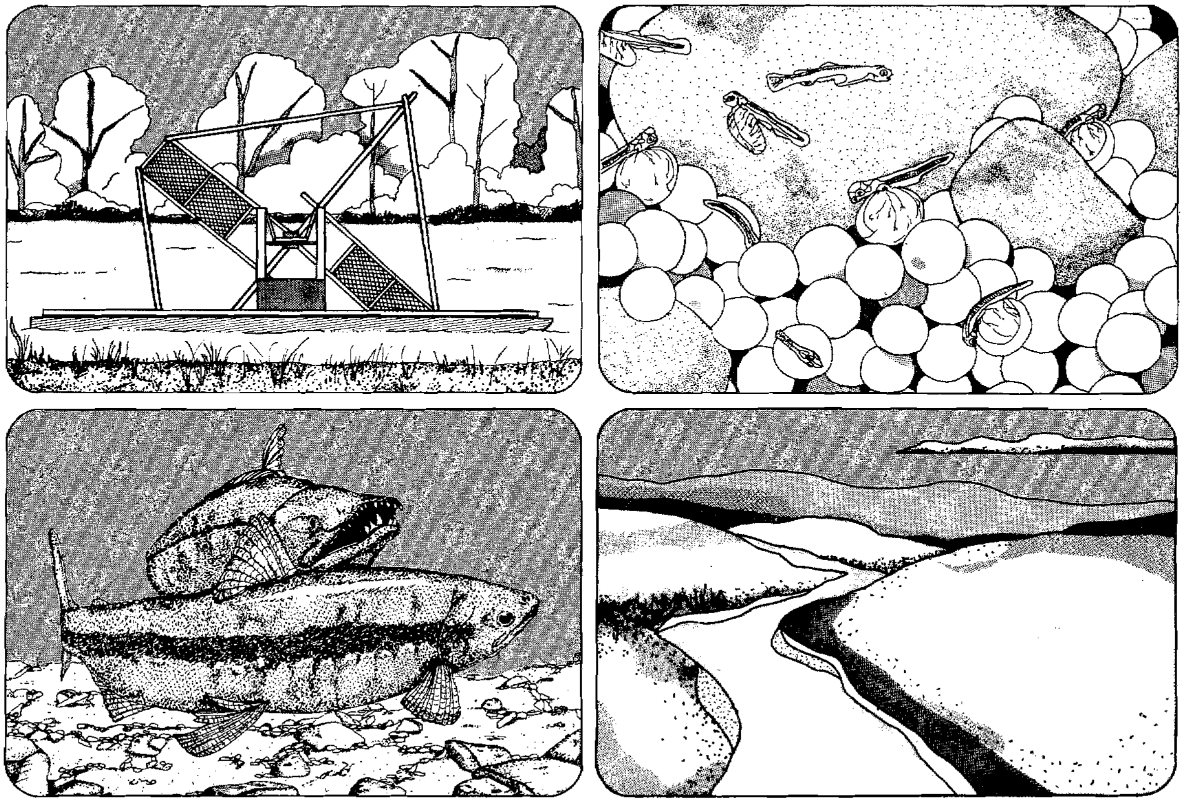

REPORT NO. 3

AQUATIC HABITAT AND INSTREAM FLOW INVESTIGATIONS (MAY-OCTOBER 1983)

Chapter 6: An Evaluation of Passage Conditions for Adult Salmon in Sloughs and Side Channels of the Middle Susitna River

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Chapter 6: An Evaluation of Passage Conditions for Adult Salmon in Sloughs and Side Channels of the Middle Susitna River

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September 1984

NOTICE

ANY QUESTIONS OR COMMENTS CONCERNING THIS REPORT SHOULD BE DIRECTED TO THE ALASKA POWER AUTHORITY SUSITNA PROJECT OFFICE

PREFACE

This report is one of a series of reports prepared for the Alaska Power Authority (APA) by the Alaska Department of Fish and Game (ADF&G) to provide information to be used in evaluating the feasibility of the proposed Susitna Hydroelectric Project. The ADF&G Susitna Hydro Aquatic Studies program was initiated in November 1980. The five year study program was divided into three study sections: Adult Anadromous Fish Studies (AA), Resident and Juvenile Anadromous Studies (RJ), and Aquatic Habitat and Instream Flow Studies (AH). Reports prepared by the ADF&G prior to 1983 on this subject are available from the APA.

The information in this report summarizes the findings of the 1983 open water field season investigations. Beginning with the 1983 reports, all reports were sequentially numbered as part of the Alaska Department of Fish and Game Susitna Hydro Aquatic Studies Report Series.

TITLES IN THE 1983 SERIES

Report Number	Title	Publication Date
1	Adult Anadromous Fish Investigations: May - October 1983	April 1984
2	Resident and Juvenile Anadromous Fish Investigations: May - October 1983	July 1984
3	Aquatic Habitat and Instream Flow Investigations: May - October 1983	1984
4	Access and Transmission Corridor Aquatic Investigations: May - October 1983	1984

This report, "Aquatic Habitat and Instream Flow Investigations" is divided into two parts. Part I, the "Hydrologic and Water Quality Investigations", is a compilation of the physical and chemical data collected by th ADF&G Su Hydro Aquatic Studies team during 1983. These data are arranged by individual variables and geographic location for ease of access to user agencies. The combined data set represents the available physical habitat of the study area within the Cook Inlet to Oshetna River reach of the Susitna River. Part II, the "Adult Anadromous Fish Habitat Investigations", describes the subset of available habitat compiled in Part 1 that is utilized by adult anadromous fish studied in the middle and lower Susitna River (Cook Inlet to Devil Canyon) study area. The studies primarily emphasize the utilization of side slough and side channel habitats of the middle reach of the Susitna River for spawning (Figure A). It represents the first stage of development for an instream flow relationships analysis report which will be prepared by E.W. Trihey and Associates.

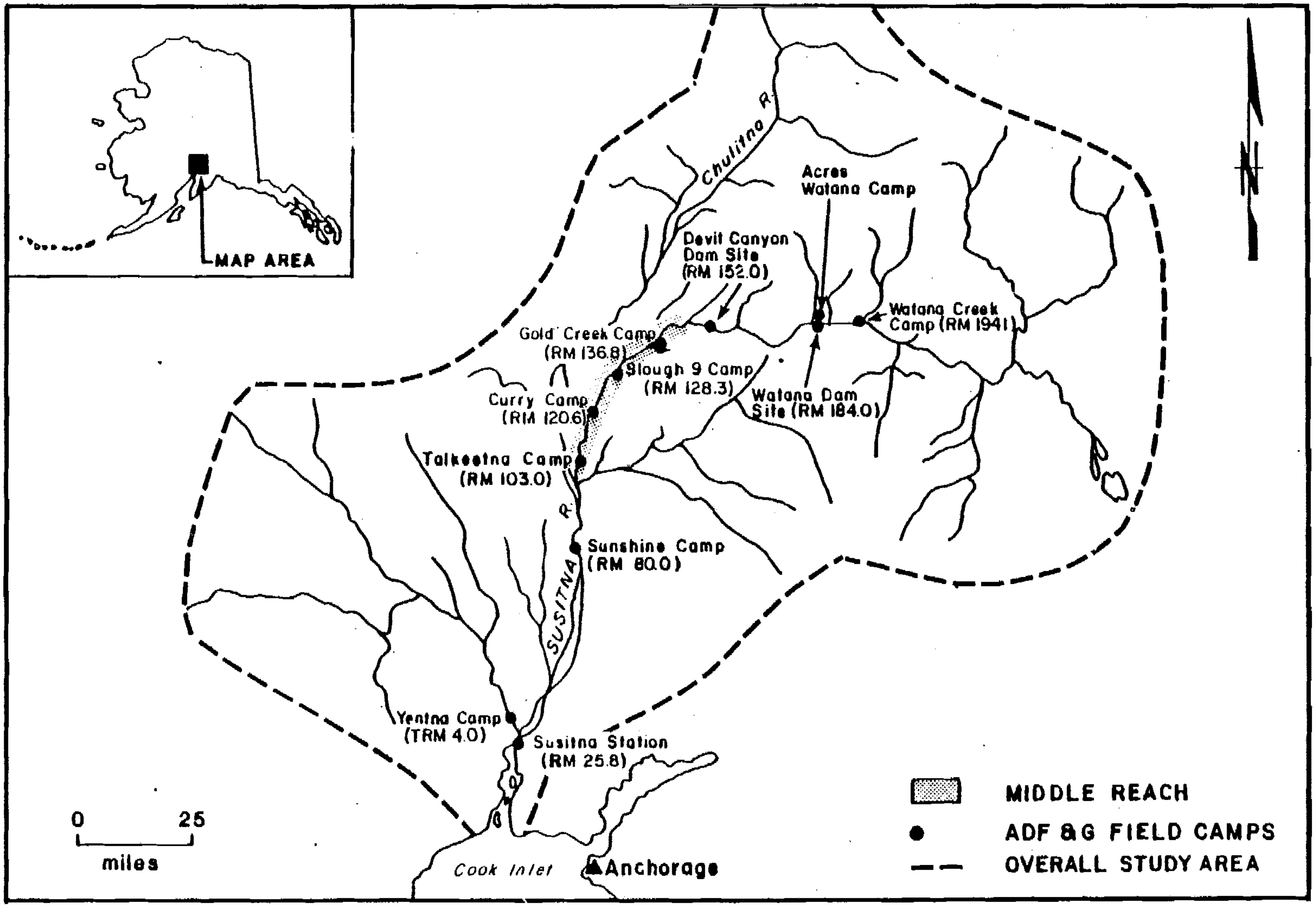

Figure A. Susitna River drainage basin.

CONTENTS OF REPORT NO. 3

Part One

Part Two

Questions concerning this and prior reports should be directed to:

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

1984 Report, Chapter 6

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ABSTRACT

An interim evaluation of passage conditions for adult Pacific salmon into and within twelve slough and side channel sites in the middle reach of the Susitna River is presented to determine the effects of mainstem discharge on passage conditions into these habitat types. These habitats were selected for evaluation as they are affected by mainstem Susitna River discharges. A final evaluation will be completed in FY85. The sites account for the majority of chum, sockeye and pink salmon which spawn in sloughs and side channels in this reach. The evaluation of salmon passage conditions at each site included the effects of mainstem breaching discharge 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 also evaluated as they relate to passage conditions and flow patterns in the Susitna River system.

Daily salmon catch data at three fishwheel sites on the mainstem river were compared to mean daily discharge levels. These discharge data and 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 from the mainstem Susitna River. All analyses of passage were therefore restricted to this time period.

Reaches within study sites which were restrictive to salmon passage (passage reaches) were identified at each site on the basis of water depth requirements for passage by salmon. Depth requirements for successful passage increase with and increase in the length of a passage. The analyses of breaching and backwater discharges 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 discharges affect all passage reaches within a site simultaneously; whereas, backwater staging usually affects 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 interim evaluation of selected channel geometry and hydraulic characteristics which influence passage conditions for adult chum (Oncorhynchus keta), sockeye (O. nerka) and pink (O. gorbuscha) salmon from the middle reach of the Susitna River into and within selected slough and side channel habitats located between Talkeetna (RM 98.0) and Devil Canyon (RM 152.0) (Figure 6-1). 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 is also examined. Timing and distribution patterns of these salmon species are addressed only 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. This analysis is an interim step towards a final analysis which will be completed in FY85.

1.1 Background

Five species of Pacific Salmon [chum, sockeye, pink, coho (O. kisutch) and chinook (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 among 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 received limited use 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 critical to ensure that salmon will arrive at spawning areas when environmental conditions (flows, water depths, etc.) are suitable for passage into and within these areas. 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, b: Appendix B) indicate that it is unlikely that hydraulic velocity barriers would exist at these or other spawning locations under present or projected flow regimes. Therefore, the ability for salmon to enter slough and side channel habitats from the mainstem Susitna River and access spawning areas within these habitats is primarily a function of water depth and the length of a reach when the water is shallow (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 the available spawning areas may be excessive. If these conditions persist,

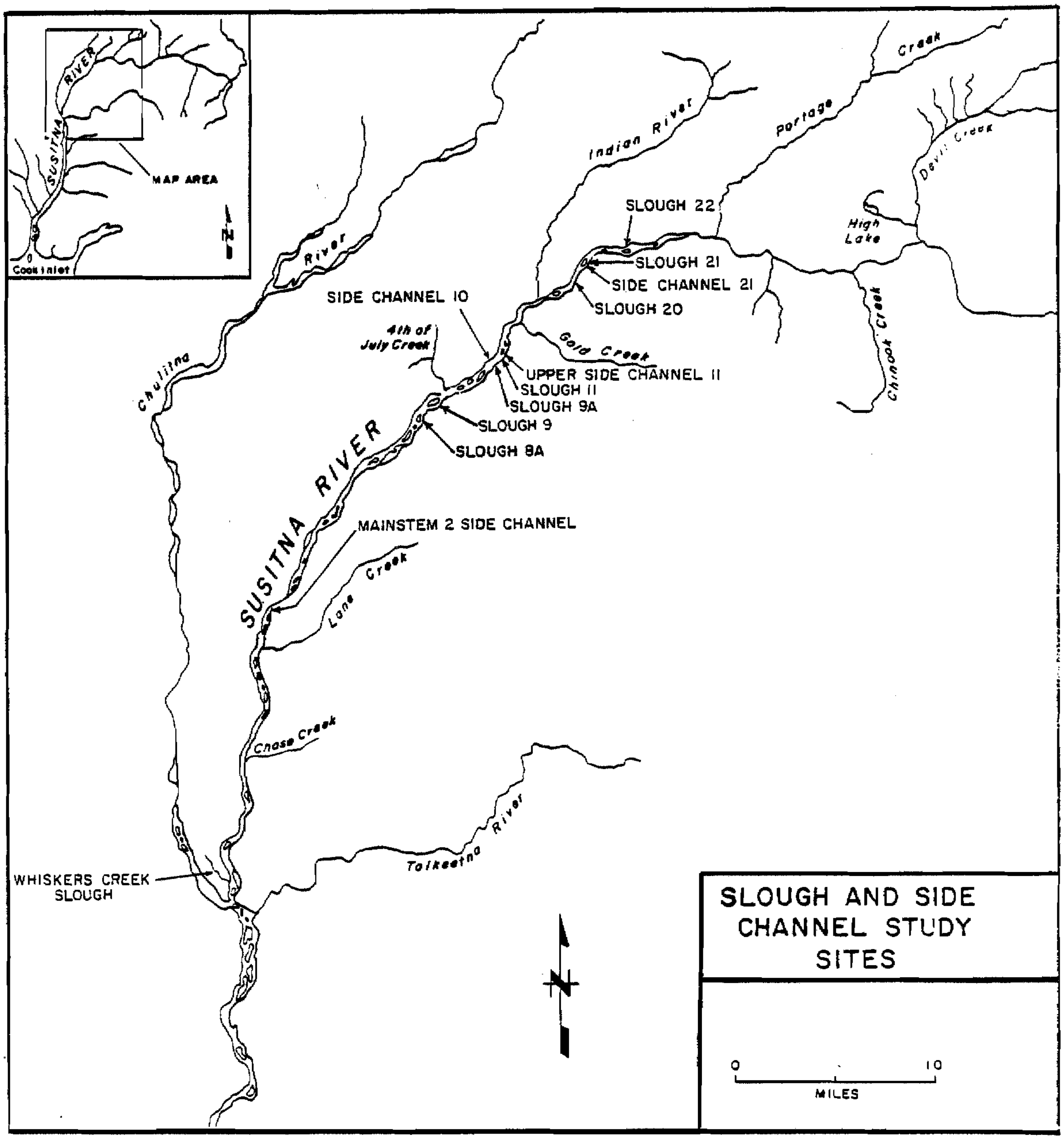

Figure 6-1. Slough and side channel study sites selected for passage evaluation, 1983.

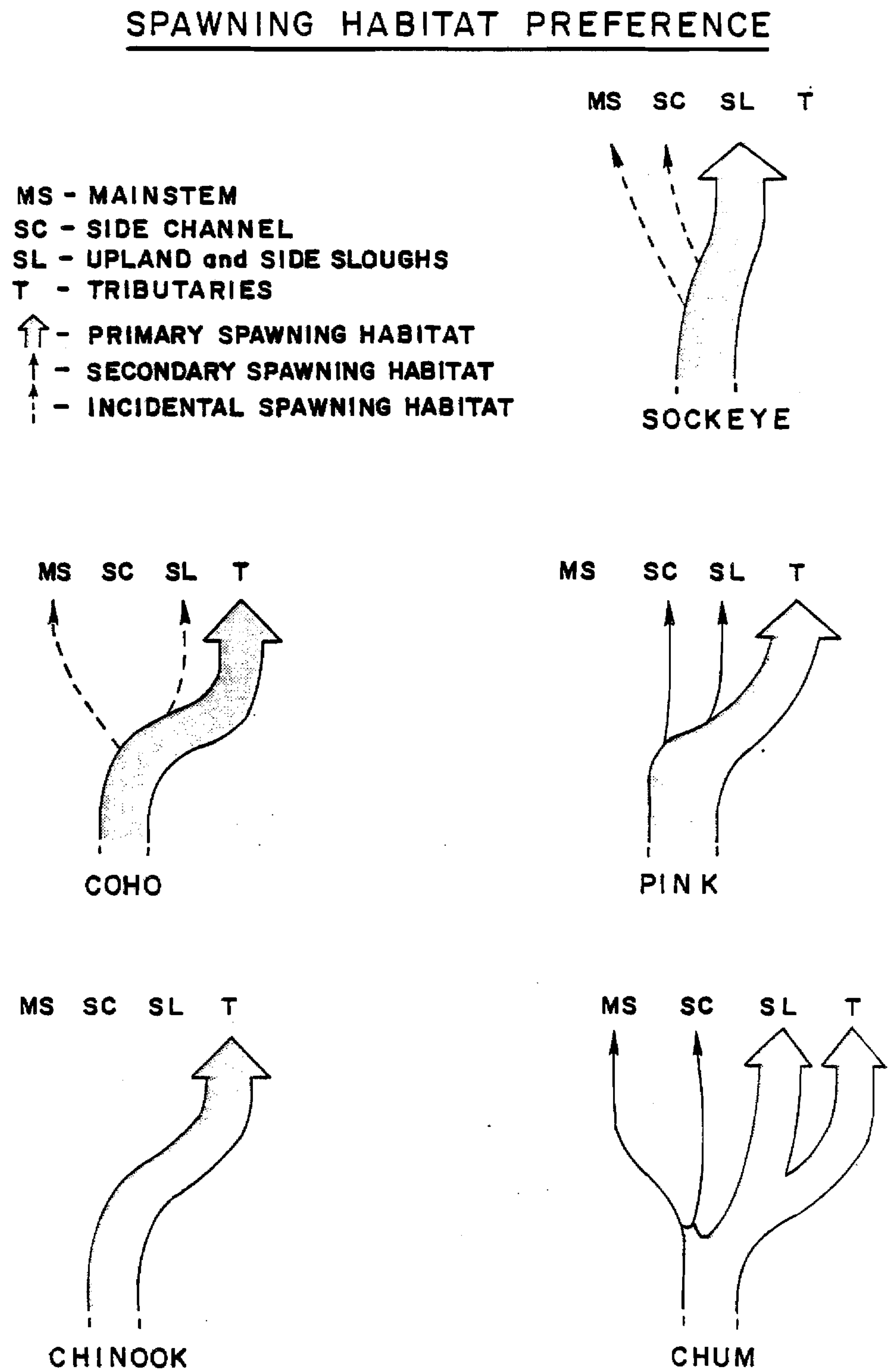

Figure 6-2. General spawning habitat preference of the five species of salmon utilizing the Susitna River Basin.

it will result in a reduction in the number of salmon originating from and returning to the affected habitats.

Mainstem discharge levels directly 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 of fish from the mainstem into the site. As mainstem discharge increases, the backwater area normally increases in depth and extends its influence upstream, thus increasing depths within those critical passage reaches affected by the backwater. This elimination of passage restrictions within a reach by inundation continues in the upstream direction with increasing mainstem discharge, until a controlling discharge levels is achieved at which point depths become adequate for passage at all passage reaches in most slough and side channel habitats.

During conditions when the mainstem river breaches the upstream head of the site, local flow (e.g., upwelling, tributaries, precipitation) normally constitutes a negligible contribution to the overall flow in the site. However, during unbreached conditions, changes in local flow alone can result in significant changes in passage conditions within critical passage reaches.

Naturally occurring mainstem discharge levels and local flows provide suitable depths and velocities during most years and support successful passage conditions for adult salmon into traditional slough and side channel spawning sites. These naturally occurring discharges in the Susitna River (as recorded daily 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 between 7,000 and 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 some of these habitats. Water levels within these habitats would be primarily dependent upon local flow from small tributaries, surface runoff, and upwelling groundwater under these controlled mainstem discharge conditions (ADF&G 1981a, 1982, 1983a, 1983b: Appendix B).

Therefore, evaluations of timing of the adult salmon migration within the mainstem and to slough and side channel spawning sites, and the passage conditions available at various mainstem discharges are 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 essential for evaluating the effects that regulated discharges of the proposed hydroelectric project will have upon these habitats. Additionally, these data are necessary to assist in developing appropriate mitigative options.

1.2 Objective

The primary objective of this continuing study is 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 are 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 (ADF&G 1983b:Appendix B; Trihey 1982) 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. This was due to the relatively small number of sites investigated, the lack of an evaluation of local flow conditions, and a need to refine previous methods. The present study is the first stage in expanding the number of study sites (including relevant side channel sites) and refining the methods previously employed to provide a more comprehensive and precise evaluation of salmon passage conditions in the middle Susitna River. Also included is a preliminary evaluation of local flow conditions at most of these sites. The second and final stage of the analyses will be completed in FY85.

The primary objective of this analysis 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. Available information on sockeye and pink salmon is also included to present a more comprehensive overview of salmon utilization and potential passage problems within the middle reach Susitna River slough and side channel habitats.

2.0 METHODS

2.1 Site Selection

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

2.2 Timing and Distribution of Salmon

Comprehensive timing and distribution data have been collected on adult salmon in the middle Susitna River since 1981 [ADF&G 1981b, 1982, 1983b: (Appendix B), 1983; Barrett et al. 1984]. A compilation and comparison of these data are discussed below by habitat type.

2.2.1 Mainstem Sites

Timing of the upstream migration of adult salmon in the mainstem Susitna River was compared to mainstem discharge for the 1981, 1982, and 1983 open water field seasons. For each year, catch per unit effort data were combined with 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 and related data analyses are presented in ADF&G (1983c) and Barrett, et al., (1984).

Discharge data used to construct the timing plots were obtained from two United States Geological Survey (USGS) gaging stations. 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.

Catch per unit effort data 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. Therefore, fishwheel catch data are plotted as catch per unit effort rather than numbers of salmon. 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

ADF&G 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. 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 on 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 live salmon, by species, were recorded. Surveys conducted during periods of 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.

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 this was the period of peak occurrence of salmon within these habitats. For periods of poor or fair survey conditions, where no usable data were available, the data points were interpolated.

Timing plots were constructed for all slough and side channel study sites with the exceptions of Side Channel 10 and Mainstem 2 Side Channel these two sites were excluded because there were insufficient data to construct a complete plot.

Numbers of fish counted in Upper Side Channel 11 were not differentiated from those in Slough 11 due to sampling limitations. 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 the location of 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 from the mainstem 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, b: 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 comparing passage reach characteristics (i.e., channel morphology, substrate composition, water depths and lengths) at various mainstem discharges to chum salmon passage requirements. A flow chart of the methodology employed to evaluate passage reach conditions is 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 using standard surveying techniques of differential leveling (Bovee and Milhous 1978; Trihey and Wegner 1981, ADF&G 1983c). 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.

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 more accurate representations of water depth in the shallowest areas in the passage reach. These cross sections were located on riffles that were 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

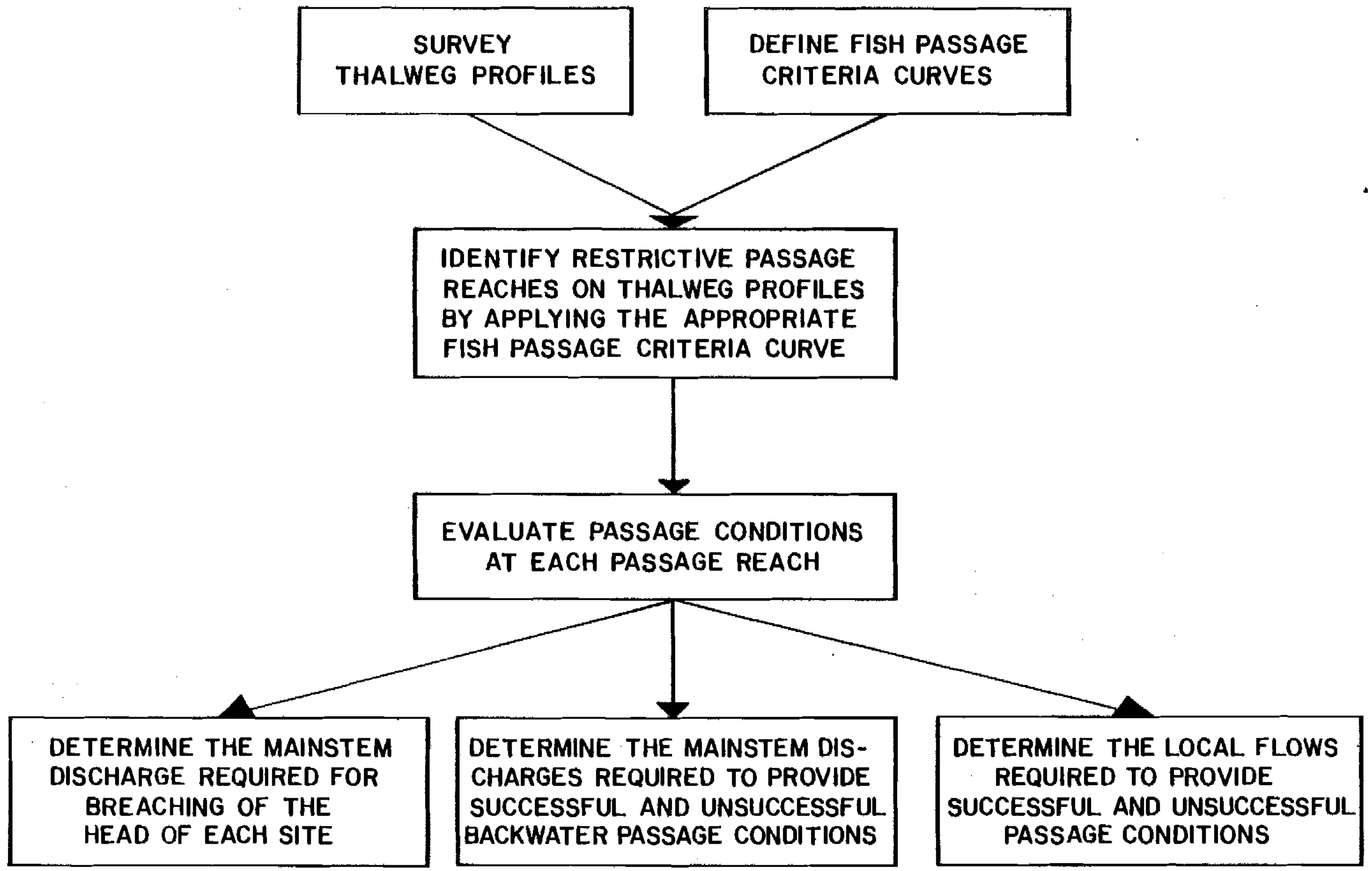

Figure 6-3. Flow chart displaying the methods employed to evaluate passage reach conditions.

conducted according to standard surveying techniques of differential leveling (Bovee and Milhous 1978; Trihey and Wegner 1981).

2.3.1.3 Stage and Flow Measurements

Stage data were generally collected over a range of local flows (low, medium and high) or local flows plus mainstem breaching discharges. However, at some sites, insufficient data were collected to evaluate the entire range of discharges. 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. Flows were measured using techniques described in ADF&G 1983d. All staff gages were surveyed to a known elevation using basic survey techniques of differential leveling 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. 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.

1) Define the necessary water depth and reach length 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 (under all 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

Several environmental variables may affect fish passage. In general, at a given passage reach the water conditions (depth and velocity) interact with conditions of the channel (length and uniformity, substrate size) to characterize the passage conditions that a particular fish encounters when attempting to migrate upstream. The likelihood of a particular fish successfully navigating through a difficult passage reach will depend upon both the environmental conditions as well as the unique capabilities of that individual fish. In turn, the capabilities of a particular fish will depend upon the unique genetic characteristics of the individual, and the amount of stresses previously encountered.

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[a].

Study Site	Staff Gage #	Staff Gage Location[b]
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)

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

[a] Additional information on these staff gage sites is presented in Quane, et al., 1984.

[b] Q site refers to a site where discharge measurements were obtained.

Thus, the process of evaluating salmon passage must account for the natural variability of the environment where fish encounter passage problems as well as the variability present in the population of migrating fish. Fish passage criteria in this study deal only with the environmental variables, mainly those which may be subject to change under with project conditions.

Two environmental variables (depth of water and length of the passage reach) were assumed to be the most significant influences affecting migrating fish in slough and side channel habitats of the middle Susitna River. This assumption was based upon field observations made in those habitats during the migrational period, at which time those habitats were often unbreached by mainstem water and were characterized by relatively low water velocities (2.0 f/s) and shallow water depths at many riffle areas. Factors of secondary importance were assumed to be substrate size, and channel uniformity.

Previous criteria used for passage elevation into slough habitats in the middle Susitna River include a single set of depth and length criteria - a depth of 0.3 feet for a length of 100 feet. Since a single set of criteria provided little guidance for evaluating longer or shorter passage reaches, a number of criteria sets were developed in the form of curves showing depth in relation reach length.

Based upon this concept of passage depth versus length of travel (i.e. passage reach) two sets of fish passage curves were developed from the results of previous work conducted by 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. Woody Trihey and Associates, and the ADF&G Su Hydro Aquatic Studies biologists. These curves were developed to reflect different substrate conditions and channel uniformity between habitats. One set of curves was developed for habitat conditions with small substrate ($\leq$3 inches diameter) and a uniform, unobstructed channel. These conditions are typical of many of the sloughs. The second set of curves was developed for sloughs and side channels with large substrates ($>$3 inches in diameter) and a non-uniform, obstructed channel. Each set of curves consisted of two lines. The upper line represented the threshold limit between successful passage and difficult passage while the lower line represents the threshold limit between difficult passage and unsuccessful passage.

The resulting criteria curves for small substrate and uniform, unobstructed channel are presented in Figure 6-4 and the curves for large substrate and non-uniform obstructed channel are presented in Figure 6-5.

