PRELIMINARY ASSESSMENT OF ACCESS BY SPAWNING SALMON INTO PORTAGE CREEK AND INDIAN RIVER

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ACKNOWLEDGMENTS

This report is based on field data obtained during the summer and fall of 1982 by the Alaska Department of Fish and Game's Su-Hydro Aquatic Studies Team and R&M Consultants, Inc. Graphics were prepared by Sally Donovan, Alaska Department of Fish and Game, Su-Hydro Aquatic Studies Team. Technical reviews were provided by Larry Rundquist, Woodward-Clyde Consultants; Stephen Bredthauer and Jeff Coffin, R&M Consultants, Inc.; Charles "Mike" Prewitt and Mike Kelly, University of Alaska, Arctic Environmental Information and Data Center; and Bruce Barrett and Christopher Estes, Alaska Department of Fish and Game, Su-Hydro Aquatic Studies Team. Editorial assistance with the organizational structure and format was provided by Linda Perry Dwight.

CONTENTS

SUMMARY

Indian River and Portage Creek are the most important tributaries used by spawning salmon in the Susitna River upstream from Talkeetna. The mid-summer discharge of the Susitna River will be reduced by operation of the proposed Susitna hydroelectric project. There is concern that resulting shallow depths or high velocities at the mouths of these tributaries could prevent adult salmon from accessing traditional salmon habitats. An analysis was conducted of pre- and postproject depths and velocities, which govern access by adult salmon into Indian River and Portage Creek, and compared with recommended passage criteria for adult salmon obtained from the literature. The analysis is based on field data collected during the 1982 field season by R&M Consultants, Inc. (R&M) and the Alaska Department of Fish and Game (ADF&G), Su-Hydro Aquatic Studies Team.

Entrance conditions at the mouths of Portage Creek and Indian River were evaluated for mainstem discharges at Gold Creek of 8,000, 13,400, 21,500 and 34,500 cfs, which represent different operating scenarios. The analysis indicates that access into Portage Creek and Indian River by spawning salmon has not been a problem, and that it is unlikely to become a problem were the proposed Susitna hydroelectric project operated as outlined in Chapter 2 of the draft Exhibit E (Acres American Incorporated 1982).

It is quite likely that naturally occurring tributary flows will alter streambed gradients near the mouths of Portage Creek and Indian River as

a direct result of reduced mid-summer discharge in the Susitna River. The downcutting, which is not expected to extend any great distance up the tributaries, is suspected to establish new entrance conditions (depths and velocities) at the mouths of these streams that would not be much different from existing conditions. In the event that Portage Creek or Indian River did not downcut their streambed, naturally occurring tributary flows are expected to provide adequate depths for adult salmon to enter these streams without the assistance of mainstem backwater effects. Therefore, it is not expected that operation of the proposed project will have any negative impact on the ability of adult salmon to enter Portage Creek or Indian River during the spawning season. A discussion of the rationale supporting these statements is provided in later sections of this paper.

INTRODUCTION

The proposed Susitna hydroelectric project will alter the existing streamflow, sediment, and thermal regimes of the Susitna River. The project would reduce streamflows at Gold Creek during summer and increase them during winter. Suspended sediment, turbidity, and water temperatures are expected to follow similar patterns. Natural flows for the Susitna River at the Gold Creek stream gage commonly range between 20,000 and 30,000 cfs during June, July, and August (R&M Consultants, Inc. 1982a). Average monthly postproject streamflows at Gold Creek are forecast to be in the range of 7,000 to 11,000 cfs during June, July, and early August. A controlled flow of no less than 12,000 cfs from mid-August to mid-September is proposed by the Alaska Power Authority (Acres American Incorporated 1982).

Although some mainstem spawning has been documented, the most intensively used spawning areas within the Talkeetna to Devil Canyon reach are located in tributary streams and side sloughs. Indian River and Portage Creek are the most important tributaries used by spawning salmon in the Susitna drainage upstream from Talkeetna. The combined escapements of chinook and chum salmon into these two tributaries exceeds the total escapement of these species into all other tributaries entering the Susitna River above Talkeetna (ADF&G 1981, 1983b).

Presently, mid-summer streamflows in the Susitna River are large enough to cause a backwater effect at the mouth of Portage Creek and Indian

River. The backwater effect reduces velocity and increases depth at the mouths of these tributaries and is generally thought to facilitate access for migrating fish.

The proposed project flows would reduce mid-summer water surface elevations of the Susitna River near Portage Creek and Indian River approximately 3 feet below present levels. Because of the magnitude of this anticipated decrease in mainstem water surface elevations during the salmon inmigration and spawning period, there is concern regarding the ability of adult salmon to enter Portage Creek and Indian River. The purpose of this paper is to present a preliminary analysis of the influence that mainstem discharge has on access to spawning areas in Portage Creek and Indian River. The paper has been prepared at the request of the Alaska Power Authority and in cooperation with the Alaska Department of Fish and Game's Su-Hydro Aquatic Studies Team and R&M Consultants, Inc.

Insufficient data are available to provide a rigorous comparison between pre- and postproject hydraulic conditions at the mouths of Portage Creek and Indian River. However, it is possible to estimate mid-channel depths and velocities at the mouths of these tributaries, in the absence of mainstem backwater effects, and then compare these values with passage criteria for adult salmon available in the literature. Used in this manner, the existing data base is adequate to determine whether or not mainstem backwater effects are necessary in order for adult salmon to enter Portage Creek or Indian River.

By assuming that uniform flow occurs in the lower reaches of these tributaries, the data base is also sufficient to support a preliminary evaluation of stream channel stability and to determine whether or not naturally occurring tributary flows appear adequate to provide for the passage of adult salmon into Portage Creek or Indian River in the event that their existing streambed elevations change.

Several hydraulic terms and equations are used in this report that may warrant further explanation than is presented in the Methods or Results sections. An appendix has been prepared to provide definitions for the various types of open channel flow mentioned in the report and to explain how Manning's equation and Shield's criteria were used in the analysis. These explanations are based upon the author's general knowledge of river mechanics or were extracted from lecture notes previously prepared by the author while serving as training officer for the U.S. Fish and Wildlife Service's Cooperative Instream Flow Service Group. A list of relevant text books follows the appendix for those interested in pursuing the concepts further.

METHODS

Field Work

Cross section and streambed profile surveys were completed during the 1982 field season by R&M at the mouths of Portage Creek and Indian River. Each confluence area is described by three mainstem cross sections, a fourth cross section across the mouth of the tributary, and a streambed and water surface profile for the tributary, which extends 800 to 1,000 feet upstream from the tributary mouth (R&M Consultants, Inc. 1982b).

ADF&G personnel installed staff gages at mainstem river cross sections upstream and downstream from each tributary and periodically recorded the mainstem water surface elevation (WSEL) throughout the 1982 open water field season (ADF&G 1983a). The timing of the arrival of each species of adult salmon in Indian River and Portage Creek was established through aerial and ground surveys (ADF&G 1983b).

In addition, a partial record of daily streamflows was obtained for both tributaries. A pressure transducer was installed by the author in the streambed of each tributary and connected to a milli-volt recorder to obtain a continuous record of water depth. Periodic streamflow measurements and gage height readings were obtained by R&M to develop preliminary discharge curves for Portage Creek and Indian River. These rating curves and the WSEL traces from the pressure transducers were used by ADF&G to determine average daily streamflows for both streams from August 9 through October 22, 1983 (ADF&G 1983a).

Analysis

Cross section and streambed profiles were plotted to describe the channel geometry near the mouth of each tributary. Mainstem water surface elevations and discharge on the date of the cross section survey were noted.

The observed mainstem water surface elevations at each staff gage site were tabulated, and stage-discharge curves were developed for each gage by plotting the observed water surface elevations against the corresponding average daily discharge of the Susitna River at Gold Creek. These plots were compared with simulated stage discharge curves developed for the same mainstem river cross sections using results from a 1981 HEC-2 analysis (R&M Consultants, Inc. and Acres American Inc. 1982). When making this comparison, more credence was given to the field observations than to the predicted water surface elevations. However, the simulated WSEL data from the HEC-2 analysis were useful for extending the empirical curves beyond observed values.

Mainstem water surface elevations were determined at each staff gage location directly from the stage-discharge curves for mainstem flows at Gold Creek between 8,000 and 34,500 cfs. The slope of the mainstem water surface profile was assumed constant between the the staff gage locations upstream and downstream of the tributary mouth. The water surface elevations of the mainstem directly opposite the mouths of the tributaries were determined by linear interpolation. Mainstem water surface elevations corresponding to Gold Creek discharges of 8,000, 13,400, 21,500 and 34,500 cfs were plotted for comparison with surveyed streambed and water surface profiles of the tributaries.

Characteristic mid-summer tributary flows were estimated on the basis of partial streamflow records for 1982 and a comparison of 1982 precipitation data with the historic record available for Talkeetna, Alaska. Unit discharge (cfs per foot of channel width) relationships were determined for each tributary as a function of total streamflow. These relationships were used throughout the analysis to facilitate computational procedures and to provide pre- and postproject estimates of the hydraulic conditions that would govern access by salmon into the tributaries. Representative mid-channel depths and velocities were calculated as functions of unit discharge based on fully developed uniform flow existing in a natural channel. Because this is unlikely to occur, a conscious effort was made throughout the analysis to evaluate plausible worst case entrance conditions.

It was assumed that postproject mainstem water surface elevations would not cause a backwater effect in the mouth of Portage Creek or Indian River. Although this assumption may not be completely valid, it results in a more critical evaluation of postproject entrance conditions for adult salmon attempting to enter these tributaries. By assuming that a backwater effect does not exist, shallower depths and higher velocities are calculated for postproject entrance conditions than would actually exist. Thus, if it is determined that adult spawners could migrate upstream given the calculated depths and velocities in the absence of backwater effects, they should have less difficulty in passing through actual postproject conditions encountered.

A somewhat similar approach was taken with regard to evaluating streambed stability and estimating the resultant (postproject) slope of the streambed upstream from the mouth of the tributary. Because of a limited data base and the inability to calculate specific depths and velocities in the tributaries, envelope curves representing populations of plausible depths and velocities were generated for use in evaluating entrance conditions for migrating salmon and the stability of various streambed particle sizes. A postproject streambed slope was selected for use in the analysis that might never actually exist, but which is thought to represent a plausible worst case entrance condition for upstream migrants.

Much of the discussion and the conclusions presented in the latter portion of this report are based on the author's experience and direct observation. Corroborative field data to support the hydraulic analysis presented in this report are limited. Continuing field work and analysis could be undertaken to substantiate various figures and estimates contained in this report. Although this work might result in different numerical values being calculated, it is not likely that the concluding statements in this report regarding project effects on access by adult salmon into Portage Creek or Indian River would be altered.

RESULTS

Portage Creek

A planimetric sketch of the Portage Creek-Susitna River confluence is provided as Figure 1. Field observations indicate that Portage Creek flows within a well-defined single channel nearly rectangular in shape throughout much of its length. Approximately 300 feet above its confluence with the Susitna River, Portage Creek divides into two channels, which cross alluvial outwash and enter the Susitna River at River Mile 148.9

The mainstem study reach extends 1,100 feet between LRX-61 and LRX-62; LRX-61 is 710 feet downstream and LRX-62 is 390 feet upstream of the center line of Portage Creek. The study area also includes an 800-foot reach of Portage Creek immediately upstream from its mouth. Staff gages were installed on the north bank of the Susitna River at LRX-61 and LRX-62, and a stage recorder was installed on the east bank of Portage Creek approximately 550 feet above its mouth.

Cross section data indicate that this reach of the mainstem Susitna River is approximately 300 feet wide and 15 feet deep during a typical summer discharge of 21,500 cfs (Figure 2). Stage discharge curves developed for LRX-61 and LRX-62 from 1982 staff gage data (ADF&G 1983a) and a 1981 HEC-2 analysis (R&M Consultants, Inc. and Acres American Inc. 1982) indicate that the response of mainstem water surface elevations to incremental changes in discharge is well defined in this reach for a range of flows between 8,000 cfs and 34,000 cfs (Figure 3). Results from the HEC-2 analysis were used as a guide to extend the stage discharge curves beyond the upper limit of observed data.

Table 1. Water Surface Elevations of the Susitna River at the mouth of Portage Creek for selected mainstem streamflows at Gold Creek.

Mainstem Discharge Gold Creek (cfs)	Mainstem WSEL LRX-61 (ft)	Mainstem WSEL Portage Creek (ft)	Mainstem WSEL LRX-62 (ft)
8,000	832.4	833.6	834.3
12,000	833.7	835.1	835.9
13,400	834.2	835.7	836.5
16,000	834.8	836.2	837.1
20,000	835.6	837.1	838.0
21,500	836.1	837.6	838.4
24,000	836.5	837.9	838.8
28,000	837.2	838.7	839.6
32,000	838.0	839.4	840.3
34,500	838.5	840.0	840.8

Mainstem WSEL. Mainstem water surface elevations were determined above and below the mouth of Portage Creek from the stage discharge curves for mainstem streamflows between 8,000 and 34,500 cfs (Table 1). The slope of the mainstem water surface profile between the staff gages at LRX-61 and LRX-62 was assumed constant and water surface elevations of the mainstem opposite the mouth of Portage Creek were calculated. Mainstem water surface elevations were determined to range from 833.6 to 840.0 feet as the mainstem discharge at Gold Creek increased from 8,000 to 34,500 cfs. Mainstem water surface profiles across the mouth of Portage Creek were plotted for discharges of 8,000, 13,400, 21,500 and 34,500 cfs (Figure 4).

