of flow.

The first assumption is justified by field experience. Unless the data indicate a change in slough discharge, the effect of upwelling is considered negligible. Additional data will allow refinement of this assumption.

The second assumption is justified by empirical calculations using data from surveyed cross sections.

The last three assumptions relate to the use of Manning's equation and will be refined when additional data become available.

Field observations form the primary justification of the assumptions made in the analysis. The accuracy of these assumptions are thus difficult to evaluate. However, for the present conditions, the analysis correlates well with observed conditions.

#### 4.2 Timing

Data on the migration of chum, sockeye and pink salmon in the mainstem Susitna River indicate that there is a reduction in the numbers of salmon moving upstream during periods of high mainstem discharge (ADF&G 1981a, 1983b). It is likely that the higher velocities associated with periods of high mainstem discharge temporarily impede upstream movement of some salmon. However, as these discharges recede salmon migration increases, resulting in little overall affect on the timing of salmon movement in the mainstem.

Fishwheel catch rates of salmon in the mainstem show that peak periods of migrational activity occurred at approximately during the same time period (mid-August) for the years 1981, 1982 and 1983. Since the overall timing of the salmon migration remained relatively constant during all three years, despite higher than normal discharges in 1981, it appears that present flow regimes of the Susitna River provide adequate passage conditions to allow proper timing of the salmon migration in the mainstem Susitna River.

Similarly, surveys at slough and side channel sites show that peak numbers of salmon occurred during the same general time period (August 20 to September 20) for all three years. These data indicate that wide variations recorded in mainstem discharges under the present flow regimes do not affect timing of the arrival of salmon at these sites. However, survey counts during the three year period show that there are fluctuations in the numbers of salmon at these sites from year to year. This may indicate that although present mainstem discharges may not affect salmon timing to those sites, they may affect numbers of salmon that are able to utilize portions of the slough due to passage restrictions.

### 4.3 Passage Conditions at Study Sites

#### 4.3.1 Slough Sites

##### 4.3.1.1 Whiskers Creek Slough

Whiskers Creek Slough is not utilized as a spawning site for chum or sockeye salmon. Pink salmon spawn in the slough below the confluence with Whiskers Creek. The slough is primarily used by chum salmon as a migrational corridor to gain access to Whiskers Creek where they spawn. Therefore, any passage restrictions in Whiskers Creek Slough could affect the spawning distribution of salmon in Whiskers Creek.

Three passage reaches have been identified in Whiskers Creek Slough. Successful passage conditions exist at all three of these passage reaches at a controlling breaching discharge of 23,000 cfs, which occurs only 14 per cent of the time during the critical spawning period. There are no backwater effects on these passage reaches at mainstem discharges below the breaching discharge. The relatively high local flow estimates of about 18 cfs required for successful passage at Passage Reaches I and II, may occur frequently due to the input of flow from Whiskers Creek and may be the primary water source for providing successful passage conditions within the slough.

##### 4.3.1.2 Slough 8A

Slough 8A provides spawning habitat for relatively large proportions of chum and sockeye salmon in slough habitats within the middle reach of the Susitna River. In addition, it provides spawning habitat for a relatively smaller proportion of pink salmon. The distribution of spawning adults for each species is affected by a series of beaver dams located approximately 2,000 feet upstream from the mouth. These dams impede upstream movements of fish significantly at mainstem discharges below those required for breaching.

Nine passage reaches were identified, ranging in lengths from 80 to 510 feet. Successful passage conditions occur at all passage reaches when the head of the northeast channel is breached at a controlling breaching discharge of 33,000 cfs. Successful passage conditions occur at the three lowermost passage reaches at a discharge of 27,000 cfs when the northwest channel breaches. At discharges below 27,000 cfs, passage conditions are determined by local slough flows and/or backwater.

Backwater affects only the two lowermost passage reaches. Successful passage conditions occur at Passage Reaches I and II at mainstem discharges of 10,600 and 15,600 cfs, respectively (rating curve not defined for mouth gage below discharge of 10,600 cfs). At these discharges the length of the backwater affected zone is approximately 1,000 and 1,200 feet, respectively.

Estimated base slough flow is relatively high in this slough compared to most other sloughs evaluated in this study (Estes and Vincent-Lang 1984). This flow is primarily maintained by surface runoff and

groundwater sources. Estimates of local flow requirements for passage in this slough range from 2 to 5 cfs and are well below the estimated base flow of 10 cfs for this slough.

#### 4.3.1.3 Slough 9

Slough 9 provides spawning habitat for a relatively large proportion of the spawning chum salmon within the middle reach of the Susitna River. In addition, it provides habitat for relatively smaller proportions of sockeye and pink salmon. Within this slough, the majority of adult spawners of each species are restricted in distribution to the lower half of the slough because the upper half is largely dewatered under non-breached conditions.

A total of five passage reaches were identified, ranging in lengths from 30 to 3,140 feet. Successful passage conditions occur at all reaches at a controlling breaching discharge of 19,000 cfs. At mainstem discharges below 19,000 cfs, passage conditions at individual passage reaches may be affected by backwater and/or local slough flows. Although both Passage Reaches I and II are affected by backwater at mainstem discharges below the controlling breaching discharge, successful passage conditions do not occur at Passage Reach II until the head of the slough breaches (19,000 cfs). However, successful passage conditions at Passage Reach I occur at a mainstem discharge less than 12,000 cfs. This discharge is presently unrefined because the rating curve developed for the staff gage in the mouth of the slough is undefined at mainstem discharges less than 12,000 cfs.

Base slough flow is primarily maintained by two small creeks and upwelling groundwater. Collectively, these sources provide a base flow of approximately 5 cfs. This base flow appears adequate to provide successful passage conditions at Passage Reaches I-II, which require estimated slough flows of 2 and 1 cfs, respectively. However, this flow is not adequate to provide successful passage conditions at Passage Reach III, which requires 6 cfs. Although it is not certain, it is likely that successful passage conditions would also occur at Passage Reach IV at a similar slough flow. However, Passage Reach V is located upstream from the uppermost tributary and is typically dewatered except for a small trickle of water maintained by upwelling groundwater. This passage reach restricts upstream access to over 3,000 ft of slough. It therefore represents a major restriction to the full utilization of this slough by spawning salmon at mainstem discharges less than 19,000 cfs due to the absence of sufficient local flow.

#### 4.3.1.4 Slough 9A

Chum salmon is the predominant salmon species utilizing Slough 9A for spawning. They have been observed throughout the entire length of the slough. A limited number of sockeye salmon have also been observed in the slough, mostly in the lower third portion.

Ten passage reaches have been identified in this slough, ranging from 20 to 320 feet in length. Stage data are not available for this site to evaluate the effects of mainstem backwater and breaching on passage

conditions within the slough. An analysis of local flow conditions indicates that a slough flow of approximately 3 cfs provides successful passage throughout the slough. Salmon have been observed in the upper reaches of the slough under base flow conditions, which are maintained predominately by upwelling. Since chum salmon have had access to the entire slough during 1981, 1982 and 1983, it appears that they are able to surmount all passage reaches under natural flow conditions.

#### 4.3.1.5 Slough 11

Slough 11 supports a major proportion of the chum, sockeye and pink salmon which spawn in slough and side channel habitats within the middle reach of the Susitna River. Distribution of salmon within the slough is normally restricted to the lower half because under typical flow conditions the habitat in the upper reaches of the slough is mostly dewatered.

Five passage reaches have been identified within this slough. The first three are affected by backwater at mainstem discharges below the controlling breaching discharge. Successful passage conditions due to backwater effects, for these three passage reaches will occur at mainstem discharges of 16,200, 33,200 and 39,600 cfs, respectively. However, it appears that local flow from upwelling and/or other groundwater sources provides successful passage conditions at mainstem discharges less than those required for backwater effects. During the critical spawning period Passage Reaches II and III, which are seldom affected by backwater (less than two percent of the time), and Passage Reach IV, which is not affected by backwater, have been accessible to salmon in past years without any influence from mainstem discharge.

During periods of higher than normal mainstem discharges (42,000 cfs or above) the slough head is breached and there are no apparent passage problems. Under these conditions salmon have access to habitats above Passage Reach V and have been observed throughout most of the length of the slough. However, this controlling breaching discharge occurs less than one percent of the time during the critical spawning period. These conditions last occurred during 1981 due to higher than normal precipitation.

#### 4.3.1.6 Slough 20

Slough 20 supports a relatively small proportion of the spawning chum salmon that use slough and side channel habitats in the middle reach of the Susitna River. However, pink salmon in Slough 20 have accounted for an average of 12.6 percent of the pink salmon population in this reach of the Susitna River over the last three years. Only a few, apparently incidental, sockeye salmon have been observed at this site. Salmon use the lower part of the slough from the large pool above Waterfall Creek to the mouth.

Six passage reaches have been identified in Slough 20 ranging from 50 to 660 feet in length. The first five passage reaches are located below the confluence with Waterfall Creek. Only Passage Reach one is fully affected by backwater with successful passage conditions occurring at a

mainstem discharge of 22,100 cfs. However, this discharge occurs only 16 percent of the time. It appears that local flow, primarily from Waterfall Creek, is adequate to provide successful passage conditions during most of the critical spawning period. Local flows needed for successful passage conditions through Passage Reach V have been estimated to be approximately 9 cfs.

Both chum and pink salmon were observed approximately 2,000 feet upstream in the large pool above Passage Reach V during 1982. However, chum salmon distribution during 1983 was limited to the first 900 feet of the slough even though successful passage conditions appeared to have been provided periodically during the critical spawning period. This may have been due to the fact that the low densities of chum salmon in 1983 did not allow for full utilization of the habitat.

Passage Reach VI begins above the large pool above the mouth of Waterfall Creek and extends for 660 feet. Spawning salmon have not been observed within or above this passage reach. The low percent exceedence value (14%) associated with the controlling breaching discharge for this slough results in passage conditions at Passage Reach VI being unsuccessful the majority of the time.

#### 4.3.1.7 Slough 21

Slough 21 provides spawning habitat for a major proportion of the chum, sockeye, and pink salmon within the middle reach of the Susitna River. Side Channel 21 serves as a migrational corridor through which fish must pass in order to reach the mouth of Slough 21. Once fish reach the mouth, they are able to mill and hold in a relatively large pool area before continuing up the slough to spawn. In general, salmon of each species are restricted in distribution to the lower half of the slough during periods when the slough is not breached. If breaching occurs temporarily, fish are able to continue upstream and spawn in pools that later become shallow isolated pools when breaching flows subside.

Three passage reaches were identified, ranging in lengths from 30 to 2,080 feet. None of these reaches are affected by backwater at mainstem discharges below those required for breaching. Breaching of the left fork occurs at a mainstem discharge of 25,000 cfs, at which time Passage Reaches I and II are inundated. At present the controlling breaching discharge for the right fork is unknown. However, based on an initial breaching flow of 26,000 cfs, it is likely that the controlling discharge is in the range of 27,000 to 29,000 cfs.

Base flow in this slough is estimated to be approximately 5 cfs. This flow is maintained by upwelling groundwater and a very small tributary. Estimates of local flow requirements at passage reaches were not possible due to an insufficient data base. However, observations made by ADF&G personnel during the spawning period for chum salmon in 1982 (a relatively dry year) suggest that local flow is insufficient for providing successful passage conditions at any of the three passage reaches identified.

During the spawning period in 1982, four observations were made.

- 1) The majority of the local flow was maintained by upwelling groundwater originating in the lower half of the slough (below the confluence of the two forks);
- 2) Chum salmon were densely concentrated in the pool directly below Passage Reach I;
- 3) Attempts to pass through Passage Reach I were not successful by adult chum salmon during unbreached conditions; and
- 4) During mid September, the slough was breached and several chum salmon moved upstream and spawned in areas within the defined limits of Passage Reaches IIL and IIR.

These observations suggest that during 1982, local flows were not adequate to provide successful passage conditions at any of the three defined passage reaches. However, since 1982 was an exceptionally dry year, local flow contributions from the small tributary are also likely to have been unusually low. But, even if local flows were significantly higher than those observed during 1982, it is not likely that passage would be successful at Passage Reaches IIL and IIR since these passage reaches are above the region where most of the upwelling groundwater originates and have exceptionally steep gradients (refer to Appendix Figure 6-E-11).

#### 4.3.1.8 Slough 22

Chum salmon, the only salmon species recorded at Slough 22, were first observed spawning there in 1983. Previous to this salmon had not been observed at this site. Although this slough does not appear to be a major spawning habitat for chum salmon, 7.8 per cent of chum salmon recorded at slough and side channel habitats in the middle reach of the Susitna River used this site during 1983. The salmon were distributed in the lower 1,500 feet of the slough, primarily in the second large pool located between Passage Reaches III and IV.

Four passage reaches have been identified in Slough 22 ranging from 30 to 350 feet in length. All passage reaches have successful passage conditions at a controlling breaching discharge of 23,000 cfs. Below this discharge, passage conditions are dependent upon backwater and/or local flow.

Only the first passage reach is affected by backwater. However, since backwater rating curves are not available for this site, it is not possible to determine specific mainstem discharges required for successful and unsuccessful passage. Backwater affects this passage reach at discharges somewhere below 23,000 cfs.

Data on required local slough flows for successful and unsuccessful passage are only available for Passage Reaches I and IV. Slough flows required for successful passage at these two passage reaches are 11 and 2 cfs, respectively. It is likely that a combination of slough flow and backwater act to provide successful passage conditions in Passage Reach I. Passage Reaches II and III are relatively short and may be passable under local flow conditions. Since estimates of local flow are not available for this slough it is difficult to determine why salmon do not use habitat within or above Passage Reach IV. Since it is a relatively long passage reach without backwater, local flows may not be adequate to provide successful passage conditions.

#### 4.3.2 Side Channel Sites

##### 4.3.2.1 Mainstem 2 Side Channel

Chum salmon were observed spawning in Mainstem 2 Side Channel during 1982 and 1983. Spawning occurs mainly in the right channel, although spawning salmon have been observed in the lower 200 feet of the left channel. Other salmon species have not been observed at this site.

Nine passage reaches were identified within this side channel. The first two Passage Reaches (I and II) occur in the main channel, one passage reach is located in the left channel, and six passage reaches were identified in the right channel.

Passage Reaches I and II, located in the main channel, and Passage Reach III, located in the left channel, have successful passage conditions at a relatively low controlling breaching discharge of 16,000 cfs, which occurs 45 per cent of the time during the critical spawning period. Passage Reach I becomes successful due to backwater influence at a discharge of 12,200 cfs. These relatively low discharge requirements for successful passage at these sites indicates that passage is not a problem a large portion of the time.

Passage Reaches IIIR and VIIIR in the right channel have successful passage conditions at a controlling breaching discharge of 25,000 cfs. This discharge occurs only 10 per cent of the time during the critical spawning period. Passage Reach IIIR is affected by backwater at a discharge of 19,200 cfs (successful passage). Available data on local flows indicates that a flow of 5 cfs is needed for successful passage at Passage Reaches IVR to VIIIR. With the limited data available on local flows it is not possible to determine how often successful passage conditions would exist at these sites at discharges below the controlling breaching discharge.

##### 4.3.2.2 Side Channel 10

Side Channel 10 is not known to be used by spawning salmon. However, some portions of this channel contain what appears to be suitable habitat for spawning. Thus, passage conditions within this site were evaluated to determine if the absence of spawning salmon was attributable to fish passage restrictions.

Six passage reaches were identified ranging in lengths from 10 to 365 feet. Successful passage conditions occur at all reaches at a controlling breaching discharge of 19,000 cfs in the mainstem Susitna River.

Passage Reaches I and II are affected by backwater at discharges below the breaching discharge. Successful passage conditions occur at Passage Reach I at a mainstem discharge of 18,200, but successful passage conditions do not exist at Passage Reach II due to backwater, below the controlling breaching discharge.

A base flow of 5 cfs is maintained in this channel by groundwater upwelling and local runoff. Estimates of local flow requirements for successful passage at passage reaches were not possible due to an insufficient data base. It does not appear that passage restrictions account for the total absence of spawning salmon in this channel because passage conditions in this channel do not differ substantially from those in some sloughs where spawning occurs.

#### 4.3.2.3 Upper Side Channel 11

Upper Side Channel 11 provides spawning habitat for a significant number of chum salmon. The majority of fish spawn in the lower one third of the channel which is affected by backwater. Significant numbers of fish will also spawn in the middle reaches of this channel if temporary breaching flows permit passage into the area. Salmon have not been observed spawning in the upper one third of this channel.

Three passage reaches were identified, ranging in lengths from 105 to 935 feet. All reaches are inundated with mainstem water at a controlling breaching discharge of 16,000 cfs. At flows less than 16,000 cfs, passage conditions are determined by backwater and local flows.

Successful passage conditions due to backwater occur at Passage Reach I at a mainstem discharge of 12,400 cfs. At this discharge, the backwater extends approximately 450 feet up the channel to the beginning of Passage Reach II. Successful passage conditions at Passage Reaches II and III do not occur as a result of backwater, at mainstem discharges below that required for breaching.

Base flow in this channel is primarily maintained by groundwater upwelling originating within the area defined as Passage Reach II. Above this reach, some upwelling occurs, but it accounts for a relatively small proportion of the base flow. Collectively, these sources maintain an estimated base flow of 5 cfs (Estes and Vincent-Lang 1984) which is less than the local base flow requirements for Passage Reaches I and II (6 and 12 cfs, respectively). Passage Reach III could not be evaluated for local flow requirements due to an insufficient data base. Because this passage reach exists above the primary source of groundwater, it is probable that local slough flows are substantially less than 5 cfs and are not adequate to provide passage into the uppermost reaches of this channel.

#### 4.3.2.4 Side Channel 21

Side Channel 21 provides spawning habitat for a significant proportion of the chum salmon and a relatively small proportion of the sockeye salmon spawning within slough and side channel habitats in the middle reach of the Susitna River. However, a refined estimate of the total number of spawning salmon is not possible because turbid water is often present in the channel, reducing the potential to visually identify spawning fish. However, it is known that chum spawn throughout the entire length of the side channel and that sockeye salmon spawn in the upper one third.

Ten passage reaches were identified, ranging in lengths from 40 to 940 feet. Passage conditions at these reaches are primarily affected by breaching conditions at one or more of the numerous side channels which connect Side Channel 21 to the mainstem Susitna River. Successful passage conditions occur at all but the uppermost passage reach at a controlling breaching discharge of 12,000 cfs in the mainstem Susitna River. The uppermost passage reach requires a mainstem discharge of 24,000 cfs for successful passage conditions due to breaching flows.

Only the lowermost passage reach is affected by backwater at discharges below breaching discharges. Successful passage conditions are provided at a mainstem discharge of somewhat less than 12,000 cfs (rating curve not defined below 12,000 cfs).

Base flow in this channel is maintained by flow originating from Slough 21, upwelling groundwater and two small tributaries. Due to an incomplete data base, only four of the ten passage reaches were evaluated for local flow requirements. However, for Passage Reaches II, IV, V, and IX, estimated local flow requirements for successful passage ranged from 7 to 20 cfs. These flows are well within the base flow of 25 cfs estimated for this channel (Estes and Vincent-Lang 1984).

## 5.0 SUMMARY AND CONCLUSIONS

### 5.1 Summary

#### 5.1.1 General

The mainstem Susitna River influences salmon passage conditions in two fundamental ways. The most overwhelming influence occurs when the head of a slough or side channel is breached. When this occurs, all passage reaches are inundated and depth related passage restrictions are alleviated. In addition to breaching, mainstem discharges affect passage in the mouth area of a site by creating a backwater area. In general, as mainstem discharge levels rise, the stage rises in the mouth region creating a relatively quiescent pool which progressively inundates the lower portion of a site. The extent of inundation depends upon both the river stage and the gradient of the streambed. If the gradient is steeply inclined, the length of the inundated reach will be less than if the gradient is relatively flat.

In this study, breaching of most sites occurred at relatively high mainstem discharges (19,000-42,000) cfs. At mainstem discharges less than those required for breaching, the combined effects of backwater and local flows determine the conditions for salmon passage. Backwater influences only a few passage reaches (generally one or two per site), yet may restrict the movement of salmon into the entire slough or side channel. In contrast, local flows influence a greater number of passage reaches than backwater, but regulate fish passage into less habitat.

At any particular site, the relative importance of breaching backwater and local flows will vary primarily with changes in mainstem stage and secondarily with local hydrologic conditions at the site (e.g., local rainshowers and upwelling groundwater). Both of these factors may vary concurrently, providing a shift in the relative importance of factors affecting passage conditions.

In spite of the limitations of reducing a dynamic system to fit a static scheme, the relative importance of breaching, backwater and local flow are classified at each site (Table 6-8). This classification is admittedly limited, but represents the present level of understanding of the factors that are most probable to affect passage conditions at each site during the critical spawning period (20 August - 20 September). In general, local flows are relatively more important in affecting passage conditions in sloughs than side channels, whereas, breaching is relatively more important in side channels. The influence of backwater may be of critical importance at some sites because it may regulate passage of salmon into an entire site. However, in this summary, backwater has been considered as a relatively less important factor, and was ranked behind breaching and/or backwater at most sites (Table 6-8). It is important to note that this ranking in no way suggests that backwater is a less important factor than breaching or local flow; only that it is less likely or is less probable to be the dominant factor affecting fish passage under natural conditions during the critical spawning period.

Table 6-8. Summary of the relative importance of breaching, backwater and local flow effects on salmon passage conditions in sloughs and side channels in the middle Susitna River, Alaska.

Site	Relative Importance <sup>a</sup> of Factors Affecting Salmon Passage		
	Breaching	Backwater	Local Flows
<u>Sloughs</u>			
Whiskers Creek Slough	3	2	1
Slough 8A	2	3	1
Slough 9	3	2	1 <sup>b</sup>
Slough 9A	2	3	1 <sup>b</sup>
Slough 11	2	3	1
Slough 20	2	3	1
Slough 21	1	3	2
Slough 22	1	3	2
<u>Side Channels</u>			
Mainstem 2 Side Channel	1	2	3
Side Channel 10	1	2	3
Upper Side Channel 11	1	2	3
Side Channel 21	1	2	3

<sup>a</sup> Number one indicates most important factor.

<sup>b</sup> Local flow important in lower half of this slough; upper half of slough dominated by breaching flows.

5.1.2 Mainstem Influence

The combined effects of breaching and backwater on passage reaches in sloughs and side channels are summarized in Figure 6-13. The mainstem Susitna River discharge is plotted versus the cumulative linear distance of slough and side channel habitat (sites evaluated in this study) for which salmon passage is successful at the corresponding discharge. In general, passage reaches located in the lower portion of a study site regulate fish passage into relatively greater lengths of potential spawning habitat than passage reaches located in mid and upper portions of a site. To account for this difference in importance between passage reaches, a linear distance (measured along the thalweg, from beginning point of one passage reach to the beginning point of the next) was determined for each passage reach which represents the length of potential spawning habitat into which fish passage is controlled. From a total of more than 48,000 linear feet of habitat (combined slough and side channel sites evaluated), only 25% was accessible due to mainstem influence at a mainstem discharge of 15,000 cfs. Fifty percent of the habitat was accessible at a mainstem discharge of approximately 23,000 cfs, and 75% of the habitat at 30,000 cfs.

5.1.3 Local Flow Influence

Current information on the effects of local flow on passage conditions within each site is incomplete (refer to Table 6-7). However, it is clear that the effect of local flow is relatively greater in sloughs flow in sloughs appears to be adequate to conditions at many passage reaches. However, ries among sites as discussed previously. In are less important for providing successful breaching becomes relatively more important relatively less important in these habitats ve no adjoining tributaries and have less

*In the critical spawning period the mainstem flow is critical access provided by the mainstem habitat. Winter is a critical access period. Accessible habitat is 20-30% of total.*

Distribution of Salmon

em Susitna River primarily as a migrational r natal spawning grounds in slough and side e middle reach of the Susitna River basin.

salmon in the mainstem river varies inversely ge levels, particularly at relatively high

period for chum salmon in the middle Susitna ximately 20 August to 20 September.

Salmon

a particular slough or side channel in the re primarily a function of breaching and/or ws.