Common cross-sectional depth measurements observed in the field are mean depth and thalweg depth, neither of which accurately represent fish passage conditions. Use of maximum or thalweg depth is not always an accurate indicator of passage since it often represents the depth at one location on a transect and this location may not be contiguous with the maximum depth on an adjacent upstream transect. Since neither mean depth nor thalweg depth present an accurate representation of fish

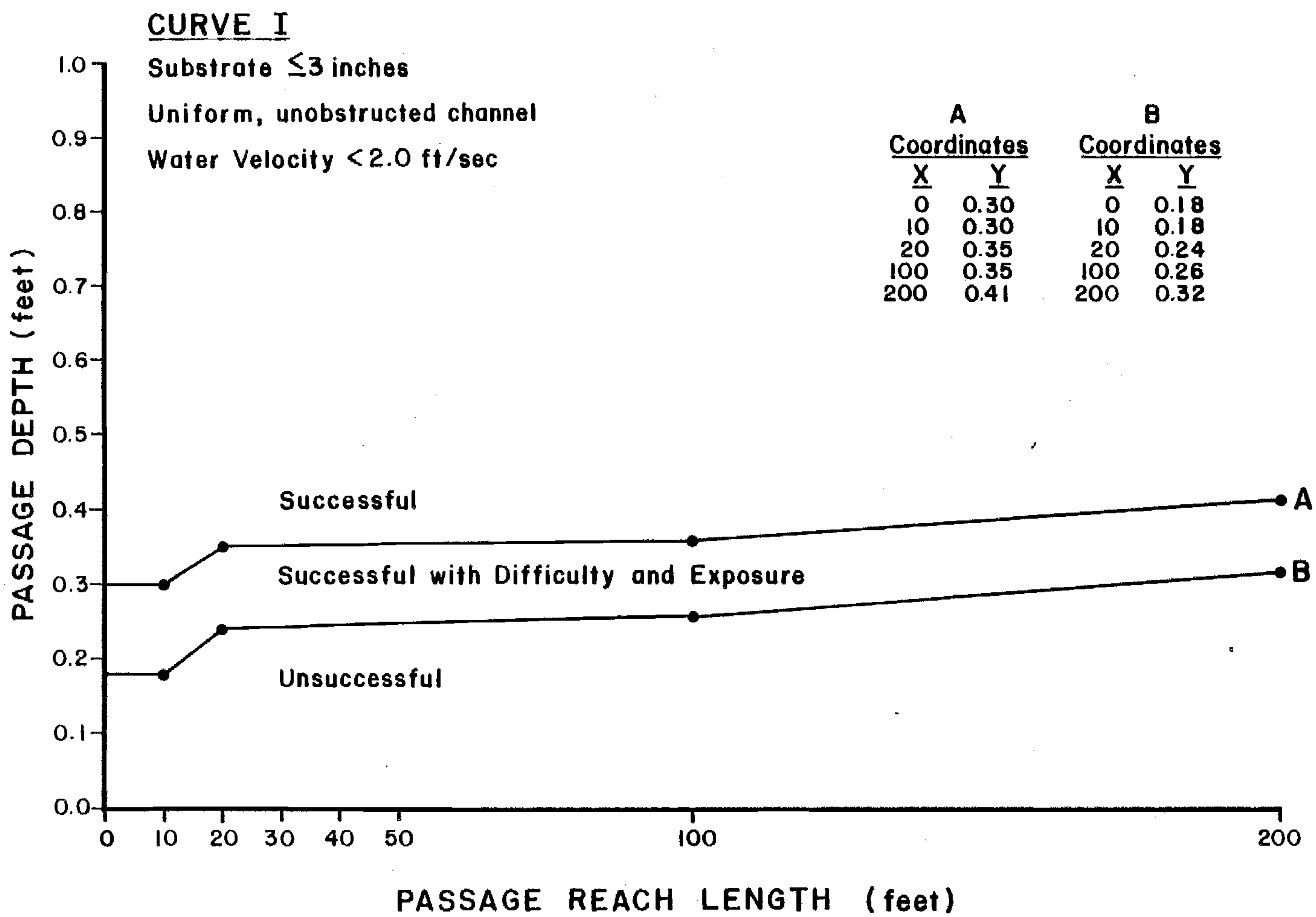

Figure 6-4. Passage depth requirements for chum salmon as a function of passage reach length within sloughs and side channels having substrates less than 3.0 inches in diameter, uniform morphology and water velocities less than 2.0 ft/sec.

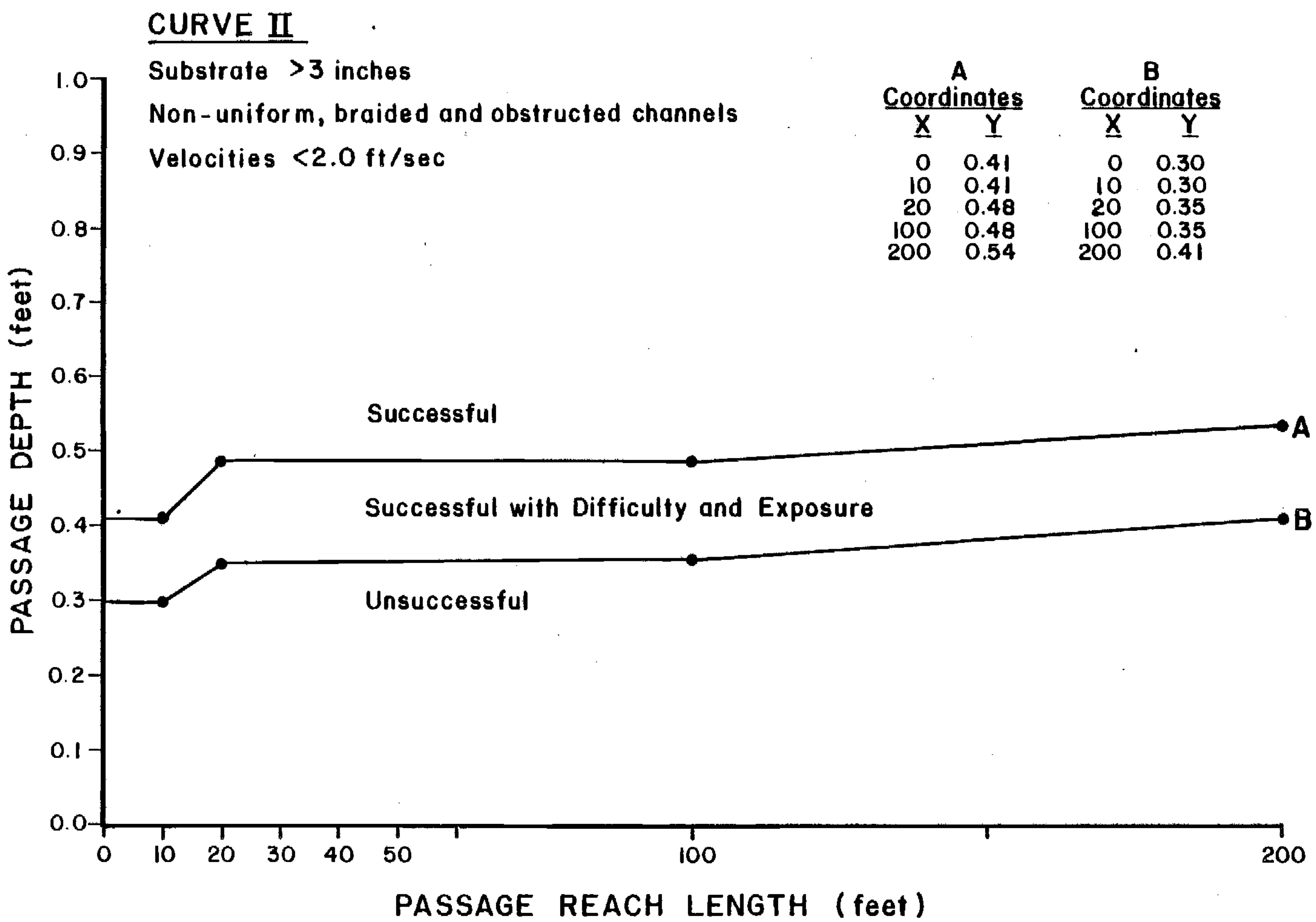

Figure 6-5. Passage depth requirements for chum salmon as a function of passage reach length within sloughs and side channels having substrates greater than 3.0 inches in diameter, non-uniform, braided and obstructed channels and velocities less than 2.0 ft/sec.

passage conditions within a particular reach of slough, a new parameter was developed - passage depth - which integrates mean depth and thalweg depth. Simply stated, passage depth is an average of the mean depth and maximum depth of a transect. Passage depth (d_p) was related to thalweg depth (d_t) by the relation $d_p = .77\ d_t^{0.909}$. The curves were developed by estimating the required thalweg depth for fish passage for a selected reach length (ranging to 500 ft). These thalweg depths were then converted to passage depths by use of the equation.

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:

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:

Condition	Passage Depth	Criteria Curves	Figure Number
Substrate ≤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 depths 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 and backwater discharges, and local flows. Breaching and backwater analyses were used to evaluate all passage reaches, whereas, the local flow analysis was used to evaluate only a subset of passage reaches which are most problematic for salmon passage. It is anticipated that the local flow analysis will eventually be applied on the complete set of passage reaches with the collection of additional information being obtained in ongoing field studies.

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 the three categories of passage conditions established (successful, successful with difficulty and exposure, or unsuccessful) were evaluated. In each analysis, the discharges and/or 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 discharge requirements for passage reaches influenced by mainstem discharge are equalled or exceeded. Although a flow duration curve of local flows is also desired, the limited historical data base 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 an evaluation of all passage reaches which were physically located in areas directly influenced by the rising stage of the mainstem Susitna River the mouth of each site (backwater

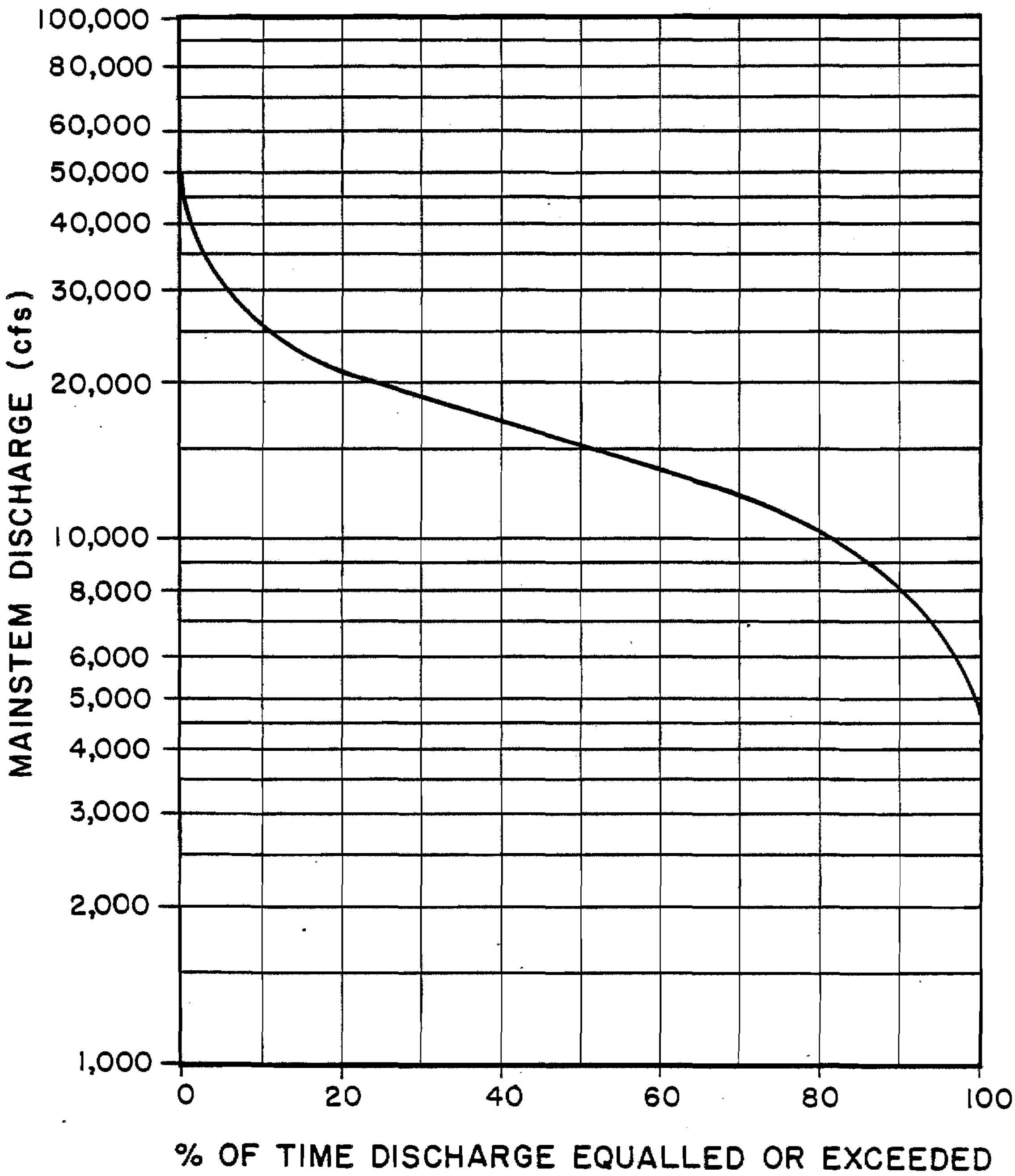

Figure 6-6. Flow duration curve depicting Susitna River discharge at Gold Creek for the salmon migrational period (20 August to 20 September). Data obtained for years 1950-1981 at gage number 1529200 of the United States Geological Survey.

area) before breaching occurs. 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 discharge at most sites, 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 or the frequency that one can expect various local flow conditions to exist.

As the water surface elevation of the backwater increases, it shortens the length of the passage reach by inundating its downstream end. Intuitively, it can be deducted that passage will be successful at a passage reach when the water surface elevation (i.e., water depth) submerges the highest thalweg elevation in the reach by a depth corresponding to successful passage for a passage reach having a length of zero feet on the appropriate criteria curves (0.35 ft and 0.50 ft for uniform and nonuniform channels, respectively). However, because of the relatively minor break in thalweg gradient at the peak elevation of many passage reaches and the relatively rapid rise in passage depth criteria for a reach length of 20 ft, the successful passage criteria for 20 ft reach lengths often requires water surface elevations greater than those for 0 ft reach length. Thus, the analysis for successful and unsuccessful passage involved computing required water surface elevations for both 0 and 20 ft reach lengths and selecting the greater of the computed values.

Six steps involved in the backwater analysis of each passage reach are presented below. A diagram outlining each of these six steps is presented in Figure 6-7.

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 in Figure 6-7A);

2) Identify the nearest surveyed point upstream (Station 3) and downstream (Station 1) of the index station (Station 2) and determine their streambed stations and true elevations on the thalweg axes (Figure 6-7A).

3) Determine which criteria curve applies to the thalweg based on substrate size and channel morphometry of the site. Assume Criteria Curve II (Figure 6-5) applies for purposes of the example depicted in Figure 6-7B.

4) Determine the depth required for successful passage for a zero reach length (0.41 ft) from Criteria Curve II (Figure 6-5). Add this depth to the index station elevation to obtain the water surface elevation required for successful passage over that point.

5) Calculate a common bed elevation (EL-5) for two points which are 20 ft apart and which are positioned on both sides of the index station. This calculation uses linear interpolation of

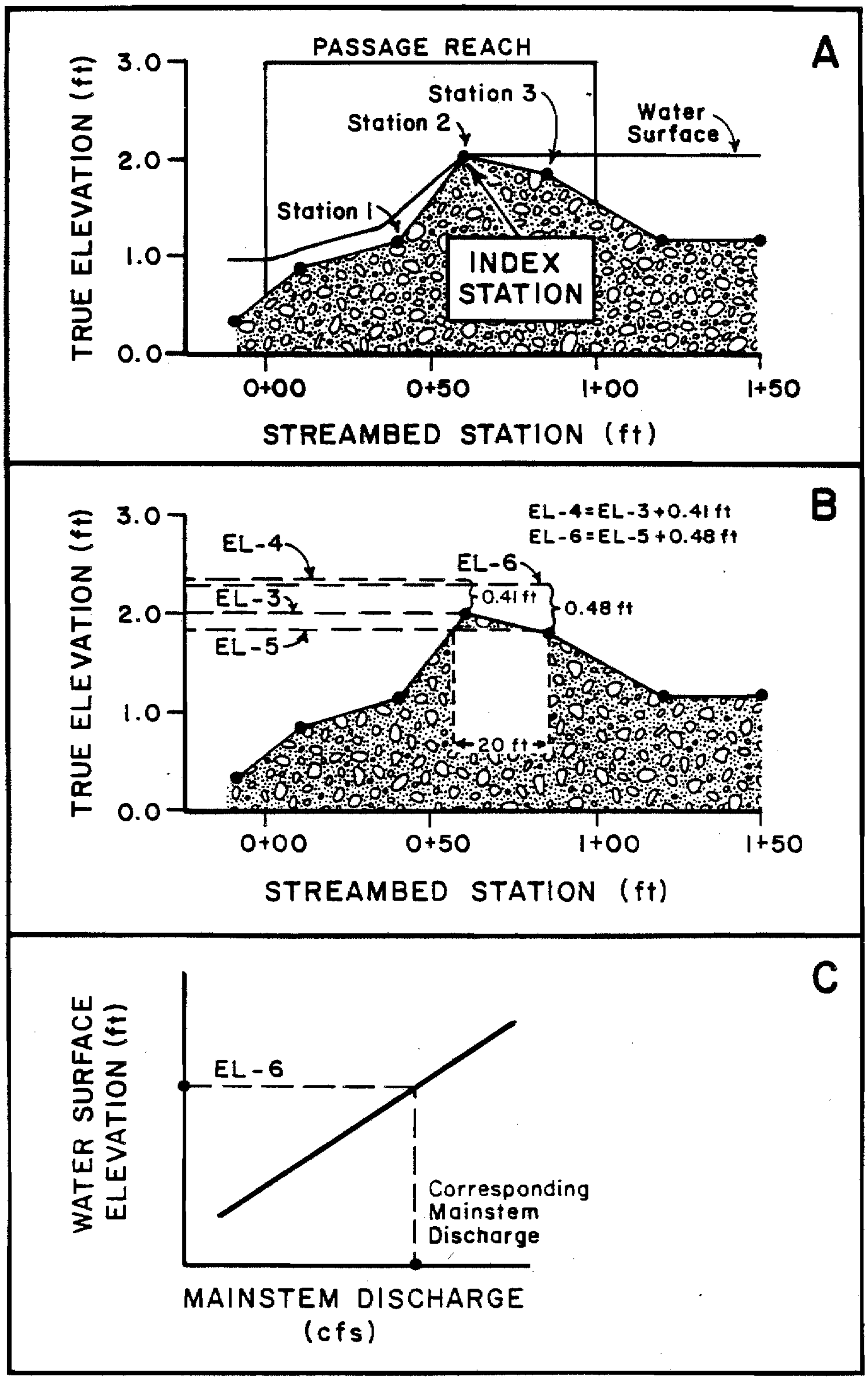

Figure 6-7. Supplement to methods for the backwater analysis.

thalweg survey data points determined for Stations 1 and 3 to define intermediate thalweg points with equal elevations. Add the depth required for successful passage for a 20-foot passage reach to this bed elevation to obtain a WSEL (EL-6 in Figure 6-7B). This new elevation is 2.28 ft (1.8 ft for EL-5 plus 0.48 ft).

6) Determine the resultant WSEL determined in steps 4 and 5 and select the larger value; and

7) Use the WSEL derived in step 6 to obtain a corresponding mainstem discharge. The mainstem discharge is calculated from a rating curve equation representing the hydraulic relationship in the mouth of the study site (Figure 6-9C). The mainstem discharge value represents the minimum discharge required to meet the threshold condition of successful passage defined in the criteria curve.

8) Repeat steps 2 through 7 for unsuccessful passage conditions.

2.3.2.3.3 Local Flow

The local flow analysis estimated the amount of local flow required at a site to provide adequate depth of flow for passage reaches within a site which are independent of backwater and breaching affects. Although the data base varied for each slough, the general approach follows the four steps outlined below:

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 that is representative of the most difficult passage condition within the reach.

3) Obtain a rating curve for each cross section; and

4) Calculate the water surface elevations (WSEL's) that correspond to the required passage depths for successful and unsuccessful passage from Step 1. Use the rating curve to match the required WSELs to the local flows necessary for successful and unsuccessful passage.

The two key items of information at each passage reach for the methods described above are a surveyed cross section and a rating curve for the cross section. Of the 74 passage reaches being evaluated in this report, 14 reaches had a surveyed cross section and a corresponding rating curve which was representative of, or assumed to be representative of, the passage reach (Table 6-2). Three other passage reaches had surveyed cross sections, but no rating curve. The remaining reaches had neither. There were 36 passage reaches which were not analyzed for

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

		Data Base at Passage Reach		Method Used				
Site	Passage Reach	Surveyed Cross Section	Rating Curve	General Approach	Aerial Photographic	Mannings Equation	Field Observations	Local Flows Not Calculated
Whiskers Creek	I				x			
	II				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	Passage Reach	Data Base at Passage Reach: Surveyed Cross Section	Data Base at Passage Reach: Rating Curve	Method Used: General Approach	Method Used: Aerial Photo-graphic	Method Used: Mannings Equation	Method Used: Field Observations	Local Flows Not Calculated
Slough 9A	I	x				x		
	II			x	x			
	III	x				x		
	IV			x	x			
	V							x
	VI							x
	VII							x
	VIII							x
	IX	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)

Table 6-2 (Continued).

Site	Passage Reach	Data Base at Passage Reach: Surveyed Cross Section	Data Base at Passage Reach: Rating Curve	Method Used: General Approach	Method Used: Aerial Photo-graphic	Method Used: Mannings Equation	Method Used: Field Observations	Local Flows Not Calculated
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			

local flow (Table 6-2) as explained in Section 2.3.2.3 (Evaluation of Passage Reaches).

In order to provide estimates of local flow required for passage while the passage reach cross sections and rating curve data are collected and analyzed, special analytical techniques were developed. For sites with surveyed cross sections but no rating curve, a technique based on Manning is equation was developed. For those sites with no cross section, a technique based on aerial photographs was developed. Descriptions of these techniques are provided in Appendix B.

The process for selecting the appropriate analytical technique is depicted schematically in Figure 6-8. At two sites (Mainstem 2 Side Channel and Slough 11), the aerial photographic coverage was inadequate for using the aerial photographic method; local flow estimates for successful and unsuccessful passage through passage reaches at these sites were provided by E.W. Trihey and Associates based on field observations. Table 6-2 indicates the method used for analysis for each passage reach analyzed during this phase of the study.

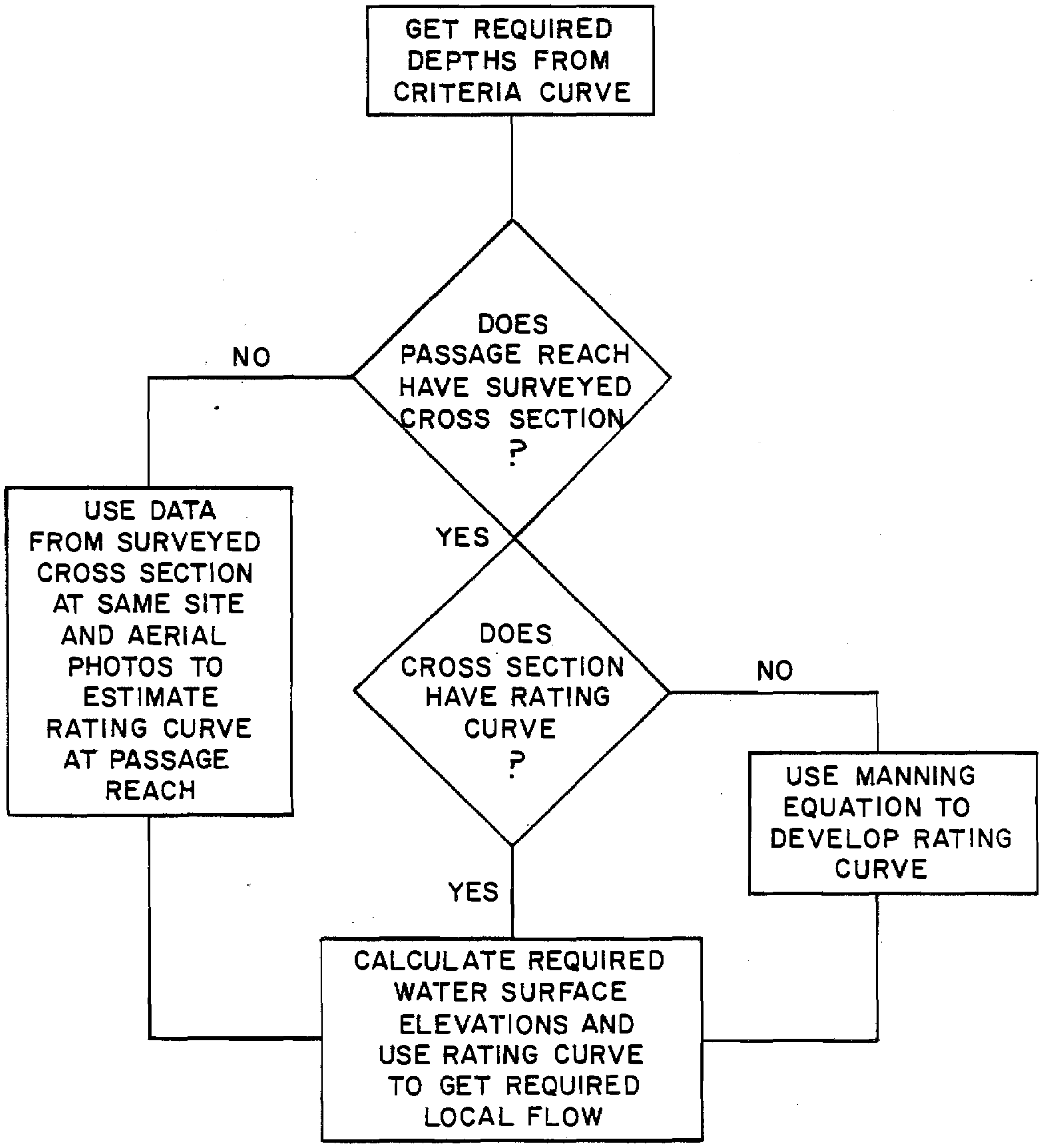

Figure 6-8. Flow diagram depicting the process for selecting methods employed in the local flow analysis.

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 6-9 to 6-11. 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 61,000 cfs at the Talkeetna and Curry fishwheels (Gold Creek gaging station). The 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. However, migrations for both these species slightly preceded those of chum salmon.

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 6-12 and 6-13. 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 occur between mid August and late September over the three year period. Generally, chum salmon are more prevalent in late July and early August while larger numbers of sockeye appear in late August through September. Sloughs 8A, 9, 11 and 21 account for the majority of chum and sockeye salmon which spawn in slough habitats evaluated in this study.

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 appropriate thalweg profile (Appendix E) and selected physical characteristics of each reach are 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).

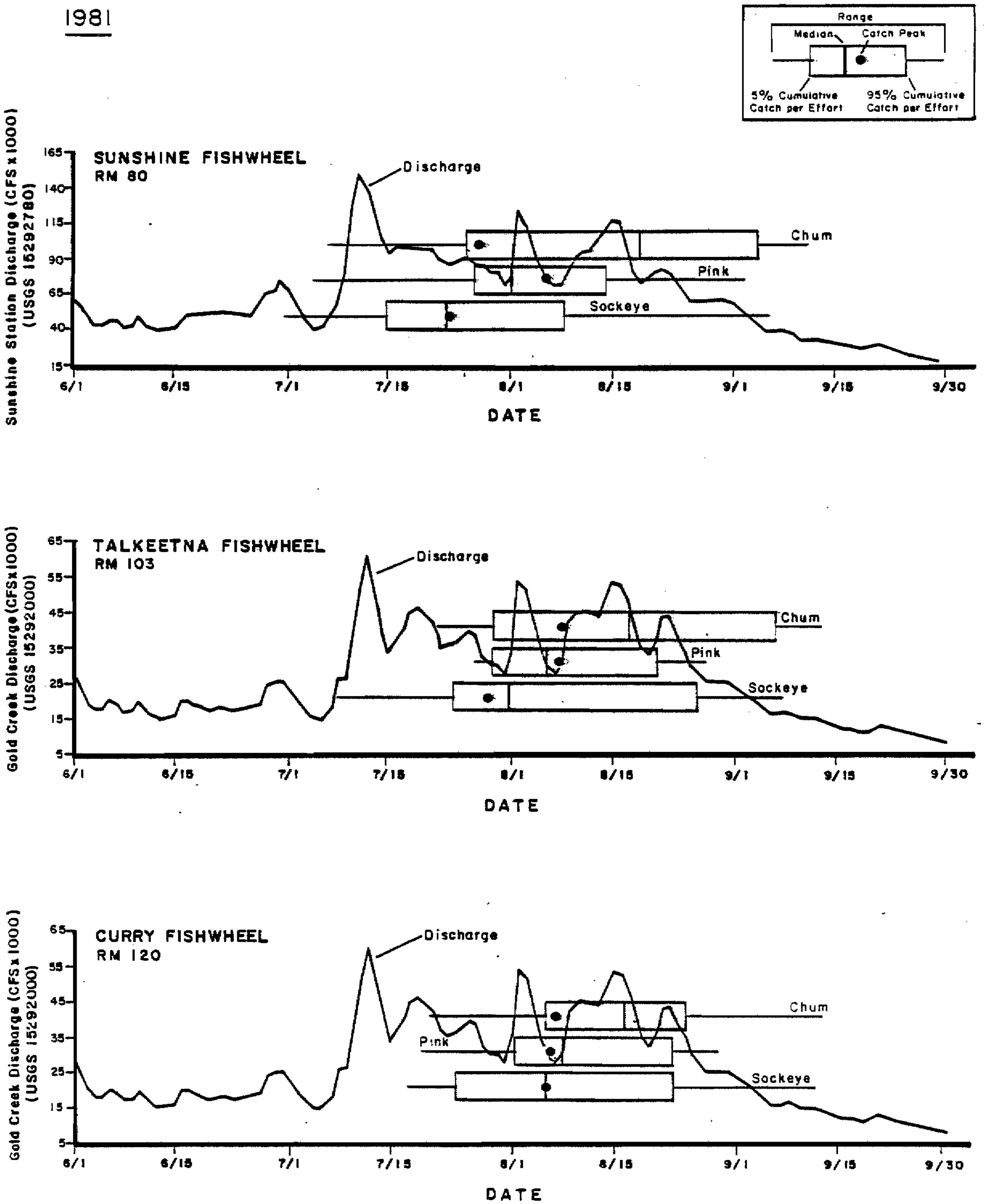

Figure 6-9. Timing plots showing peak occurrence of chum, pink and sockeye salmon migration at mainstem Susitna River fishwheel sites, 1981. (Note: first run sockeye salmon not included).

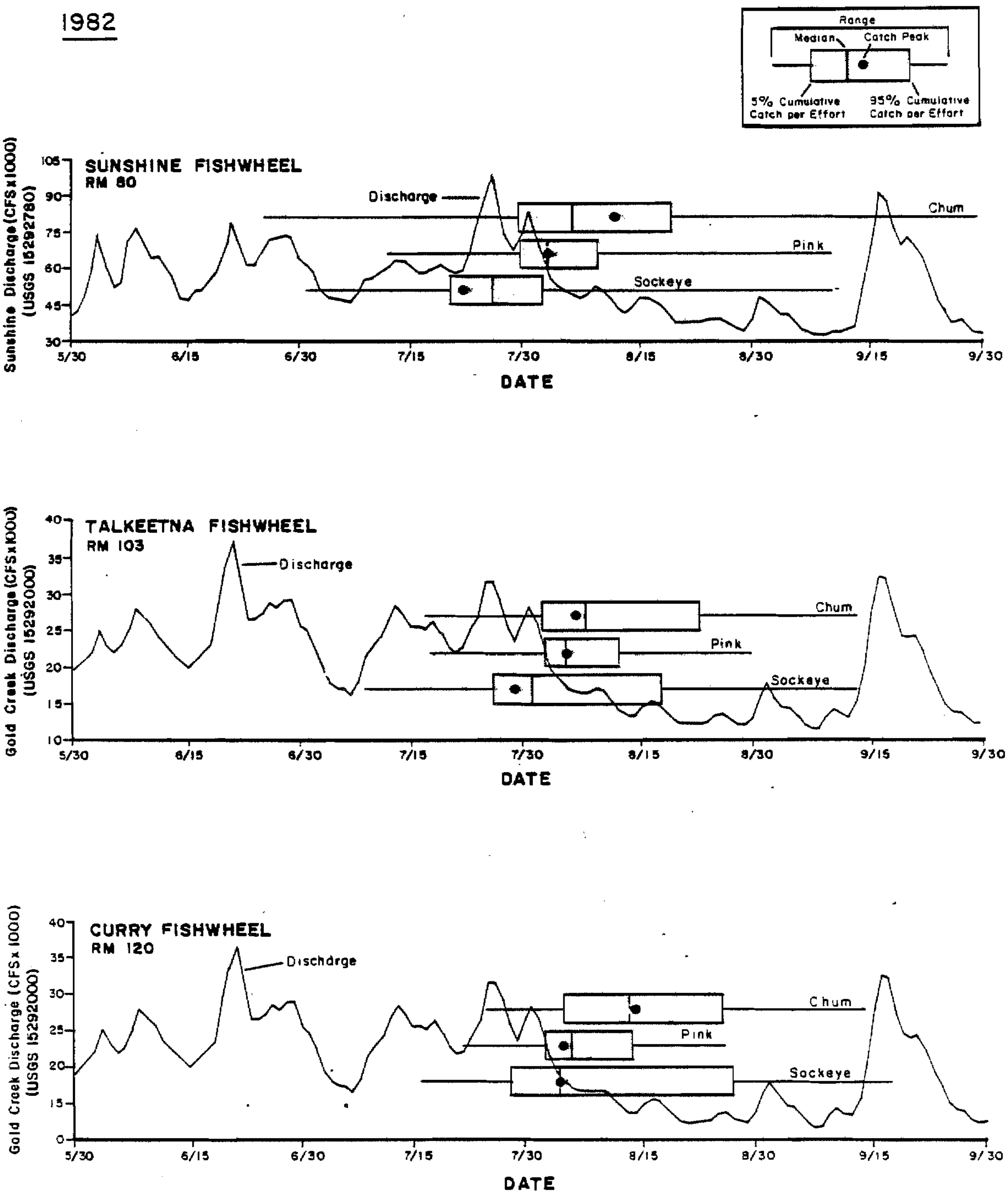

Figure 6-10. Timing plots showing peak occurrence of chum, pink and sockeye salmon migration at mainstem Susitna River fishwheel sites, 1982. (Note: first run sockeye salmon not included).

