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SUSITNA HYDROELECTRIC PROJECT

FEDERAL ENERGY REGULATORY COMMISSION
PROJECT No. 7114

INSTREAM FLOW RELATIONSHIPS REPORT SERIES

PHYSICAL PROCESSES OF THE MIDDLE SUSITNA RIVER

TECHNICAL REPORT No. 2

PREPARED BY

R & M CONSULTANTS, INC. &
WOODWARD-CLYDE CONSULTANTS

UNDER CONTRACT TO

HARZA-EBASCO
SUSITNA JOINT VENTURE

FINAL REPORT

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NOTICE

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

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PREFACE

This is the second technical report of the Instream Flow Relationships Study technical report series prepared for the Susitna Hydroelectric Project. The primary purpose of the Instream Flow Relationships Report and its associated technical report series is to present technical information and data to facilitate the settlement process. These reports are specifically intended to identify the relative importance of interactions among the primary physical and biological components of aquatic habitat. The presentation is primarily limited to the Middle Susitna River, the reach from the mouth of Devil Canyon downstream to the confluence with the Chulitna River. This section of the river is also referred to herein as "the middle reach". It encompasses river miles (RM) 151 to 99, the downstream section of river in which the aquatic habitat will be most affected by construction and operation of the Susitna Hydroelectric Project. Discussion is also presented for sedimentation that would occur in the Watana and Devil Canyon Reservoirs. The two reservoirs constitute the impoundment zone and extend from RM 151 to RM 230.

The Instream Flow Relationships Report and its associated technical report series are not intended to be an impact assessment. However, these reports present a variety of natural and with-project relationships that provide a quantitative basis to compare alternative streamflow regimes, conduct impact analyses, and prepare mitigation plans.

The technical report series is based on the data and findings presented in a variety of baseline data reports. The Instream Flow Relationships Report and its associated technical report series provide the methodology and appropriate technical information for use by those deciding how best to operate the proposed Susitna Hydroelectric Project for the benefit of both power production and downstream fish resources. The technical report series is described below.

Technical Report No 1. Fish Resources and Habitats in the Middle Susitna River. This report consolidates information on the fish resources and habitats in the Talkeetna-to-Devil Canyon reach of the Susitna basin available through June 1984 that is currently dispersed throughout numerous reports.

Technical Report No 2. Physical Processes Report. This report describes naturally occurring physical processes within the Talkeetna-to-Devil Canyon river reach pertinent to evaluating project effects on riverine fish habitat.

Technical Report No 3. Water Quality/Limnology Report. This report consolidates existing information on water quality in the Susitna basin and provides technical discussions of the potential for with-project bioaccumulation of mercury, influences on nitrogen gas supersaturation, changes in downstream nutrients and changes in turbidity and suspended sediments. This report is based principally on data and information that are available through June 1984.

Technical Report No 4. Instream Temperature Report. This report consists of three principal components: (1) reservoir and instream temperature modelling; (2) selection of temperature criteria for Susitna River fish stocks by species and life stage; and (3) evaluation of the influences of with-project stream temperatures on existing fish habitats and natural ice processes.

Technical Report No 5. Aquatic Habitat Report. This report describes the availability of various types of aquatic habitat in the Talkeetna-to-Devil Canyon river reach as a function of mainstem discharge.

Technical Report No. 6, Ice Processes Report. This report describes the naturally-occurring ice processes in the middle river, anticipated changes in those processes due to project construction and operation, and discusses effects of naturally occurring and with-project ice conditions on fish habitat.

1.0 INTRODUCTION

1.1 Purpose

This report was designed to bring together the available information on sedimentation, stream channel stability and slough hydrology that has been collected in the Middle Reach of the Susitna River, and to discuss the changes likely to occur due to construction and operation of the Susitna Hydroelectric Project. The Middle Reach encompasses the river from Talkeetna, at river mile (RM) 99, to the outlet of Devil Canyon at RM 151. This is the section of the river downstream of the impoundments that will be most affected by the construction and operation of the Susitna Hydroelectric Project. Also included in this report is discussion of reservoir sedimentation within Watana and Devil Canyon Reservoirs, which extend from RM 230 to RM 151.

The with-project conditions discussed in this report are based on analyses conducted for a two-dam, two-stage development. Watana Dam was to be constructed first, followed by construction of Devil Canyon Dam. However, in April 1985, the APA proposed that the Susitna Hydroelectric Project be changed from the two-dam, two-stage development to a two-dam, three-stage development (APA 1985). Under the proposal, a 705-foot high material-fill dam will be built during Stage 1 development at Watana (RM 184). Stage 2 includes the construction of a 646-foot concrete-arch dam, with a fill saddle dam at Devil Canyon (RM 152). Stage 3 development will raise the Stage 1 Watana dam 180 feet to a crest height of 885 feet. Stage 2 and 3 developments will result in the two-dam system described in the FERC license application (APA 1983a).

Until the Stage 3 development is completed, with-project conditions will differ from those under the two-stage development, primarily due to the smaller capacity of the Stage 1 Watana Reservoir. The Stage 1 Watana Dam will be large enough so that reservoir sedimentation estimates will be very similar. However, reservoir releases will be greater in late summer since the reservoir will tend to fill earlier in the year. The higher flows may have some effect on channel stability and slough hydrology.

While these differences are not explicitly stated in this report, they may be estimated from the information presented.

1.2 Organization

Following a brief review of environmental effects downstream of other large hydropower projects in the Introduction, the next three sections of the report review pertinent Susitna Hydroelectric Project studies to date on specific types of physical processes. They discuss the effects of those processes on the aquatic habitat in the Susitna River. Section 2 addresses sedimentation processes in the reservoir, Section 3 deals with stability of channels in the Middle Reach downstream of the project, and Section 4 discusses groundwater upwelling and local surface runoff as related to aquatic habitat in sloughs downstream of the project. Section 5 presents a summary of the three types of processes and the specific project effects. References are listed in Section 6.

1.3 Impacts Downstream of Other Projects

Construction of dams at Watana and Devil Canyon would affect the terrestrial and aquatic habitat downstream of Devil Canyon, with possible effects on fish, riparian vegetation, and wildlife. The effects on the physical processes of sedimentation (reservoir and stream channel) and groundwater upwellings are the focus of this report. The following descriptions of environmental impacts downstream of similar projects introduce the subject of downstream effects of dams on these processes.

Kellerhals and Gill (1973), Petts (1977), Taylor (1978) and Baxter and Glaude (1980) have summarized channel response to flow regulation. Operation of reservoirs significantly alters the flow regime. There is often an increase in the diurnal variation of flow due to the variation in the amount of water passing the turbines in order to follow the load demand. Annual peak discharges are reduced not only due to storage, which allows no overflow over the spillway, but also due to the surcharge storage provided by the rise in water level above the spillway crest. Routing through a reservoir with no available storage may reduce some flood peaks by over 50% (Moore, 1969), depending on the characteristics of the spillway, reservoir, and flood hydrograph. The magnitude of the mean annual flood of the Colorado River below Hoover Dam has been reduced by 60% (Dolan, Howard, and Gallenson, 1974). The total volume of flow may be reduced due to the increase in time during which seepage and evaporation losses may occur. Base flow tends to be increased due to seepage and to minimum releases to the channel below the dam.

Reservoirs with a large storage capacity may trap and store over 95% of the sediment load transported by the river (Leopold, Wolman, and Miller, 1964). Although reservoir shape, reservoir operation, and sediment characteristics have some influence (Gottschalk, 1964), the actual percentage depends primarily on the storage capacity-inflow ratio (Brune, 1953).

The effect of dams on the sediment load must be considered in relation to changes in river sediment transport capacity, flow regime, channel morphometry, and tributary inflow. Tributaries which transport large quantities of sediment into a regulated stream with reduced capacity to flush away sediments may stimulate mainstem aggradation, an increase in bed slope of the tributary, and trenching of the deposit to form a channel that is in quasi-equilibrium with the flow regime (King, 1961; Kellerhals, Church and Davies, 1977). A reduced water-surface elevation in the mainstem also produces an increased hydraulic gradient at the tributary mouth. The increased gradient results in increased velocities, bank instability, possible major changes in the geomorphic character of the tributary stream, and increased local scour (Simons and Senturk, 1976).

All of the bedload entering a reservoir is deposited in the reservoir. This reduction in sediment supply is usually greater than the reduction in sediment-transport capacity. This deficit in sediment transport generally results in erosion downstream of the dam, except where an armor layer or an outcrop of bedrock occurs (Petts, 1977). Degradation will occur where the regulated flow has sufficient tractive force to initiate sediment movement in the channel (Gottschalk, 1964). Once the channel bed has been stabilized, either by armoring or by the exposure of bedrock, then the banks, which usually consist of finer material than the bed, begin to fail and the channel will widen. Where armoring or bedrock occur across the width of the channel, a simple adjustment will occur where streamflow is accommodated in the existing channel.

The sediment load plays an important role in the process of meander migration across alluvial plains by forming point bars from bed load deposition on the inside bank. These point bars are then aggraded to floodplain levels due to the deposition of suspended sediment in the emerging vegetation during peak flows. The reduction in sediment load may disrupt this process, with at least local ecological changes. Widening of channels at meander bends and lateral instability may also be expected (Kellerhals and Gill, 1973).

Maximum degradation normally occurs in the tailwater of the dam, but may extend downstream. Rates of degradation up to 15 cm per year have been observed in sand-bed rivers, both in the United States (Leopold, Wolman, and Miller, 1964) and in Europe (Shulits, 1934). Channel adjustment to bed degradation and the associated reduction in slope was observed for nearly 250 km below Elephant Butte Dam (Stabler, 1925), also involving silt and sand size bed material. When an armored condition occurs where the river is unable to recharge itself to capacity, the river may pick up additional material downstream, as was observed on the Colorado River below Hoover Dam (Stanley, 1951).

The channel properties of gravel-bed rivers such as the mainstem of the Peace River in Alberta appear to be controlled by floods with a recurrence interval of 1.5 to 2 years (Bray, 1972). Regulation reduces these flows, effectively reducing the size of the gravel-bed river without immediately changing the channel, but certain channel properties will adjust to the channel regime over a longer period of time. On the Peace River, the entrenched layer of the channel, the proximity of bedrock, and the resistant bed material preclude significant changes in width and depth relationships or in the slope (except near tributary junctions), but deep scour holes at bends will fill to some degree, and gravel bars exposed above the new high water mark will have emerging vegetation (Kellerhals and Gill, 1973).

Vegetation encroachment on the higher elevations of the gravel bars downstream of a dam can be expected due to the reduced summer streamflows and the lower flood peaks, and in time could encroach on present high water channels (Tutt, 1979; Kellerhals, Church and Davies, 1977). The effect of the additional vegetation would be to increase the channel roughness, thus decreasing the channel water conveyance. The channel size and capacity could gradually decrease due to vegetation encroachment, deposition of suspended load in the newly vegetated areas, accumulation of material from the valley walls and deposition of sediment brought in by the tributaries. During periods of high flow, higher river stages could be expected.

The W.A.C. Bennett Dam on the Peace River had a dramatic unplanned impact on the Peace-Athabasca Delta (Baxter and Glaude, 1980). The delta is a series of marshes interspersed with lakes and ponds of various sizes. Before the dam was built, the delta was maintained in this state due to almost annual flooding, which prevented vegetation typical of drier ground from being able to establish itself. The hydrological situation itself was complex. The Peace River, passing to the north of the delta, contributed little to the actual flooding, but its flood waters blocked the exit of the Athabasca River, which entered from the south and caused the actual flooding. After construction of Bennett Dam, the delta started drying up, with dry-ground vegetation establishing itself. The effect of the dam was initially obscured due to lower than normal precipitation for some years previously, but it was eventually concluded that the dam was at least a contributing factor, as flood levels on the Peace River were lowered, resulting in the Peace River no longer blocking the exit of the Athabasca River.

1.4 Data Sources

1.4.1 Streamflow

Streamflow records are available from the U.S. Geological Survey (U.S.G.S.) for various stations on the river and its tributaries. The periods of available records are shown in Table 1.1. The stream gaging locations are shown in Figure 1.1. The mean annual and seasonal flows and floods of selected recurrence intervals are shown in Table 1.2.

1.4.2 Suspended Sediment

Suspended sediment data are available from the USGS at ten sampling stations and are also shown in Table 1.1.

The mean annual suspended loads are about 5,660,000 tons, 7,260,000 tons and 16,714,000 tons, respectively, for the Susitna River near Cantwell, at Gold Creek and at Sunshine, 7,412,000 tons for the Chulitna River near Talkeetna and 1,642,000 tons for the Talkeetna River near Talkeetna.

The suspended sediment concentration for the Susitna River upstream from the confluence with the Chulitna River ranges from essentially zero milligrams per liter (mg/l) in winter to nearly 1,000 mg/l during summer floods. The Chulitna River, with 27 percent of its basin covered by glaciers, has recorded suspended concentrations up to 4,690 mg/l (Knott and Lipscomb, 1985).

1.4.3 Bedload and Bed Material

Limited bed load discharge data are available from the U.S.G.S. as are also shown in Table 1.1. Typical size distributions of the bedload are shown in Table 1.3.

A total of 48 bed material samples were collected from the mainstem and side channels of the Susitna River between the mouth of Devil Canyon (RM 150) and the confluence between the Susitna and Chulitna Rivers (RM 98.6) (Harza-Ebasco, 1984c). These samples were used to determine the size distributions by sieve analysis. Bed material size distribution had also been estimated in an earlier study (R&M Consultants, Inc. 1982b) by grid sampling techniques. Figures 1.2a and 1.2b show some examples of typical bed material. Average size distributions are shown in Table 1.3.

1.4.4 River Cross Sections

Cross sections of the Susitna River have been surveyed at 106 locations between RM 84.0 near Talkeetna and RM 150.2, about 1.3 miles upstream from the confluence with Portage Creek (R&M, 1981a; 1982c, 1984a). Cross sections at 23 locations also are available between RM 162.1 at Devil Creek and RM 186.8 at Deadman Creek (R&M, 1981a), all 23 of which are in the impoundment zone.

TABLE 1.1 - STREAMFLOW AND SEDIMENT DATA, SUSITNA RIVER BASIN

Gaging Station	USGS Gage No.	Drainage Area, mi^2 (km^2)	Streamflow Period of Record	Suspended Sediment Number of Samples	Suspended Sediment Period of Record	Bedload Number of Samples	Bedload Period of Record
Susitna River near Cantwell	15291500	4,140 (10,720)	5/61-9/72 5/80-Pres.	43	62-72,82	--	--
at Gold Creek	15292000	6,160 (15,950)	8/49-Pres.	375	49,51-58,62 67-68,74-83	3	7/81-9/81
near Talkeetna	15292100		-	27	6/82-10/83	29	6/82-2/84
right channel below Chulitna R. near Talkeetna	15292439		-	5	5/83-10/83	7	5/83-2/84
left channel below Chulitna R. near Talkeetna	15292440		-	5	5/83-10/83	7	5/83-2/84
at Sunshine	15292780	11,100 (28,750)	5/81-Pres.	53	71,77,81-84	34	7/81-2/84
at Susitna	15294350	19,400 (50,250)	10/74-Pres.	44	75-83	--	--
Chulitna River near Talkeetna	15292400	2,570 (6,656)	2/58-9/72, 5/80-Pres.	53	58-59,67-72, 80-83	18	7/81-9/82
below canyon near Talkeetna	15292410		-	13	83	15	3/83-2/84
Talkeetna River near Talkeetna	15292700	2,006 (5,196)	10/74-Pres.	133	66-83	33	7/81-2/84

SOURCE: Table reproduced from Wang, Bredthauer, and Marchegiani (1985)

TABLE 1.2 - MEAN FLOWS AND FLOODS
SUSITNA RIVER BASIN

Gaging Station	Periods of records used in analysis	Mean Flows, cfs (m^3/sec)			Max. Floods, cfs (m^3/sec)		
		Summer[1/]	Winter[2/]	Annual	2-year	10-year	50-year
Susitna River near Cantwell	1962-72 81-83	11,900 (337)	1,000 (28)	6,400 (181)	32,000 (906)	54,000 (1530)	65,000 (1840)
at Gold Creek	1950-83	17,800 (504)	1,600 (45)	9,720 (275)	48,000 (1,360)	73,700 (2,090)	97,700 (2,770)
at Sunshine	1982-83	45,600 (1,290)	4,500 (127)	25,100 (710)	142,000 (4,020)	182,000 (5,150)	212,000 (6,000)
Chulitna River near Talkeetna	1959-72 81-83	16,200 (459)	1,400 (40)	8,800 (249)	42,000 (1,190)	62,000 (1,760)	87,000 (2,460)
Talkeetna River near Talkeetna	1965-83	7,300 (207)	700 (20)	4,000 (113)	27,500 (780)	49,000 (1390)	61,000 (1730)

1/ May through October

2/ November through April

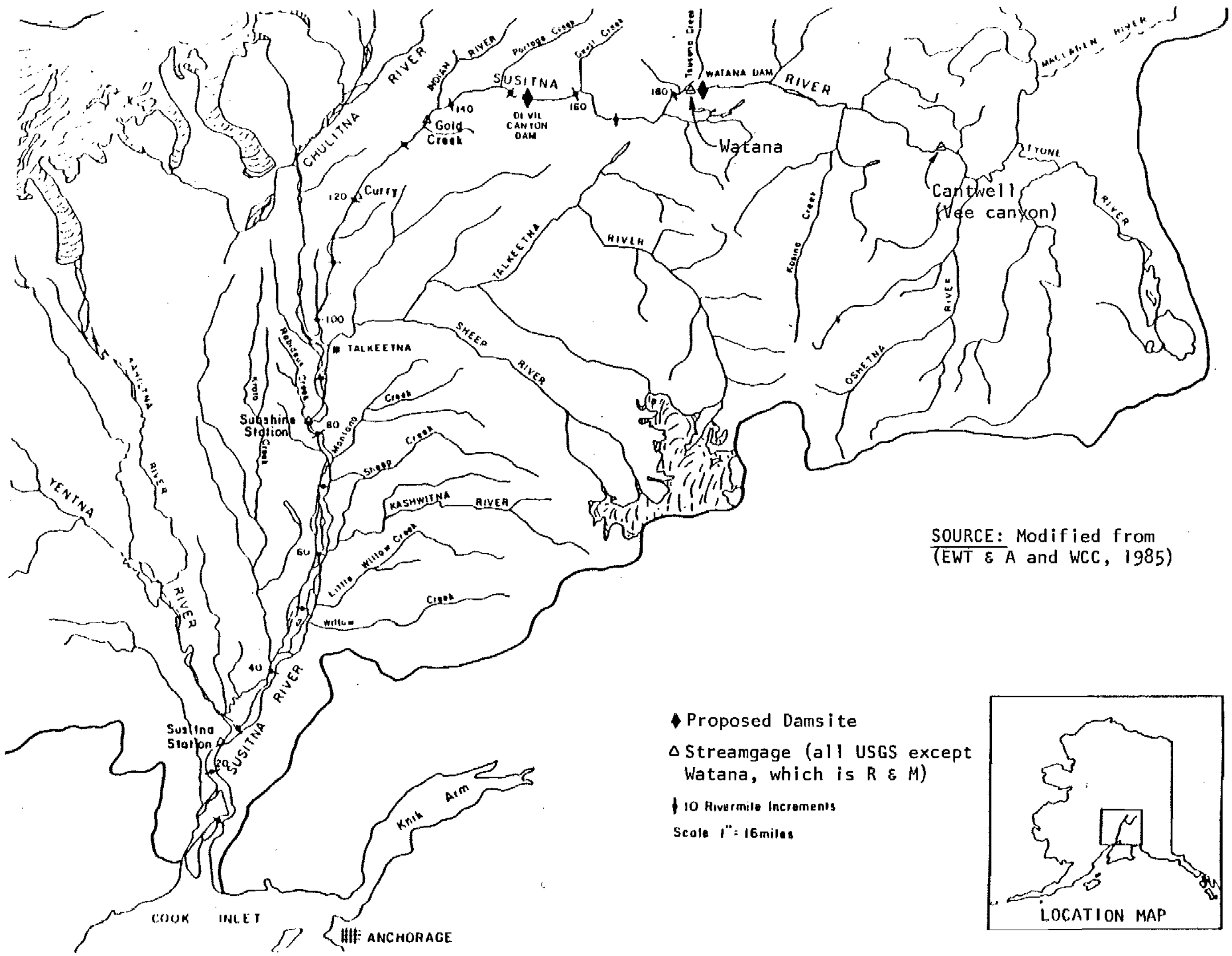
SOURCE: Wang, Bredthauer, and Marchegiani (1985)

TABLE 1.3 - SIZE DISTRIBUTION OF BEDLOAD AND BED MATERIAL, 1982 DATA

	Size Distribution of Particles %					
	Bedload			Bed Material		
Gage	Sand	Gravel	Cobble	Sand	Gravel	Cobble
Susitna River near Talkeetna	78	16	6	0	30	70
Chulitna River near Talkeetna	41	58	1	26	64	10
Talkeetna River near Talkeetna	75	23	2	5	52	43
Susitna River at Sunshine	56	42	2	5	66	29

Source: Knott and Lipscomb (1983)
Harza-Ebasco Susitna Joint Venture (1984)

(Table reproduced from: Wang, Bredthauer, and Marchegiani (1985)



SUSITNA RIVER STREAMGAGE LOCATIONS

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FIGURE 1.1

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(a) On a gravel bar near the Confluence of the Susitna and Chulitna Rivers

(b) The Susitna River near Talkeetna River bed under 1 ft. (0.3m) of water

Fig. 1.2 - Typical River Bed Material

SOURCE: Wang, Bredthauer, and Marchegiani (1985)

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2.0 RESERVOIR SEDIMENTATION

2.1 Factors Affecting Reservoir Sedimentation

The effect of the project on sediment transport in the Susitna River is of concern as it relates to aquatic habitat. This section briefly describes the processes of reservoir sedimentation and details the factors which affect trap efficiency. Trap efficiency is the percentage of incoming sediment which is retained in the reservoir. Section 3 discusses downstream project effects on channel stability, which are derived from changes to the flow and sediment regimes of the river. Changes to the sediment regime result from trapping all the bedload sediment and a large proportion of the suspended sediment which enters the reservoir, thus substantially reducing the sediment supply downstream. Sediment effects on water quality are addressed in Report Number 3, the Water Quality/Limnology Report.

Trap efficiency of a reservoir depends on the sediment particle fall velocity and on residence time of the sediment within the reservoir. Fall velocity is determined by a number of factors, including particle size and shape, particle density, sediment chemical composition, water temperature, water viscosity and sediment concentration (R&M 1982d; PN&D and Hutchison 1982; Jokela, Bredthauer and Coffin 1983). The chemical composition may cause electrochemical interactions which lead to particle aggregation or dispersion. Small particles may aggregate into clusters which have settling properties similar to larger particles and fall more rapidly (R&M 1982d). A review of data from glacial lakes (R&M 1982d) indicated that particle sizes of 2 microns (0.002 mm) and less would pass through the reservoir.

Another report (PN&D and Hutchison, 1982) concluded that particles smaller than 3 to 4 microns would likely remain in suspension and be carried through the reservoir. Wind mixing would be significant enough to retain particles of diameter 12-microns and less in suspension above the

50-foot depth. Strong windstorms would cause re-entrainment of sediment, resulting in short-term increases in suspended sediment at the reservoir edges.

Data collected at Eklutna Lake (R&M 1982a, 1985b), approximately 100 miles south of the Watana damsite, indicate that the mean particle size of sediment carried through the lake is 3 to 4 microns equivalent diameter, with larger particles being deposited most rapidly and forming a delta.

Residence time of sediment within the reservoir is determined by the capacity-inflow ratio, by the reservoir geometry (plan shape and depth), and by size and location of reservoir outlets. Capacity-inflow ratio is the major factor, but it may be modified by "short-circuiting" of sediment-laden inflow to the outlet if little mixing occurs. Shallow, open lakes are more conducive to formation of internal currents (due to winds) than are deep, confined lakes. These internal currents slow down the settling processes, especially for fine, slowly-falling particles. Deep reservoirs with large surface areas are almost continuously subjected to mixing processes generated by climatic influences (wind and surface energy transfer) and by inflowing and outflowing currents. This mixing creates a substantial amount of turbulence which tends to keep the fine sediments in suspension (PN&D and Hutchison 1982). Location and size of reservoir outlets also affect trap efficiency, with bottom outlets more effective in removing the higher sediment concentrations near the bottom (R&M 1982d).

Short-circuiting of inflow may occur if hydraulic conditions in the reservoir are such that the inflow plume travels to the dam outlet and is discharged with little interaction having taken place with the ambient water. The plume may travel through the reservoir as overflow, underflow or interflow, depending on whether it follows a top, bottom, or middle layer in the reservoir depth. The flow depth is determined by the relative densities of the stream water and the lake water, the equilibrium depth being that where densities of the two are the same. Density is primarily a function of temperature and suspended-sediment concentration and to some extent of dissolved-solids concentration. Frequency, duration, and intensity of underflows and interflows have also been attributed to lake bathymetry, especially near the stream mouth (R&M 1982d). Illustrations of the variation of turbidity (and thus of suspended sediment concentration) versus depth and time are shown for Eklutna Lake for 1984 in Figure 2.1. An example of interflow is seen during mid-August in Figure 2.1.

Another process which can affect sediment levels in a reservoir is slope failure and deposition from the surrounding banks. Soil stability is reduced by the reservoir raising the ground water table, especially when it also acts to thaw permafrost that had been binding the soil. The primary types of slope failure and subsequent erosion that are expected in the Watana Reservoir are shallow rotational slides and other shallow slides, mainly skin and bimodal flows (Acres American 1982). Devil Canyon Reservoir slopes are expected to be stable after impounding due to shallow overburden materials and stable bedrock.

Rotational slides are landslides with well-defined, curved shear surfaces, concave upward in cross-section. Skin flows are detachments of a thin veneer of vegetation and mineral soil, with subsequent movement over a planar, inclined surface. In the reservoir impoundment area, this usually indicates thawing of fine-grained overburden over permafrost. Bimodal flows along the reservoir shore are slides that consist of steep headwalls containing ice or ice-rich sediment. The ice-rich sediment retreats retrogressively through melting to form a debris flow which slides down the face of the headwall to its base (Acres American 1982).

The Alaska Power Authority (1983) made quantitative estimates of the increases in suspended sediments expected from skin slides, bimodal flows, and shallow rotational slides in the two reservoirs, including where they were likely to occur. A "worst case" scenario was assumed, in which $2x10^8$ cubic meters of unconsolidated materials would slide into the reservoirs. It was assumed that all particles less than or equal to 10 microns would become suspended in the water. This resulted in an estimate of 35 percent (by dry weight) of the material being suspended. Seventy-five percent of this suspended material was assumed to be trapped in the reservoir. This reduced to an estimated maximum yield of 33 million metric tons of suspended particulates which could pass through the reservoirs and on downstream. Most of this activity would probably occur during the first five years of reservoir operation.

2.2 Reservoir Sedimentation

2.2.1 General Approach

Suspended sediment loads at the Watana and Devil Canyon dam sites were estimated by interpolating the loads at the Cantwell (Vee Canyon) and Gold Creek gages on the Susitna River. Sediment trap efficiencies of the reservoirs were estimated by the Brune and Churchill curves (Harza-Ebasco, 1984c). Sediment deposits in Devil Canyon Reservoir were estimated for with- and without-Watana Reservoir conditions.

Bedloads were estimated as percentages of suspended sediment loads using available data at the Gold Creek, Talkeetna, and Sunshine gages on the Susitna River. All bedloads were assumed to be trapped by the reservoirs. Bedloads at Devil Canyon Reservoir were computed for with- and without-Watana Reservoir conditions.

2.2.2 Sediment Load

Sediment discharges at the Cantwell (Vee Canyon) and Gold Creek gages were computed by the sediment rating flow duration curves method. Suspended sediment discharges and the corresponding water discharges for the Cantwell (Vee Canyon) gage are shown in Figure 2.2. The data for the Cantwell (Vee Canyon) gage were grouped into three groups, each corresponding to the period from June to October, November to April, and May, in order to estimate sediment discharge during the summer, winter, and breakup periods. Only one sample was available for the November-April period and two samples for the May period. These data were insufficient to develop separate curves. Therefore, one sediment rating curve was fitted visually to all data points. Using this suspended sediment rating curve and the flow-duration curve for Vee Canyon on Figure 2.3, the mean annual suspended sediment discharge at the Cantwell (Vee Canyon) gage was computed to be about 5,660,000 tons/year.

Suspended sediment discharges and the corresponding water discharges for the Gold Creek gage are shown on Figure 2.4. The data for the Gold Creek gage, collected in the period from 1949 to 1982, were divided into three groups corresponding to June-October, November-April, and May periods. The points for the June-October and May periods indicated separate trend lines and were fitted with two curves. Limited data points were available for the low-flow period of November-April. These points appeared to be fitting the lower part of the May curve. Therefore, the May curve was used for the November-April period. The daily flow duration curves for the Gold Creek gage for the June-October and November-May periods were derived using the 1950-1982 flow data and are shown on Figure 2.5. The mean annual suspended sediment discharge at the Gold Creek gage was computed to be about 7,260,000 tons/year.

2.2.3 Reservoir Sediment Inflow

Suspended-sediment inflows to Watana and Devil Canyon Reservoir were computed by transposing sediment discharges at the Cantwell (Vee Canyon) and Gold Creek gages, whose locations bracket the two reservoirs. Sediment discharges at the two gages were assumed to follow the following exponential relationship (Vanoni; 1975):

$$\frac{q_{s2}}{q_{s1}} = \left(\frac{A_2}{A_1}\right)^n$$

in which:

q_{s1} = sediment discharge per unit drainage area (unit sediment discharge) at point 1

q_{s2} = unit sediment discharge at point 2

A_1 = drainage area for point 1

A_2 = drainage area for point 2

n = exponent

Using the unit sediment discharges at the Cantwell (Vee Canyon) and Gold Creek gages, exponent "n" in the above equation was computed to be -0.376. Thus, suspended-sediment discharge at the Watana damsite was computed to be 6,530,000 tons/year for the drainage area of 5,180 square miles. Assuming no Watana Reservoir, the suspended-sediment discharge at the Devil Canyon was computed to be 7,030,000 tons/year using a drainage area of 5,810 square miles.

Bedload discharge was estimated to be three percent of suspended-sediment discharge, based on the following analysis. Bedload and suspended sediment discharges for the Susitna River near Talkeetna were estimated to be 43,400 and 2,610,000 tons/year, respectively, for water year 1982. Thus, the bedload discharge is about 1.6 percent of suspended sediment discharge. For the Sunshine gage, bedload discharge is about 3.2 percent of suspended sediment discharge, based on the bedload and suspended sediment discharges of 423,000 and 13,330,000 tons/year, respectively for water year 1982. A value of 3 percent was used in the analysis.