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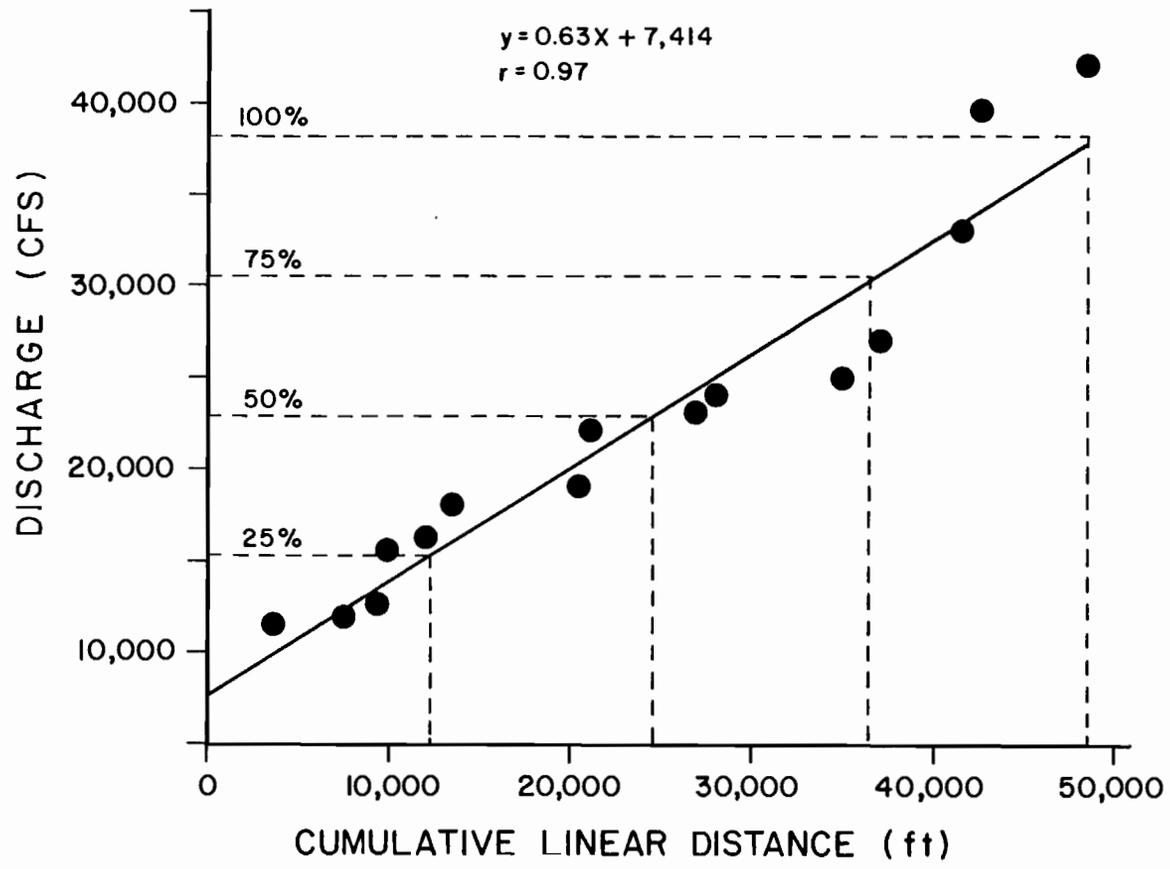


Figure 6-13 The relationship between mainstem Susitna River discharge and the amount of slough habitat (measured in linear feet) inundated to a depth sufficient to provide successful passage of chum salmon (successful defined on basis of Passage Criteria Curves, Figures 6-4 and 6-5).

2. Breaching discharges are relatively more important in providing successful passage conditions in side channels than in sloughs.
3. Local flows are relatively more important in providing successful passage conditions in sloughs than in side channels.
4. Backwater may be the dominant factor in providing successful passage conditions in either sloughs or side channels. Backwater normally affects the lower most passage reaches in each site. A total restriction of fish passage through a backwater affected reach would deny fish access to spawning areas above the restricted reach.
5. Excluding the effects of local flow, successful passage conditions occur in 25, 50, and 75% of the total length of slough and side channel habitat studied at mainstem discharges of approximately 15,000, 23,000, and 30,000 cfs, respectively.
6. The effects of local flow vary widely but appear to provide successful passage conditions at a majority of passage reaches in slough habitats. More reliable estimates on local flow requirements at each site are anticipated in a forthcoming ADF&G technical memorandum which will supplement the data presented in this report.
7. Of the sloughs evaluated in this study, Sloughs 9 and 21 have the most serious passage restrictions for mainstem discharges less than the breaching discharge.

*200, of the total length of slough and side channel habitat studied at mainstem discharges of approximately 15,000, 23,000, and 30,000 cfs, respectively.*

## 6.0 GLOSSARY

Acute passage condition: See unsuccessful passage.

Backwater Area: A segment of flowing water in which the depth of water is greater than that which would otherwise exist for a given discharge due to an obstruction downstream of the channel.

Berm: The controlling elevation of the alluvial material at the head of a side slough or side channel that separates the side slough or side channel from the mainstem Susitna River or other side channels.

Breaching: Any one of three conditions of overtopping the head of a side channel or side slough (see also initial, intermediate, and controlling breaching discharges).

Controlling Breaching Discharge: The breaching condition in which mainstem discharges at Gold Creek are equal to or greater than the mainstem discharges required to directly govern the hydraulic characteristics within a side slough or side channel. This condition can be denoted as equalling the flow rating curve beginning with the point of inflection and beyond mainstem discharge at Gold Creek.

Cross Section Profile: A streambed profile which describes the bank to bank cross sectional shape of the channel.

Discharge: Water volume passing a fixed location at a specific point in time. In this report, the term specifically refers to mainstem habitat.

Flow: Water volume passing a fixed point per unit. In this report, the term specifically refers to non-mainstem habitats.

Gaging Station: A location site which has been established for monitoring water surface elevation, flow or discharge.

Gradient: Change in vertical elevation per unit horizontal distance.

Head: The upstream confluence or point of origin of a lotic environment.

Inflection Point: The point at which a rating curve changes slope.

Initial Breaching Discharge: The mainstem discharge at Gold Creek when mainstem water initially begins to enter (overtops) the upstream berm of a side slough or side channel.

Intermediate Breaching Discharge: The range of mainstem discharges at Gold Creek representative of the conditions between the initial and controlling breaching discharges. Intermediate breaching discharges occur from immediately after mainstem surface water begins to overtop the head (berm) of a side slough or side channel up to

the point when the mainstem discharge begins to govern the hydraulic characteristics of the site.

Mainstem Habitat: Consists of those portions of the Susitna River that normally convey water throughout the year. Both single and multiple channel reaches are included in this habitat category. Groundwater and tributary inflow appear to be inconsequential contributors to the overall characteristics of mainstem habitat. Mainstem habitat is typically characterized by high water velocities and well armored streambeds. Substrates generally consist of boulder and cobble size materials with interstitial spaces filled with a grout-like mixture of small gravels and glacial sands. Suspended sediment concentrations and turbidity are high during summer due to the influence of glacial melt-water. Discharges recede in early fall and the mainstem clears appreciably in October.

Mouth: The area of a lotic environment at its confluence with another. Used in this report in reference to sloughs and side channels.

Overtopping: See breaching.

Passage: Ability of adult salmon to migrate within a slough, side channel or tributary. (See successful passage, successful passage with difficulty and exposure, and unsuccessful passage conditions).

Passage Depth: The depth of water through which a fish must pass in order to proceed upstream. As used in our report, passage depth is the average of the mean depth and maximum depth at a transect.

Passage Reach: Segments of a channel between its mouth and head which are potentially limiting to adult salmon migration to spawning areas within it.

Peripheral Habitats: Aquatic habitats located adjacent to the mainstem Susitna River habitat (e.g., side channel, side slough, upland slough, tributary mouth and/or tributary habitats).

Pool: A portion of a lotic environment that is relatively deep and slow-moving in comparison to other areas.

Project Datum: An elevation to which all other elevations that are used within the project area are referenced.

Rating Curve: A curve that describes the relationship between water surface elevation and discharge at a site.

Riffle: A portion of a lotic environment that is relatively shallow and fast-running in comparison to other areas.

Side Channel Habitat: Consists of those portions of the Susitna River that normally convey water during the open water season but become appreciably dewatered during periods of low mainstem discharge.

Side channel habitat may exist either in well defined overflow channels, or in poorly defined channels flowing through partially submerged gravel bars and islands along the margins of the mainstem river. Side channel streambed elevations are typically lower than the mean monthly water surface elevations of the mainstem Susitna River observed during June, July and August. Side channel habitats are characterized by shallower depths, lower velocities and smaller streambed materials than the adjacent habitat of the mainstem river.

Side Slough Habitat: This habitat is located in overflow channels between the edge of the floodplain and the mainstem and side channels of the Susitna River. It is usually separated from the mainstem and/or side channels by well vegetated bars. An exposed alluvial berm often separates the head of the slough from mainstem discharge or side channel flows. The controlling streambed/bank elevations at the upstream end of the side sloughs are slightly less than the water surface elevations of the mean monthly discharges of the mainstem Susitna River observed for June, July, and August. At intermediate and low-discharge periods, the side sloughs convey clear water from small tributaries and/or upwelling groundwater. These clear water inflows are essential contributors to the existence of this habitat type. The water surface elevation of the Susitna River generally causes a backwater area to extend well up into the slough from its lower end. Even though this substantial backwater area exists, the sloughs function hydraulically very much like small stream systems and several hundred feet of the slough channel often conveys water independent of mainstem backwater effects. At high discharges the water surface elevations of the mainstem river is sufficient to overtop the upper end of the slough. Surface water temperatures in the side sloughs during summer months are principally a function of air temperature, solar radiation, and the temperature of the local runoff.

Staff Gage: A device used to visually monitor changes in water surface elevation at a site.

Successful Passage (unrestricted): Fish passage into and/or within the spawning area is uninhibited, and would not affect natural production in the area.

Successful Passage With Difficulty & Exposure: Fish passage into and/or within the spawning area is accomplished, but with stress and exposure to predation; although a sufficient number of fish pass to allow continued production in the area, this condition over a long period of time may result in a decline in natural production in the area.

Thalweg Profile: A longitudinal profile that describes the streambed elevation of the deepest portion of the channel parallel to flow.

Tributary Habitat: Consists of the full complement of hydraulic and morphologic conditions that occur in the tributaries. Their seasonal flow, sediment, and thermal regimes reflect the

integration of the hydrology, geology, and climate of the tributary drainage. The physical attributes of tributary habitat are not dependent on mainstem conditions.

Tributary Mouth Habitat: Extends from the uppermost point in the tributary influenced by mainstem Susitna River or slough backwater effects to the downstream extent of the tributary plume which extends into the mainstem Susitna River or slough.

Turbid: The condition of water quality at a site when water clarity is decreased by inorganic and/or organic suspended materials.

Unsuccessful Passage: Fish passage into and/or within the spawning area may be accomplished by a limited number of fish; however, exposure to excessive stress and increased predation (which are associated with these conditions) may eventually eliminate or greatly reduce the natural production in the area.

Unrestricted Passage Condition: See successful passage.

Upland Slough Habitat: Differs from side slough habitat in that the upstream end of the slough does not interconnect with the surface waters of the mainstem Susitna River or its side channels even at high mainstem discharges. These sloughs are characterized by the presence of beaver dams and an accumulation of silt covering the substrate resulting from the absence of mainstem scouring discharges.

Water Surface Elevation (WSEL): The elevation of the water surface at a particular location.

## 7.0 CONTRIBUTORS

Aquatic Habitat and Instream Flow Studies (AH) Project Leader and Principal Contact	Christopher Estes
AH Fish Habitat Utilization Subproject Leader	Andrew Hoffmann
AH Instream Flow Subproject Leader	Tim Quane
Hydraulic Engineer	E. Woody Trihey
Data Processing Project Leader	Allen Bingham
Graphics	Sally Donovan Carol Hepler Carol Kerkvliet Ann Reilly
Typing Staff	Vicki Cunningham Peggy Skeers Mary Gressett
Editors	Christopher Estes
Data Collection	Jeff Blakely Andrew Hoffmann Chris Kent Jody Miller Pat Morrow Tim Quane Issac Qeral Sheryl Salasky Gene Sandone Don Seagren Kathy Sheehan Rick Sinnot Kim Sylvester Tommy Withrow
Data Analysis	Jeff Blakely Elizabeth Bradley Janet Hearn Tim Quane Issac Qeral Craig Richards Larry Rundquist Gene Sandone Joe Sautner Don Seagren Len Vining

CONTRIBUTORS (Continued).

Text

Larry Rundquist  
Joe Sautner  
Len Vining

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## 10.0 APPENDICES

Appendix A. Site Descriptions

Appendix B. Supplement to Methods of Local Flow Analysis

Appendix C. Timing Plots

Appendix D. Salmon Spawning Distribution Maps

Appendix E. Thalweg Profiles of Sloughs and Side Channels

Appendix 6-A  
Study Site Descriptions

## APPENDIX 6-A

This appendix presents a site by site description of the physical and hydrological characteristics of slough and side channel study sites. The sites are presented in order beginning with the most downstream site, Whiskers Creek Slough (RM 101.2), and continuing upstream to Slough 22 (RM 144.2).

### Whiskers Creek Slough - RM 101.2

Whiskers Creek Slough is located on the west bank of the Susitna River, 3.3 miles above the confluence of the Chulitna and Susitna Rivers (Appendix Figure 6-C-1). The slough is 2940 feet long and semi-circular in shape. Whiskers Creek enters the slough approximately 1200 feet upstream of the slough mouth. The lower third of the slough has a gradient of 18.8 ft/mi while the upper two thirds is relatively flat with a gradient of 4.9 ft/mi. The slough has both steep and gentle sloping banks with sparse vegetative cover. Gravel/rubble substrate is predominant in the lower half of the slough with mostly cobble/boulder substrate in the upper half of the slough. Silt/sand deposits are found in the pools in the backwater area at the mouth.

Whiskers Creek drains an area of approximately 20 square miles. The primary water source of the tributary is surface runoff from bogs. Tannins originating from the bog discolor the creek, along with suspended silts at high discharges. The slough's water clarity is affected by the creek and mainstem backwater in the lower section, and by the mainstem Susitna River when breached, causing the entire slough to flow turbid. When unbreached, the slough flows clear above its confluence with Whiskers Creek.

The controlling breaching discharge of the slough is 23,000 cfs. At this, or higher discharges, the typical pool/riffle sequence changes to long runs or pools. At mainstem discharges below the controlling breaching level, slough flow is maintained by ground seepage and flow from Whiskers Creek. A backwater pool at the mouth extends 700 feet up the slough at mainstem discharges of 21,600 cfs or higher, eliminating the first riffle upstream of the mouth.

### Mainstem 2 Side Channel - RM 114.5

Mainstem 2 is a broad Y-shaped side channel located on the east bank of the Susitna River (Appendix Figure 6-C-2). The left channel extends 4,400 feet upstream from the mouth in a northerly direction. The right channel joins the left channel approximately 1600 feet upstream of the mouth and extends 4,400 feet upstream in a north-northeasterly direction. Cobble/boulder is the predominate substrate throughout the side channel, especially in the right channel. Gravel/rubble and silt/sand deposits can be found in the pool and riffle areas. Silt/sand substrate is especially predominant in the backwater area at the mouth. The side channel has both steep and gentle sloping banks with sparse vegetative cover. The Alaska Railroad parallels the slough on a high steep bank from the mouth to the head of the right channel (RM 116).

The two channels of Mainstem 2 have different controlling breaching discharges. The controlling breaching discharge of the left (NW) channel is 16,000 cfs, while the right (NE) channel is 25,000 cfs. When the left channel breaches, it affects the backwater pool at the mouth and the left channel itself. Except at the confluence of the two channels, it has little if any effect on the right channel. Below controlling breaching discharges, base side channel flow is maintained by seepage from the mainstem and runoff from the surrounding area.

A typical pool/riffle sequence is evident in both channels below breaching flows. The water in both channels remains clear until it enters the area at the mouth where it mixes with the turbid water that enters from the mainstem, and forms the backwater area.

#### Slough 8A - RM 125.3

Slough 8A is located on the east bank of the Susitna River (Appendix Figures 6-C-3 to 6-C-5). The slough is approximately two miles in length and is separated from the mainstem Susitna River by a large vegetated gravel bar. The slough mouth is adjacent to a side channel. Two principal channels connect the slough with the mainstem Susitna River. The slough channel is relatively straight with a gentle bend near the head of the slough. Approximately 2,000 feet upstream of the mouth, a series of beaver dams are located across the braided channel which inhibit upstream migration of salmon. Some dams are completely filled in with cobble resulting in a semi-permanent barrier while others are frequently modified by stage changes. During the 1983 season, another beaver dam was constructed approximately 3,200 feet upstream of the mouth. The banks range from low, gently sloping banks to five-foot high steep cut banks. The Alaska Railroad parallels the south bank of the slough. The overall slough gradient is 10.5 ft/mi. Cobble/boulder substrate predominates in the upper half of the slough. Gravel/rubble is the predominant substrate in the lower half of the slough. Silt/sand deposits are found in the backwater area at the mouth and in the pools formed by the beaver dams.

A backwater area extends approximately 1,000 feet upstream of the mouth during periods of moderate to high mainstem discharge. Above the backwater area is a 100-300 foot riffle followed by a large beaver dam. The northwest overflow channel flows into a large pool behind the beaver dam. Another dam 1,200 feet further upstream impounds the water from the northeast channel. The controlling breaching discharge of the northwest channel is 27,000 cfs, while that of the northeast channel is approximately 33,000 cfs. Base slough flow is maintained by surface runoff, groundwater seepage and upwelling.

#### Slough 9 - RM 128.3

Slough 9 is a 1.2 mile long unobstructed "S"-shaped channel on the south bank of the Susitna River (Appendix Figures 6-C-6 to 6-C-8). Both the head and mouth of the slough open into side channels of the mainstem Susitna River. The lower half of the slough has a relatively shallow gradient which steepens past a point roughly 3,000 feet upstream of the mouth where the slough makes a sharp bend. The overall slough gradient

is 13.7 ft/mi. Gravel/rubble substrate is predominant in the lower half of the slough, while cobble/boulder predominates in the upper half. Silt/sand deposits are found in the pool areas and the backwater area at the mouth. The area at the mouth consists of sand bars that are in a constant state of change. The banks generally have a moderate to steep slope and are 3-4 feet high. A small slough (9B) branches off in a northeasterly direction near the head of Slough 9. The Alaska Railroad parallels the southeast bank of the lower half of the slough.

The head of the slough has an initial breaching discharge of 16,000 cfs. Below this discharge the upper half of the slough is primarily dry, with an intragravel flow of water. There is little, if any, intragravel flow in the lower half of the slough. At controlling breaching discharge conditions of 19,000 cfs or above, water flows freely through the slough, changing it to a completely turbid environment.

At mainstem discharges less than 12,000 cfs the backwater area at the mouth extends 500 feet upstream to the base of the first riffle. At higher mainstem discharges, the riffles are inundated and the lower half of the slough becomes one long pool. The lower half of the slough is a series of pools and riffles ending with the backwater area at the mouth. Base slough flow is maintained by two small creeks and contributions from groundwater percolation (upwelling). Contributions to base slough flow by Slough 9B are negligible. A beaver dam was constructed across the mouth of Slough 9B in early 1983.

#### Slough 9A - RM 133.2

Slough 9A is located on the south bank of the Susitna River (Appendix Figures 6-C-9 and 6-C-10). It is a winding slough about 3,200 feet long with an overall slough gradient of 16.1 ft/mi. The slough is separated from the mainstem by a vegetated gravel bar with steep cut banks. The south bank is generally lower in elevation than the north bank. A vegetated flood plain is formed along the south bank before it rises sharply. The Alaska Railroad parallels the slough on the south.

The slough habitat consists of a series of long pools separated by riffles. A gravel bar at the mouth extending from the north bank is exposed to varying degrees, depending upon mainstem discharge. This can result in displacement of the mouth several hundred feet further downstream at low mainstem discharge levels. Cobble/boulder is the predominant substrate type in the slough. Silt/sand deposits are found in the pools and the backwater area at the mouth. Base slough flow appears to be maintained by ground water seepage (upwelling) and surface water runoff.

#### Side Channel 10 - RM 133.8

Side Channel 10 is approximately 2,300 feet long and is located on the west side of the Susitna River (Appendix Figure 6-C-11). It joins with Slough 10, 379 feet upstream of the mouth of the slough. It is separated from the mainstem Susitna River on the south bank by a low, sparsely vegetated gravel bar with gently sloping banks. The north bank is a

high steep cut bank that is thickly vegetated with shrubs and trees. Pool/riffle sequence predominates throughout the side channel except for a backwater area at the mouth. The lower half of the side channel consists mostly of a gravel/rubble substrate, while the upper half is cobble/boulder. Silt/sand deposits are found in the pool areas and in the backwater area at the mouth. The overall side channel gradient is 20.5 ft/mi.

Side Channel 10 is initially breached at a mainstem discharge of approximately 19,000 cfs. The initial and controlling breaching discharges are the same at this site. Once the channel is breached, the water becomes turbid. The first 900 feet of the side channel is a long pool, influenced by mainstem backwater. It generally remains turbid while the rest of the slough is clear. There are several intermittent channels intersecting the gravel bar forming the south bank, which contributes additional flow to the side channel. The exact discharge at which they become watered has not been determined. Below the breaching discharge, base channel flow is maintained by runoff and groundwater seepage.

#### Slough 11 - RM 135.3

Slough 11 is approximately one mile long and is located on the east bank of the Susitna River (Appendix Figures 6-C-12 to 6-C-14). Both the head and the mouth of the slough join side channels of the mainstem Susitna River. The slough has a winding channel that is a series of pools and riffles with an overall gradient of 19.8 ft/mi. Substrate in the upper half of the slough is composed mostly of cobble/boulder with the lower half composed of gravel/rubble. Silt/sand deposits are confined mostly to the backwater pool at the mouth. This pool is formed by a relatively stable sand/gravel bar at the mouth. The slough channel is broad in general, being enlarged by dramatic break-ups which occurred in previous years. The steep banks are approximately six feet high and sparsely vegetated.

Slough 11 has an identical initial and controlling breaching discharge of approximately 42,000 cfs. The slough was last observed breached in 1981.<sup>a</sup> In an unbreached state, intragravel flow can be observed entering the slough through the berm at the head. However, this flow is minimal and below breaching discharges most of the upper third of the slough is dewatered with isolated shallow pools. Surface runoff and upwelling maintain flow in the lower two thirds of the slough. The backwater pool at the mouth exhibits considerable fluctuation in direct response to changes in mainstem discharge. The backwater area is quite broad, encompassing the entire slough width, in contrast to the narrow channel in the rest of the slough.

#### Upper Side Channel 11 - RM 136.0

Upper Side Channel 11 is located on the east bank of the Susitna River and flows in an approximate east-west direction (Appendix Figures 6-C-12 to 6-C-14). The head of the approximately 2,300 foot side channel is

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<sup>a</sup> Although it was not observed during this study period, mainstem discharge records indicate that this slough was breached in the spring of 1984.

located immediately downstream of the Alaska Railroad bridge at Gold Creek. The north bank of the channel is a low lying, gently sloping, sparsely vegetated gravel bar. The south bank is characterized by a steep high bank that is thickly vegetated. The predominant substrate is cobble/boulder interspersed with silt/sand deposits in pool areas and at the backwater area at the mouth. The relatively gentle gradient (11.0 ft/mi) for the first 500 feet of the side channel changes to a steep (21.9 ft/mi) gradient for the remainder of the side channel. A pool/riffle sequence is predominant except for the first 500 feet of the channel which is usually a backwater area.

The head of Upper Side Channel 11 has a controlling breaching discharge of 16,000 cfs. Below this breaching level, the slough flow is maintained by upwelling, seepage and runoff. The side channel is a series of riffles and pools that become a long run once the head is breached. The backwater area at the mouth is generally turbid. As mainstem discharge increases to 19,000 cfs or above, the backwater area extends further up the side channel inundating the first riffle.

#### Slough 20 - RM 140.1

Slough 20 is located on the south bank of the Susitna River (Appendix Figures 6-C-15 and 6-C-16). The winding 3,100 foot channel has two tributaries associated with it, Waterfall Creek (thalweg station 15+00) and a smaller tributary near the head (thalweg station 27+00). The slough habitat consists of alternating pools and riffles with an overall gradient of 13.5 ft/mi. Gravel/rubble substrate predominates throughout the slough, especially in the lower half. The upper half is interspersed with cobble/boulder deposits. The mouth area and a deep pool immediately upstream of Waterfall Creek are silt covered. The banks are thickly vegetated.

Below the controlling breaching discharge of 23,000 cfs, the primary source of base slough flow is Waterfall Creek. The tributary near the head contributes flow to a lesser degree along with runoff and seepage. Due to the contribution of Waterfall Creek, below controlling breaching discharge, there is no direct correlation between water surface elevation in the slough and mainstem discharge. A deep 500 foot long pool is formed immediately upstream of the mouth of Waterfall Creek due to a gravel delta at the mouth of the creek. The slough mouth area and pool above Waterfall Creek are generally turbid, with the rest of the slough remaining clear below controlling breaching discharges.

#### Side Channel 21 - RM 140.6

Side Channel 21 is located along the south bank of the Susitna River and is approximately 0.9 miles long (Appendix Figures 6-C-17 and 6-C-18). The head of the side channel flows directly into the mouth of Slough 21. The channel is relatively straight with a uniform shape and average width of 200 feet. The north bank is a vegetated low lying gravel bar with gentle sloping banks and several intermittent channels connecting the side channel with the mainstem. The south bank is high, steep and vegetated. There is a small creek with intermittent flows entering the

side channel along this bank, approximately 1,500 feet upstream of the mouth. The middle of the side channel, with a gradient of 18.7 ft/mi, is mostly a riffle/run area, while the mouth and head, which have lower gradients (9.4 and 3.2 ft/mi, respectively) are pool areas. Cobble/boulder substrates, are predominant throughout the side channel with silt/sand deposits in the pools, especially in the backwater area at the mouth.

Base channel flow is primarily maintained by flow from Slough 21. Groundwater seepage, runoff and flow from the small creek and channels are other contributing sources to the base flow. Except for the backwater area at the mouth and the pool at the head, the side channel remains clear at base flow levels. The backwater at the mouth extends approximately 1,300 feet into the side channel. Controlling breaching flows are difficult to assess because of the numerous intermittent channels connecting the side channel with the mainstem and the two heads to Slough 21. One or more of the channels will be breached in the range of mainstem discharge between 12,000 to 26,000 cfs. All channels are breached at a discharge of 26,000 cfs. Once breaching occurs, the side channel increases in velocity, turbidity and depth.

#### Slough 21 - RM 141.8

Slough 21 is approximately 3,000 feet long and is located on the south bank of the Susitna River (Appendix Figures 6-C-19 and 6-C-20). The main channel, with a relatively uniform width of 100 feet, divides into two channels for the upstream half of the slough. The gradient of the slough is 22.9 ft/mi. The slough is separated from the mainstem on the north bank by a thickly vegetated gravel bar. The steep cut banks are approximately five feet high and are thickly vegetated. Cobble/boulder is the predominant substrate with silt/sand deposits at the mouth. The mouth of Slough 11 flows directly into the head of Side Channel 21.