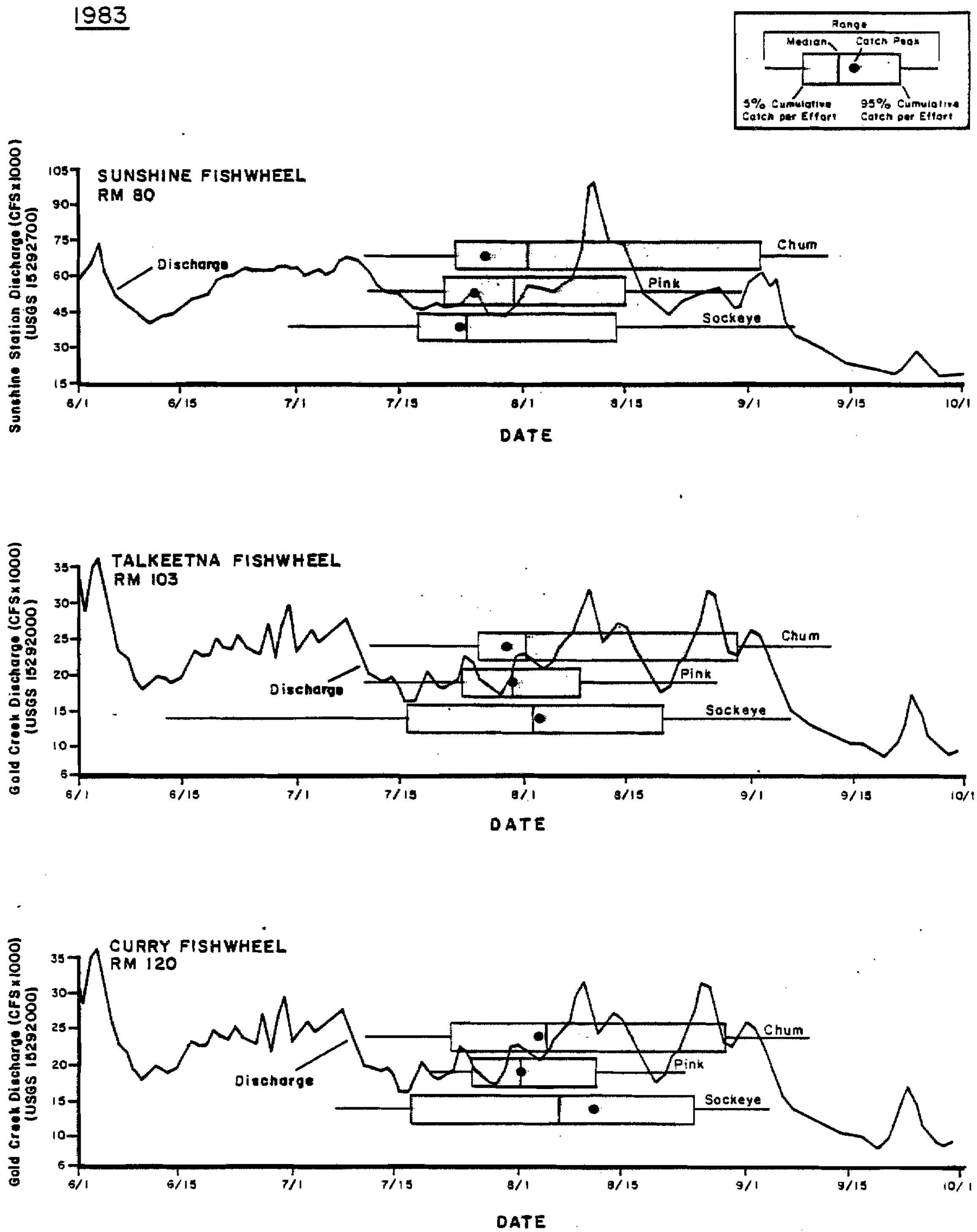

Figure 6-11. Timing plots showing peak occurrence of chum, pink and sockeye salmon migration at mainstem Susitna River fishwheel sites, 1983. (Note: first run sockeye salmon not included).

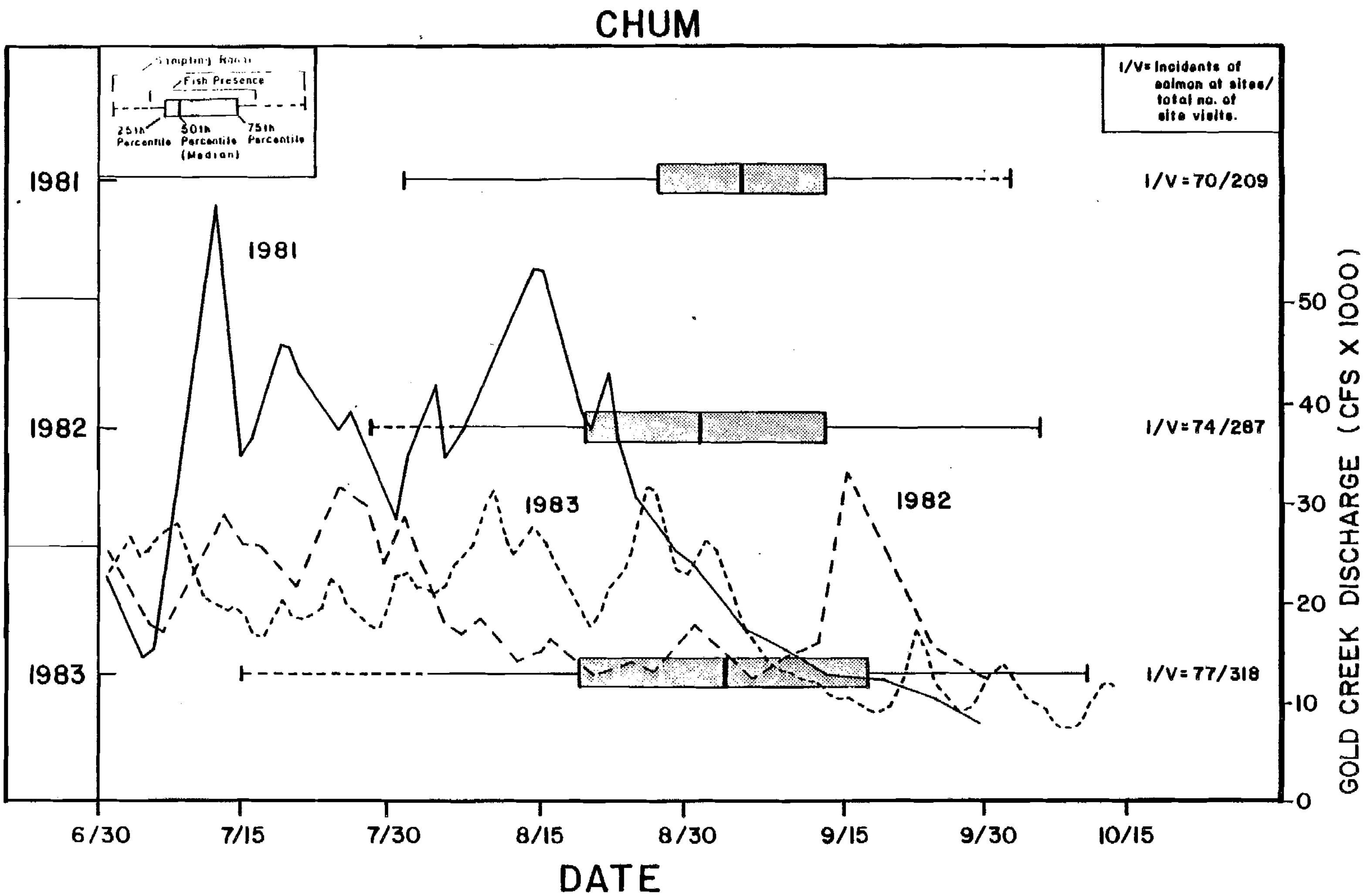

Figure 6-12. Peak periods of chum salmon presence in relation to mainstem Susitna River discharge in slough and side channel study sites, 1981, 1982, 1983.

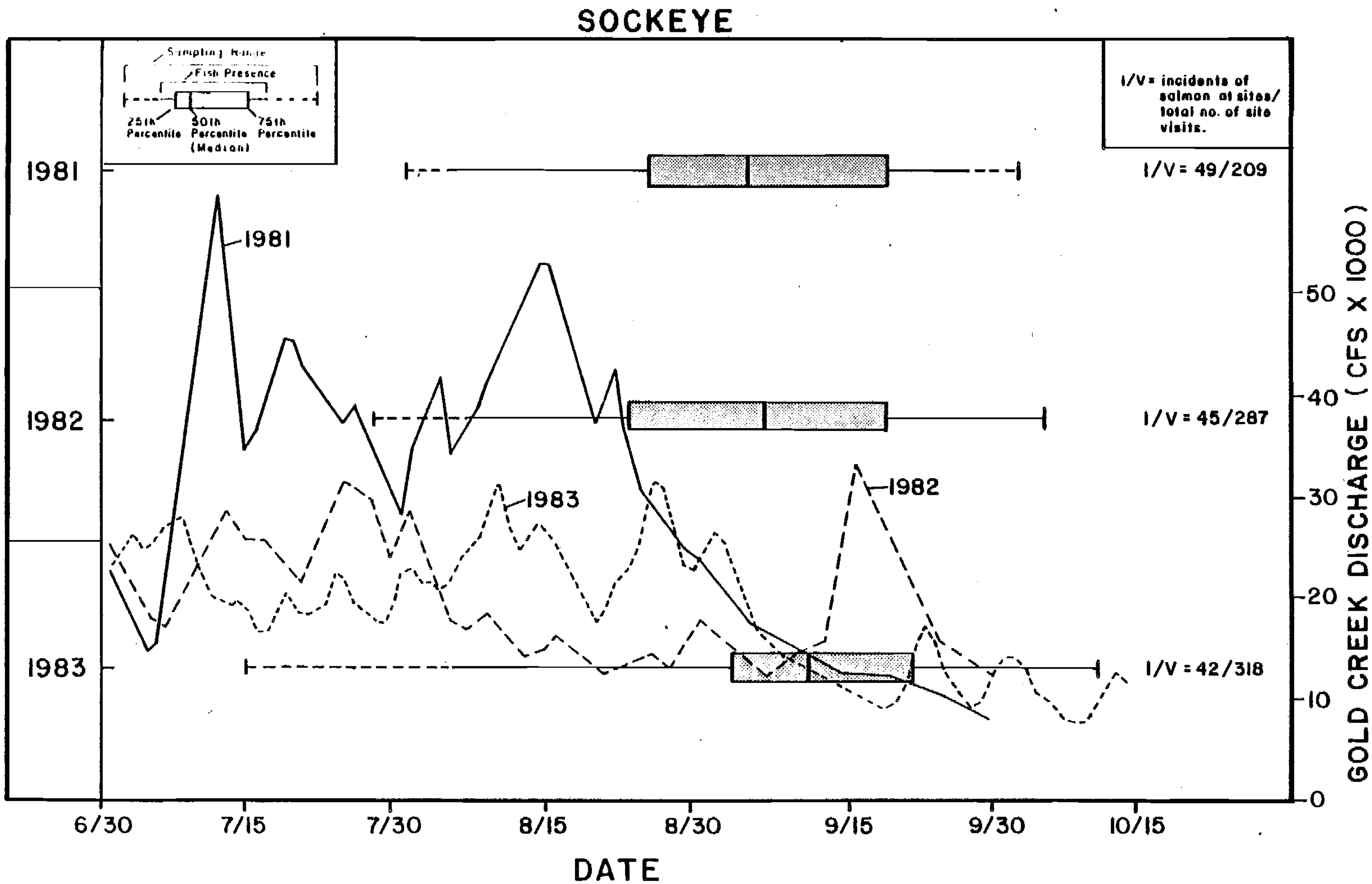

Figure 6-13. Peak periods of sockeye salmon presence in relation to mainstem Susitna River discharge in slough and side channel study sites 1981, 1982, 1983.

Table 6-3. Dates and counts of peak escapement of chum and sockeye salmon observed in selected sloughs in the middle Susitna River during 1981, 1982 and 1983 (Data derived from ADF&G 1981b; 1983c; Barrett et al., 1984).

		Chum Salmon						Sockeye Salmon					
		1981		1982		1983		1981		1982		1983	
Site	River Mile	Date/No. Fish		Date/No. Fish		Date/No. Fish		Date/No. Fish		Date/No. Fish		Date/No. Fish	
Whiskers Creek Slough[a]	101.2	--		--		--		--		--		--	
Mainstem 2 Side Channel[a]	114.5	--		--		--		--		--		--	
Slough 8A	125.3	9/4	(330)	8/23	(307)	8/30	(34)	9/4	(170)	8/12	(68)	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[a]	133.8	--		--		--		--		--		--	
Slough 11 Complex[b]	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[c]	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)	--		--		--	

[a] Complete survey data are not available for determining peak counts of chum and sockeye salmon in these sites of these three sites chum salmon have been observed only at Mainstem 2 Side Channel.

[b] Includes fish from Slough 11 and Upper Side Channel 11.

[c] Includes fish from Slough 21 and Side Channel 21.

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. (Derived from data presented in ADF&G 1981b; 1983c; Barrett et al., 1984).

		Percent Distribution											
	River	1981			1982			1983			Average		
Location	Mile	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	a	0.2	0.0	b	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	b	b	0.0	0.0	b	b	7.8	0.0	0.0	5.2	0.0	0.0

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

b = Insufficient data.

Table 6-5. Selected physical characteristics of passage reaches at the time thalwegs were surveyed at each site[a].

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

(Continued)

Table 6-5 (Continued).

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

(Continued)

Table 6-5 (Continued).

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

[a] Mainstem discharge values are from data collected at the United States Geological Survey gaging station at Gold Creek. Mainstem discharges correspond to date of survey and do not necessarily reflect base flow conditions at each site.

3.2.1 Breaching and Backwater Discharges

Mainstem discharges and corresponding percent exceedence values that are required to provide successful and unsuccessful salmon passage conditions at selected spawning sites are summarized 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.

Table 6-6. Summary of mainstem discharges required to provide successful and unsuccessful salmon passage conditions at selected spawning sites in the middle Susitna River, Alaska, 1983[a].

		BREACHING ANALYSIS (CFS)				BACKWATER ANALYSIS[a] (CFS)					
Site (River Mile)	Passage[b] Reach	Initial Breaching Discharge	Exceedence %[c]	Controlling Discharge	Exceedence %[c]	Unsuccess-ful	Exceedence %[c]	Success-ful	Exceedence %[c]	Criteria Curve Used	Staff Gage Used
Whiskers Creek Slough	I	22,000	16	23,000	14	22,500	15	d	-	II	101.2W1
(101.2)	II	22,000	16	23,000	14	d	-	d	-	II	-
	III	22,000	16	23,000	14	d	-	d	-	II	-
Mainstem 2	I	12,000	71	16,000	45	11,500	74	12,200	70	I	114.6W6
Side Channel	II	12,000	71	16,000	45	d	-	d	-	I	-
(114.4)											
	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[e]	I	27,000	7	27,000	7	< 10,600	79	< 10,600	79	I	125.3W5
(125.9)	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	I	16,000	45	19,000	29	< 12,000[f]	71	< 12,200[f]	70	I	128.3W3
(128.3)	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	I-X	No data		No data		No data		No data		-	-
(133.6)											

(Continued)

Table 6-6 (Continued).

Site (River Mile)	Passage Reach[b]	BREACHING ANALYSIS (CFS) Initial Breaching Discharge	Exceedence %[c]	Controlling Discharge	Exceedence %[c]	BACKWATER ANALYSIS[a] (CFS) Unsuccess-ful	Exceedence %[c]	Success-ful	Exceedence %[c]	Criteria Curve Used	Staff Gage Used
Side Channel 10	I	19,000	29	19,000	29	17,400	37	18,200	33	I	133.8W5
(133.8)	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	I	42,000	1	42,000	1	15,200	50	16,200	44	I	135.3W1
(135.3)	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	I	13,000	65	16,000	45	11,400	75	12,400	68	I	136.2W3
Channel 11	II	13,000	65	16,000	45	d	-	d	-	II	-
(136.1)	III	13,000	65	16,000	45	d	-	d	-	II	-
Slough 20	I	22,000	16	23,000	14	20,800	21	22,100	16	II	140.1W4
(140.1)	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	I	9,200	85	12,000	71	<12,000[f]	71	<12,000[f]	71	II	No Gage
(140.6)	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[b]	BREACHING ANALYSIS (CFS) Initial Breaching Discharge	Exceedence %[c]	Controlling Discharge	Exceedence %[c]	BACKWATER ANALYSIS[a] (CFS) Unsuccessful	Exceedence %[c]	Successful	Exceedence %[c]	Criteria Curve Used	Staff Gage Used
Slough 21	I	23,000	14	25,000	10	d	-	d	-	II	142.0W5
(141.8)	II L	23,000	14	25,000	10	d	-	d	-	II	-
	II R	26,000	14	No Data	-	d	-	d	-	II	-
Slough 22	I	20,000	24	23,000	14	< 23,000[f]	14	< 23,000[f]	14	II	144.3W3
(144.2)	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	-

[a]This analysis assumes that local flows are negligible.

[b]Left and right channels of sites (facing upstream) are indicated as "L" and "R", respectively.

[c]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).

[d]Influence of backwater was not evaluated since breaching occurs at discharges lower than those required for providing backwater influence.

[e]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.

[f]Backwater rating curve not defined below the indicated (or preceeding) table value.

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[b]	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)

Table 6-7 (Continued).

Site	River Mile	Passage Reach: Number	Passage Reach: Length (ft)	Successful Conditions: Passage Depth (ft)	Successful Conditions: Local Flow (cfs)	Unsuccessful Conditions: Passage Depth (ft)	Unsuccessful Conditions: 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[b]	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	2,639	.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

[a] Values not determined

[b] Discharge values obtained by observation (personal communication, E.W. Trihey).

4.0 DISCUSSION

4.1 Assumptions and Limitations of Analyses

4.1.1 Passage Criteria Assumptions and Limitations

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

1. All passage reaches can be described as either uniform, straight channels with small substrate, or as 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. Existing 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. This assumption is a simplification. Velocities occasionally approach 4 fps in the middle of some side channels during high mainstem discharges; 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 appear 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 using repeated field observations. 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 while others relate to the method of analysis. The general assumptions which apply to all analytical methods are as follows:

1. The channel geometry at cross section locations does not change with varying discharge. No erosion or deposition occurs over the study period.

2. Reach lengths remain 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 can be applied at all cross sections.

The first assumption appears 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 stable long-term, system. Erosion and deposition would be approximately in equilibrium 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 be used in an attempt to provide refinement and verification of this assumption.

4.1.2 Analytical Assumptions and Limitations

The breaching analysis assumes that when breaching occurs, passage is successful throughout the slough. This assumption appears justified based on repeated field observations. When a slough is breached, sufficient volumes of water are present to permit fish access throughout the slough.

In the backwater analysis, it is assumed that local base flow is 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.

Five assumptions are made specifically for the analysis of the local flow. These are:

1. Slough flow is constant throughout the length of the slough unless data exist for 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; that is Manning's 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 appears justified by field experience. Unless the data indicate a change in slough flow, the effect of upwelling is considered negligible. Additional data will be used in an attempt to refine this assumption in the FY85 report on fish passage.

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 natural variations in mainstem discharge from year to year during the salmon spawning migration period do not affect the overall timing of salmon arrival at the mouth of slough and side channel spawning sites. Fishwheel catch rates of salmon show that peak periods of migrational activity in the mainstem occurred at approximately 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. However, survey counts (conducted at these same sites) during the three year period show that there are fluctuations in the numbers of salmon within these sites from year to year. This suggests that although present mainstem discharges may not affect the time period when salmon arrive at those sites, they may affect the numbers of salmon that are able to successfully spawn in portions of the slough due to passage restrictions. Fluctuations in the numbers of salmon observed at study sites may also be attributed to year to year variations in escapement.

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 discharge of 23,000 cfs. However, this discharge only occurs 14 percent of the time during the critical spawning period. There are no backwater effects on these passage reaches at mainstem discharges below the breaching discharge. Relatively high local flow estimates of about 18 cfs are required for successful passage at Passage Reaches I and II. These flows probably occur frequently due to the input of flow from Whiskers Creek which is the primary water source for providing successful passage conditions within the slough under unbreached conditions.

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 ranging in lengths from 80 to 510 feet, were identified in this slough. Successful passage conditions occur at all passage reaches when the head of the northeast channel becomes breached at a controlling discharge of 33,000 cfs. Successful passage conditions occur at the three lowermost passage reaches at a controlling 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 (Quane, et al., 1984). This flow is primarily maintained by surface runoff and groundwater sources. Estimates of local flow requirements for passage reaches 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 spawning habitat for relatively smaller proportions of sockeye and pink salmon. Within this slough, the distribution of adult spawners of each species are restricted to the lower half of the slough because the upper half is largely dewatered under non-breached conditions.

A total of five passage reaches, ranging in lengths from 30 to 3,140 feet, were identified in this slough. 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 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 and 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 passage 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 to provide passage depth.

4.3.1.4 Slough 9A

Chum salmon are 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, however, their distribution is limited to 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 to the entire slough during 1981, 1982 and 1983, it appears that they are able to surmount all passage reaches under natural flow conditions to provide passage depth.

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 this 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 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 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 (Barrett, et al., 1984). Only a few, apparently incidental, sockeye salmon have been observed at this site. Distribution of salmon is limited to 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 I 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 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 fish are able to continue upstream and spawn in pools that later become shallow isolated pools when breaching flows subside.

Three passage reaches ranging in lengths from 30 to 2,080 feet were identified in this slough. 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 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 were 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 (Barrett, et al., 1984). 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 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 primarily 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 IIIL (located in the left channel) have successful passage conditions at a controlling 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 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 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 discharge of 19,000 cfs in the mainstem Susitna River.

Passage Reaches I and II are affected by backwater at discharges below the controlling discharge. Successful passage conditions due to backwater influence occur at Passage Reach I at a mainstem discharge of 18,200 cfs. However, the backwater influence on Passage Reach II is not sufficient to provide successful passage conditions 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 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 into the side 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 (Quane, et al., 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 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 (Quane, et al., 1984).

4.4 Previous Studies: Comparison of Results

Upstream passage of adult salmon into selected slough habitats in the middle Susitna River has been previously evaluated in two reports (Trihey 1982; ADF&G 1983b). These reports used a conceptually similar approach as used in the present study but differed in scope, methods employed and terminology used (Table 6-8). The earlier of the two reports (Trihey 1982) only evaluated two passage reaches in the mouth of Slough 9 where adult chum salmon were observed to have passage difficulty. In that report, the consideration of passage included only the question of access of adult salmon into the mouth of the slough and viewed passage as a threshold phenomenon in which conditions were evaluated as either a "problem" to fish access or "no restriction" to fish access. In spite of these limitations, the study was valuable for two primary reasons: 1) it provided emperically based depth criteria for passage requirements of chum salmon (0.3 ft for reach lengths $\leq$100 ft), and 2) it focused attention on the need to evaluate passage in greater detail.

In the second report ADF&G evaluated passage conditions into 9 sloughs, including a reevaluation of Slough 9 (ADF&G 1983b). In four of the nine sloughs, the methods employed were similar to those presented in Trihey (1982). For the other five sloughs a less labor-intensive method was employed, using available cross sectional data obtained in the mouth reaches of each site (for methods refer to ADF&G 1983b). As in the earlier report, mainstem Susitna River discharges were provided for two threshold conditions at the restrictive passage reach at the mouth of each slough. The threshold conditions evaluated were described as "acute" and "unrestrictive" for access and essentially described the same condition reported in Trihey (1982).

The results of the second report (ADF&G 1983b) significantly expanded the data base regarding access conditions in the mouths of slough habitats. However, there were conceptual and operational difficulties during the evaluation process used in determining threshold passage conditions. One such difficulty was that the "threshold" concept of passage was insufficient to represent the passage conditions which actually exists at study sites. Conceptually, the "threshold" concept was deficient in that it failed to account for conditions that occurred between acutely restrictive and unrestrictive conditions. Operationally, the concept was difficult to apply because the criteria were defined for a single depth/reach length (i.e. 0.3 ft depth and 100 ft reach length). Additionally, the criteria were difficult to apply to conditions in which the length of reach changed with increasing mainstem stage. In light of the conceptual and operational difficulties of the previous reports, the approach undertaken in the present report was modified to account for the continuum of depth/length combinations encountered at various passage reaches (refer to Figures 6-4 and 6-5). In addition, the present report expands the analyses of passage within a site beyond the consideration of backwater, to include the effects of breaching mainstem discharges and local flows. Finally, the present report was expanded in scope to include the side channel sites which were not evaluated in previous studies.

In spite of the differences in scope, methods and terminology, the results from the two previous passage reports are in general agreement for most sites with the findings in this chapter. Table 6-8 provides a comparison of the results of the three passage studies (Trihey 1982, ADF&G 1983b, and the present study) for seven sloughs evaluated in the middle Susitna River. In one of the seven sloughs for which data is reported (Whiskers Creek Slough), passage reaches were identified and evaluated at different locations on the thalweg; therefore results are not directly comparable. Of the remaining six sloughs, only one (Slough 9) was evaluated in each of the three reports.

Generally, the differences between reports are smaller for estimates of mainstem discharges which provide successful (or unrestricted) passage conditions. This general trend is likely to be a result of rating curves being better defined for discharges in the higher ranges.

In general, where discrepancies in the results occur, it should be assumed that the results of the present study are more reliable than that in previous reports. This assumption cannot be verified at the present time, but is in part substantiated by the combined results reported for Slough 9. The same two passage reaches were evaluated at Slough 9 in each of the three reports. For both passage reaches in Slough 9, the discharge estimates for successful and unsuccessful passage conditions reported in the present study are bracketed by the values reported in the previous two reports. We believe that this suggests that the values presented in this chapter are refinements of those reported previously.

The largest discrepancy in reported values occurred in Slough 11. This difference is most likely related to the differential effects of dual flow on the estimates in both the ADF&G 1983b report and this chapter. In this report, attempts were made to eliminate the effects of local flow in the backwater analysis. However, in the previous report (ADF&G 1983) local flows were included in the backwater analysis. Thus, one

Table 6-8. Comparison of results of the present passage study to results of previous reports involving sloughs in the middle Susitna River.

Location	Passage Reach	Present Study Unsuccessful	Present Study Successful	ADF&G 1983b Acute	ADF&G 1983b Unrestricted	Trihey 1982 Acute	Trihey 1982 Unrestricted
Whiskers Creek	1	22,500	23,000[a]	b	b	b	b
Slough	1	b	b	8,000	10,000		
Slough 8A	1	< 10,600[e]	10,600	7,860[d]	12,000[d]	b	b
	2	14,600	15,600	12,000[d]	16,000[d]	b	b
Slough 9	1	12,000	12,200	< 12,500	12,500[d]	10,000	12,000
	2	16,000	19,000[a]	18,000	20,000	12,000	18,000
Slough 11	1	15,200	16,200	c	6,700	b	b
Slough 20	1	20,800	22,100	20,000	21,500	b	b
Slough 21	1	23,000[a]	25,000[a]	b	b	b	b
	2	23,000[a]	25,000[a]	20,000	23,000	b	b
Slough 22	1	< 23,000	23,000	20,000	22,500	b	b

[a] Breaching occurs at discharges lower than those required for providing backwater influence. Initial breaching and controlling discharges are provided for unsuccessful and successful conditions, respectively.

[b] Site not evaluated.

[c] Insufficient data.

[d] Data derived from report text, not summary Table B-5.

[e] Backwater rating curve not defined below the indicated table value.

would expect the estimated flows to be greater in the present study. The amount of difference between the estimates should depend, in part, on the relative amount of local flow contribution. In Slough 11, the local flow is relatively large, and its affect may be compounded by the restricted channel width of the slough.

The second largest discrepancy is reported for unsuccessful (Acute) conditions in Slough 9. Trihey (1982) reports the lowest value (12,000 cfs) and ADF&G (1983b) the highest (18,000 cfs). Since the present study is in reasonably close agreement with the value reported in ADF&G (1983b) it is likely that the 12,000 cfs estimate reported in Trihey (1982) is not reliable.

All other reported differences do not exceed 3,000 cfs. In the case of Slough 8A, the estimate reported for acute passage conditions in ADF&G (1983b) is probably more realistic than the one reported in the present study. This discrepancy is due to the lack of definition of the rating curve for the backwater gage used in this study in the mouth of Slough 8A. This same reasoning applies to the discrepancy for unsuccessful passage conditions in Slough 22.

5.0 SUMMARY AND CONCLUSIONS

5.1 Summary

5.1.1 Mainstem Influence

The mainstem Susitna River influences salmon passage conditions in two ways. The most obvious influence occurs when the head of a slough or side channel becomes 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 backwater pools. 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 conditions influence only the initial few passage reaches (generally one or two per site), yet regulate the movement of salmon into the entire slough or side channel from the mainstem river. In contrast, local flows can influence a greater number of passage reaches than backwater within a site, but usually do not influence passage from the mainstem site into the slough or side channel. 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). These factors may vary concurrently, providing a shift in the relative importance of factors affecting passage conditions.

5.1.2 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 than side channels. Local flow in sloughs appears to be adequate to provide successful passage conditions at many passage reaches if fish are able to access the slough from the mainstem. However, the effect of local flow varies among sites as discussed previously. In side channels, local flows are less important for providing successful passage conditions, whereas breaching becomes relatively more important. Local flow is relatively less important in these habitats because they generally have no adjoining tributaries and have less upwelling groundwater.

5.2 Conclusions

5.2.1 Timing and Distribution of Salmon

1. Salmon use the mainstem Susitna River primarily as a migrational corridor to reach their natal spawning grounds in slough and side channel habitats in the middle reach of the Susitna River basin.

2. Overall timing of salmon migration to the mouth slough and side channel spawning sites appears to be independent of mainstem discharge under present flow regimes.

3. The critical spawning period for chum salmon in the middle Susitna River occurs from 20 August to 20 September.

5.2.2 Passage of Salmon

1. Passage conditions at a particular slough or side channel in the middle Susitna River are influenced by breaching and, backwater effects of mainstem discharge and local flow conditions.

2. Breaching discharges are relatively more important in providing successful passage conditions within side channels than in sloughs.

3. Local flows are relatively more important in providing successful passage conditions within sloughs than in side channels.

4. Backwater may be the dominant factor in providing successful passage conditions from the mainstem into some slough or side channel sites. 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. The effects of local flow vary widely but appear to provide successful passage conditions at a majority of passage reaches within slough habitats if fish are able to access the site from the mainstem. 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.

6. 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.

7. Insufficient data are available to project the influence of mainstem discharge on sources of local flow such as upwelling during unbreached conditions. This information is required to refine the analyses.

8. Duration analyses of local flow conditions are also required to refine these analyses. That is, the significance of a local flow condition is dependent on the frequency that the flow can be expected. Although insufficient data are presently available for this type of analysis, attempts will be made to execute this or a similar analysis in FY85.

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 with the potential of reducing the level of successful spawning 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.

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10. Appendices

Appendix 6-A

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.

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 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 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 side channel have different controlling discharges. The controlling 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 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 inwith 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 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 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 breaching and controlling 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.

<u>Slough 11 - RM 135.3</u>

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 breaching and controlling discharge of approximately 42,000 cfs. The slough was last observed breached in 1981.[a] 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.

<u>Upper Side Channel 11 - RM 136.0</u>

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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[a] 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 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 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 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 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 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 groundwater 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.