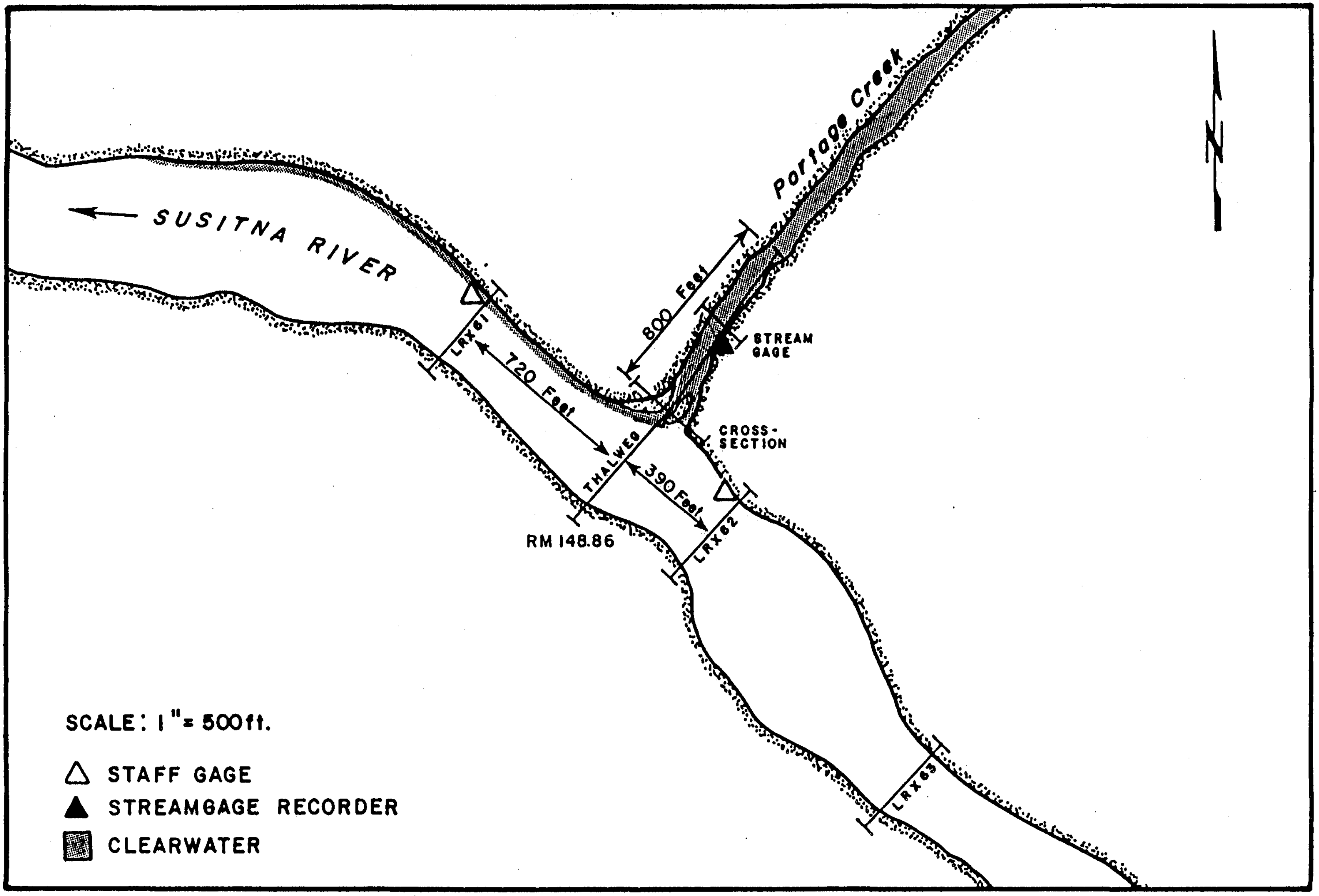


Figure 1. Planemetric sketch of the Mouth of Portage Creek. (Adopted from 1:6000 scale blueline prints, R&M Consultants, Inc., 1980)

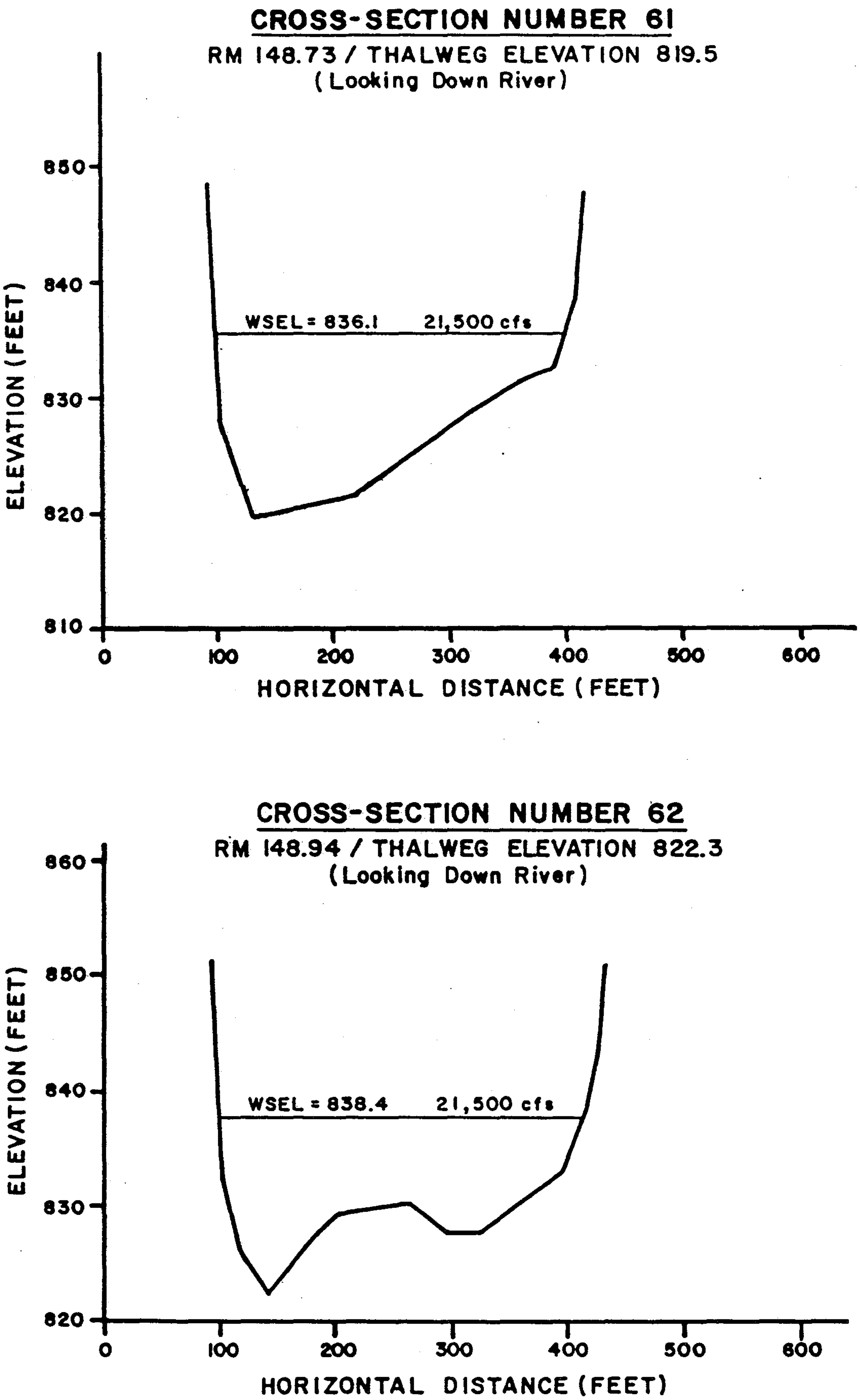
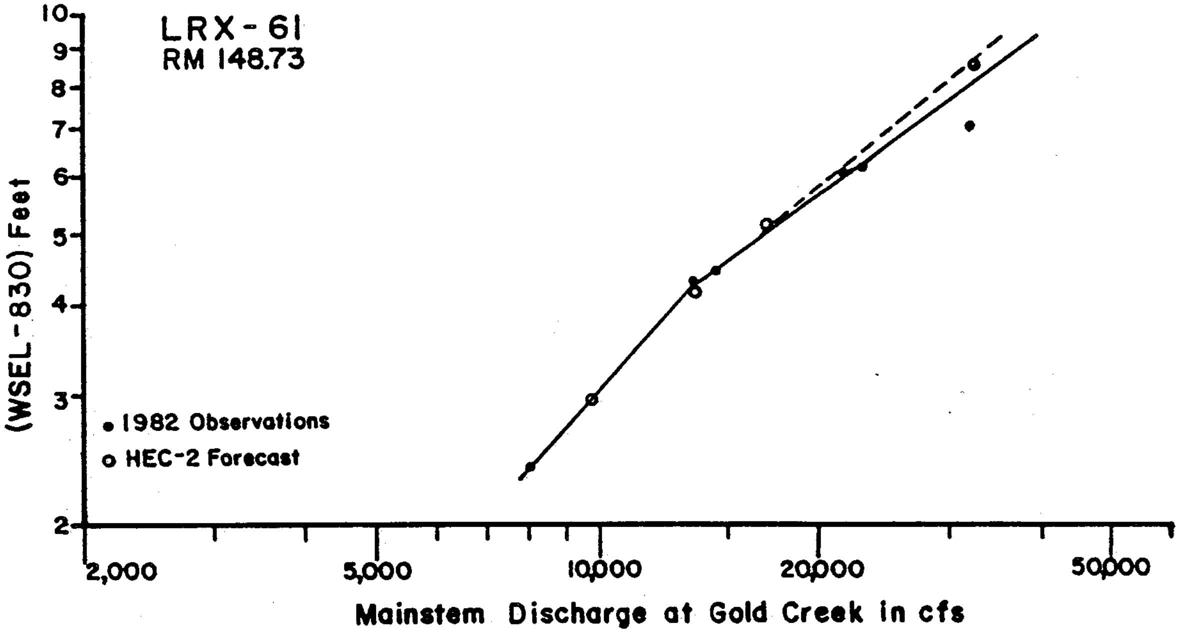


Figure 2. Mainstem River Cross Sections near the mouth of Portage Creek. (Adapted from R&M Consultants, Inc. and Acres American Inc. 1982)



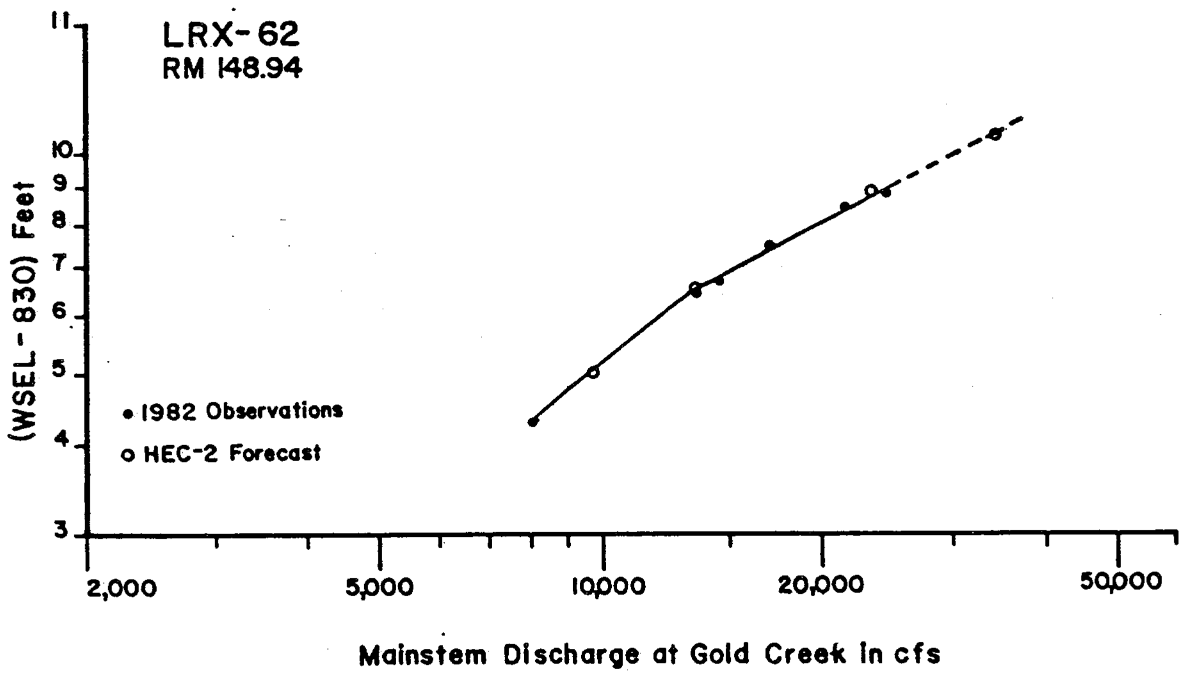


Figure 3. Comparison between observed and forecast mainstem water surface elevations near the mouth of Portage Creek. (Adapted from R&M Consultants, Inc. and Acres American Inc. 1982, ADF&G 1983a.)

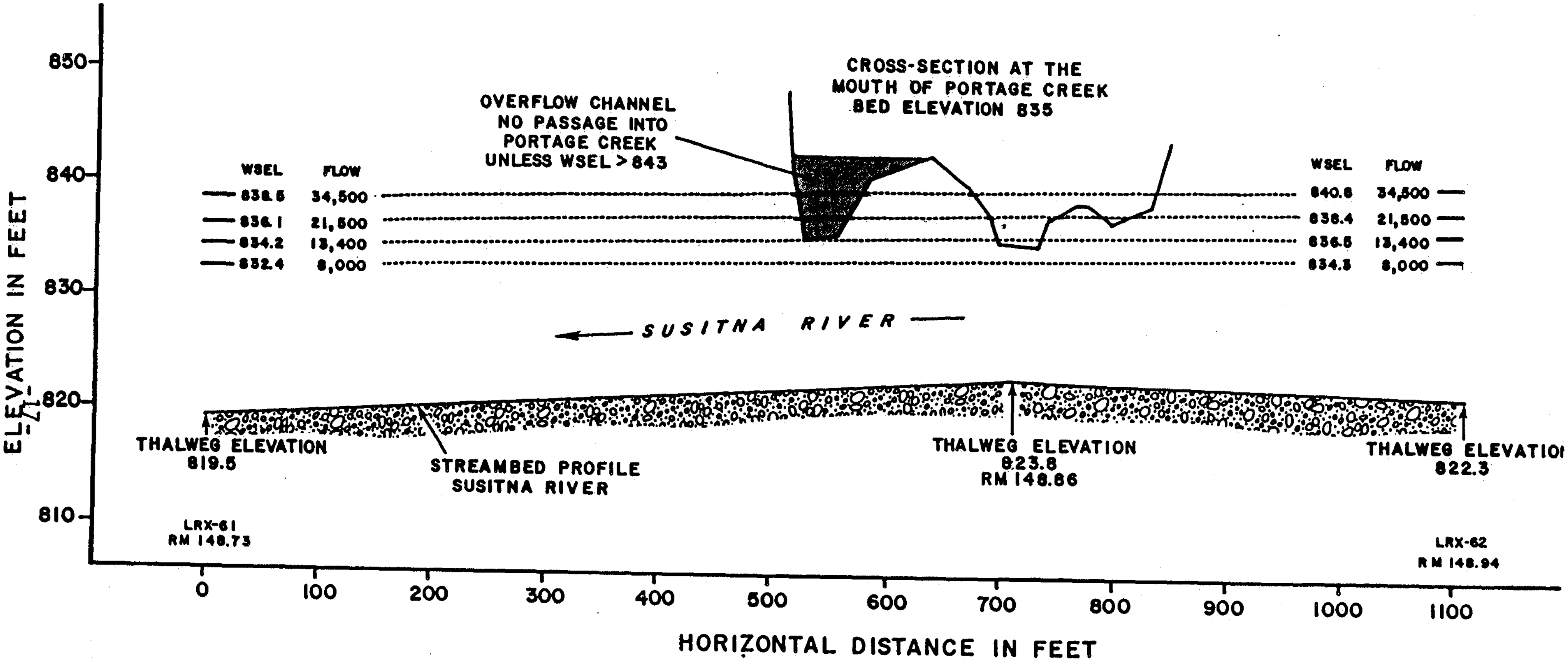


Figure 4. Streambed and water surface profiles of the Susitna River at the Mouth of Portage Creek.

Mainstem water surface elevations were also compared with surveyed streambed and water surface profiles for Portage Creek (Figure 5). A representative streambed elevation for the mouth of Portage Creek is 835 feet. Mainstem water surface elevations opposite the mouth of Portage Creek can be shown to equal or exceed 835 feet for discharges in excess of 12,000 cfs at Gold Creek.