The heads of the NE and NW channel of the slough are initially breached at approximately 23,000 cfs and 26,000 cfs, respectively. At this discharge range slough flow, depth and turbidity increase rapidly. Controlling breaching discharge occurs at 25,000 cfs in the NE channel and 28,000 cfs in the NW channel. Additional water enters through channel A-6 at mainstem discharges over 17,000 cfs. This additional discharge increases the downstream flow of water into Side Channel 21 and creates a backwater pool at the mouth of Slough 21. A small tributary, surface water runoff and groundwater (upwelling) maintain the base slough flow below initial breaching conditions. Below initial breaching conditions, the upper half of the slough is dewatered with isolated pools. The lower half is a shallow narrow channel with a pool at the mouth.

#### Slough 22 - RM 144.2

Slough 22 is semi-circular in shape and is located on the north bank of the Susitna River (Appendix Figure 6-C-21). The overall gradient of the slough is 15.2 ft/mi. Both banks are thickly vegetated with shrubs and trees with a moderate to steep slope. The approximately 3,000 foot

channel can be roughly divided into two parts. The lower half of the slough consists of two long, deep (3-4 feet) pools separated by riffles. The gradient of this lower section is 6.3 ft/mi. The upper half, with a steeper gradient of 20.7 ft/mi, is a short shallow pool followed by a long riffle. A small tributary and spring fed channel enter the slough from the north bank near the head of this last pool (approximately thalweg station 21+00). Cobble/boulder is the predominant substrate throughout the slough. Gravel/rubble is the predominant substrate in the riffle area in the middle section of the slough (streambed station 15+00). The two pools in the lower half of the slough have thick deposits of silt/sand substrate.

The head of the slough is initially breached at a mainstem discharge of approximately 20,000 cfs with a controlling breaching discharge of 23,000 cfs. Below the initial breaching discharge, the upper quarter of the slough becomes dewatered. Base slough flow is maintained primarily by the small tributary and spring fed fork. Surface runoff and ground-water seepage (upwelling) add to the base slough flow. Below breaching discharges the slough is clear, including the two pools in the lower half of the slough. Except at high mainstem discharges (23,000 cfs and above), these pools have little or no backwater effect. They are cut off from the mainstem by a 300 foot riffle.

Appendix 6-B

Supplement to Methods  
of Local Flow Analysis

The general method used to estimate local flows as explained in Section 2.3.2.3.3 could not be applied to all passage reaches. For passage reaches lacking a surveyed cross-section, the Aerial Photographic Method may be used; for passage reaches lacking a rating curve, the Manning Equation Method may be used. The use of these methods, however, requires additional assumptions and may result in less accurate local flow estimations. Therefore, these methods should only be used if the data necessary for the general method are not available.

#### Manning Equation Method

The Manning Equation Method is used to develop a rating curve for a surveyed cross-section. From the rating curve, the required local flows for successful and unsuccessful passage may be calculated. The Manning equation Method is described as follows:

- 1) Establish a value for the Manning roughness coefficient by calibrating to a nearby riffle reach having a developed rating curve.
- 2) Calculate the overall reach gradient that includes the passage reach and set this equal to the energy slope in the Manning Equation.
- 3) Use the Manning equation to calculate local flows for a range of water surface elevations to define the rating curve for the passage reach cross-section.

#### Aerial Photographic Method

The Aerial Photographic Method is used to evaluate the required local flow at a passage reach when a surveyed cross-section does not exist. Several sets of aerial photographs at different mainstem flows are required as is at least one surveyed cross-section in each slough. The method proceeds as follows.

- 1) Use the Manning Equation Method for each surveyed cross-section to calculate, for a range of water surface elevations, the top width and local flow; plot top width versus local flow for each surveyed cross-section.
- 2) Calculate the mean depths for each passage reach that correspond to the passage depths for successful and unsuccessful passage using Appendix Figure B-1.
- 3) Calculate the overall reach gradient applicable to each passage reach from the thalweg survey data.
- 4) Evaluate the unit flows for successful and unsuccessful passage using the mean depths, reach gradient, and Appendix Figure B-2.
- 5) Measure the top width of local flow at the surveyed transect(s) and at each passage reach on each set of aerial photographs.

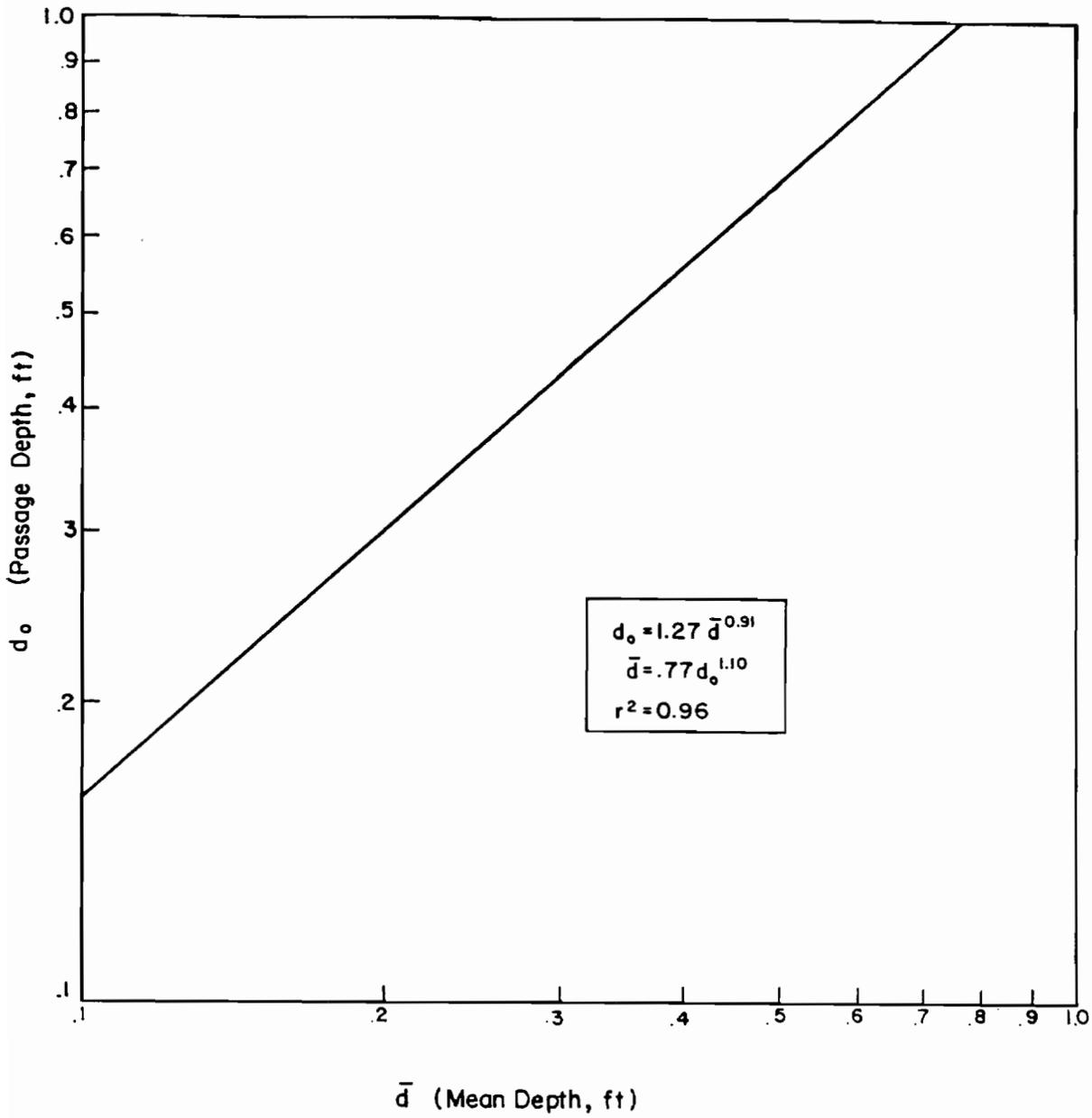


Figure  $\beta$ -1 Relationship between mean depth and passage depth.

6-B-3

6-B-4

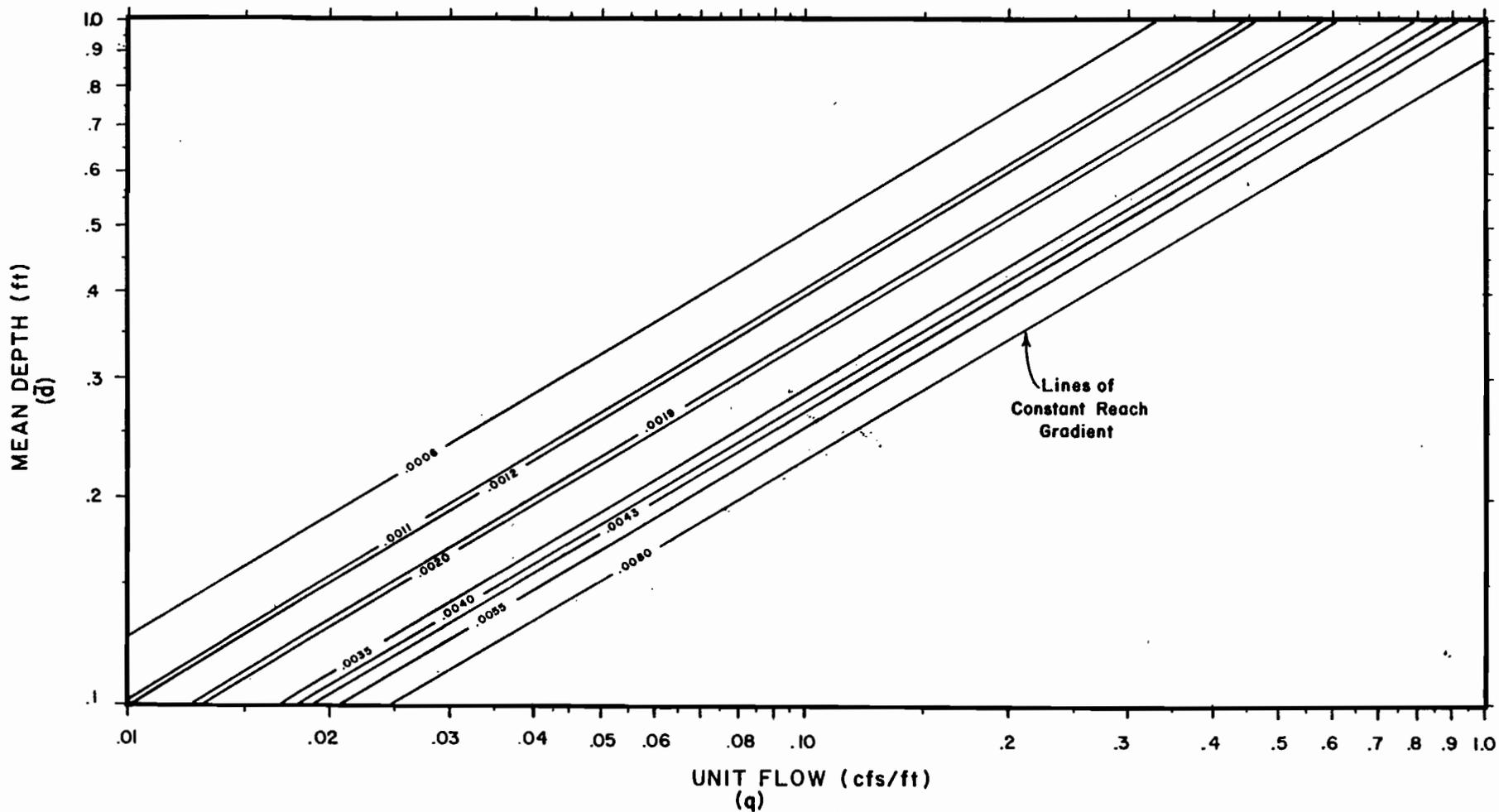


Figure 6-B-2. Relationship between mean depth and unit flow.

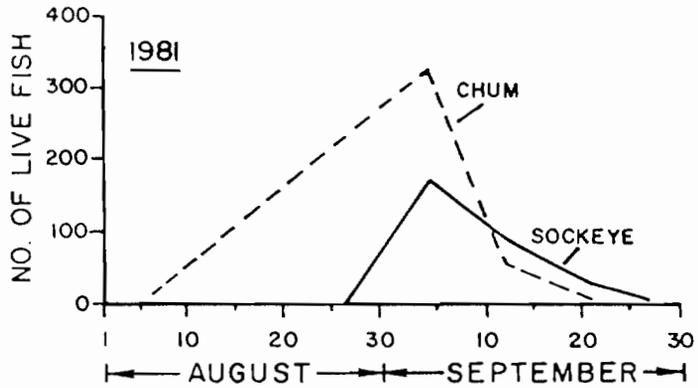
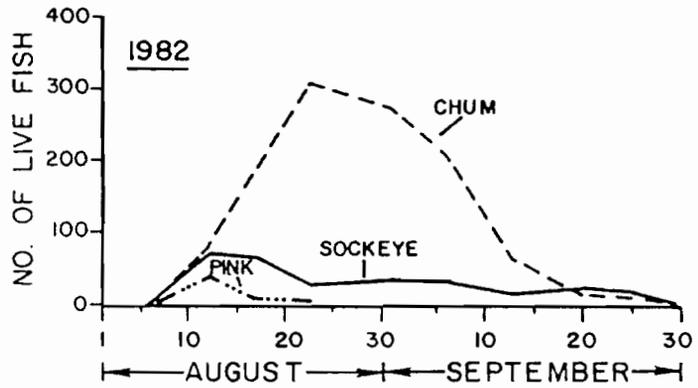
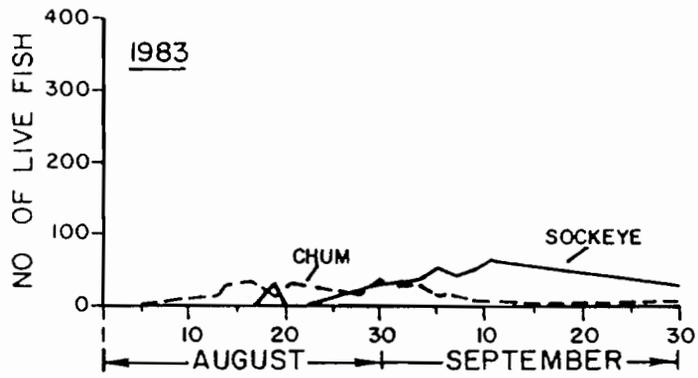
- 6) Use the measured top widths at the surveyed transect(s) and the top width versus local flow plot developed in Step 1 to get the local flow represented in each set of aerial photographs.
- 7) Adjust the local flow estimates for upwelling or tributary inflow between the applicable surveyed transect and each passage reach.
- 8) Plot the adjusted local flow estimates against the corresponding measured top widths from the aerial photographs to define several points on a curve of top width versus local flow for each passage reach.
- 9) Plot lines of constant unit flow (evaluated in Step 4) on the top width versus local flow curves (developed in Step 8) for each passage reach; the intersection of these lines with the top width versus local flow curves gives the local flows corresponding to successful and unsuccessful passage.



Appendix 6-C

Timing Plots

SLOUGH  
8A

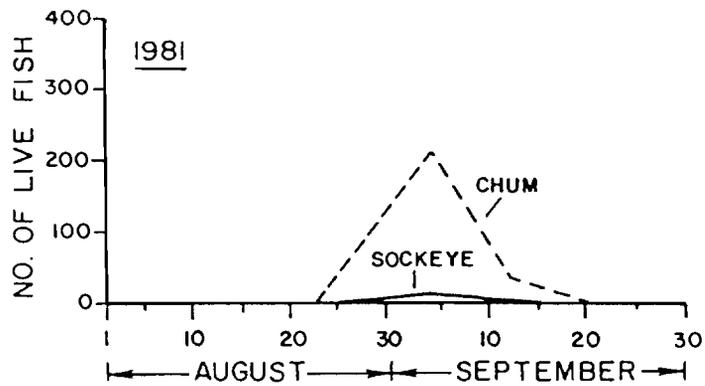
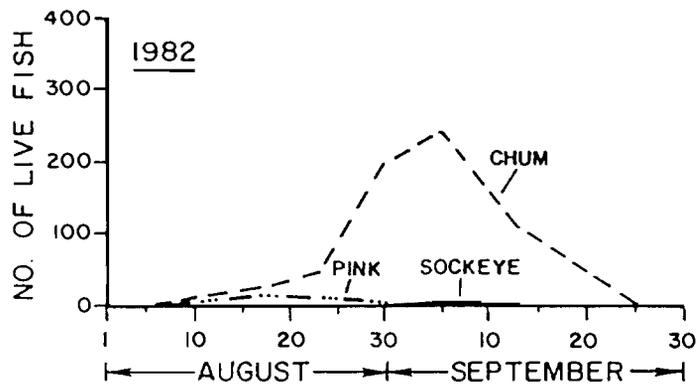
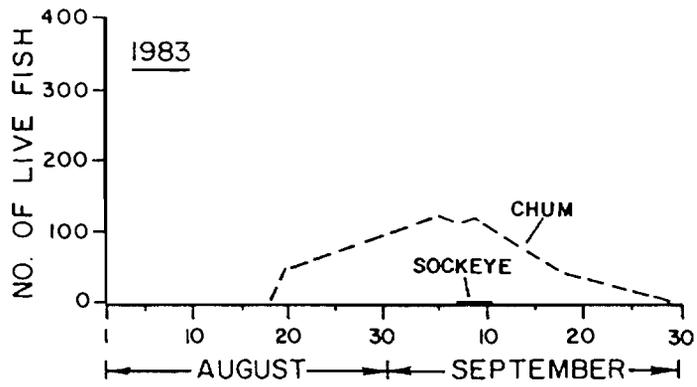


6-C-1

Timing of salmon presence, Slough 8A,  
1981, 1982, 1983.

6-C-2

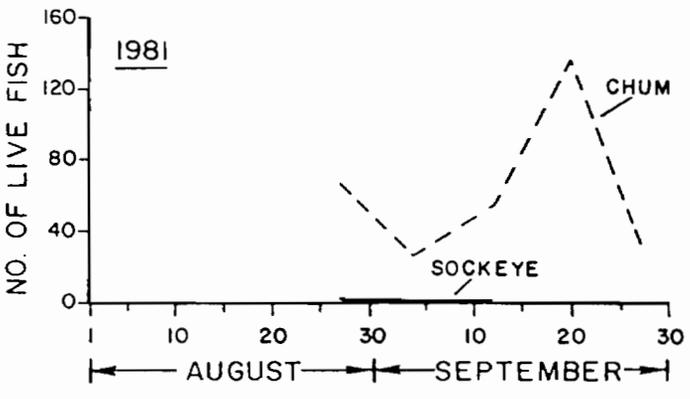
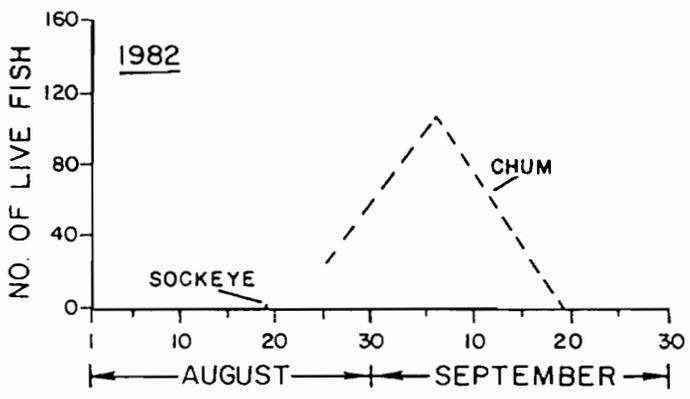
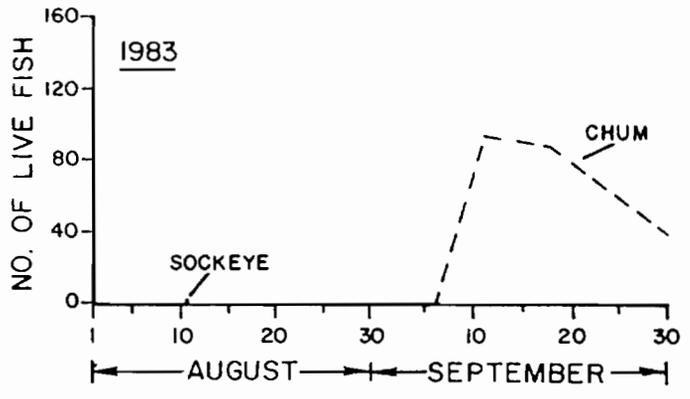
SLOUGH  
9



6-C-2

Timing of salmon presence, Slough 9, 1981,  
1982, 1983.

SLOUGH  
9A

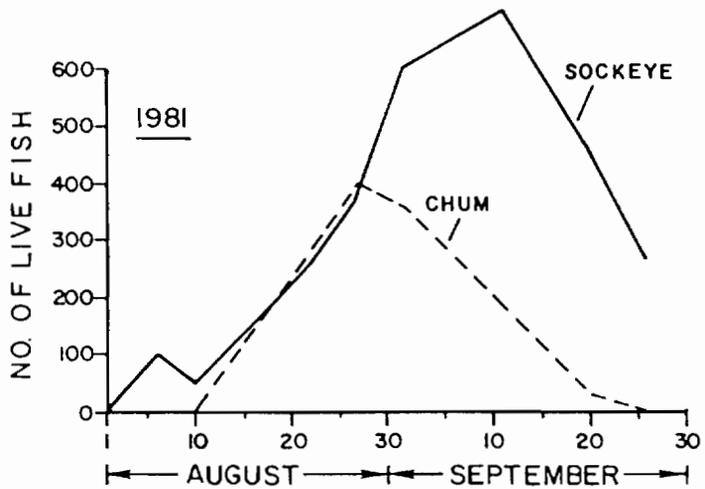
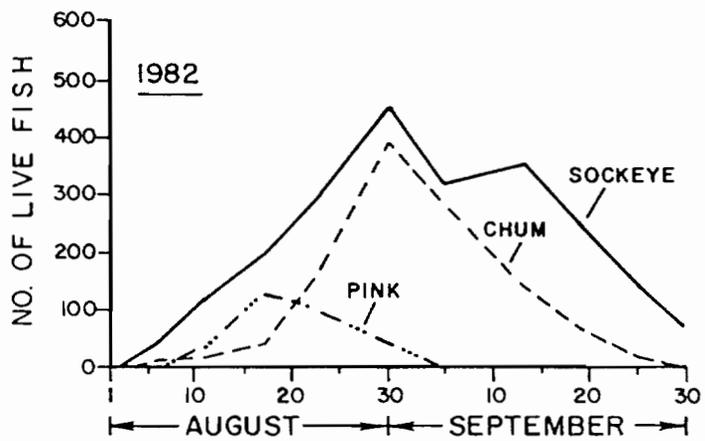
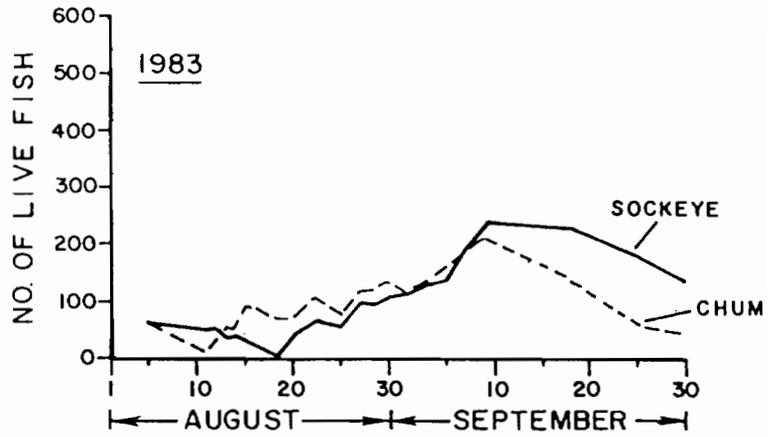


6-C-3

Timing of salmon presence, Slough 9A, 1981, 1982, 1983.

6-C-4

SLOUGH  
II  
COMPLEX

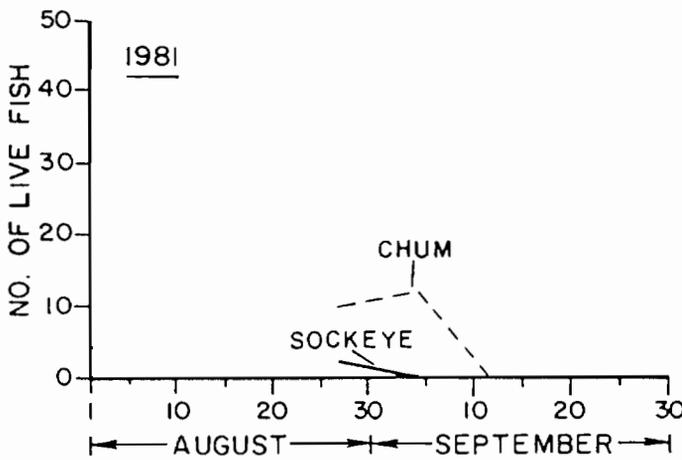
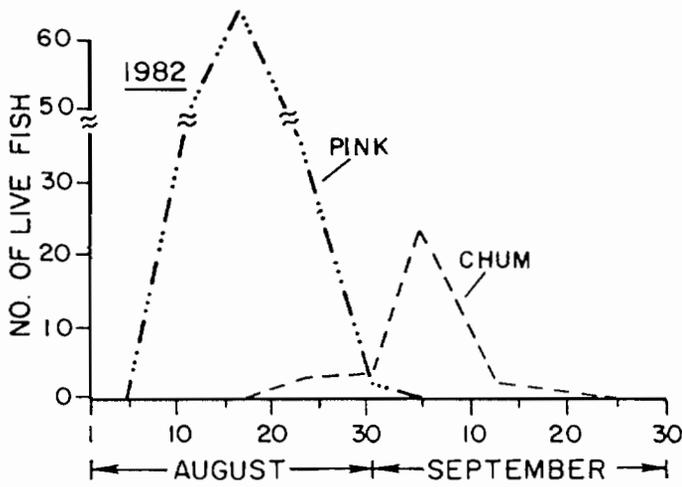
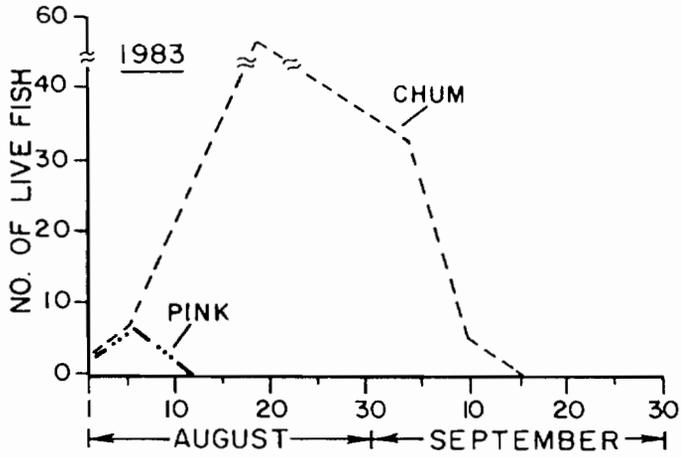


6-C-4

Timing of salmon presence, Slough 11  
Complex, 1981, 1982, 1983

6-C-5

SLOUGH  
20



6-C-5

Timing of salmon presence, Slough 20,  
1981, 1982, 1983.