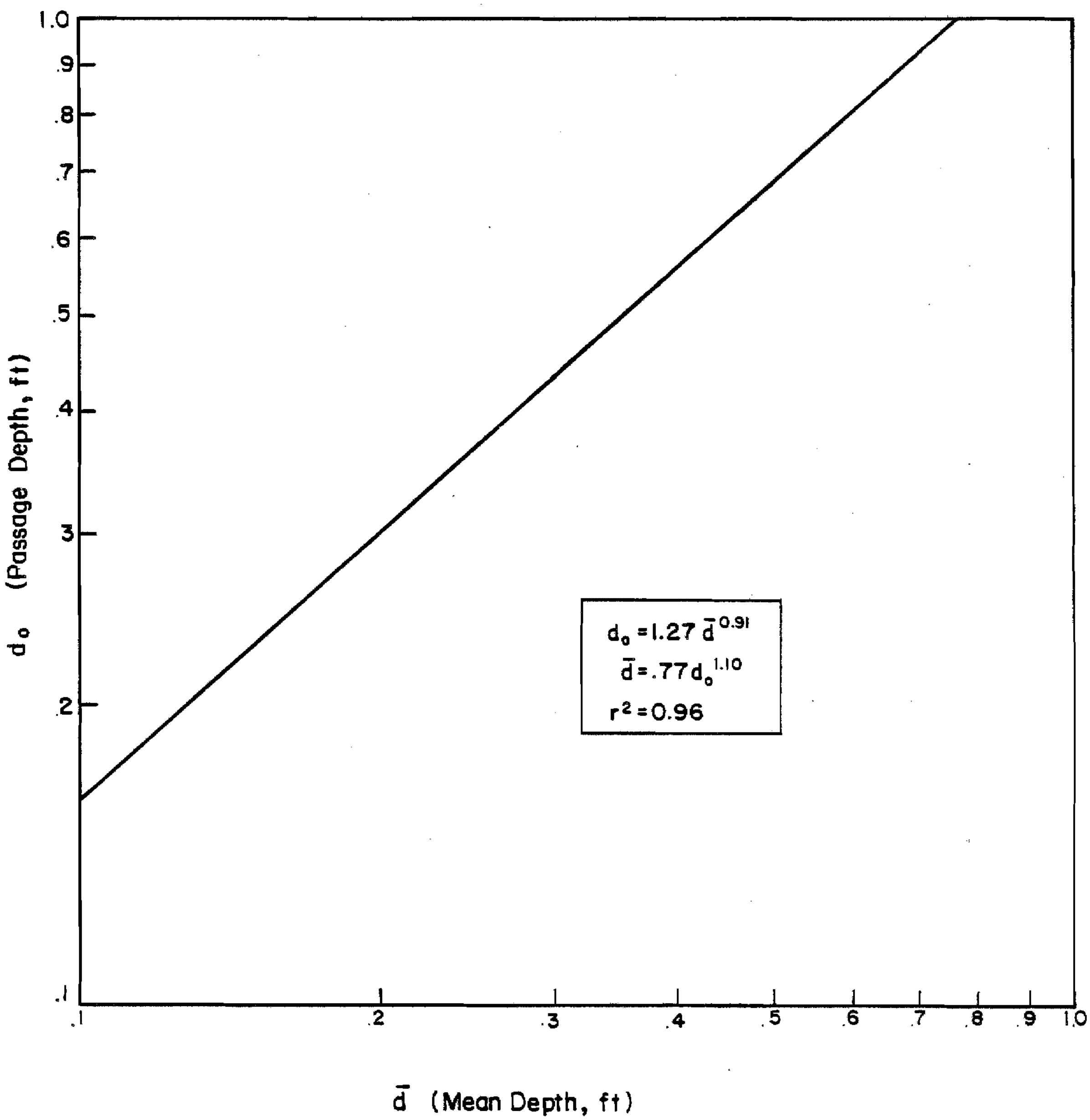

Figure 6-B-1. Relationship between mean depth and passage depth.

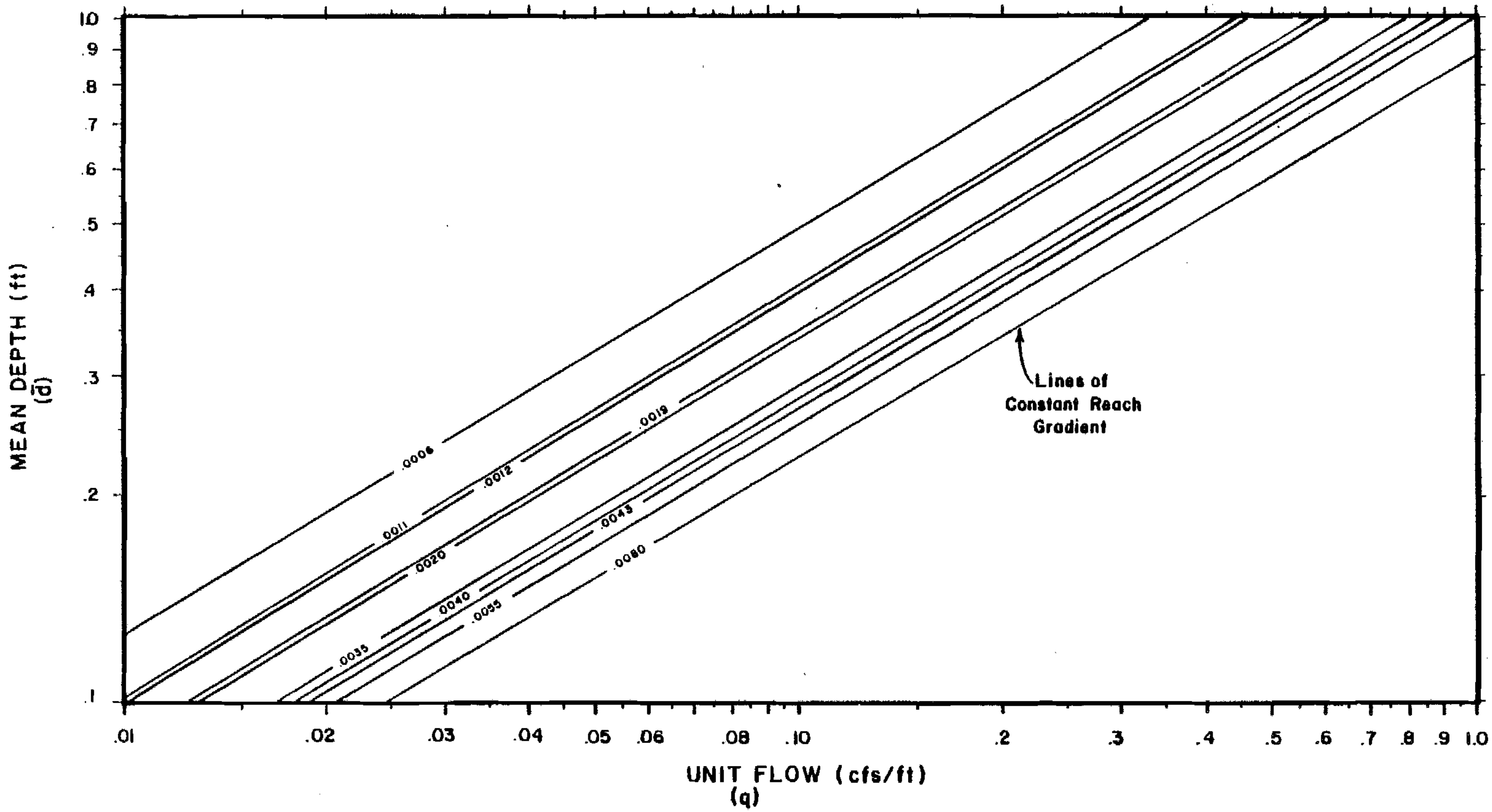

Figure 6-B-2. Relationship between mean depth and unit flow.

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. (Note: Data were available only at Whiskers Creek Slough and Slough 9A for making this adjustment).

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

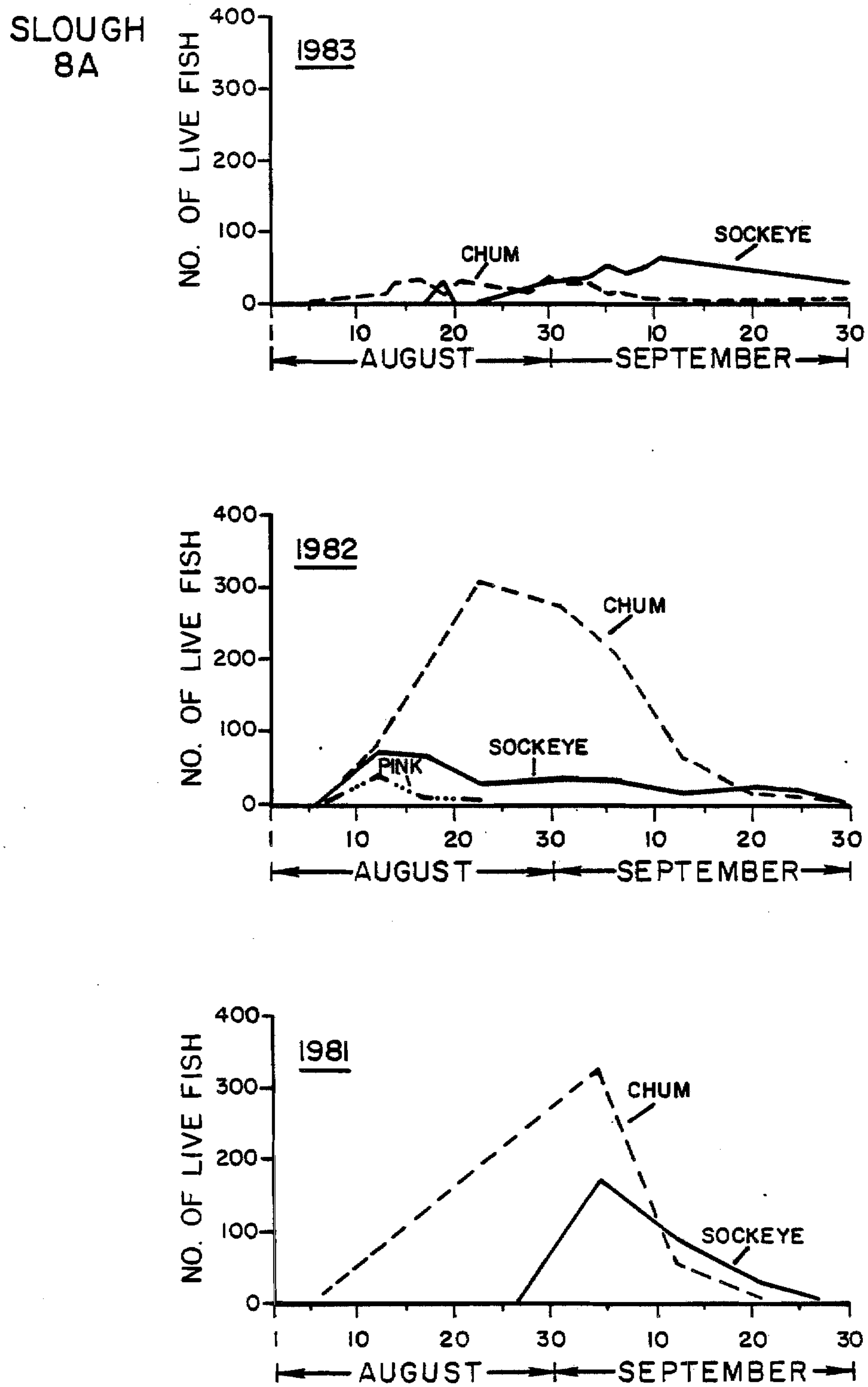

Figure 6-C-1. Timing of salmon presence, Slough 8A, 1981, 1982, 1983.

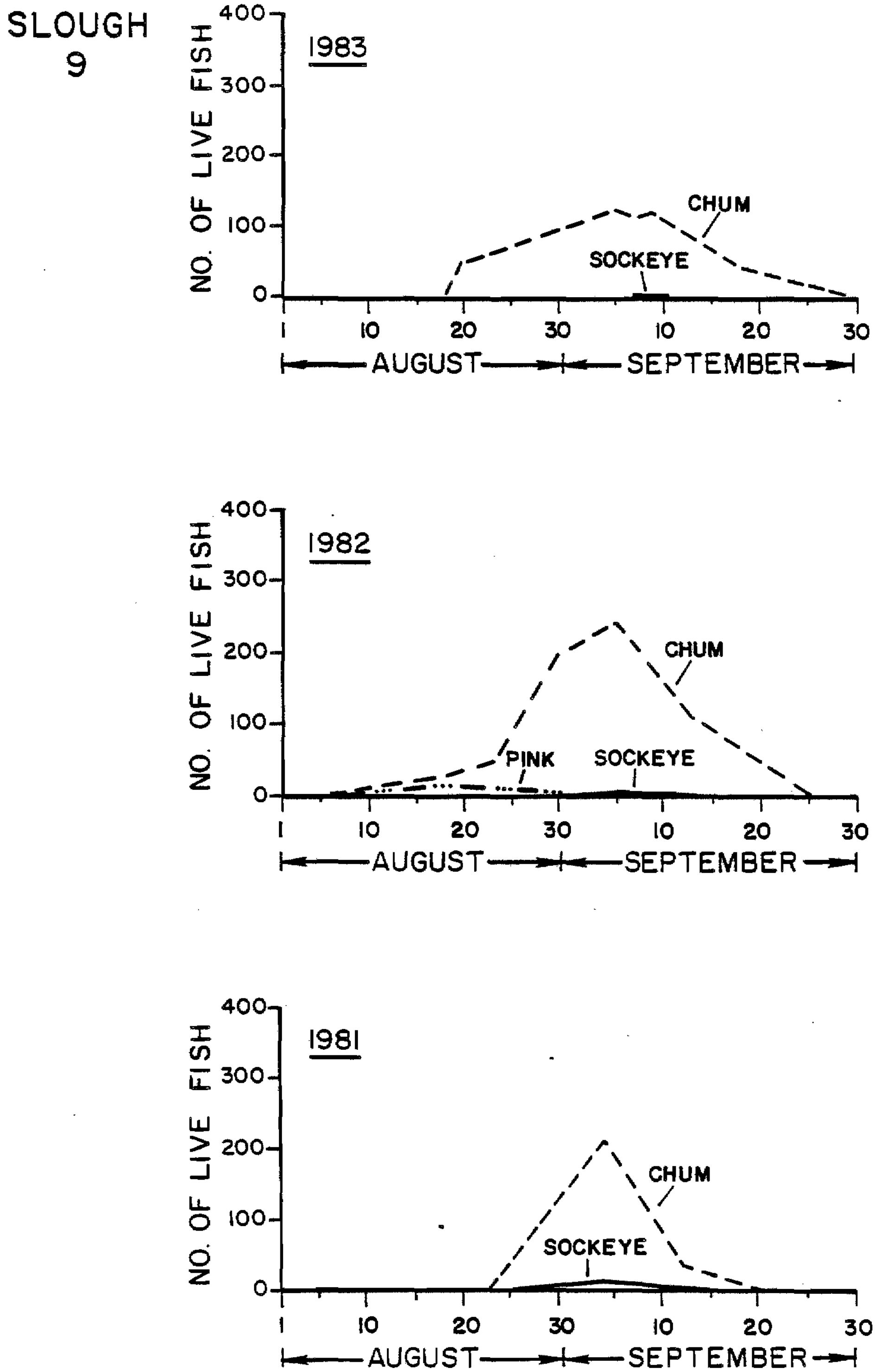

Figure 6-C-2. Timing of salmon presence, Slough 9, 1981, 1982, 1983.

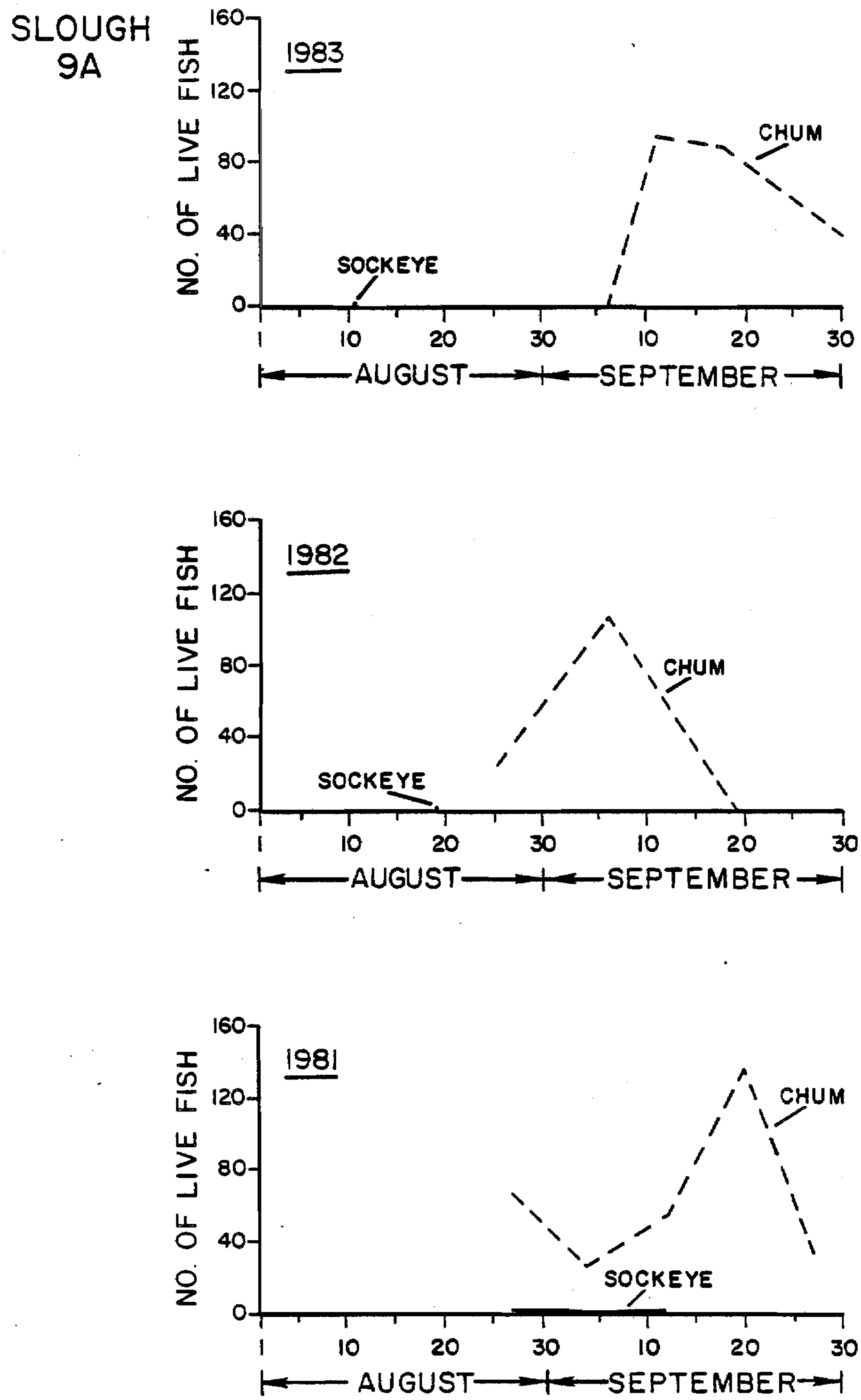

Figure 6-C-3. Timing of salmon presence, Slough 9A, 1981, 1982, 1983.

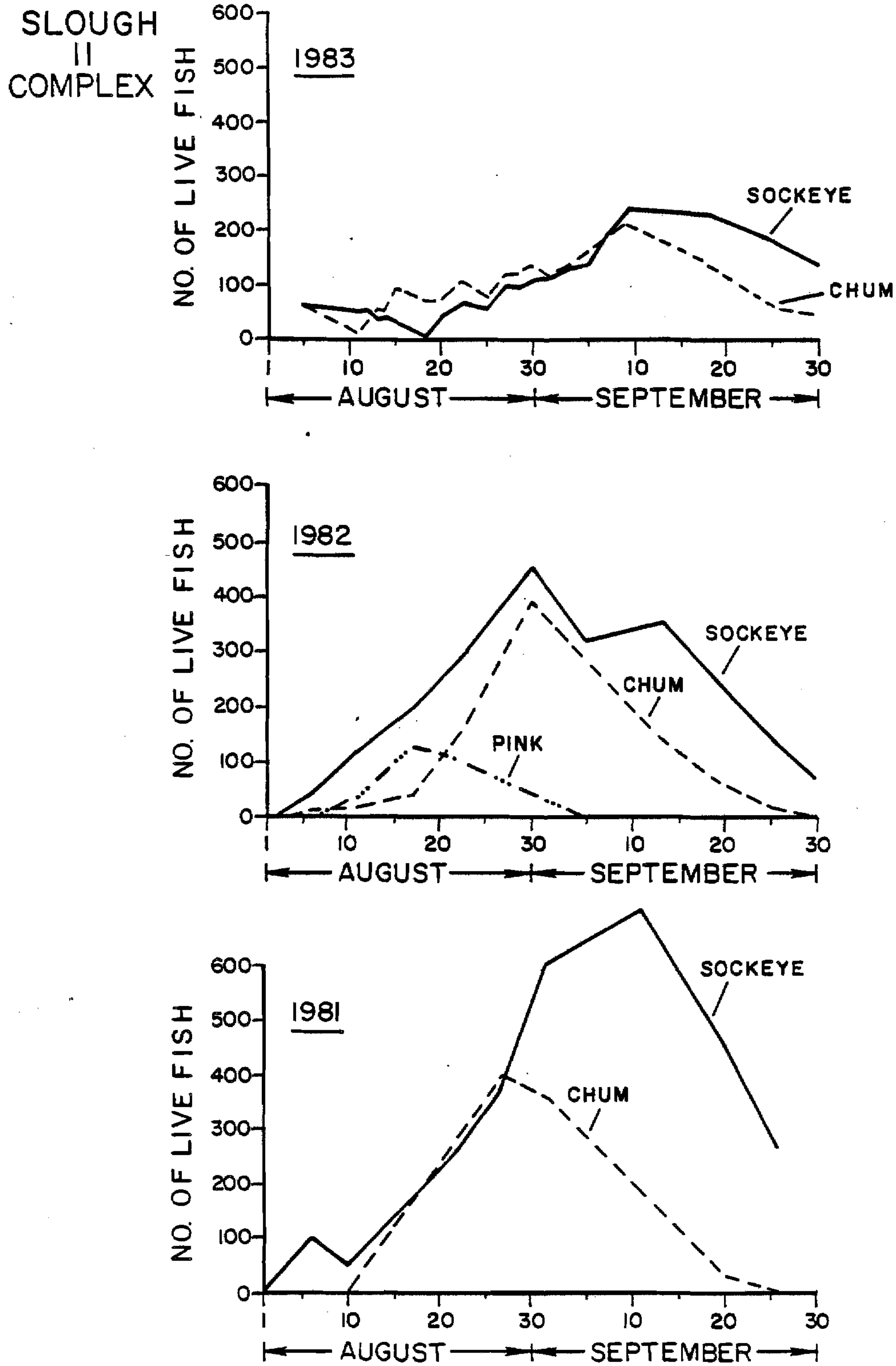

Figure 6-C-4. Timing of salmon presence, Slough 11 Complex, 1981, 1982, 1983.

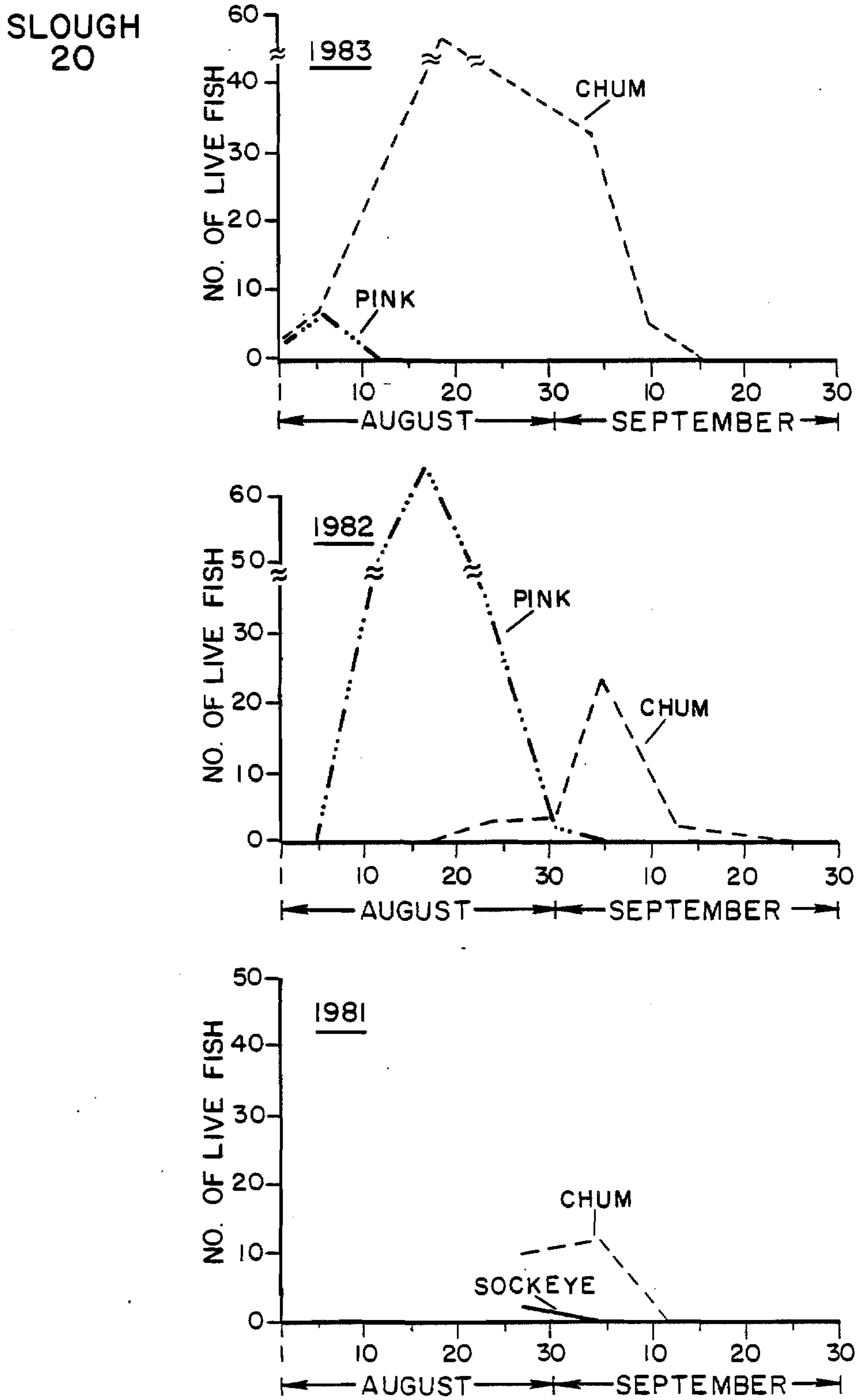

Figure 6-C-5. Timing of salmon presence, Slough 20, 1981, 1982, 1983.

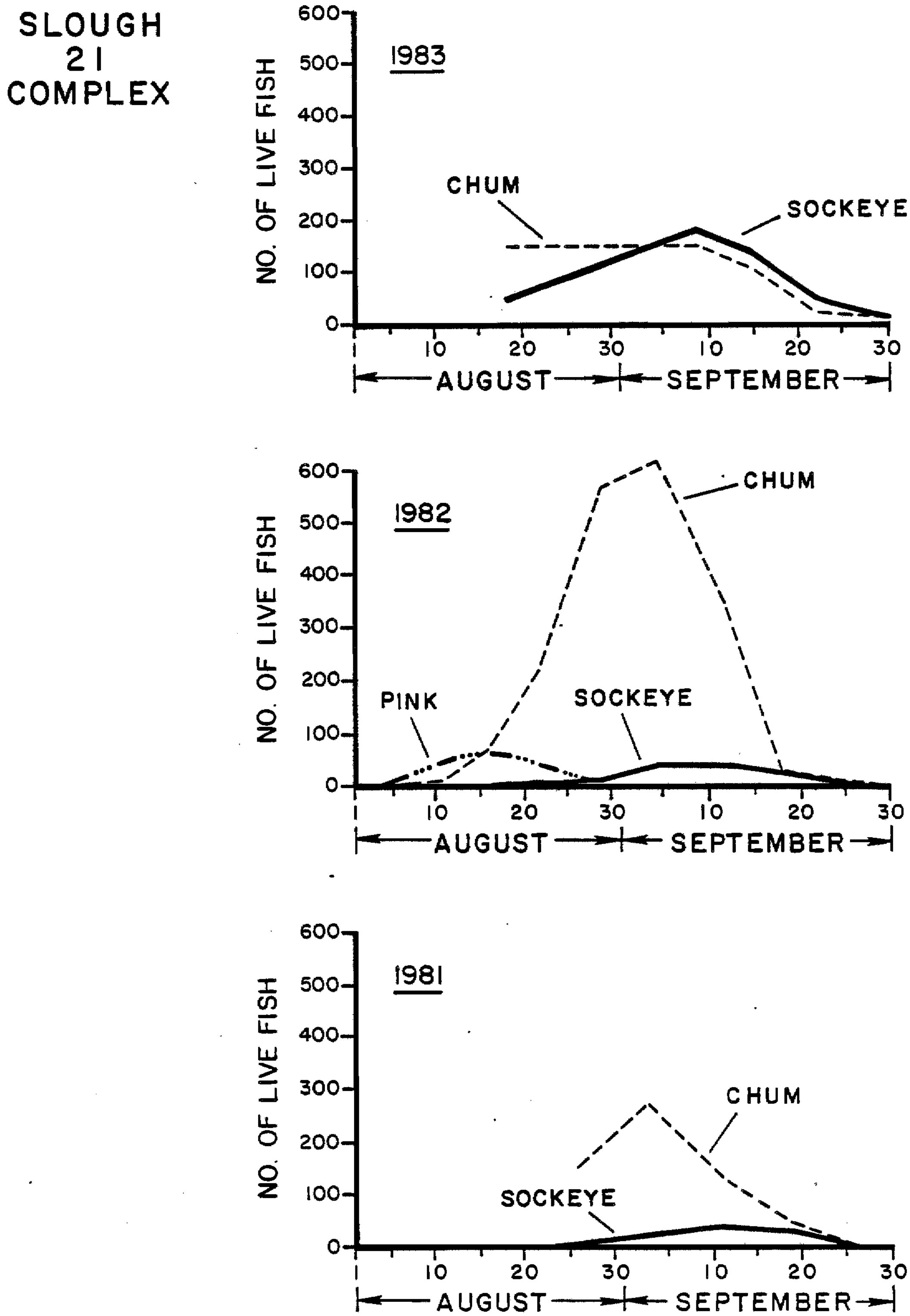

Figure 6-C-6. Timing of salmon presence, Slough 21 Complex, 1981, 1982, 1983.

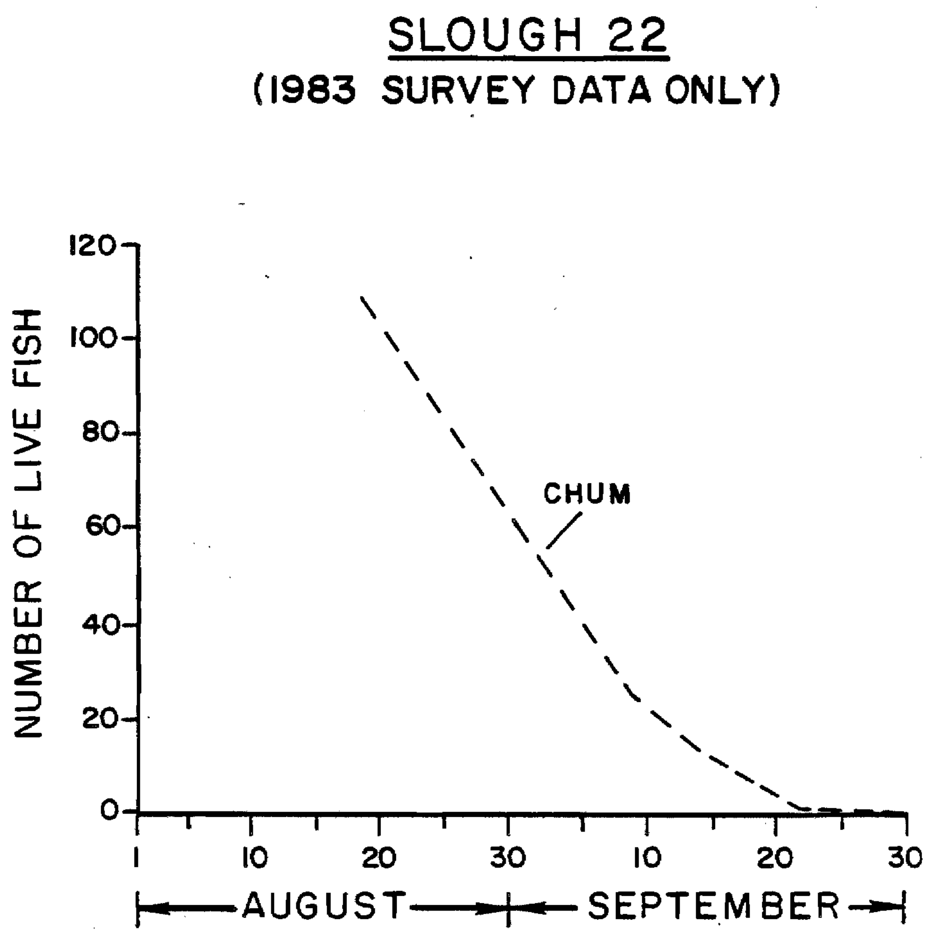

Figure 6-C-7. Timing of salmon presence, Slough 22, 1981, 1982, 1983.