2.2.4 Sediment Trap Efficiency 78-100%

Sediment trap efficiencies of Watana and Devil Canyon Reservoirs were estimated by the Brune's and Churchill's curves (U.S. Bureau of Reclamation, 1977). The trap efficiency of Watana was also estimated by PN&D and Hutchison (1982) using a sedimentation model. Similar modeling is not available for Devil Canyon Reservoir.

A comparison of the trap efficiencies of Watana and Devil Canyon Reservoirs estimated by the three methods is shown in Table 2.1. The Watana trap efficiency ranges from 96 to 100 percent based on Brune's curves. The trap efficiency is about 100 percent based on the Churchill's curves for local silt. The trap efficiency computed by a reservoir sedimentation model, DEPOSITS, ranges from 78 to 96 percent depending on reservoir mixing and dead storage volume.

The trap efficiency of Devil Canyon Reservoir ranges from 86 to 98 percent based on the Brune's curves. The trap efficiency estimated with the Churchill's curves is 95 percent for local silt and 88 percent for fine silt, the latter case being for sediment discharged from an upstream reservoir. Tables 2.2 and 2.3 show the estimation of the trap efficiencies by Brune's curves and Churchill's curves.

2.2.5 Sediment Deposition

Based on the estimated trap efficiencies shown in Table 2.1, Watana Reservoir was assumed conservatively to trap all sediment inflow to the reservoir. The resulting sediment deposition over a 50- and 100-year period will be about 210,000 and 410,000 acre-feet. The gross reservoir volume is about 9,470,000 acre-feet at a normal maximum pool elevation of 2,185 feet, of which 5,730,000 acre-feet is the dead storage (APA, 1983a). The 100-year sediment deposit is only about 7 percent of the dead storage volume.

Without Watana Reservoir, the 50- and 100-year sediment deposits in Devil Canyon Reservoir would be about 226,000 and 442,000 acre-feet, respectively, also assuming a trap efficiency of 100 percent. The gross reservoir volume of Devil Canyon Reservoir is about 1,090,000 acre-feet at a normal maximum pool elevation of 1,455 feet, of which about 740,000 acre-feet is dead storage. The 100-year sediment deposit is about 60 percent of the dead storage volume.

With Watana Reservoir, the 50- and 100-year sediment deposits in Devil Canyon Reservoir would be abut 16,100 and 31,400 acre-feet, respectively, or about 2 and 4 percent, respectively, of the dead storage volume, assuming 100 percent trap efficiency for sediments from the intervening drainage area. Any fine suspended sediment passed through Watana Reservoir was assumed to also pass through Devil Canyon Reservoir.

The sediment volumes presented above were computed using the procedures of the U.S. Bureau of Reclamation (1977). Percentages of clay, silt, and sand of the incoming suspended sediment were estimated to be 20, 38 and 42, respectively, using sediment data for the Cantwell (Vee Canyon)and Gold Creek gages (Table 2.4). Using unit weights for clay, silt and sand of 26, 70 and 97 lb/ft^3, respectively, the unit weights of the sediment deposits after 50 and 100 years were estimated to be about 80 and 82 lbs/ft^3, respectively. The unit weight of bedload was estimated to be 120 lb/ft^3.

TABLE 2.1 COMPARISON OF TRAP EFFICIENCIES ESTIMATED BY BRUNE'S CURVES, CHURCHILL'S CURVE, AND SEDIMENTATION MODEL

Method	Trap Efficiency, %	
	Watana	Devil Canyon
Brune's Curves		
Coarse Sediment	100	98
Median Curve	99	94
Fine Sediment	96	86
Churchill's Curve		
Local Silt	100	95
Fine Silt	-	88
DEPOSITS Model		
Quiescent	94 to 96*	-
Minimum Mixing	86 to 93*	-
Maximum Mixing	78 to 90*	-

* Corresponding to dead storage volumes from 5,340,000 acre- feet to 900,000 acre-feet (reservoir capacity = 9,470,000 acre-feet at normal maximum pool).

SOURCE: Harza-Ebasco (1984c)

TABLE 2.2

RESERVOIR TRAP EFFICIENCY
BY BRUNE'S CURVES

Reservoir	Storage Capacity af	Average Annual Inflow af	Capacity ÷ Inflow	Trap Efficiency Max.	Trap Efficiency Median	Trap Efficiency Min.
Watana	9,470,000 1/	5,780,000 3/	1.64	100	99	96
Devil Canyon	1,090,000 2/	6,580,000 4/	0.17	98	94	86

1/ At normal maximum pool elevaton 2185 feet above mean sea level. From License Application, Exhibit E, Chapter 2, page E-2-55 (11).

2/ At normal maximum pool elevation 1455 feet above mean sea level. From License Application, Exhibit E, Chapter 2, page E-2-55 (11).

3/ Converted from average annual flow of 7990 cfs at Watana, as shown in License Application, Exhibit E, Chapter 2, Table E.2.4 (11).

4/ Converted from average annual flow of 9080 cfs, as shown in License Application, Exhibit E, Chapter 2, Table E.2.4 (11).

SOURCE: Harza-Ebasco (1984c)

TABLE 2.3

RESERVOIR TRAP EFFICIENCY
BY CHURCHILL'S CURVES

(1) Reservoir	(2) Storage Capacity 1/	(3) Average Inflow 2/	(4) Retention Period 3/	(5) Reservoir Length 4/	(6) Average 5/ Cross-Sectional Area	(7) Mean Velocity 6/	(8) Retention Period ÷ Velocity	(9) % of Silt Passing	(10) Trap Efficiency
	ft^3	cfs	sec	ft	ft^2	ft/sec	sec^2/ft		%
Watana	4.13×10^{11}	7990	5.17×10^{7}	2.75×10^{5}	1.50×10^{6}	0.53×10^{-2}	9.70×10^{9}	< 0.1	100
Devil Canyon (local silt)	0.48×10^{11}	9080	0.52×10^{7}	1.69×10^{5}	0.28×10^{6}	3.23×10^{-2}	0.16×10^{9}	5	95
Devil Canyon (fine silt)								12	88

1/ At normal maximum pool elevation 2185 ft for Watana and 1455 ft for Devil Canyon. From License Application, Exhibit E, Chapter 2, page E-2-55.
2/ From License Application, Exhibit E, Chapter 2, Table E.2.4.
3/ Col. (2) ÷ Col. (3).
4/ Converted from 52 reservoir miles for Watana and 32 reservoir miles for Devil Canyon.
5/ Col. (2) ÷ Col. (5).
6/ Col. (3) ÷ Col. (6).

SOURCE: Harza-Ebasco (1984c)

TABLE 2.4

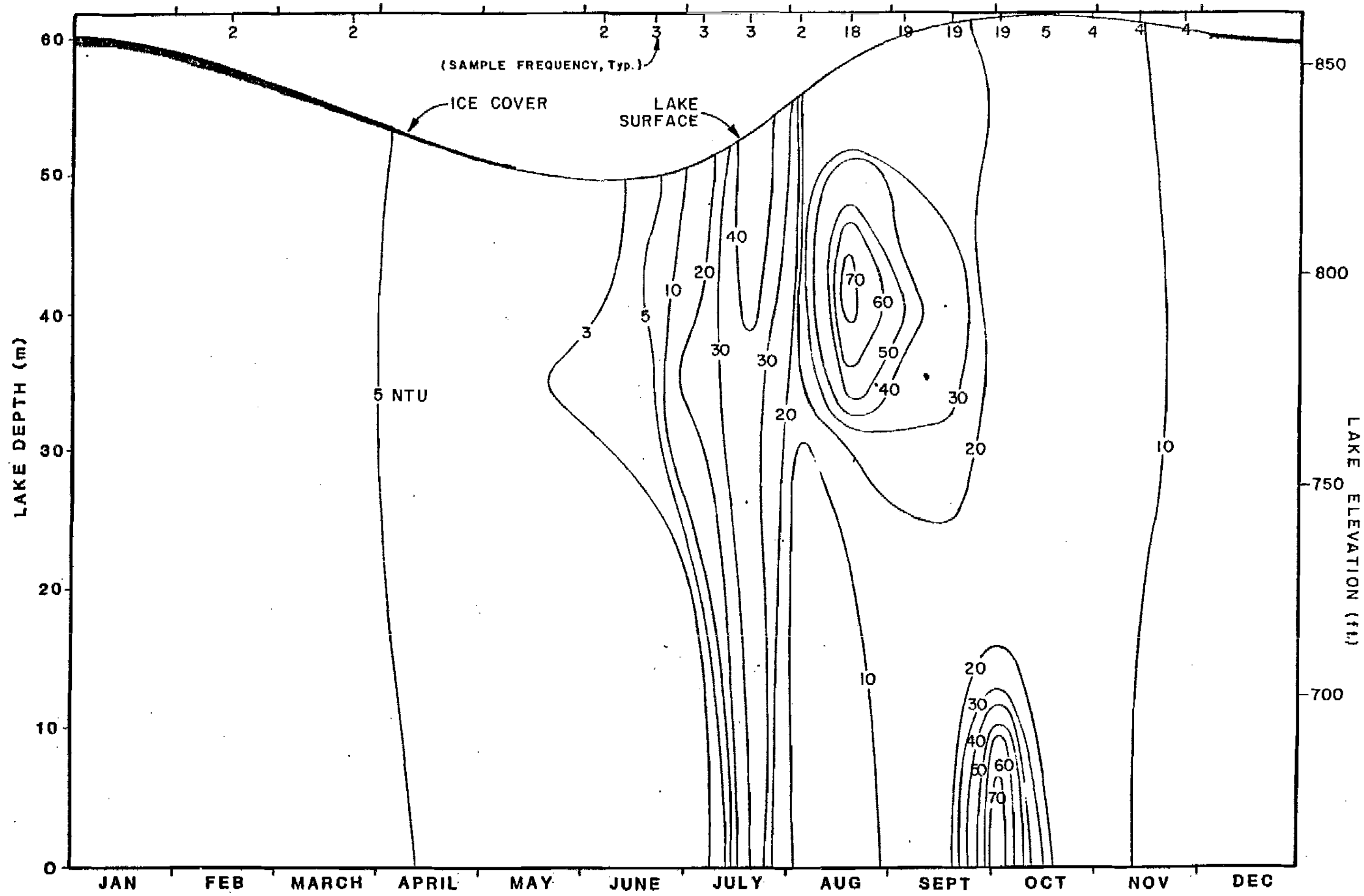
PARTICLE SIZE DISTRIBUTION OF SUSPENDED SEDIMENT

Stream Gaging Station	No. of 1/ Sample	.002	.004	.008	.016	.031	.062	.125	.250	.500	1.000
		Particle Size (mm) — Percent Finer Than 2/									
Susitna River nr. Denali	34	12	16	23	31	41	53	64	81	96	100
Susitna River nr. Cantwell	27	12	18	25	33	43	54	67	86	97	100
Susitna River at Gold Creek	24	15	19	27	35	47	61	75	86	98	100
Susitna River nr. Talkeetna	13	29	35		53		72	79	90	100	
Chulitna River nr. Talkeetna	36	21	31	37	46	55	62	72	85	99	100
Talkeetna River nr. Talkeetna	16	9	16	22	31	41	53	65	85	99	100
Susitna River at Sunshine	17	22	33	43	53	62	67	79	90	100	
Susitna River at Susitna Station	9	16	23	33	43	52	60	82	94	100	

1/ Samples for which full range of size distributions were analyzed.

2/ The percentages given are the median values from a range of oberved percentages for various sizes.

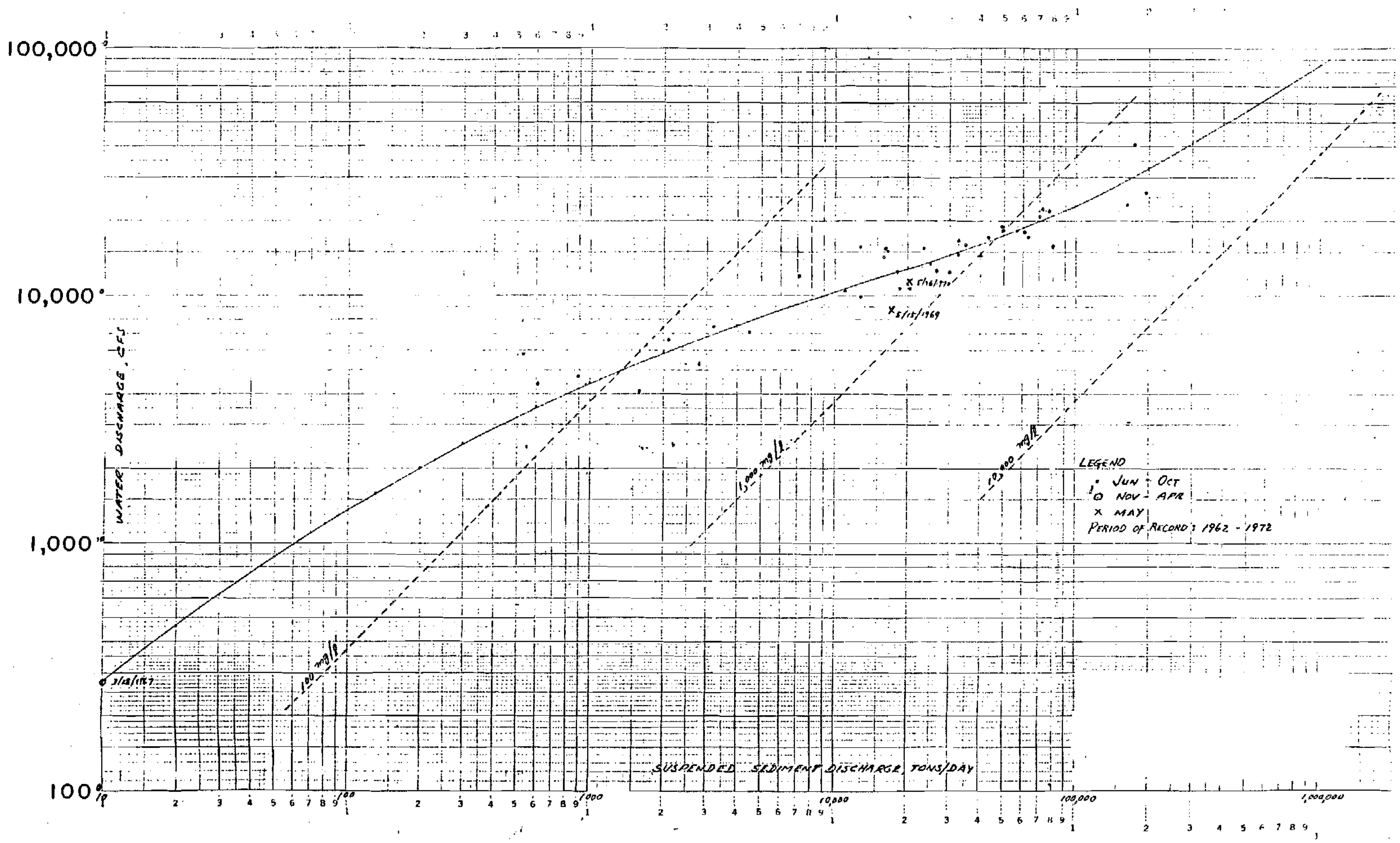
SOURCE: Harza-Ebasco (1984d)



ISO-TURBIDITY vs. TIME, EKLUTNA LAKE @ STATION 9 (1984)

Source: Figure reproduced from (R & M 1985b)

PREPARED BY:		PREPARED FOR:
R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	**FIGURE 2.1**	HARZA-EBASCO SUSITNA JOINT VENTURE



SOURCE: Harza-Ebasco (1984c)

Suspended Sediment Rating Curve
Susitna River near Cantwell
(Vee Canyon)

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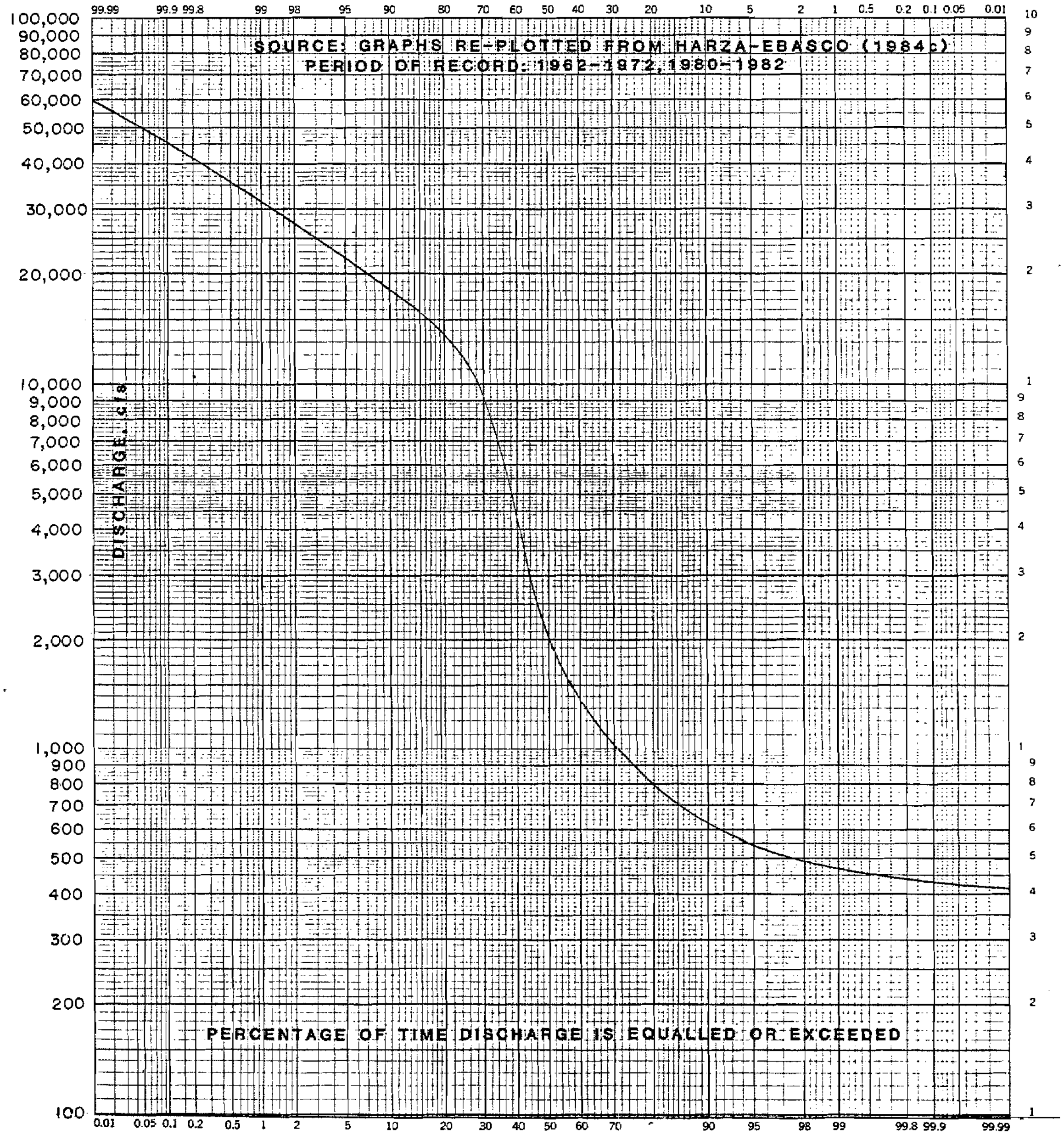
FIGURE 2.2

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE



ANNUAL FLOW DURATION CURVE,
SUSITNA RIVER NEAR CANTWELL
(VEE CANYON)

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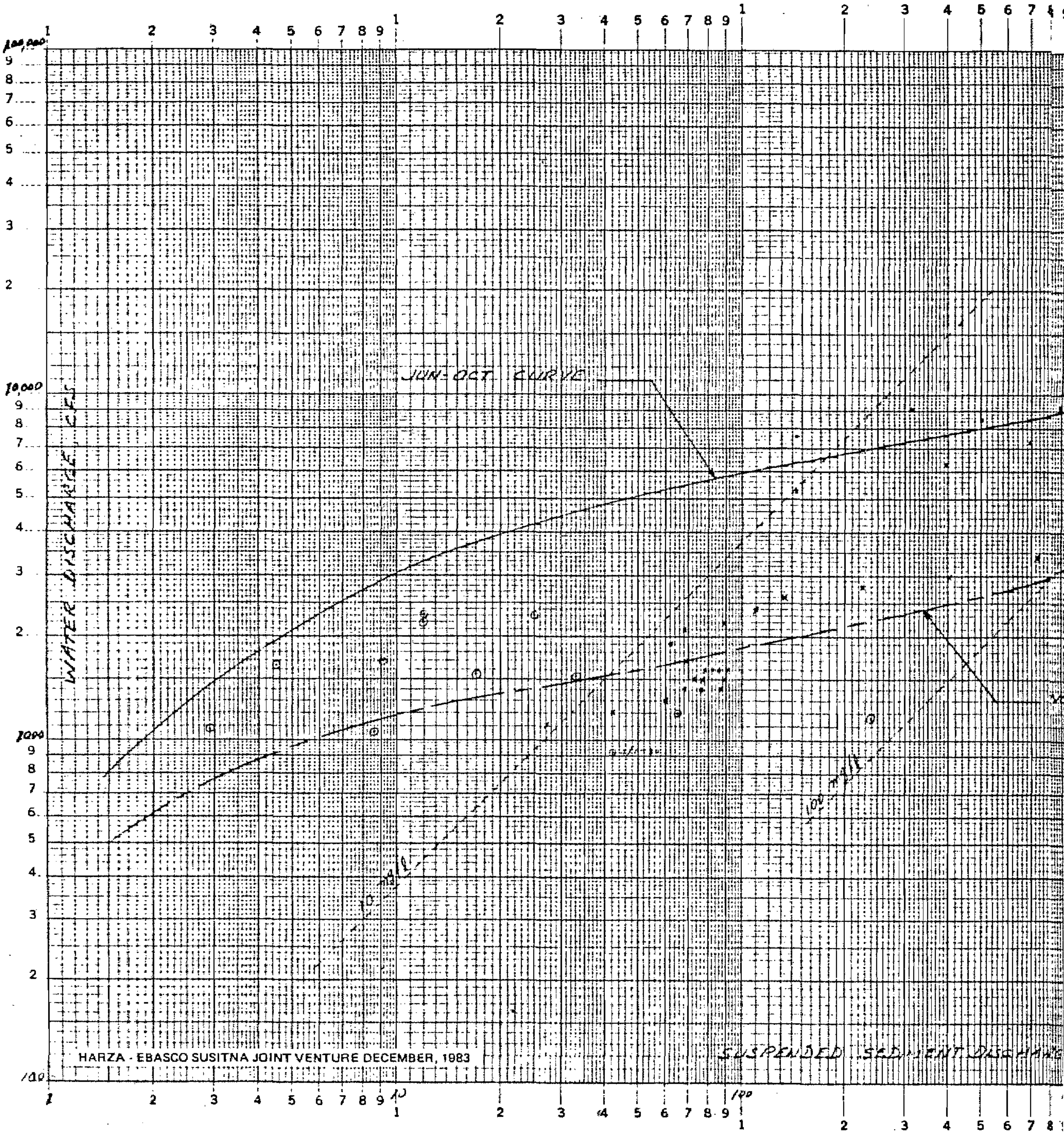
FIGURE 2.3

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE



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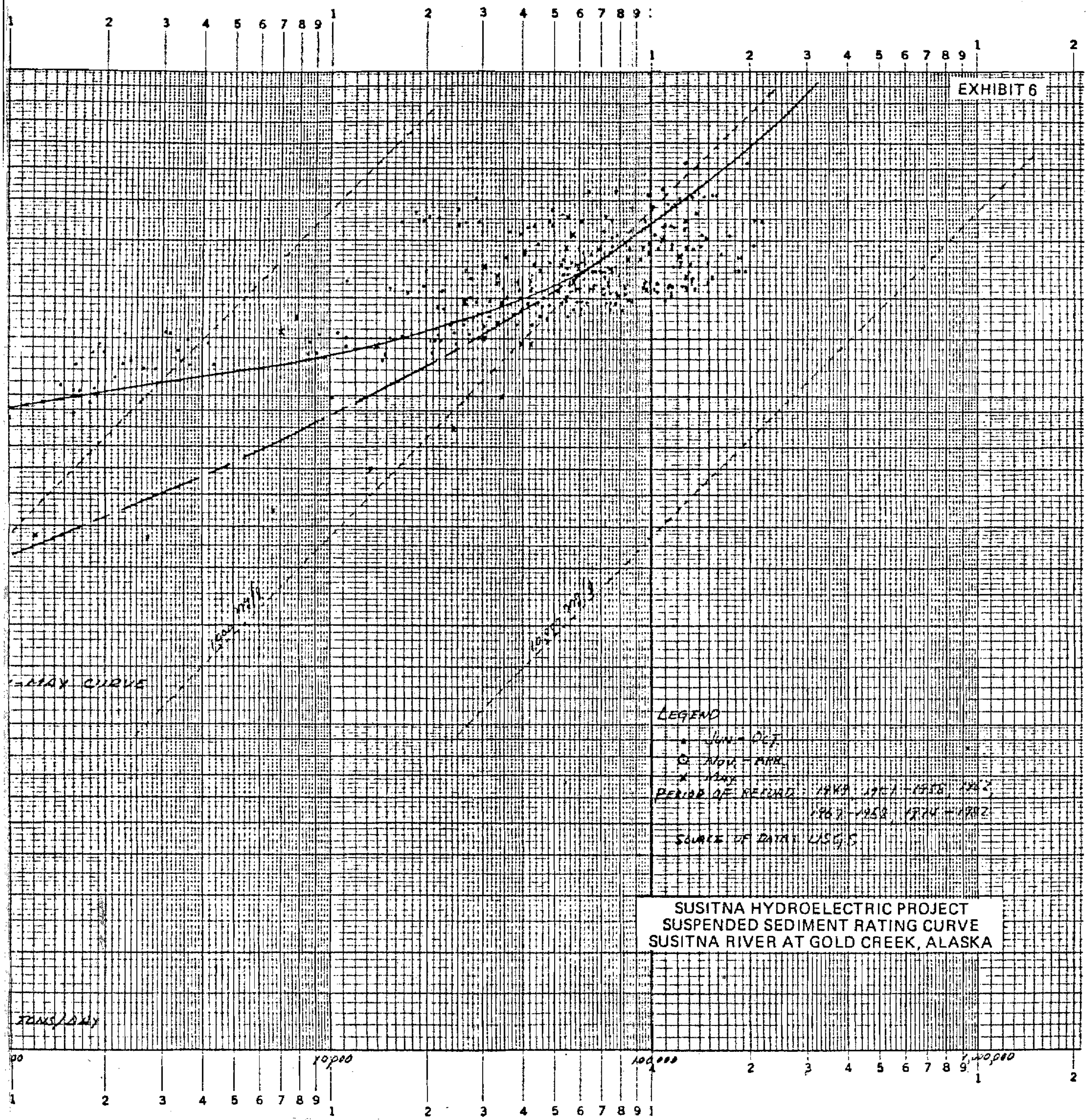

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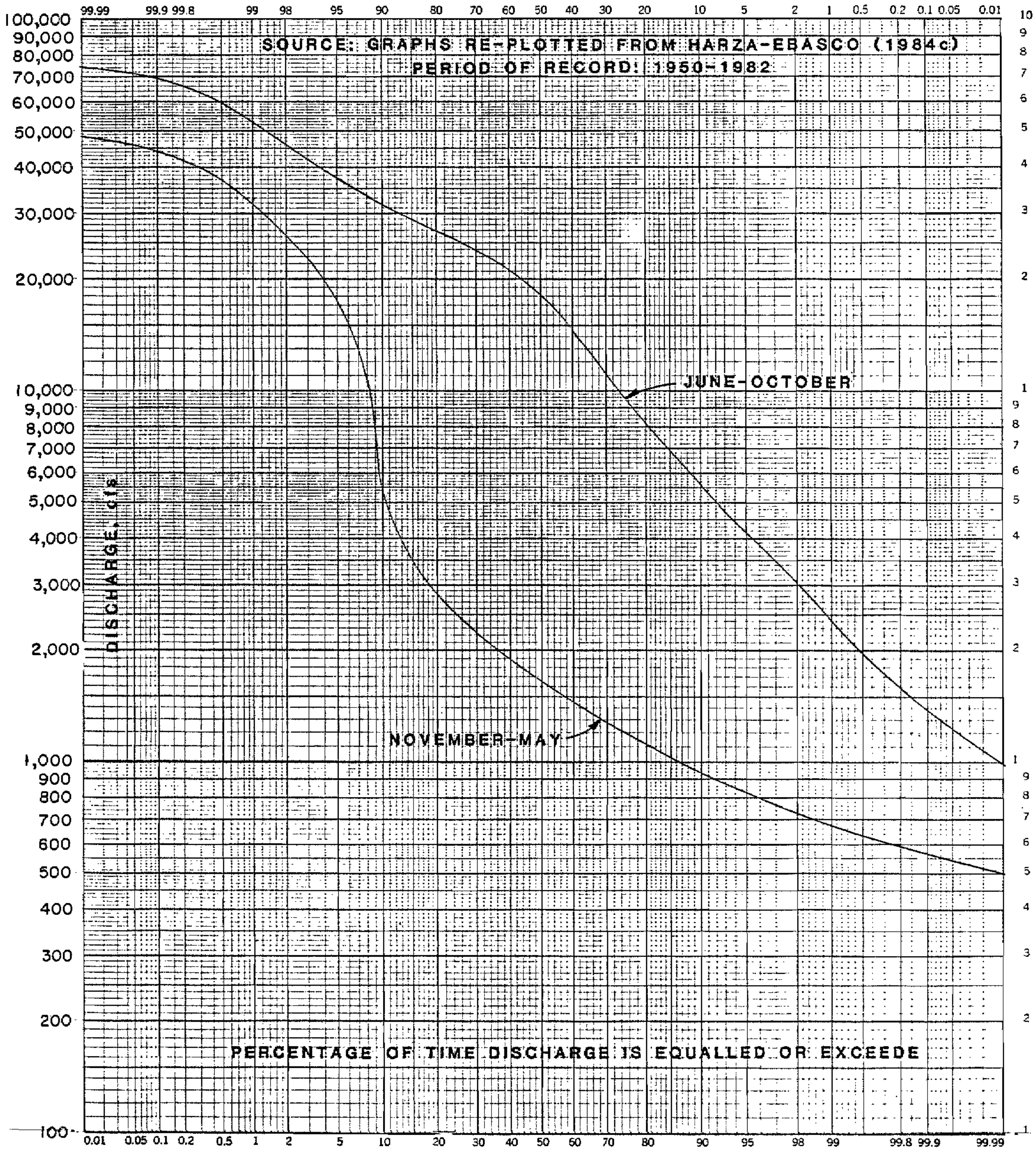
SUSITNA JOINT VENTURE



ANNUAL FLOW DURATION CURVES,
SUSITNA RIVER at GOLD CREEK

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FIGURE 2.5

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE

3.0 CHANNEL STABILITY

3.1 Introduction

The middle reach of the Susitna River alternates between single-channel and split-channel configurations. A number of barren gravel bars or vegetated islands exist in the river. The mid-channel gravel bars appear to be mobile during moderate to high floods (R&M, 1982e). A number of tributaries, including Portage Creek, Indian River, 4th of July Creek, and Lane Creek, join the main river in this reach. Almost every tributary has built an alluvial fan into the river valley. Due to relatively steep gradients of some of these tributaries, the deposited material is somewhat coarser than that normally carried by the Susitna River.