6-C-6

9/20

Comments on Chapt 6.

P. Meyer

1. Overall, I thought it was a good report with good use of graphics + tables.
2. I had a problem understanding the method used in the backwater analysis (p 17-18). It may be a confusing process, or it just may be confusingly written.
3. There is some confusion on Table 6.5, noted by Mike Kelly. Are the initial condition mainstem discharges listed in the 3<sup>rd</sup> column of Table 6.5 those flows used for the identification of passage reaches (section 2.3.2.2, p. 13-14). This needs clarification.
4. I agree with Mike K's comment on p. 58. Noting that M Prewitt raised the same issue in his comment letter (6/27/84) on the original draft, its probably a dead issue with ADF+G.

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Report #3

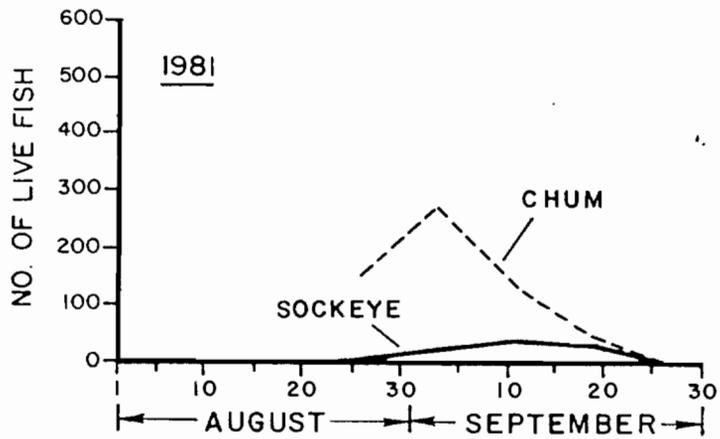
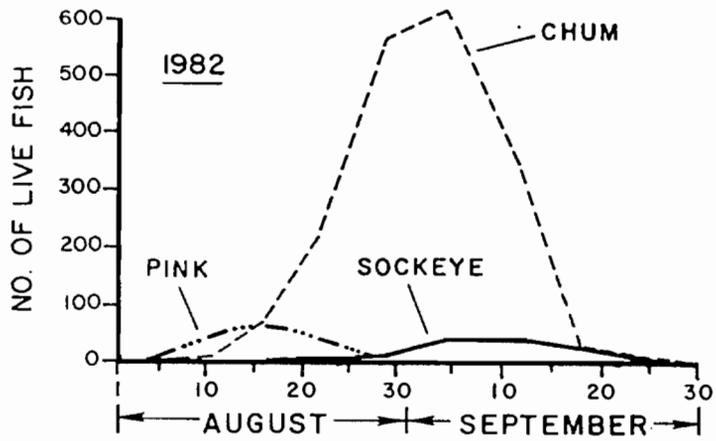
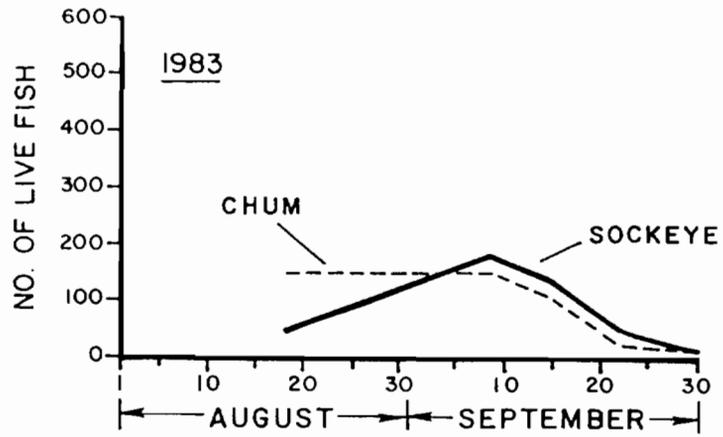
Aquatic Habitat & Instream Flow Investigations

May-Oct. 1983

Chapt 6: Review Draft

Sautner, Vining (ADF+G)  
Rundquist (WCC)

SLOUGH  
21  
COMPLEX

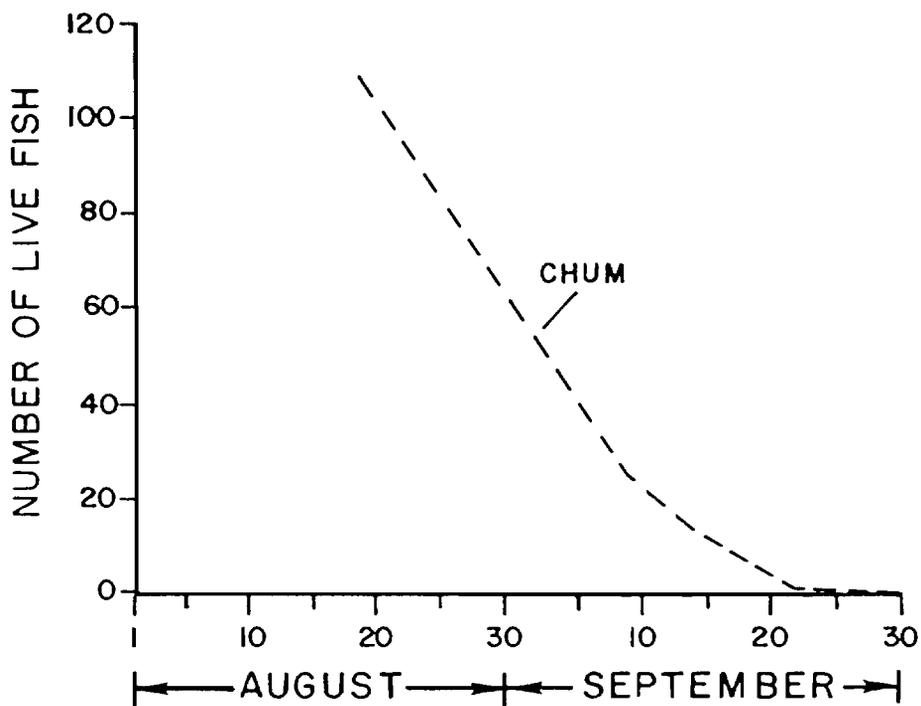


6-C-6

Timing of salmon presence, Slough 21  
Complex, 1981, 1982, 1983.

6-C-7

SLOUGH 22  
(1983 SURVEY DATA ONLY)



6-C-7

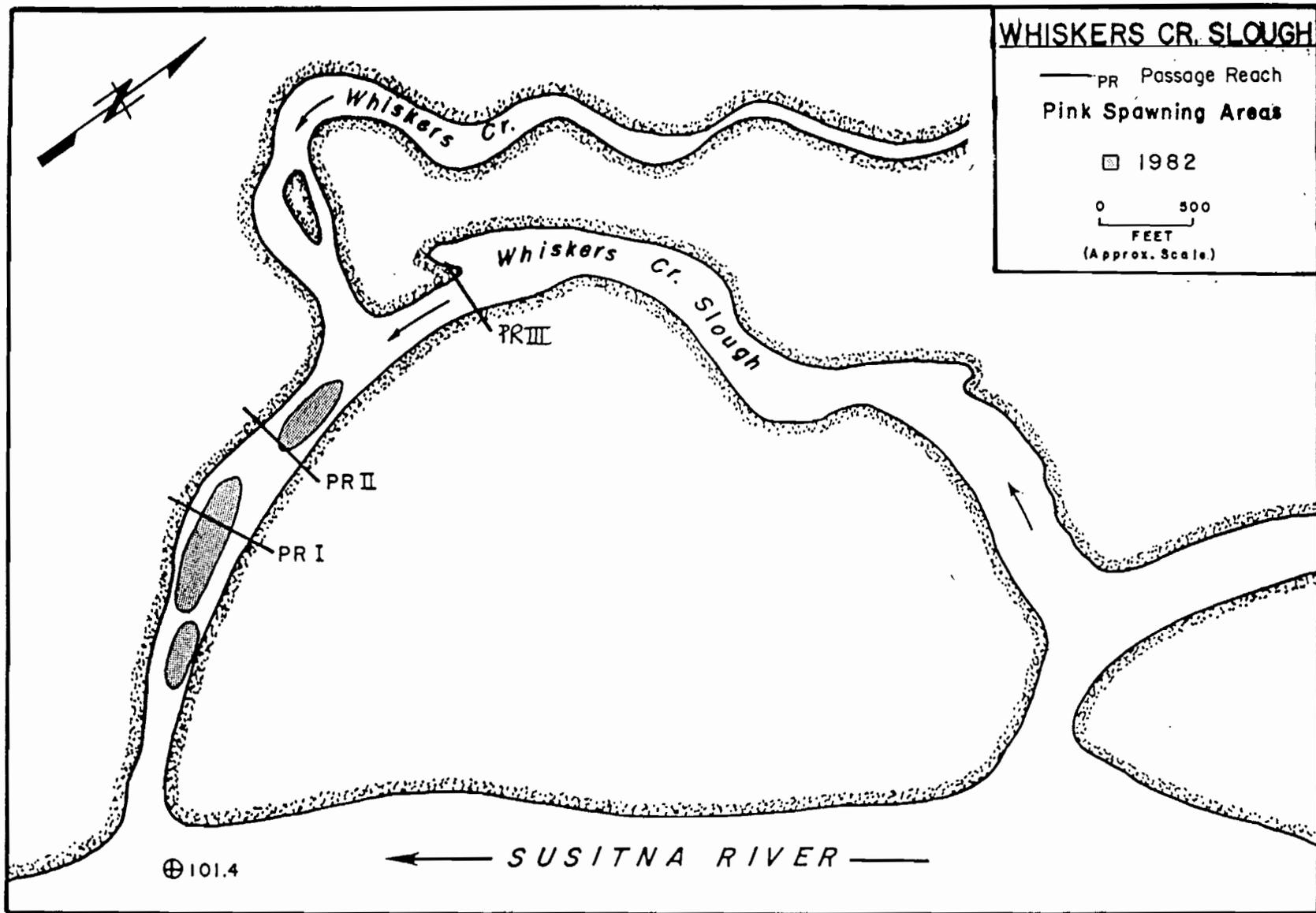
Timing of salmon presence, Slough 22,  
1981, 1982, 1983.

6-C-8

Appendix 6-D

Salmon Spawning Distribution Maps

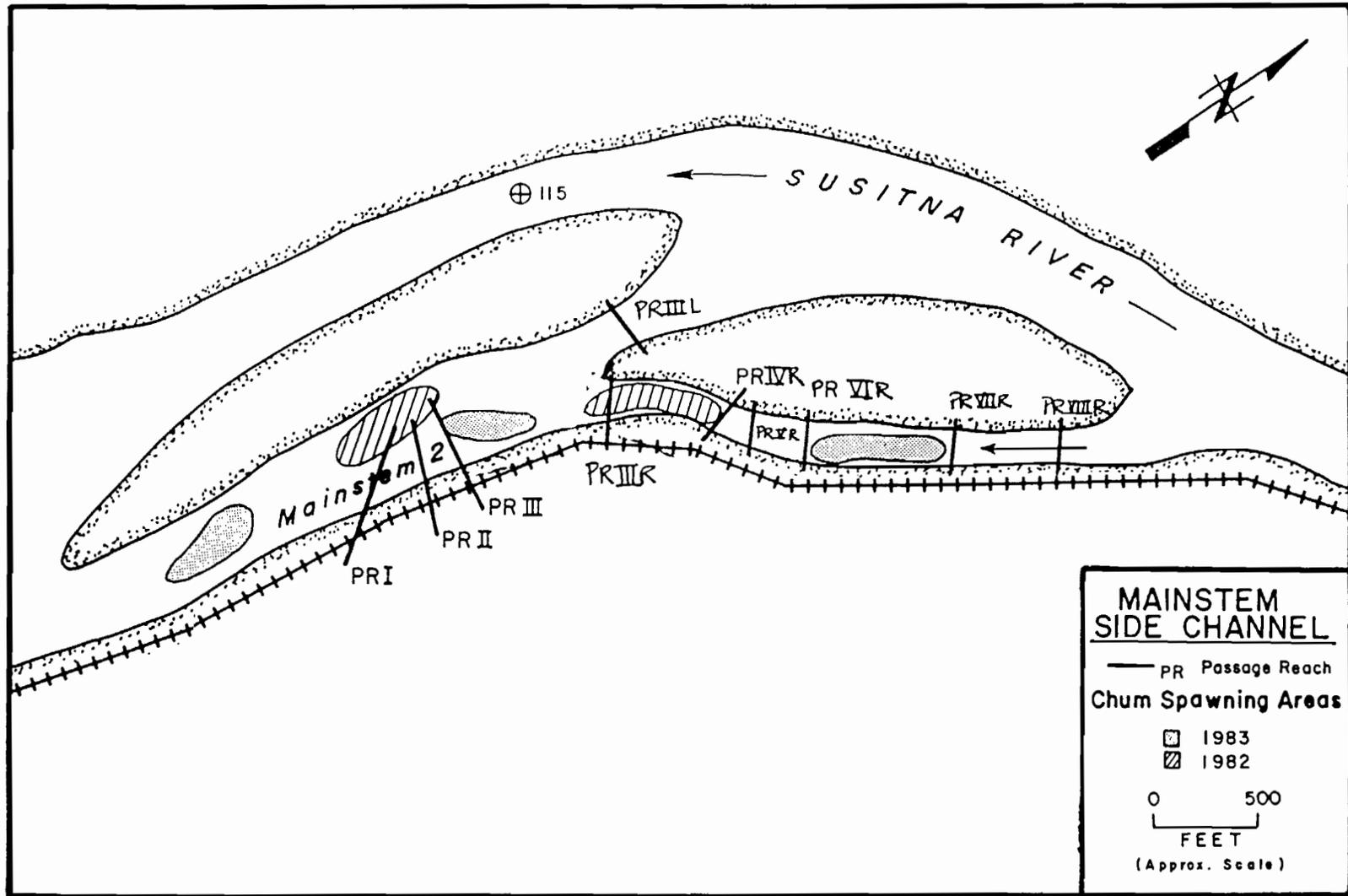
6-D-2



6-D-1

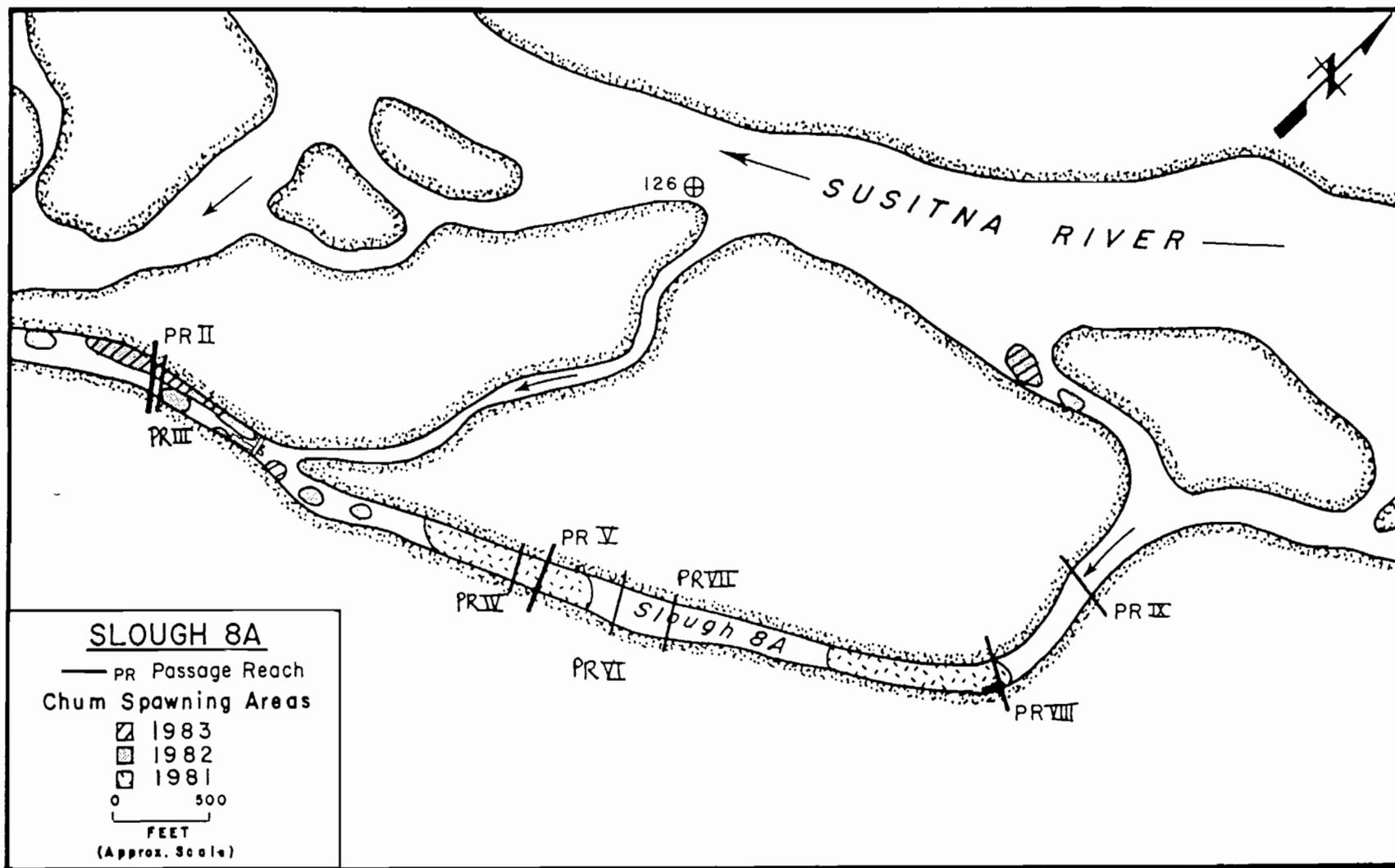
Pink salmon spawning areas, Whiskers Creek Slough, 1982.

6-D-3



6-D-2

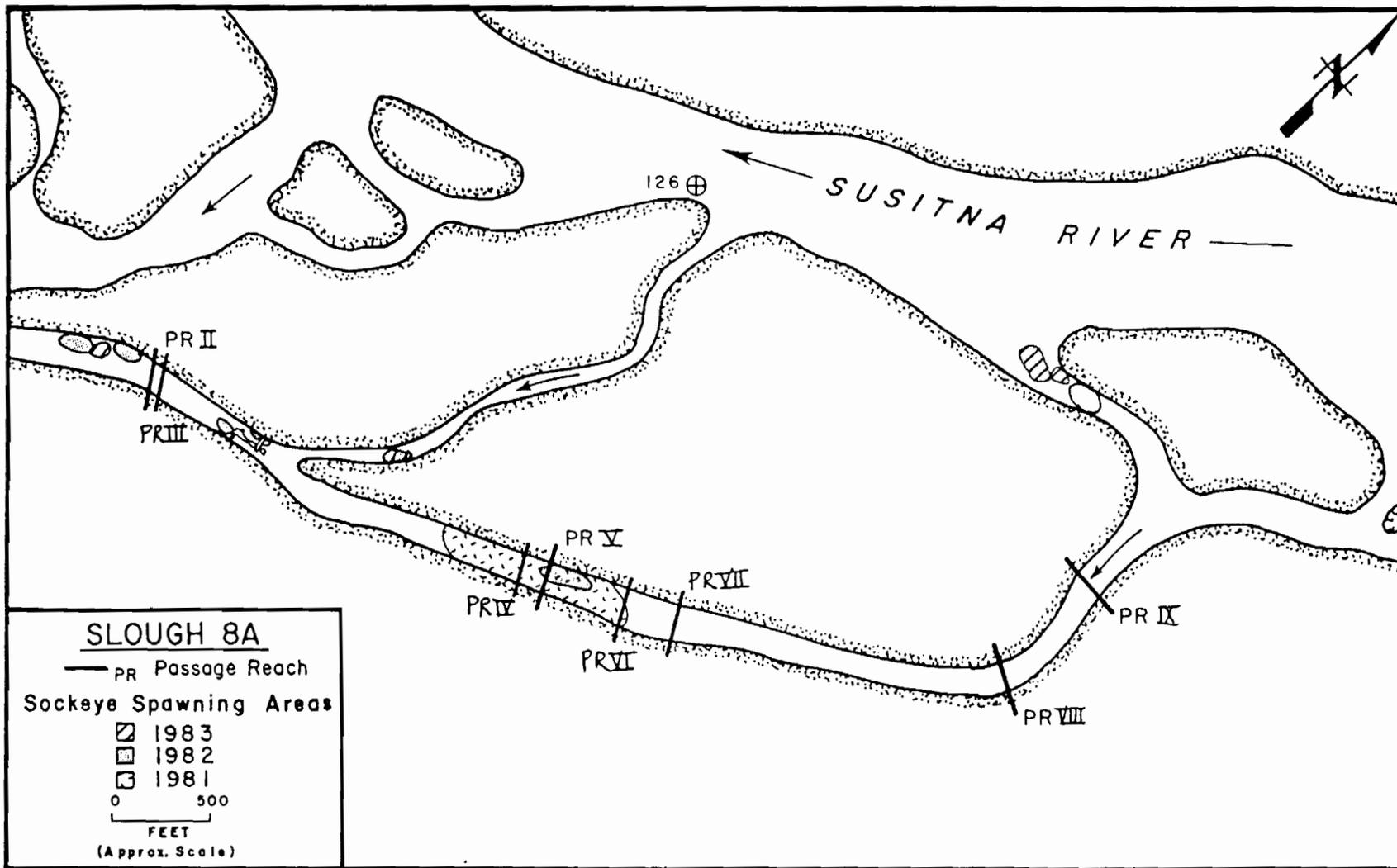
Chum salmon spawning areas, Mainstem 2  
Side Channel, 1982, 1983



6-D-3

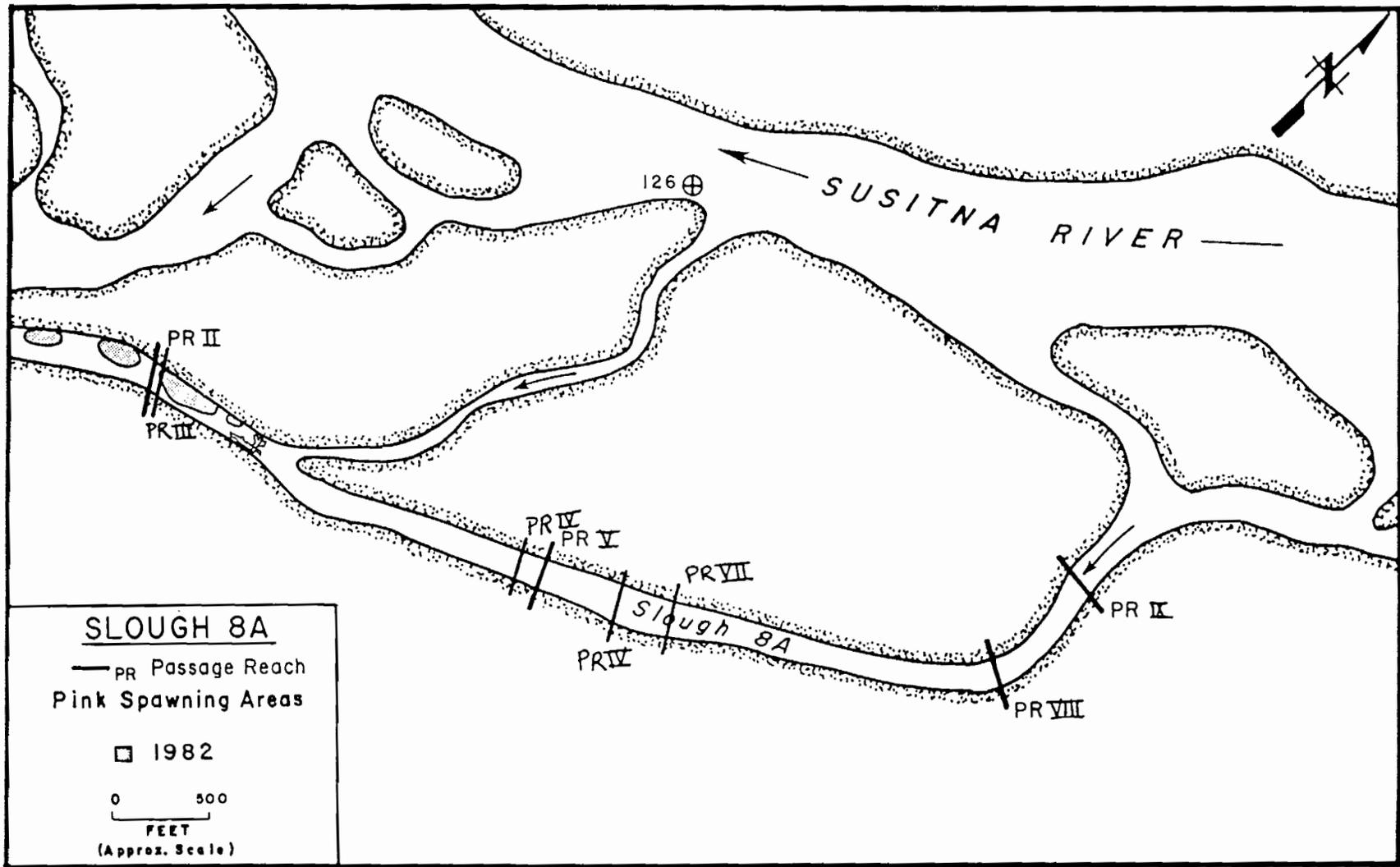
Chum salmon spawning areas, Slough 8A,  
1981, 1982, 1983.