Appendix 6-D

Salmon Spawning Distribution Maps

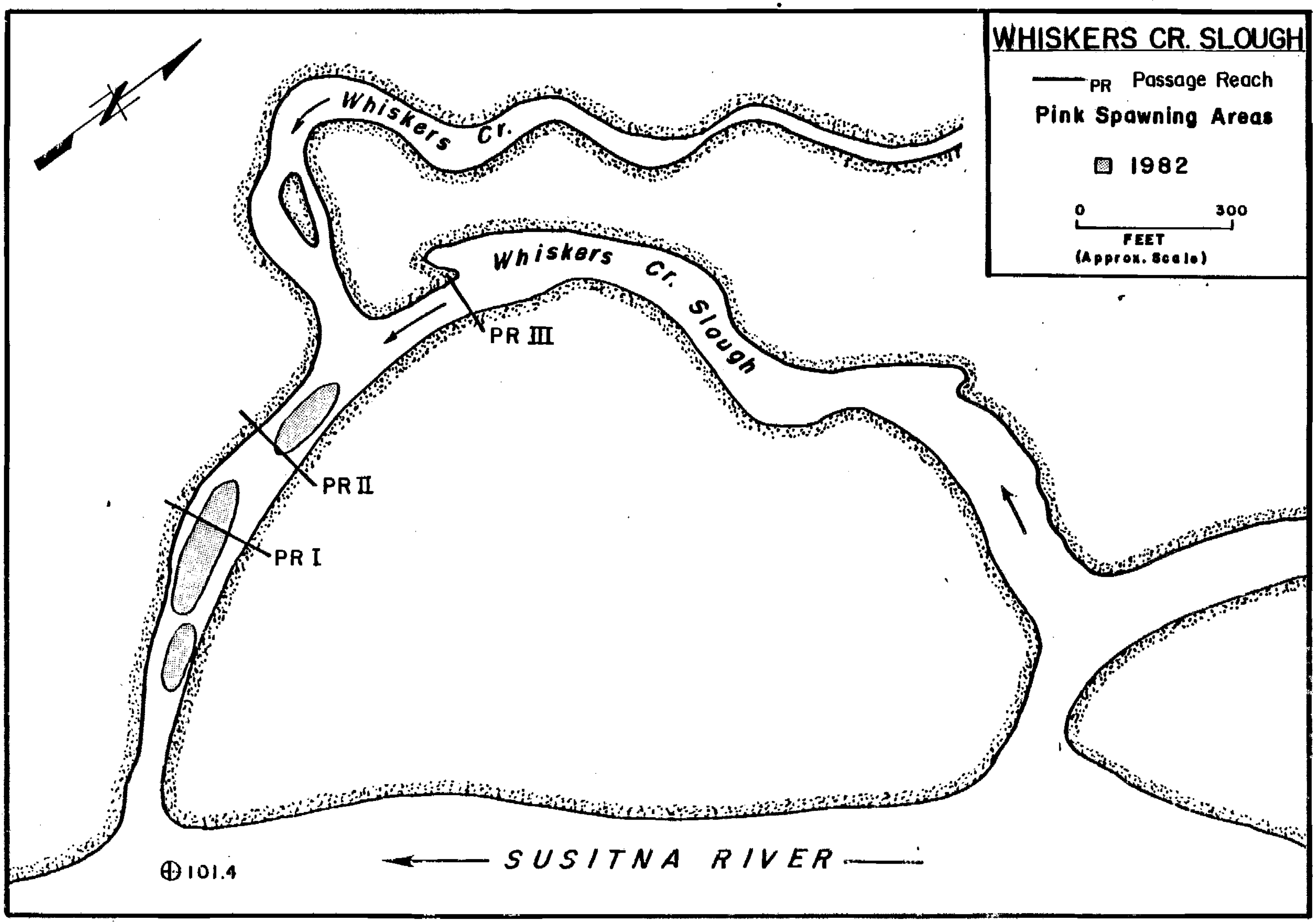

Figure 6-D-1. Pink salmon spawning areas, Whiskers Creek Slough, 1982.

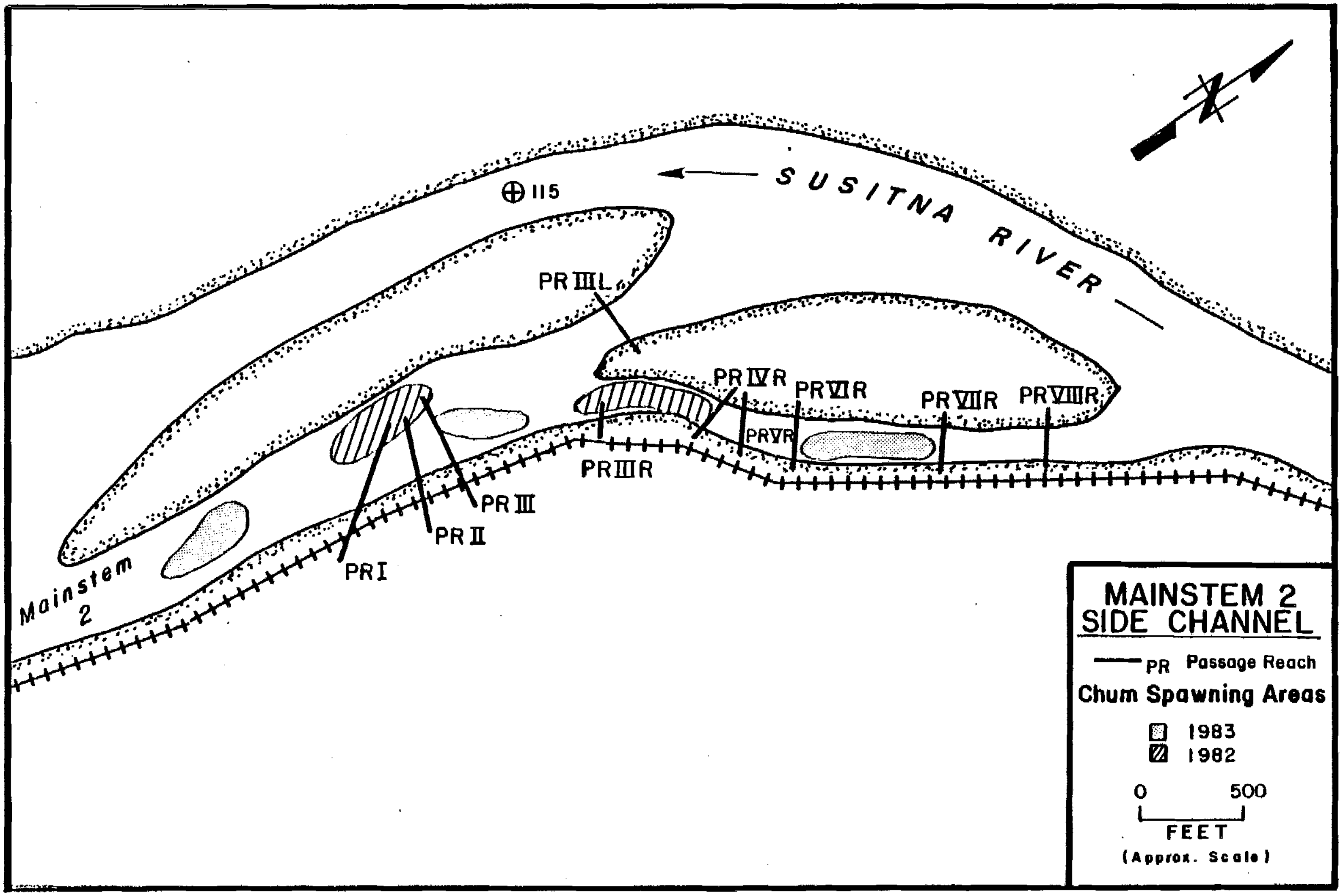

Figure 6-D-2. Chum salmon spawning areas, Mainstem 2 Side Channel, 1982, 1983.

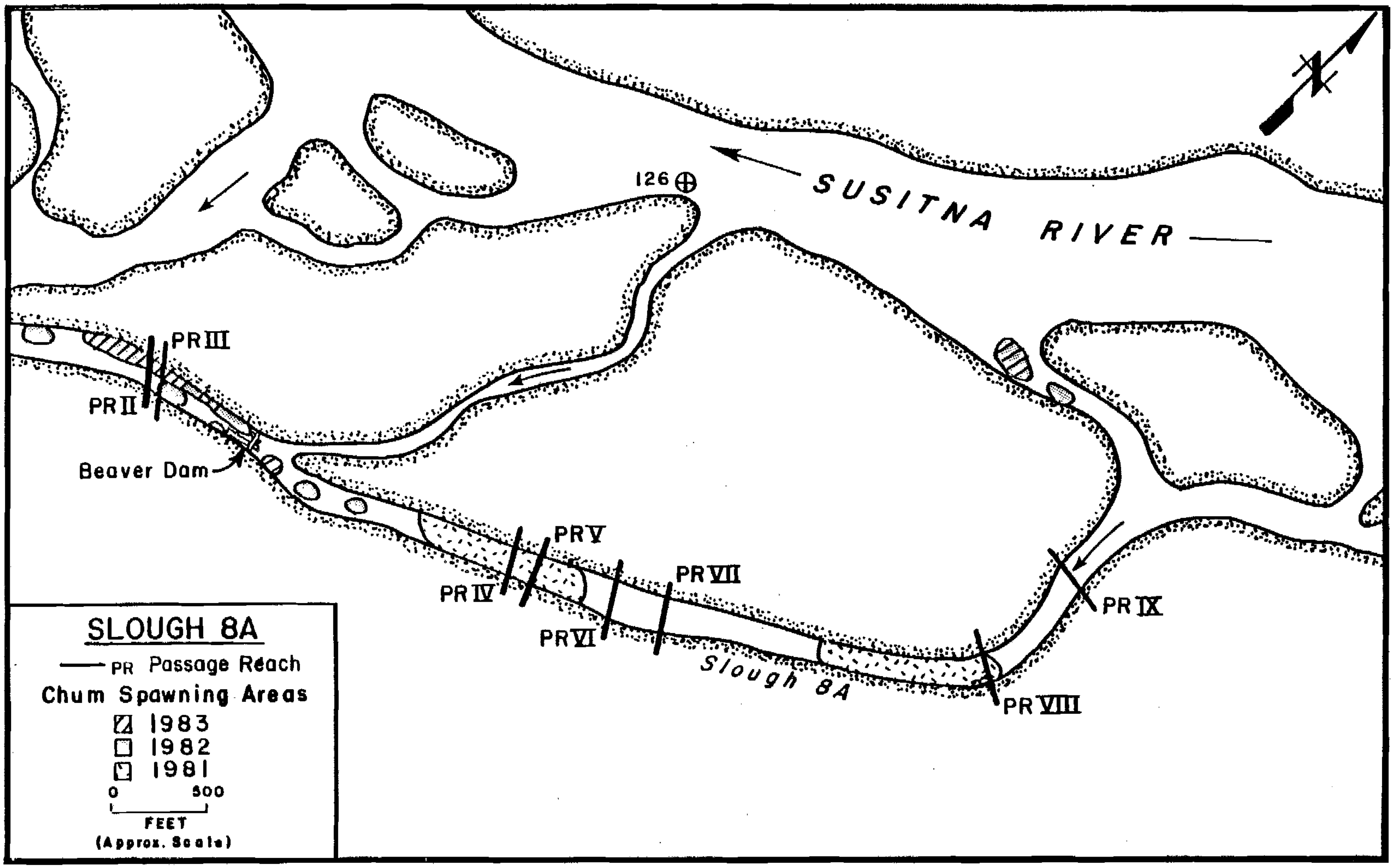

Figure 6-D-3. Chum salmon spawning areas, Slough 8A, 1981 1982, 1983.

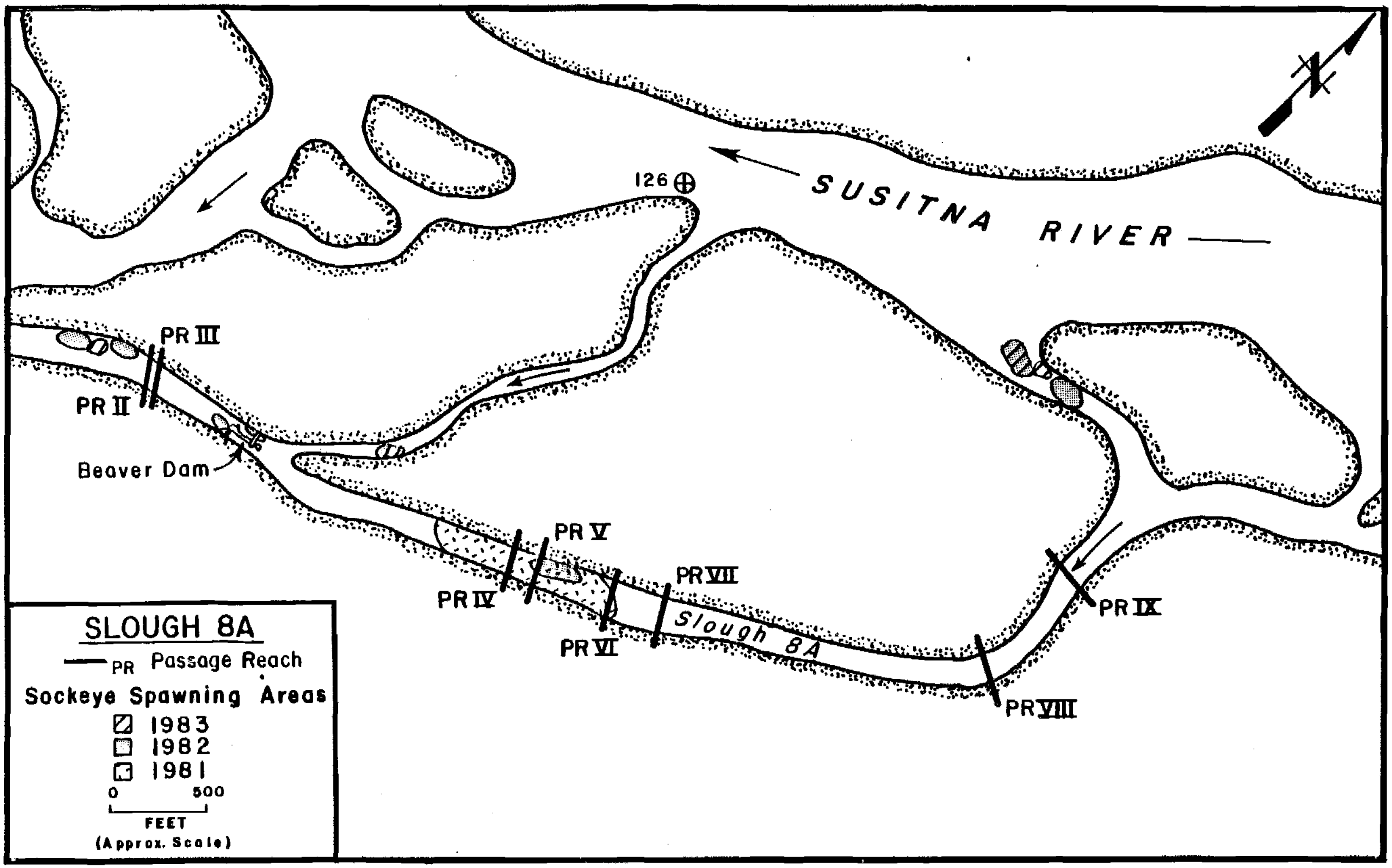

Figure 6-D-4. Sockeye salmon spawning areas, Slough 8A, 1981, 1982, 1983.

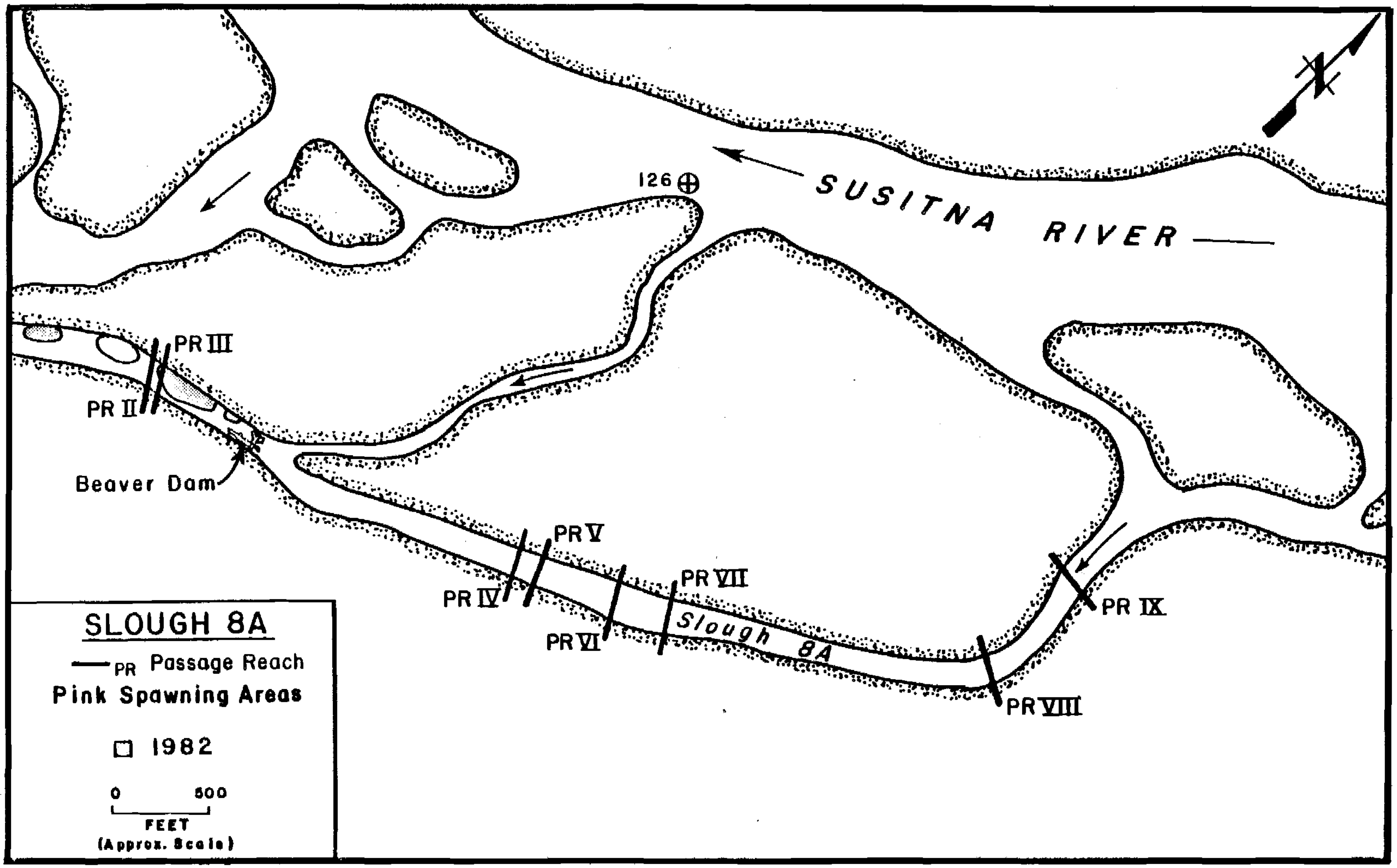

Figure 6-D-5. Pink salmon spawning areas, Slough 8A, 1982.

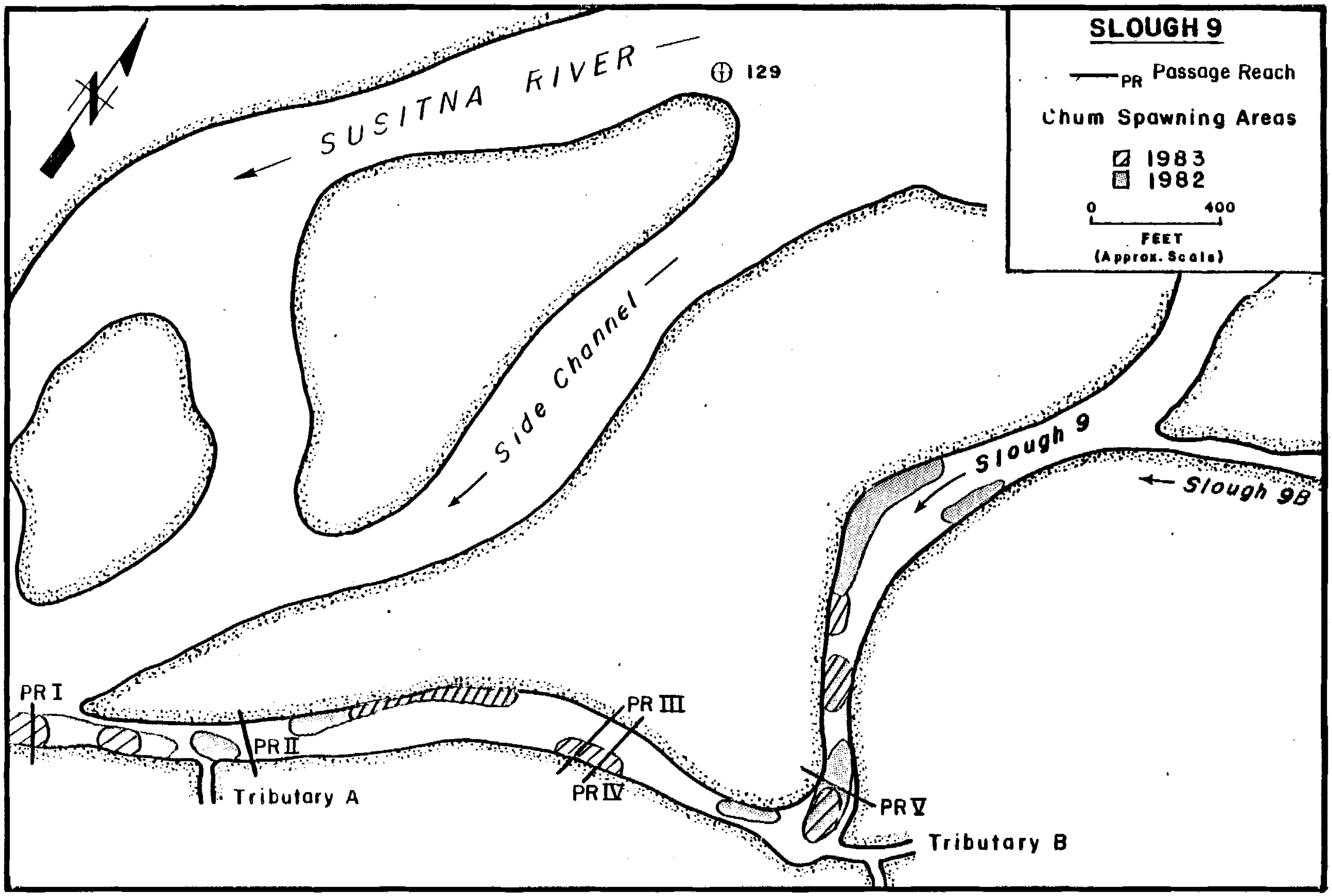

Figure 6-D-6. Chum salmon spawning areas, Slough 9, 1982.

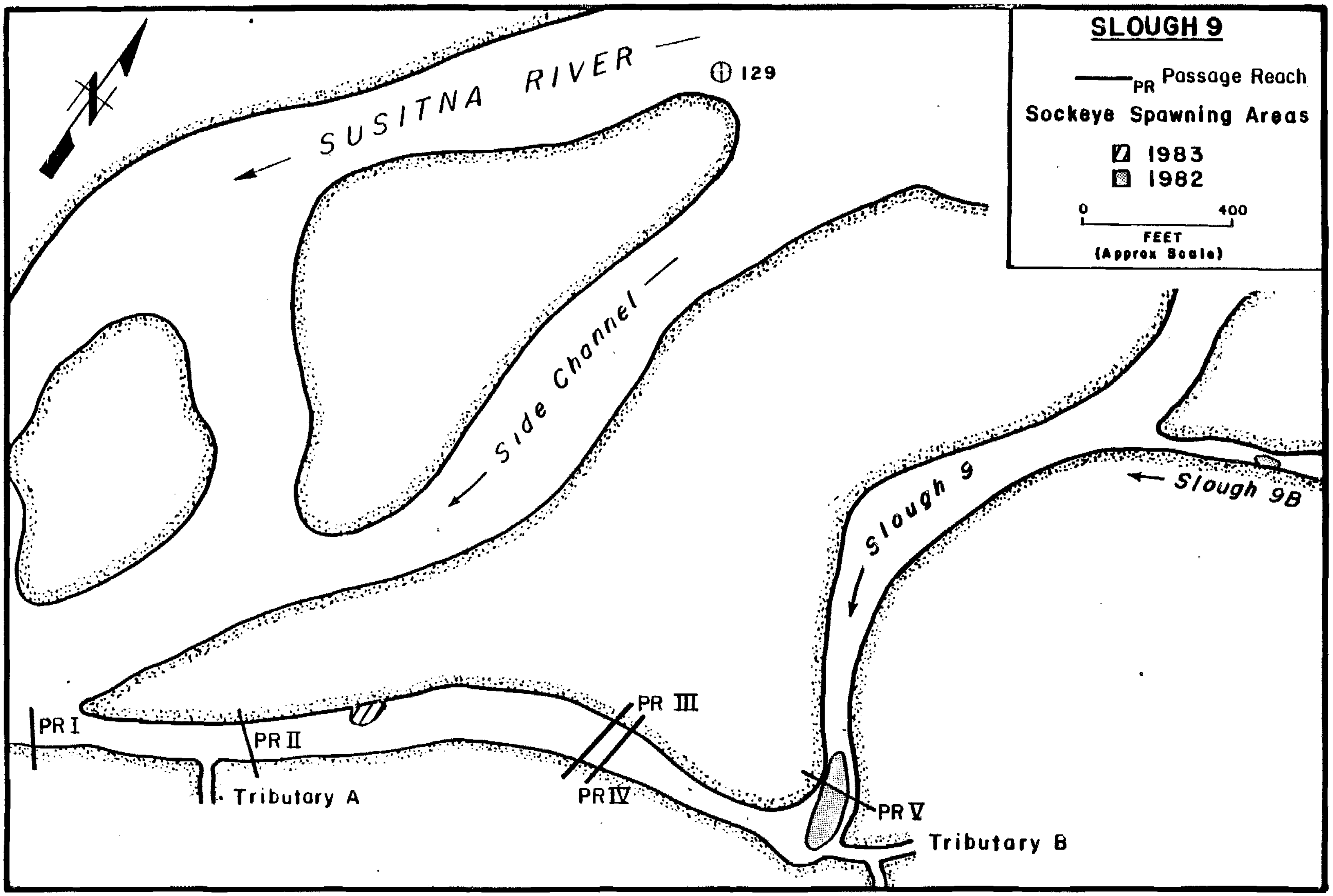

Figure 6-D-7. Sockeye salmon spawning areas, Slough 9, 1982, 1983.

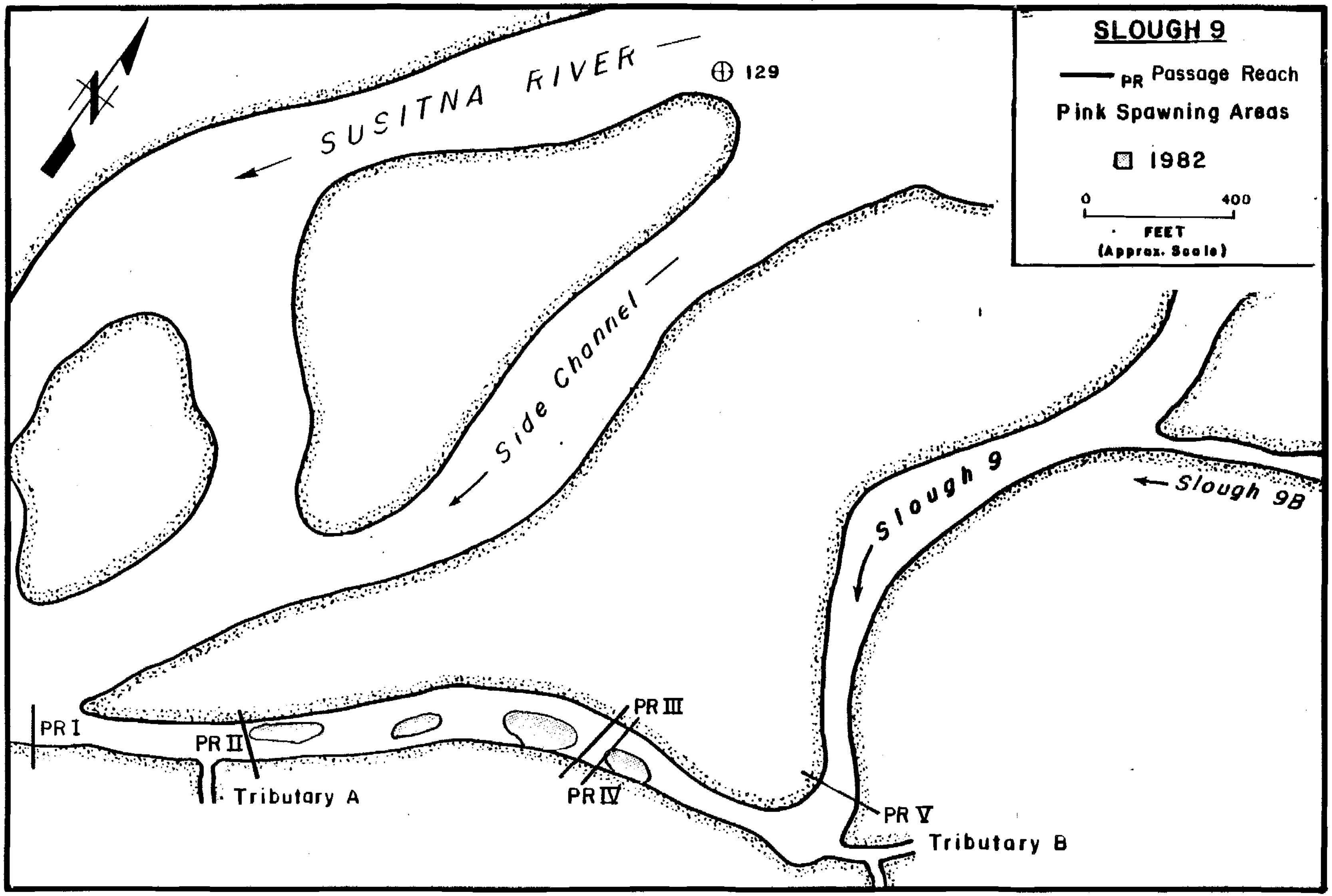

Figure 6-D-8. Pink salmon spawning areas, Slough 9, 1982.