Portage Creek Hydraulics. The total discharge of a stream divided by the representative channel width is called the unit discharge (q). The concept of a unit discharge is often used when applying hydraulic formulas to open channel flow to facilitate computational procedures. This concept is most applicable to straight, rectangular channels with a known top width.

Field observations indicate that the lower reach of Portage Creek is relatively straight and nearly rectangular in cross section. Approximately 300 feet downstream of the gage site, Portage Creek divides into two channels, which also are nearly rectangular in cross section. Field measurements were obtained near the Portage Creek stream gage site that indicate the degree to which top width varies with discharge (Table 2). Based on these data and observations, the relationship between total discharge and unit discharge was estimated for Portage Creek (Figure 6).

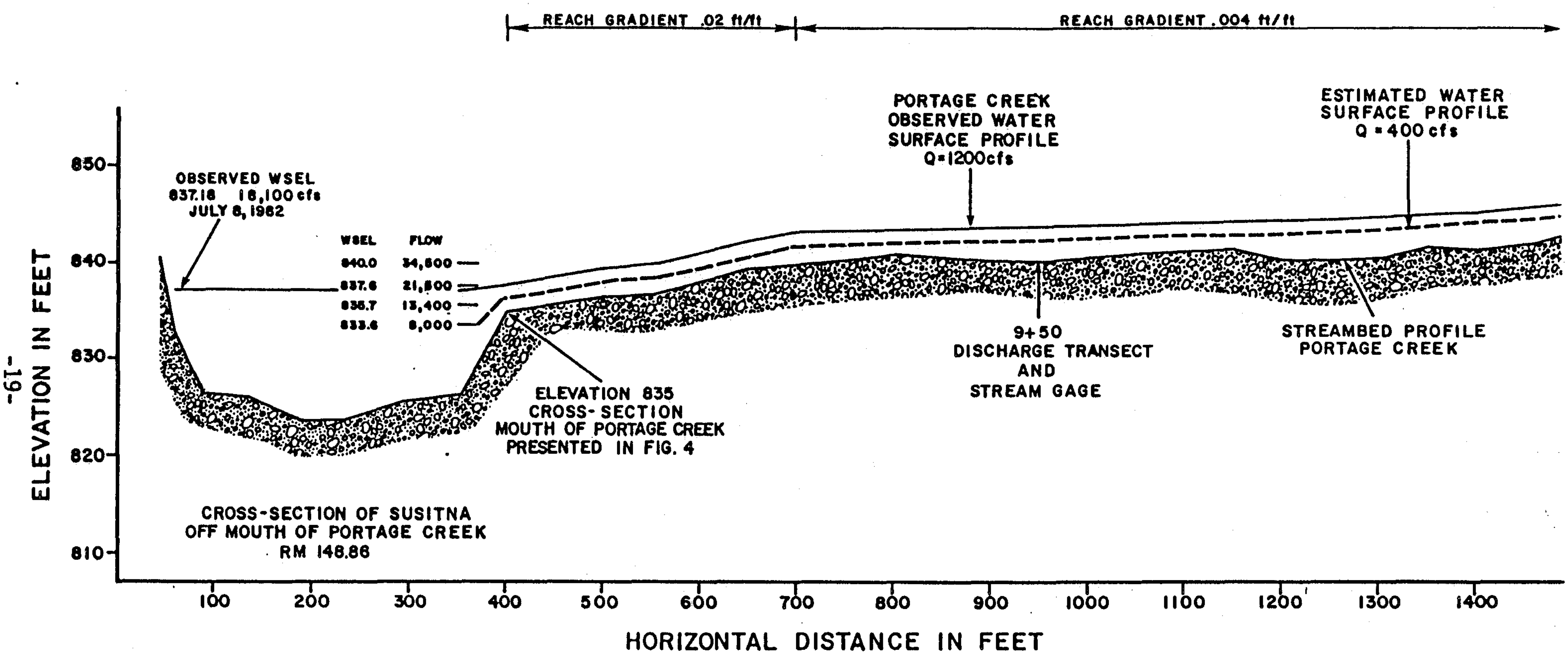


Figure 5. Existing streambed profile of Portage Creek and the adjoining cross section for the Susitna River at RM 148.86.

Table 2. Hydraulic parameters for Portage Creek.

Date 1982	Discharge (cfs)	Top Width (ft)	X-Sect Area (ft^2)	Mid-Chnl Velocity (fps)	Hydraulic Depth (ft)	Average Velocity (fps)
Oct 6	434	84	185	2.3-3.3	2.2	2.3
Sep 4	632	84	215	2.5-4.0	2.6	2.9
Jul 8	1188	94	272	3.3-5.9	2.9	4.4

R&M Consultants, Inc., 1982, unpublished streamflow data.

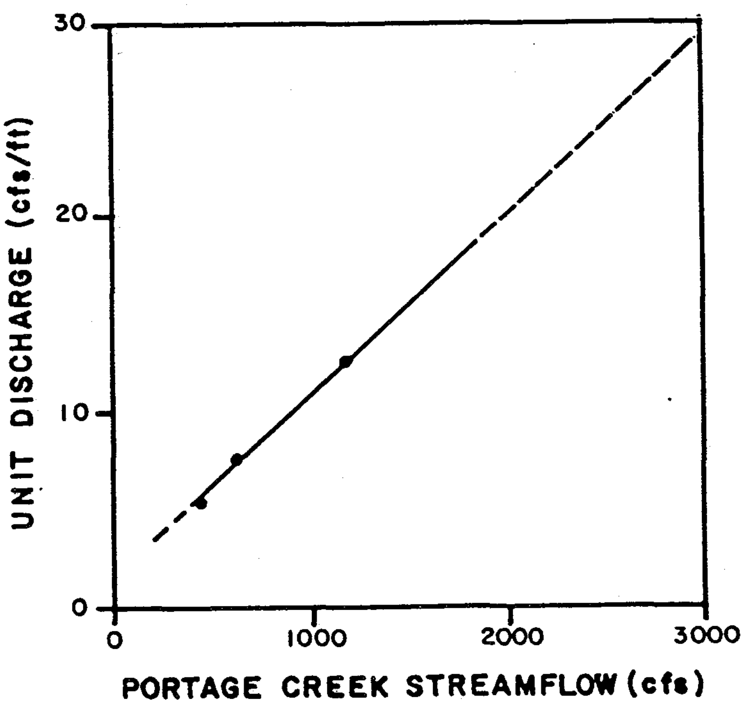


Figure 6. Relationship between unit discharge and total discharge for the single channel reach of Portage Creek above its mouth.

Streambed and water surface profiles for Portage Creek (Figure 5) show that a noticeable change in gradient occurs near station 700. Given the relatively uniform width for this reach of Portage Creek, the much steeper gradient downstream of station 700 can be expected to cause higher velocities and shallower depths downstream of station 700 than occur upstream of this location. (Hydraulic calculations indicate that for streamflows in excess of 650 cfs (7.5 cfs/ft) flow passes from subcritical to supercritical near station 700).

Depths and velocities calculated to occur near station 700 and in the adjacent upstream and downstream reach are presented in Figure 7 as functions of unit discharge. Depths and velocities upstream of station 700 (represented by the dotted curve) are not considered a potential impediment to upstream migrants, which could pass through the adjacent downstream reach. The dashed line represents depths and velocities near station 700; the solid line depicts depths and velocities for fully-developed uniform flow downstream of station 700.

It is likely that streambed irregularities would prohibit the exact depths and velocities depicted by these curves from being attained. These curves do, however, describe a plausible envelope of theoretical depths and velocities forecast for an 800-foot tributary reach immediately upstream from the mouth of Portage Creek. The occurrence of depths and velocities depicted by the dashed line will be restricted to the immediate vicinity of station 700. Depths and velocities represented by the solid line can be expected to occur anywhere that mainstem backwater effects are not present between station 700 and the

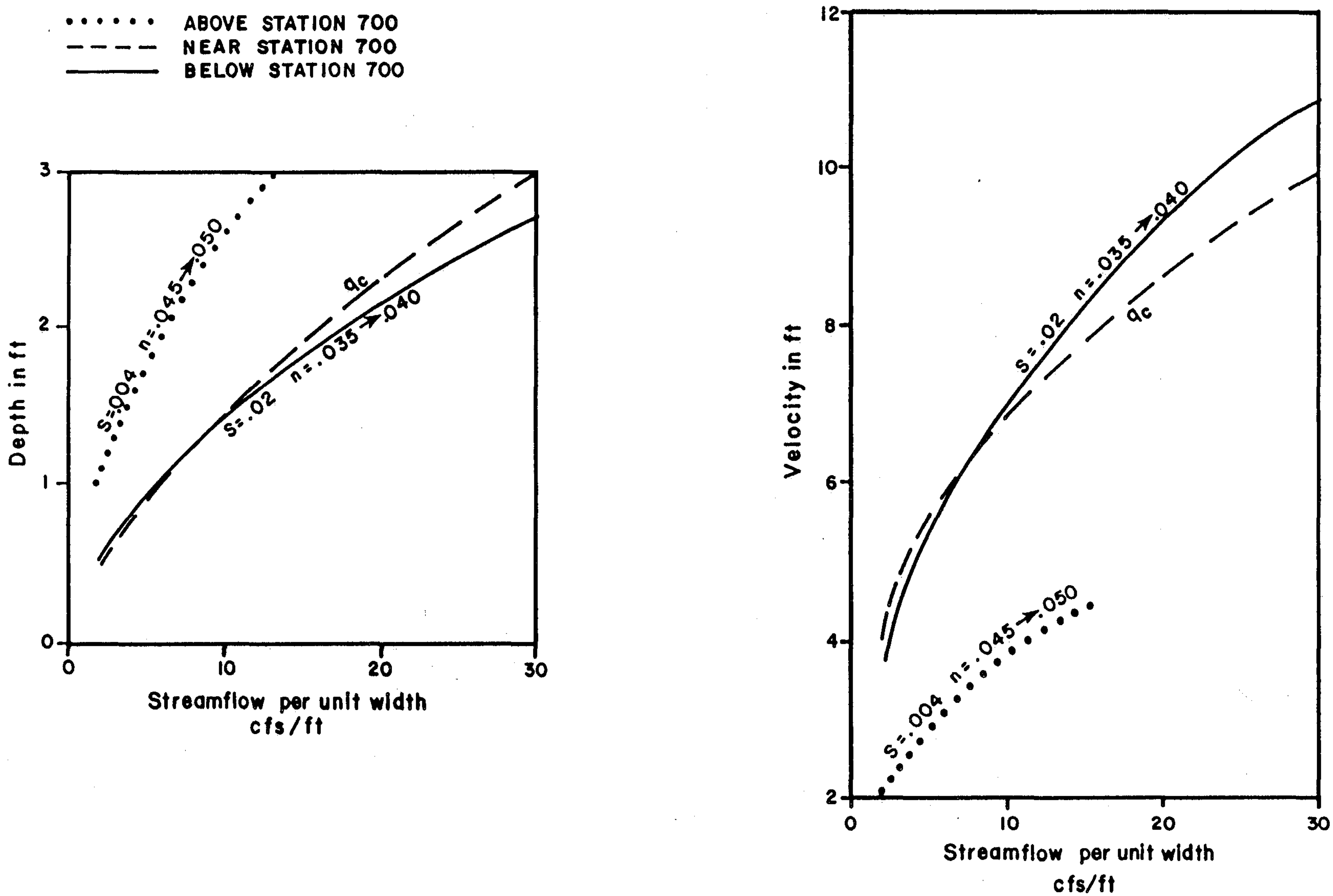


Figure 7. Depths and velocities above the mouth of Portage Creek calculated as functions of unit discharge in the absence of mainstem backwater effects.

mouth of Portage Creek. Mainstem backwater effects would reduce the velocities and increase the depths depicted by this curve. Inasmuch as the depths and velocities defined by the solid line in Figure 7 represent plausible worst case entrance conditions for adult salmon entering Portage Creek, these curves were used as the principal indicators of access for the existing channel geometry.

The 1982 streamflow data for Portage Creek suggest that typical streamflows during the June through August period are in the range of 500 to 800 cfs (ADF&G 1983a). Review of these data in association with 1982 and long-term precipitation data for Talkeetna suggests that 300 cfs might be an abnormally low summer streamflow for Portage Creek. This figure was used to determine entrance depths associated with a probable "worst case" low flow for Portage Creek.

Field observations and cross section data indicate that a stream flow of 300 cfs in Portage Creek would result in an effective top width of approximately 75 feet near the stream gage and approximately 60 feet for the primary channel at the mouth (Table 2, and R&M Consultants, Inc. 1982b). Within the single channel reach of Portage Creek near the stream gage site, a total discharge of 300 cfs and top width of 75 feet is equivalent to a unit discharge of approximately 4 cfs (refer to Figure 6). For an effective primary channel width of 60 feet at the mouth of Portage Creek, 300 cfs is equivalent to a discharge per unit width of 5 cfs/ft. Given existing channel geometry for Portage Creek and no backwater effect from the Susitna River (Gold Creek flow less than 12,000 cfs), a discharge of 300 cfs would provide an average depth of approximately 0.9 feet and mid-channel velocities of approximately 5.5 fps at the mouth of Portage Creek. The presence of mainstem backwater effects would tend to increase this depth and reduce the velocity.

Mean annual floods for Portage Creek have been estimated to range between 1,450 and 1,850 cfs (R&M Consultants, Inc. 1982b). The peak daily discharge recorded during 1982 for Portage Creek was 1,673 cfs (ADF&G 1983a). This author estimates peak daily streamflows may be as large as 2,500 to 3,000 cfs (15 to 20 cfs/ft). Streamflows of this magnitude would likely result in depths near 2 feet and mid-channel velocities between 8 and 9 fps at the mouth of Portage Creek, were no mainstem backwater effects present (Figures 6 and 7).

Review of a previous analysis of flow variability (R&M Consultants, Inc. 1981) and the 1982 streamflow data for Portage Creek suggests that the duration of streamflows of such magnitude would probably be limited to three days or less. Once Portage Creek streamflows decreased to the 500 to 800 cfs range (6 to 10 cfs/ft), depths should range between 1.0 and 1.5 feet at the mouth of Portage Creek and mid-channel velocities would be from 6 to 7 fps.

Channel Stability. It is not expected, however, that the streambed above the mouth of Portage Creek will remain stable (R&M Consultants, Inc. 1982b). The movement of streambed particles is principally a function of discharge, reach gradient, and particle size. Threshold values of incipient motion for various particle sizes were estimated

(Figure 8) as a function of discharge using Shield's criteria and the depth and velocity curves previously introduced. Application of these threshold values to the 800-foot study reach above the mouth of Portage Creek indicates that a stable channel would exist if the size of the predominant streambed materials were in the range of 6 to 8 inches. These are theoretical values and are somewhat conservative. Particles in the 5- to 7-inch range would likely be stable in a "seasoned" natural channel.

Personal observations indicate that streambed particles in the lower reach of Portage Creek are typically 6 to 7 inches in size, interbedded among boulders and large gravels. Smaller particle sizes (3 to 5 inches) are fairly common near the mouth of Portage Creek along streambank margins and in the streambed. The occurrence of smaller particle sizes near the mouth of Portage Creek is attributed to backwater effects of the mainstem, which reduce the sediment transport capacity of Portage Creek near its mouth. This hypotheses is, in part, supported by the flatter slope of the streambed and water surface profiles at the mouth of Portage Creek (Figure 5), which reflect the desposition of streambed material at this location.