6-D-5



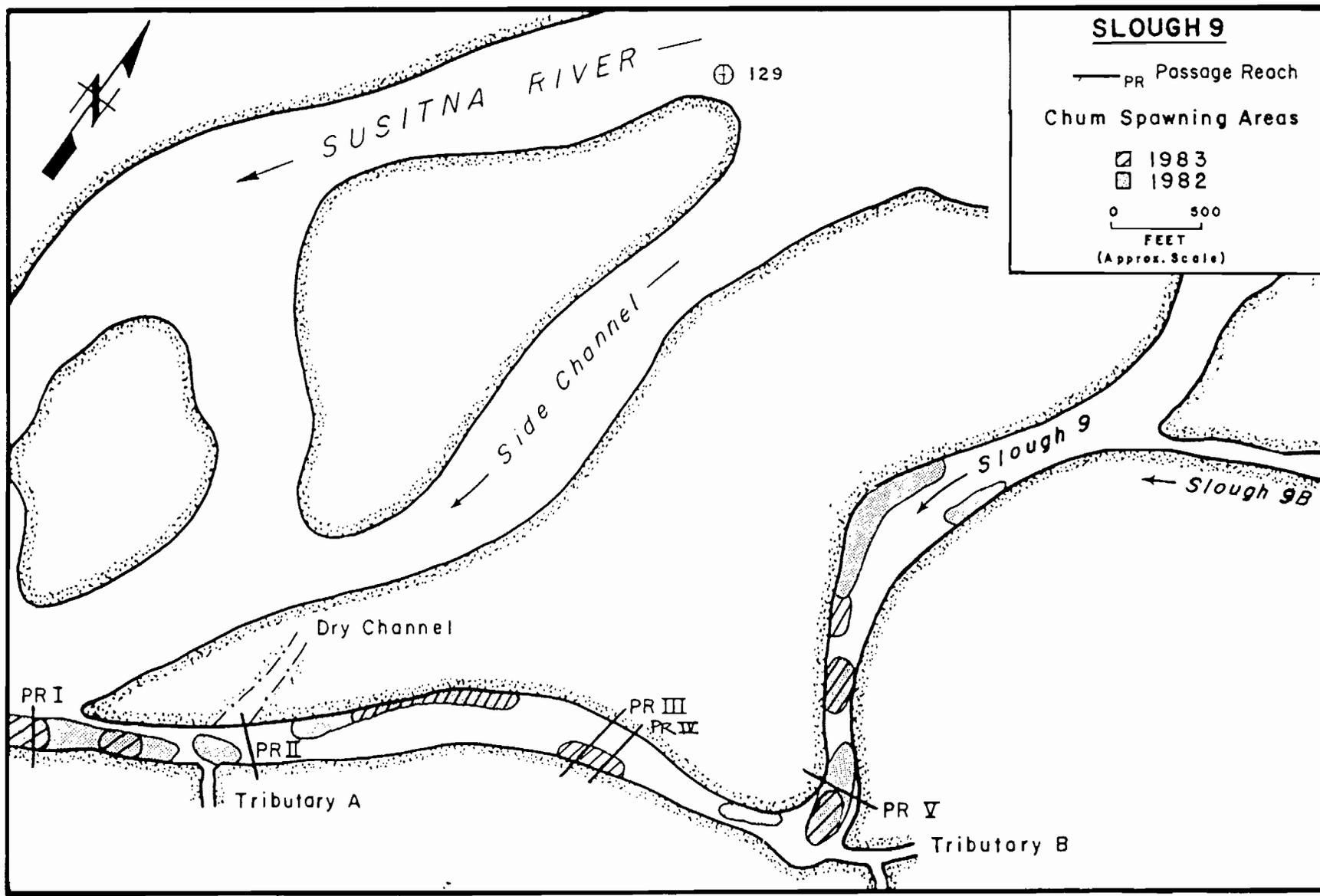
6-D-4

Sockeye salmon spawning areas, Slough 8A,  
1981, 1982, 1983



6-D-5 Pink salmon spawning areas, Slough 8A, 1982.

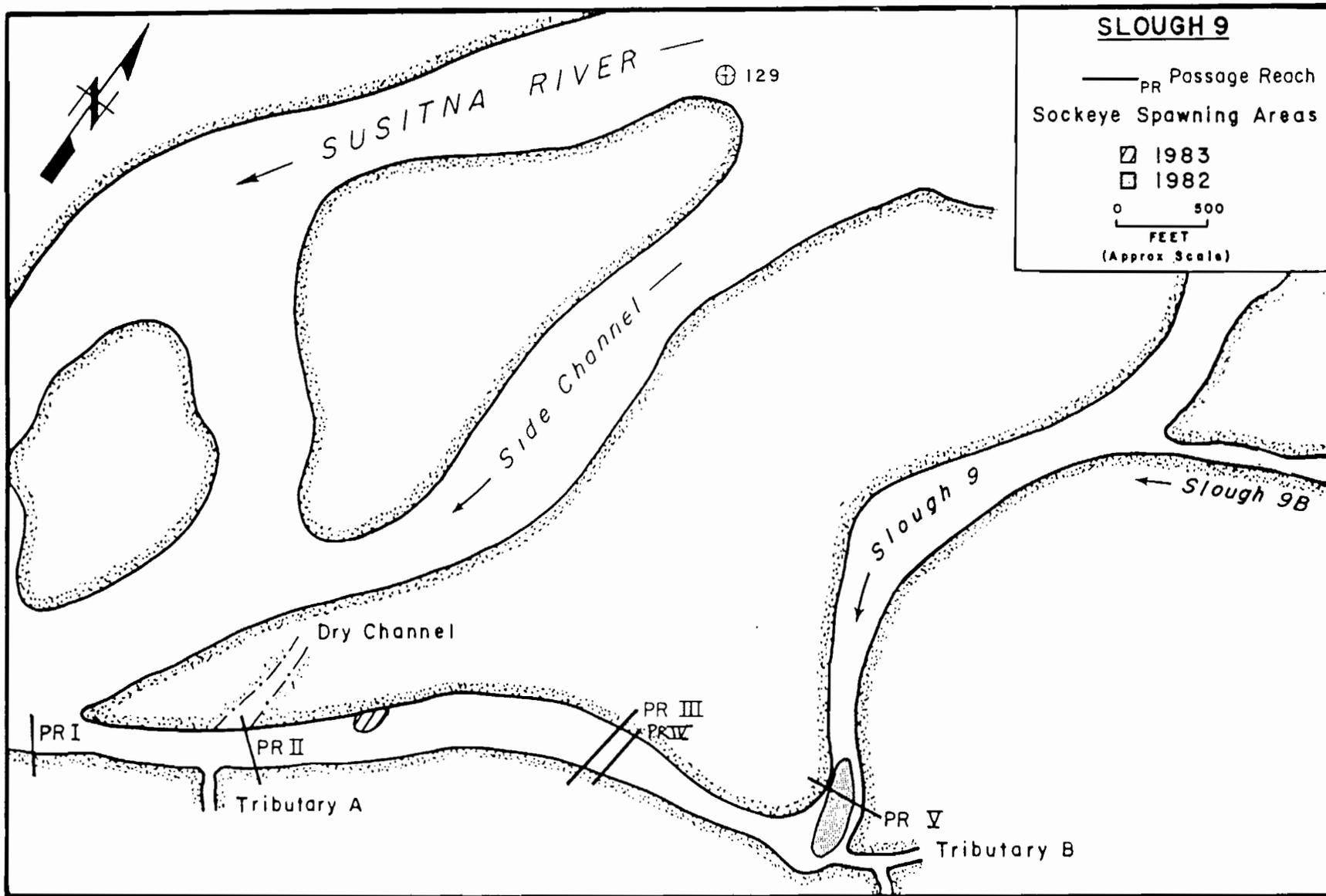
6-D-7



6-D-6

Chum salmon spawning areas, Slough 9, 1982 .

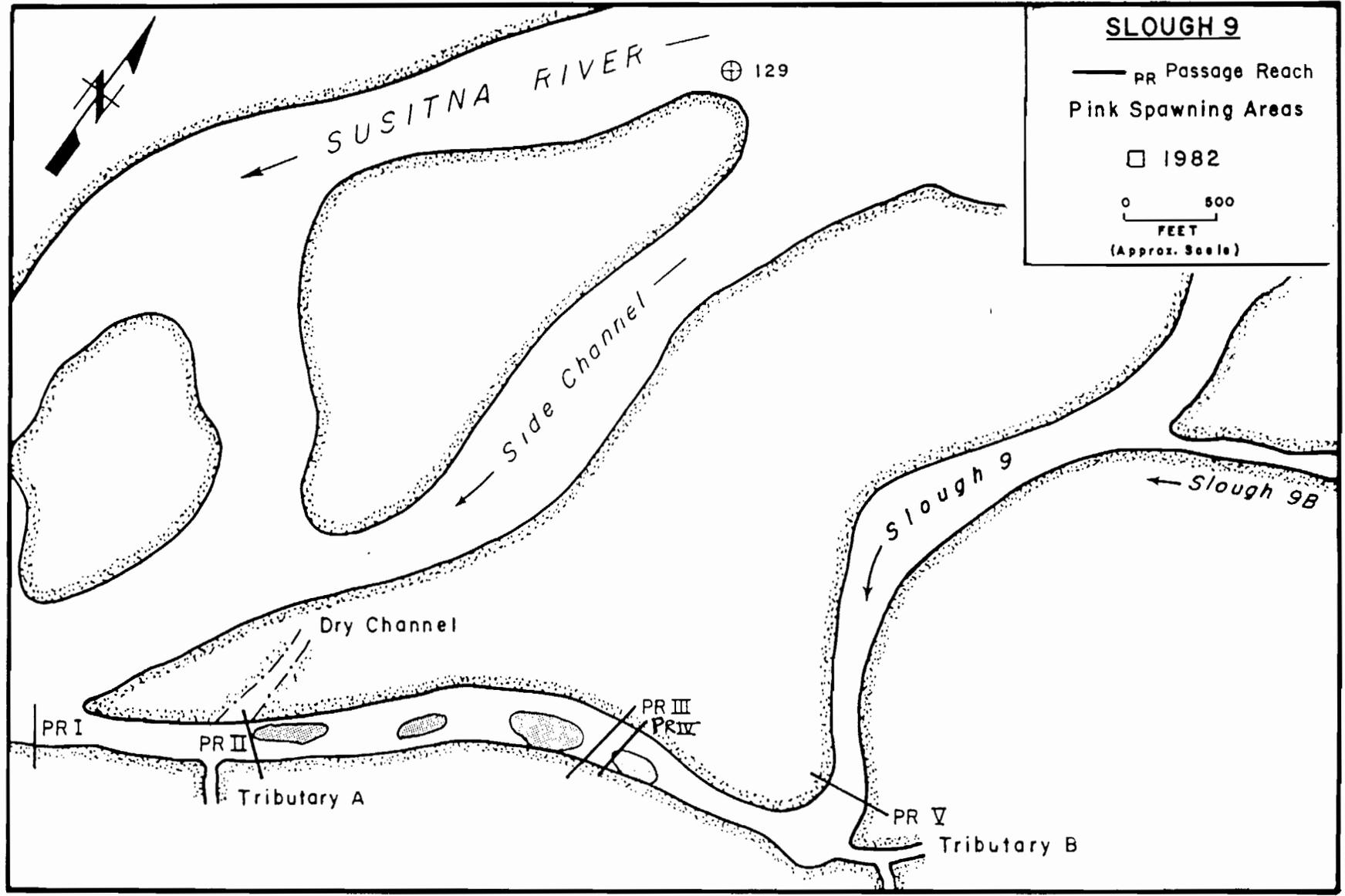
6-D-7



6-D-7

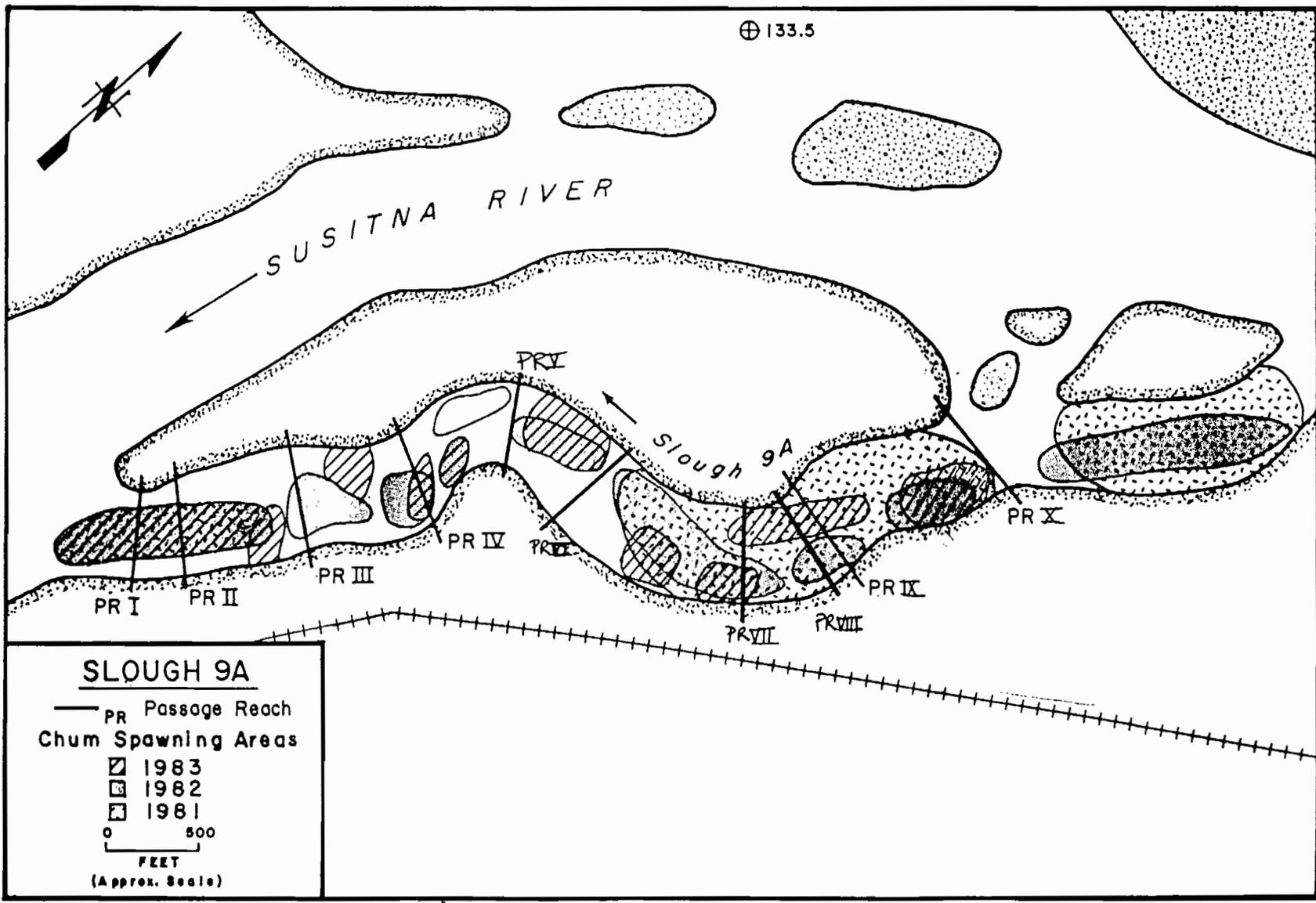
Sockeye salmon spawning areas, Slough 9,  
1982, 1983<sub>e</sub>

6-D-9



6-D-8 Pink salmon spawning areas, Slough 9, 1982 c

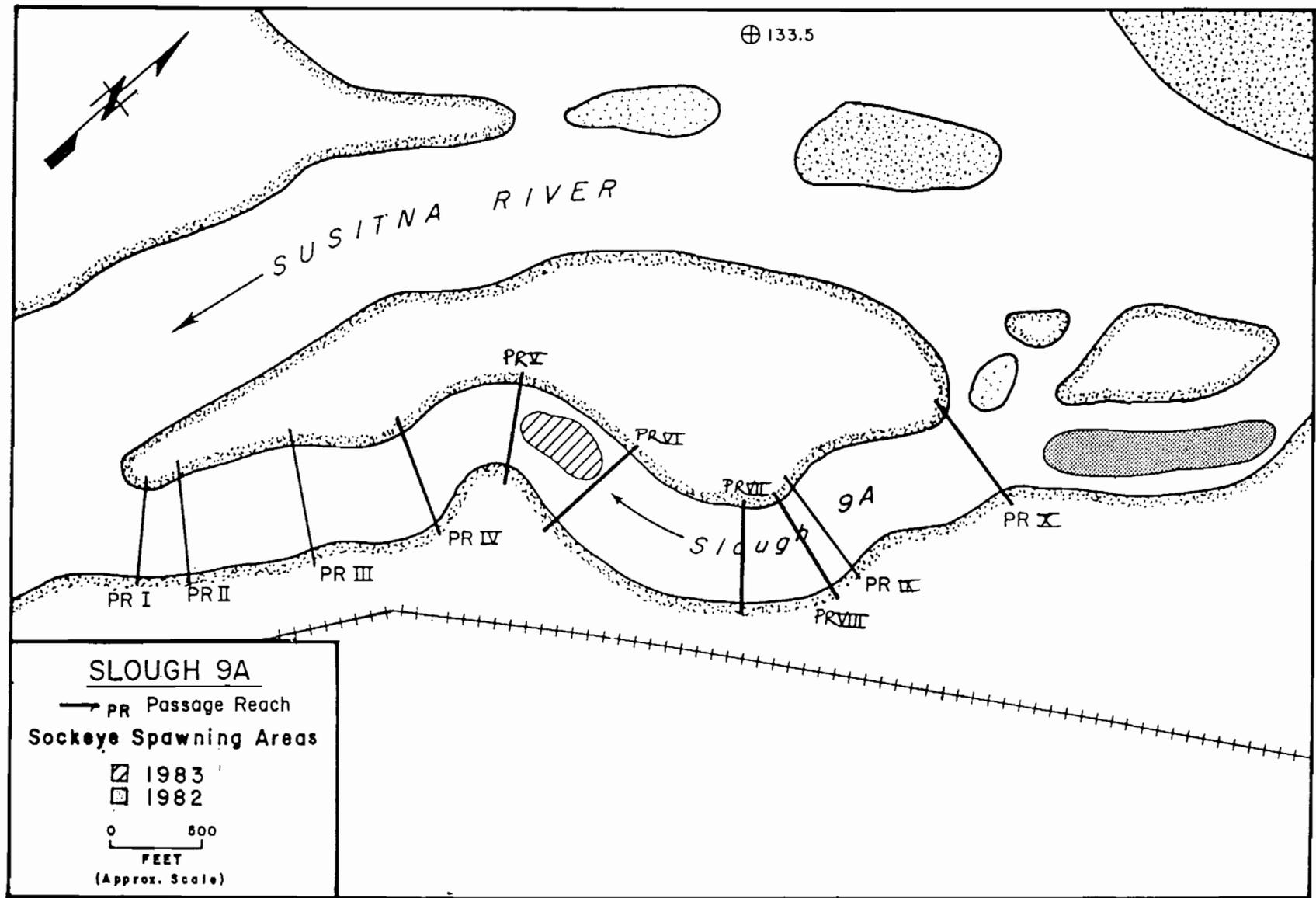
6-D-10



6-D-9

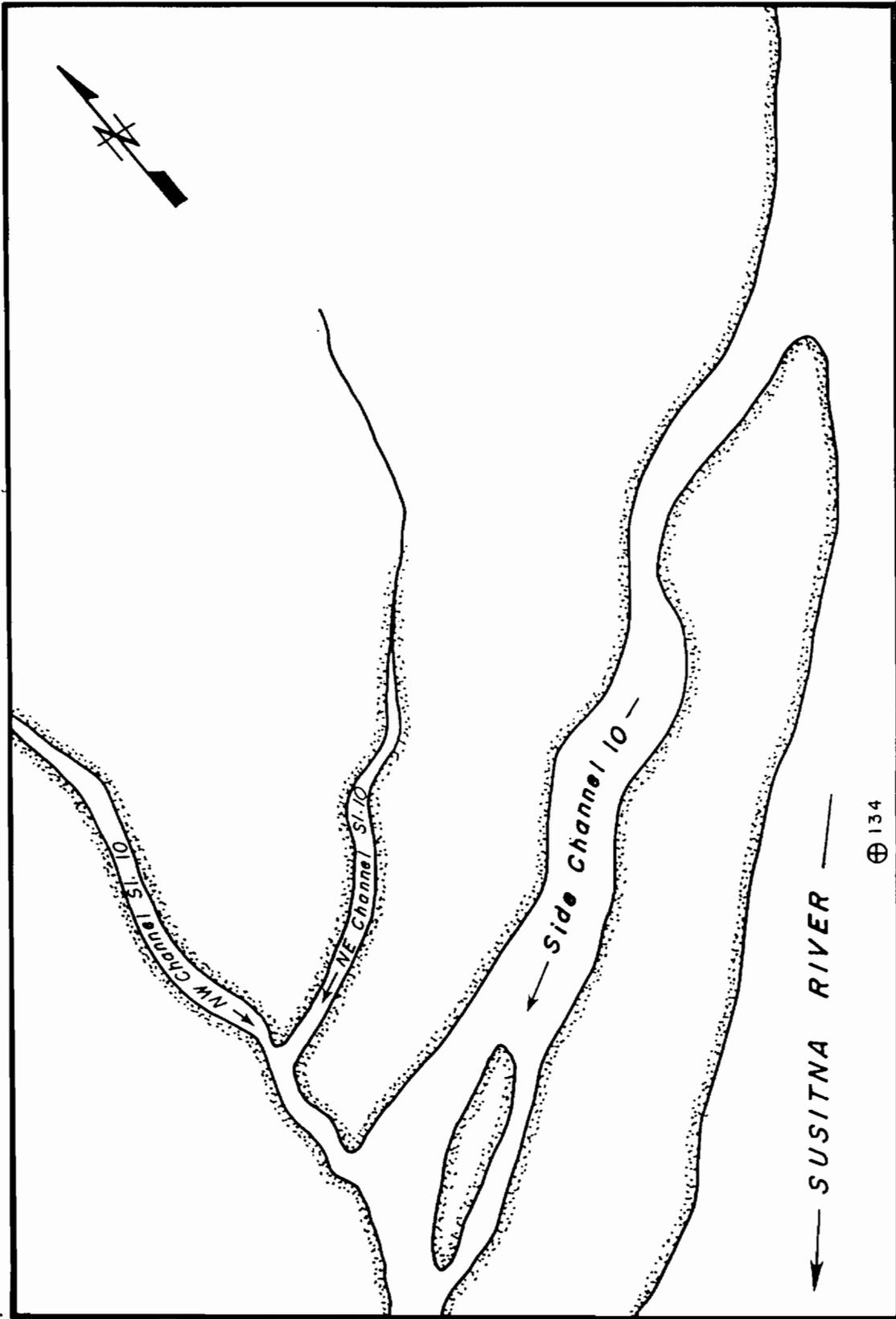
Chum salmon <sup>(SPAWNING)</sup> areas, Slough 9A, 1981, 1982, 1983.