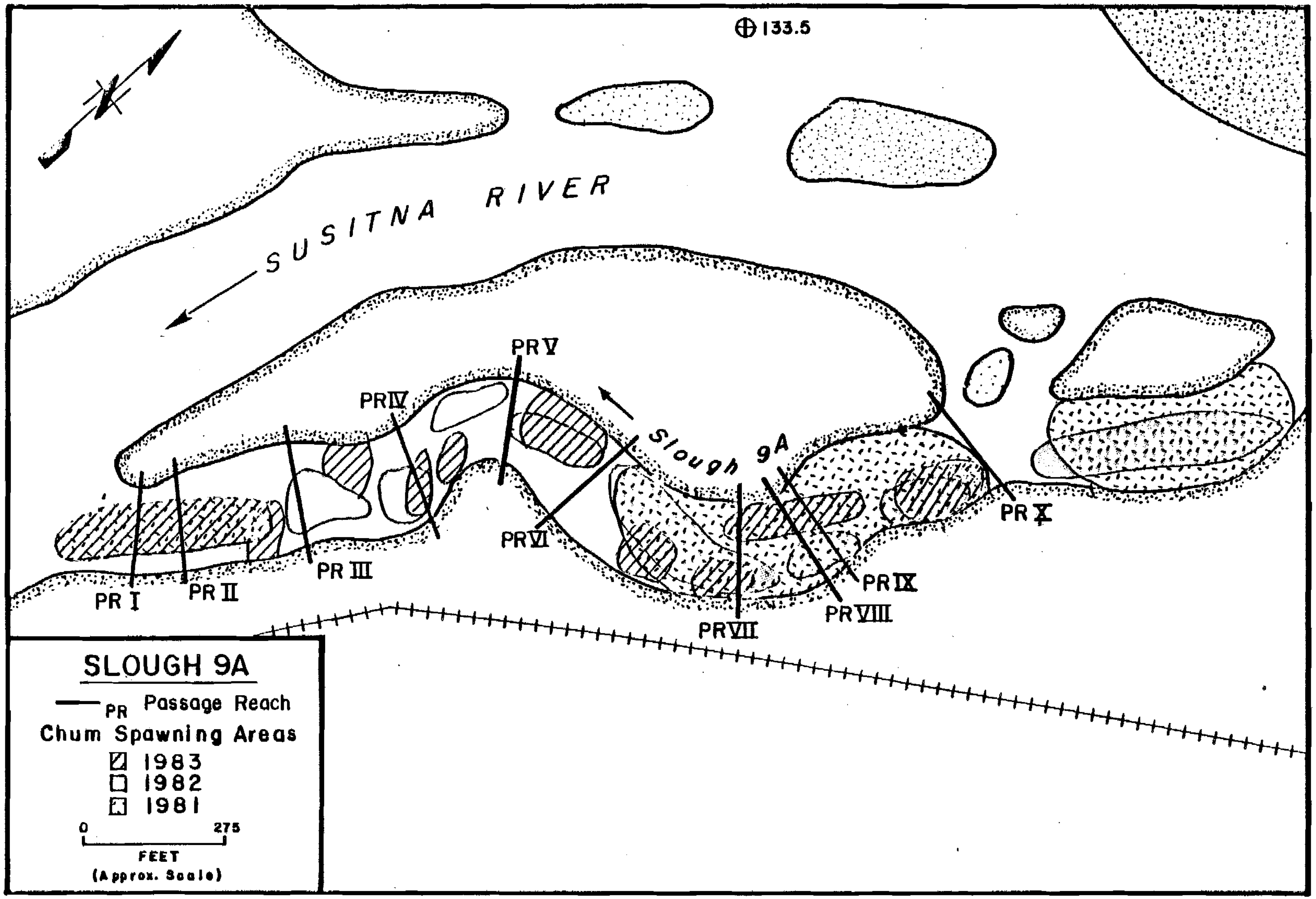

Figure 6-D-9. Chum salmon spawning areas, Slough 9A, 1981, 1982, 1983.

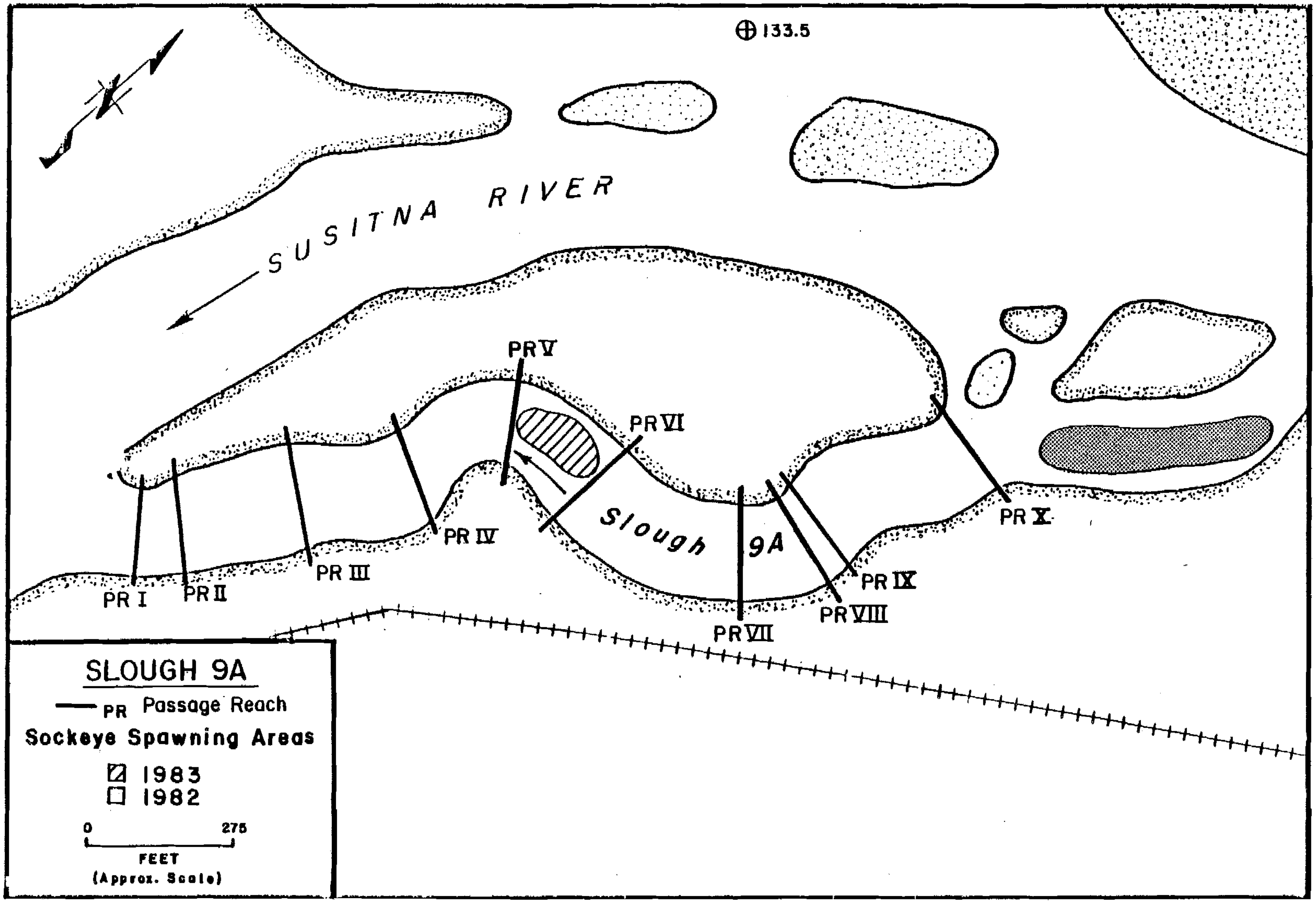

Figure 6-D-10. Sockeye salmon spawning areas, Slough 9A, 1981, 1982, 1983.

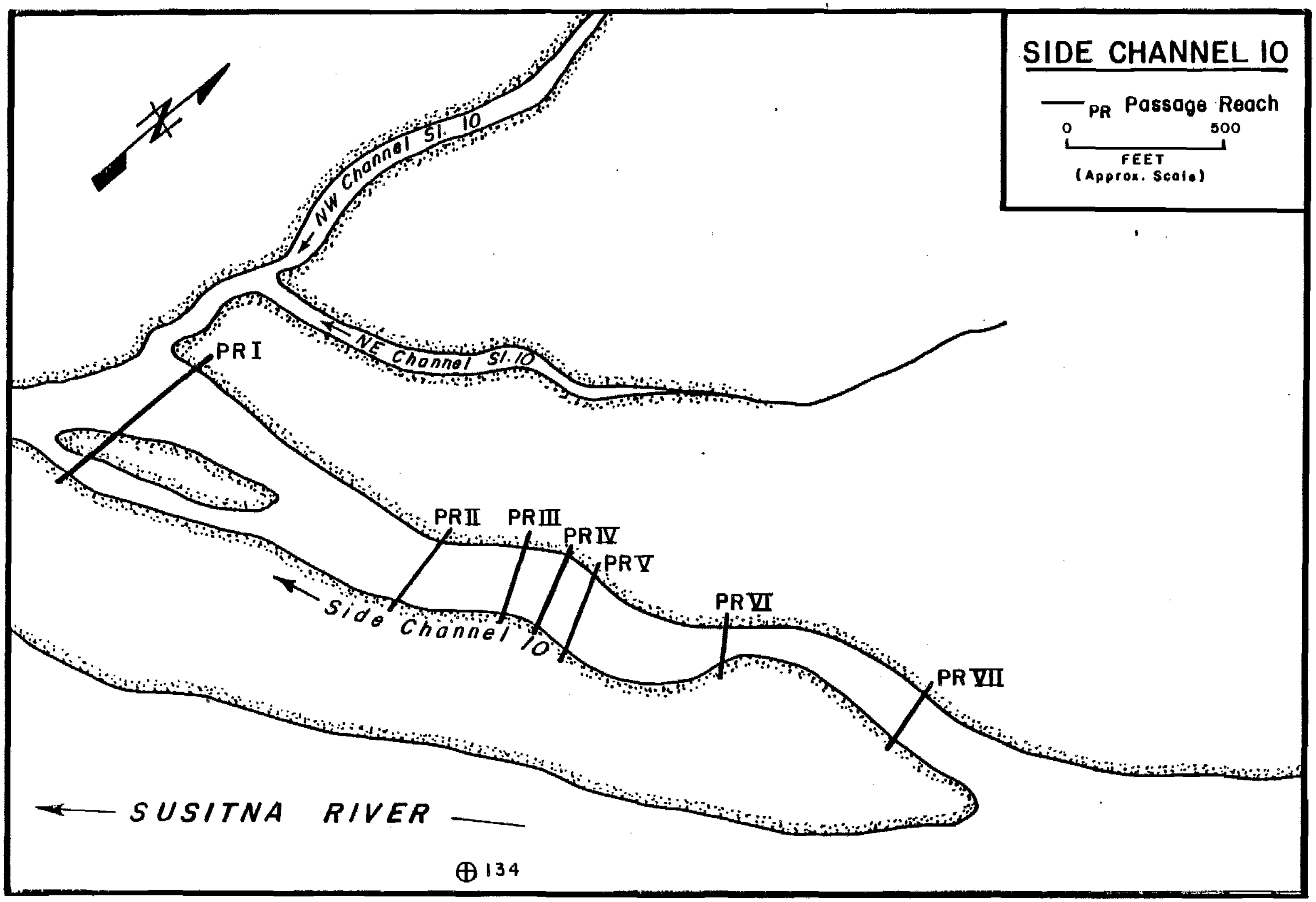

Figure 6-D-11. Site map of Side Channel 10.

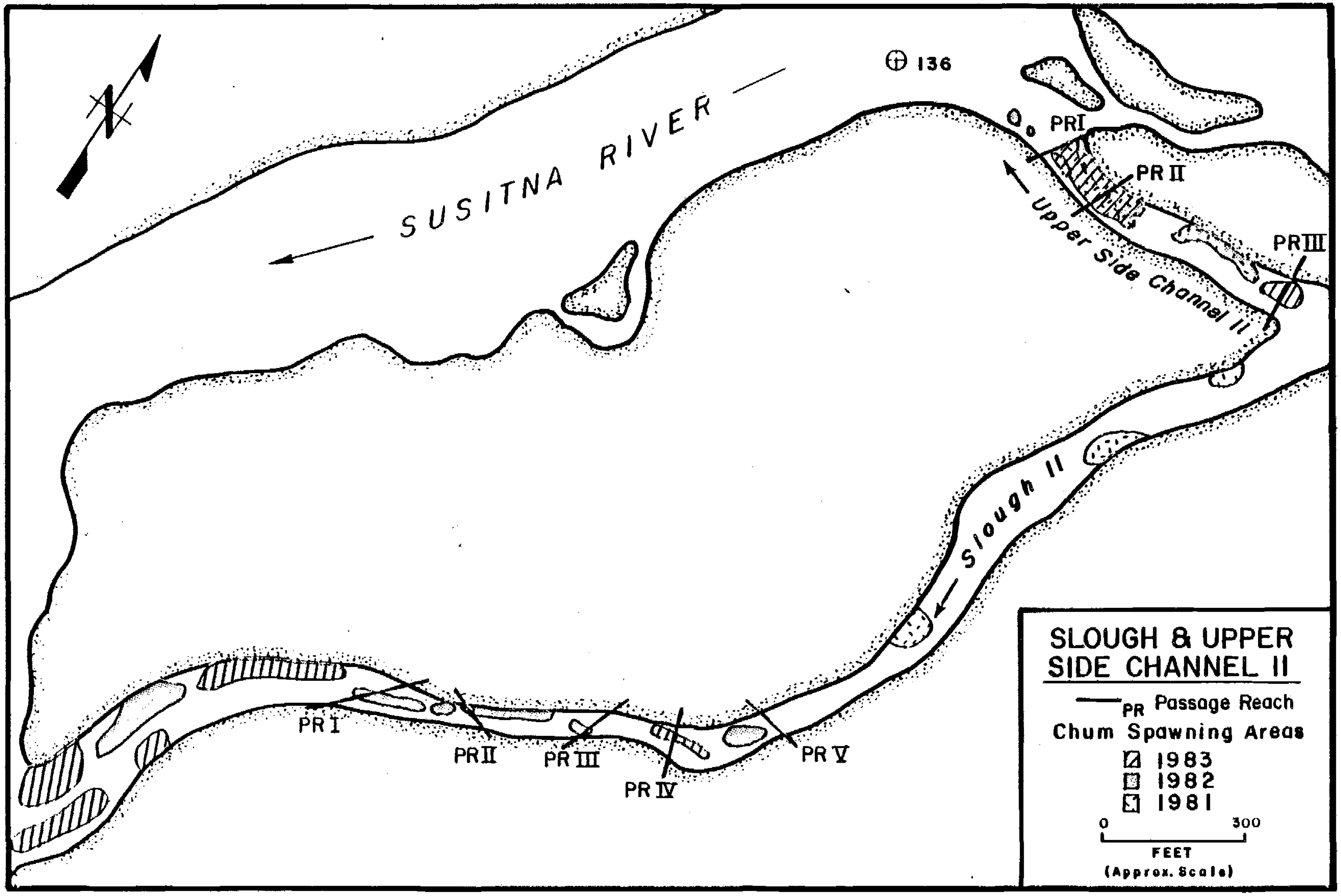

Figure 6-D-12. Chum salmon spawning areas Slough and Upper Side Channel 11, 1981 1982, 1983.

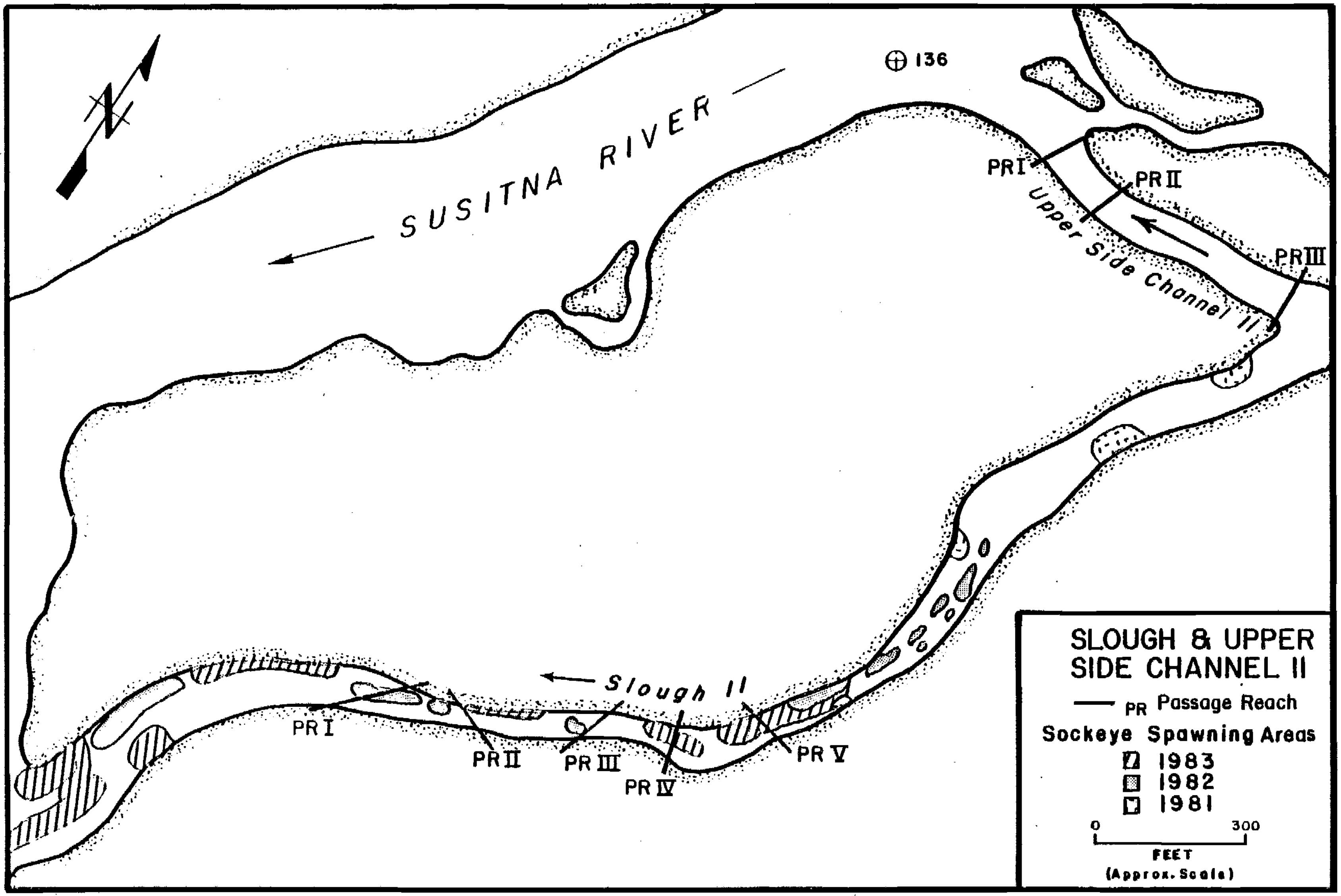

Figure 6-D-13. Sockeye salmon spawning areas, Slough and Upper Side Channel 11, 1981, 1982, 1983.

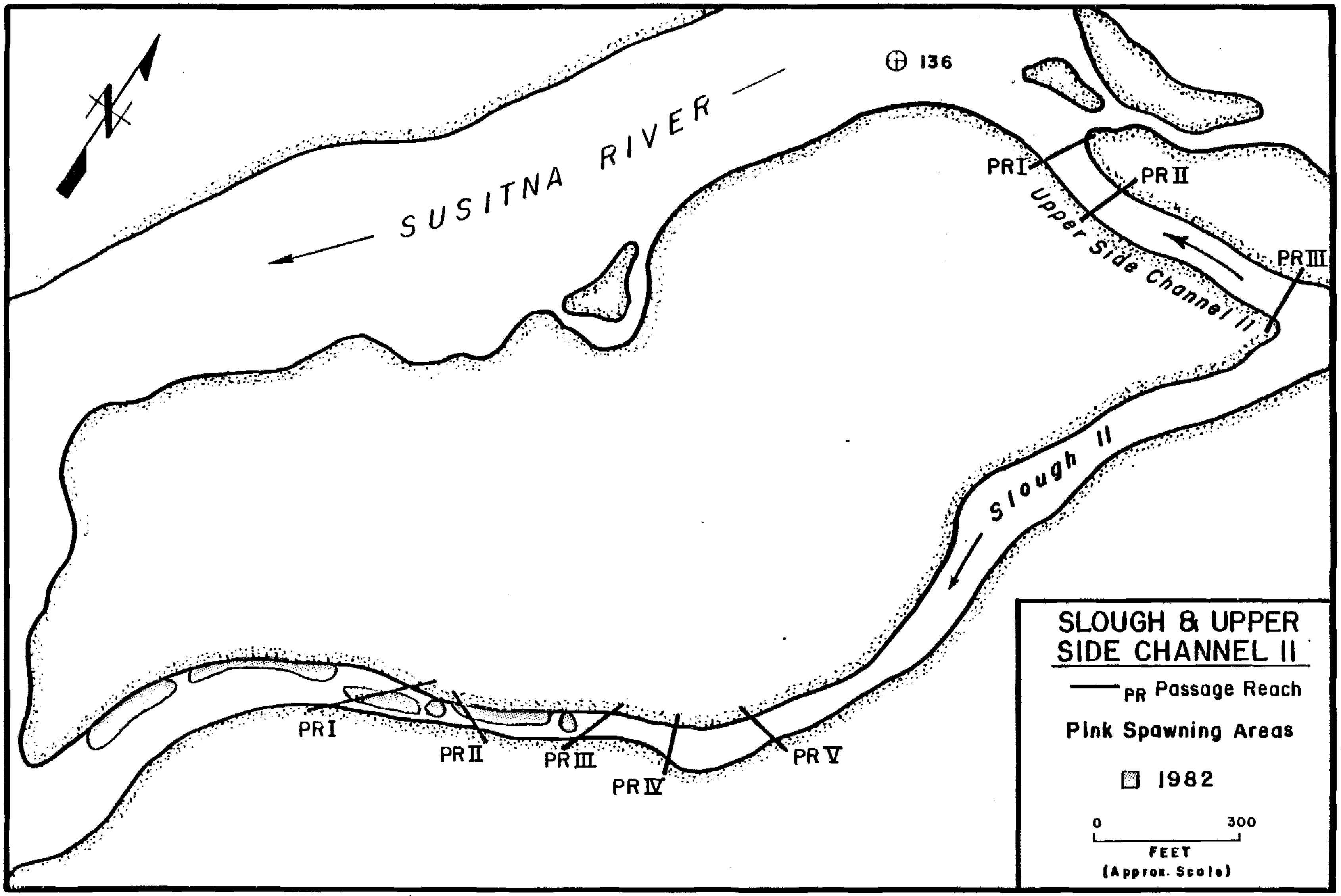

Figure 6-D-14. Pink salmon spawning areas, Slough and Upper Side Channel 11, 1982.

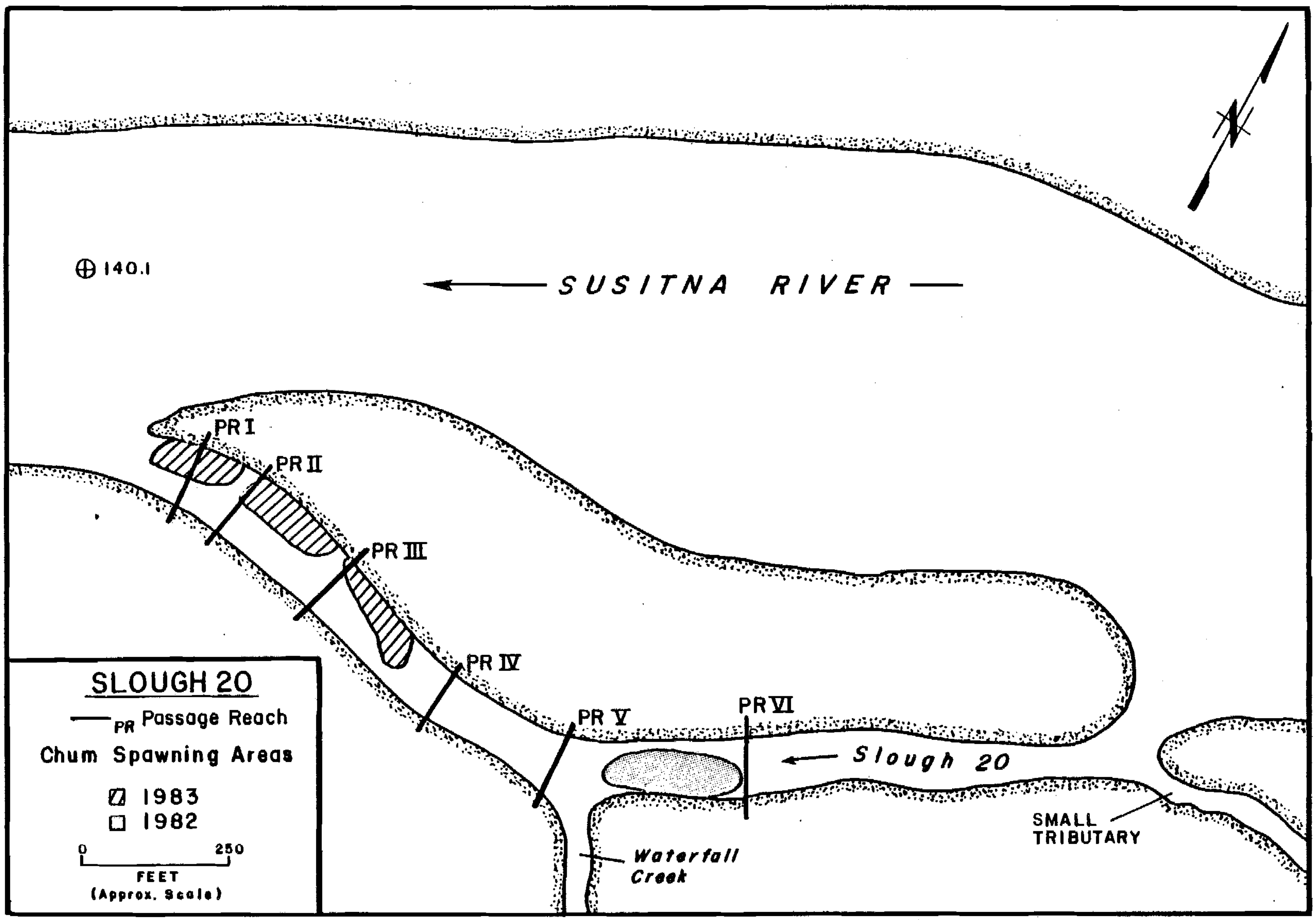

Figure 6-D-15. Chum salmon spawning areas, Slough 20, 1982, 1983.

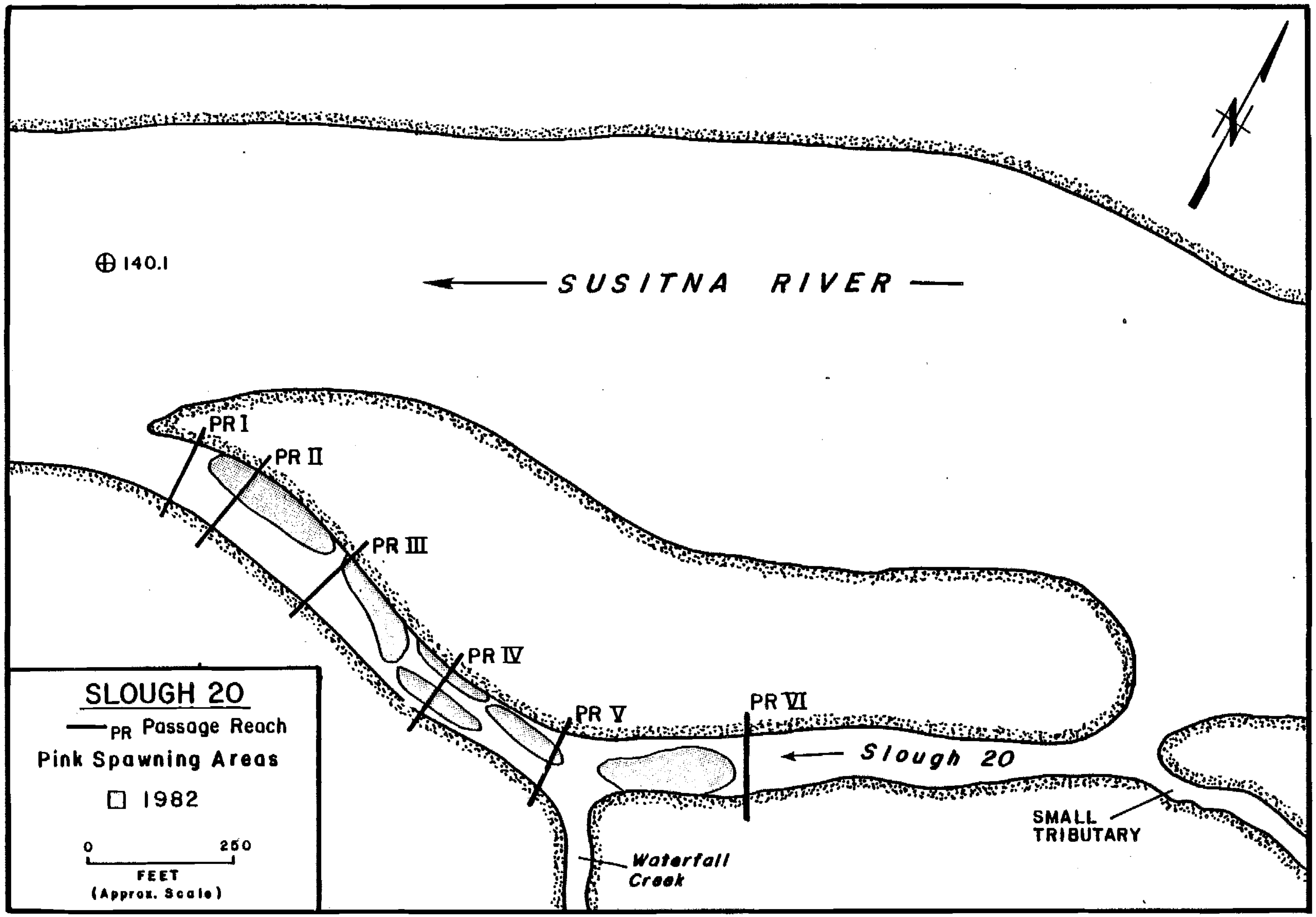

Figure 6-D-16. Pink salmon spawning areas, Slough 20, 1982.

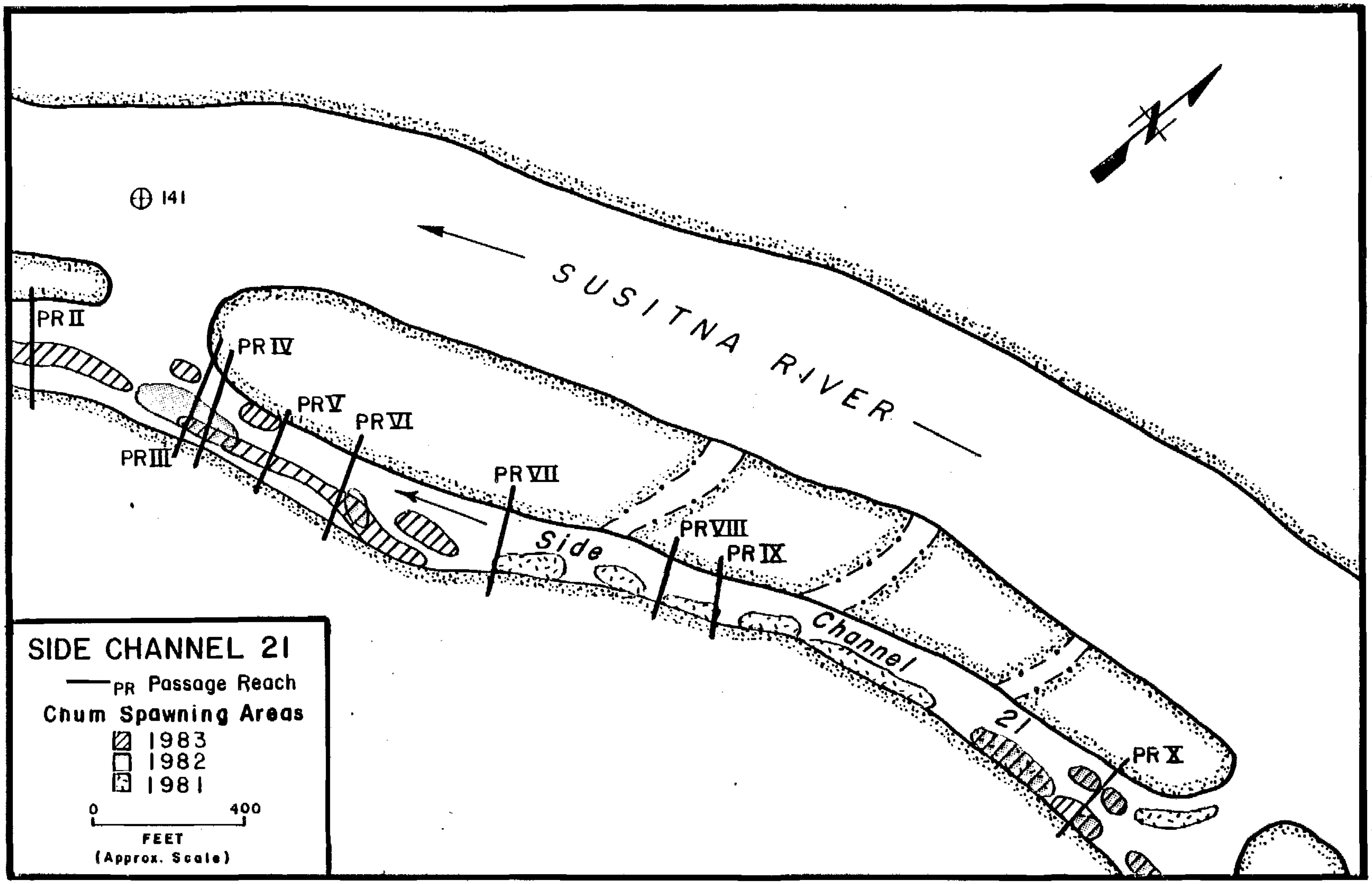

Figure 6-D-17. Chum salmon spawning areas, Side Channel 21, 1981, 1982, 1983.