In the absence of mainstem backwater effects, midchannel velocities and the associated sediment transport capacity would be expected to increase near the mouth of Portage Creek. As a result, smaller particle sizes (3 to 5 inches) would be removed and the streambed would degrade. Degradation would increase the channel slope, thereby increasing velocities and allowing even larger particles to be transported. The degradation

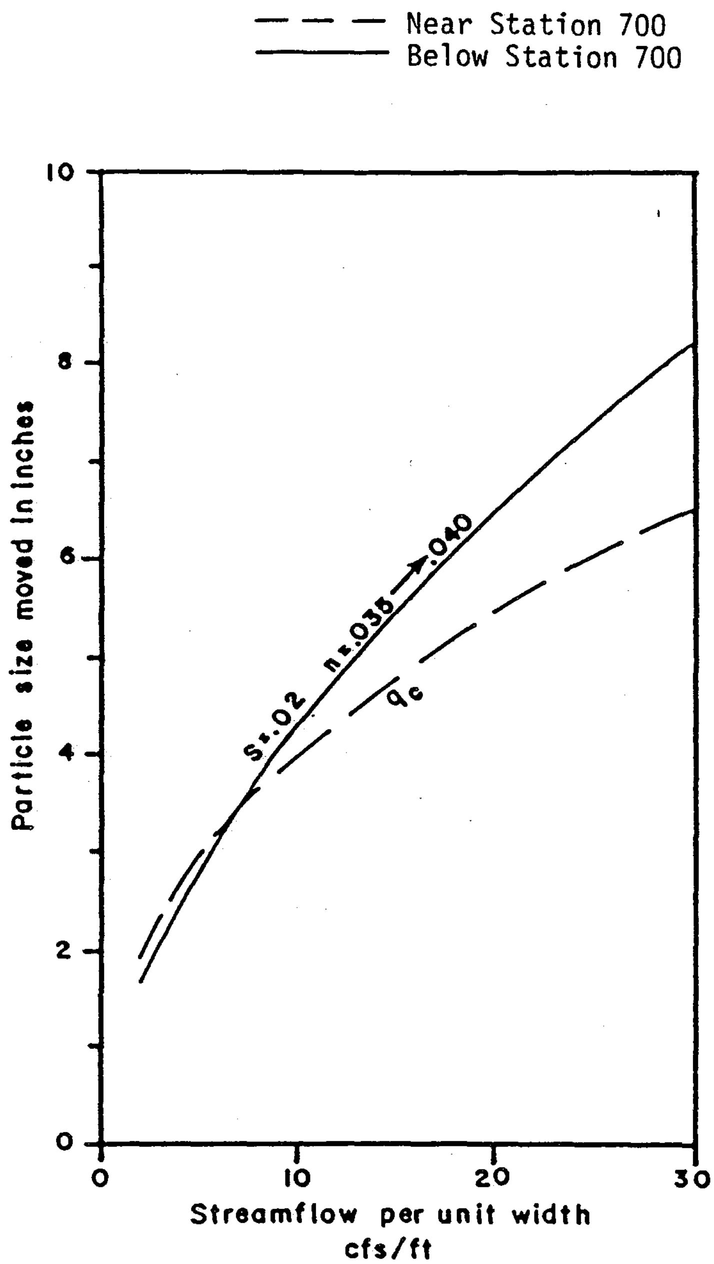


Figure 8. Streambed particle sizes moved near the mouth of Portage Creek in the absence of mainstem backwater effects as a function of unit discharge.

process would depend to a large degree on the frequency and duration of Portage Creek flows in excess of 1,500 cfs and the availability of 6- to 8-inch diameter material within the existing alluvial deposit at the mouth of Portage Creek.

This author estimates that naturally occurring tributary flow in association with the proposed regulation of mainstem discharge could result in Portage Creek downcutting its mouth approximately 3 feet. This is approximately the same magnitude as the difference forecast between mainstem water surface elevations associated with the most prevalent pre- and postproject summer streamflows. Based on the assumptions that Portage Creek would downcut approximately 3 feet and that a moderate amount of 6- to 8-inch material is present within the alluvial deposit at the mouth of Portage Creek, the streambed gradient immediately upstream from the mouth of Portage Creek is expected to increase from .02 ft/ft to .03 ft/ft (Figure 9). This increased gradient is forecast to result in slightly shallower depths and approximately 1 fps increase in the mid-channel velocities above those that would occur at the mouth of Portage Creek if the streambed were not to degrade (Figure 10). The predominant size of streambed materials would probably increase from 6 to 7 inches to 7 to 8 inches.

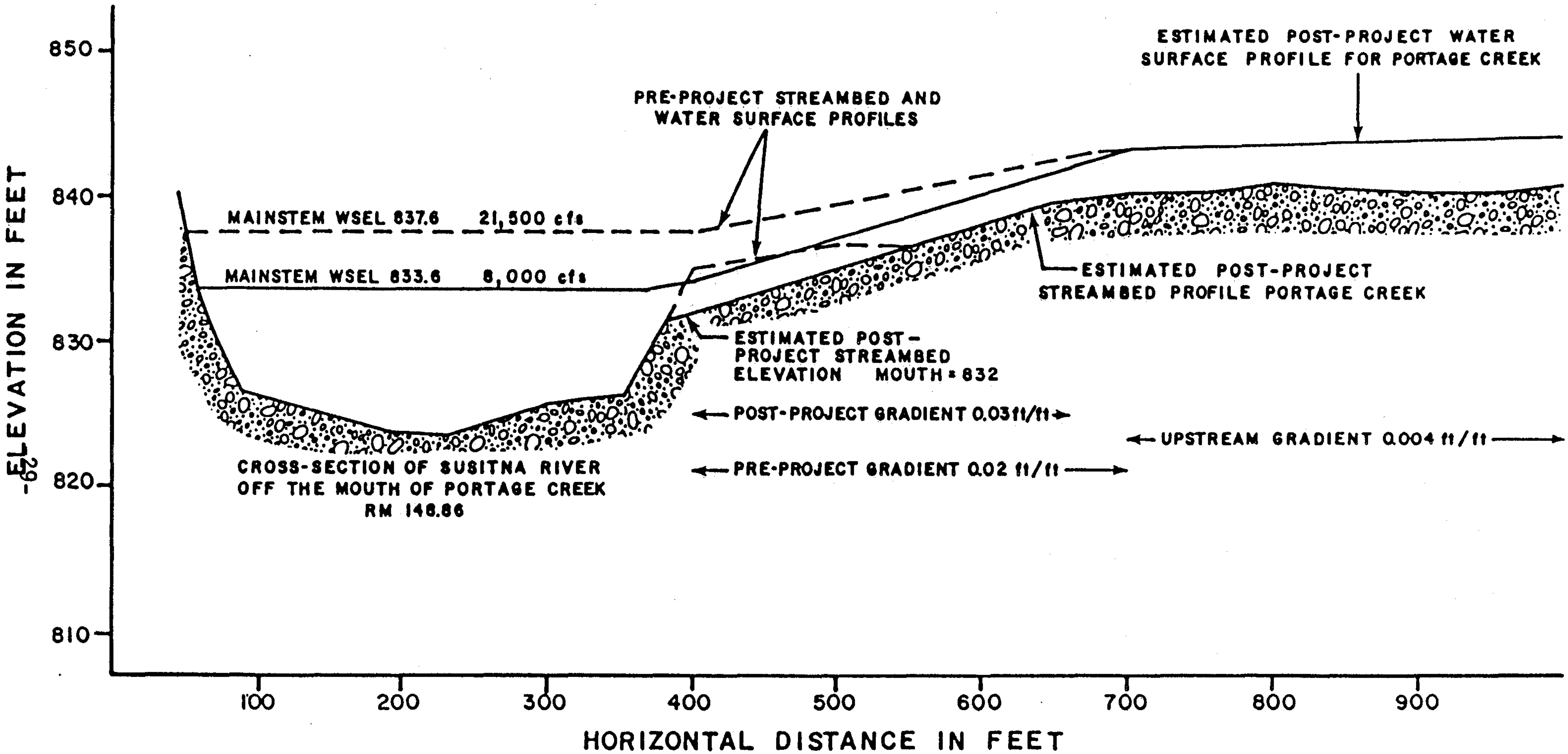


Figure 9. Estimated postproject streambed and water surface profiles for Portage Creek adjoining the Sustina River at RM 148.86.

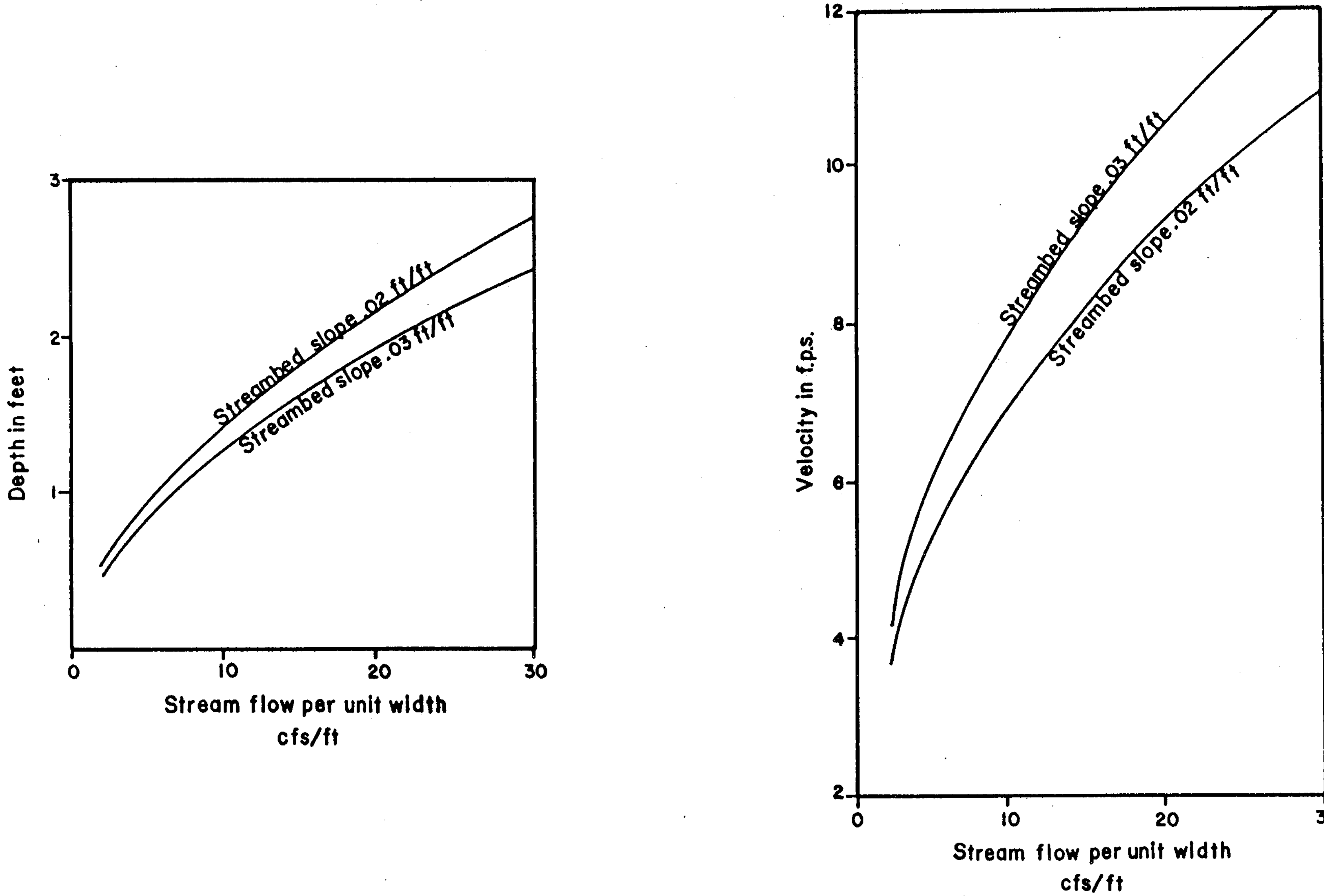


Figure 10. Influence of streambed slope (degradation) on mid channel depths and velocities at the mouth of Portage Creek in the absence of Susitna River backwater effects.

Indian River

Field observations indicate that Indian River is highly braided. A large alluvial deposit exists at the mouth, which extends approximately one mile upstream. In the first mile above its mouth two, and in some reaches three, secondary channels convey streamflow in addition to the main channel. Indian River enters the Susitna at River Mile 138.7. A planimetric view of the Susitna-Indian River confluence is presented in Figure 11. The mainstem study reach extends from LRX-50 (RM 138.48) upstream 2,165 feet to LRX-51 (RM 138.89). The study area also includes the 1,000-foot reach of Indian River immediately upstream from its mouth. Staff gages were installed on the north bank of the Susitna River at LRX-50 and LRX-51 and a stage recorder was installed on Indian River approximately one mile above its mouth.