Vegetated islands generally separate the main channel from side channels and sloughs. These sloughs and side channels exist on one bank of the river at locations where the main river channel is confined towards the opposite bank. The flows enter into these sloughs and side channels, depending upon the elevations of the berms at their heads relative to the mainstem river stages (Table 3.1). Coarser bed materials are generally found at the heads of sloughs and side channels, as the flow entering these sloughs and side channels is from the upper layer of the flow in the main channel and does not carry coarse material. This relatively sediment-free flow picks up finer bed material at the heads, thereby leaving coarser material.

Evaluation of morphological changes between 1949-1951 and 1977-1980 (AEIDC, 1984) indicates that some sloughs have come into existence since 1949-51, some have changed character and/or type significantly, and others have not yet changed enough to be noticeable. Many sloughs have evolved from side channels to side sloughs or from side sloughs to upland sloughs (definitions of slough types and other habitat types may be found in (EWT&A and WCC, 1985)). Thus, they are now higher in elevation relative to the water surface in the mainstem at a given discharge. The perching of the sloughs and increased exposure of gravel bars above the water surface are indicative of river degradation over the 35-year period. However, the photographs presented in the report also show significant increase in the number and/or size of barren gravel bars, which indicates that localized sediment depositions have also occurred. Therefore, both degradation and localized deposition can be expected to occur in the Susitna River under natural conditions, depending upon the flows and sediment loads.

Under with-project conditions, the flow regime of the Susitna River will be modified, and the reservoirs will trap most sediment except the smaller particle sizes of fine silt and clay size material. The river will strive to adjust itself to a new equilibrium. The main channel will have the tendency to be more confined with a narrower channel. This may cause the main channel to recede from the heads of some sloughs and side channels.

Of major concern are potential aggradation or degradation in the sloughs and side channels at their entrances, and at sites in the main channel. Also of concern are intrusion of fine sediment into the gravel bed and its subsequent entrapment. In case of fine sediment deposition on the gravel bed, appropriate measures may be necessary to flush out the sediments so that the bed can be kept clean.

Another concern is the potential change in hydraulic conditions at the mouths of tributaries due to lower mainstem water levels. Of special interest are Indian River and Portage Creek, which receive the majority of the escapement of chinook and chum salmon entering tributaries upstream of the Chulitna River confluence. Potential perching of these and other tributaries above the mainstem, the decrease or elimination of the backwater area at the mouth, and increased velocities could restrict fish access to spawning areas (Trihey, 1983). Conversely, excessive degradation at some tributaries could potentially cause maintenance problems at stream crossings of the Alaska Railroad (R&M, 1982f).

This segment of the report discusses the analyses of sedimentation processes conducted by Harza-Ebasco (1985), R&M (1982e,f) and Trihey (1983) in order to evaluate stream channel stability under natural and with-project conditions for study sites in the mainstem, in selected sloughs and side channels, and in significant tributaries. For these analyses, a stable channel means that its shape, slope and bed material size distribution do not change significantly with time. Thus, these physical parameters are relatively constant, although there may actually be exchange of soil particles in the bed from time to time. Major items discussed in this section are:

1. Evaluation of sedimentation processes under natural conditions;
2. Evaluation of potential degradation or aggradation under with-project conditions;
3. Determination of discharge rates at which the mainstem flows are likely to overtop the entrances of the sloughs and side channels under natural and with-project conditions;
4. Estimation of discharge rates for the sloughs and side channels at which their beds will be unstable, and also estimation of the rates required to flush out fine sediment deposits; and
5. Estimation of changes in tributary mouth conditions at significant tributaries.

3.2 Factors Affecting Channel Stability

To provide some background for analyzing the specific problems under study, a brief description of sediment transport in a river is given below.

Sediment particles are transported by the flow as bedload and suspended load. The suspended load consists of wash load and bed-material load. In large rivers, the amount of bedload generally varies between about 3 and 25 percent of the suspended load (Harza-Ebasco, 1985). Although the amount of bedload is generally small compared to the suspended load, it is important because it shapes the bed and affects the channel stability.

The amount of material transported or deposited in a stream under a given set of conditions depends upon the interaction between variables representing the characteristics of the sediment being transported and the capacity of the stream to transport the sediment. A list of these variables is given below (Simons, Li and Associates, 1982).

Sediment Characteristics:

Quality: Size, settling velocity, specific gravity, shape, resistance to wear, state of dispersion and cohesiveness.

Quantity: Geology and topography of watershed; magnitude, intensity, duration, distribution and season of rainfall; soil condition; vegetal cover; cultivation and grazing; surface erosion; and bank cutting.

Capacity of Stream:

Geometric shape: Depth, width, form and alignment.

Hydraulic Properties: Slope, roughness, hydraulic radius, discharge, velocity, velocity distribution, turbulence, tractive force, fluid properties and uniformity of discharge.

The above variables are not independent, and in some cases the effect of a variable is not definitely known. However, the responses of channel pattern and longitudinal gradient to variation of the variables have been studied by various investigators, including Lane (1955), Leopold and Maddock (1953), Schumm (1971) and Santos-Cayudo and Simons (1972). The studies by these investigators support the following general relationships (Simons and Senturk, 1977):

29 (i) depth of flow is directly proportional to the cube root of water discharge;

5 (ii) channel width is directly proportional to sediment discharge and to the square root of water discharge;

(iii) channel shape expressed as width to depth ratio is directly related to sediment discharge;

(iv) channel slope is inversely proportional to water discharge and directly proportional to both sediment discharge and grain size;

(v) sinuosity is directly proportional to valley slope and inversely proportional to sediment discharge; and

(vi) transport of bed material is directly related to streampower (defined as product of bed shear and cross-sectional average velocity), and to concentration of fine material, and inversely related to bed material sizes.

Because of the complexity of interaction between various variables, the river response to natural or man-made changes is generally studied by (i) qualitative analysis, involving morphological concepts; (ii) quantitative analysis involving application of morphological concepts and various empirical or experimental relationships; and (iii) quantitative analysis using mathematical models. The insight to the problems obtained through the qualitative approach provides understanding of the methods required to quantify the changes in the system. Mathematical modeling can help to study many factors simultaneously. Work by Simons and Li (1978) and others indicate that physical process computer modeling provides a reliable methodology for analyzing the impacts and developing solutions to complex problems of aggradation, degradation and river response to engineering activities.

For river channels of non-cohesive sediment, qualitative predictions of river response have been made using Lane's relationship (Lane, 1955):

$$QS \sim G_s d_s$$

in which

Q = stream discharge

S = longitudinal slope of stream channel

G_s = bed material discharge

d_s = particle size of bed material, generally represented by d_{50} (median diameter)

The use of the above relationship to predict potential responses of the Susitna River under natural and with-project conditions is discussed in Section 3.5.1.

Prediction of quantitative changes in a river system requires geomorphic and hydraulic data or information which are generally not readily available. Considerable effort, time and money are required to collect such information. The data of primary needs include hydrological and topographic maps and charts, large scale aerial and other photos of the river and surrounding terrain, existing river conditions (roughness coefficient, aggradation, degradation, local scour near structures), discharge and stage data (under natural and with-project conditions), existing channel geometry (main channel, side channels, islands), sediment data (suspended load and bed-load, size distribution of bank and bed material and suspended sediment), and size and operation of anticipated reservoir(s) on the river system.

Because the available data did not permit meaningful mathematical modeling using computer techniques, the morphological concepts and empirical relationships were used to predict potential aggradation or degradation at the study sites.

3.3 General Analytical Approach

Harza-Ebasco (1985) evaluated the sedimentation processes of degradation and aggradation under natural and with-project conditions in the Susitna

River at the study sites (Table 3.1), using the approaches discussed below.

3.3.1 Degradation

Generally, river bed degradation occurs downstream of newly constructed diversion and storage structures. The rate of degradation is rapid at the beginning, but is checked by either the development of a stable channel slope or by the formation of an armor layer if sufficient coarse sediment particles are available in the bed. The important variables affecting the degradation process are:

1. Characteristics of the flow released from the reservoir;

2. Sediment concentration of the flow released from the reservoir;

3. Characteristics of the bed material;

4. Irregularities in the river bed;

5. Geometric and hydraulic characteristics of the river channel; and

6. Existence and location of controls in the downstream channel.

The assumptions used in the analysis of degradation include:

1. Bedload is completely trapped by the reservoir, but suspended sediment particles of .004 mm and less in diameter will remain in suspension and pass through the reservoir (PN&D, 1982). The sediment passing through the reservoir would be about 18 percent of the sediment inflow (Harza-Ebasco, 1984d);

2. Irregularities in the river and channel configurations remain unchanged;

3. Sediment supply due to bank erosion is negligible;

4. Sediment eroded from the river bed is carried downstream as bedload;

5. Sediment injections by tributaries are carried downstream without significant deposition;

6. Size distribution of bed material is constant throughout the depth at each study site; and

7. Sufficient coarse material exists in the river bed to form an armoring layer which prevents further degradation.

The size of armoring bed material was estimated using (i) the competent bottom velocity concept of Mavis and Laushey (1948) and U.S. Bureau of Reclamation (1977); (ii) the tractive force versus transportable size relationship derived by Lane (1953); (iii) the Meyer-Peter, Muller formula (U.S. Bureau of Reclamation, 1977); (iv) the Schoklitsch formula (U.S. Bureau of Reclamation, 1977); and (v) Shields criteria (Simons, and Li and Associates, 1982).

The depth of degradation or the depth from original streambed to top of the armoring layer was computed by the following relationship given in (U.S. Bureau of Reclamation, 1977):

$$Y_d = Y_a \left(\frac{1}{Wp} - 1\right)$$

in which:

Y_d = depth of degradation, feet

Y_a = thickness of armoring layer, assumed as 3 times transportable size or 0.5 feet, whichever is smaller

Wp = decimal percentage of material larger than the size

The transportable size for a given discharge was the average of the five sizes estimated by using the five methods mentioned above.

3.3.2 Aggradation

Potential aggradation at the entrances of sloughs and side channels was estimated by comparing the transportable size for the flow in the mainstem before diversion into the slough or side channel and the transportable size for the remaining flow in the main channel after diversion into side channel or slough. If the two sizes were significantly different, it was concluded that some of the bedload being transported would be deposited near the entrance.

3.3.3 Stability of Tributary Mouths

The regulation of floods by reservoir operation results in a decrease in stage during the mean annual flood of from 3.2 to 7.6 feet at the mouths of tributaries between Devil Canyon and the Chulitna River confluence. Similarly, the decrease in average summer flows results in average reductions in water levels of 1-4 feet. A smaller proportion of the material transported to the tributaries' mouths will be transported downstream. Consequently, alluvial fans will increase in size at the mouth of affected tributaries. Also, the reduced summer water levels may result in headcutting and scour by the tributaries through their delta materials.

Field data were collected at nineteen tributaries. A qualitative analysis was conducted to determine if the above problems were likely to occur. A semi-quantitative analysis (R&M, 1982f) was done on six creeks, and considered channel slope, the sediment discharge rate, the bed material size distribution and the decrease in stage expected at the tributary mouth. Due to their importance to chinook and chum salmon spawning, Indian River and Portage Creek were analyzed in more detail for changes in hydraulic conditions due to project operation, including bed changes and average velocities (Trihey, 1983).

3.4 Analysis of Natural Conditions

The basic data used in this study were taken from various reports prepared for Alaska Power Authority by the Alaska Department of Fish and Game, Susitna Hydro Aquatic Studies Team (ADF&G); R&M Consultants, Inc. (R&M); and Harza-Ebasco Susitna Joint Venture (H-E). Discharge and sediment data also were taken from the publications of the U.S. Geological Survey, Water Resources Division (USGS), prepared in co-operation with the Alaska Power Authority (Knott and Lipscomb, 1983, 1985).

Hydraulic parameters such as stage-discharge relationships, channel widths, average channel depths, measured velocities and bed slopes of selected side channels and sloughs, were taken from various reports of R&M (R&M, 1982 b, c, f, g) and ADF&G (ADF&G, 1983b, 1984b). The hydraulic parameters for the main channel reaches were derived from the data given in (Harza-Ebasco, 1984b). Some unpublished data were obtained from USGS, R&M and ADF&G through correspondence. The site characteristics and hydraulic parameters for study sites in the mainstem, side channels and sloughs are shown in Tables 3.1, 3.2 and 3.3.

The Manning's roughness coefficients for various main channel reaches, side channels and sloughs (Table 3.1) were estimated based on field reconnaissances made in 1983 and 1984 and on the analysis presented by Harza-Ebasco (1984b).

The representative bed material size distribution for each site was derived from the analysis of the bed material samples collected by Harza-Ebasco. In the mainstem of the Susitna River, the surface material is generally coarser than the sub-surface material. The bed material samples collected in the sloughs and side channels, however, did not show any distinct difference between the surface and sub-surface materials. The surface and sub-surface samples at a given site were combined to determine the size distribution. The adopted size distributions are given in Table 3.4. These are considered only indicative of the bed material at the specific sites because many additional samples would be required to determine a representative size distribution for the whole length of the study reach.

The sizes of armoring bed material corresponding to a selected range of discharges (Table 3.5) were estimated as the average of the five sizes computed using the methods of competent bottom velocity; tractive force; Meyer-Peter, Muller formula; Schoklitsch formula; and Shields criteria. A comparison of median bed material size and the armoring size at each site indicated that under natural conditions, most of the selected sites are subject to temporary scour and/or deposition, depending upon the magnitude and characteristics of the sediment load and high flows caused by floods or breaching of ice jams.

About 96 percent of the suspended sediment load carried by the river at Gold Creek under natural conditions is finer than 0.5 millimeter (medium to fine sand, silt and clay). This fine sediment has been observed to deposit in side channels and sloughs. However, many of these deposits are re-suspended and removed during high flows, probably because of disturbances of the surface bed material layer.

3.5 With-Project Conditions

3.5.1 River Morphology

The construction of the Susitna Hydroelectric Project will change the streamflow pattern and sediment regime. The essentially sediment-free flows from the reservoirs will have the tendency to pick up bed material and cause degradation. The modified discharges downstream from the dams, however, will have reduced competence to transport sediment, especially that brought by the tributaries. These two factors tend to compensate each other, resulting in the overall effects discussed below.

The Lane relationship discussed in Section 3.2 is based on an equilibrium concept, that is, if any change occurs in one or two parameters of the water and sediment discharge relationships, the river will strive to compensate the other parameters so that a new equilibrium is attained. In the case of the Susitna River, both water discharge and bed load discharge will be modified by the reservoirs. Therefore, adjustments will occur in the slope of the river channel and in the particle sizes of the bed material. A number of studies (Hey, et al 1982) have indicated that the new median diameter under with-project conditions may correspond to the D_{90} or D_{95} of the original bed material.

The potential morphological changes of the Susitna River also were addressed qualitatively by R&M (1982e). It was argued that the Susitna River between Devil Canyon and the confluence of the Susitna and Chulitna Rivers would tend to become more defined with a narrower channel. The main channel river pattern will strive for a tighter, better defined meander pattern within the existing banks. A trend of channel width reduction by encroachment of vegetation and sediment deposition near the banks would be expected.

3.5.2 Channel Stability

Potential degradation at the selected sites was estimated for various discharges using the discussed procedure. The potential degradation at each site estimated from these relationships is listed in Table 3.6. These estimates are based on the assumptions that there would not be a significant supply of coarse sediments by the tributaries and that there would not be redeposition of bed material eroded from the upstream channel.

Table 3.7 shows average weekly flows at Gold Creek for four project operation scenarios and for natural conditions (Harza-Ebasco, 1985). These data indicate about 50 percent reduction in flows during the May through September period and about 3 to 4 times increase in flows during the October through April period. Table 3.8 shows annual maximum weekly flow at Gold Creek for natural and with-project conditions. Under with-project conditions, the maximum weekly flows occur under 2002 load conditions for almost every year. Using the average of these annual maximum weekly flows as the dominant discharge (about 30,000 cfs), the potential local degradation at the main channel sites would be in the range of about 1.0 to 1.5 feet. In the sloughs and side channels, the local degradation would be about 0 to 0.5 feet. These estimates, however, are based on the assumptions that there will not be significant injection of bedload by the tributaries and that there would not be redeposition of sediment eroded from the upstream channel. In actual situations, there will be sediments carried down by the tributaries, of which some will be deposited in the main river. Redeposition of some sediment eroded from the upstream channel will also occur. Therefore, actual degradation at the main channel sites would be less than that estimated.

An accurate estimate of the actual degradation is difficult because of many unquantifiable parameters, such as bed material transport from tributaries and bank erosion, the degree of armoring by the present bed, and the actual streamflows and floods which would occur during the early years of project operation. However, based on available data and using empirical relationships, the above estimated degradation values are considered to be reasonable. The larger degradation would occur immediately downstream of the Devil Canyon Dam, and would decrease with distance downstream.

Table 3.3 shows that bifurcation of flow at the heads of the sloughs and side channels would not significantly reduce the discharge rates in the main channel. Therefore, the competence of flow to transport bed material will not be affected due to bifurcation of flow and little aggradation should be expected in the main channel near the entrances to the sloughs and side channels.

When the system energy demand increases (as in 2010), and less flow is discharged in July and August, the armoring layer developed earlier would be stable, more so than under natural conditions. However, infrequent high flood events would not be controlled to as great an extent as the smaller floods. These floods would have the ability to disturb the armor layer and may cause bed degradation. Reservoir operation studies indicate that floods up to the 50-year event will be reduced by about 50 percent at Gold Creek for project energy demands in 2020. Control of infrequent flood events will also be improved as energy demand increases, and the potential for further bed degradation would therefore be reduced.

Because of anticipated degradation in the mainstem, discharges higher than those under natural conditions would be required to overtop the berms at the heads of the sloughs and side channels. Assuming that the river bed at the entrances would be lowered by about one foot due to degradation, the with-project discharges that would overtop the sloughs and side channels were estimated to range between 4,000 and 12,000 cfs higher than those under natural conditions.

3.5.3 Intrusion of Fine Sediments

The reservoir would trap all sediment except for particles sizes of .004 mm and less, which constitute about 18 percent of the suspended load. The velocities at the study sites (Tables 3.2 and 3.3) would be sufficiently high to carry these fine particles in suspension, and the substrate would generally be cleaner. However, some coarse silt and fine sand might be picked up from the river bed, especially during the early years of project operation. These fine materials would have the tendency to settle out in pools and backwater areas. Therefore, some deposition of such silt and sand in the sloughs and side channels is possible.

3.5.4 Tributary Stability

The semi-quantitative assessment of the nineteen tributaries (R&M, 1982f) indicated that three creeks (Jack Long, Sherman and Deadhorse) are likely to have perched stream mouths, due to the streams not having the capability to downcut through their delta after the water level drops. The tributaries at RM 127.3, RM 110.1, and Skull Creek are estimated to degrade and to possibly affect the railroad bridges. The other tributaries studied will either degrade or aggrade, but without anticipated effects on fish access or railroad. The assessment is summarized in Table 3.9.

The analysis of hydraulic conditions at Portage Creek and Indian River indicates that fish access has not been a problem and is unlikely to be a problem under with-project conditions (Trihey, 1983). These creeks will adjust their streambed gradients and will re-establish entrance conditions similar to those under natural conditions.

TABLE 3.1
CHARACTERISTICS OF STUDY SITES
ON MIDDLE SUSITNA RIVER[1]

	Approx. River Miles	Overall Slope of Study Reach	Overall Slope of Main River	Observed Overtopping Discharge[2]	Estimated Bed Elev. at Head	Estimated Manning's Roughness
Main Channel Nr. River Cross Section 4	99.0 to 100.0	.0017	.0017	NA[3]	NA	.030
Main Channel Between River Cross Sections 12 and 13	108.5 to 110.0	.0012	.0012	NA	NA	.035
Main Channel Upstream from Lane Creek	113.6 to 114.2	.0017	.0017	NA	NA	.035
Mainstem 2 Side Channels at River Cross Section 18.2		.0030	.0017	12,000	476.3	.035
NW Channel	114.4	.0020	.0017	12,000	476.3	.035
NE Channel	115.5	.0024	.0017	23,000	484.6	.035
Slough 8A (main channel)		.0024	.0017	26,000		.032
NW Channel	126.2	.0024	.0017	26,000		.032
NE Channel	126.7	.0024	.0017	33,000	576.5	.032
Slough 9	128.3	.0026	.0016	16,000	604.6	.032
Main Channel Upstream From the 4th of July Creek	131.2 to 132.2	.0015	.0015	NA	NA	.035
Side Channel 10	134.2	.0039	.1017	19,000	656.6	.035
Lower Side Channel 11	135.0	.0024	.0020	5,000		.035
Slough 11	135.4	.0029	.0020	42,000	684.6	.032
Upper Side Channel 11	136.2	.0045	.0020	13,000	684.3	.035
Main Channel Between Cross Sections 46 and 48	136.9 to 137.4	.0017	.0017	NA	NA	.035
Side Channel 21		.0030	.0032			
Downstream from A5	140.6			12,000		.030
Upstream from A5	141.9			20,000		.030
Slough 21		.0043	.0023			.030
NW Channel	142.2			23,000	753.8	
NE Channel	142.3			26,000	756.9	

1/ Data taken from various reports of H-E; ADF&G and R&M.
2/ Discharges at Gold Creek Station
3/ Not applicable.

SOURCE: Harza-Ebasco (1985)

TABLE 3.2

HYDRAULIC PARAMETERS FOR MAINSTEM SITES

Location	Gold Creek Discharge (cfs)								
	3,000	5,000	7,000	9,700	13,400	17,000	23,400	34,500	52,000
Near River Cross Section 4									
Discharge, cfs	3,090	5,150	7,210	9,990	13,800	17,500	24,100	35,500	53,600
Width, ft	650	750	860	1,010	1,200	1,380	1,640	2,060	2,680
Depth, ft	2.9	3.4	3.9	4.6	5.5	6.3	7.3	8.9	10.6
Velocity, ft/sec	2.7	3.4	3.8	4.4	4.4	4.3	4.2	4.6	4.9
Between River Cross Sections 12 and 13									
Discharge, cfs	3,090	5,150	7,210	9,990	13,800	17,500	24,100	35,500	53,600
Width, ft	380	410	425	445	460	473	495	518	545
Depth, ft	5.6	6.6	7.6	8.0	9.2	9.9	11.2	13.1	16.0
Velocity, ft/sec	2.3	3.0	3.4	4.2	4.7	5.3	6.1	7.0	7.7
Upstream from Lane Creek									
Discharge, cfs	3,090	5,150	7,210	9,990	13,800	17,500	24,100	35,500	53,600
Width, ft	850	960	1,020	1,110	1,350	1,680	1,790	1,860	1,900
Depth, ft	5.9	6.8	7.4	8.2	8.5	9.3	10.0	11.0	12.9
Velocity, ft/sec	1.7	2.2	2.6	3.1	4.1	4.3	5.2	6.7	7.5
Upstream from 4th of July Creek									
Discharge, cfs	3,000	5,000	7,000	9,700	13,400	17,000	23,400	34,500	52,000
Width, ft	250	340	430	580	800	970	1,150	1,250	1,380
Depth, ft	6.3	7.2	7.7	8.3	9.0	9.3	10.1	10.6	11.6
Velocity, ft/sec	2.1	2.7	3.3	4.0	4.9	5.8	6.2	7.4	8.8
Between River Cross Sections 46 and 48									
Discharge, cfs	3,000	5,000	7,000	9,700	13,400	17,000	23,400	34,500	52,000
Width, ft	305	385	465	545	600	650	710	800	920
Depth, ft	5.1	6.2	6.9	8.1	9.0	9.7	10.6	12.0	14.1
Velocity, ft/sec	3.6	4.1	4.6	4.9	5.7	6.4	6.8	8.2	9.4

SOURCE: Harza-Ebasco (1985)

TABLE 3.3
HYDRAULIC PARAMETERS FOR SIDE CHANNELS AND SLOUGHS

Location (1)	Gold Creek Discharge (cfs) (2)	Slough/Side Channel Discharge (3)	Slough/Side Channel Width (ft) (4)	Slough/Side Channel Depth (ft) (5)	Slough/Side Channel Velocity (ft/sec) (6)
Mainstem 2 Side Channel					
Northwest Channel	17,000	150	112	1.0	1.39
	23,400	940	117	1.9	2.78
	34,500	2,940	228	2.5	5.20
	52,000	6,700	264	2.9	8.75
Northeast Channel	34,500	650	111	3.4	1.71
	52,000	2,900	124	3.8	6.09
Main Channel Below Confluence	17,000	150	128	0.5	2.31
	23,400	940	250	1.4	3.78
	34,500	3,590	341	2.7	3.89
	52,000	9,600	366	4.4	6.00
Slough 8A					
Northwest Channel	30,000	19	45	0.7	0.62
	35,000	47	45	0.9	1.18
	40,000	98	45	1.0	2.21
	45,000	183	45	1.1	3.75
	52,000	383	46	1.3	6.58
Northeast Channel	30,000	17	70	1.0	.42
	35,000	26	71	1.1	.51
	40,000	37	73	1.2	.59
	45,000	51	75	1.4	.67
	52,000	74	78	1.6	.77
Main Channel Below Confluence	30,000	36	62	0.8	.72
	35,000	73	66	1.0	1.14
	40,000	135	70	1.1	1.74
	45,000	234	72	1.2	2.68
	52,000	457	78	1.5	3.96
Slough 9	23,400	80	73	1.3	0.82
	34,500	580	151	2.2	2.34
	45,000	1,600	156	3.0	4.03
	52,000	2,650	160	3.2	5.30

TABLE 3.3 (con't)

HYDRAULIC PARAMETERS FOR SIDE CHANNELS AND SLOUGHS

Location	Gold Creek Discharge (cfs)	Slough/Side Channel Discharge	Slough/Side Channel Width (ft)	Slough/Side Channel Depth (ft)	Slough/Side Channel Velocity (ft/sec)
(1)	(2)	(3)	(4)	(5)	(6)
Side Channel 10	21,000	30	38	0.8	1.00
	25,000	150	83	1.5	1.25
	30,000	430	102	2.1	2.05
	34,500	860	108	2.6	3.07
	45,000	2,800	119	3.7	6.36
	52,000	4,900	127	4.4	8.75
Lower Side Channel 1	7,000	520	275	0.9	1.75
	9,700	862	280	1.3	2.27
	13,400	1,420	285	1.8	2.96
	17,000	2,053	290	2.3	3.60
	23,400	3,365	295	3.2	4.64
	34,500	6,133	300	4.8	6.46
	45,000	9,248	300	6.3	7.87
	52,000	11,565	300	7.5	8.90
Upper Side Channel 11	17,000	38	101	0.5	.75
	23,400	170	117	1.0	1.52
	34,500	1,060	146	2.2	3.30
	45,000	3,900	155	4.0	6.70
	52,000	7,800	170	5.2	8.80
Slough 11	44,000	21	24	0.5	1.65
	46,000	33	30	0.6	1.80
	48,000	94	49	0.9	2.25
	50,000	176	64	1.1	2.60
	52,000	332	84	1.3	3.00
Side Channel 21	12,000	67	77	1.0	0.87
	16,000	205	105	1.4	1.40
	20,000	420	130	1.7	1.90
	25,000	810	162	2.0	2.50
	30,000	1,350	189	2.3	3.10
	40,000	2,900	260	2.7	4.15
	52,000	5,600	298	3.3	5.70
Slough 21	25,000	13	52	0.5	0.50
	30,000	39	72	0.9	0.60
	35,000	105	94	1.4	0.80
	40,000	235	98	2.0	1.20
	45,000	500	99	2.8	1.80
	50,000	970	99	3.9	2.52

SOURCE: Harza-Ebasco (1985)

TABLE 3.4

REPRESENTATIVE BED MATERIAL SIZE DISTRIBUTION
FOR SELECTED SLOUGHS, SIDE CHANNEL AND MAINSTEM SITES

	Particle Size, mm — Percent Finer Than											Bed Material Sizes (mm) For Given Percentage		
	.062	.125	.250	.500	1.00	2.00	4.00	8.00	16.0	32.0	64.0	D_{16}	D_{50}	D_{90}
Main Channel near Cross Section 4[1]	2	3	7	10	13	16	22	29	42	70	89	1.7	20	65
Main Channel between Cross Sections 12 and 13[2]	1	2	3	5	8	12	18	24	32	50	77	3.0	34	78
Main Channel upstream from Lane Creek[3]	2	3	5	7	9	10	14	21	32	48	77	5.0	35	84
Mainstem 2 Side Channels at Cross Section 18.2[4]	3	5	7	10	13	17	22	29	37	53	73	1.7	30	110
Slough 8A[5]	1	3	6	10	12	13	15	18	28	47	83	4.3	35	70
Slough 9[6]	1	2	7	15	18	20	23	30	41	63	93	0.5	22	58
Main Channel upstream from 4th of July Creek[7]	2	4	6	8	11	14	20	27	36	55	78	2.5	28	85
Side Channel 10[8]	1	3	6	12	17	20	25	34	44	62	82	0.8	20	80
Lower Side Channel 11, downstream from Slough 11[9]	1	2	5	7	10	14	19	30	41	58	84	2.6	25	72
Slough 11[10]	1	2	5	8	12	15	20	27	35	50	68	2.2	32	100
Upperside Channel 11, upstream from Slough 11[10]	1	2	5	8	12	15	20	27	35	50	68	2.2	32	100
Main Channel between Cross Section 46 and 48[11]	1	2	3	7	10	13	17	24	33	53	72	3.3	30	100
Side Channel 21, downstream from Slough 21[12]	0	0	1	4	6	8	12	17	23	40	62	7.5	46	96
Slough 21[12]	0	0	1	4	6	8	12	17	23	40	62	7.5	46	96

[1] Based on 6 samples taken at three locations near cross section 4.
[2] Based on 2 samples taken near river miles 109.3.
[3] Based on 2 samples taken in main channel upstream from Lane Creek.
[4] Based on 4 samples taken in the Mainstem 2 side channel, at four locations.
[5] Based on 6 samples taken near the slough in the main channel at RM 125.6.
[6] Based on 5 samples taken near the slough in the main channel at RM 128.7.
[7] Based on 3 samples taken in the main and side channels near 4th of July Creek.
[8] Based on 2 samples taken in Slough 10.
[9] Based on 2 samples taken in Side Channel 11, downstream from Slough 11.
[10] Based on one sample taken in Slough 11.
[11] Based on 2 samples taken between cross sections 46 and 48.
[12] Based on one sample taken near the upstream end of side channel.