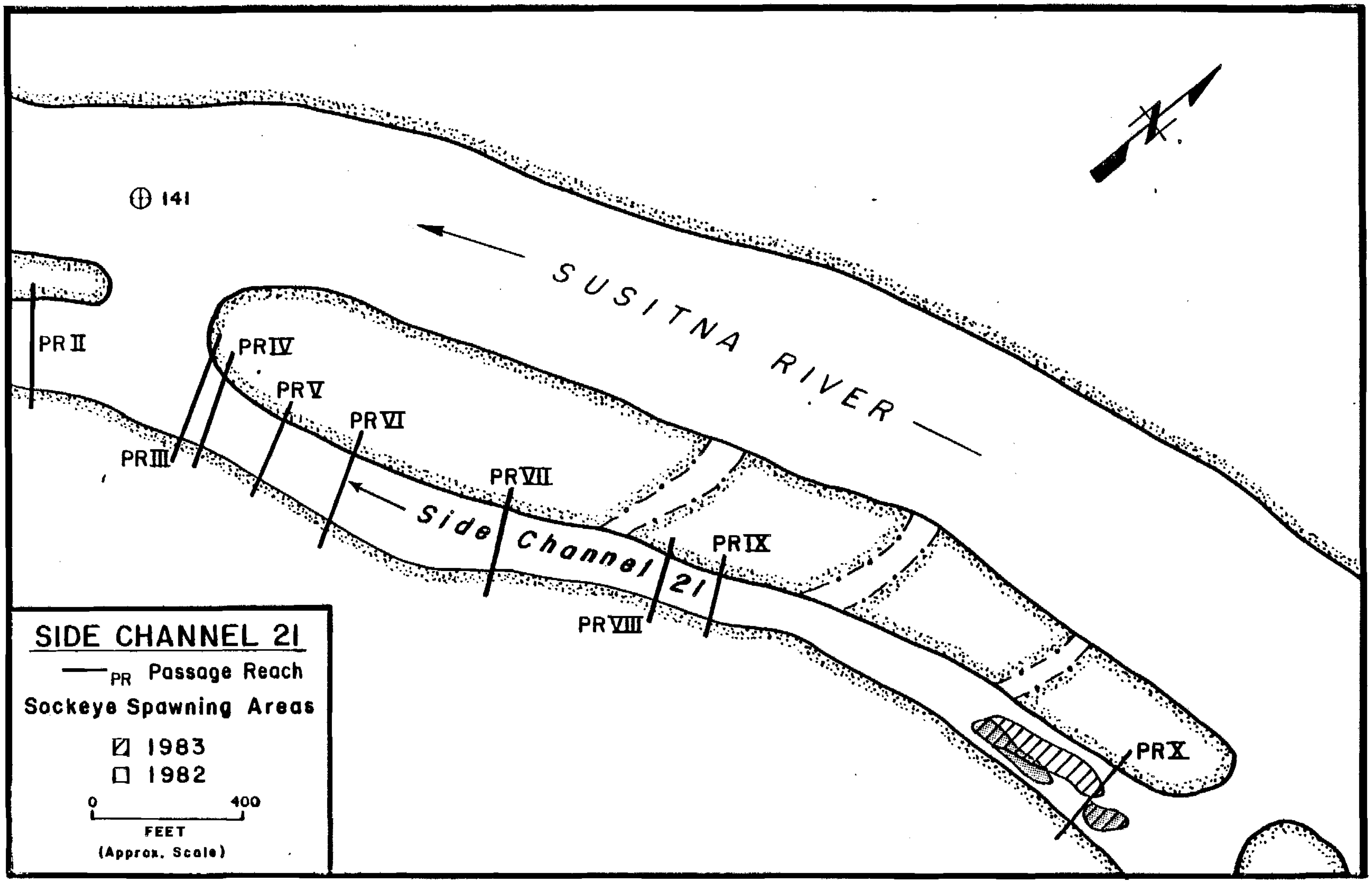

Figure 6-D-18. Sockeye salmon spawning areas, Side Channel 21, 1982, 1983.

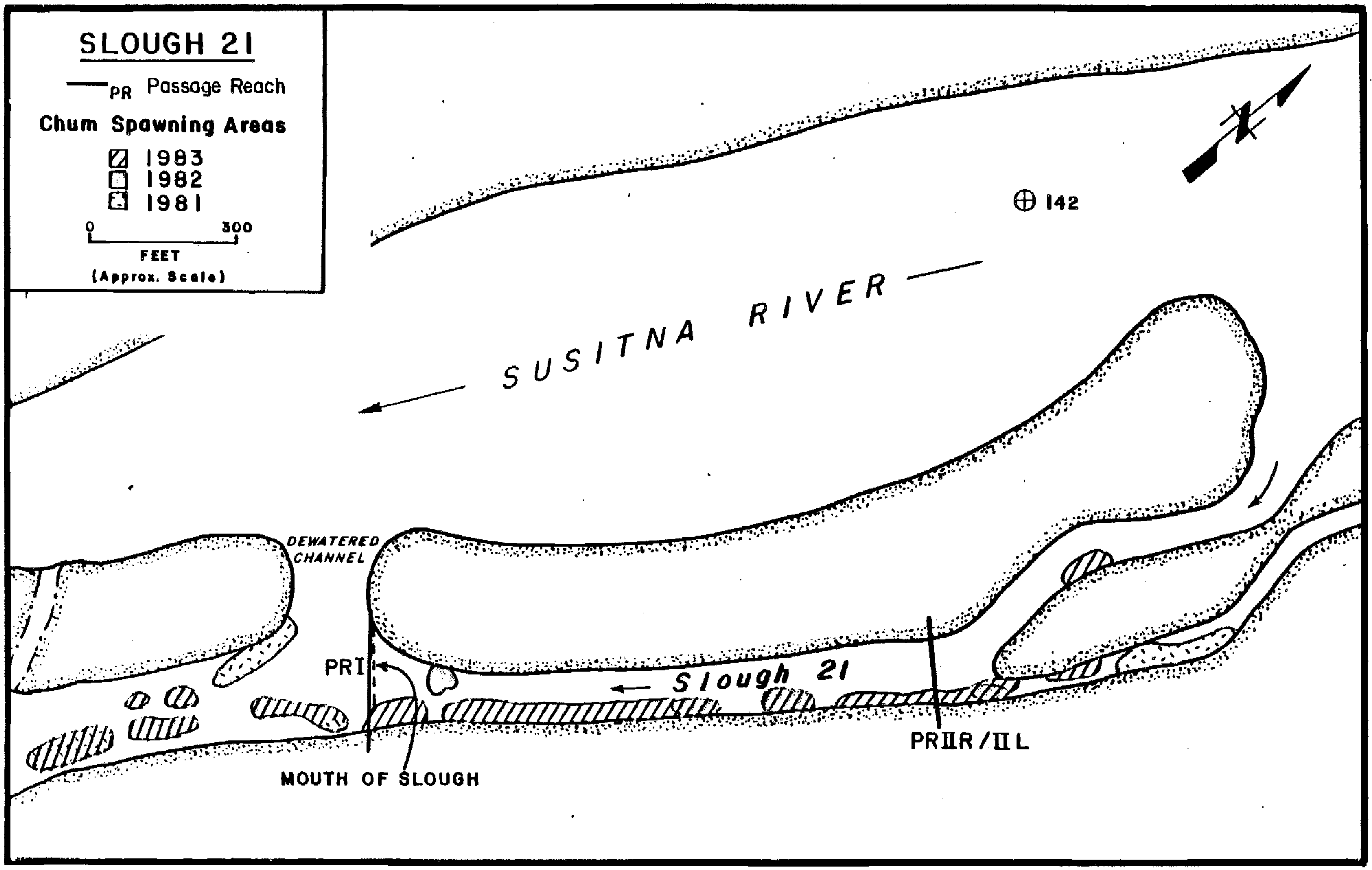

Figure 6-D-19. Chum salmon spawning areas, Slough 21, 1981, 1982, 1983.

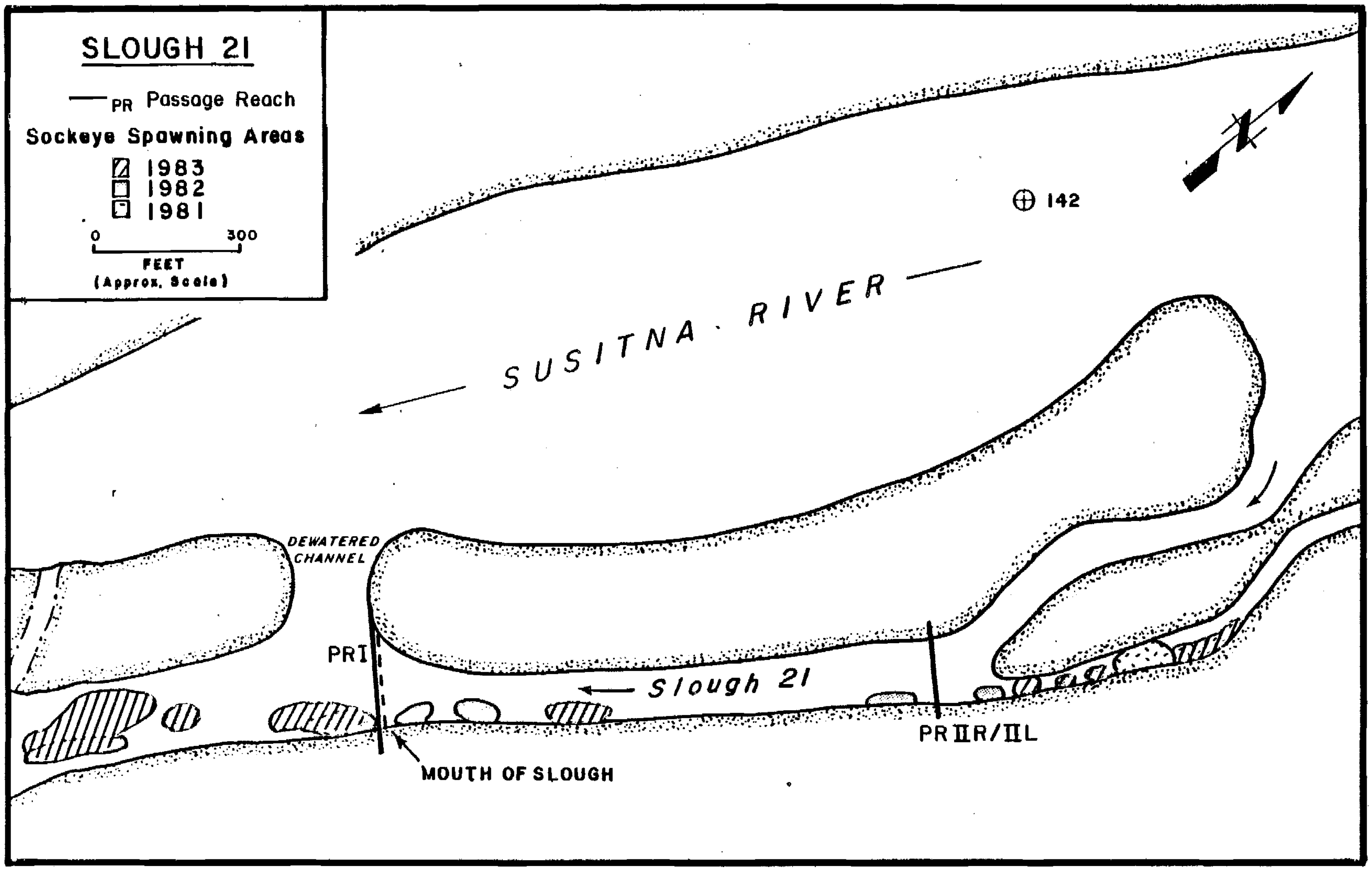

Figure 6-D-20. Sockeye salmon spawning areas, Slough 21, 1981, 1982, 1983.

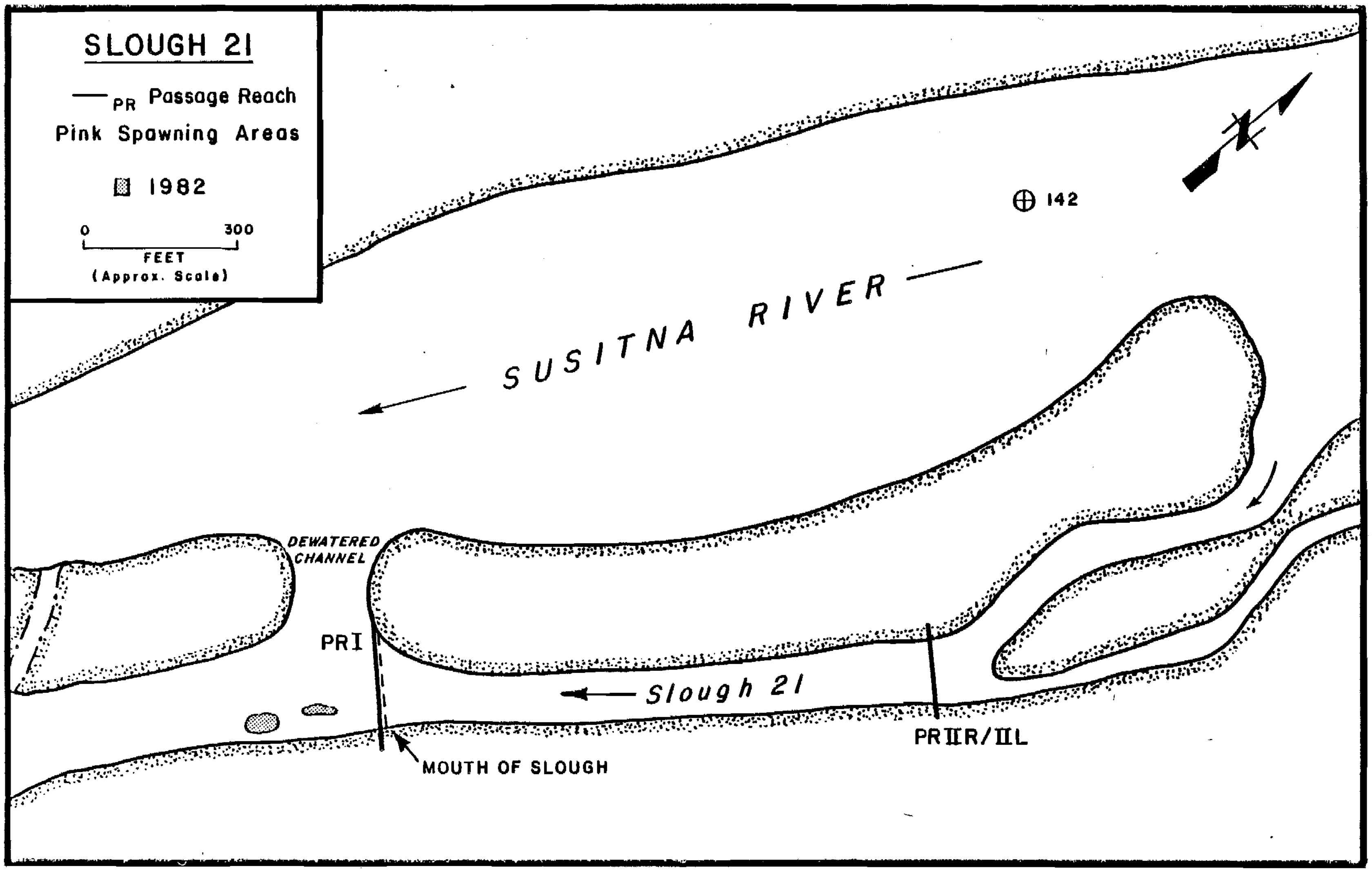

Figure 6-D-21. Pink salmon spawning areas, Slough 21. 1982. Note that spawning areas are located downstream of the designated mouth of the slough.

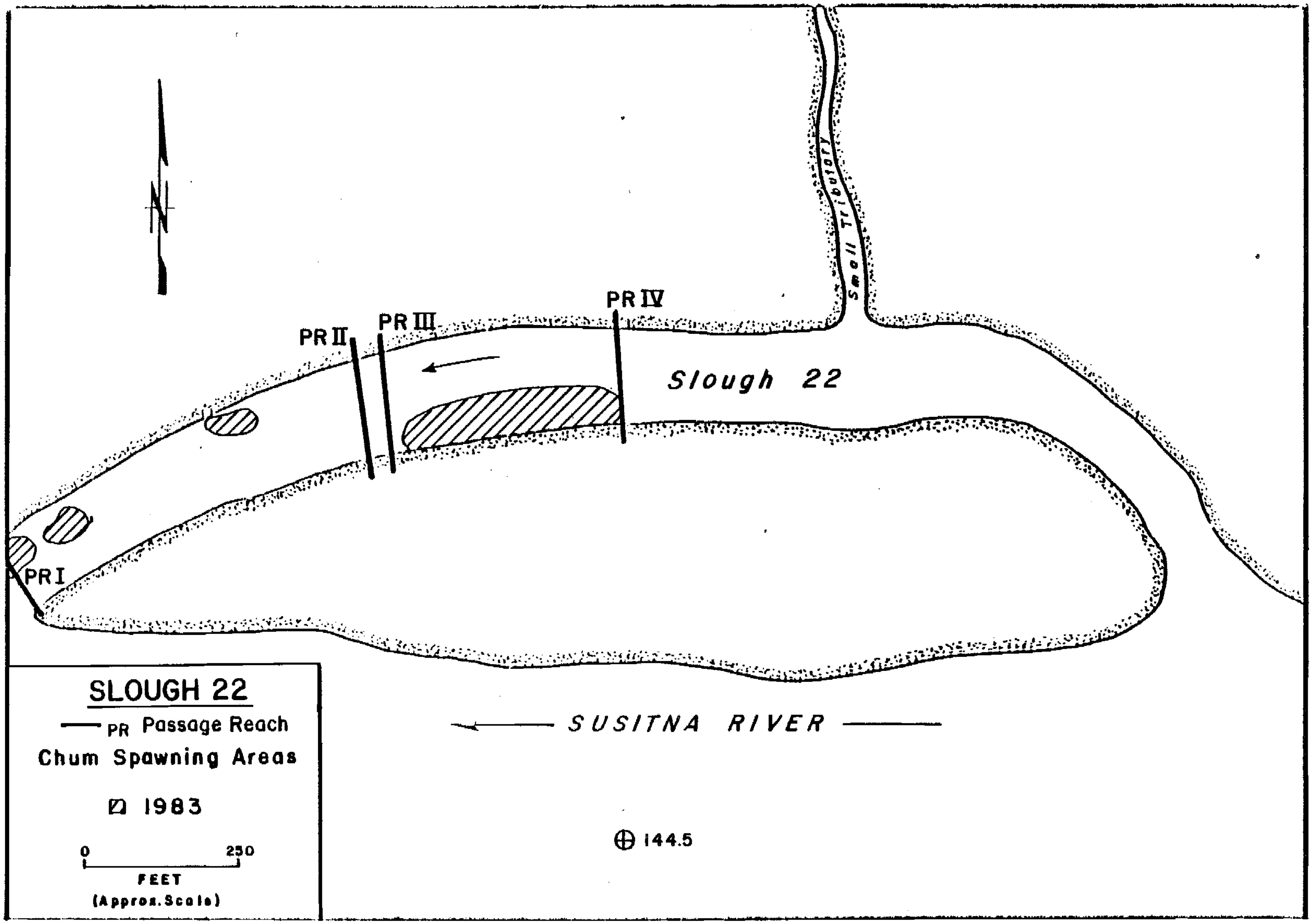

Figure 6-D-22. Chum salmon spawning areas, Slough 22, 1983.

Appendix 6-E

Thalweg Profiles of Sloughs and Side Channels

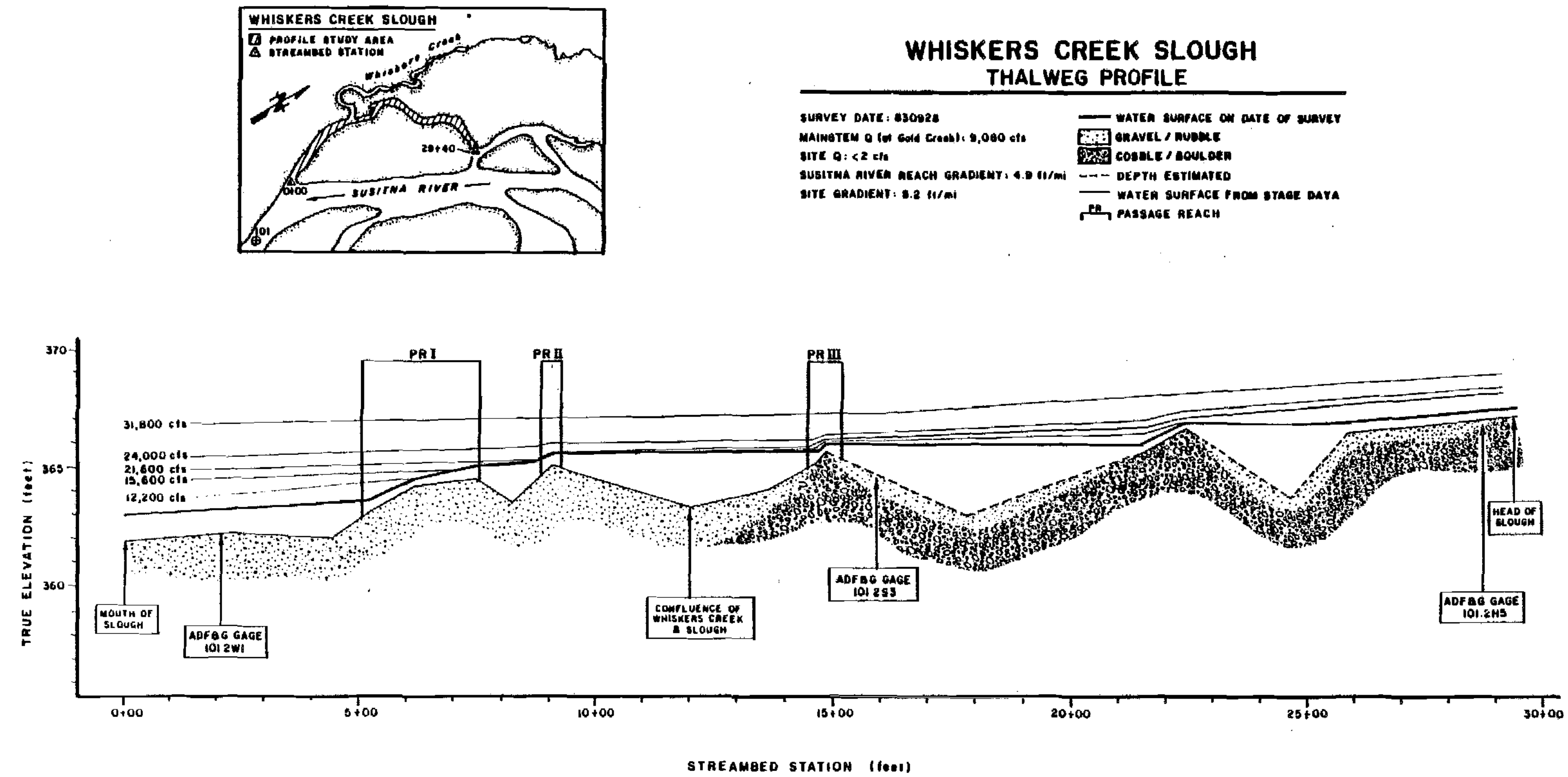

Figure 6-E-1. Thalweg profile of Whiskers Creek Slough.

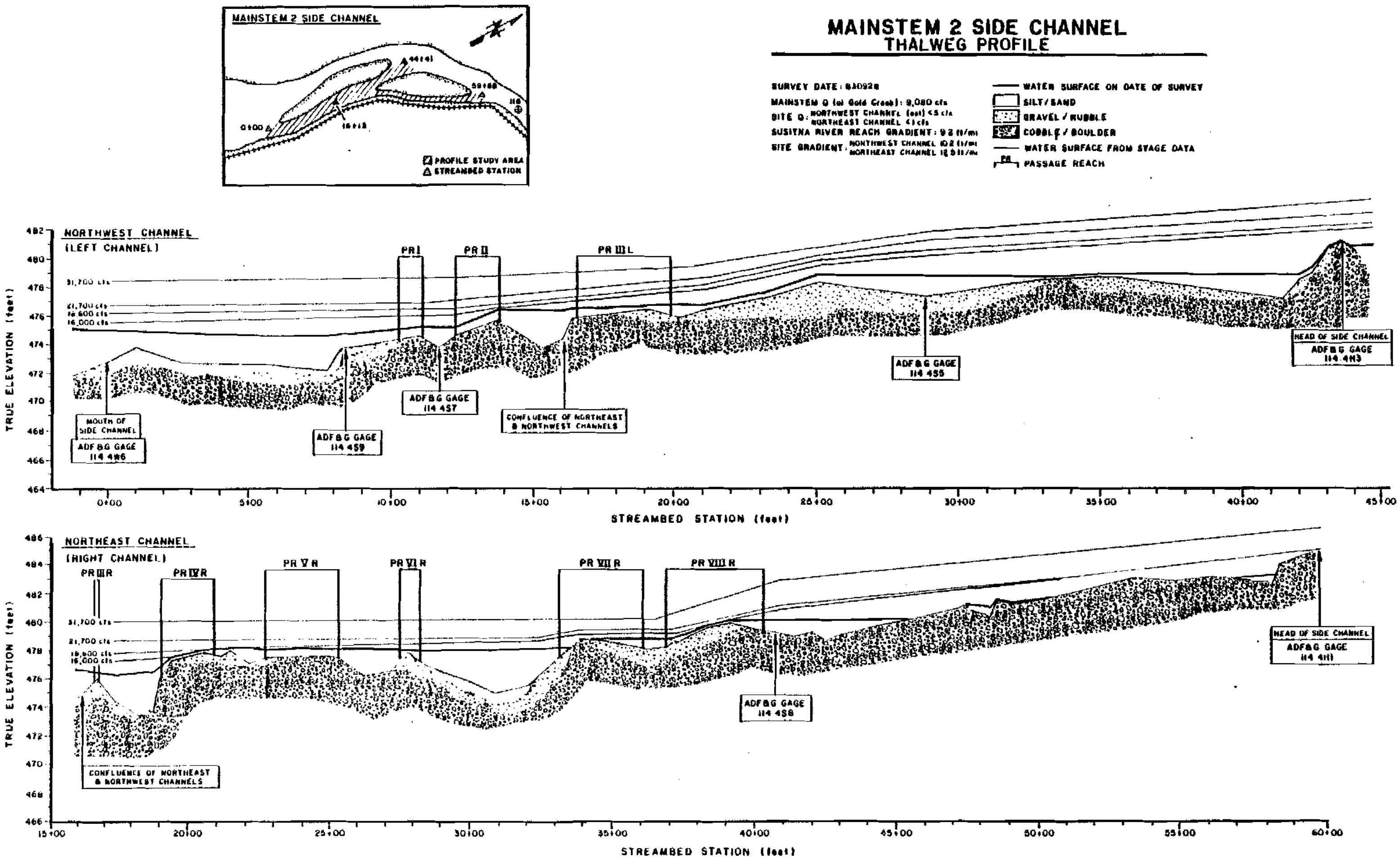

Figure 6-E-2. Thalweg profile of Mainstem 2 Side Channel.

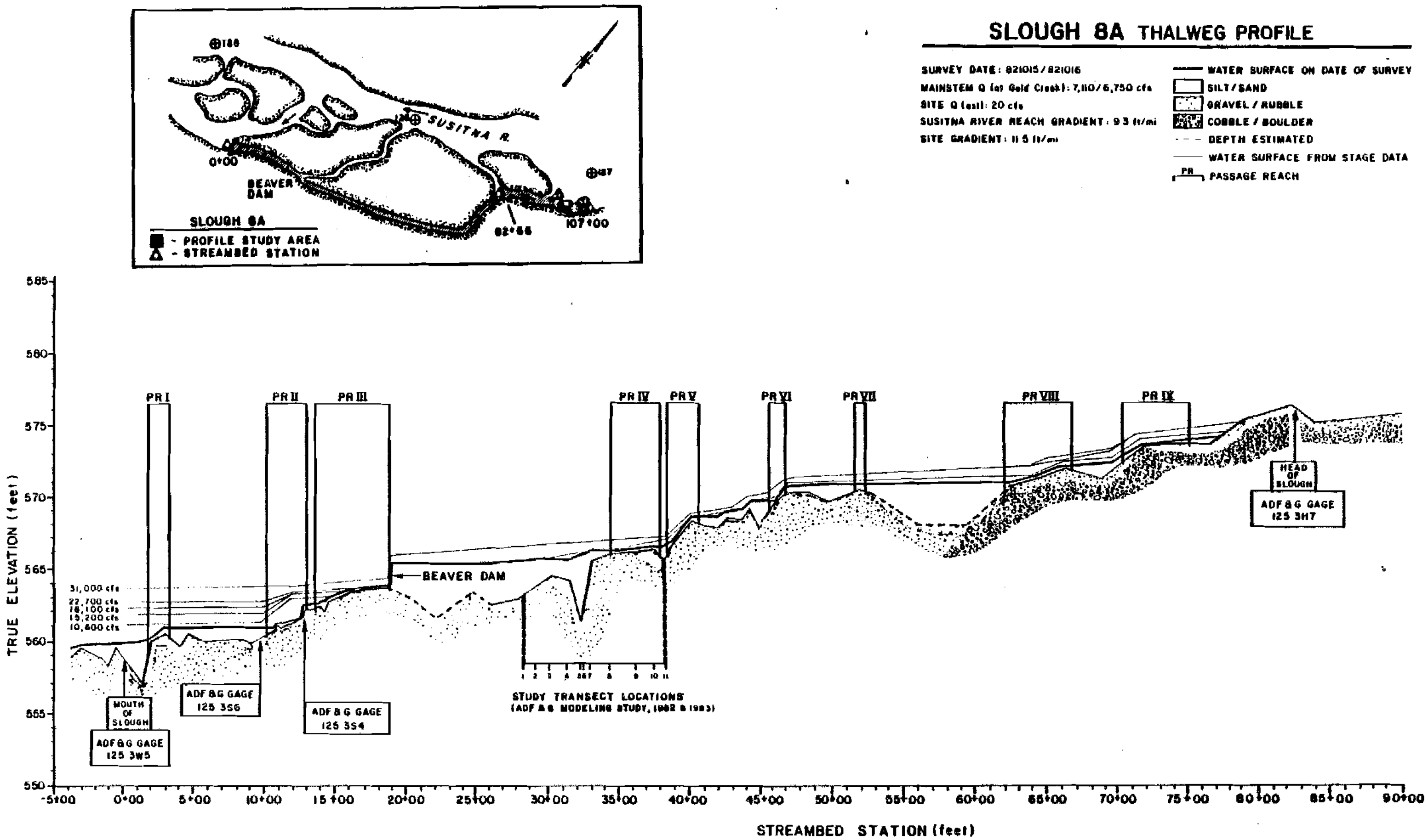

Figure 6-E-3. Thalweg profile of Slough 8A.