Mainstem cross section data indicate that, for a typical summer discharge (21,500 cfs), this reach of the Susitna River is approximately 550 feet wide and 10 feet deep (Figure 12). Stage-discharge curves for LRX-50 and LRX-51 developed from 1982 staff gage data (ADF&G 1983a) and a 1981 HEC-2 analysis (R&M Consultants, Inc. and Acres American Inc. 1982) indicate that the response of mainstem water surface elevations to incremental changes in discharge is fairly well defined for a range of flows between 8,000 and 25,000 cfs (Figure 13). Since results from the HEC-2 analysis for this reach did not coincide closely with observed WSEL's, they were not considered as useful for extending the stage-discharge curves beyond the upper limit of observed data for this study reach as they were at the mouth of Portage Creek. The best fit

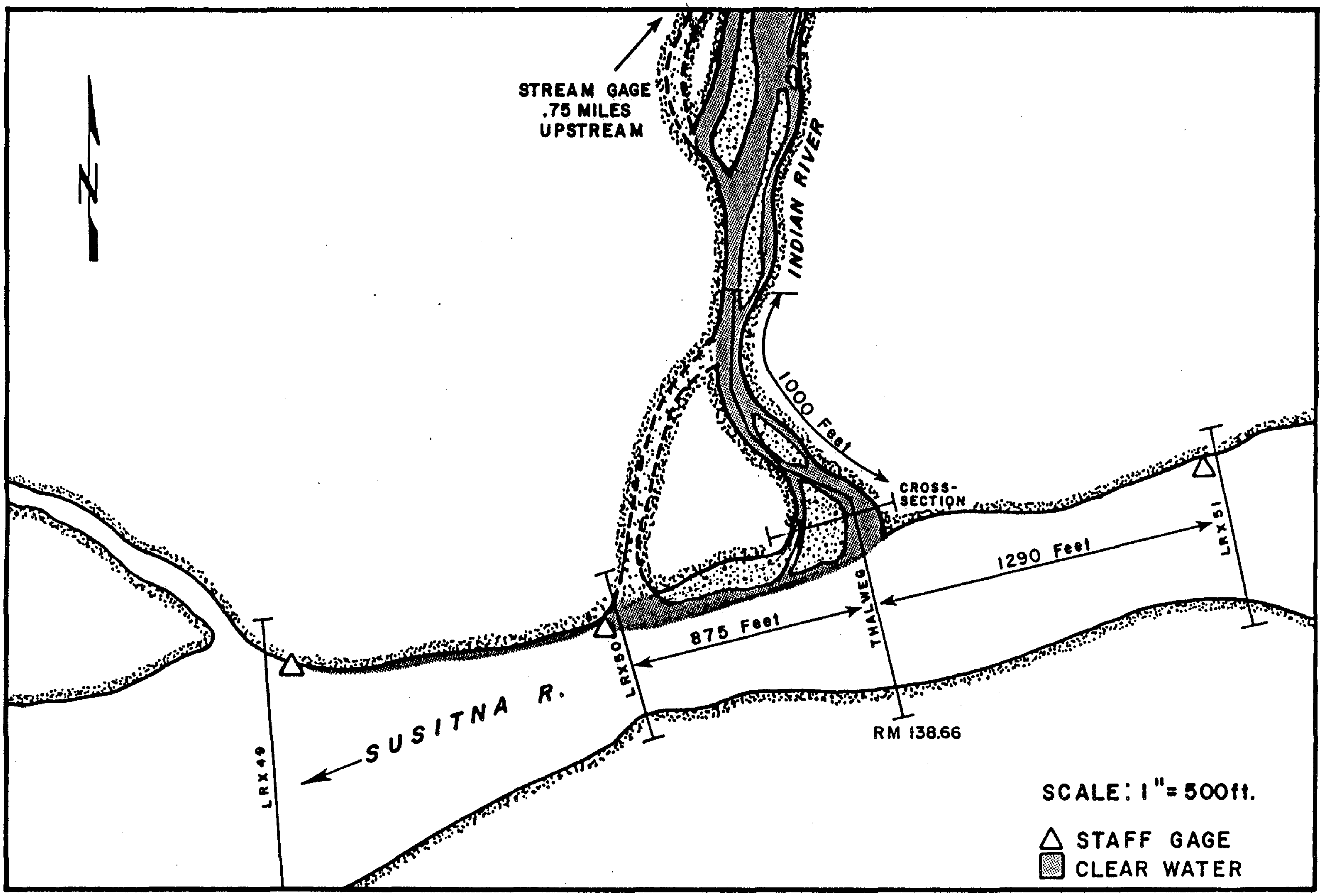
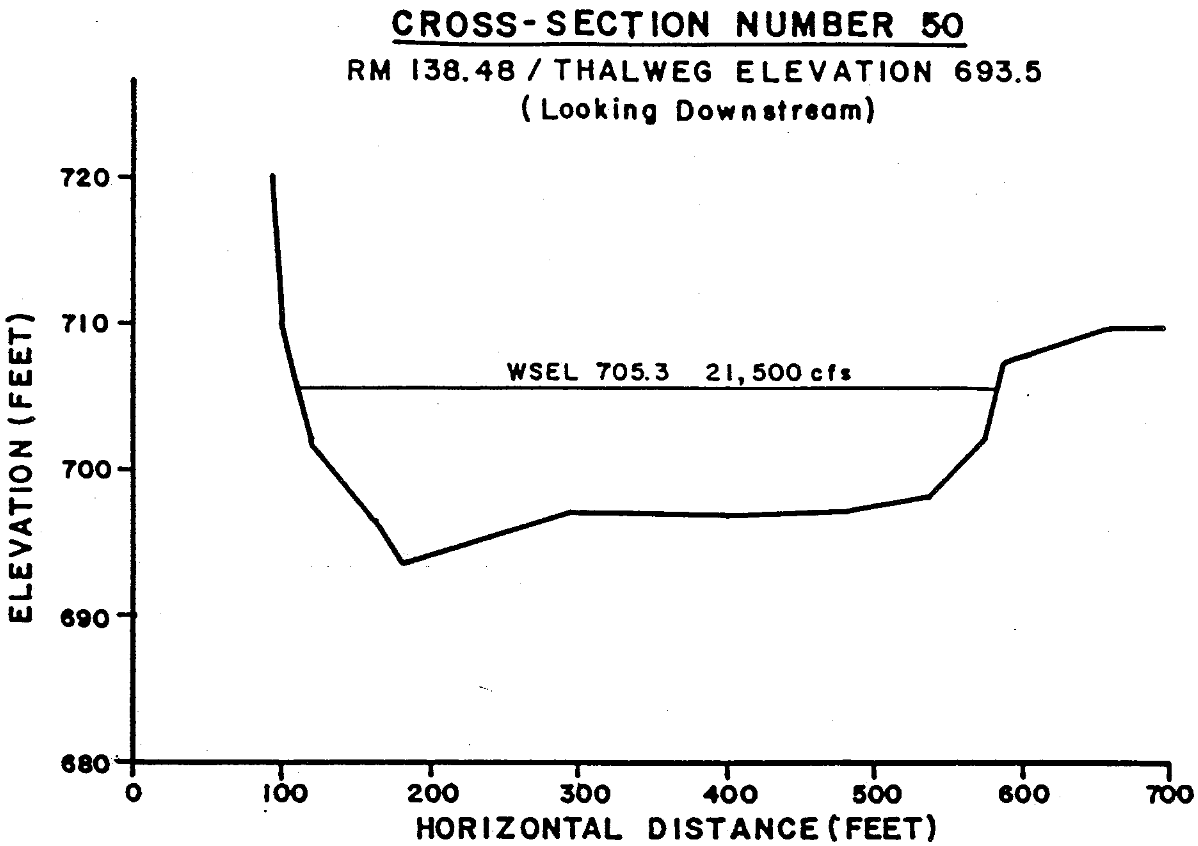


Figure 11. Planemetric sketch of the Mouth of Indian River
(Adopted from 1:6000 scale blueline prints, R&M Consultants, Inc., 1980)



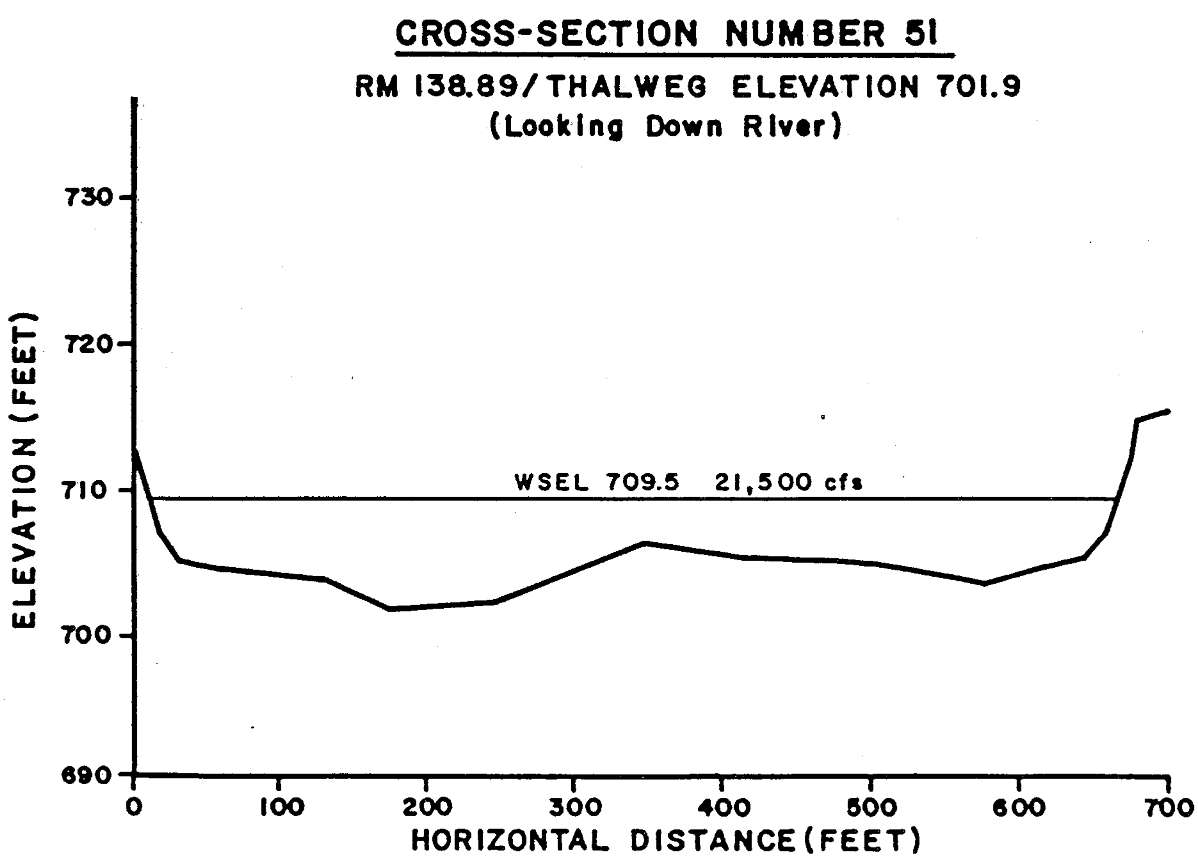
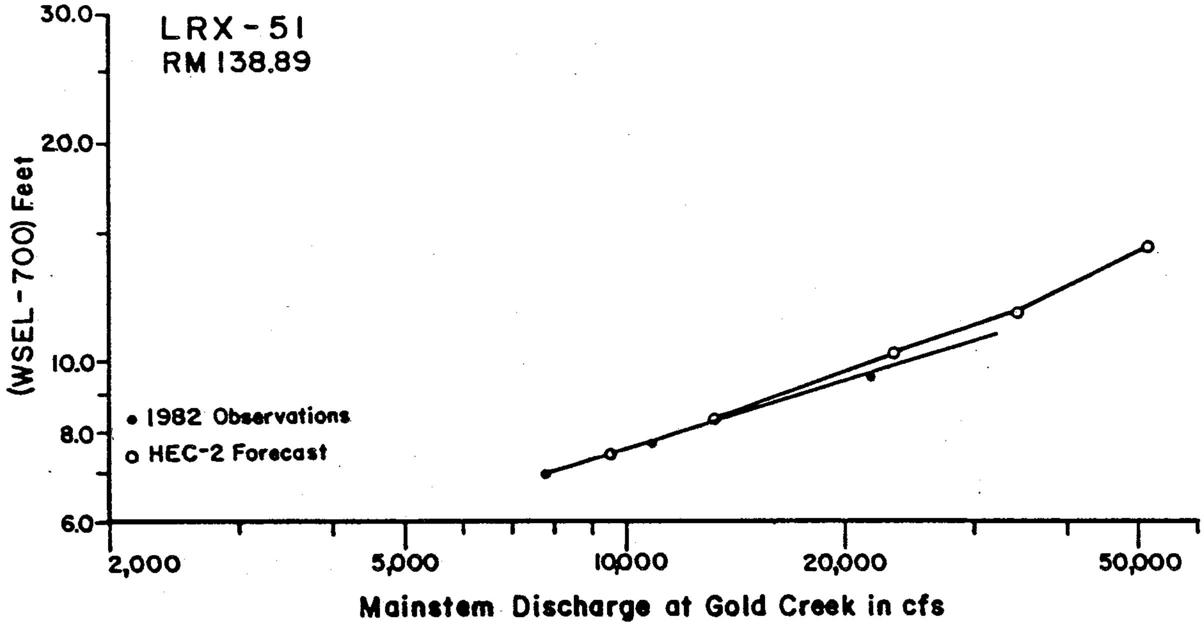


Figure 12. Mainstem River Cross Sections near the mouth of Indian River. (Adapted from R&M Consultants, Inc. and Acres American Inc. 1982)



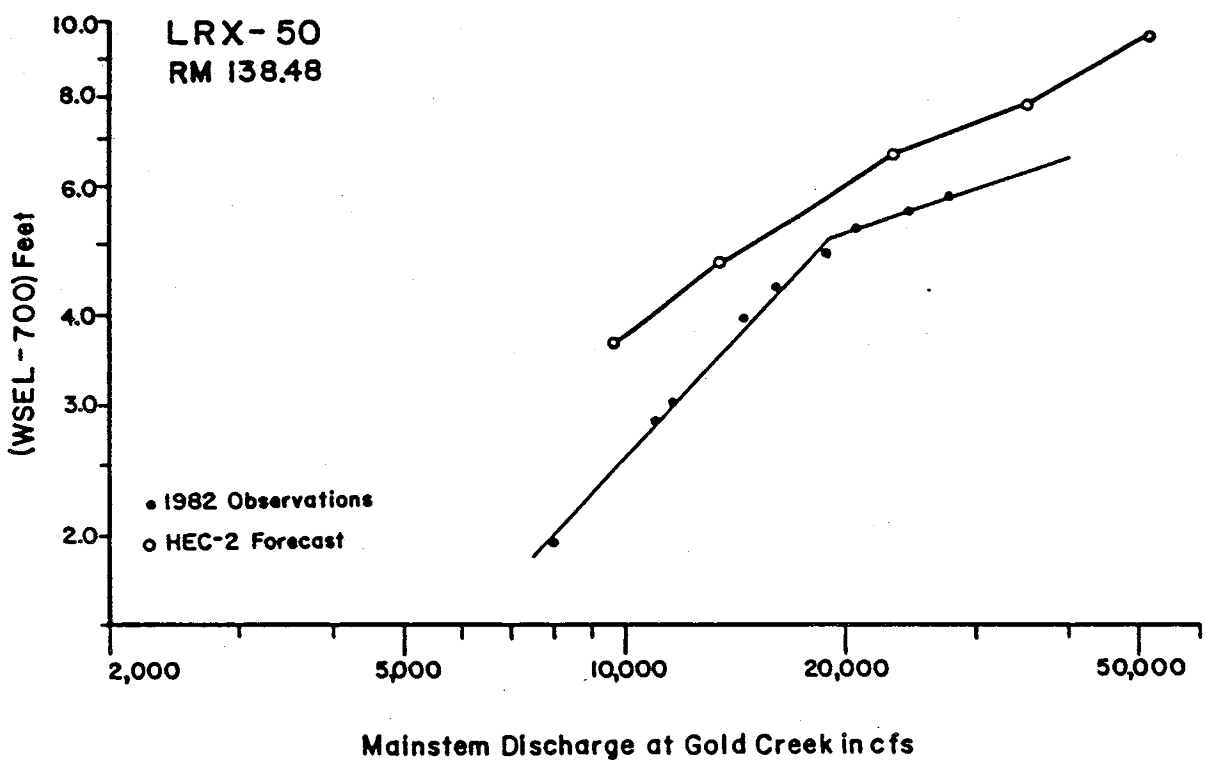


Figure 13. Comparison between observed and forecast mainstem water surface elevations near the mouth of Indian River. (Adapted from R&M Consultants, Inc. and Acres American Inc. 1982, ADF&G 1983a.)

line through observed data points at LRX-50 and LRX-51 was simply extended as a means for estimating mainstem water surface elevations associated with flows in excess of 25,000 cfs.

Mainstem water surface elevations were determined above and below the mouth of Indian River from the stage-discharge curves for various mainstem streamflows and between 8,000 and 34,500 cfs (Table 3). The

Table 3. Water Surface Elevations of the Susitna River at the mouth of Indian River for selected mainstem streamflows at Gold Creek.