SOURCE: Harza-Ebasco (1985)

TABLE 3.5
ARMORING BED MATERIAL SIZES IN SELECTED
SLOUGHS, SIDE CHANNELS AND MAINSTEM SITES

Location	Discharge at Gold Creek (cfs)										
	5,000	7,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000	45,000	55,000
				Armoring Bed Material Size (mm)							
Main Channel near Cross Section 4	18	21	24	29	33	36	38	41	43	44	48
Main Channel between Cross Sections 12 & 13	21	25	28	37	44	48	53	57	60	65	76
Main Channel upstream from Lane Creek	25	28	32	37	44	48	52	56	60	64	72
Mainstem 2 Side Channel at Cross Section 18.2											
Main Channel				6	11	18	25	31	37	43	56
North-east Fork				5	9	13	16	18	21	24	29
North-west Fork				5	9	13	16	17	19	21	24
Slough 8A							4	6	8	9	12
Slough 9						9	13	17	20	24	31
Main Channel upstream from 4th of July Creek	27	31	35	40	45	50	54	57	61	64	71
Side Channel 10					5	13	22	29	37	45	60
Lower Side Channel 11		5	9	16	22	28	34	39	45	50	61
Slough 11										5	17
Upper Side Channel 11					7	13	20	30	44	57	84
Main Channel between Cross Sections 46 and 48	30	35	41	49	56	62	68	73	79	84	94
Side Channel 21			6	10	15	18	22	25	28	31	37
Slough 21					3	5	9	14	21	30	58

SOURCE: Harza-Ebasco (1985)

TABLE 3.6

POTENTIAL DEGRADATION AT SELECTED SLOUGHS, SIDE CHANNELS AND MAINSTEM SITES

Location	Discharge at Gold Creek (cfs)										
	5,000	7,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000	45,000	55,000
	Estimated Degradation, ft										
Main Channel near Cross Section 4	0.1	0.2	0.3	0.6	0.8	1.1	1.3	1.5	1.7	1.9	2.4
Main Channel between Cross Sections 12 & 13	0.1	0.2	0.3	0.4	0.6	0.8	1.1	1.3	1.8	2.4	3.7
Main Channel upstream from Lane Creek	0.2	0.2	0.3	0.4	0.6	0.8	1.0	1.2	1.5	1.8	2.5
Mainstem 2 Side Channel at Cross Section 18.2											
Main Channel	0	0	0	0	0	0.1	0.2	0.3	0.5	0.7	1.2
North-east Fork	0	0	0	0	0	0	0	0.1	0.1	0.2	0.2
North-west Fork	0	0	0	0	0	0	0	0.1	0.1	0.2	0.2
Slough 8A	0	0	0	0	0	0	0	0	0	0	0
Slough 9	0	0	0	0	0	0	0	0.1	0.2	0.3	0.5
Main Channel upstream from 4th of July Creek	0.3	0.3	0.4	0.6	0.8	1.1	1.3	1.5	1.7	2.0	2.5
Side Channel 10	0	0	0	0	0	0.1	0.2	0.4	0.6	1.0	2.0
Lower Side Channel 11	0	0	0	0.1	0.2	0.3	0.5	0.7	1.0	1.3	2.1
Slough 11	0	0	0	0	0	0	0	0	0	0	0.1
Upper Side Channel 11	0	0	0	0	0	0.1	0.2	0.3	0.6	0.9	1.8
Main Channel between Cross Sections 46 and 48	0.3	0.4	0.6	0.9	1.2	1.4	1.7	1.9	2.1	2.4	2.8
Side Channel 21	0	0	0	0	0	0	0.1	0.1	0.2	0.2	0.3
Slough 21	0	0	0	0	0	0	0	0	0.1	0.2	0.5

SOURCE: Harza-Ebasco (1985)

TABLE 3.7

NATURAL AND WITH-PROJECT AVERAGE WEEKLY FLOWS
OF SUSITNA RIVER AT GOLD CREEK
(1950-1983)

		With-Project Flows[2]			
Week[1]	Natural Flow	1996 Load Conditions[3]	2001 Load Conditions[3]	2002 Load Conditions[4]	2020 Load Conditions[4]
(1)	(2)	(3)	(4)	(5)	(6)
1	1607	9552	9695	7027	10323
2	1554	9540	9679	6997	10300
3	1512	9526	9655	6965	10285
4	1494	9537	9666	6936	10201
5	1427	9518	9639	6897	10225
6	1354	9561	9789	6903	10262
7	1300	9603	9775	6851	10141
8	1258	9502	9669	6802	10082
9	1204	9357	9521	6709	9957
10	1152	8711	8971	6376	9448
11	1149	8338	8486	6167	9117
12	1157	7953	8093	5959	8781
13	1167	7715	7852	5840	8581
14	1216	7593	7682	5832	8500
15	1240	7260	7303	5670	8245
16	1408	7028	7028	5543	8000
17	1667	6765	6765	5534	7644
18	3654	6912	6875	5481	7532
19	7914	7449	7559	5910	7932
20	13466	8886	9001	6780	9067
21	18715	10440	10521	7434	9896
22	23556	11910	11953	8115	10782
23	27284	11367	11438	9014	10252
24	29369	11679	11741	8960	10452
25	27860	11415	11539	10227	10322
26	26313	10974	11142	11773	10112
27	23987	10006	10161	13951	9317
28	24491	10124	10254	16950	9383
29	24708	10153	10275	19797	9460
30	24031	10013	10204	20915	9355
31	25294	11002	11103	22285	9613
32	23320	10470	10629	21810	9415
33	22387	11770	11072	21224	10756
34	20411	12367	12177	20478	11875
35	18377	12280	11929	18366	11281
36	15621	12685	12088	15756	11772
37	14039	11783	11100	14030	10998
38	12871	11269	10790	12790	10211
39	10663	10304	10033	10750	9649
40	8102	8990	8726	8297	8812
41	6782	8384	8266	7258	8695
42	5348	8543	8374	6443	8557
43	4303	8636	8456	6531	8514
44	3332	8440	8345	6620	8461
45	2861	8792	8691	6824	8908
46	2562	9215	9165	7032	9554
47	2358	9727	9698	7255	10122
48	2204	10196	10195	7476	10603
49	1978	10892	11025	7775	11108
50	1886	11162	11312	7918	11474
51	1785	10796	10915	7675	11162
52	1739	10080	10142	7263	10590

1/ First week is the first week of month of January.
2/ Based on environmental constraints, E-6.
3/ Watana Operation.
4/ Watana - Devil Canyon operation.

SOURCE: Harza-Ebasco (1985)

TABLE 3.8

MAXIMUM NATURAL AND WITH-PROJECT WEEKLY
FLOWS OF SUSITNA RIVER AT GOLD CREEK

Year	Natural Flow	1996 Load Conditions	2001 Load Conditions	2002 Load Conditions	2020 Load Conditions
1950	26171	10092	11534	21157	10327
51	30057	15024	11374	30057	11856
52	38114	14216	14216	37243	12721
53	35114	14356	15779	25643	11771
54	31143	13975	13975	31143	12664
55	37243	22402	19671	35236	18572
56	43543	25394	22429	32000	26000
57	37443	20071	19275	25943	13414
58	38686	12426	12426	37485	11817
59	44171	28700	16498	41415	14829
60	32043	13342	13914	28943	12203
61	38714	15622	15622	26000	13787
62	58743	26057	26057	35557	23571
63	40257	19900	19543	38549	22106
64	75029	18410	18410	29834	14941
65	33643	21913	21913	28514	19812
66	47686	17098	17098	28014	14719
67	54871	41459	29071	41589	30600
68	37343	14439	15125	29429	12551
69	18114	9861	8000	8000	10228
70	26429	9211	9409	8126	10226
71	47186	22857	22857	37427	22857
72	44243	18029	19488	33149	18029
73	36443	11756	11756	23171	10293
74	31357	11846	11846	16614	10828
75	36400	19886	18629	29900	19886
76	29843	11965	11965	25844	11530
77	46300	15438	15438	25514	14420
78	22786	11800	11921	20214	11685
79	32457	12955	13558	32457	12927
80	33557	13106	13264	33557	13304
81	46729	37029	37029	39966	37029
82	28857	12141	12145	27500	11895
83	27343	12683	13481	26586	12875

SOURCE: Harza-Ebasco (1985)

TABLE 3.9

SUSITNA TRIBUTARY STABILITY ANALYSIS

SUMMARY OF SEMI-QUANTITATIVE ASSESSMENT

No.	Name	Q_2[1] (cfs)	S[2] (ft/ft)	D_{50}[3] (mm)	ΔE[4] (ft)	Reason for Concern	Response to Increased Slope at Mouth	Impacts Foreseen
1	Portage	1680	.0158	33	7.6	fish	degrade	
2	Jack Long	181	.0276	-	6.1	fish	perch	possible restriction of fish access
3	Indian	786	.0150	50	5.5	fish	degrade	
4	Gold	260	.0194	36	5.2	fish	degrade	
5	132.0	17	.1280	-	3.2	RR	perch	
6	4th of July	187	.0219	25	6.1	fish	degrade	
7	Sherman	72	.0403	30	4.4	RR, fish	perch	possible restriction of fish access
8	128.5	14	.0607	-	4.0	RR	perch	
9	127.3	28	.0597	-	3.6	RR	degrade	possible limited scour at RR bridge
10	Skull	51	.0159	20	4.2	RR	degrade	possible limited scour at RR bridge
11	123.9	67	.0230	-	5.0	fish	perch	
12	Deadhorse	51	.0344	19	4.4	fish, RR	perch	possible restriction of fish access
13	121.0	16	.0483	20	4.4	fish	degrade	
14	L. Portage	23	.0048	26	5.0	RR	perch	
15	McKenzie	21	.0316	18	6.2	fish	degrade	
16	Lane	117	.0214	13	5.0	fish	degrade	
17	Gash	4	N/A	-	5.2	fish	degrade	
18	110.1	21	.0757	-	7.0	RR	degrade	possible limited scour at RR bridge
19	Whiskers	114	.0011	-	3.5	fish	perch (but backwater)	

SOURCE: R & M (1982f)

1 Mean annual flood
2 Average channel slope
3 Median bed particle size
4 Decrease in Susitna River stage at mouth

4.0 SLOUGH HYDROLOGY

4.1 Introduction

Flow into side-channel and upland sloughs comes from overtopping of upstream berms by mainstem flow, from local surface tributaries, and from groundwater upwelling. Slough discharges and hydraulic conditions when the upstream berms are overtopped are dominated by mainstem flow. The relationship between mainstem flow and slough flow for overtopped conditions has been previously shown in Table 3.3. Under with-project conditions, the upstream berms will be overtopped much less frequently. Consequently, groundwater upwelling and local surface runoff will control slough hydrology. This section of the report describes these two aspects of slough hydrology.

During non-overtopped conditions, sufficient local runoff and upwelling are required to provide sufficient flow to allow access to spawning areas in the side sloughs for chum and sockeye salmon (ADF&G 1983a). Upwelling also provides water which both keeps incubating embryos from freezing and supplies them with oxygen. Much of this upwelling water is at 2° to 4°C throughout the winter. This warmer water keeps developing embryos alive during early incubation and maintains development at a level elevated above that which would occur in the mainstem at 0°C (Wangaard and Burger, 1983).

4.2 Factors Affecting Upwelling

4.2.1 Sources of Groundwater

Groundwater sources for the Middle Reach can be separated into mainstem and local upland sources. The origin of all groundwater is at the surface, ultimately coming from precipitation. Sources controlled by the mainstem originate at undefined points upstream of the upwelling location. During the summer, upstream precipitation events and glacial melt supply the surface water, which percolates into the groundwater. Much of the winter flow is maintained by water stored during the summer in the broad gravel floodplains below the glaciers at the headwaters of the basin. Water from alluvial fans at the bases of upstream slopes and tributaries add to the flow. This is considered to be the basic source of groundwater in the system (Acres American 1983).

The upland component of groundwater upwelling comes from precipitation falling on the slopes above the river. After reaching the earth's surface, precipitation and/or snowmelt move as surface runoff or go into soil storage or groundwater. Recent precipitation and snowmelt history determine the amounts of each which occur. Large precipitation events are usually required to contribute much water into the groundwater system. Upland sources are independent of mainstem discharge levels, since local events drive the system. These local events also are unpredictable. The effects of upland sources on upwelling are most pronounced for steeper, higher and closer valley walls.

4.2.2 Aquifer Conditions

An aquifer is generally considered to be a geological formation that is porous enough to hold significant quantities of water and also permeable enough to readily transmit it horizontally. The material of the floodplain aquifer in the Middle Reach typically consists of a thin layer of topsoil overlying 2 to 6 feet of sandy silt. Below this is a heterogeneous alluvium of silt, sand, gravel, cobbles, and boulders. Non-stationary streambed deposition is believed to be responsible for the heterogeneous pattern. The heterogeneous nature of the material results in variable hydraulic conductivities, both laterally and vertically (Acres American 1983). Depth through this material to bedrock is approximately 100 feet at the abutments to the Alaska Railroad bridge at Gold Creek (Prince 1964).

Groundwater flow through an aquifer may be confined or unconfined, depending on the location. Unconfined aquifers are similar to underground lakes in porous materials. There is no restricting material at the top of the aquifer, so the groundwater levels are free to rise and fall. The top of the unconfined aquifer is the water table. Below the water table the aquifer is saturated, while above the water table it is only partially saturated. Much of the sand, gravel and cobble alluvium underlying the Susitna River's bed is an unconfined aquifer. This unconfined aquifer is bounded by bedrock on the sides and bottom. Groundwater flow through the system is downhill, running parallel to the valley walls and following the general course of the surface river, but at a much slower rate.

Conditions in unconfined aquifers are such that changes in mainstem stage have a delayed and minimal effect on water table elevation. This is caused by the large volume of aquifer that must be filled to raise the water table by a given amount.

A confined aquifer is a layer of saturated, porous material located between two layers of much less permeable material. If these confining layers are essentially impermeable, they are called aquicludes. If the layers are permeable enough to transmit water vertically to or from the confined aquifer, but not permeable enough to laterally transport water as an aquifer, they are called aquitards. A confined aquifer bounded by one or two aquitards is called a leaky or semiconfined aquifer. Aquitards consisting of layers of fine silt often bound the highly permeable sand and gravel alluvium, creating piping zones where groundwater is easily transmitted. Along the Susitna River, such piping zones are believed to be sources of shallow lateral flow to the upwelling areas. These piping zones would be most likely to rapidly respond to changes in mainstem stage, because such changes would be transmitted into the aquifer as pressure effects rather than by filling or draining the pore space of the aquifer. A regional confined aquifer may be providing water to the sloughs and mainstem. However, the preponderance of near-surface bedrock along the valley walls and nearby mountains minimizes the likelihood of a confined regional aquifer being a significant water source, although some local springs and seeps may occur at faults in the bedrock. According to APA (1984b), neither regional flow from the valley walls into the alluvium nor downriver flow through the alluvium appears to be sufficient to provide all of the apparent groundwater upwelling to the side sloughs.

Ice processes have a dramatic effect on lateral flow during the winter. As an ice cover forms on the river, the effective water surface level (WSL) in the mainstem rises dramatically. Flow becomes confined by the ice at the water surface. Friction caused by movement against the stationary ice cover reduces the velocity of the river water. Water level rises as the velocity drops. The ice cover also acts directly to increase the WSL by floating on the surface. The increased pressure supplied by the floating ice increases the effective WSL to near the top of the ice cover. In the Middle Reach, confined 2,000-cfs flow may have the same effective WSL as 20,000 cfs with no ice cover present. The result of this increase in stage is a much higher hydraulic head, increasing lateral flow from the mainstem into the groundwater system and, presumably, resulting in increased upwelling in the side channels and sloughs.

Groundwater temperatures are buffered from seasonal climatic variations by the heat storage in the aquifer. As groundwater moves through the system, it adds to or removes heat from the surrounding material. Heat transfer during groundwater movement can occur by both conduction and convection. The groundwater temperature approaches that of the surrounding material, and remains stable through the year. The net energy balance is such that groundwater temperature in the Middle Reach stabilizes at about 2-4°C, approximating the mean annual (time-weighted) mainstem temperature.

The temperature of the groundwater is a function of time. This becomes important when considering groundwater temperatures in areas of confined flow. The response of flow under confined conditions can be very rapid since the changes are caused by pressure waves. However, actual time of flow is much greater. Therefore, fluctuations of groundwater temperatures in these areas are similar to those in areas of unconfined flow. The distance through the alluvium that is travelled is much more important on the moderating effect on the temperature of the groundwater than the presence or absence of a confining layer.

4.3 Local Surface Runoff

Runoff from a drainage basin is influenced both by climatic factors and physiographic factors (Chow, 1964). Climatic factors include the forms and types of precipitation, interception, evaporation, and transpiration, all of which exhibit seasonal variations. Physiographic factors are further classified into basin characteristics and channel characteristics. Basin characteristics include such factors as size, shape, and slope of drainage areas, permeability and capacity of groundwater formations, presence of lakes and wetlands in the basin, and land use. Channel characteristics are primarily related to the hydraulic properties of the channel which govern the movement of streamflows and determine channel storage capacity.

Many of the above factors are interdependent to a certain extent, and can be highly variable in nearby basins. The general basin characteristics of each of the study sloughs are described in the following section.

4.4 Field Studies

4.4.1 Study Sloughs

Four sloughs have been chosen for intensive sampling. These four, 8A, 9, 11 and 21, were chosen because they are the most important side sloughs for salmon spawning and incubation (ADF&G 1984c). They also encompass a wide range of physical variables, allowing a better understanding of the general upwelling conditions in the Middle Reach. The relative locations of each of the study sloughs are shown in Figure 4.1.

Slough 8A, located between RM 125 and RM 127, is a side slough on the east side of the river. The two-mile long slough is relatively straight with two upstream channels connecting it to the mainstem (Figure 4.2). Overtopping of the northwest channel at RM 126.2 occurs at about 26,000 cfs, while overtopping of the northeast channel at RM 126.7 occurs at 33,000 cfs. The substrate in the upper slough is primarily cobble and boulders, and in the lower slough is gravel and cobble. At present, several beaver dams, some of them armored with cobble, are located along the slough. Surface water input is supplied by 6 to 8 streams coming down from steep slopes adjacent to the slough with shallow or exposed bedrock.

Slough 9 is a 1.2 mile-long S-shaped side slough on the east side of the river between RM 128 and RM 129.3 (Figure 4.3). The upper slough has a fairly steep slope and cobble/boulder substrate. The lower slough has a low gradient and smaller substrate consisting of gravel/cobble. Overtopping discharge of the berm at the upper end of the slough is about 16,000 cfs. A major water source during non-overtopped conditions is slough 9B (Figure 4.3). This small slough drains a marshy area near the head of the slough. A small tributary (Tributary 9B) with a drainage area of about 1.5 square miles enters the slough further down.

Slough 11, located between RM 135 and RM 136.5, is another side slough on the east bank of the river. This mile-long slough was formed in 1976 as an overflow channel when an ice jam blocked the river during breakup. The upper slough has a cobble/boulder substrate while the lower slough is less steep and has a mostly gravel/cobble substrate. The slough overtops at approximately 42,000 cfs. There are no tributaries into the slough. Non-overtopped flow in the slough comes from seepage and upwelling in the lower two-thirds of the slough (Figure 4.4).

Slough 21 is located at about RM 142, on the east side of the river, and is about one-half mile long. The upper one-half of the slough is divided into two channels, with overtopping flows of 23,000 and 26,000 cfs. There are no tributaries conveying surface runoff to this slough. Groundwater upwelling is very obvious, as large areas of strong upwelling and springs occur throughout the slough (Figure 4.5). A large upland area may provide considerable input into the local groundwater.

4.4.2 Field Investigations

In order to explain the relationship between the mainstem and upwelling in the sloughs, several studies, described in the following section, were conducted in the study sloughs. The data are described in this section, while the results from the data are discussed in the following section.

Slough discharges were recorded in Sloughs 8A, 9, 11 and 21. Daily mainstem flow or stage measurements have been compared with slough flow using linear regression analysis, with slough flow as the dependent variable (Table 4.1) (R&M 1982, 1985a; Acres American 1983; APA 1984b; Beaver, 1985). Analysis was complicated by frequent overtopping of the upstream berms in Sloughs 8A and 9 during much of the summer. Data collected in 1984 were particularly useful in investigating groundwater upwelling to the sloughs because a significant portion of the 1984 open-water data are for very low mainstem discharge rates, thus minimizing complicating effects such as surface runoff and overtopping of berms. Correlations between slough discharge and mainstem stage are given on Table 4.2. Correlations for 1982 and 1983 are for daily data, while data for 1984 are for average weekly data. Correlation with mainstem stage, rather than mainstem discharge, makes it easier to estimate groundwater upwelling for various with-project scenarios, particularly winter conditions when ice staging effects have been simulated. Similarly, the use of weekly rather than daily averages makes it easier to apply the results of with-project simulations, which are generally expressed as weekly average mainstem stage or discharge values. Rating tables for the mainstem locations are given in Table 4.3.

Additional data were obtained by monitoring groundwater surface levels in shallow wells dug in the vicinities of sloughs 8A and 9 (R&M 1982g, APA 1984b). The data allow groundwater flow direction to be determined in the areas immediately around sloughs 8A and 9. Comparison of the plots for different dates and mainstem flows shows the temporal variability of flow patterns in the groundwater system (Figures 4.6-4.11).

In order to better estimate aquifer permeability, pump tests were attempted at several existing wells near Slough 9. However, the pump tests were unsuccessful in providing usable data. Consequently, falling head tests were conducted to provide estimates of aquifer transmissivity. The results are shown in Table 4.4.

Mainstem, groundwater, intragravel and slough water temperatures have been continuously recorded (ADF&G 1983a, b; 1984 b, c, d). These data show the range in variations for different locations (Figures 4.12 - 4.19).

Seepage meter data were obtained at upwelling sites in several sloughs (APA 1984b). The data serve as another indicator of flow rate through the groundwater system. Relationships between mainstem discharge and upwelling rates are tabulated in Table 4.5.

In 1984, the water balance in the sloughs was investigated (R&M 1985a). Studies focused on quantifyin... put into slo... ributary flo... monthly wat... spatial var... as also inv... other loca...

∴ If pre-project effective winter WSEL corresponds to a 20,000 cfs Q and with-project winter WSEL corresponds to a 12,000 cfs Q, Then

20,000 (.0001) = 2cfs
12,000 (.0001) = 1.2cfs
Δ8,000 change = -0.8cfs (40% Δ)

20,000(.00035) = 7cfs
12,000 (.00035) = 4.2cfs
Δ8,000 change = 2.8cfs (40%)

Therefore, there will be a 40% loss of groundwater in sloughs due to project effects.

4.4.3 Res...

A s... e the disch... ich of the ... hydraulic and thermal behavior of each slough is substantially different from that of the other sloughs studied. The discharge at Slough 11 seems to correlate very well with mainstem discharge, while the discharge at Slough 9 is largely controlled by mainstem overtopping of the berm. The discharge at Slough 8A may be complicated by factors such as surface runoff and groundwater underflow from sources other than the mainstem of the Susitna River. However, where it has been possible to remove the effects of some of these complicating factors and isolate attention on only the groundwater upwelling contribution to slough discharge, fairly good correlations between slough discharge and mainstem discharge have been observed. In very general terms, based on available information, it appears that variations in the groundwater contribution to slough discharge at Sloughs 8A, 9, and 11 might be reasonably represented by 0.0001 to 0.00035 of corresponding variations in mainstem discharge at Gold Creek (APA, 1984b).

Regardless of the complicating factors affecting discharge from each slough, the available data suggest that the temperature of upwelling groundwater remains fairly constant throughout the year, at a temperature approximately equal to the mean annual (time-weighted, not discharge-weighted) mainstem temperature. Heat exchange between groundwater and soil materials, and mechanical dispersion during groundwater transport through the aquifer, are reasonable mechanisms to account for the observed groundwater temperatures.

Since a general model can not be formulated to describe each slough, results from the individual sloughs are described below.

4.4.3.1 **Slough 8A**

Slough discharge at Slough 8A is moderately well correlated to mainstem discharge and stage (Tables 4.1, 4.2). Local runoff from the adjacent steep, rocky hillslopes causes some disruption of the relationship. The data for the period September 1 - October 20, 1984, when little precipitation fell, yielded the best relationship between slough discharge and mainstem discharge. The complicating effects of local runoff and groundwater are further illustrated by seepage investigations. Seepage data collected at an upwelling site (meter 8-2) near the upstream berm in Slough 8A had a poorer correlation to mainstem discharge (R^2 = 0.38) than did a site (meter 8-1) located in a small channel adjacent to a steep bank (R^2 = 0.81) (Table 4.5) .

Water surface elevation data collected in 1983 from wells and boreholes indicate the general downvalley movement of groundwater in the vegetated island separating Slough 8A from the mainstem. Data collected with an ice cover on the mainstem (Figure 4.8) show a definite trend of groundwater flow down valley and from the mainstem towards the side-channel. The trend was also evident during the open-water period (Figure

4.6). When streamflow is dropping, groundwater levels in the island may be higher than the water surface in either the slough or the mainstem (Figure 4.7).

Intragravel water temperature in the slough rose from 0.0°C during the winter (ADF&G 1983a) to 5.5°C in August (ADF&G 1984a) of 1983. During the open water season mainstem surface water ranged from 0.2°C in May to 15.8°C in July (ADF&G 1984a) (Figures 4.12-4.13). Temperatures in the middle of the slough are generally higher than those in the upper end of the slough, except in the latter half of July. The intragravel temperatures generally appear to be subdued reflections of the surface water temperatures at corresponding points. However, surface water temperatures for the middle of the slough exhibit greater variations. The high temperatures recorded in the surface water at the middle of the slough can probably be attributed to solar heating, rather than to surface water discharge as a result of overtopping.

A monthly water balance study of Slough 8A conducted in 1984 (R&M, 1985a) determined that 62%-73% of available precipitation falling on the Slough 8A watershed ran off as surface water (Table 4.7). Higher percentages of runoff may occur with large storms, as the soil layer on the slopes above the river is relatively thin.

Analysis of local precipitation data for 27 September to 7 October 1983 (Bredthauer 1984) shows an immediate response in slough discharge to a major rainstorm (Figure 4.20). The event occurred after a fairly long dry period (over one month). It was an intense storm, with 1.12 inches of rain falling in Talkeetna on 29 September. This amount of precipitation apparently was sufficient to raise the groundwater table and produce a rapid response.

The daily surface runoff pattern into Slough 8A was estimated for high, moderate, and low monthly precipitation (Tables 4.10, 4.11, 4.12). The recorded slough discharges for August 1984 (high precipitation), September 1983 (moderate precipitation), and September 1984 (low precipitation) were separated into surface runoff and groundwater flow. Groundwater flow was estimated using the regression equation for slough discharge shown on the tables and the average daily flows for the Susitna River at Gold Creek. The estimated groundwater flow was then subtracted from the recorded value. (When the groundwater flow estimate from the regression equation exceeded the recorded value, groundwater flow was reduced to the recorded value.) Surface runoff was assumed to be the difference between the recorded discharge and the estimated groundwater flow. Although the estimates for surface runoff are not precise, Tables 4.10 through 4.12 do indicate that there are long periods when little surface runoff is contributed to Slough 8A, even in months when precipitation is well above average. The data in Table 4.10 also indicate that the runoff period extends for several days after a major precipitation event. Apparently, there is sufficient shallow subsurface flow on the valley slopes to maintain the flow for several days.

4.4.3.2 **Slough 9**

Due to the relatively low flow (16,000 cfs) required to overtop the upstream berm, hydraulic conditions in Slough 9 are dominated by mainstem flow for much of the summer. Upwelling occurs in the slough (Figure 4.3), contributing flow throughout the year. Linear regression equations for mainstem and slough discharge data collected in 1983 and 1984 during periods of non-overtopping are shown in Table 4.1. The slopes of the equations for both the 1983 and the 1984 data are very similar. Table 4.2 gives the linear regression equations for the apparent mainstem related component of groundwater upwelling as a function of mainstem stage. Rating tables for the mainstem stage vs. flow at Gold Creek are shown in Table 4.3.

Results of groundwater surface elevation measurements (Figures 4.9 - 4.11) show movement from the side channel upstream of the slough toward the upper reach of Slough 9 between its head and Tributary 9B (APA 1984). A subdued response was often seen even at well 9-3, on the upland side of the slough. An analysis of lateral flow to the slough based on curves derived from an analytical solution to the flow problem showed slough flow to be much less than expected (APA 1984b). Major variations in the results of falling head tests performed in 1984 (R&M 1985a) indicate semiconfined aquifer conditions (Table 4.4). Data from seepage meters in 1983 showed a higher correlation at the downstream end of the slough than in a marshy area near the head of the slough (Table 4.5) (APA 1984). The poor correlation in the marshy area is likely due to water seeping into the groundwater system from Tributary 9B.

Intragravel water temperatures were very stable throughout the study, at just over 3°C (Figures 4.14 and 4.15). Groundwater temperatures from boreholes 9-1A and 9-5 show a limited rise from 2°C in April to 4°C in September of 1983 (Figure 4.16) (APA 1984). Temperature data from borehole 9-3 show no variation related to the mainstem. There appears to be a strong inverse relationship between variations in temperature of the groundwater and distance from the mainstem. Figures 4.14 and 4.16 also show mainstem temperature for comparative purposes.

Tributary 9B was gaged at 2 locations in 1984: (1) at the base of the slope and (2) above its confluence with Slough 9. The intervening area between these 2 gages is an alluvial fan with meadows and beaver ponds. A significant portion of the water measured at the base of the slope infiltrates into the ground before reaching the slough. The data indicate that the amount of infiltration loss is controlled by the water table level, which in turn is controlled by the stage in the mainstem (R&M, 1985a).