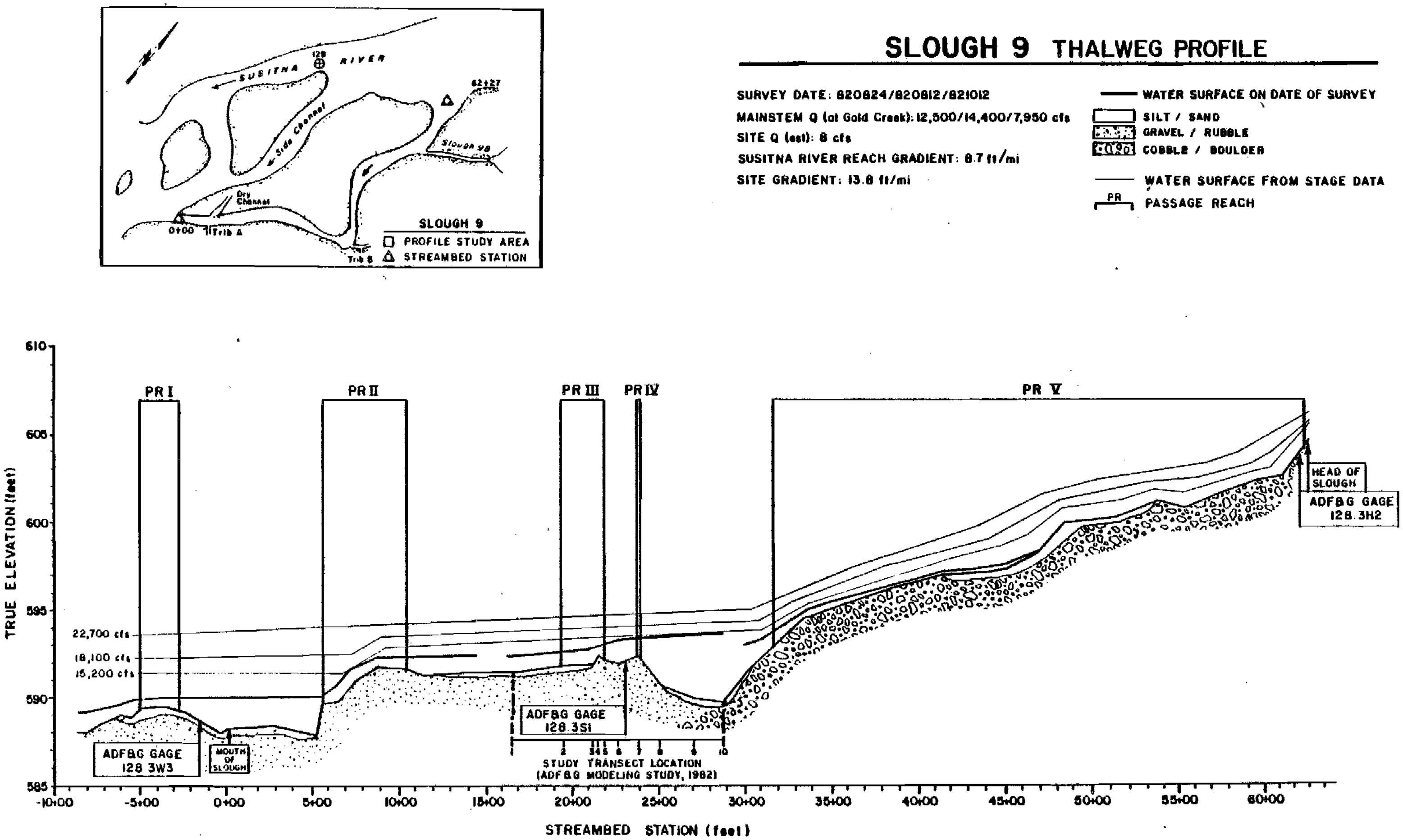

Figure 6-E-4. Thalweg profile of Slough 9.

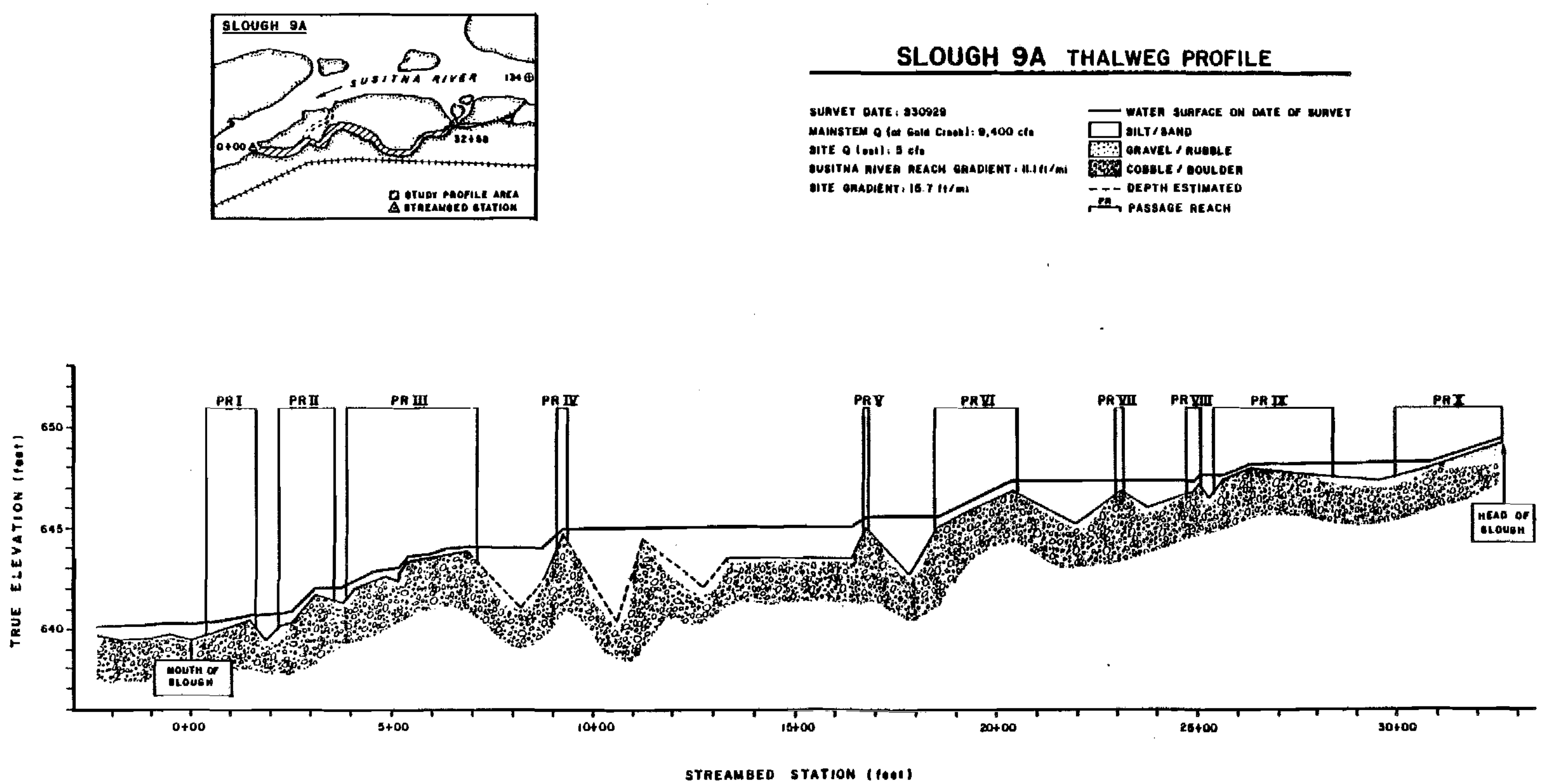

Figure 6-E-5. Thalweg profile of Slough 9A.

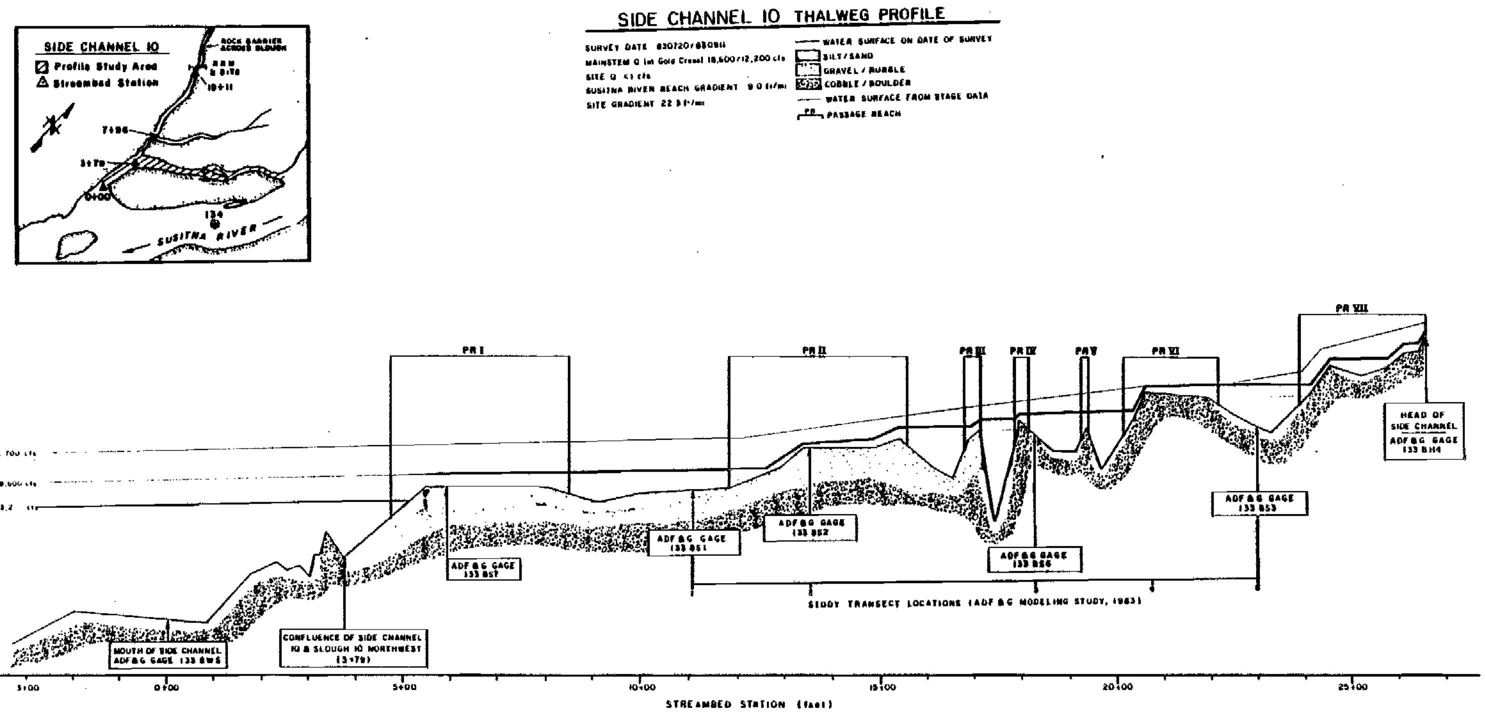

Figure 6-E-6.. Thalweg profile of Side Channel 10.

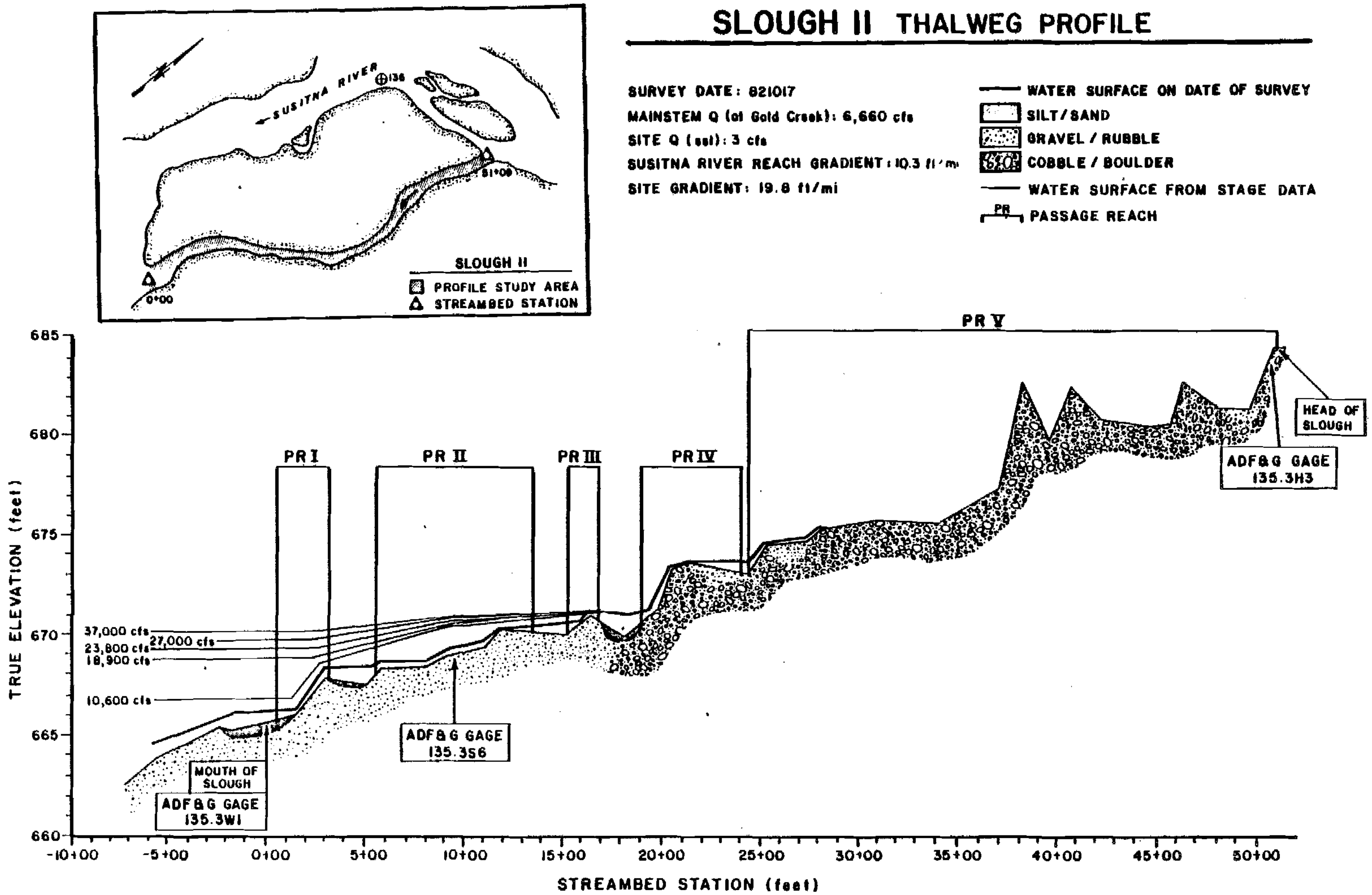

Figure 6-E-7. Thalweg profile of Slough 11.

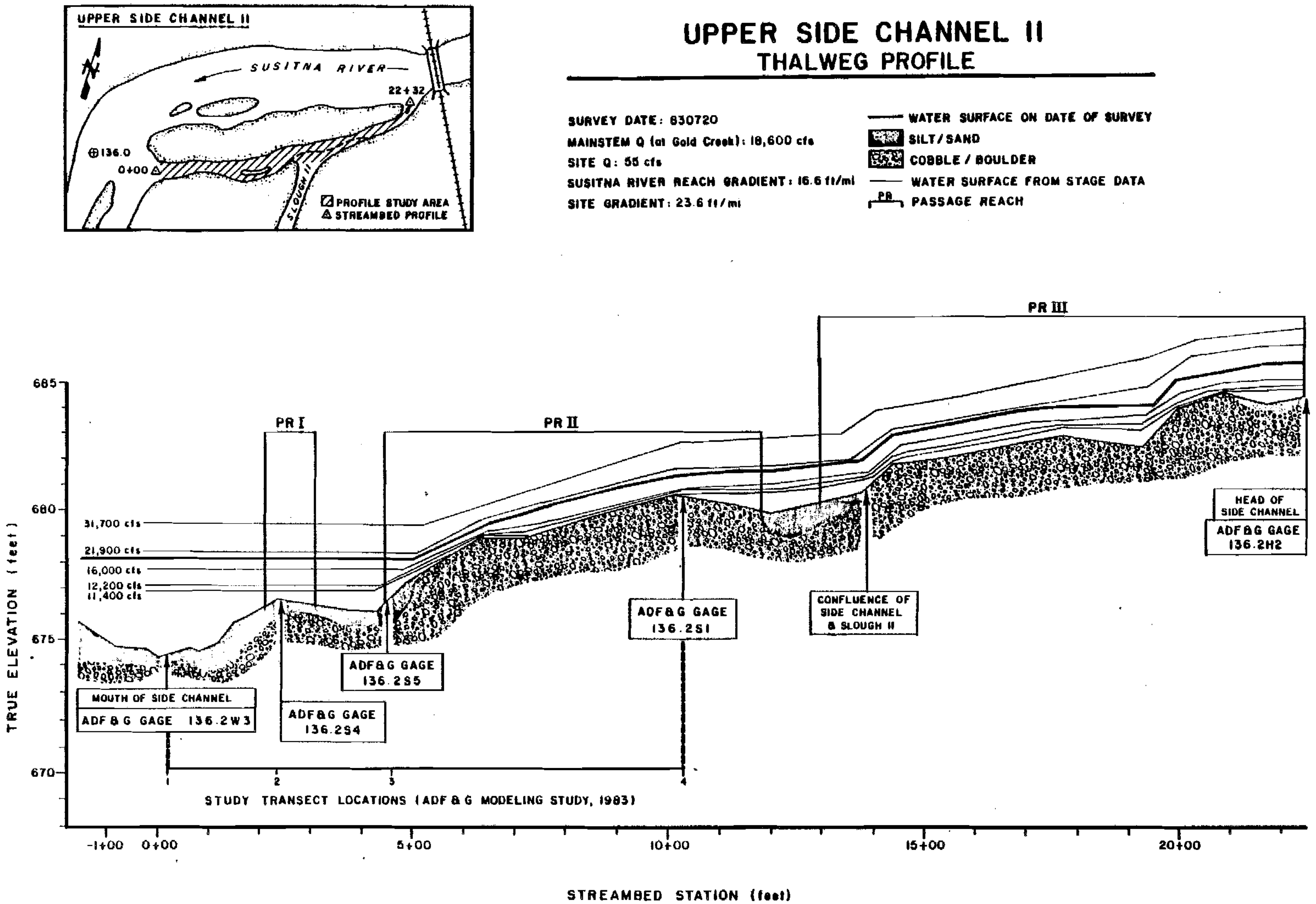

Figure 6-E-8. Thalweg profile of Upper Side Channel 11.

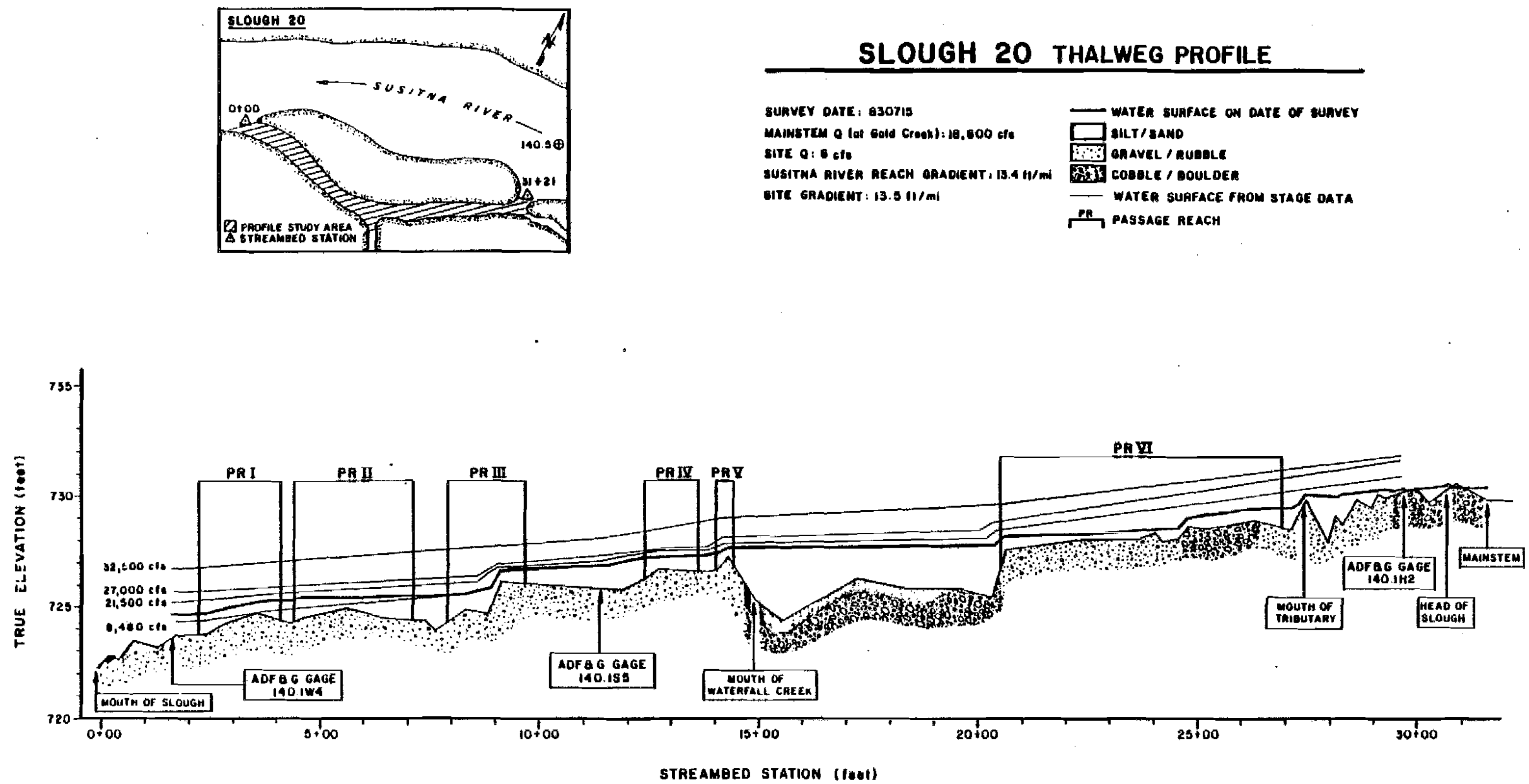

Figure 6-E-9. Thalweg profile of Slough 20.

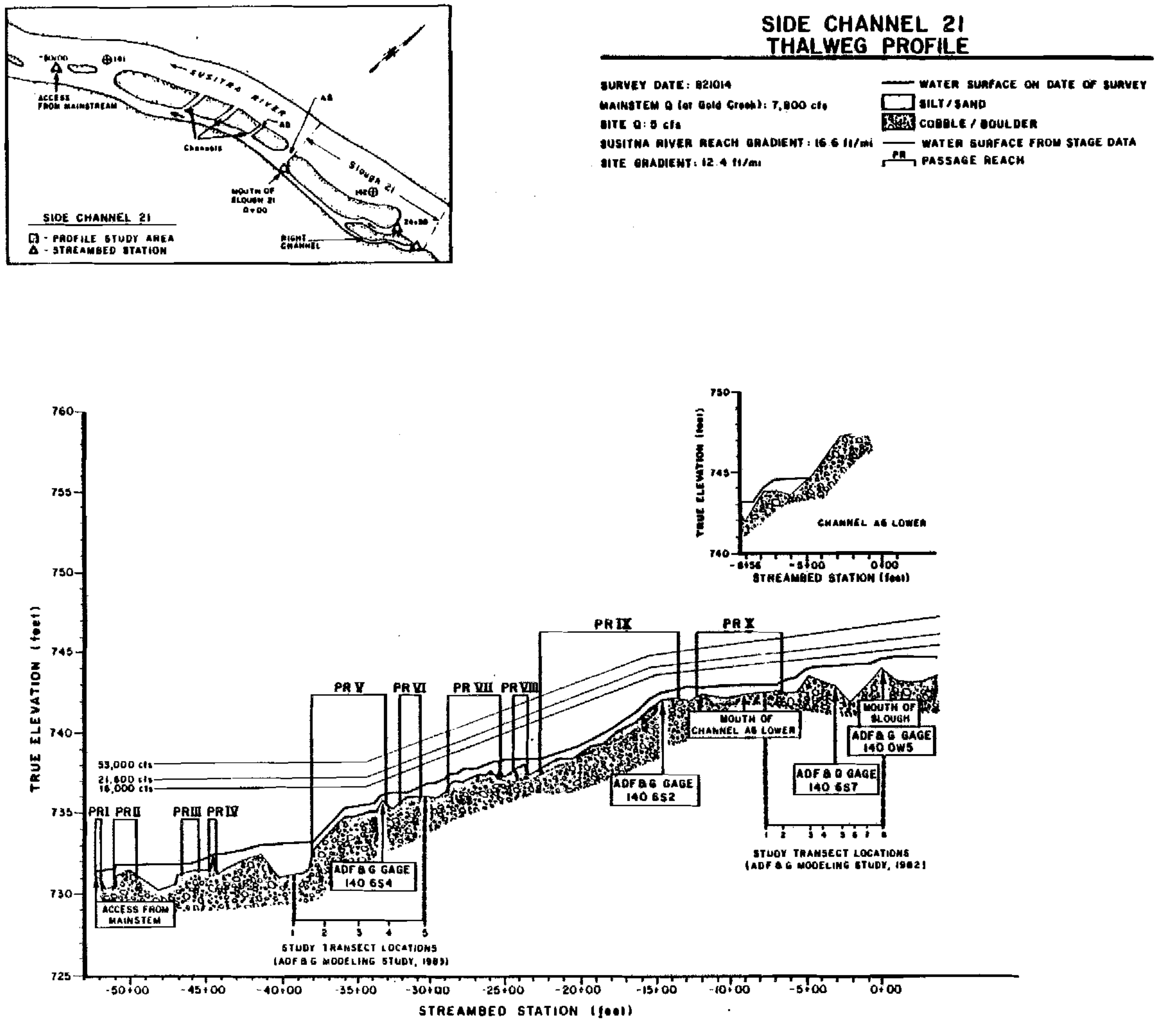

Figure 6-E-10. Thalweg profile of Side Channel 21.

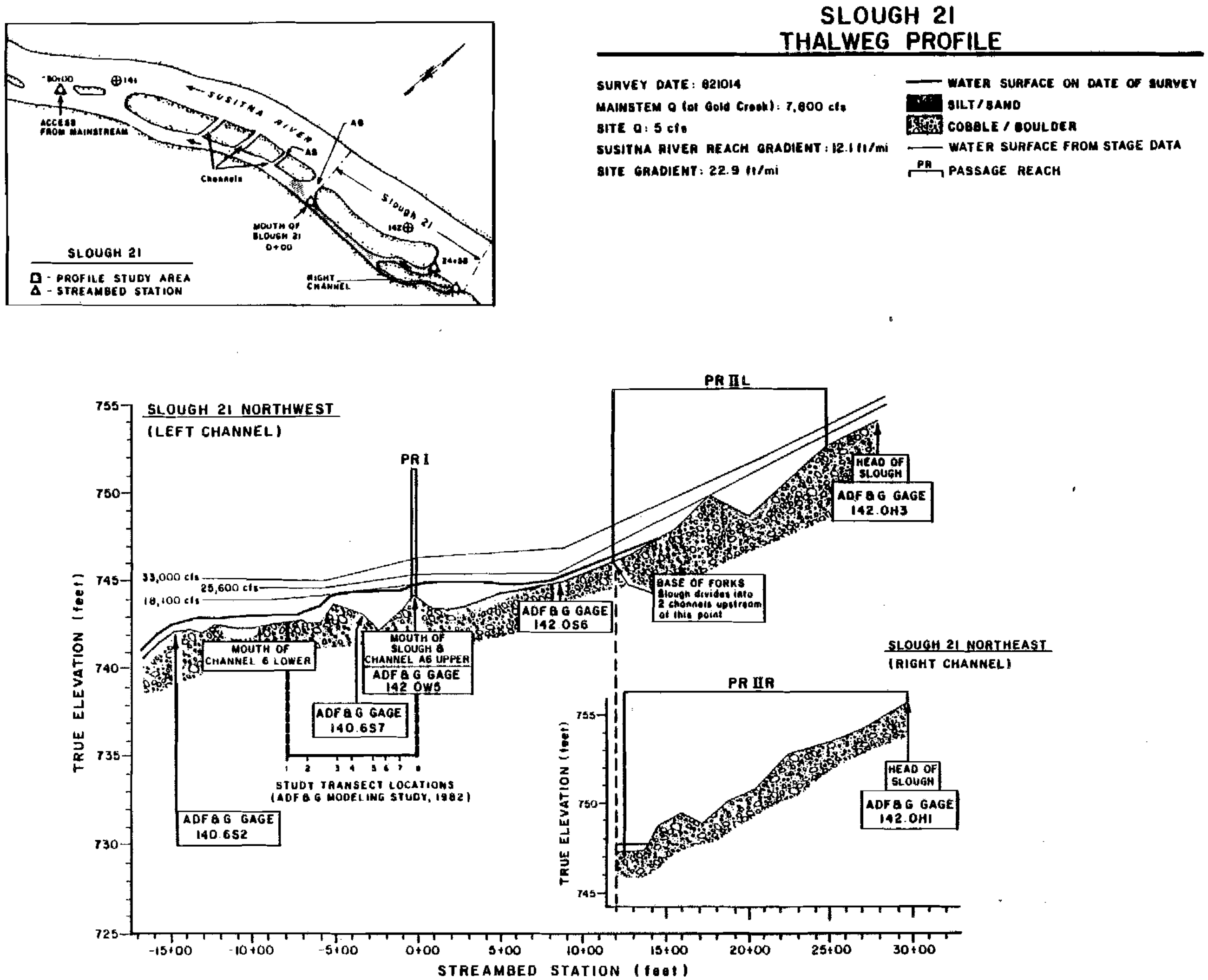

Figure 6-E-11. Thalweg profile of Slough 21.

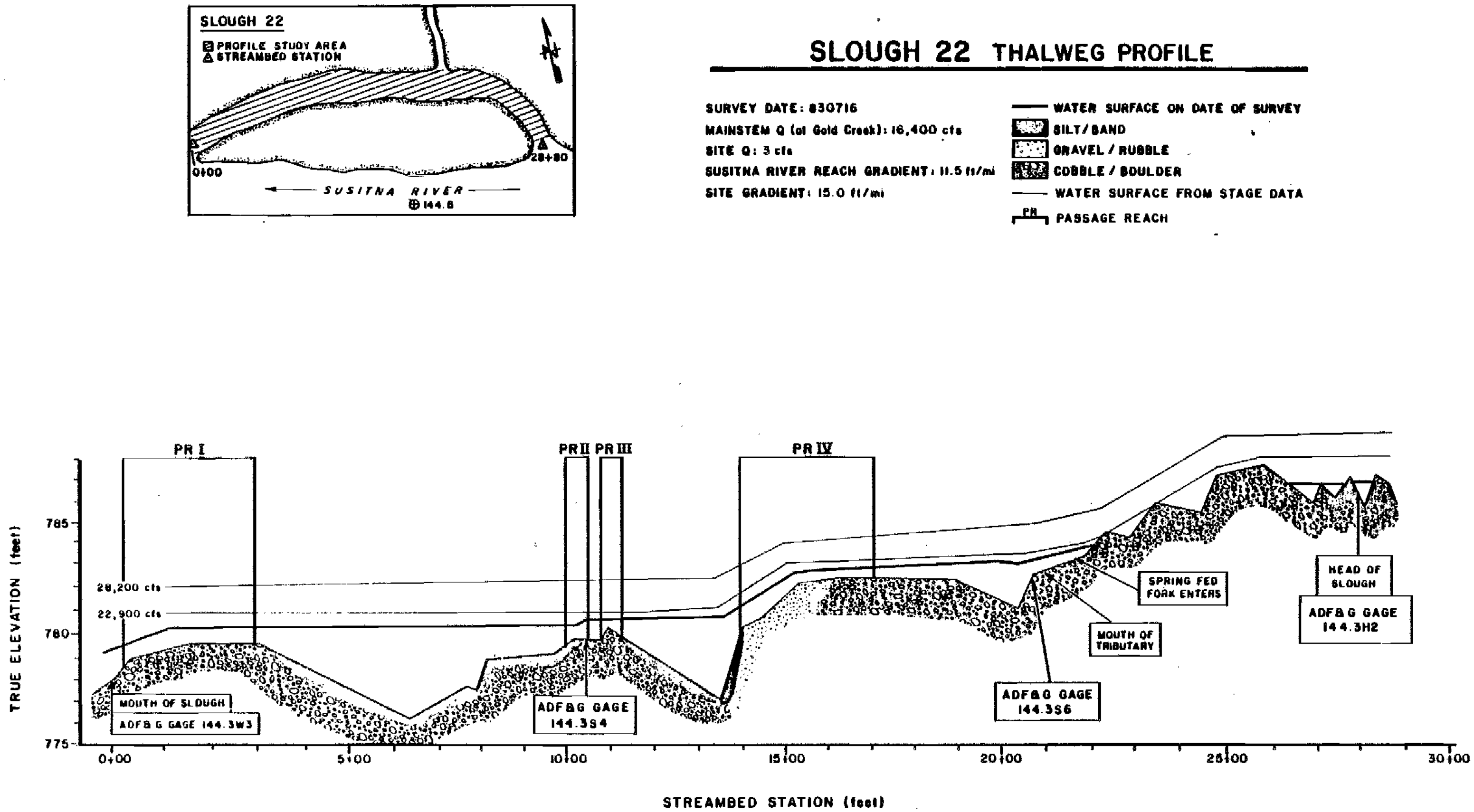

Figure 6-E-12. Thalweg profile of Slough 22.