6-5-11



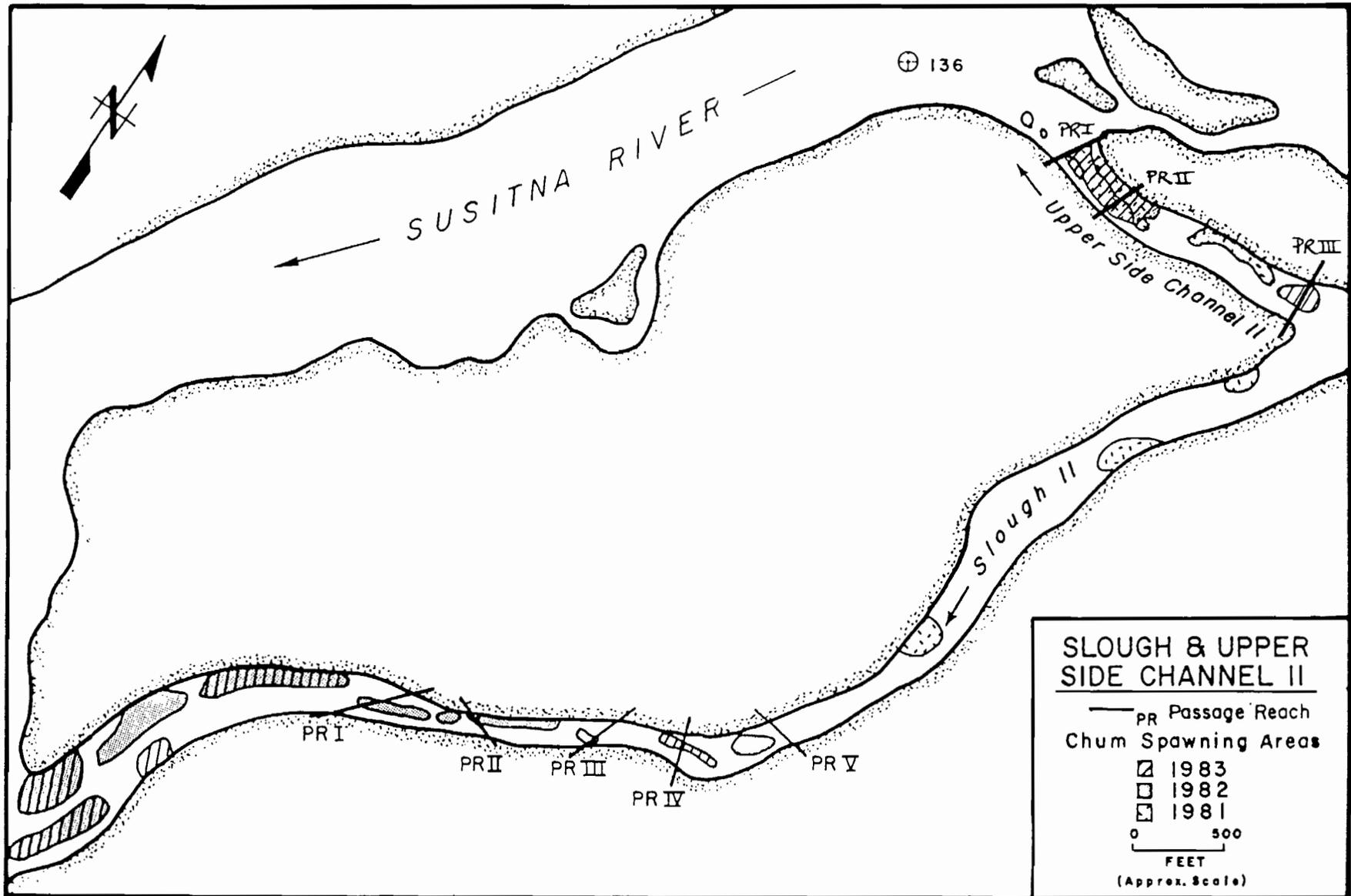
6-D-10

Sockeye salmon spawning areas, Slough 9A,  
1981, 1982, 1983



6-D-11 Site map of Side Channel 10

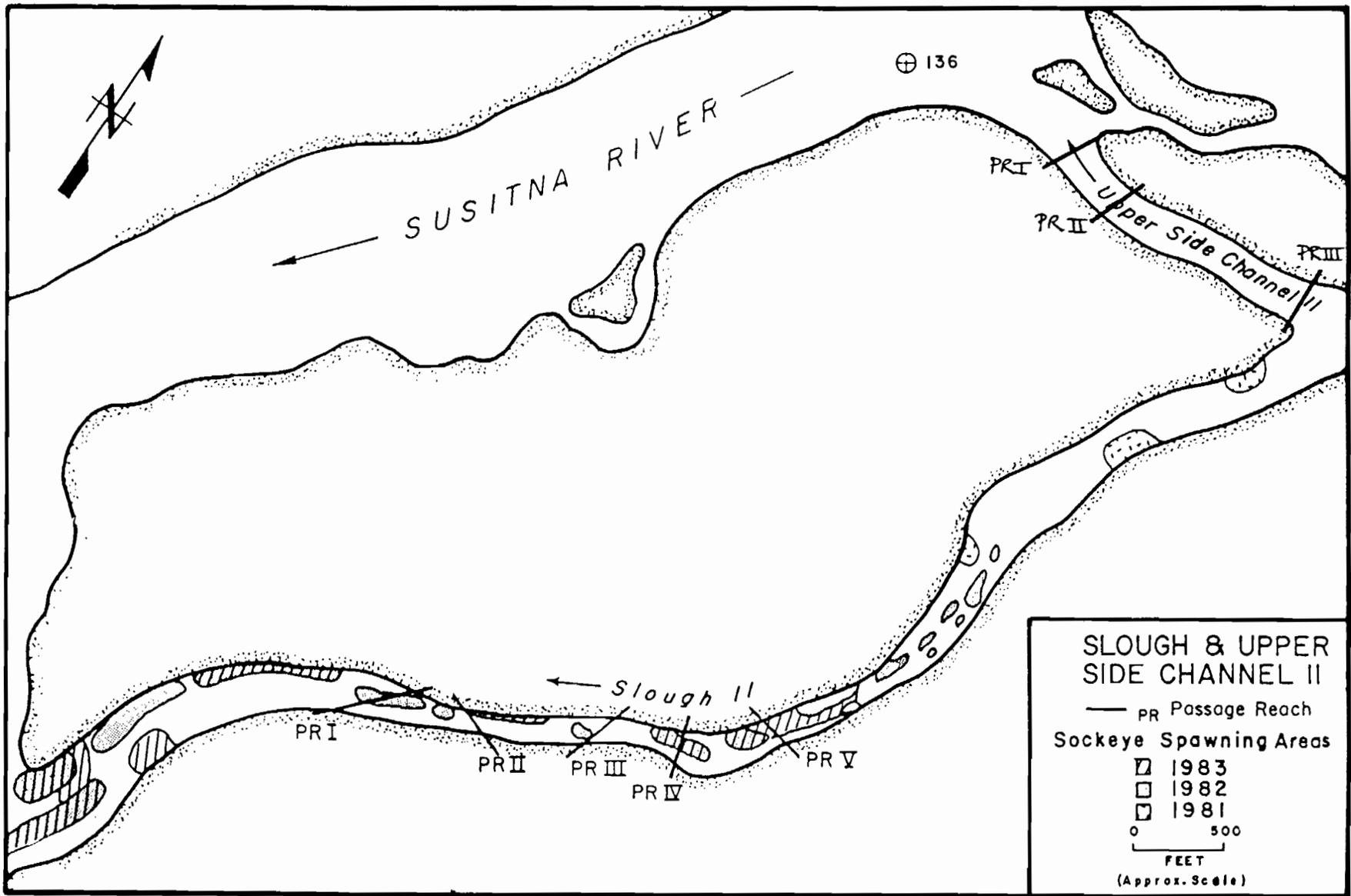
6-D-13



6-D-12

Chum salmon spawning areas, Slough and Side Channel 11, 1981, 1982, 1983.

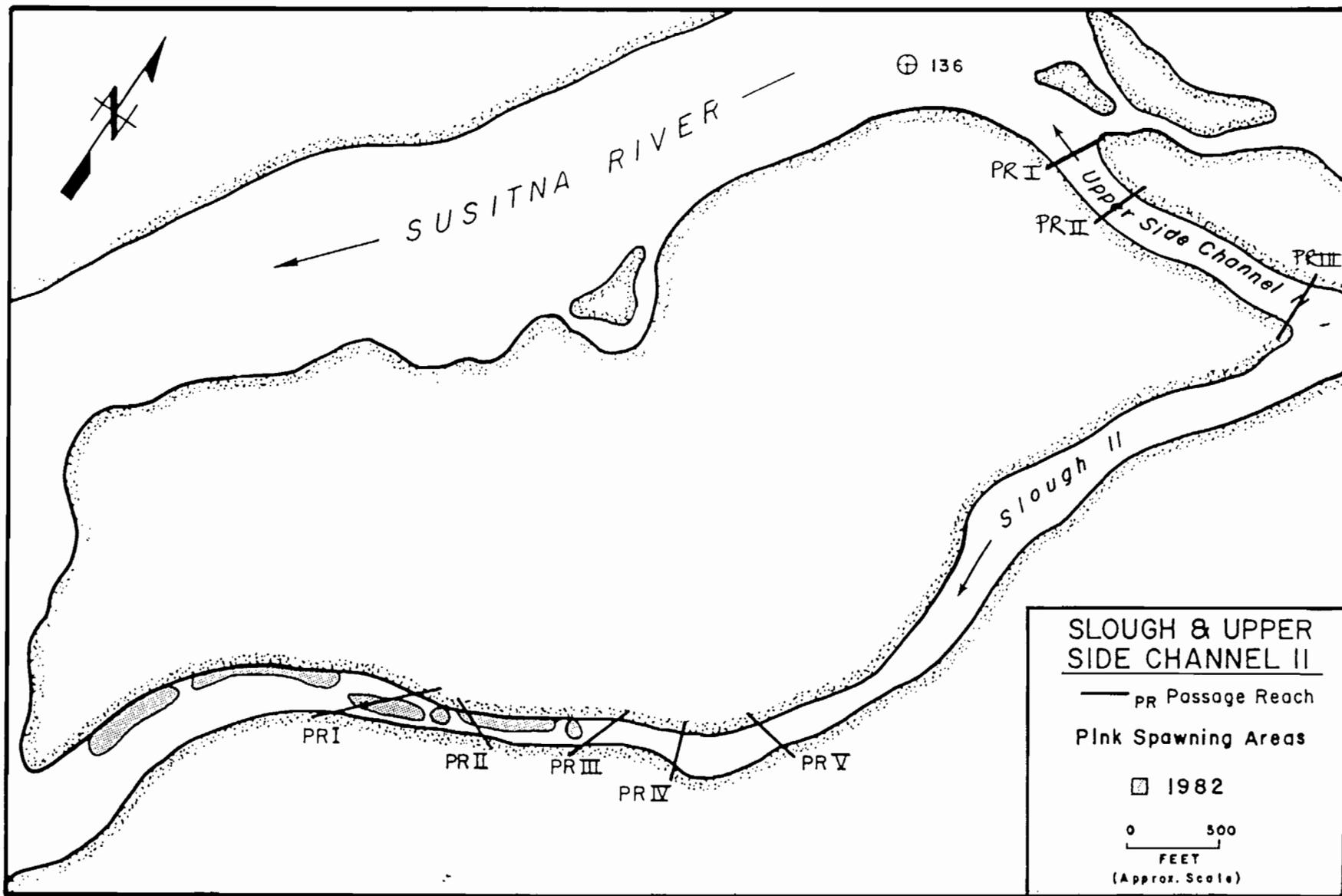
6-D-14



6-D-13

Sockeye salmon spawning areas, Slough and Side Channel 11, 1981, 1982, 1983.

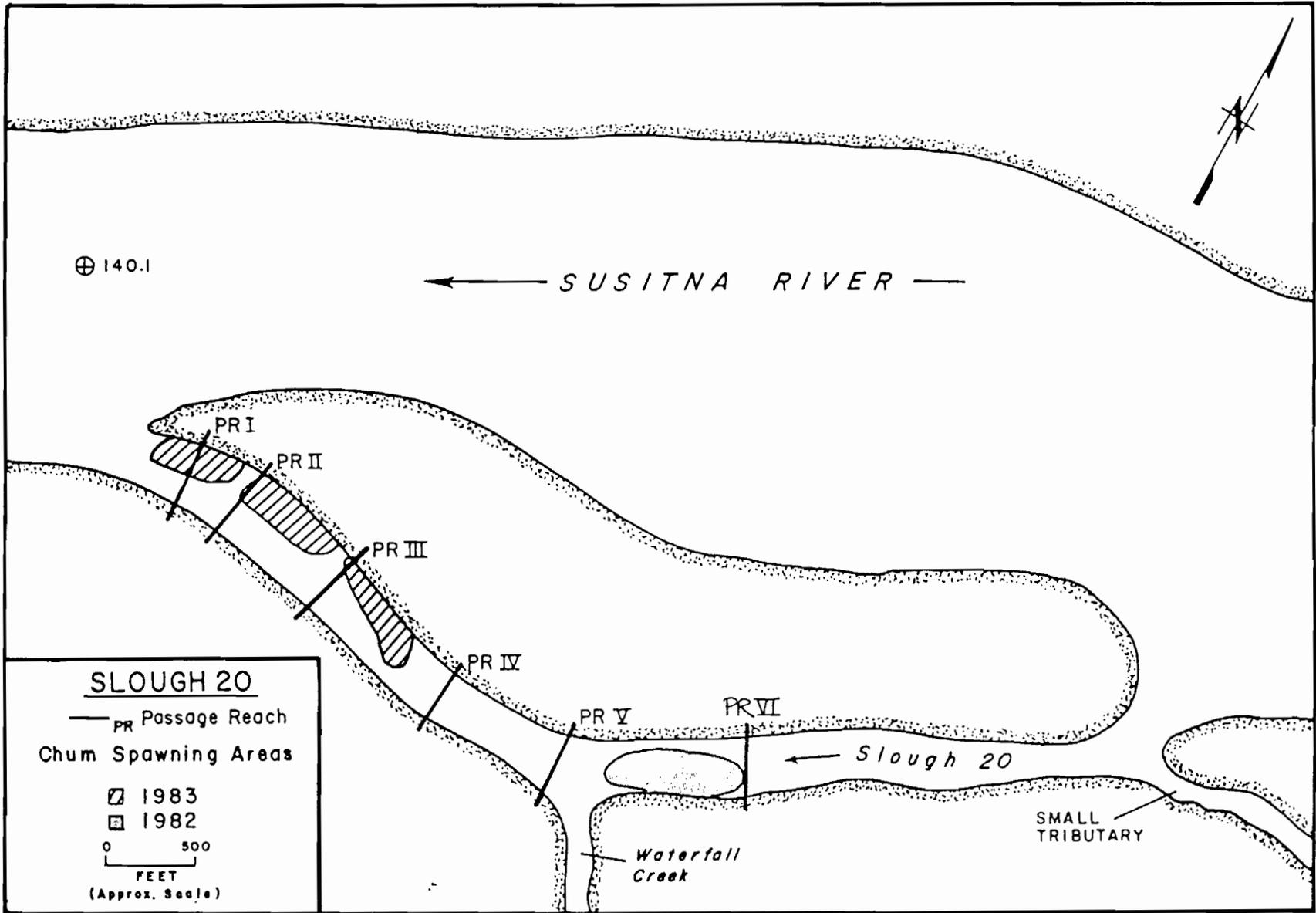
6-D-15



6-D-14

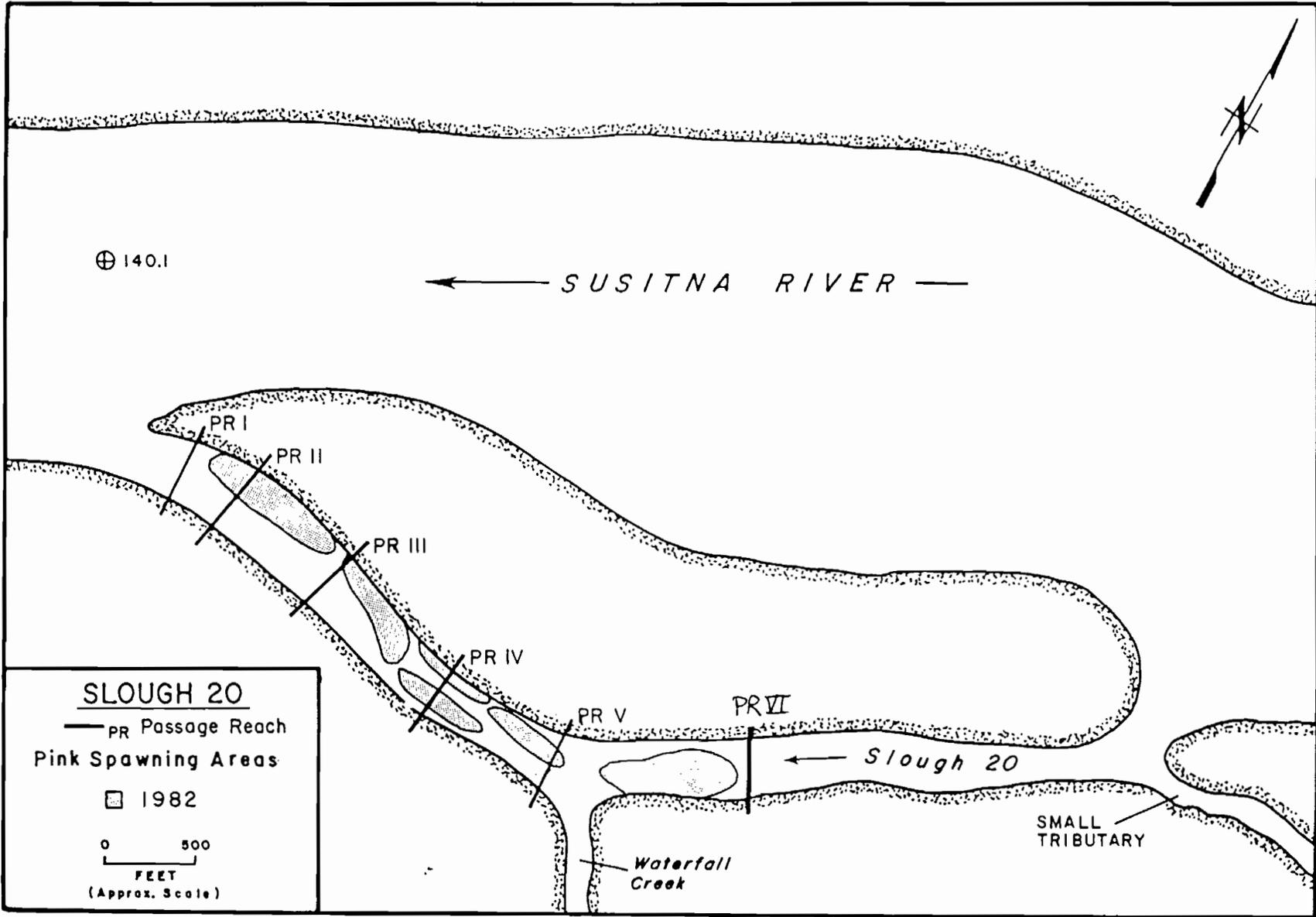
Pink salmon spawning areas, Slough and Side Channel 11, 1982.

6-D-16



6-D-15

Chum salmon spawning area, Slough 20,  
1982, 1983

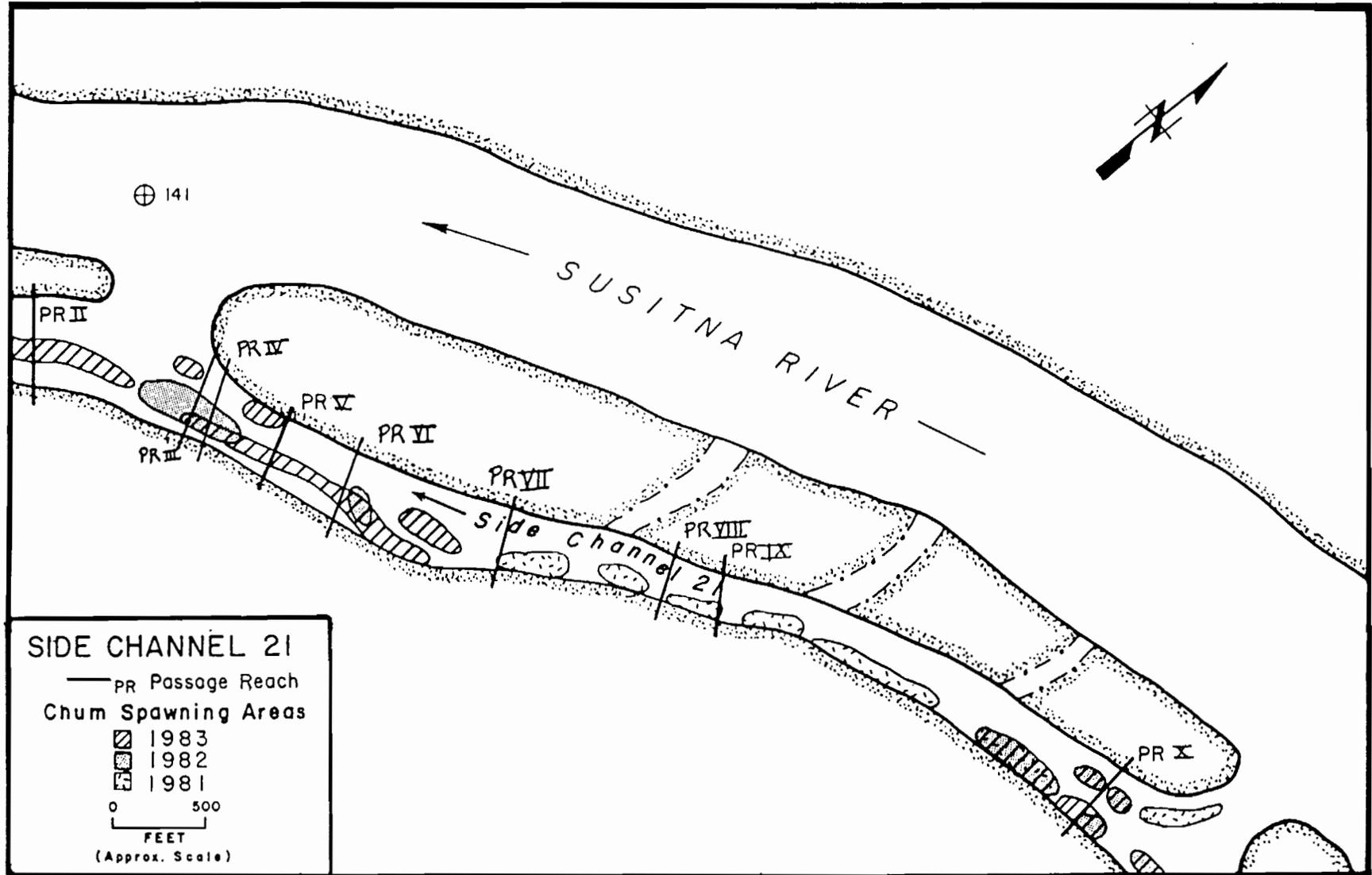


6-D-16

Pink salmon spawning areas, Slough 20, 1982.

6-D-17

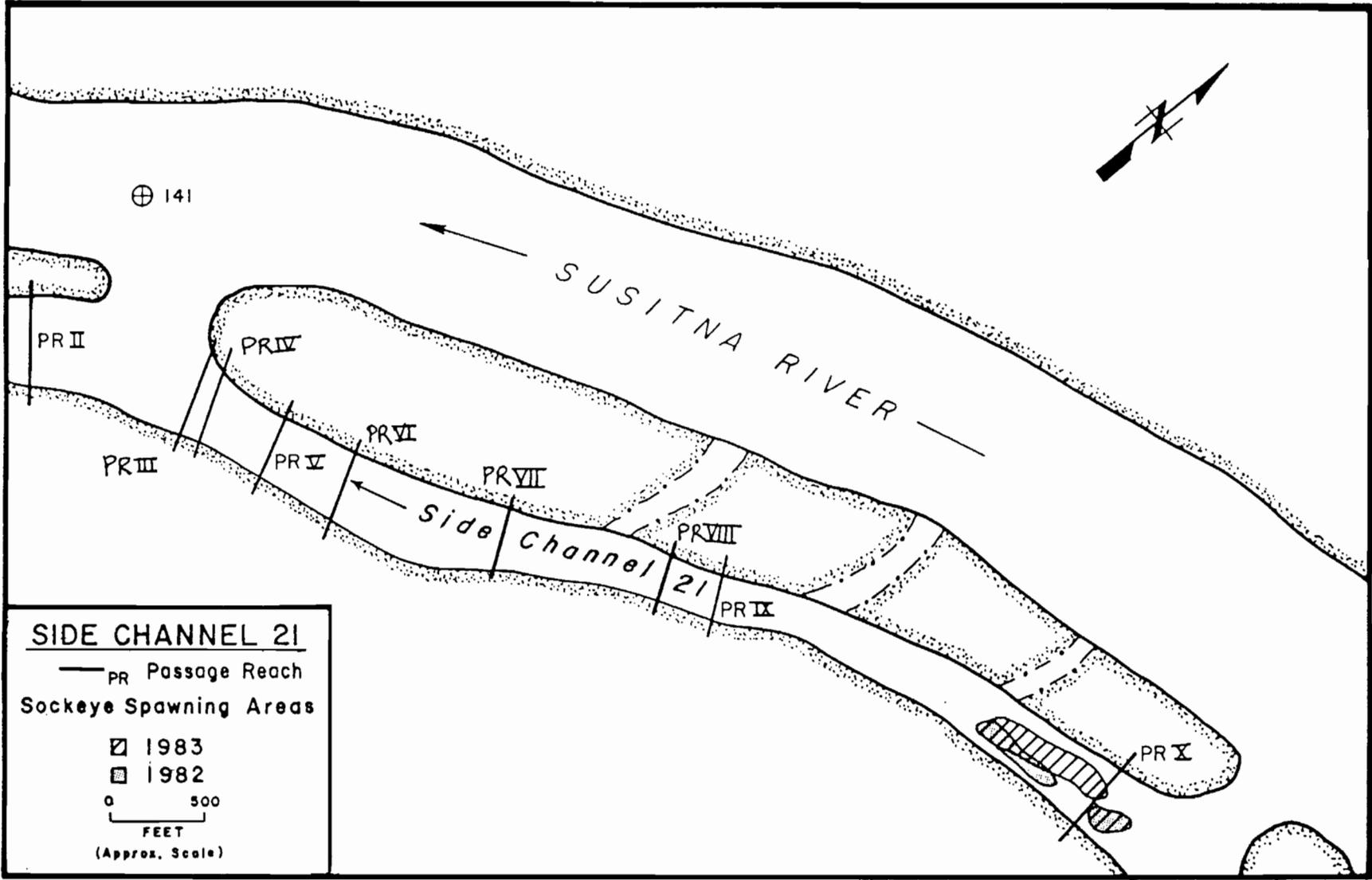
81-11-7



6-D-17

Chum salmon spawning areas, Side Channel  
21, 1981, 1982, 1983.