This is illustrated by the runoff analyses for two storm events in 1984, shown in Table 4.6. In the August 1984 storm, the downstream gage had about triple the peak flow of the upstream gage. This is in marked contrast to the flow patterns of the Septmber 1984 storm, in which streamflow at the downstream gage barely responded to the precipitation, and was about 1 cfs less than at the upstream gage. This pattern of water loss likely explains the delayed response of Slough 9 to the September 1983 storm (Figure 4.20). Runoff percentages for the 2 sites for the months of August-October 1984 are shown in Table 4.8.

The daily surface runoff pattern into Slough 9 was estimated for moderate and low monthly precipitation (Tables 4.13 and 4.14) in the same manner as for Slough 8A. (An estimate could not be made for high precipitation, since the upstream berm was breached in these cases.) This analysis indicated that surface flow occurred more frequently than at Slough 8A. This is likely due to Tributary 9B originating from a small lake.

4.4.3.3 **Slough 11**

Slough 11 is the simplest of the sloughs studied, with no direct surface tributaries. Since its upstream berm is overtopped only at relatively high flows (42,000 cfs), no surface water contributes to slough discharge for most of the year. Consequently, streamflow is maintained by bank seepage and upwelling throughout the year (Figure 4.4).

The relationship between slough flow and the mainstem is shown in Tables 4.1 and 4.2. Seepage meters, used to get an index of intragravel flow on the slough banks, also showed a strong relationship to the mainstem at both the lower (R^2 = 0.94) and upper (R^2 = 0.83) sites (Table 4.5) (APA 1984).

There was little effect on slough discharge from precipitation events. The analysis of the data from the September 1983 storm event (Figure 4.20) showed no immediate response in slough discharge, and only a minimal response to the mainstem level. The lack of response is in keeping with the lack of tributary input and small drainage area for the slough. This is further illustrated in the monthly water balances (Table 4.7). Flow was stable through the summer, despite high precipitation in July and August.

Intragravel water temperatures in the slough were very stable year-round at about 3.6°C. Surface water temperatures were less constant and did not show a pattern similar to that for intragravel temperatures. Surface water temperatures were also dissimilar to mainstem temperatures (Figure 4.17).

All of the above relationships tend to confirm that Slough 11 flow is derived from mainstem recharge to the local groundwater aquifer. Responses to changes in the mainstem are minimized and delayed. The delays and buffering also account for a very stable intragravel temperature and minimal response to the September 1983 storm.

4.4.3.4 **Slough 21**

Upwelling and seepage locations at Slough 21 are shown on Figure 4.5. The relationship between mainstem discharge and slough discharge appears to be different at Slough 21 than at other study sloughs (Table 4.5). Seepage appears to be negatively correlated to mainstem flow at one site, with seepage increasing as mainstem flow decreases, while no correlation existed between seepage and mainstem flow at a second site. The regression relationships between slough discharge and mainstem discharge (Table 4.1) were poor when all data were used, but had a very good relationship for data obtained late in 1982 (September 22 - October 22), when little precipitation occurred. Similar relationships were obtained for correlation with mainstem water surface elevations (Table 4.2).

Water temperature patterns were fairly complex (Figure 4.18 and 4.19). The intragravel water temperature in the upper slough ranged from a winter low of 2.0°C in October to a high of 8.6°C during much of the summer (ADF&G 1984a). Higher temperatures of up to 13.1°C were also recorded during overtopping for short periods. Surface water temperature at the same location ranged from 0.7° to 9.2°C (with the same overtopping exception). Generally, intragravel temperatures closely mirrored surface water temperatures throughout the year. In the lower slough, intragravel temperatures were about 3.3°C in March (ADF&G 1984a).

The geologic structure of the area around the slough may explain the data. Above the east side of the slough there is a bench of old alluvial material at least ¼-mile wide. This bench may act as a large groundwater reservoir. It is a possible reason for the constant intragravel water temperature in the lower slough. The measurements from the seepage meters may also be a function of local upland flow. The intragravel and surface water temperatures from the upper slough, on the other hand, seem to be more closely related to mainstem temperatures. Slough 21 may show the effects of different sources at different points along the slough.

4.5 With-Project Changes

Detailed projections can not be made of the slough discharge or temperature variations which might result from changes in mainstem conditions as a result of project operation. Because of the substantial differences among the sloughs in their hydraulic and thermal behavior, it would be necessary to construct mathematical models of each individual slough in order to make detailed predictions of the effects on the sloughs of changes in mainstem conditions. The different responses of Sloughs 8A, 9, and 11 to the same storm event are illustrated in Figure 4.20. The mainstem discharge in Figure 4.20 is in the range of summer with-project flows, with none of the sloughs upstream berms overtopped.

Some sloughs, such as Slough 11, will probably respond fairly directly to changes in mainstem discharge. Slough 11 is generally characterized by a lack of tributary streams and rare overtopping of its upstream berm. Sloughs with similar environmental features might be expected to respond similarly to changes in mainstem discharge. Any such relationship for Slough 11 could be approximated by the regression equation in Table 4.1.

Some sloughs, such as Slough 9, are overtopped during much of the time as a result of high river stage or ice staging. During such periods, such sloughs might be effectively considered as side channels of the river, rather than sloughs. If the overtopping flows for these sloughs are known, it can be estimated how often such sloughs will carry predominantly mainstem flow (at mainstem temperatures), rather than groundwater discharge. With-project flows will be less than normal summer flows, so the frequency of overtopping will be reduced. Slough 9 discharge under with-project conditions might be estimated from correlations of slough discharge to mainstem discharge during periods when the upstream berm is overtopped, and by the best-fit regression equation in Table 4.1 during periods when the berm is not overtopped. Flow from local tributaries would increase this last estimate during snow melt and precipitation events.

Most sloughs will probably be similar to slough 8A in that it will not be possible to separately determine each factor contributing to the discharge of the slough without conducting additional field investigations at each slough. Slough upwelling will be reduced due to the reduction in mainstem discharge, but the sloughs will have similar contributions of flow due to upland groundwater and local surface runoff.

Temperatures of groundwater discharge to the sloughs appear to be reasonably approximated by the mean annual (time-weighted) river temperature. It is likely that any variations in mean annual river temperature as a result of project operation will also result in a similar change in the temperature of groundwater upwelling to the sloughs, to the extent that such upwelling is derived from the mainstem (e.g., as is probably the case at Slough 11). Any changes in water temperature of mainstem flow which is diverted down sloughs during overtopping could have some influence on the average temperature of groundwater. However, as noted above, overtopping will be much less frequent during project operation than under present conditions.

TABLE 4.1 LINEAR REGRESSION EQUATIONS
FOR SLOUGH DISCHARGE VS. MAINSTEM DISCHARGE (1982-84)

Slough	Year	Regression Equation	R^2	Comments
8A	1984(1)	Q8 = -0.08 + 0.00017 G	0.53	7/3 - 10/30 (excl 8/23-8/28); Flow rate
		log Q8 = -5.0 +1.29 log G	0.79	(2,200-27,900 cfs)
		Q8 = -0.67 + 0.00025 G	0.73	9/1 - 10/20; Flow range (2,200-12,500 cfs)
		log Q8 = -7.13 + 1.85 log G	0.91	
	1983(2)	Q8 = -3.83 + 0.000526 G	0.103	All values.
		Q8 = 5.10 + 0.0000377 G	0.001	Excluding overtopping flows, G > 30,000
		Q8 = 0.155 + 0.000117 G	0.086	6/6 - 8/7 only; excluding G > 30,000
		Q8 = -0.627 + 0.000128 G	0.631	6/6 - 8/7 only; excluding G > 30,000, Q8 > 3
9	1984(1)	Q9 = -0.62 + 0.00039 G	0.82	9/8 - 10/30; Flow range (2,200-11,400 cfs)
		log Q9 = -4.1 + 1.15 log G	0.84	
	1983(2)	Q9 = -149.7 + 0.010008 G	0.264	All values.
		Q9 = 2.94 + 0.000307 G	0.089	Excluding overtopping flows, G > 16,000
		Q9 = 1.97 + 0.000351 G	0.805	Excluding G > 16,000, Q9 > 8
11	1984(1)	Q11 = 1.3 + 0.000072 G	0.68	6/1 - 10/30; Flow range (2,200-40,600 cfs)
		log Q11 = -1.5 + 0.45 log G	0.76	
	1983(2)	Q11 = 1.51 + 0.000102 G	0.766	All values.
	1982(2)	Q11 = 2.15 + 0.000104 G	0.504	All values.
21	1982(2)	Q21 = -7.62 + 0.00105 G	0.543	All values.
		Q21 = -0.570 + 0.000445 G	0.405	Excluding overtopping flows, G > 24,700
		Q21 = -2.71 + 0.000803 G	0.916	September 22 - October 22 only; excluding G > 24,700

Notes: Q8 = Slough 8A discharge, cfs; G = Mainstem discharge at Gold Creek, cfs

(1) Source: R&M (1985a)

(2) Source Beaver (1984)

TABLE 4.2

LINEAR REGRESSION EQUATIONS
FOR SLOUGH DISCHARGE VS. MAINSTEM STAGE (1982-84)

Slough	Year	Regression Equation	R^2	Comments
8A	1984(1)	Q8 = -368.21 + 0.6356 W1	0.78	Average weekly values, discharge and stage
	1983(2)	Q8 = -2149.8 + 3.698 W1	0.065	All values
		Q8 = -92.3 + 0.1683 W1	0.000	Excluding overtopping flows, G > 30,000
		Q8 = -740.96 + 1.2737 W1	0.626	June 6 - August 7 only; excluding G > 30,000, Q8 > 3
9	1984(1)	Q9 = -171.88 + 0.28892 W2	0.84	Average weekly values, discharge and stage
	1983(2)	Q9 = -32801 + 54.380 W2	0.228	All values
		Q9 = -769.1 + 1.2871 W2	0.085	Excluding overtopping flows, G > 16,000
		Q9 = -877.21 + 1.4658 W2	0.755	Excluding G > 16,000, Q9 > 8
11	1984(1)	Q11 = -335.39 + 0.49209 W3	0.96	Average weekly values, discharge and stage
	1983(2)	Q11 = -367.04 + 0.54004 W3	0.783	All values
	1982(2)	Q11 = -327.05 + 0.48278 W3	0.531	All values
21	1982(2)	Q21 = -4400.2 + 5.8554 W4	0.491	All values
		Q21 = -1810.6 + 2.4130 W4	0.391	Excluding overtopping flows, G > 24,700
		Q21 = -3244.1 + 4.3212 W4	0.938	September 22 - October 22 only; excluding G > 24,700

NOTES: Q8 = Slough 8A discharge, cfs; Q9 = Slough 9 discharge, cfs; Q11 = Slough 11 discharge, cfs;
Q21 = Slough 21 discharge, cfs.
G = Mainstem discharge at Gold Creek, cfs
W1= Mainstem stage at RM 127.1, ft.

(1) Source: Beaver (1985).

(2) Source: Beaver (1984).

TABLE 4.3

RATING TABLES, MAINSTEM NEAR STUDY SLOUGHS

Discharge, Susitna River at Gold Creek (cfs)	Elevation, Feet Above Mean Sea Level RM 127.1	RM 129.3	RM 136.68	RM 142.2
5,000	580.6	600.6	682.2	750.8
10,000	581.9	602.2	684.0	752.0
15,000	582.7	603.3	685.3	752.9
20,000	583.2	604.2	686.4	753.7
25,000	583.8	605.0	687.2	754.5
30,000	584.2	605.6	687.9	755.2
40,000	584.9	606.8	689.1	756.6
50,000	585.5	607.8	690.1	757.8

Source: Harza-Ebasco Susitna Joint Venture. 1984b. Middle and Lower Susitna River, Water Surface Profiles and Discharge Rating Curves, Volumes I and II Draft Report. Susitna Hydroelectric Project Document No. 481. Prepared for Alaska Power Authority. January.

TABLE 4.4

FALLING HEAD TEST RESULTS
SLOUGH 9 - BOREHOLES

Borehole	Well I.D. (ft)	Depth of Screen (ft)	Date of Test	Transmissivity Ft^2/Day	Comments
9-1	0.146	24-27	07/17/84	3.5	Good curve fit
9-1	0.146	24-27	07/31/84	5.4	Good curve fit, retest
9-1	0.146	24-27	08/15/84	3.4	Good curve fit, retest
9-1	0.063	9.4-10.7	08/15/84	0.2	Good curve fit
9-1	0.063	9.4-10.7	08/29/84	0.2	Good curve fit, retest
9-2	0.146	7-10	08/13/84	50	Sparse data, poor curve fit
9-2	0.146	7-10	08/15/84	92	Sparse data, poor curve fit, retest
9-2	0.146	7-10	08/29/84	12	Poor curve fit, retest
9-2	0.063	10.7-12.1	08/15/84	--	No curve fit
9-2	0.063	10.7-12.1	08/25/84	2.6	Poor curve fit, retest
9-3	0.146	37-40	07/31/84	3.4	Good curve fit
9-3	0.146	37-40	08/14/84	3.6	Retest
9-3	0.146	37-40	08/14/84	2.4	Retest after surging well. Value probably affected by previous testing.
9-4	0.063	11.7-13.1	08/13/84	--	No useable data
9-4	0.063	11.7-13.1	08/13/84	--	No useable data, retest

Source: R&M (1985a)

TABLE 4.5

REGRESSION EQUATIONS FOR SEEPAGE RATE VS. MAINSTEM DISCHARGE

Seepage Meter	Regression Equation	R^2	Mainstem Flow Range (cfs)	Location
8-1	S = 0.00691 G - 50.20	0.81	5,300 - 31,900	Adjacent to bank.
8-2	S = 0.00255 G + 33.76	0.38	9,300 - 31,900	300 feet downstream of berm.
9-1	S = 0.0067 G + 77.3	0.62	5,300 - 22,000	Downstream end on right bank.
9-2	No Correlation	--	5,300 - 31,900	Downstream meter of 2. Marshy area feeding Tributary 9B.
9-3	S = 0.00227 G + 66.1	0.19	5,300 - 31,900	Upstream meter of 2. Marshy area feeding Tributary 9B.
11-1	S = 0.0042 G + 30.18	0.94	5,300 - 24,500	Streamgage site.
11-2	S = 0.001 G + 32.95	0.83	5,300 - 24,500	100 feet upstream of streamgage.
21-1	No correlation	--	5,300 - 31,900	Right bank, lower slough.
21-2	No correlation	--	5,300 - 31,900	Left bank, lower slough.

Notes: S = Seepage rate, ml/min
G = Mainstem discharge at Gold Creek, cfs

TABLE 4.6

STORM RUNOFF ANALYSES
SLOUGH 9 TRIBUTARY

	Slough 9 Tributary, Upper Site		Slough 9, Tributary Lower Site	
Precipitation Period (1984)	08/17-08/25	09/15-09/20	08/17-08/25	09/15-09/20
Runoff Period	08/17-09/06	09/15-09/28	08/17-09/06	09/15-09/28
Total Precipitation (Inches)	6.46	1.40	6.46	1.40
Max. Daily Precipitation (Inches)	2.05	0.61	2.05	0.61
Total Precipitation Volume (million cubic feet)	10.96	2.37	21.91	4.75
Total Runoff Volume (million cubic feet)	6.468	1.081	12.181	0.149
Baseflow Volume (million cubic feet)	1.034	0.798	0.272	0.073
Storm Runoff Volume (million cubic feet)	5.434	0.283	11.909	0.076
% Runoff	50%	12%	54%	1.6%
Groundwater Level, Well 9-3			606.8	604.8
Maximum Daily Flow Susitna River at Gold Creek			31,700	11,400

Source: Table reproduced from R&M (1985a).

TABLE 4.7

1984 MONTHLY WATER BALANCES
SLOUGHS 8A AND 11

	June	July	August	September	October
Slough 8A					
Flow, Q (cfs)		2.98	9.19	1.70	0.63
(million cu. ft.)		7.46 (3-31)	24.62	4.41	1.69
Precipitation, P (inches)		5.46	8.16	2.52	0.78
(million cu. ft.)		19.14	28.61	8.85	2.72
Evaporation, E (inches)		2.02	2.49	0.80	0
(million cu. ft.)		7.07 (3-31)	8.72	2.80	0
(P-E)		12.07	19.89	6.05	2.72
Q/(P-E)		0.62	1.24(1)	0.73	0.62
Slough 11					
Flow, Q (cfs)	3.17	2.82	2.75	2.44	1.45
(million cu. ft.)	8.21	7.58	7.35	6.32	3.75
Precipitation, P (inches)	1.49	4.72	6.78	2.15	0.65
(million cu. ft.)	3.93	18.55	26.60	8.44	2.56
Evaporation, E (inches)	5.66	2.21	2.49	0.80	0
(million cu. ft.)	22.14	8.68	9.76	3.13	0
(P-E) (million cu. ft.)	-18.21	9.87	16.84	5.31	2.56
Q/(P-E)	-0.17	0.77	0.44	1.19	1.47

(1) Slough 8A likely overtopped in late August.

Source: Table reproduced from R&M (1985a).

Table 4.8

1984 MONTHLY WATER BALANCE
SLOUGH 9, TRIBUTARY 9B

	July	August	September	October
Slough 9 Tributary (Upper Site)				
Flow, Q (cfs)	-	2.62	0.91 (1)	0.50
(million cu. ft.)	-	7.02	2.54	1.34
Precipitation, P (inches)	-	7.44	2.11	0.87
(million cu. ft.)	-	12.62	3.58	1.48
Evaporation, E (inches)	-	2.49	0.80	
(million cu. ft.)	-	4.21	1.35	0
P-E, Precipitation-Evaporation	-	8.41	2.19	1.48
Q/(P-E)	-	0.83	1.16 (1)	0.91
Slough 9 Tributary (Lower Site)				
Flow, Q (cfs)	1.21	4.97	0.30	0.07
(million cu. ft.)	3.23	13.31	0.78	0.19
Precipitation, P (inches)	5.25	7.44	2.11	0.87
(million cu. ft.)	17.81	25.24	7.16	2.95
Evaporation, E (inches)	2.21	2.49	0.80	0
(million cu. ft.)	7.50	8.43	2.71	0
(P-E), Precipitation-Evaporation	10.31	16.81	4.45	2.95
Q/(P-E)	0.31	0.79	0.18	0.06

(1) Affected by runoff from storm in late August.

Source: Table reproduced from R&M (1985a).

TABLE 4.9

PRECIPITATION COEFFICIENTS FOR TRANSFER OF RECORDED DATA

	Continuous Station		
Site	Talkeetna	Sherman	Devil Canyon
Curry	1.5	1.2	1.7
Slough 8A	1.3	1.07	1.5
Slough 9 (Sherman)	1.2	1.0	1.4
Gold Creek	1.07	0.9	1.3

To obtain precipitation estimate for above sites, multiply precipitation at the continuous station by the appropriate multiplier.

Source: Table reproduced from R&M (1985a).

TABLE 4.10
ESTIMATED DAILY RUNOFF, SLOUGH 8A
HIGH RAINFALL PATTERN(1)

Date	Daily Precipitation(2) (inches)	Measured Flow(3) (cfs)	Estimated Groundwater Flow(4) (cfs)	Estimated Surface Runoff (cfs)	Estimated With-Project Groundwater Flow(5) (cfs)	Estimated With-Project Slough Flow (cfs)
1		5.9	5.1	0.8	1.6	2.4
2		5.6	4.7	0.9	1.6	2.5
3	0.4	5.2	4.3	0.9	1.6	2.5
4		4.8	4.2	0.6	1.6	2.2
5	.51	4.8	4.5	0.3	1.6	1.9
6		4.4	4.4(6)	0	1.6	1.6
7		4.1	4.1(6)	0	1.6	1.6
8	.55	3.8	3.8(6)	0	1.6	1.6
9		4.4	4.4(6)	0	1.6	1.6
10		4.1	4.1(6)	0	1.6	1.6
11		3.6	3.6(6)	0	1.6	1.6
12		3.2	3.2(6)	0	1.6	1.6
13		2.6	2.6(6)	0	1.6	1.6
14		2.4	2.4(6)	0	1.6	1.6
15		2.2	2.2(6)	0	1.6	1.6
16		2.0	2.0(6)	0	1.6	1.6
17	0.7	1.7	1.7(6)	0	1.6	1.6
18	1.35	2.6	2.6(6)	0	1.6	1.6
19	.58	4.1	3.6	0.5	1.6	2.1
20	.31	4.8	3.8	1.0	1.6	2.6
21	.06	5.2	4.2	1.0	1.6	2.6
22	.64	5.9	4.0	1.9	1.6	3.5
23	.37	8.0	3.8	4.2	1.6	5.8
24	2.19	34	5.0	29	1.6	3.1
25	1.33	65	6.9	58	1.6	6.0
26		44	7.3	37	1.6	34
27		17	6.3	11	1.6	13
28		11	4.7	6.3	1.6	7.9
29		8.0	3.7	4.3	1.6	5.9
30		5.9	3.3	2.6	1.6	4.2
31		4.8	2.7	2.1	1.6	3.7

(1) 20% exceedance probability
(2) August 1984 precipitation. Data are from Talkeetna through day 21, from Sherman after day 21. All data are adjusted to Slough 8A.
(3) August 1984
(4) Q8 = -0.67 + 0.00025 G
(5) Assumes flow at Gold Creek is 9,000 cfs
(6) Estimated groundwater flow exceeded measured surface flow, so reduced groundwater flow to measured flow.

TABLE 4.11
ESTIMATED DAILY RUNOFF, SLOUGH 8A
MODERATE RAINFALL PATTERN(1)

Date	Daily Precipitation(2) (inches)	Measured Flow(3) (cfs)	Estimated Groundwater Flow(4) (cfs)	Estimated Surface Runoff (cfs)	Estimated With-Project Groundwater Flow(5) (cfs)	Estimated With-Project Slough Flow (cfs)
1	.08	7.7	5.7	2.0	1.6	3.6
2		20.8	5.7	15.1	1.6	16.7
3		17.0	5.2	11.8	1.6	13.4
4		15.3	4.6	10.7	1.6	12.3
5		11.6	3.9	7.7	1.6	9.3
6		9.3	3.3	6.0	1.6	9.6
7		7.7	3.0	4.7	1.6	6.3
8	0.7	6.4	2.8	3.6	1.6	5.2
9	.39	6.0	2.6	3.4	1.6	5.0
10	.07	5.3	2.5	2.8	1.6	4.4
11		4.6	2.4	2.2	1.6	3.8
12		4.0	2.2	1.8	1.6	3.4
13		3.3	2.1	1.2	1.6	2.8
14	.39	3.3	2.0	1.3	1.6	2.9
15	.74	3.0	2.0	1.0	1.6	2.6
16		2.8	2.0	0.8	1.6	2.4
17		2.4	1.8	0.6	1.6	2.2
18		2.2	1.7	0.5	1.6	2.1
19		2.1	1.6	0.5	1.6	2.1
20		2.2	1.7	0.5	1.6	2.1
21	.04	2.8	2.0	0.8	1.6	2.4
22	.30	3.8	2.7	1.1	1.6	2.7
23	.13	3.5	3.5(6)	0	1.6	1.6
24		2.1	2.1(6)	0	1.6	1.6
25		1.6	1.6(6)	0	1.6	1.6
26		1.5	1.5(6)	0	1.6	1.6
27		3.8	1.7	2.1	1.6	3.7
28	.21	19.8	1.6	18.2	1.6	19.8
29	1.46	25.3	1.7	23.6	1.6	25.2
30	.42	19.8	2.2	17.6	1.6	19.2

(1) 61% exceedance probability.
(2) September 1983 Talkeetna precipitation adjusted to Slough 8A.
(3) September 1983
(4) Q8 = -0.67 + 0.00025 G
(5) Assumes flow at Gold Creek is 9,000 cfs.
(6) Estimated groundwater flow exceeded measured surface flow, so reduced groundwater flow to measured flow.

TABLE 4.12
ESTIMATED DAILY RUNOFF, SLOUGH 8A
LOW RAINFALL PATTERN(1)

Date	Daily Precipitation(2) (inches)	Measured Flow(3) (cfs)	Estimated Groundwater Flow(4) (cfs)	Estimated Surface Runoff (cfs)	Estimated With-Project Groundwater Flow(5) (cfs)	Estimated With-Project Slough Flow (cfs)
1		4.1	2.5	1.6	1.6	3.2
2		3.2	2.3	0.9	1.6	2.5
3		2.6	2.1	0.5	1.6	2.1
5		2.0	1.9	0.1	1.6	1.7
6		1.7	1.7(6)	0	1.6	1.6
7	.11	1.5	1.5(6)	0	1.6	1.6
8		1.4	1.4(6)	0	1.6	1.6
9		1.2	1.2(6)	0	1.6	1.6
10		1.2	1.2(6)	0	1.6	1.6
11		1.0	1.0(6)	0	1.6	1.6
12	.24	1.0	1.0(6)	0	1.6	1.6
13	.18	1.0	1.0(6)	0	1.6	1.6
14		0.9	0.9(6)	0	1.6	1.6
15	.02	0.8	0.8(6)	0	1.6	1.6
16	.12	0.9	0.9(6)	0	1.6	1.6
17	.04	0.9	0.9(6)	0	1.6	1.6
18	.61	1.2	1.2(6)	0	1.6	1.6
19	.65	1.7	1.7(6)	0	1.6	1.6
20	.05	2.2	1.9	0.3	1.6	1.9
21		2.2	2.2(6)	0	1.6	1.6
22		2.2	1.9	0.3	1.6	1.9
23		2.2	1.6	0.6	1.6	2.1
24		2.0	1.4	0.6	1.6	2.2
25	.13	2.0	1.3	0.7	1.6	2.3
26		1.7	1.2	0.5	1.6	2.1
27		1.5	1.2	0.3	1.6	1.9
28		1.5	1.1	0.4	1.6	2.0
29	.02	1.4	1.1	0.3	1.6	1.9
30	.05	1.4	1.2	0.2	1.6	1.8

(1) 93% exceedance probability
(2) September 1984 Sherman precipitation, adjusted to Slough 8A
(3) September 1984
(4) $Q8 = -0.67 + 0.00025\ G$
(5) Assumes flow at Gold Creek is 9,000 cfs
(6) Estimated groundwater flow exceeded measured surface flow, so reduced groundwater flow to measured flow.

TABLE 4.13
ESTIMATED DAILY RUNOFF, SLOUGH 9
MODERATE RAINFALL PATTERN(1)

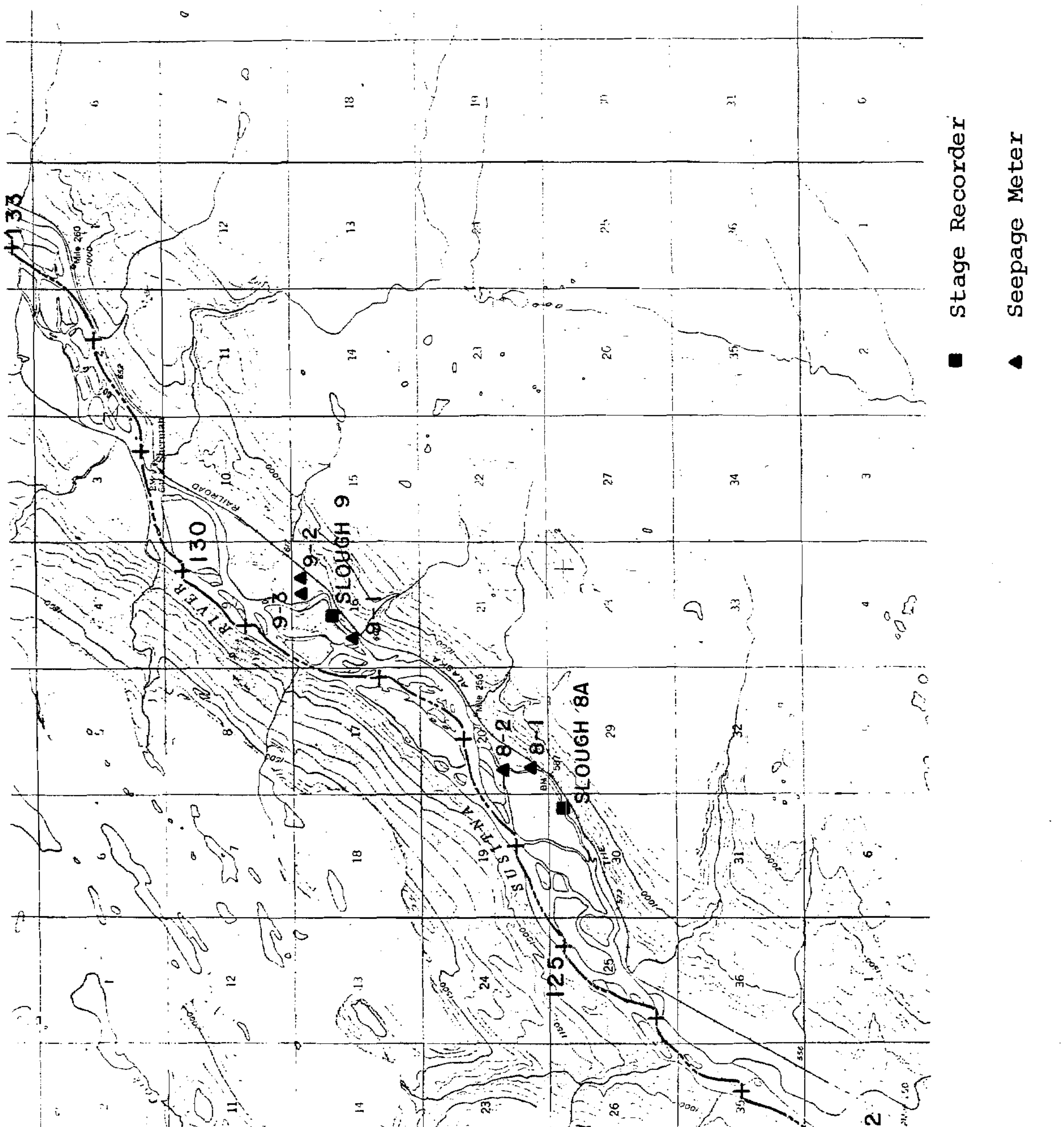
Date	Daily Precipitation(2) (inches)	Measured Flow(3) (cfs)	Estimated Groundwater Flow(4) (cfs)	Estimated Surface Runoff (cfs)	Estimated With-Project Groundwater Flow(5) (cfs)	Estimated With-Project Slough Flow (cfs)
1	.07					
2						
3						
4						
5						
6		8.3	5.6	2.7	2.9	5.6
7		7.8	5.2	2.6	2.9	5.5
8		7.1	4.7	2.4	3.9	5.3
9	.65	6.8	4.5	2.3	2.9	5.2
10	.36	6.4	4.3	2.1	2.9	5.0
11	.06	6.1	4.1	2.0	2.9	4.9
12		5.7	3.9	1.8	2.9	4.7
13		5.5	3.7	1.8	2.9	4.7
14	.36	5.3	3.6	1.7	2.9	4.6
15	.68	5.5	3.5	2.0	2.9	4.9
16		5.3	3.5	1.8	2.9	4.7
17		5.3	3.3	2.0	2.9	4.9
18		5.1	3.0	1.9	2.9	4.8
19		5.1	2.9	2.2	2.9	5.1
20		5.5	3.0	2.5	2.9	5.4
21	.04	5.7	3.5	2.2	2.9	5.1
22	.28	6.1	4.7	1.4	2.9	4.3
23	.12	6.6	6.2	0.4	2.9	3.3
24		7.3	5.3	2.0	2.9	4.4
25		6.1	4.1	2.0	2.9	4.9
26		5.9	3.5	2.1	2.9	5.3
27		5.7	3.1	2.6	2.9	5.5
28	.19	5.7	2.9	2.8	2.9	5.7
29	1.35	8.1	3.0	5.1	2.9	8.0
30	.39	14.2	3.9	10.3	2.9	13.2

(1) 61% exceedance probability
(2) September 1983 Talkeetna precipitation, adjusted to Slough 9
(3) September 1983
(4) Q9 = -0.62 + 0.00039 G
(5) Assumes flow at Gold Creek is 9,000 cfs

TABLE 4.14
ESTIMATED DAILY RUNOFF, SLOUGH 9
LOW RAINFALL PATTERN(1)

Date	Daily Precipitation(2) (inches)	Measured Flow(3) (cfs)	Estimated Groundwater Flow(4) (cfs)	Estimated Surface Runoff (cfs)	Estimated With-Project Groundwater Flow(5) (cfs)	Estimated With-Project Slough Flow (cfs)
1						
2						
3		11	3.7	7.3	2.9	10.2
4		9.5	3.6	5.9	2.9	8.8
5		7.1	3.4	3.7	2.9	6.6
6		5.6	3.4	2.2	2.9	5.1
7	.10	4.8	3.5	1.3	2.9	4.2
8		4.2	3.6	0.6	2.9	3.5
9		3.6	3.5	0.1	2.9	3.0
10		3.2	3.2	0	2.9	2.9
11		3.8	3.0	0.8	2.9	2.9
12	.22	2.4	2.4(6)	0	2.9	2.9
13	.17	2.4	2.4(6)	0	2.9	2.9
14		2.1	2.1(6)	0	2.9	2.9
15	.02	2.1	2.1(6)	0	2.9	2.9
16	.11	2.1	2.1(6)	0	2.9	2.9
17	.04	2.1	2.1(6)	0	2.9	2.9
18	.57	2.7	2.6	0.1	2.9	3.0
19	.61	3.2	3.0	0.2	2.9	3.1
20	.05	3.6	3.4	0.2	2.9	3.1
21		4.2	3.8	0.4	2.9	3.3
22		3.6	3.4	0.2	2.9	3.1
23		3.2	2.9	0.3	2.9	3.2
24		2.8	2.6	0.2	2.9	3.1
25	.12	3.3	2.5	0.8	2.9	3.7
26		3.3	2.4	0.9	2.9	3.8
27		2.8	2.3	0.5	2.9	3.4
28		2.4	2.2	0.2	2.9	3.1
29	.02	2.4	2.2	0.2	2.9	3.1
30	0.5	2.1	2.1(6)	0	2.9	2.9

(1) 93% exceedance probability
(2) September 1984 Sherman precipitation
(3) September 1984
(4) Q9 = -0.62 + 0.00039 G
(5) Assumes flow at Gold Creek is 9,000 cfs
(6) Estimated groundwater flow exceeded measured surface flow, so reduced groundwater flow to measured flow.