Mainstem Discharge Gold Creek (cfs)	Mainstem WSEL LRX-50 (ft)	Mainstem WSEL Indian River (ft)	Mainstem WSEL LRX-51 (ft)
8,000	702.0	704.2	707.0
12,000	703.1	705.1	708.0
13,400	703.5	705.6	708.2
16,000	704.2	706.0	708.7
20,000	705.2	706.8	709.3
21,500	705.3	707.0	709.5
24,000	705.5	707.3	709.9
28,000	705.8	707.6	710.3
32,000	706.1	708.0	710.9
34,500	706.3	708.4	711.1

slope of the mainstem water surface profile between the staff gages at LRX-50 and LRX-51 was assumed constant when calculating mainstem water surface elevations opposite the mouth of Indian River. Mainstem water surface elevations at the mouth of Indian River were determined to increase from 704.2 to 708.4 feet as the discharge at Gold Creek increased from 8,000 to 34,500 cfs. Water surface profiles for the Susitna River across the mouth of Indian River were plotted for discharges of 8,000, 13,400, 21,500, and 34,500 cfs (Figure 14).

The water surface elevations of the mainstem opposite the mouth of Indian River were also compared with surveyed streambed and water surface profiles for Indian River (Figure 15). The streambed elevation of the mouth of Indian River is approximately 705 feet. Mainstem discharges at Gold Creek in excess of 12,000 cfs can be shown to provide mainstem water surface elevations off the mouth of Indian River that equal or exceed 705 feet (Table 3).

Indian River Hydraulics. Field observations indicate that the lower reach of Indian River is highly braided. It is also known that secondary and main channels have often changed following high runoff periods (Pers. Comm. B. Barrett, ADF&G; S. Bredthauer, R&M). However, no data are available which define the relative amount of streamflow conveyed by these various channels. Therefore, the relationship between total instantaneous discharge of Indian River and the instantaneous discharge and top width of its main channel at the mouth (Table 4) was estimated on the basis of the cross section survey data and field observations by the author. It appeared to the author that approximately 90% of the total Indian River flow enters the Susitna River through its main channel when Indian River streamflows range from 100 to 500 cfs. During high flow periods (2,000 to 2,500 cfs) it was assumed that only two-thirds of the total flow of Indian River entered

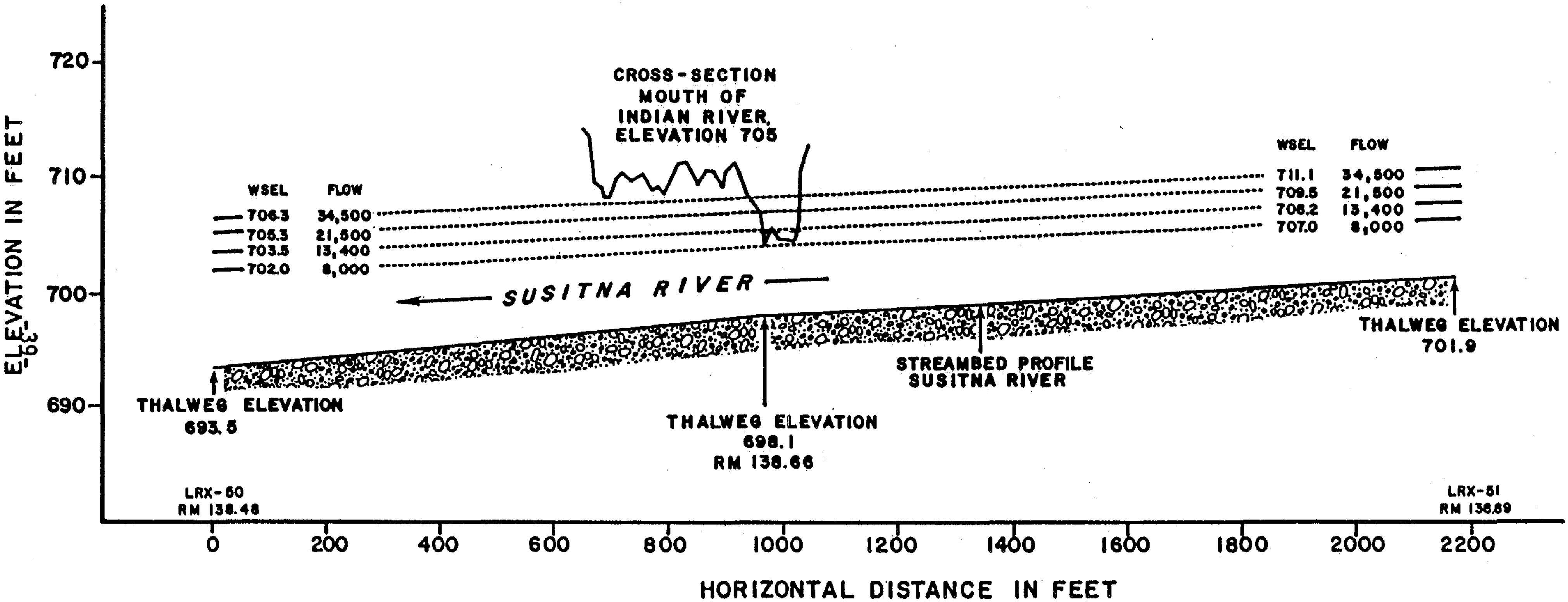


Figure 14. Streambed and water surface profiles of the Susitna River at the Mouth of Indian River.

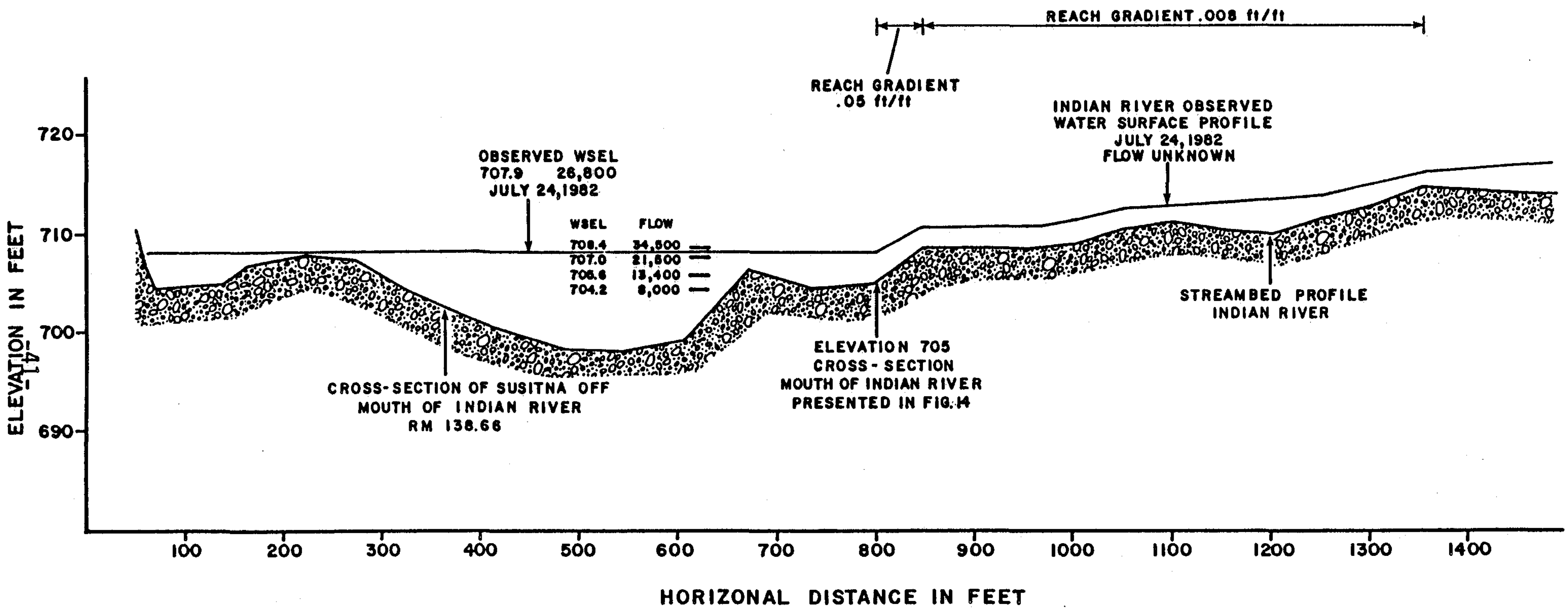


Figure 15. Existing streambed profile of Indian River and the adjoining cross section for the Susitna River at RM 138.66.

the Susitna through the main channel. Based on these opinions and the estimated top widths, a relationship between total discharge and unit discharge was derived for Indian River (Figure 16).

Table 4. Estimated primary channel streamflows and top widths at the mouth of Indian River in response to total Indian River discharge.

Total Discharge (cfs)	Primary Channel (%)	Primary Channel Flow (cfs)	Primary Channel Width (ft)
100	90	90	60
250	90	225	65
500	90	450	70
1000	80	800	90
2000	67	1340	100
2500	67	1675	100

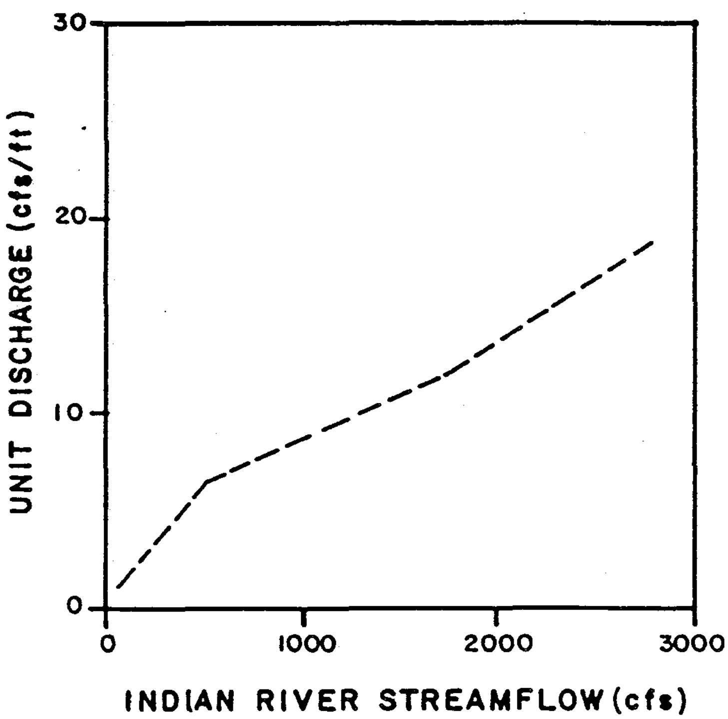


Figure 16. Relationship between unit discharge and total discharge for the primary channel of Indian River at its mouth.

The streambed and water surface profiles for Indian River presented as Figure 15 indicate a significant change in gradient occurs at station 850. The much steeper gradient downstream of station 850 will result in higher stream velocities than exist upstream, particularly when the mainstem discharge at Gold Creek is such that there is no backwater effect present in the mouth of the tributary.

Depths and velocities calculated to occur in Indian River near its mouth are presented in Figure 17 as functions of unit discharge. The dashed line depicts depths and velocities expected to occur at station 850. The solid line represents theoretical flow conditions downstream of station 850 without the influence of mainstem backwater, while the dotted line represents depths and velocities for fully-developed uniform flow upstream of station 850.

It is expected that streambed irregularities will prevent the exact depths and velocities represented by the dashed and dotted curves from being attained in the study reach above station 850. However, these curves should provide a reasonable estimate of depths and velocities in riffle and run areas. The instability of the stream channel will likely prevent the much higher theoretical velocities represented by the solid line from ever being attained. Velocities in the range of those represented by the solid line would cause the rapid degradation of the streambed near station 850, thereby reducing channel slope and velocity near the mouth (station 780). Inasmuch as the dashed line describes the more plausible worst case entrance conditions that presently exist at

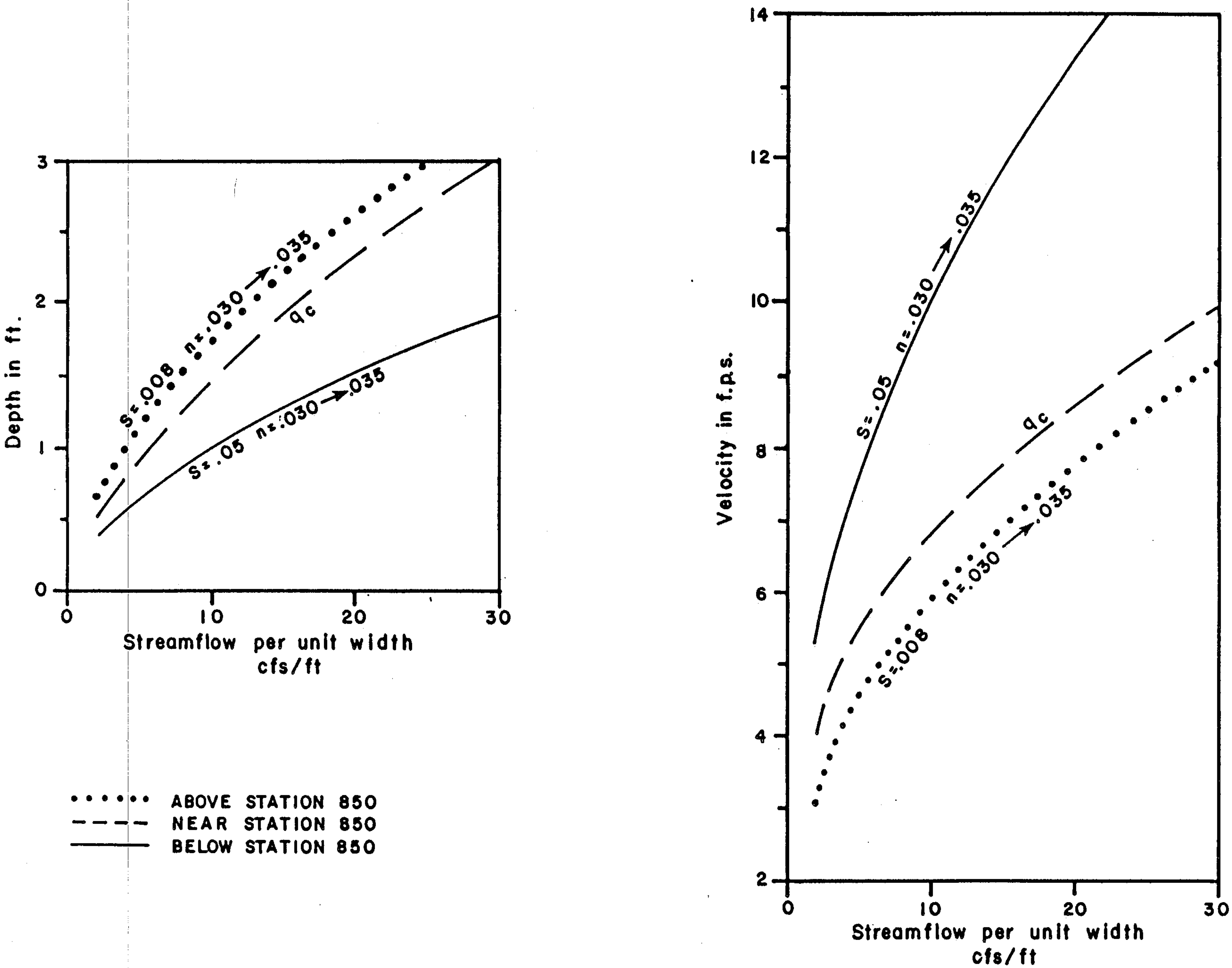


Figure 17. Depths and velocities above the mouth of Indian River calculated as functions of unit discharge in the absence of mainstem backwater effects.

the mouth of Indian River, these depths and velocities should be used as the principal indicators of access by adult salmon for existing channel conditions.