6-D-19



6-D-18 Sockeye salmon spawning areas, Side Channel 21, 1982, 1983.

# SLOUGH 21

— PR Passage Reach

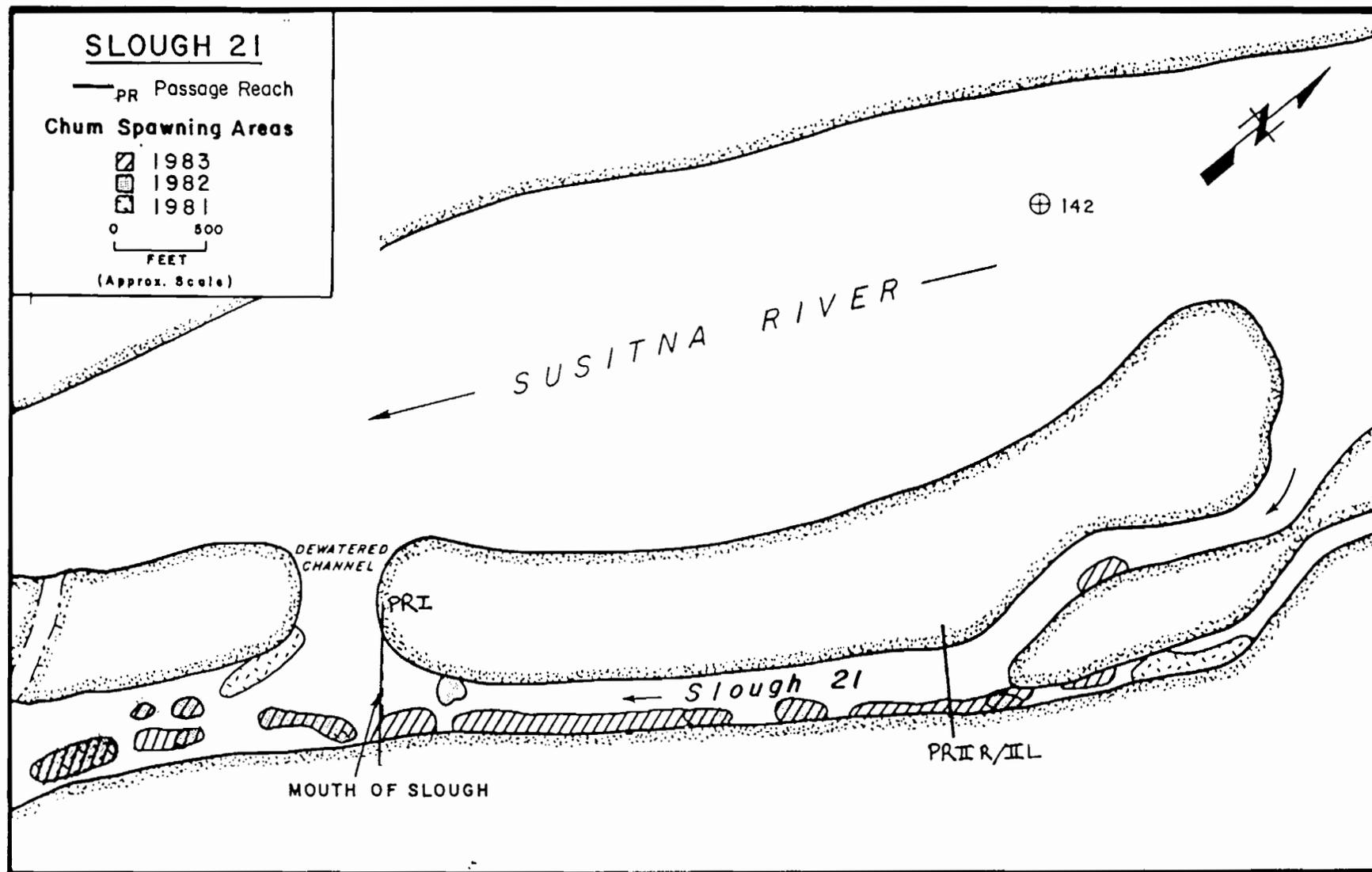
## Chum Spawning Areas

- ▨ 1983
- ▣ 1982
- ▤ 1981

0 500

FEET

(Approx. Scale)



6-D-19

Chum salmon spawning areas, Slough 21,  
1981, 1982, 1983

# SLOUGH 21

— PR Passage Reach

## Sockeye Spawning Areas

▨ 1983

▤ 1982

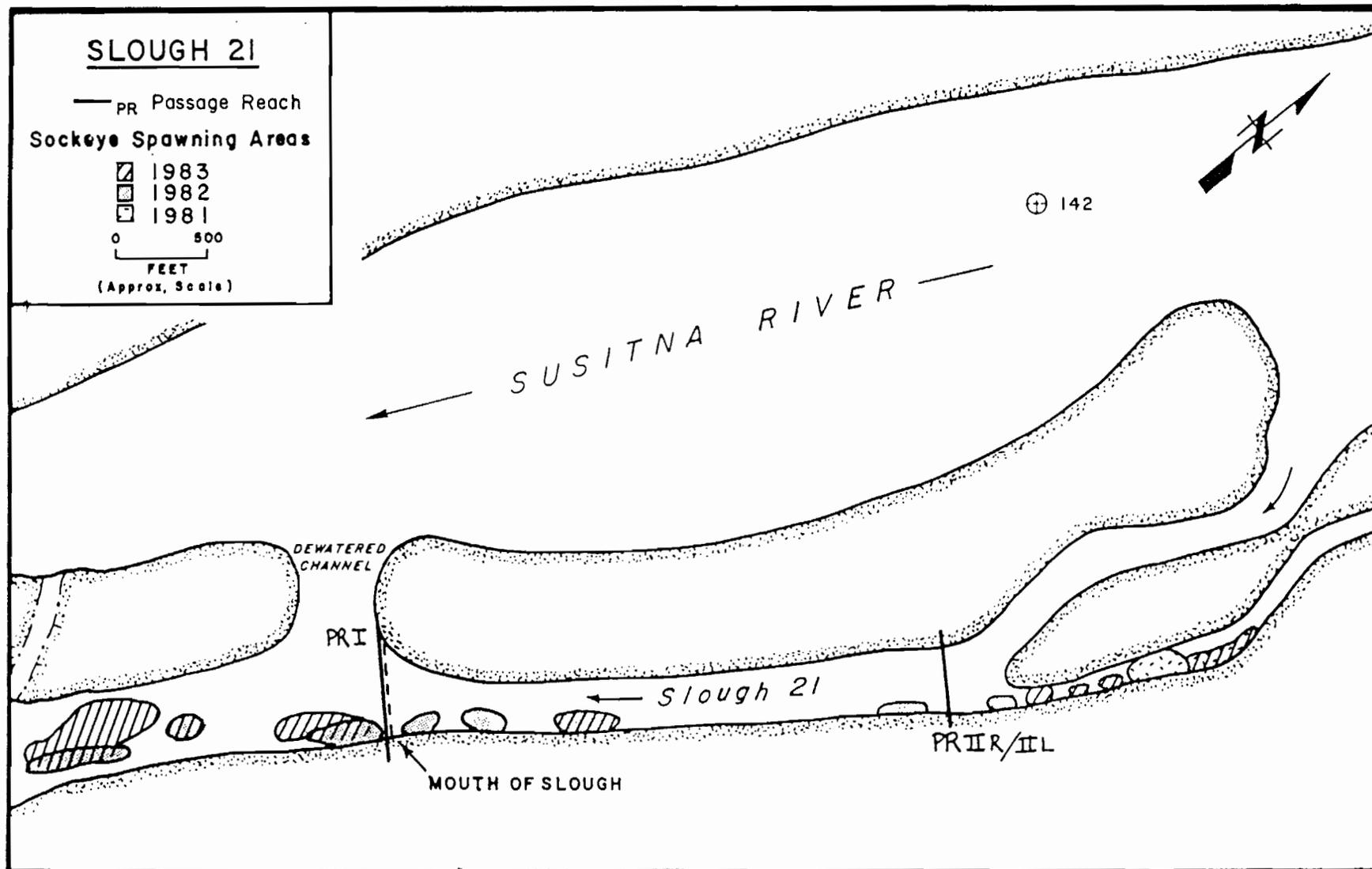
□ 1981

0 500

FEET

(Approx. Scale)

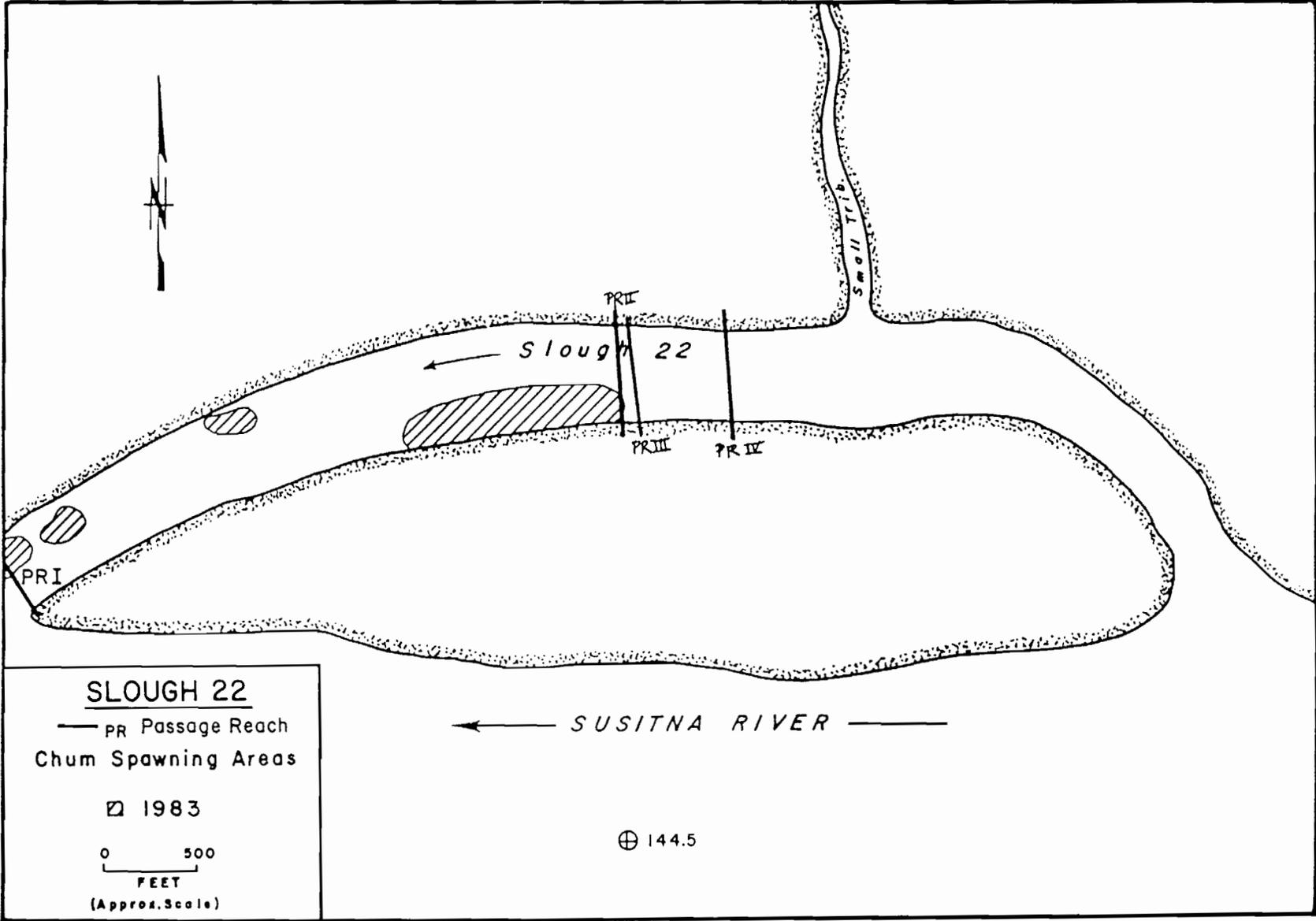
6-17-21



6-D-20

Sockeye salmon spawning areas, Slough 21,  
1981, 1982, 1983.

G-D-22



6-D-21

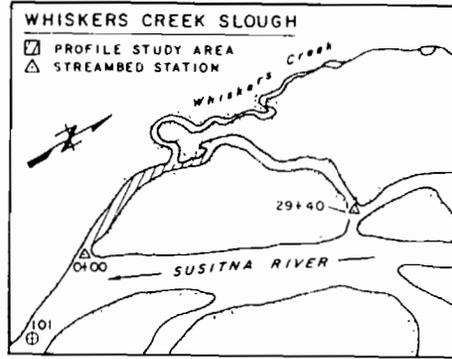
Chum salmon spawning areas, Slough 22, 1983.

Appendix 6-E

Thalweg Profiles of Sloughs  
and Side Channels

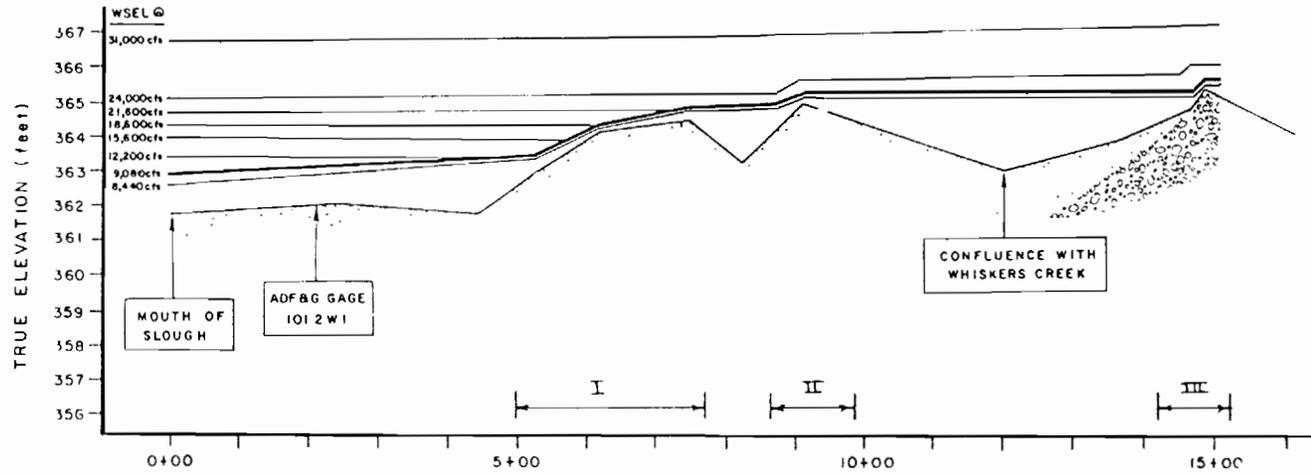
6-E-1

6-E-2



### WHISKERS CREEK SLOUGH

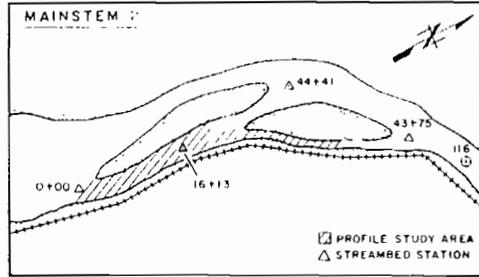
#### PASSAGE REACH LOCATIONS



6-E-1

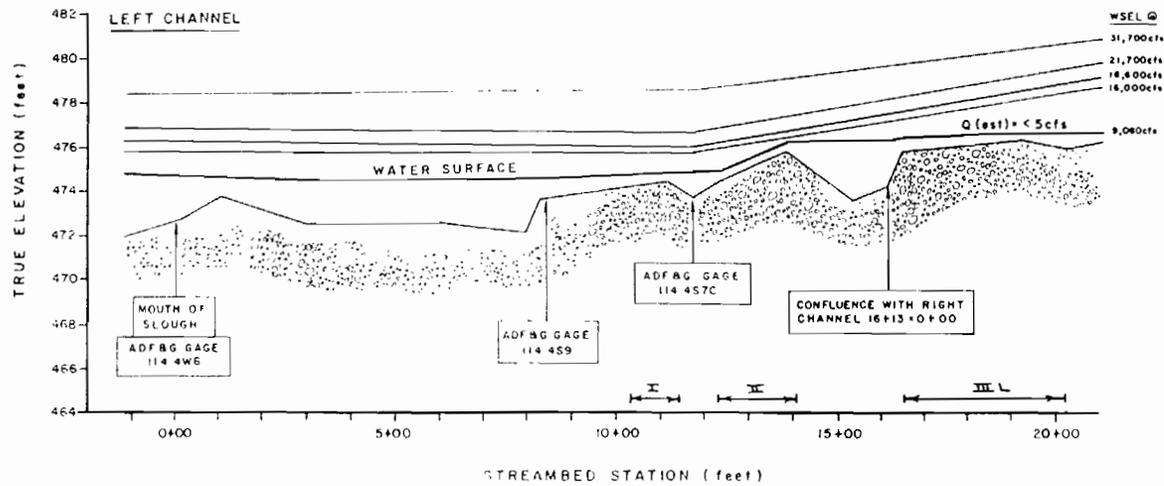
Thalweg profile of Whiskers Creek Slough.

6-E-3



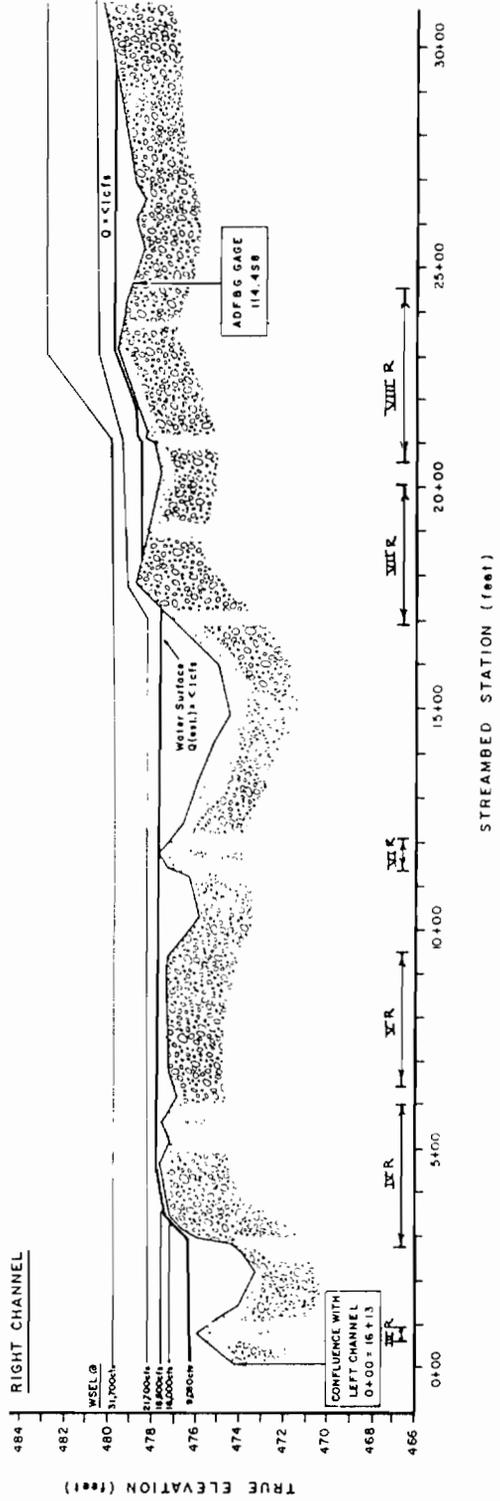
MAINSTEM 2  
PASSAGE REACH LOCATIONS

- SILT / SAND
- GRAVEL / RUBBLE
- COBBLE / BOULDER
- PASSAGE REACH

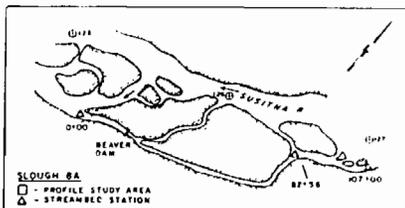


6-E-2A Thalweg profile of Mainstem 2 Side Channel (Left Channel).

MAINSTEM 2



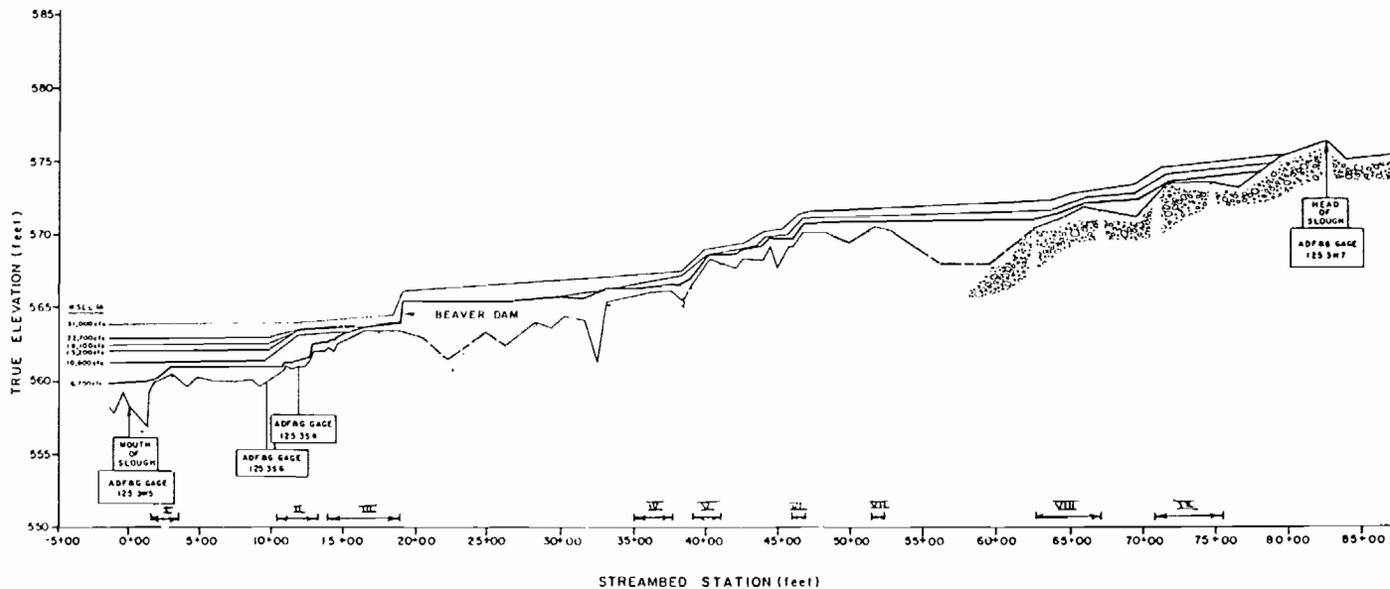
6-E-2B Thalweg profile of Mainstem 2 Side Channel (Right Channel).