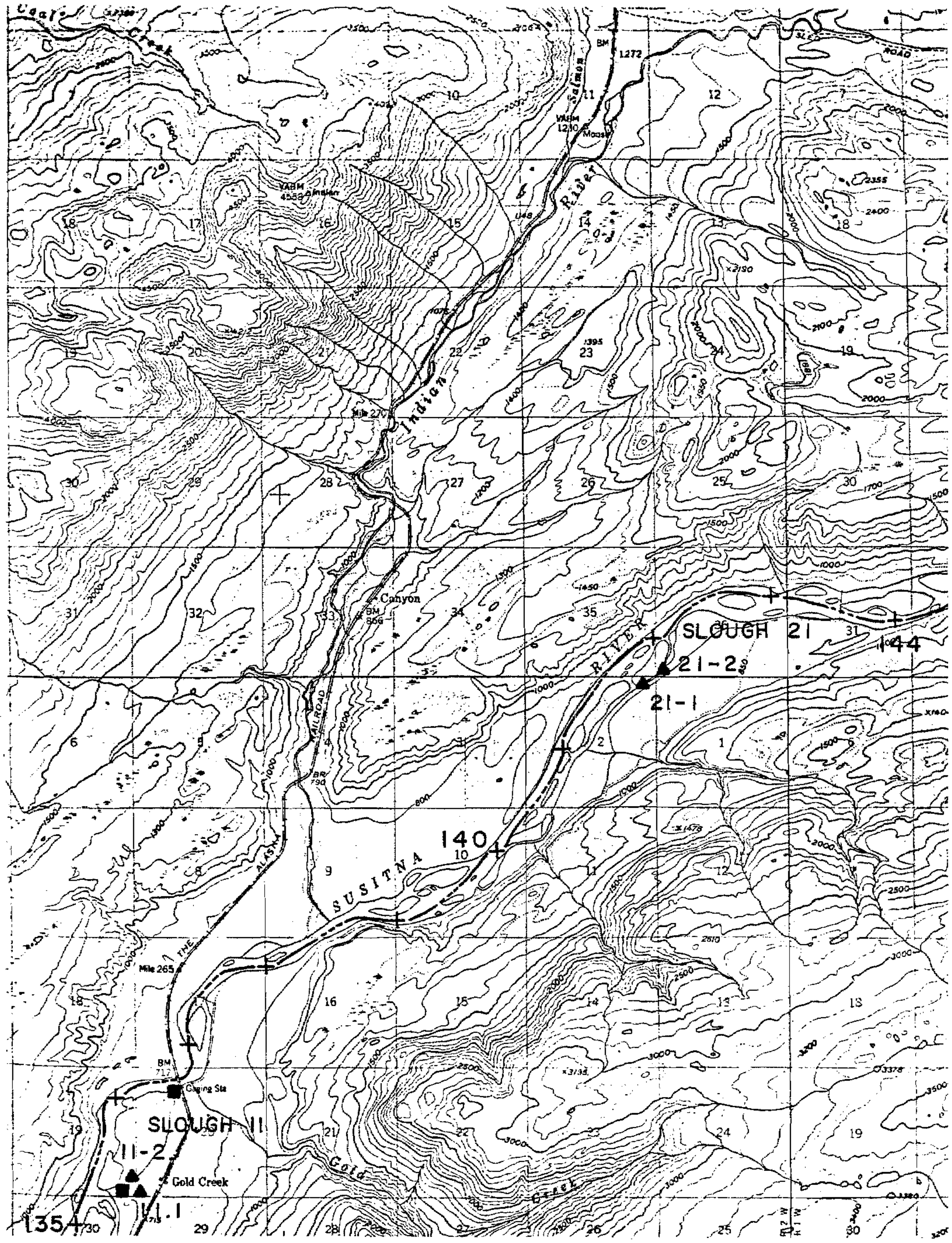


APPROXIMATE LOCATIONS OF SLOUGH STUDY SITES
AND DATA COLLECTION POINTS, STAGE RECORDERS
AND SEEPAGE METERS

PREPARED BY:
R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

FIGURE 4.1(a)

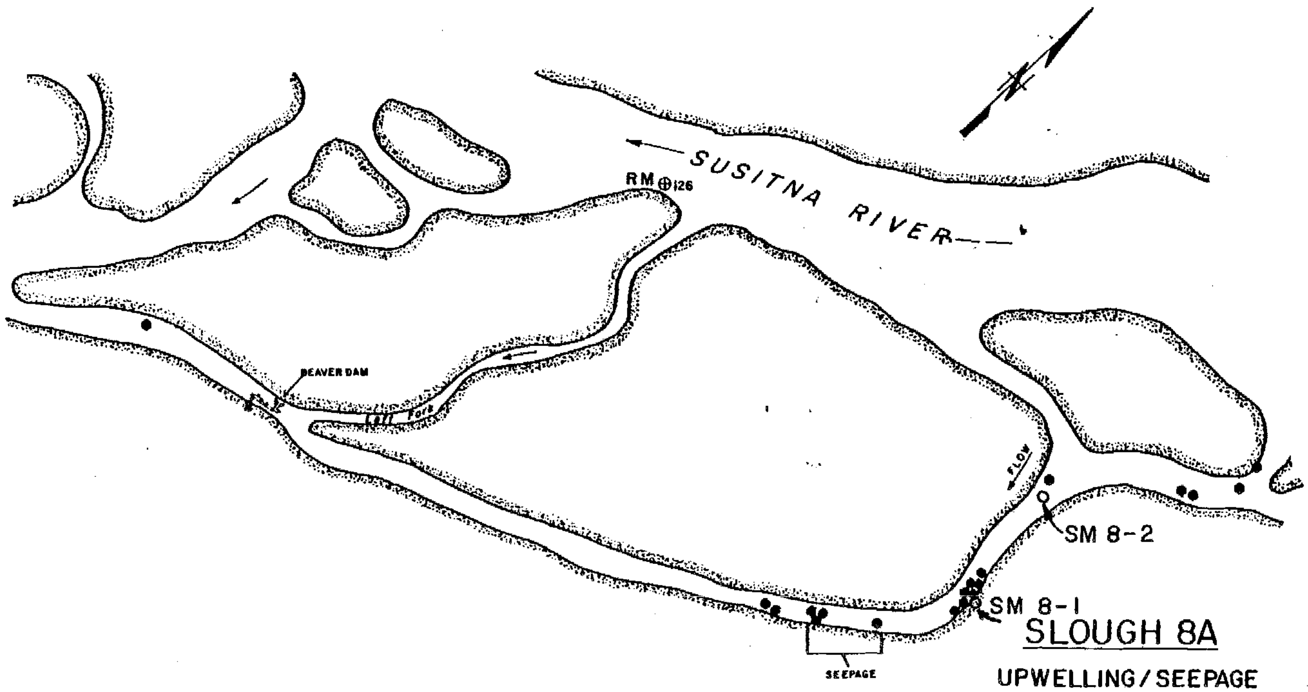
PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE



APPROXIMATE LOCATIONS OF SLOUGH STUDY SITES
AND DATA COLLECTION POINTS, STAGE RECORDERS
AND SEEPAGE METERS

■ Stage Recorder
▲ Seepage Meter

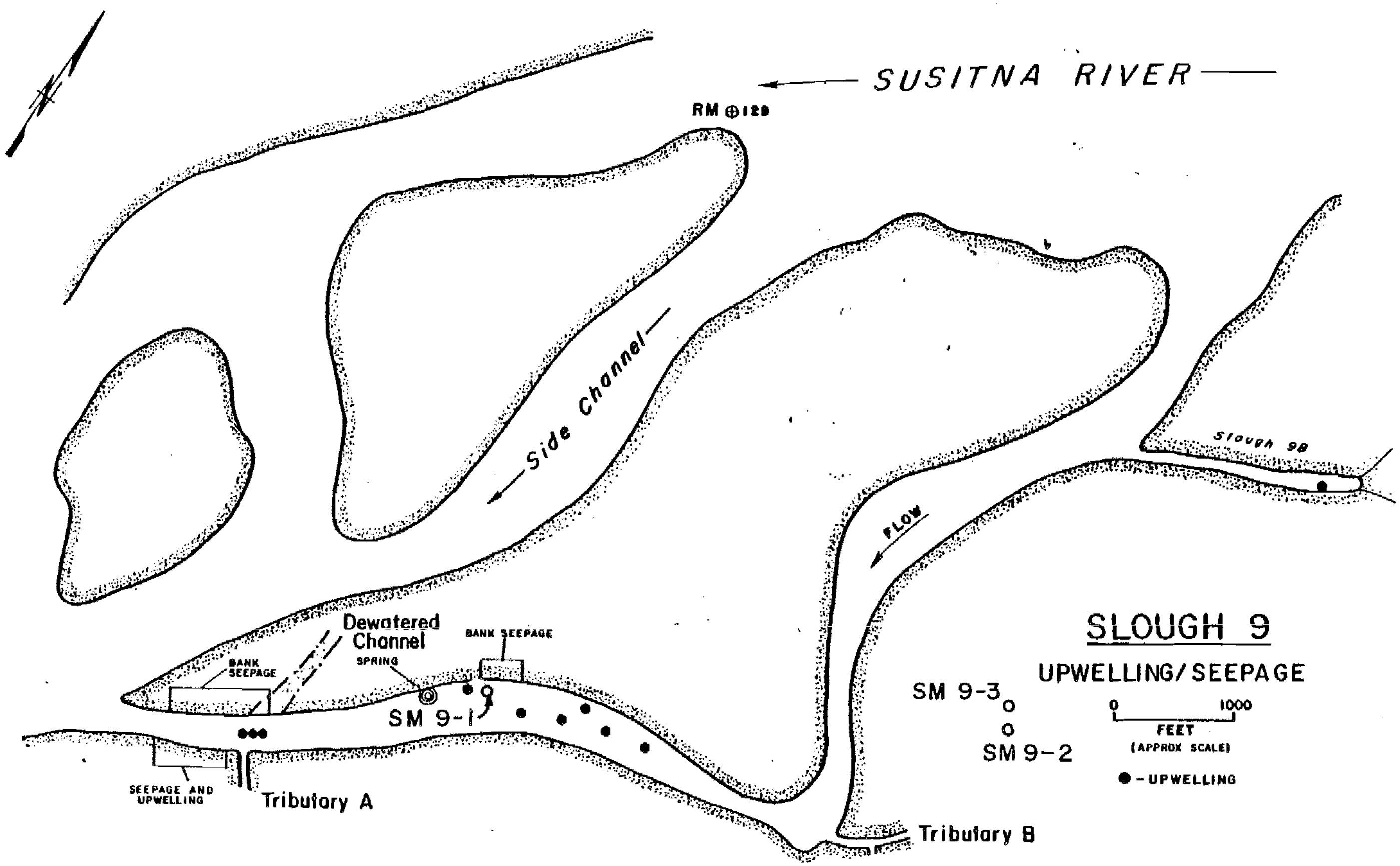
PREPARED BY: R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	FIGURE 4.1(b)	PREPARED FOR: HARZA-EBASCO SUSITNA JOINT VENTURE



Source: ADF & G(1983b)

Slough 8A upwelling/seepage, 1982.

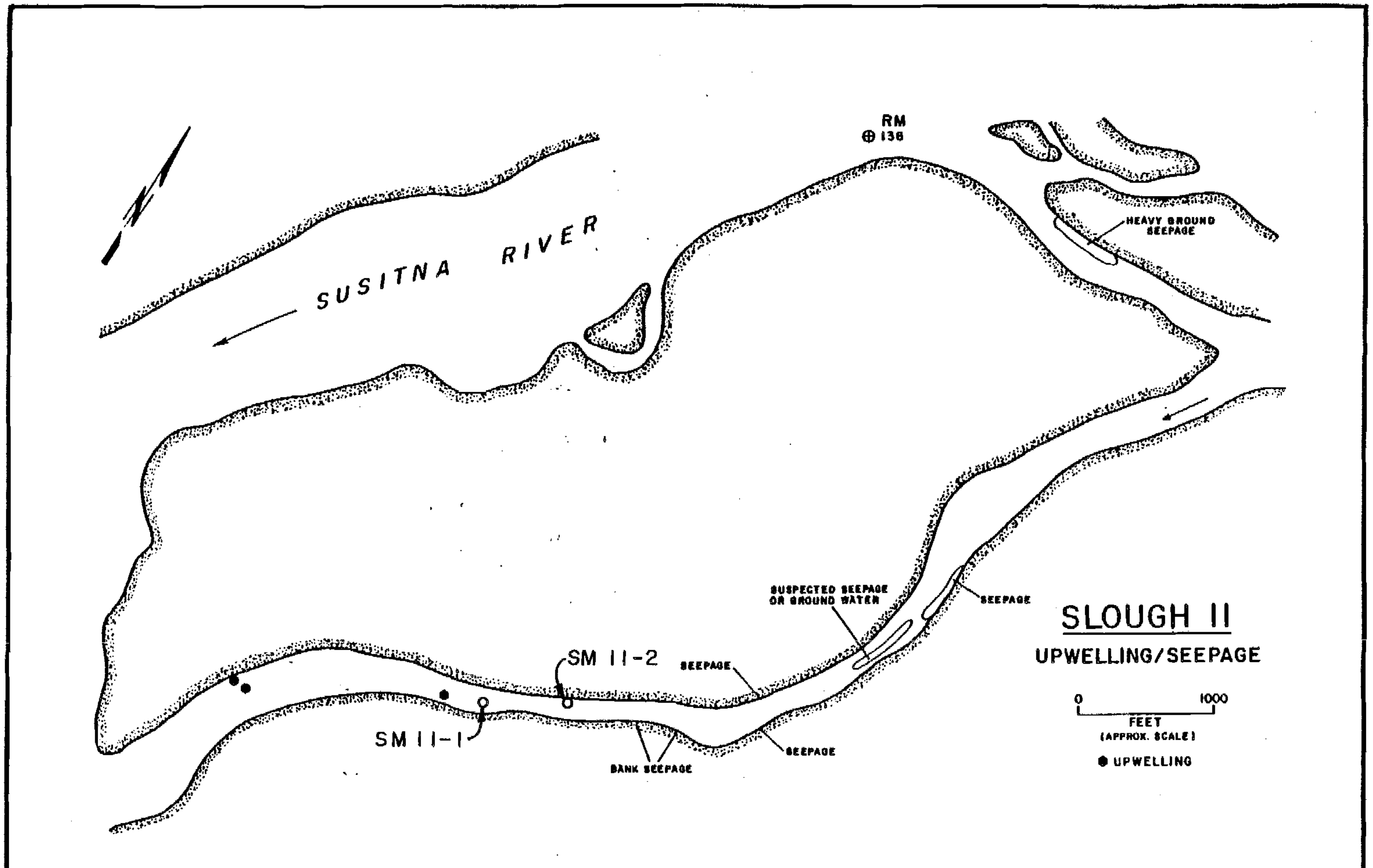
PREPARED BY: R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	FIGURE 4.2	PREPARED FOR: HARZA-EBASCO SUSITNA JOINT VENTURE



Source: ADF & G(1983b)

Slough 9 upwelling/seepage, 1982.

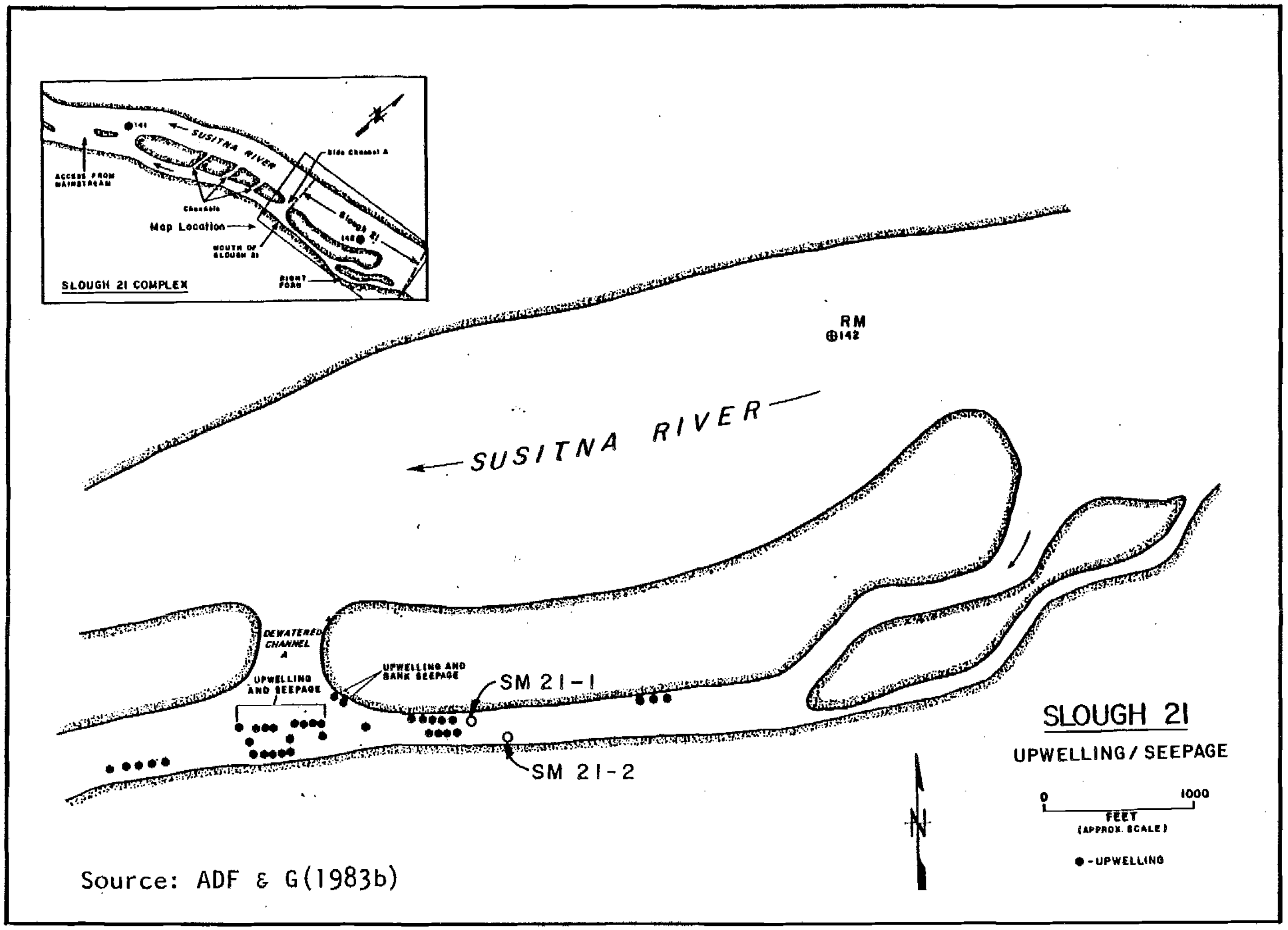
PREPARED BY: R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	**FIGURE 4.3**	PREPARED FOR: HARZA-EBASCO SUSITNA JOINT VENTURE



Source: ADF & G(1983b)

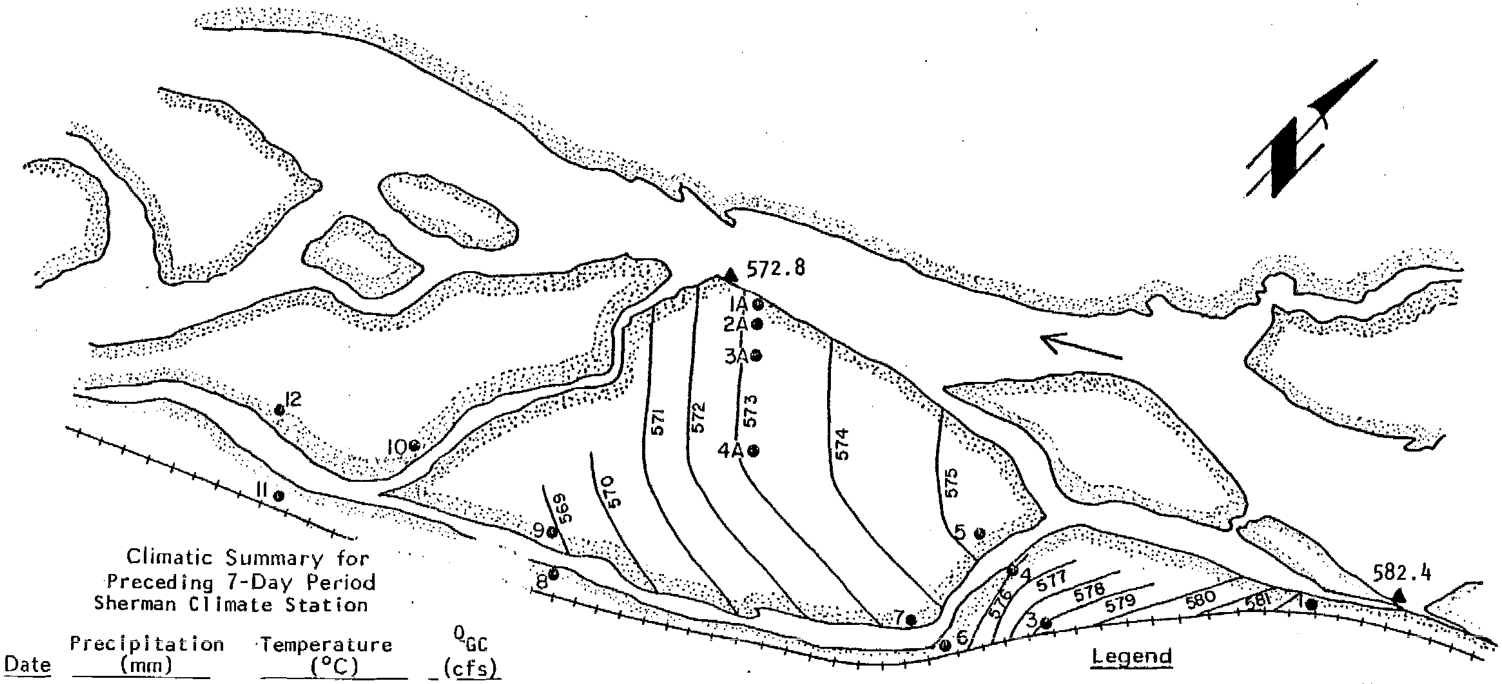
Slough 11 upwelling/seepage, 1982.

PREPARED BY: R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	**FIGURE 4.4**	PREPARED FOR: HARZA-EBASCO SUSITNA JOINT VENTURE



Slough 21 upwelling/seepage, 1982.

PREPARED BY: R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	FIGURE 4.5	PREPARED FOR: HARZA-EBASCO SUSITNA JOINT VENTURE



Climatic Summary for
Preceding 7-Day Period
Sherman Climate Station

Date	Precipitation (mm)	Temperature (°C)	Q_{GC} (cfs)
9-14	19.0	8.9	20,200
9-15	29.8	12.2	28,200
9-16	11.2	8.6	32,500
9-17	9.4	5.4	32,000
9-18	10.0	7.9	26,800
9-19	18.6	7.7	24,100
9-20	6.0	7.5	24,000

Legend

● observation well

"600" groundwater elevation

Susitna water surface elevation

Date: 9-20-82

Q_{GC}: 24,000 cfs

Source: R&M (1982g)

FIG. 4.6

PREPARED BY:

R&M CONSULTANTS, INC.

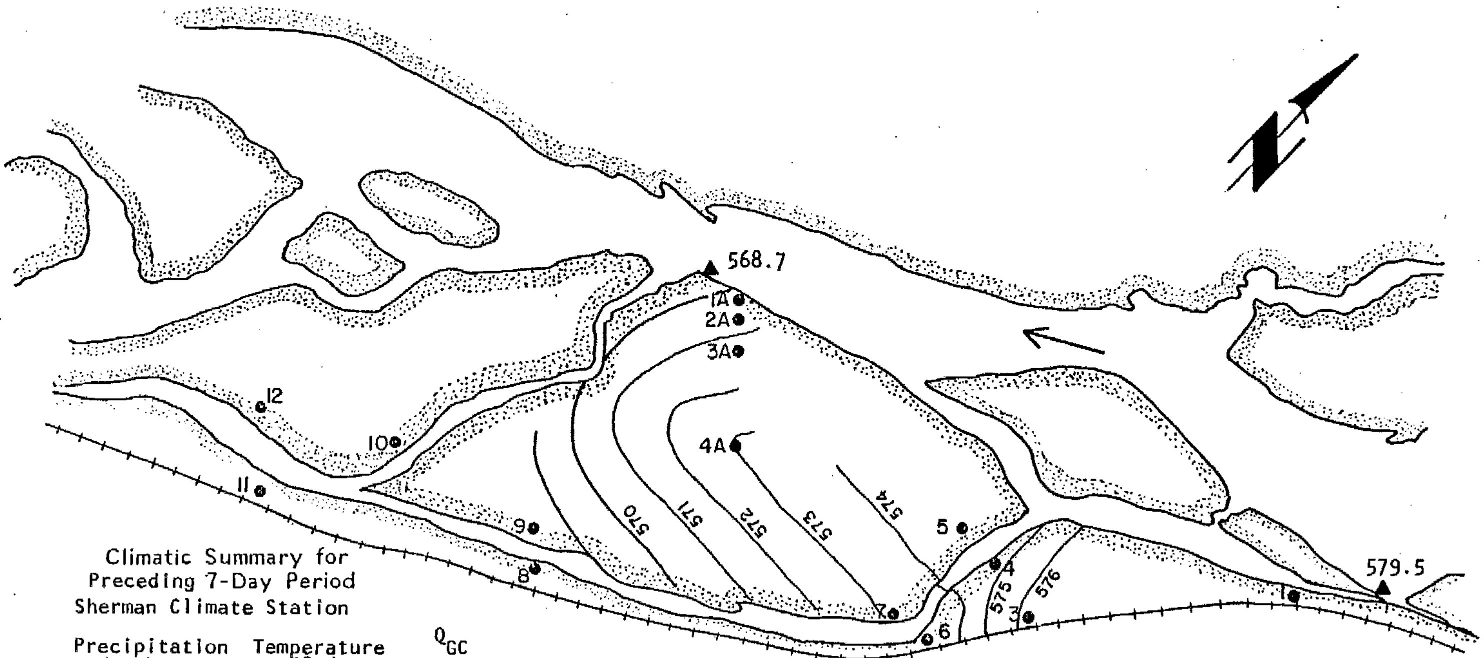
ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

GROUNDWATER CONTOURS
SUSITNA RIVER AT SLOUGH 8A

PREPARED FOR:

HARZA-EBASCO

SUSITNA JOINT VENTURE



Climatic Summary for
Preceding 7-Day Period
Sherman Climate Station

Date	Precipitation (mm)	Temperature (°C)	Q_{GC} (cfs)
9-29	7.4	6.0	12,400
9-30	8.4	4.9	12,500
10-1	N/A	2.2	12,400
10-2	N/A	3.3	11,700
10-3	N/A	2.8	11,000
10-4	N/A	1.3	10,500
10-5	N/A	0.1	9,800

N/A - Not Available

Legend

● observation well

"600" groundwater elevation

Susitna water surface elevation

Date: 10-5-82

Q_{GC}: 8,300 cfs

Source: R&M (1982g)

FIG. 4.7

PREPARED BY:

R&M CONSULTANTS, INC.