Streamflow data for Indian River suggest that typical streamflows during the June through August period might be in the range of 200 to 500 cfs (ADF&G 1983a). Review of the 1982 Indian River streamflow record in association with 1982 and long-term precipitation records from Talkeetna suggest that 100 cfs might be an abnormally low summer stream flow for Indian River. Consequently, this figure was selected to calculate the entrance depth associated with a probable "worst case" low flow in Indian River.

Based on the estimated relationship between streamflow and unit discharge at the mouth of Indian River (refer Figure 16), 100 cfs represents a discharge per unit width of 1.5 cfs/ft. Given the existing channel geometry for Indian River and no backwater effects from the Susitna River (Gold Creek flow less than 13,000 cfs), a streamflow of 100 cfs would provide depths of approximately 0.5 feet and velocities of approximately 3.5 fps at the mouth of Indian River. Mainstem backwater effects would tend to increase the depth of flow and reduce the velocity (Figure 17).

Mean annual floods for Indian River have been estimated to range between 700 and 850 cfs (R&M Consultants, Inc. 1982b). The peak daily discharge recorded during 1982 was 1,815 cfs (ADF&G 1983a). This author estimates peak daily streamflows may be in the range of 2,000 to 2,500 cfs (approximately 15 cfs/ft). Streamflows of this magnitude are forecast to result in depths near 2 feet and mid-channel velocities in excess of 7 fps at the mouth of Indian River, were no mainstem backwater effects present (Figures 16 and 17).

Based upon review of a previous analysis of flow variability for the Susitna River (R&M Consultants, Inc. 1981) and the 1982 streamflow record for Indian River, it is not expected that streamflows of this magnitude would persist for more than three consecutive days. After Indian River flows receded to the 200 to 500 cfs range, the depth of flow at its mouth should range between 0.7 and 1.2 feet and mid-channel velocities would range from 4 to 6 fps.

Channel Stability. It is not expected, however, that the streambed above the mouth of Indian River will remain stable (R&M Consultants, Inc. 1982b). Threshold values of incipient motion were estimated for various streambed particle sizes as a function of unit discharge (Figure 18) using Shields criteria (Appendix A) and the depth and velocity curves presented as Figure 17. Application of these threshold values to the lower reach of Indian River indicates that the mouth of Indian River is unstable. Upstream of station 850 the maximum streambed particle size typically transported would likely be in the range of 4 inches. However, downstream from station 850 6- to 8-inch particles could be transported with little difficulty. Field observations indicate that streambed particles in the lower portion of Indian River are generally 2 to 4 inches interbedded with 5- to 6-inch material. The larger particle sizes are more commonly found in the primary channel.

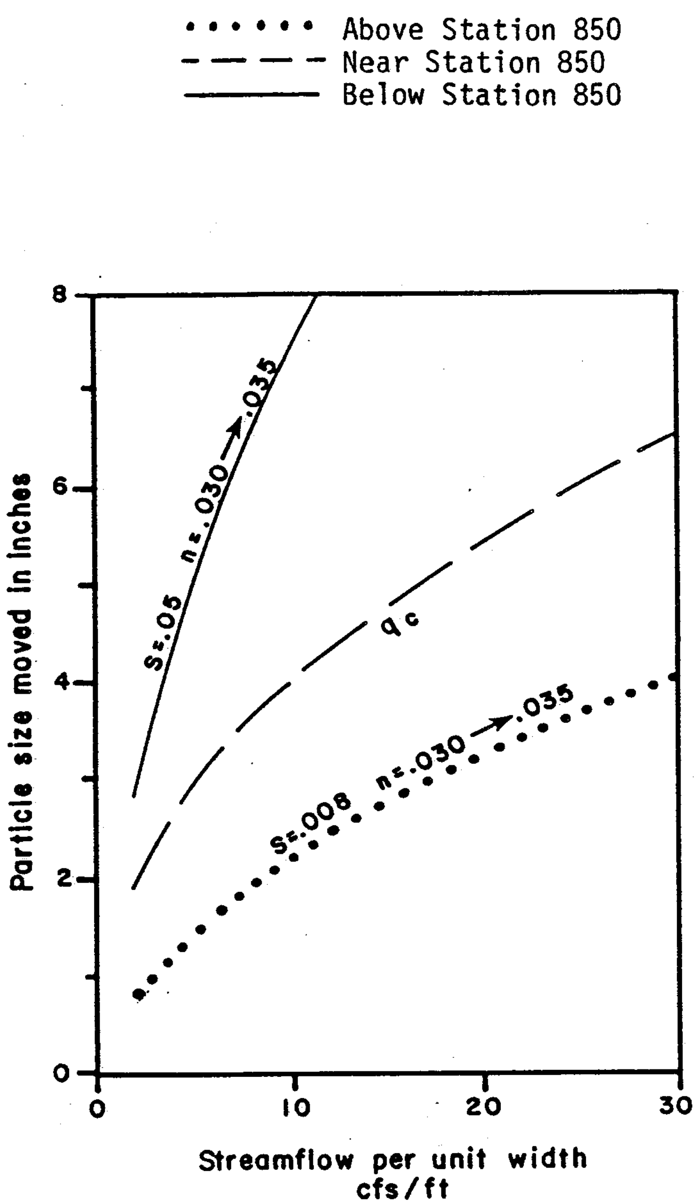


Figure 18. Streambed particle sizes moved above the mouth of Indian River in the absence of mainstem backwater effects as a function of unit discharge.

A large alluvial deposit exists at the mouth of Indian River. This author estimates that naturally occurring tributary flow in association with the proposed regulation of mainstem discharge would result in Indian River downcutting portions of its streambed above the mouth 1 to 2 feet and extending its channel into the Susitna River. Although this process is not expected to significantly reduce the streambed elevation at the mouth of Indian River, it would result in a steeper gradient channel than presently exists upstream of station 850.

In the absence of mainstem backwater effects, the gradient at the mouth of Indian River could increase from 0.01 ft/ft to 0.05 ft/ft. Such an increase would likely be only temporary. Tributary flows in excess of 1,200 cfs (10 cfs/ft) are expected to provide main channel velocities of sufficient magnitude to downcut the streambed near station 850 and extend the mouth of Indian River into the channel of the Susitna. The streambed elevation at station 850 is estimated to degrade from 708.5 to 706.0, with the elevation at the mouth (station 800) remaining near 705 (Figure 19).

Based upon this occurring, the streambed gradient in the lower 300-foot reach of Indian River is estimated to increase from 0.01 ft/ft to 0.02 ft/ft. This increased gradient would have a negligible effect on depths at the mouth of Indian River and would cause approximately a 0.5-fps increase in mid-channel velocities during typical summer streamflows (200-500 cfs). During peak flow periods, depths are forecast to be approximately 0.5 feet shallower and mid-channel velocities approximately 1 fps greater were the streambed not to have degraded (Figure 20).

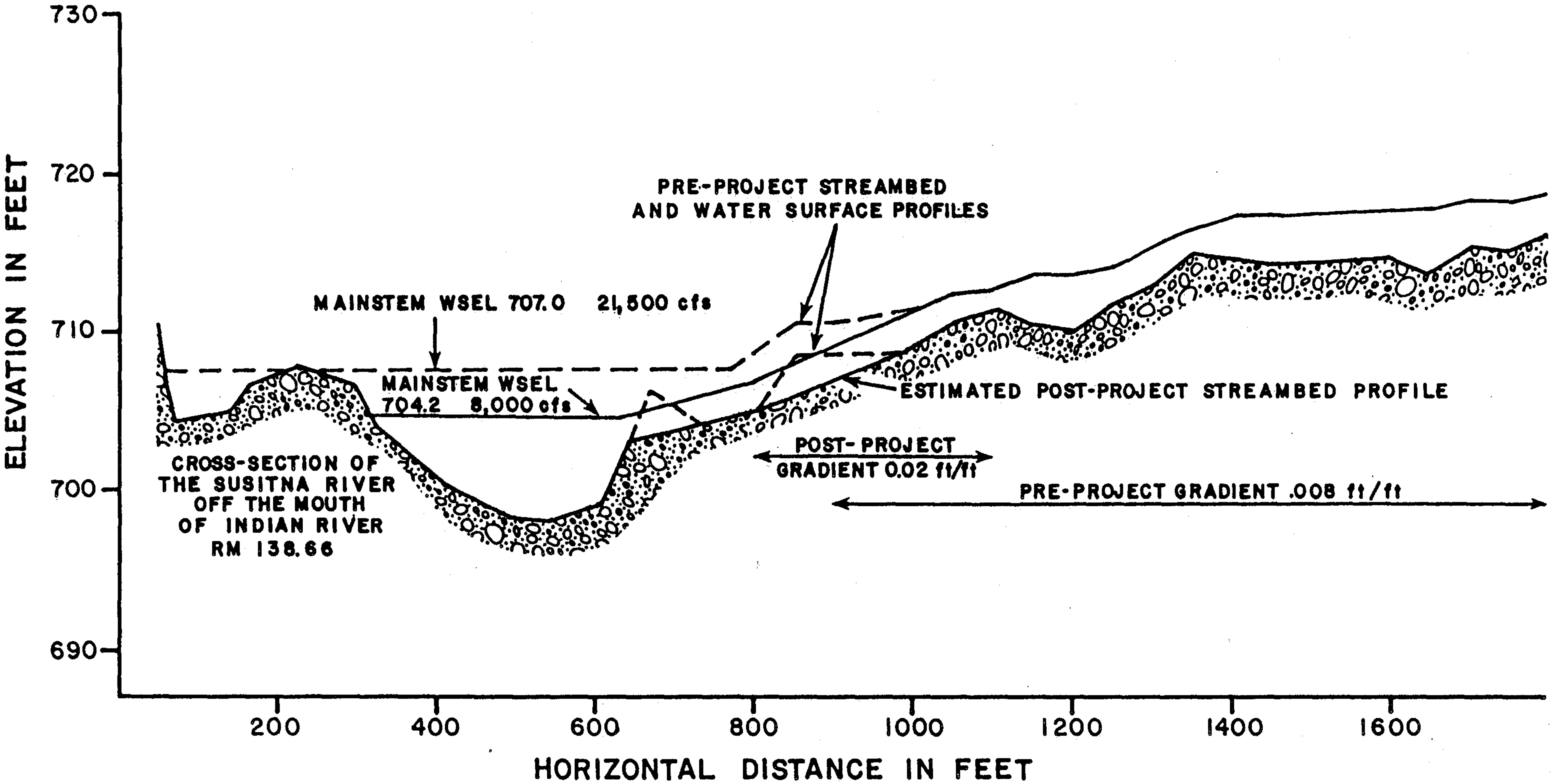


Figure 19. Estimated postproject streambed and water surface profiles for Indian River adjoining the Sustina River at RM 138.66.

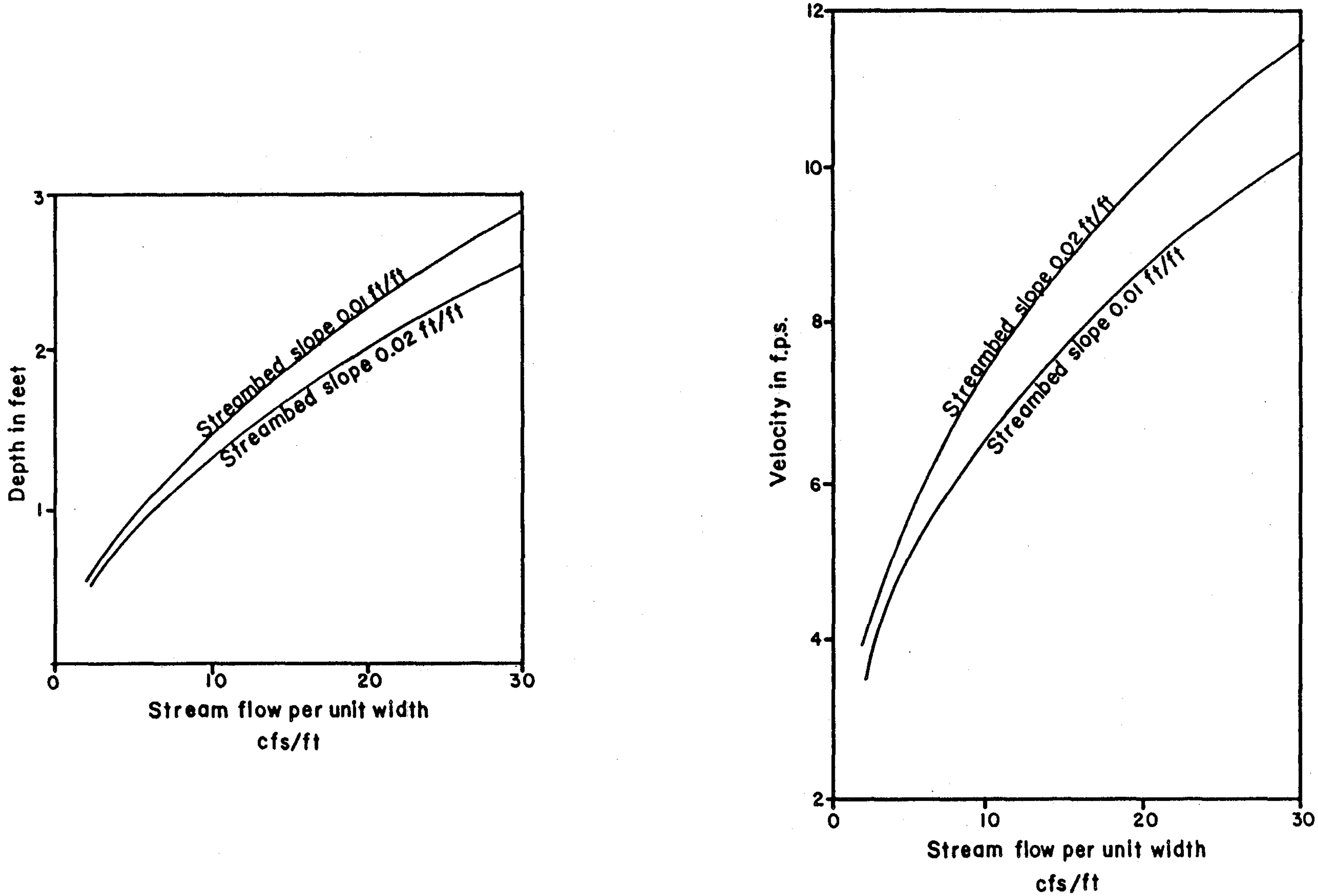


Figure 20. Influence of streambed slope (degradation) on mid channel depths and velocities at the mouth of Indian Creek in the absence of Susitna River backwater effects.