## SLOUGH 8A

### PASSAGE REACH LOCATIONS

- SILT / SAND
- GRAVEL / RUBBLE
- COBBLE / BOULDER
- ESTIMATED DEPTH
- PR PASSAGE REACH

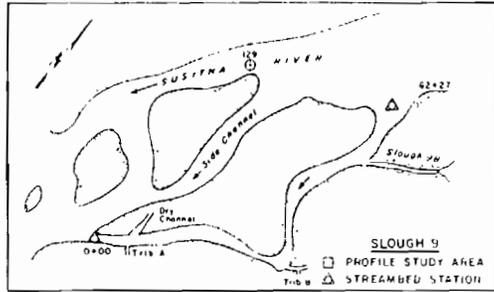


6-E-3

Thalweg profile of Slough 8A

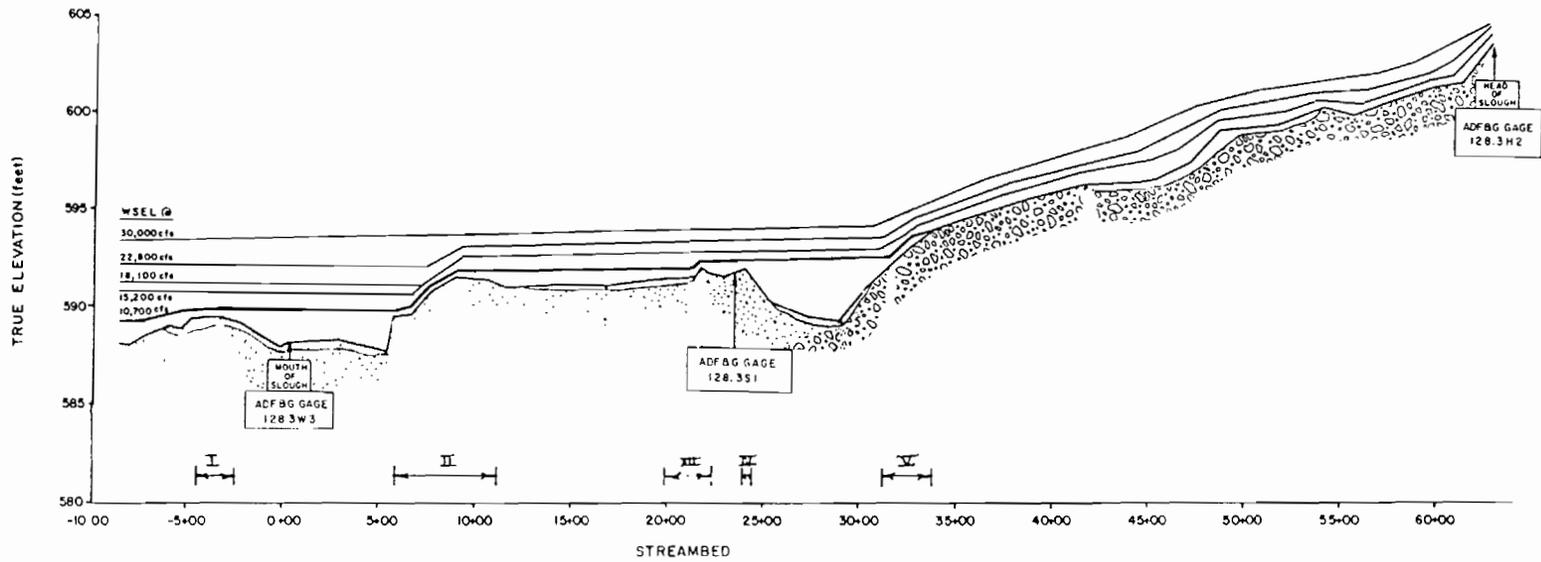
6-E-5

6-E-4

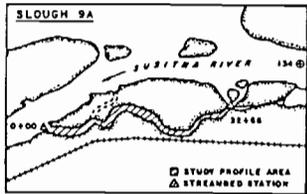


### SLOUGH 9 PASSAGE REACH LOCATIONS

- SILT / SAND
- GRAVEL / RUBBLE
- COBBLE / BOULDER
- PASSAGE REACH

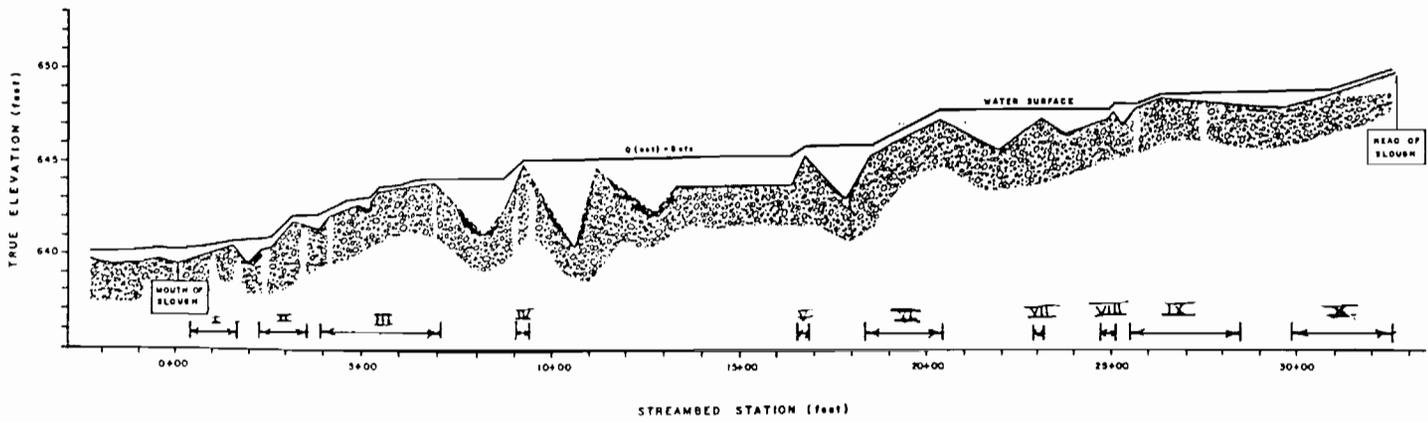


6-E-4 Thalweg profile of Slough 9



SLOUGH 9A  
PASSAGE REACH LOCATIONS

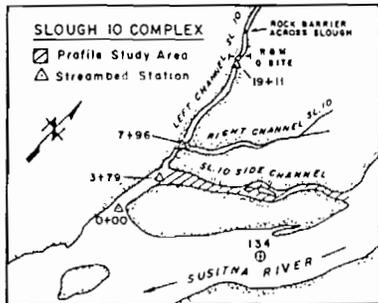
-  SILT / SAND
-  GRAVEL / RUBBLE
-  COBBLE / BOULDER
-  DEPTH ESTIMATED
-  PASSAGE REACH



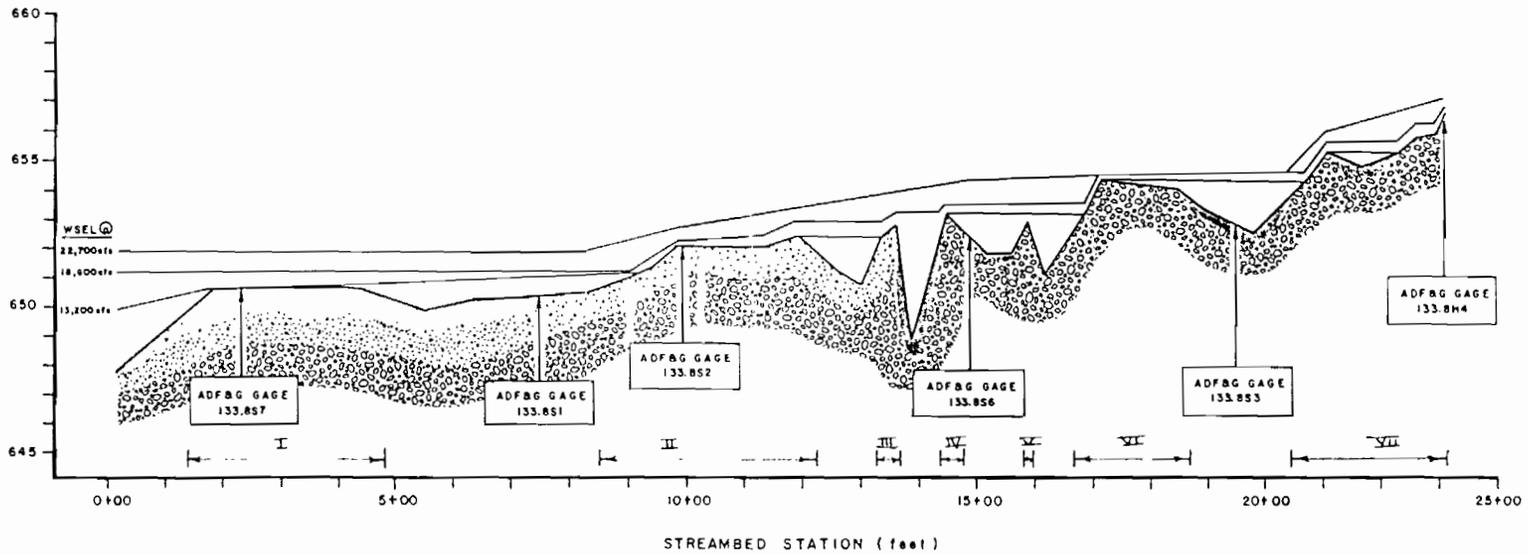
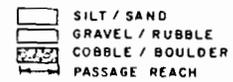
6-E-5

Thalweg profile of Slough 9A

6-E-7



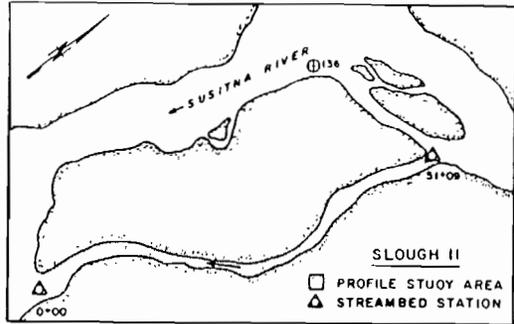
### SIDE CHANNEL 10 PASSAGE REACH LOCATIONS



6-E-6

Thalweg profile of Side Channel 10

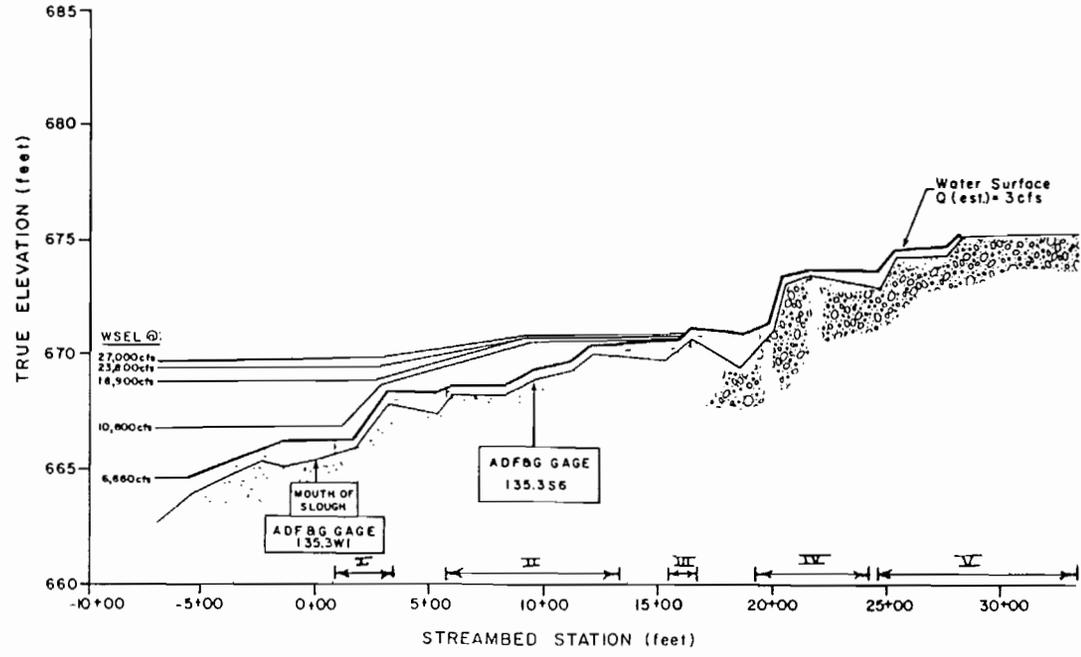
6-E-6



### SLOUGH II

#### PASSAGE REACH LOCATIONS

-  SILT / SAND
-  GRAVEL / RUBBLE
-  COBBLE / BOULDER
-  PASSAGE REACH

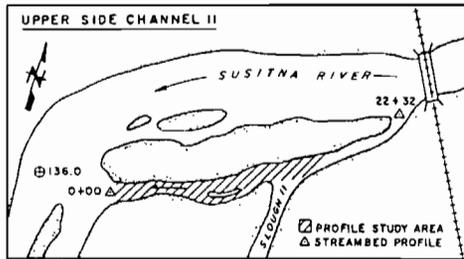


6-E-7

6-E-7

Thalweg profile of Slough 11

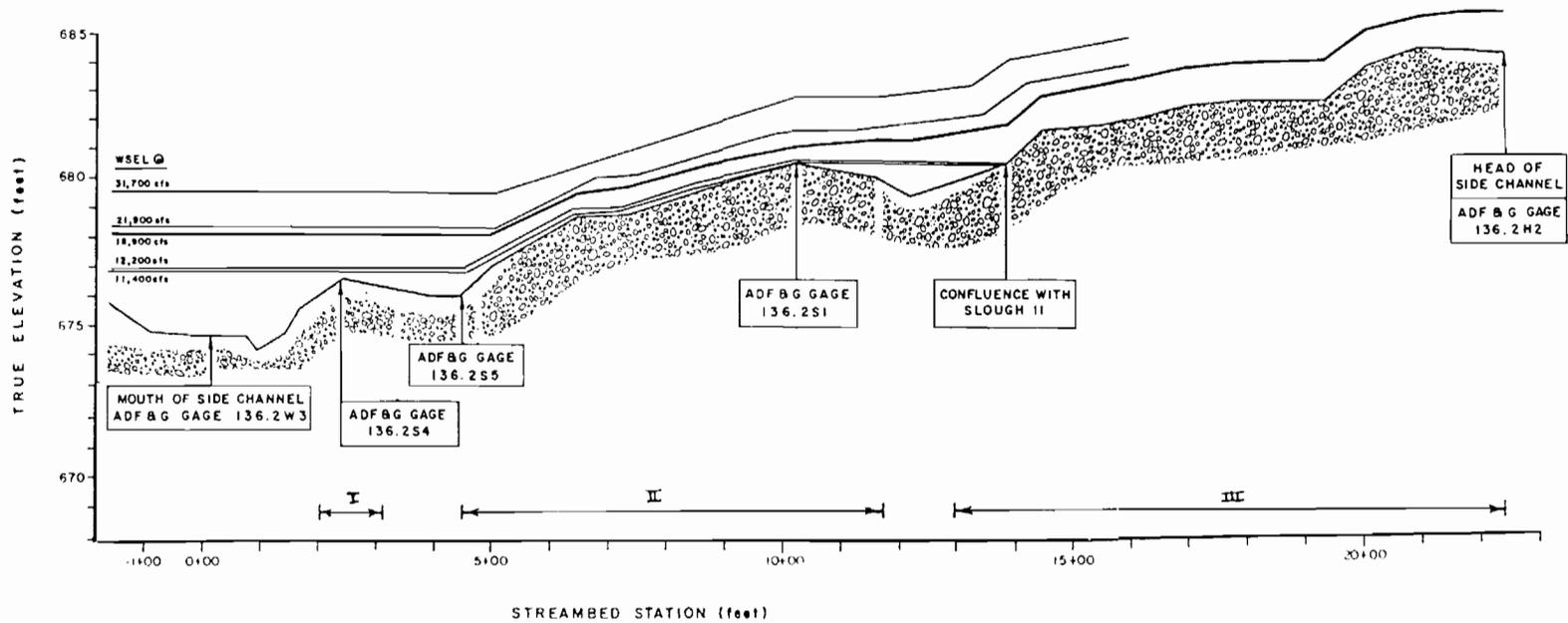
6-E-10



### UPPER SIDE CHANNEL II

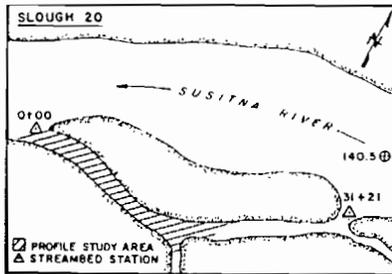
#### PASSAGE REACH LOCATIONS

- SILT / SAND
- COBBLE / BOULDER
- PASSAGE REACH



6-E-8

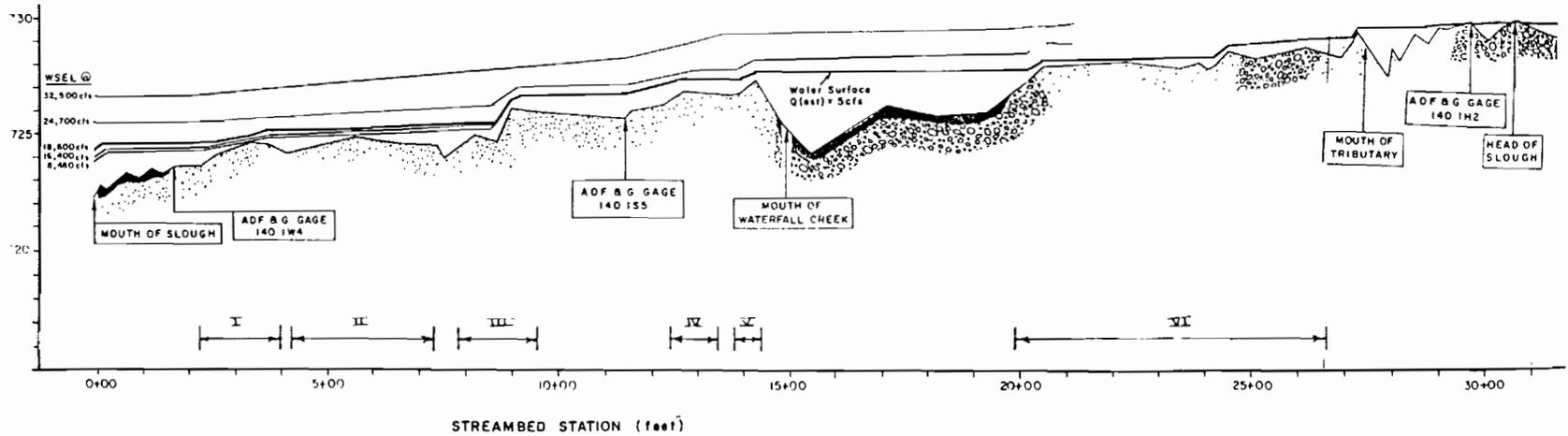
Thalweg profile of Upper Side Channel 11



## SLOUGH 20

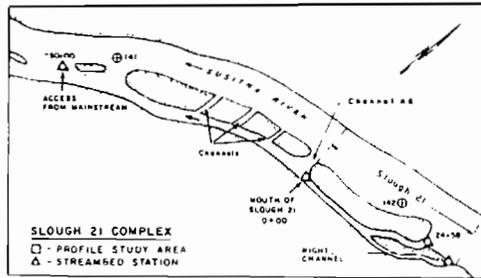
### PASSAGE REACH LOCATIONS

-  SILT / SAND
-  GRAVEL / RUBBLE
-  COBBLE / BOULDER
-  PASSAGE REACH



6-E-9

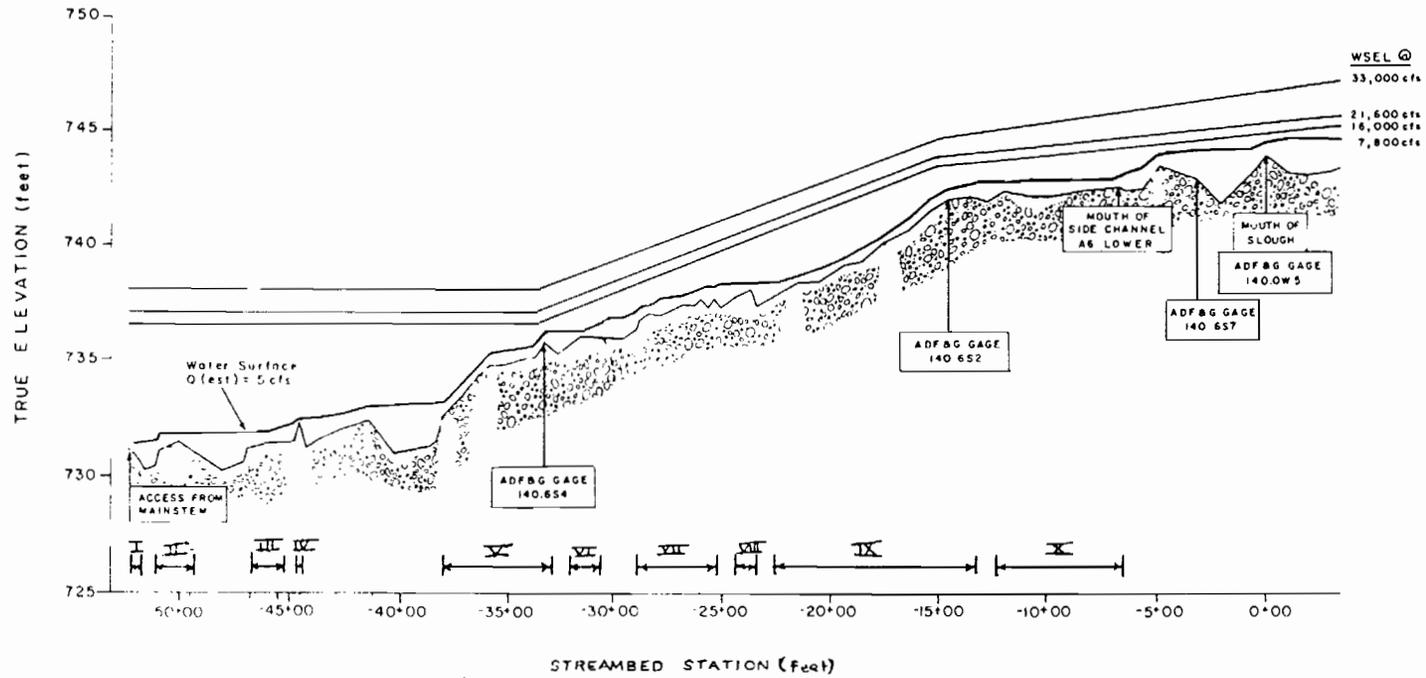
Thalweg profile of Slough 20



## SIDE CHANNEL 21

### PASSAGE REACH LOCATIONS

- SILT / SAND
- COBBLE / BOULDER
- PASSAGE REACH

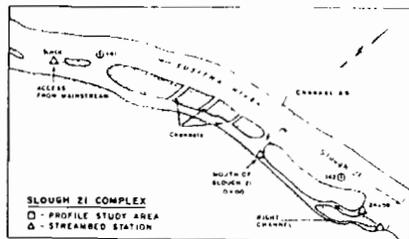


6-E-12

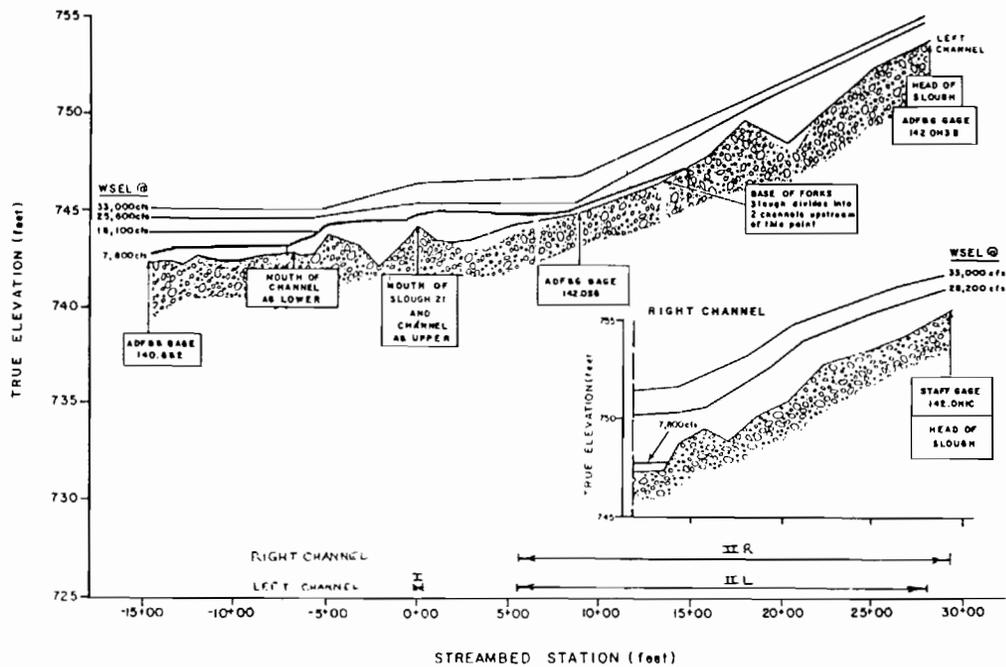
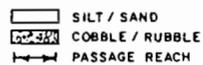
6-E-10

Thalweg profile of Side Channel 21

6-E-13

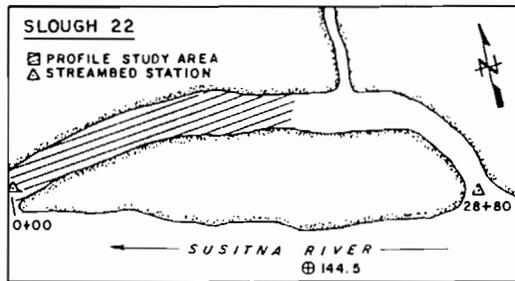


**SLOUGH 21 COMPLEX**  
**PASSAGE REACH LOCATIONS**



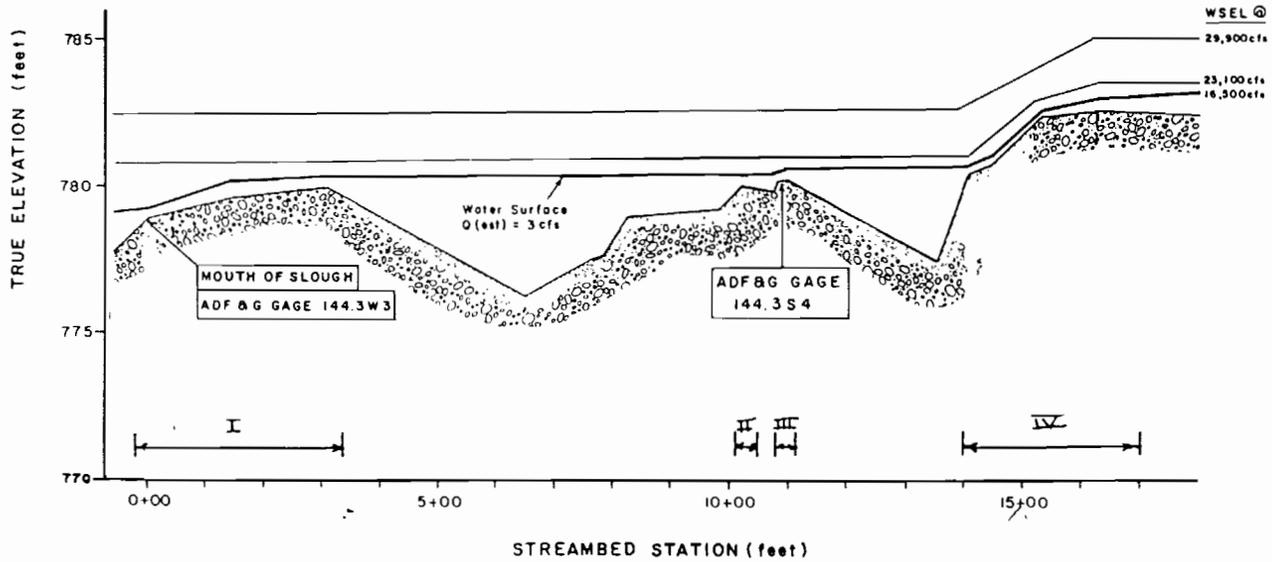
6-E-11

Thalweg profile of Slough 21



**SLOUGH 22**

PASSAGE REACH LOCATIONS



6-E-12

Thalweg profile of Slough 22