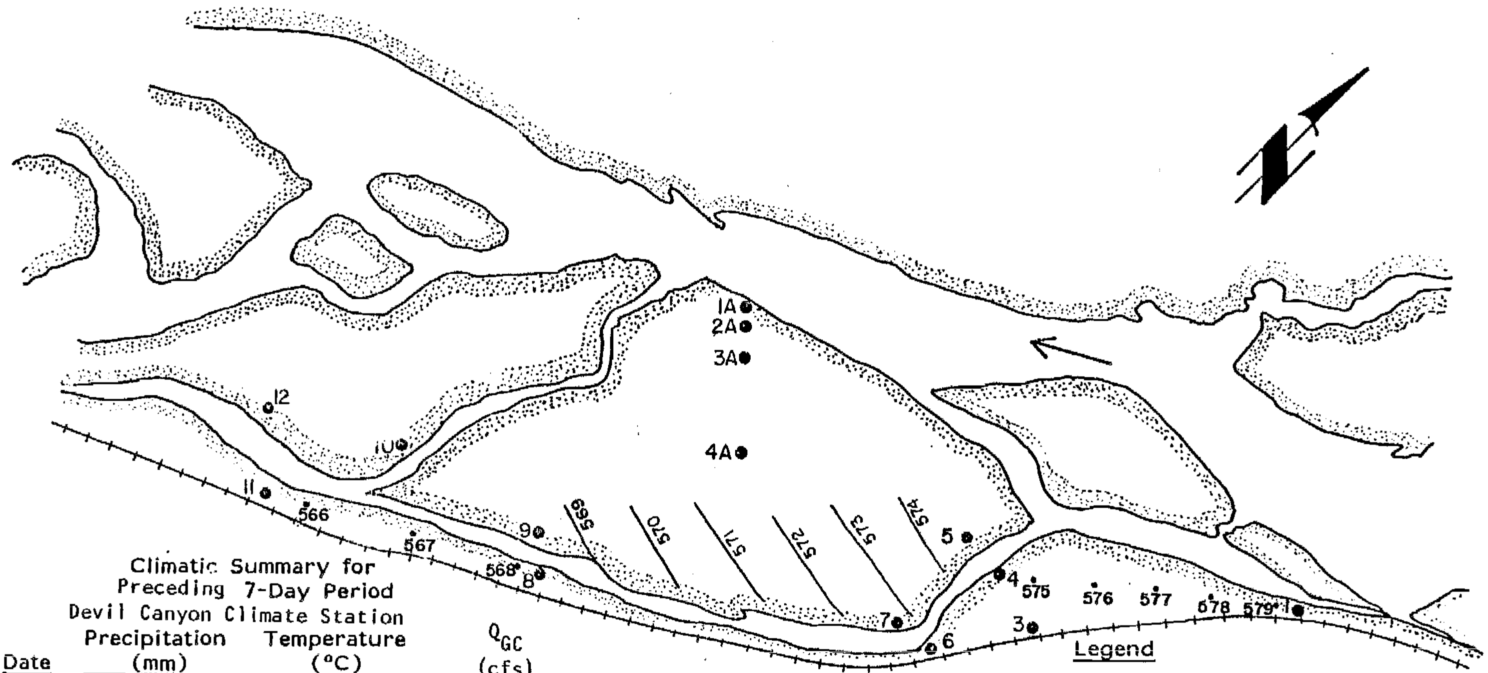
ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

GROUNDWATER CONTOURS
SUSITNA RIVER AT SLOUGH 8A

PREPARED FOR:

HARZA-EBASCO

SUSITNA JOINT VENTURE



Climatic Summary for Preceding 7-Day Period
Devil Canyon Climate Station

Date	Precipitation (mm)	Temperature (°C)	Q_{GC} (cfs)
4-20	7.0	1.7	1750 (ice)
4-21	0.0	1.5	1800 (ice)
4-22	0.0	1.2	1900 (ice)
4-23	0.0	0.1	2000 (ice)
4-24	1.6	1.1	2100 (ice)
4-25	0.0	4.4	2200 (ice)
4-26	0.0	1.0	2300 (ice)

Legend

o observation well
"600" groundwater elevation
Date: 4-26-82
Q_{GC}: 2300 cfs, ice cover on mainstem

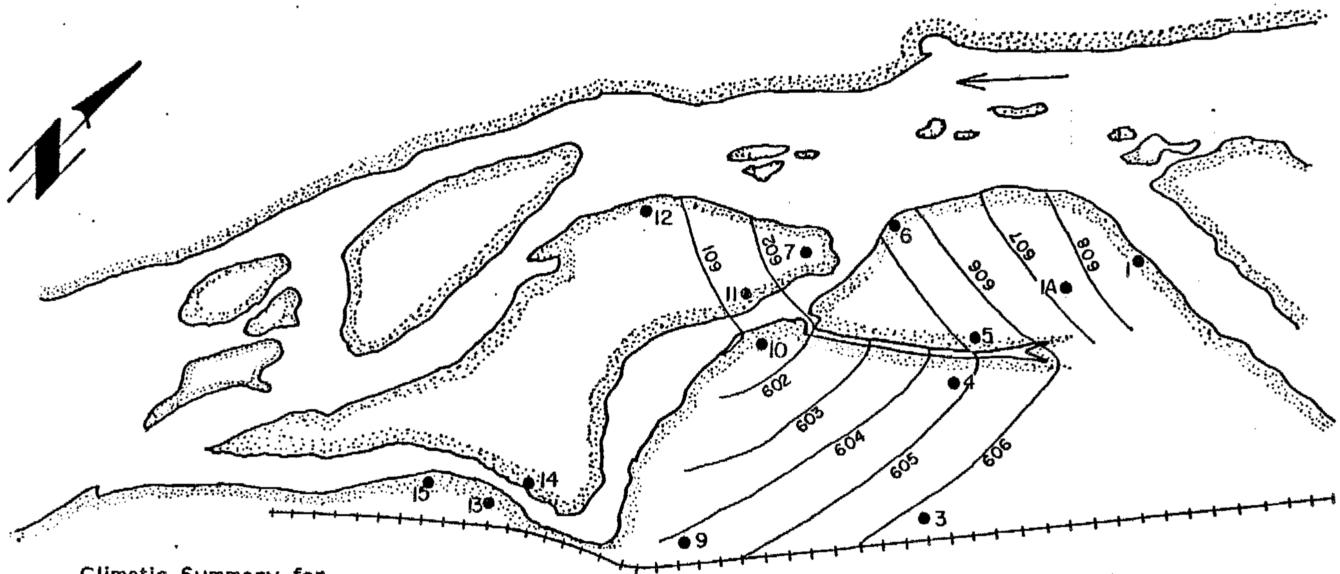
Source: R&M (1982g)

FIG. 4.8

PREPARED BY:
R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

GROUNDWATER CONTOURS
SUSITNA RIVER AT SLOUGH 8A

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE



Climatic Summary for
Preceding 7-Day Period
Sherman Climate Station

Date	Precipitation (mm)	Temperature (°C)	Q_{GC} (cfs)
6-25	2.0	16.5	27,000
6-26	0.0	15.9	28,000
6-27	0.0	14.9	29,000
6-28	0.8	12.7	30,000
6-29	0.0	13.0	29,000
6-30	9.2	13.6	27,000
7-1	1.6	10.1	25,000

Legend

● observation well

"600" groundwater elevation

Date: 7-1-82

Q_{GC}: 25,000 cfs

Source R&M (1982g)

FIG. 4.9

PREPARED BY:

R&M CONSULTANTS, INC.

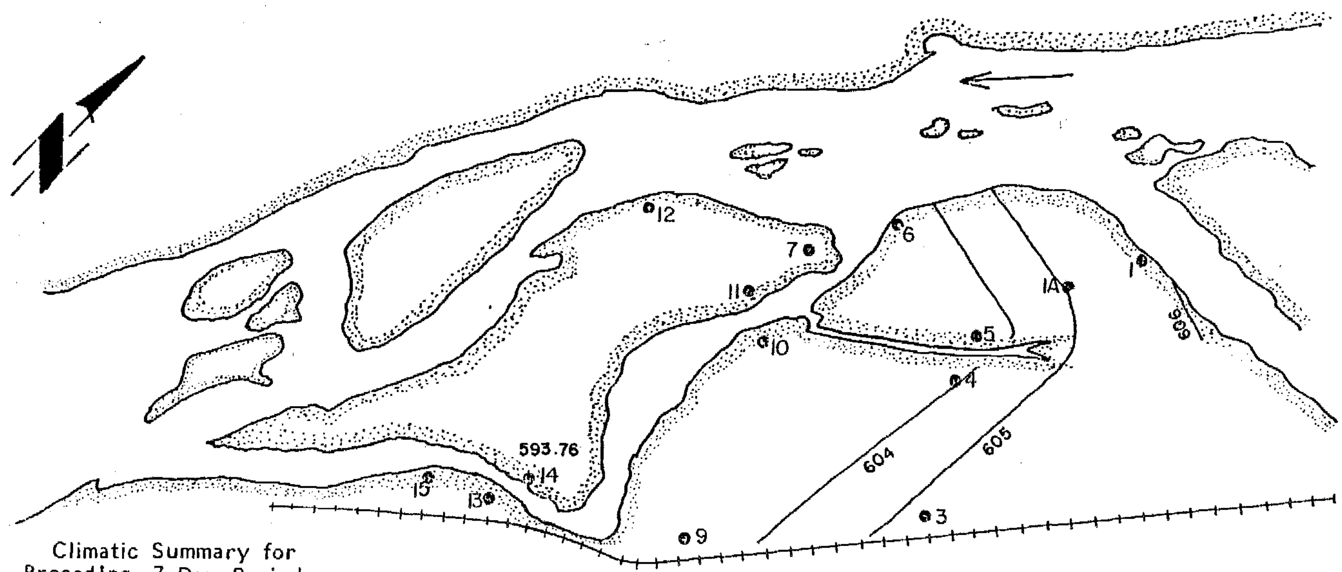
ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

GROUNDWATER CONTOURS
SUSITNA RIVER AT SLOUGH 9

PREPARED FOR:

HARZA-EBASCO

SUSITNA JOINT VENTURE



Climatic Summary for
Preceding 7-Day Period
Sherman Climate Station

Date	Precipitation (mm)	Temperature (°C)	Q_{GC} (cfs)
10-1	N/A	2.2	12,400
10-2	N/A	3.3	11,700
10-3	N/A	2.8	11,000
10-4	N/A	1.3	10,500
10-5	N/A	0.1	9,800
10-6	N/A	2.3	8,960
10-7	N/A	0.5	8,480

N/A - Not Available

Legend

● observation well

"600" groundwater elevation

Date: 10-7-82

Q_{GC}: 8,480 cfs

Source R&M (1982g)

FIG. 4.10

PREPARED BY:

R&M CONSULTANTS, INC.

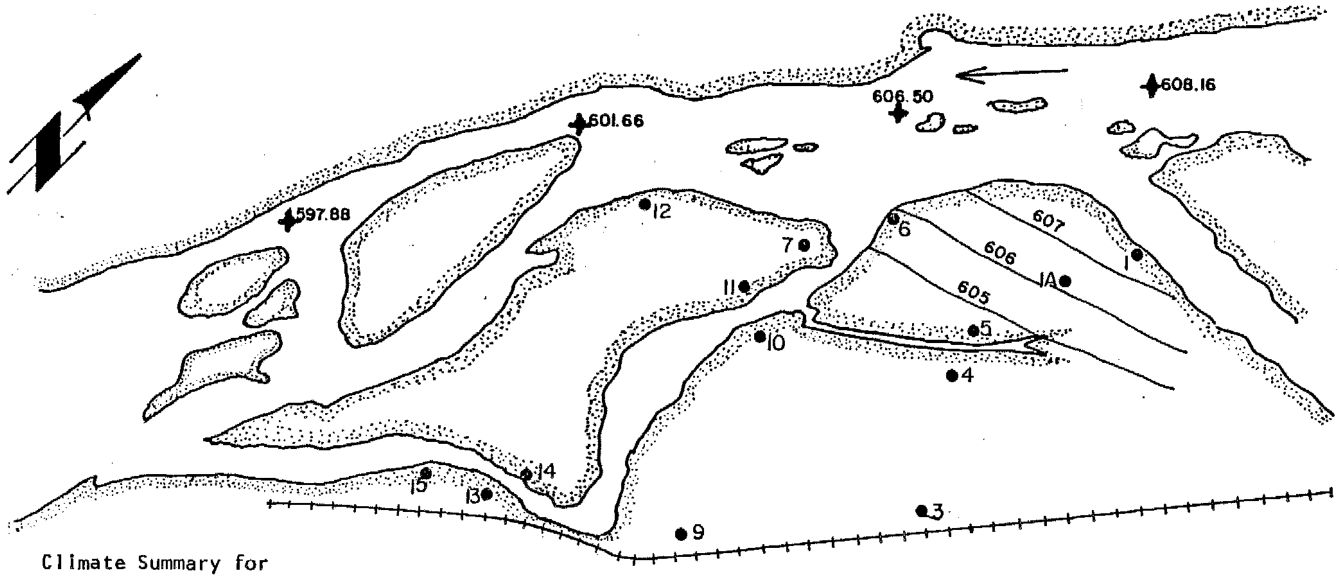
ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

GROUNDWATER CONTOURS
SUSITNA RIVER AT SLOUGH 9

PREPARED FOR:

HARZA-EBASCO

SUSITNA JOINT VENTURE



Climate Summary for
Preceding 7-day Period
Sherman Climate Station

Date	Precipitation (mm)	Temperature (°C)	Q_{GC} (cfs)
12-16	N/A	-4.6	2,300 (ice)
12-17	N/A	-8.5	2,300 (ice)
12-18	N/A	-16.2	2,300 (ice)
12-19	N/A	-12.8	2,300 (ice)
12-20	N/A	-11.4	2,300 (ice)
12-21	N/A	-18.8	2,300 (ice)
12-22	N/A	-23.3	2,300 (ice)

N/A - Not Available

Legend

● observation well

"600" groundwater elevation

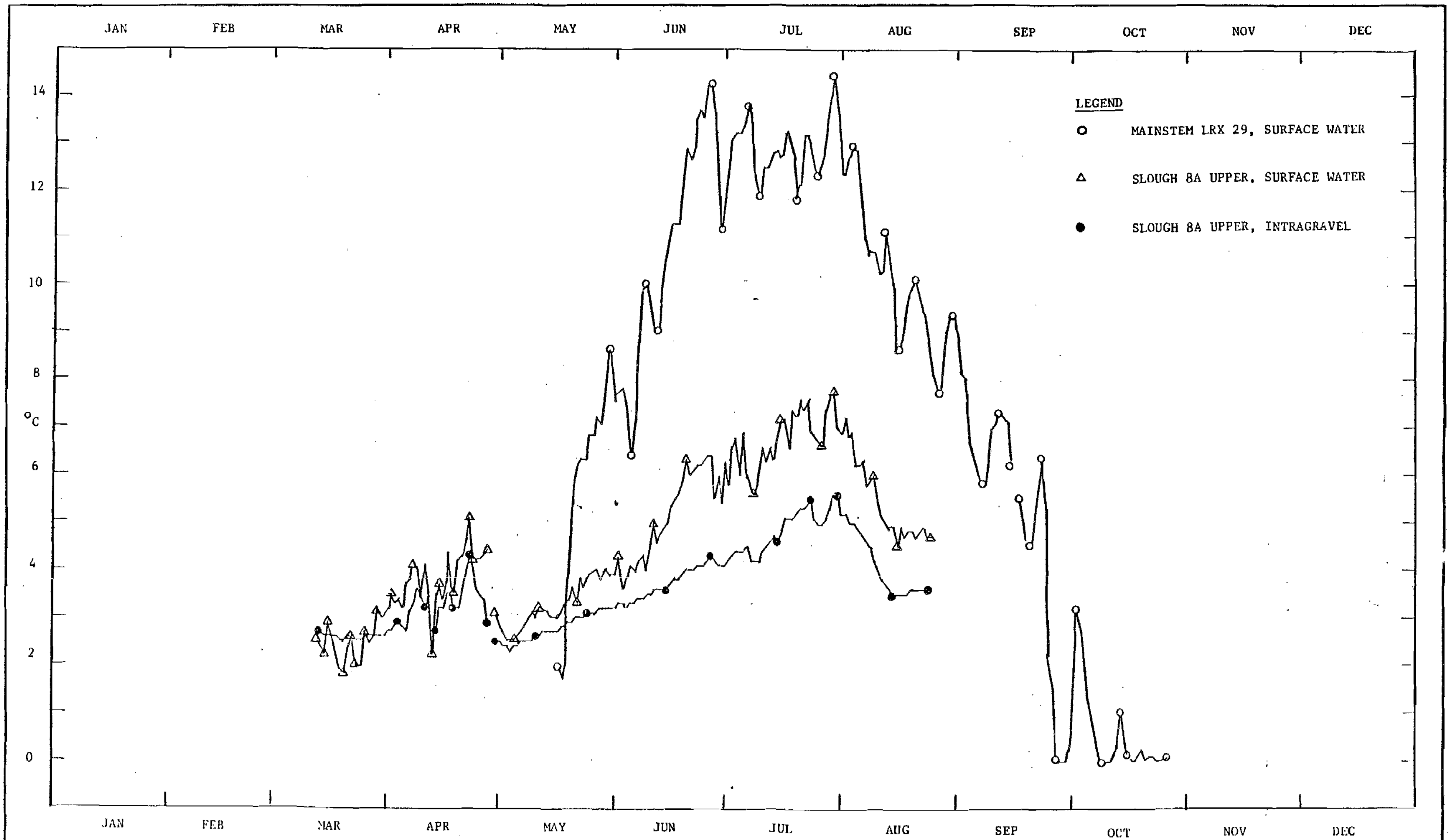
Date: 12-22-82

Q_{GC}: 2,300 cfs, ice cover on mainstem

Source: R&M (1982g)

FIG. 4.11

PREPARED BY:		PREPARED FOR:
R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	**GROUNDWATER CONTOURS SUSITNA RIVER AT SLOUGH 9**	HARZA-EBASCO SUSITNA JOINT VENTURE



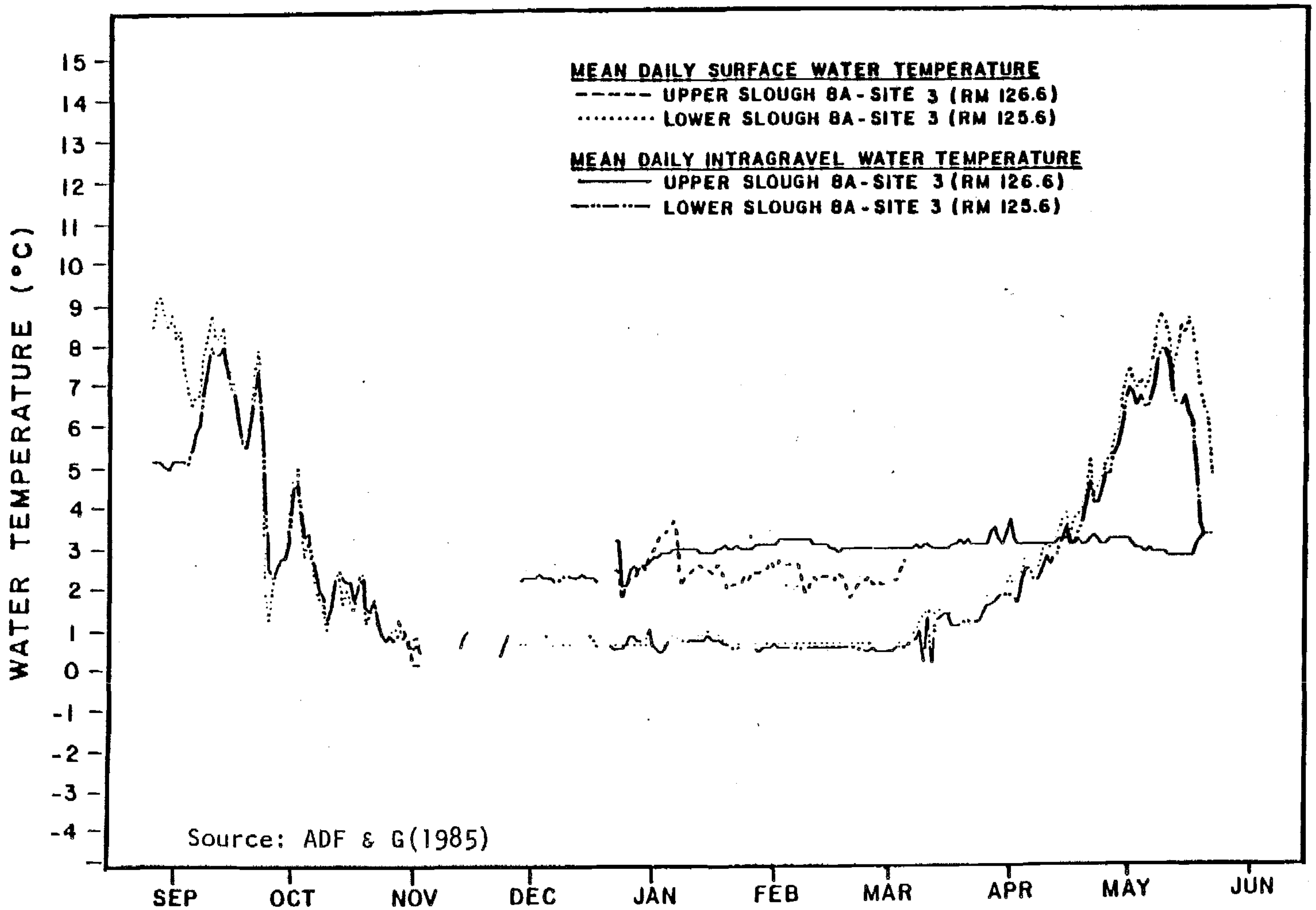
SOURCES: ADF&G (1983b)
ADF&G PROVISIONAL 1983 DATA } as presented in APA (1984b)

SLOUGH 8A WATER TEMPERATURES, 1983

PREPARED BY:
R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

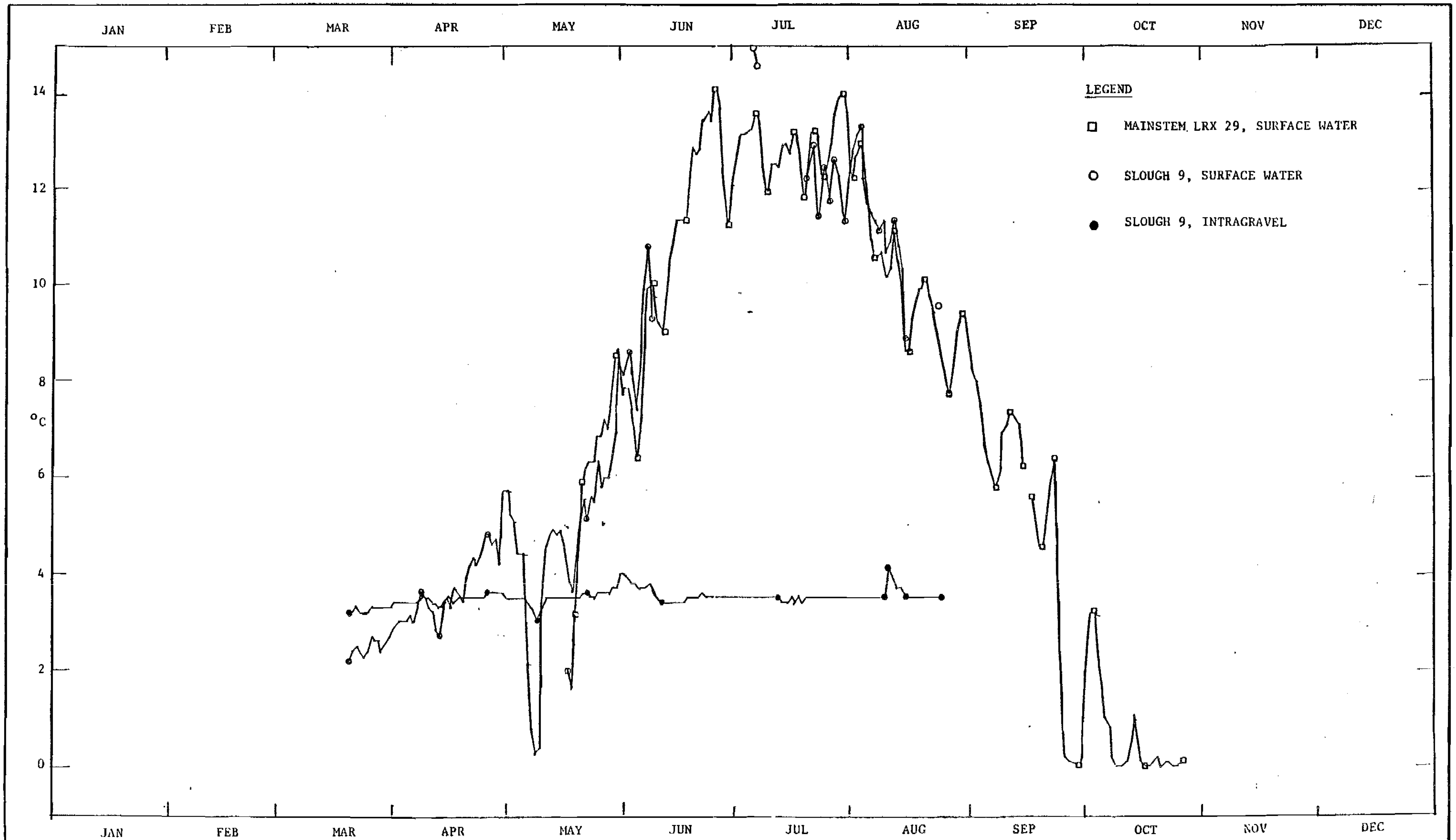
FIGURE 4.12

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE



Mean daily surface and intragravel water temperatures recorded at Lower Slough 8A - Site 3 (RM 125.6) and Upper Slough 8A - Site 3 (RM 126.6) during the 1983-84 winter season.

PREPARED BY: R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	**FIGURE 4.13**	PREPARED FOR: HARZA-EBASCO SUSITNA JOINT VENTURE



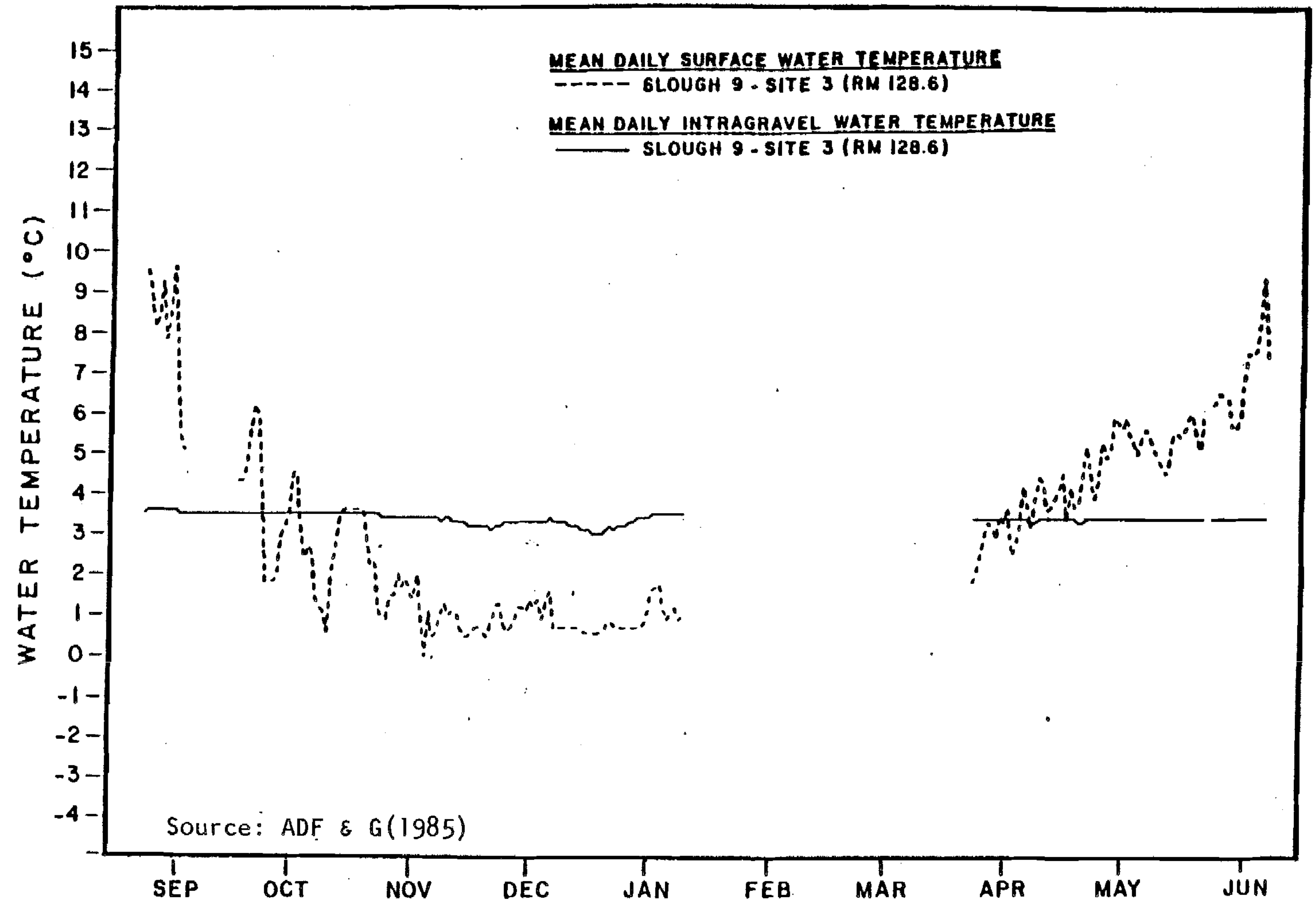
SOURCES: ADF&G (1983b)
ADF&G PROVISIONAL 1983 DATA } as presented in APA (1983b)

SLOUGH 9 WATER TEMPERATURES, 1983

PREPARED BY:
R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

FIGURE 4.14

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE

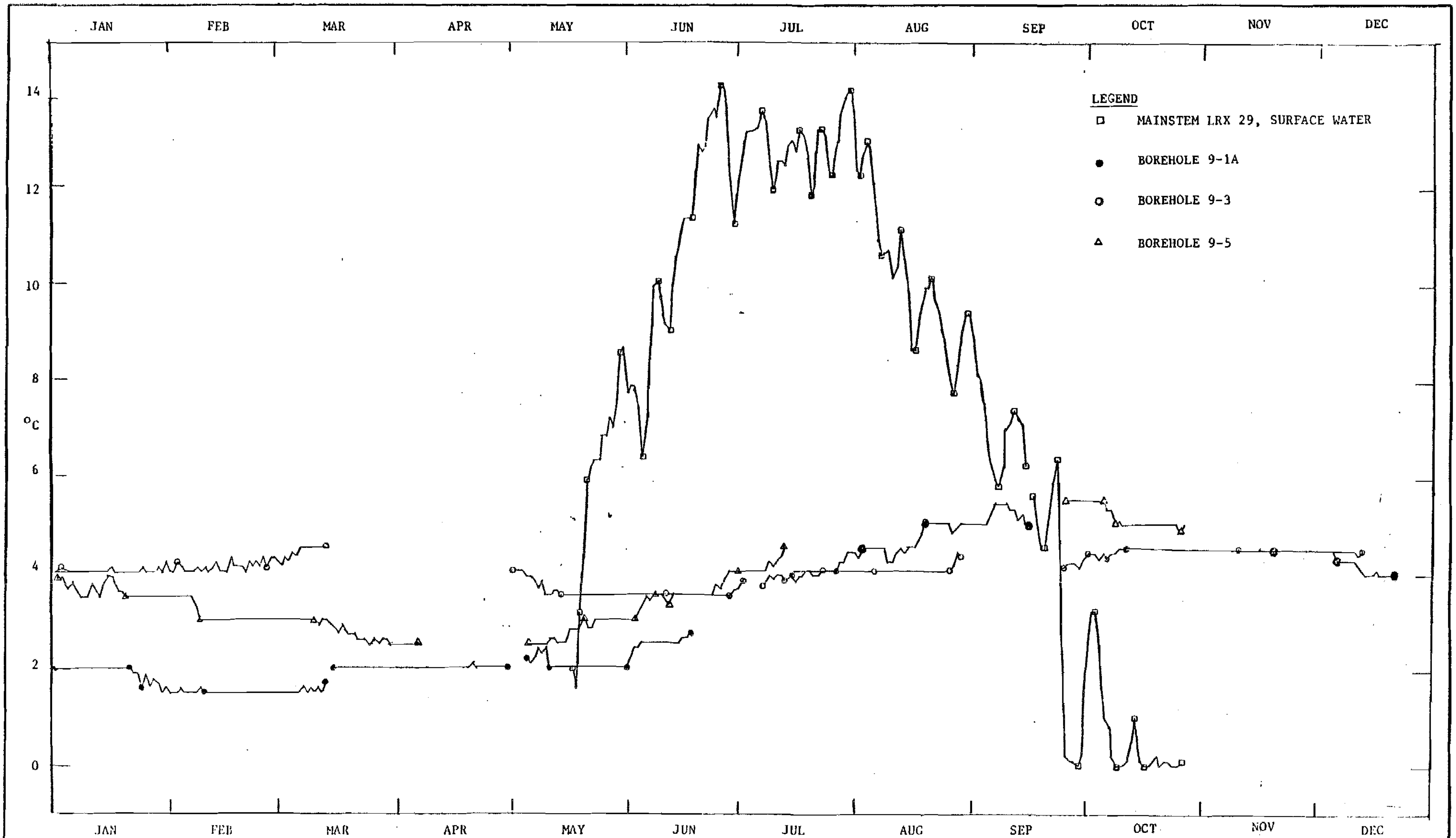


Mean daily surface and intragravel water temperatures recorded at Slough 9 - Site 3 (RM 128.6) during the 1983-84 winter season.

PREPARED BY:
R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

FIGURE 4.15

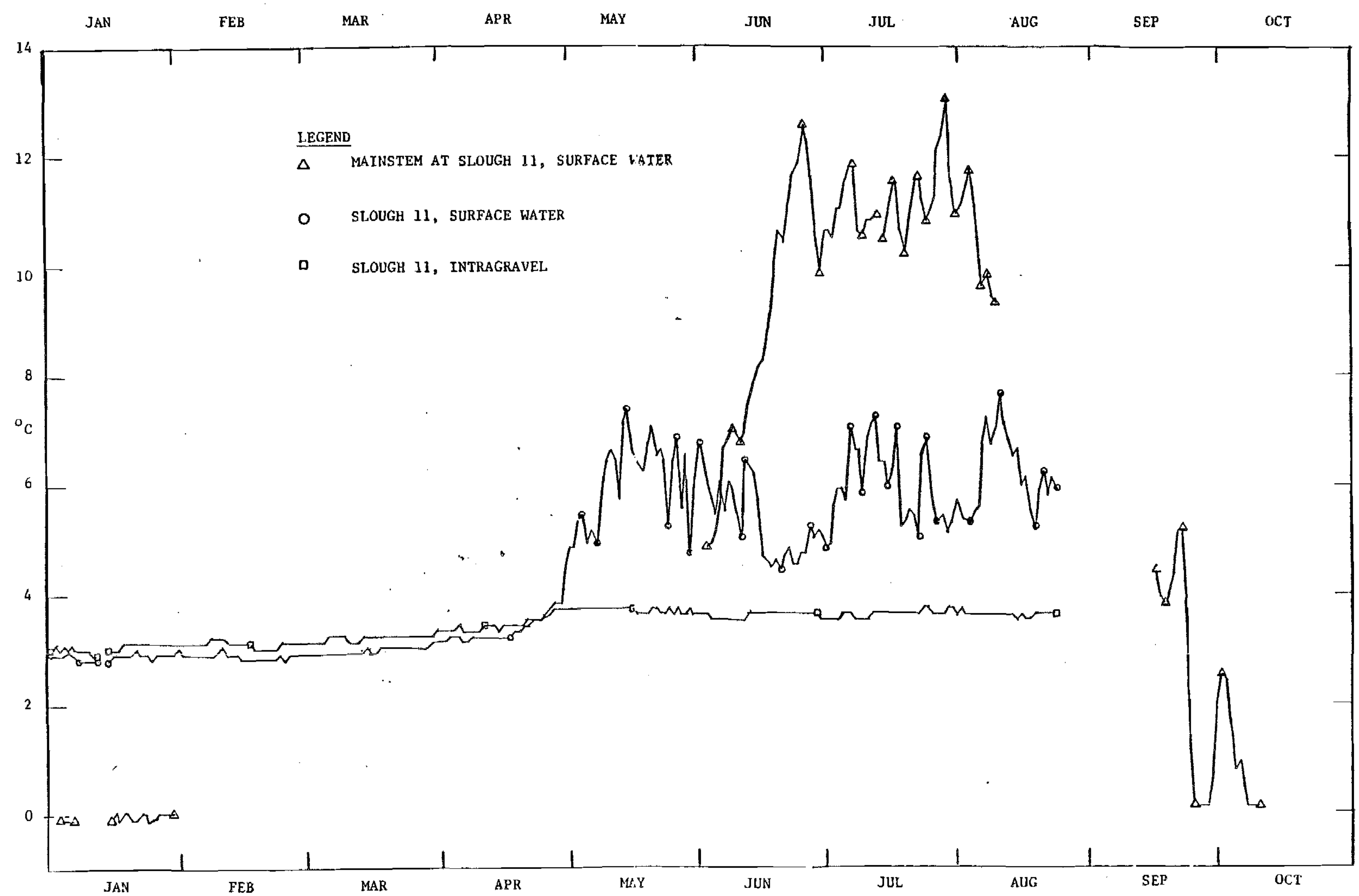
PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE



SOURCES: ADF&G (1983b)
ADF&G PROVISIONAL 1983 DATA
R & M CONSULTANTS PROVISIONAL 1983 DATA
} as presented in APA (1984b)

SLOUGH 9 WATER TEMPERATURES, 1983

PREPARED BY:		PREPARED FOR:
R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	**FIGURE 4.16**	HARZA-EBASCO SUSITNA JOINT VENTURE



SOURCES: ADF&G (1983b)
ADF&G PROVISIONAL 1983 DATA } as presented in APA (1983b

SLOUGH 11 WATER TEMPERATURES, 1983

PREPARED BY:

R&M CONSULTANTS, INC.

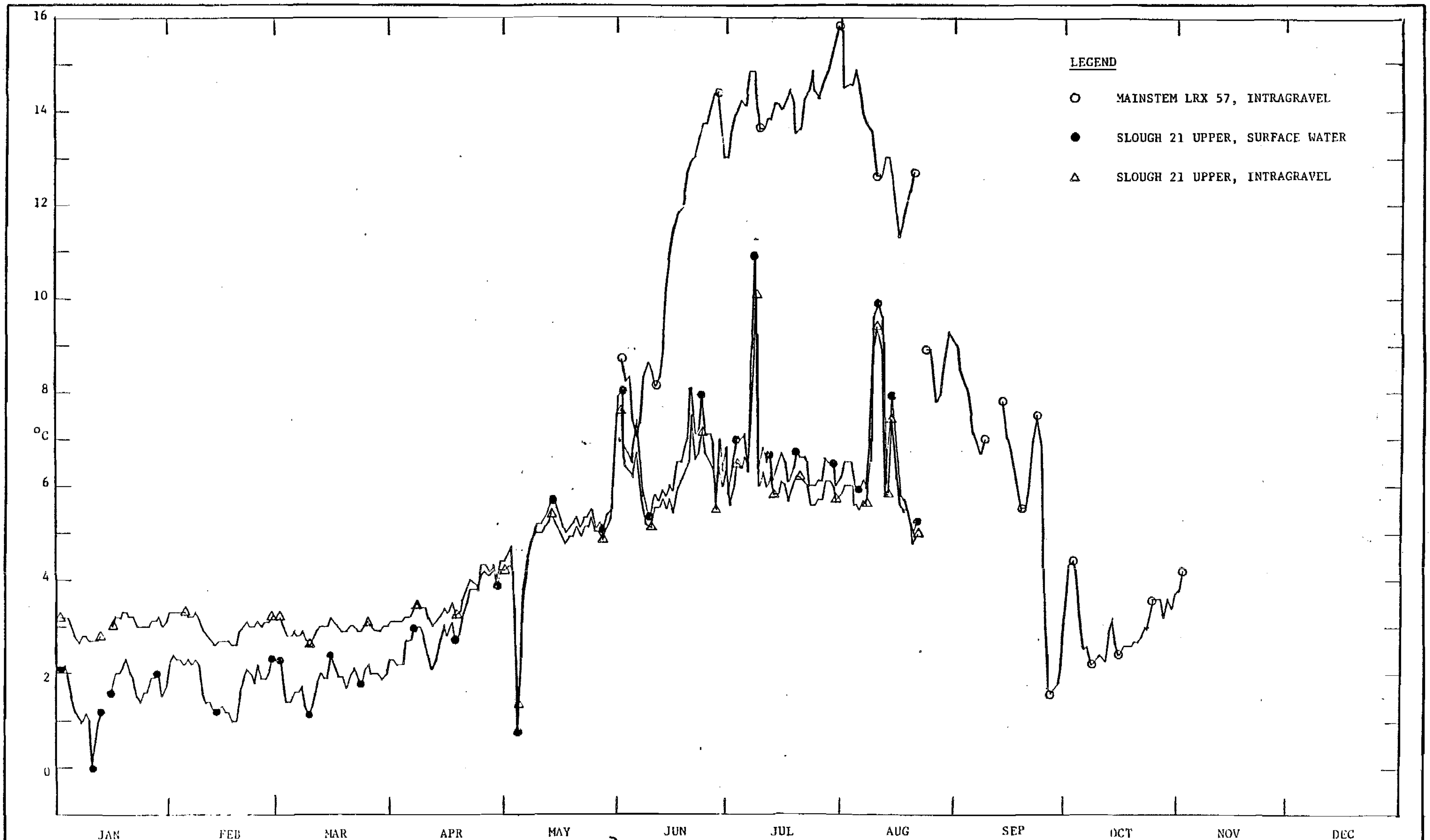
ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

FIGURE 4.17

PREPARED FOR:

HARZA-EBASCO

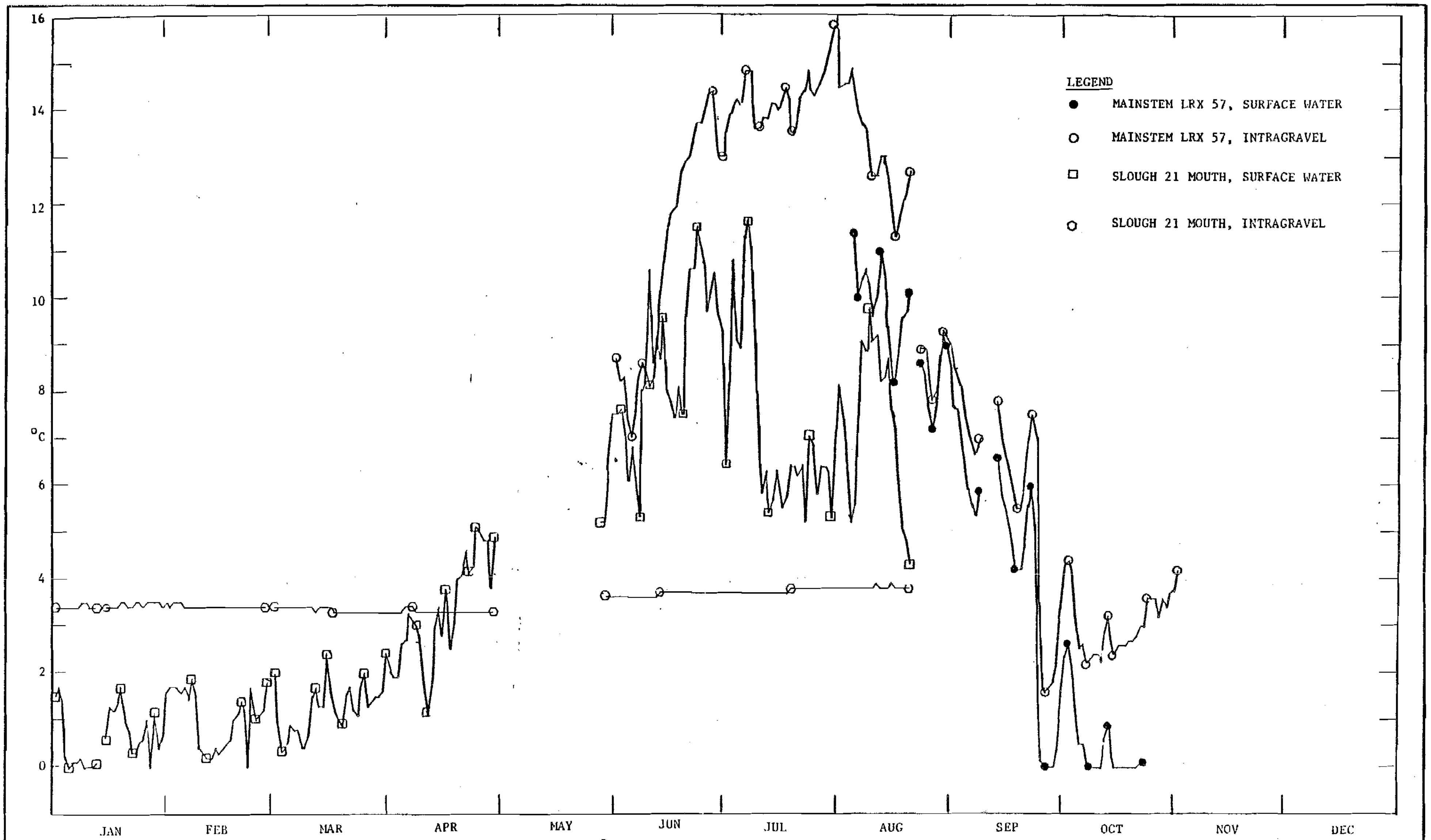
SUSITNA JOINT VENTURE



SOURCES: ADF&G (1983b) } as presented in APA (1984b)
ADF&G PROVISIONAL 1983 DATA

UPPER SLOUGH 21,
WATER TEMPERATURES, 1983

PREPARED BY: R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	**FIGURE 4.18**	PREPARED FOR: HARZA-EBASCO SUSITNA JOINT VENTURE



SOURCES: ADF&G (1983b)
ADF&G PROVISIONAL 1983 DATA } as presented in APA (1984b)

LOWER SLOUGH 21 WATER TEMPERATURES, 1983

PREPARED BY:
R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

FIGURE 4.19

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE

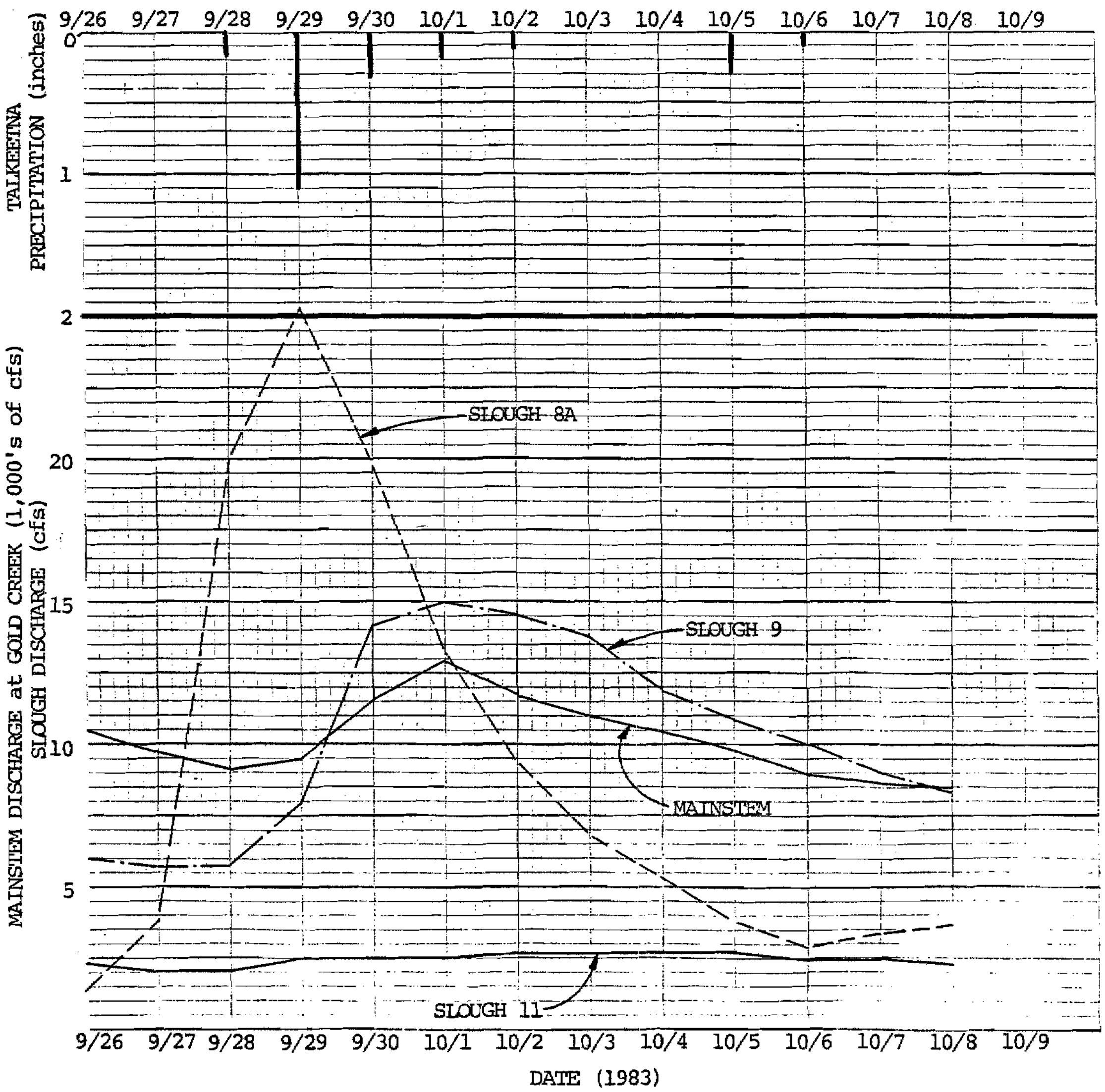


FIGURE 4.20

PREPARED BY: R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	RESPONSE OF SUSITNA RIVER AND SLOUGHS 8A, 9 AND 11 TO SEPTEMBER 1983 STORM	PREPARED FOR: HARZA-EBASCO SUSITNA JOINT VENTURE

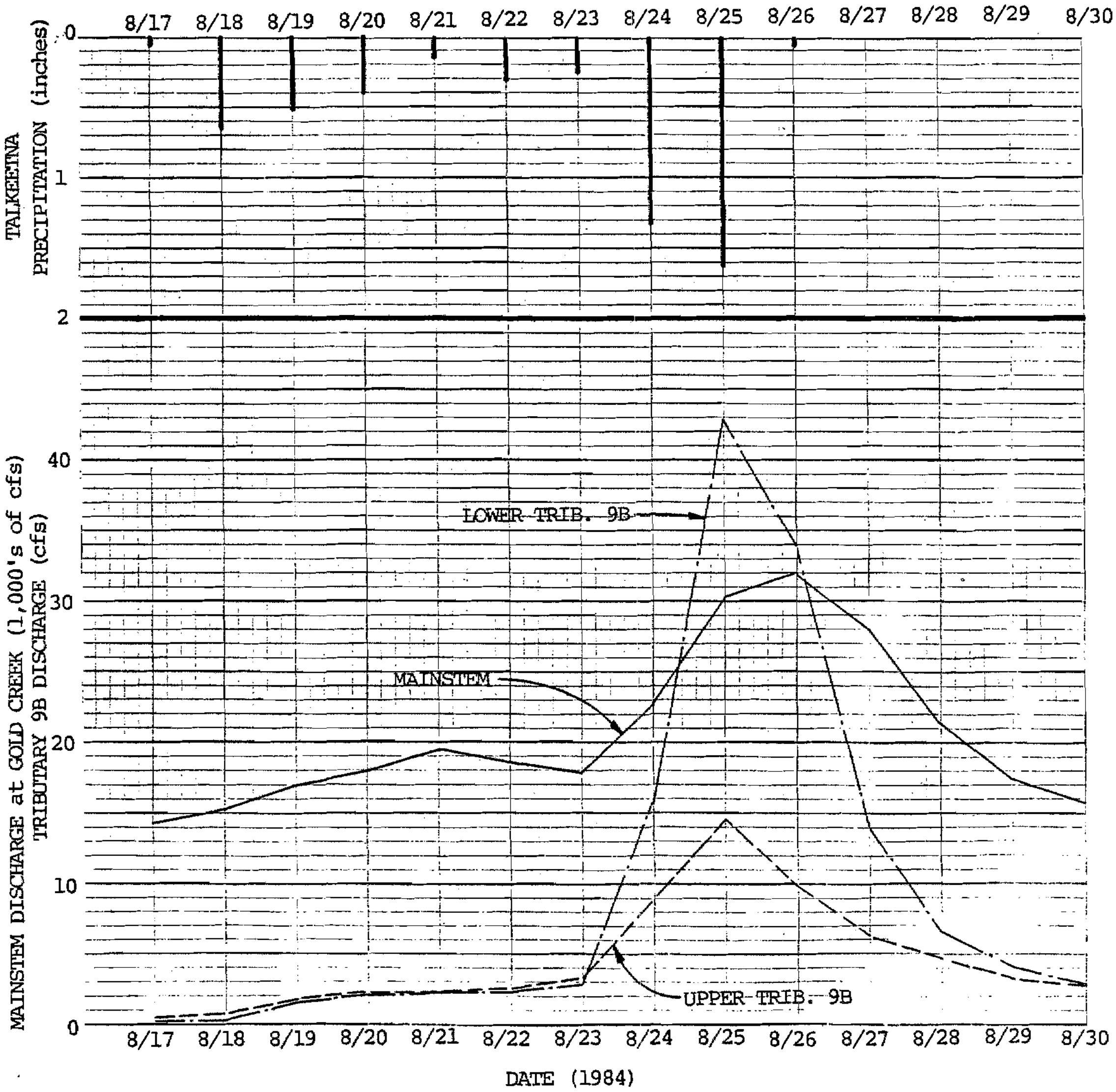


FIGURE 4.21

PREPARED BY:		PREPARED FOR:
R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	RESPONSE OF SUSITNA RIVER AND TRIBUTARY 9B TO AUGUST 1984 STORM	HARZA-EBASCO SUSITNA JOINT VENTURE

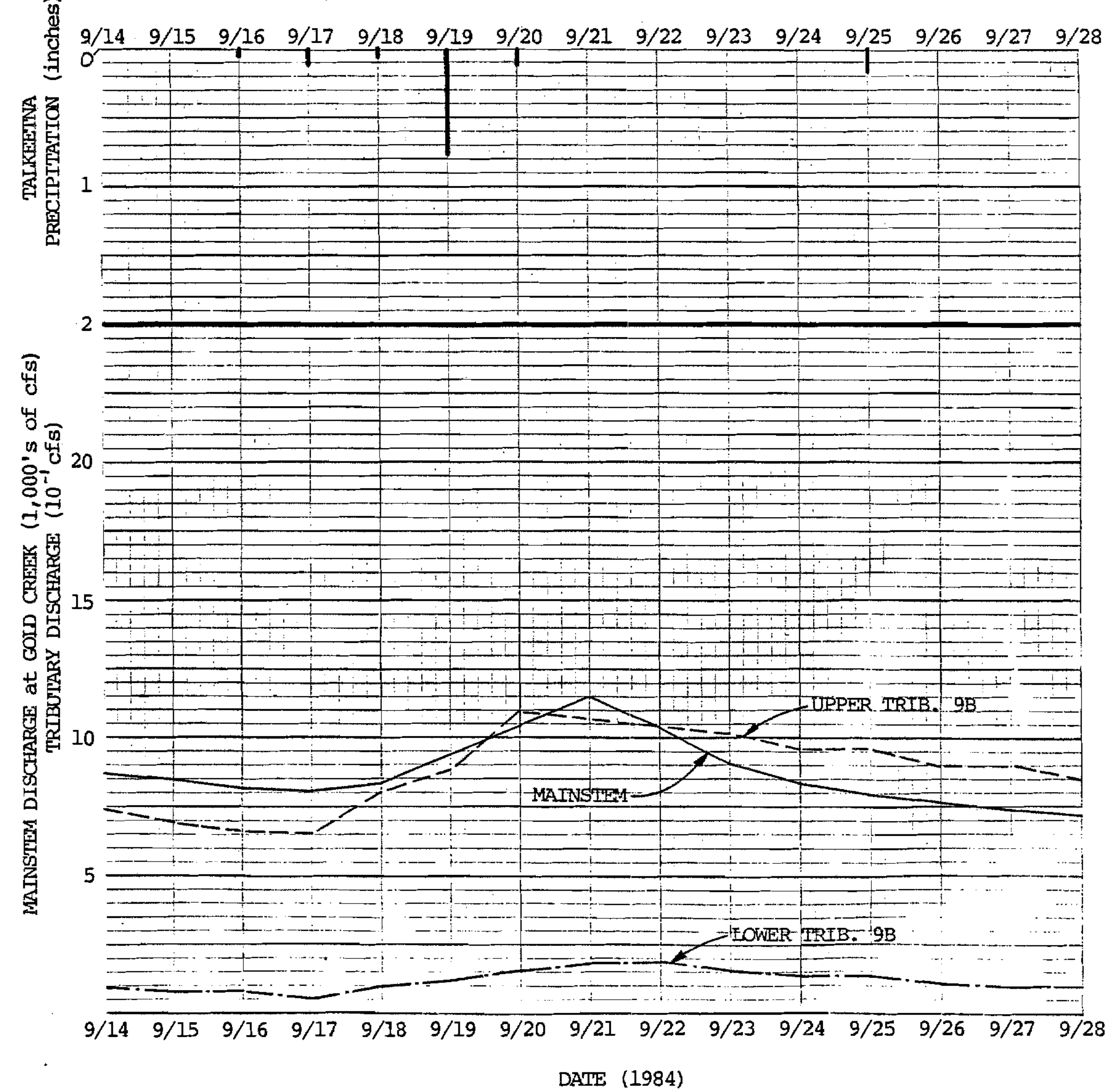


FIGURE 4.22

PREPARED BY: R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	RESPONSE OF SUSITNA RIVER AND TRIBUTARY 9B TO SEPTEMBER 1984 STORM	PREPARED FOR: HARZA-EBASCO SUSITNA JOINT VENTURE

5.0 SUMMARY

Construction and operation of the Susitna Hydroelectric Project will affect several of the physical processes which produce and regulate the aquatic habitats in the Middle Susitna River. Changes will occur in the river sedimentation processes, in the channel stability, and in the groundwater upwelling processes. The specific project effects are reviewed below.

The river sedimentation processes will change from strictly river-type to combined lake-type and river-type. A large proportion of the sediment reaching the impoundment zone from upstream will be trapped in the reservoirs, with only the fine suspended particles (smaller than about 3-4 microns) passing through to the river downstream. This will have some direct effects on the stability of the river channel below the project.

The reservoir releases will be transporting less sediment than comparable flows under natural conditions, and will consequently have capacity to transport additional sediment. The flows will thus have a tendency to pick up finer particles from the riverbed. However, with-project flows will also be smaller than naturally-occurring summer flows, with reduced ability to transport sediment. The net result of project construction and operation is that local areas of the mainstem in the Middle Reach are expected to degrade from zero to 1 foot. The median size of particles in the mainstem is likely to increase, making the channel more stable. The beds of sloughs and side channels may locally degrade from zero to 0.5 foot.

Local deposition in the mainstem, primarily due to bifurcation of the streamflow between the mainstem and other channels, is not expected to be significant. Due to possible degradation of the main river, the side channels and sloughs may require larger mainstem flows to overtop them, on the order of 8,000 cfs higher than under natural conditions. Fine sediments picked up from the river bed downstream of the dams may continue to intrude into the gravel beds of sloughs and side channels in pools and backwater areas. Jack Long, Sherman, and Deadhorse Creeks, three tributaries used by salmon, may be unable to downcut through their delta deposits, but other tributaries should not have similar problems.

Project effects on slough hydrology relate to likely changes in flow levels and water temperatures. There is considerable variation between sloughs as to the nature of their dependence on the mainstem. Sloughs similar to Slough 11, whose flows are strongly related to the mainstem water level, are likely to experience a decrease in groundwater upwelling under with-project conditions. Other sloughs which derive significant inflow from upland sources or from local surface flow will be affected to a lesser extent. Temperatures of groundwater upwelling to the sloughs are reasonably approximated by the mean annual (time-weighted) river temperature. Any variations in mean annual river temperature due to project operation will likely result in a similar change to the temperature of the slough upwelling derived from the mainstem.

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