DISCUSSION

Preproject Access

Adult pink and chum salmon did not appear to experience any difficulty entering Indian River or Portage Creek during the low-flow period witnessed during mid-August, 1982 (Table 5). The inmigration period for pink and chum salmon entering Indian River occurred during the first and second weeks of August. The inmigration period for these species entering Portage Creek was during the second and third weeks of August. During the first two weeks of August 1982, mainstem flows at Gold Creek ranged between 14,000 and 18,000 cfs. Indian River streamflows ranged from 170 to more than 260 cfs. During the second and third weeks of August 1982, Portage Creek streamflows declined from 600 to 400 cfs while the mainstem discharge at Gold Creek decreased from 17,000 to 12,000 cfs.

Mainstem discharges at Gold Creek during the second and third weeks of August, 1982 represent some of the lowest average daily streamflows of record for that month. Normally mainstem discharges at Gold Creek range between 19,000 and 21,000 cfs during August (R&M Consultants, Inc. 1982a). Streamflows of this magnitude provide mainstem water surface elevations off the mouth of Indian River and Portage Creek from 1.0 to 1.5 feet higher than those which occurred during August, 1982 (refer to Tables 1 and 3). These higher mainstem water surface elevations reduce velocities and increase depths at the mouths of these tributaries, thereby improving access conditions. Thus, it could be concluded that

TABLE 5. Comparison of 1982 pink and chum salmon inmigrations into Indian River and Portage Creek with average daily tributary and mainstem streamflows. (Adopted from USGS 1982, ADF&G 1983a, ADF&G 1983b)

Date 1982	Susitna River Discharge Gold Creek	Indian River Discharge cfs	ADULT SALMON ENUMERATED Pink Live	Pink Dead	Pink Total	Chum Live	Chum Dead	Chum Total	Portage Creek Discharge cfs	ADULT SALMON ENUMERATED Pink Live	Pink Dead	Pink Total	Chum Live	Chum Dead	Chum Total
August 3	19,800	No Record	24	-0-	24				No Record	-0-	-0-	-0-	-0-	-0-	-0-[c]
4	18,500	"							"						
5	17,400	"	202	1	203	15	-0-	16[a]	"						
6	14,800	"							"						
7	16,500	"							"						
8	16,600	"							"						
9	17,000	260							600	146	-0-	146	25	-0-	25[d]
10	16,700	240							620						
11	15,400	230	735	3	738	134	-0-	134[b]	590						
12	14,400	200							580						
13	13,600	180							490						
14	13,600	170							480						
15	14,800	170							490						
16	15,600	160	537	22	559	362	5	367[b]	450	166	3	169	71	-0-	71[e]
17	15,100	170							460						
18	14,200	180							450						
19	13,300	160							420						
20	12,500	150							390						
21	12,200	140							380						
22	12,200	130							360	111	-0-	111	143	10	153[e]
23	12,300	130	238	329	567	184	15	199[b]	370						
24	12,500	130							370						
25	13,400	130							370						
26	13,600	130							390						
27	12,900	120							360						
28	12,400	120							340						
29	12,200	140	8	339	347	120	48	168[b]	380	15	126	141	21	7	28[e]
30	13,100	280							609						
31	16,000	450							766						

[a] index area from mouth to 4 miles upstream.
[b] index area from mouth to 1 mile upstream.
[c] index area from mouth to 15 miles upstream.
d index area from mouth to .5 miles upstream.
e index area from mouth to 0.25 miles upstream.

preproject access into Indian River and Portage Creek by adult salmon is normally as good or better than it was during August, 1982.

Postproject Access

Although mainstem water surface elevations near the mouths of Portage Creek and Indian River are forecast to be from 3 to 4 feet lower than preproject elevations during the inmigration period for tributary spawners, access into Portage Creek and Indian River by adult salmon is not expected to be adversely affected. The analysis presented in this paper indicates that naturally occurring tributary flows are sufficient to provide adequate depths at the mouths of Portage Creek and Indian River for adult salmon to enter these tributaries without assistance from mainstem backwater effects (Table 6). It was also determined that streambed degradation would have little effect on the depth of flow at the mouths of these tributaries.

Table 6. Estimated depths of flow* at the mouth of Portage Creek and Indian River without mainstem backwater effects.

Portage Creek			Indian River		
Flow (cfs)	Depth (Not Degraded)	Depth (Degraded)	Flow (cfs)	Depth (Not Degraded)	Depth (Degraded)
300	0.9	0.8	100	.5	.4
500	1.1	0.9	300	.8	.7
800	1.4	1.2	500	1.1	1.0

*Refer to figures 6 and 10; 16 and 20

Insufficient data are available to compare preproject (mainstem backwater effects present) and postproject (mainstem backwater effects absent or reduced) velocities at the mouths of Portage Creek and Indian River. However, it is possible to estimate mid-channel velocities at the mouths of these tributaries in the absence of mainstem backwater effects, then compare these velocities with passage criteria for adult salmon. Used in this manner, the existing data base is adequate to determine whether or not mainstem backwater effects are necessary during periods of high tributary flow in order for adult salmon to enter Portage Creek or Indian River.

Three terms are generally used to describe swimming speeds of fish:

Cruising - a swimming speed that can be maintained for hours, usually ranging from 2 to 4 body lengths per second;

Sustained - a swimming speed that can be maintained for several minutes, ranging from 4 to 7 body lengths per second; and

Darting - a single burst of effort maintained only for a few seconds, which may range from 8 to 12 body lengths per second (Watts 1974).

Fish normally employ cruising speeds during migration, sustained speed for passage through difficult areas, and darting speed for feeding or escape. Swimming ability varies among species of salmon. Cruising speeds for adult salmon typically range between 1 and 3 fps, sustained speed 4 to 10 fps, and darting speeds may range as high as 20 fps (Bell 1973). Velocities of 10 to 13 fps approach the upper swimming ability of salmon and may retard upstream migration (Reiser and Bjornn 1979). Thompson (1972) has recommended depth and velocity criteria for successful upstream migration of adult salmon (Table 7).

Table 7. Depth and velocity criteria for successful upstream migration of adult salmon (from Thompson 1972).

Fish Species	Minimum Depth (ft)	Maximum Velocity (fps)
Chinook salmon	0.8	8
Coho salmon	0.6	8
Chum salmon	0.6	8
Pink salmon	0.6	7
Sockeye salmon	0.6	7

Swimming speeds and migration success may be affected by available oxygen and water temperature (Bell 1973 and Reiser and Bjornn 1979). However, it is not expected that the proposed project will affect naturally occurring dissolved oxygen levels or water temperatures within Portage Creek or Indian River. Nor is it thought that naturally occurring dissolved oxygen levels or water temperatures in these tributaries presently inhibit the swimming performance of adult salmon attempting to enter them.

High flows in Portage Creek and Indian River can produce velocities capable of reworking streambed materials near their mouths. The forecast reduction in mainstem water surface elevations of 3 to 4 feet during summer months would stimulate changes in the existing stream channel geometry near the tributary mouths. Streambed gradients probably would steepen, resulting in somewhat higher velocities than otherwise would have occurred at the tributary mouths (Table 8).

Table 8. Estimated mid-channel velocities* at the mouth of Portage Creek and Indian River without mainstem backwater effects.

Portage Creek			Indian River		
Flow (cfs)	Velocity (Not Degraded)	Velocity (Degraded)	Flow (cfs)	Velocity (Not Degraded)	Velocity (Degraded)
1000	7.3	8.2	750	5.8	6.6
1500	8.3	9.4	1000	6.4	7.2
2500	10.1	11.5	2000	6.5	8.4

*Refer to figures 6 and 10; 16 and 20.

Although peak flows may delay entry into Portage Creek, comparison of these velocities to swimming speeds for adult salmon does not suggest that high velocities would prohibit adult salmon from entering Portage Creek or Indian River. Mid-channel velocities associated with flows in excess of 1,000 cfs in Portage Creek and Indian River are comparable to sustained swimming speeds of adult salmon. Thus an adult salmon would be capable of holding a stationary position in the water column at mid-channel. Forward progress would be expected if the fish were to migrate along the stream margins. During the more common flow periods (500-800 cfs at Portage Creek and 200-500 cfs at Indian River), mid-channel velocities at the tributary mouths would be only slightly higher than the cruising speed of adult salmon.

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APPENDIX

Introduction

Streamflow can be classified in various ways and evaluated with a variety of hydraulic formulas. Several hydraulic terms and equations are mentioned in the preceding portions of this report that may warrant further definition and explanation. With the exception of the explanation of unit discharge and Shield's criteria, the following information has been extracted from lecture notes used by the author while serving as Training Officer with the U.S. Fish and Wildlife Service's Cooperative Instream Flow Service Group in 1978-79. The explanation of unit discharge and Shield's criteria is based upon the author's general knowledge of these concepts. A partial listing of relevant literature has been included for those interested in knowing more about the definitions and formulas introduced in this appendix.

Steady and Unsteady Flow

Streamflow is said to be steady if the depth of flow at a given location in the channel remains constant during the time interval under consideration. The flow is unsteady if the depth changes with time.

It should be apparent that the time interval chosen as the classification criterion will dictate how an actual flow event is classified. For example, if a one-year period is chosen as the time interval, then the passage of the annual stream hydrograph past some point along the stream bank is classified as being unsteady; i.e. depth of flow and velocity at that point do change within the chosen time interval. On the other hand, if an infinitessimally small increment of time were chosen as the criterion, then flow conditions associated with a flood wave or hydropower peaking surge could be classified as steady state; i.e. the time interval being considered is so brief that depth and velocity conditions would be treated as constants at the transect. Although both these situations are technically correct, neither is very compatible with field situations.

The time interval that is to be used as the criterion for classifying flow must be both representative of field conditions and pertinent to the analysis. One approach would be to define the time interval as the length of the study reach in feet divided by the mean reach velocity in feet per second.

$$\text{Time interval (seconds)} = \frac{\text{reach length (feet)}}{\text{mean reach velocity (ft/sec)}}$$

However, from an applications view the time interval chosen as the criterion must be equal to or greater than the time required for a field crew to gather the necessary flow data. The essential question to answer in the affirmative is, "Can I assume that the depth and velocity at each transect in the study reach will remain constant during the time interval required to measure and record flow data throughout the study reach?" This is of considerable importance when gathering data for calibrating hydraulic simulation models. Indifference on the part of field personnel toward ensuring that flow data is obtained in a manner consistent with steady flow assumptions can result in a very erroneous assessment.

In most natural channel problems the assumption of steady flow conditions is valid. Furthermore, most steady flow conditions are also associated with constant stream flow rates. If the flow rate is constant through a stream reach the flow is said to be "continuous". Where a steady flow condition exists, but the discharge is not constant through the stream reach (where water runs into or is diverted from a stream within the reach), the flow is called spatially varied or "discontinuous". Both continuous and discontinuous flow are commonly encountered steady flow conditions in natural channels.

Continuity Equation

For all steady flow situations, either continuous or discontinuous, the flow rate through a cross section can be expressed as the product of the average velocity and cross-sectional flow area.

$$Q = V \times A \qquad (1)$$

Where

Q = flow rate (feet^3/sec)

V = average flow velocity at the cross section (ft/sec)

A = cross-sectional flow area perpendicular to the direction of flow (ft^2).

If the streamflow is continuous, the flow rate throughout the stream reach is the same as that computed for any transect within the reach. If the streamflow is discontinuous, the flow rate in the mainstem reach is the sum of the fractional flow rates.

Uniform and non-uniform flow

Uniform flow is the fundamental type of flow treated by open channel theory. Open channel flow is said to be uniform if the average velocity and depth of flow are constant throughout the section of channel being studied. In order for the depth and average velocity to remain constant, energy must be dissipated at a constant rate. Therefore, uniform flow requires that all hydraulic parameters are constant throughout the study reach. This requires that a symmetrical channel of uniform substrate exists. Flow in natural channels is seldom uniform. Uniform flow conditions are approximated in rather long straight natural channels with constant cross sectional geometry, or in man-made canals and ditches.

Flow is non-uniform if depths and velocities are not constant throughout the study reach. Depending upon how abrupt the changes in velocity and depth are, non-uniform flow may be classified as either "rapidly" or "gradually varied". Flow is rapidly varied if velocity and depth change markedly within a short distance.

Rapidly varied flow can be viewed as a localized phenomena, such as flow around large boulders, cascading rapids, or at the head end of a plunge pool. Rapidly varied flow does not lend itself well to either field measurement or theoretical analysis; it can best be evaluated by developing site specific empirical relationships.

On the other hand, gradually varied flow lends itself quite well to analytical treatment by application of uniform flow theory. The more gradual the change in velocity or depth through the study reach, the more closely uniform flow conditions are approximated and the more applicable become fundamental hydraulic formulae. Fortunately, gradually varied flow conditions are extremely prevalent in natural channels and are quite often associated with riverine fishery habitat.

Subcritical, Critical, and Supercritical Flow

The state, or behavior, of open channel flow is governed by the effects of viscosity and gravity relative to the inertial force of the flow. Viscosity and the surface tension of water may effect the behavior of flow under certain circumstances, but neither plays a significant role in most open channel flow problems.

The effect of gravity on the state of flow is represented by the ratio of inertial force to gravitational force. This ratio is called the Froude Number (Fr) and is defined as:

$$Fr = \frac{V}{(gy)^{.5}} \qquad (2)$$

Where

Fr = a dimensionless ratio

V = average flow velocity (feet/sec)

g = gravitational acceleration (32.2 ft/sec^2)

y = depth of flow (feet)

In examining the above formula for the Froude number, three possibilities exist. The Froude number may be less than one, equal to one, or greater than one.

When the Froude number is equal to one, the flow is said to be in a critical state. Critical flow is generally an unstable (transitory) situation in natural channels. An important property of critical flow is that it connotes the point of minimum specific energy for a given discharge, but also it describes the maximum discharge for a given set of channel conditions.

If the Froude number is less than unity, the flow is called "subcritical". This is the most common type of flow occurring in natural channels. In this state, the role played by gravity forces is more pronounced so that the flow is characterized by a lower velocity and greater depth than exists in the critical flow state. Potential energy, in the form of flow depth, is dominant. Subcritical flow is often described as tranquil or streaming flow.

If the Froude number is greater than unity, flow is said to be supercritical. In this state, inertial forces are dominant. Supercritical flow is characterized by high velocity and shallow depth. It is characteristically accompanied by standing waves immediately downstream from where it occurs. Supercritical flow in natural channels is generally a temporary situation accompanying peak flow events. It is usually described as rapid or shooting flow.

Manning's Equation

Although uniform flow is not common, many natural flow situations occur which approximate the uniform flow condition. Experimental work by Robert Manning (1889) has provided the English speaking world with its most commonly used uniform flow equation. On the European continent Manning's equation is sometimes known as Strickler's equation. Other uniform flow equations, notably Ganguillet and Kutter (1869), Bazin (1897), and Powell (1950), have been proposed and used, however they have not received as wide acceptance as the Manning equation.

Manning's experimental work was done in metric units. In order to use the same value of "n" with English units, the factor 1.49 (the cube root of the number of feet in a meter) was introduced by Buckley in 1911. The Manning equation relates average flow velocity (V) to the channel slope (S), the channel roughness (n), and the hydraulic radius (R) in the following manner:

$$V = \frac{1.49}{n} R^{.67} S^{.5} \qquad (3)$$

Determination of an accurate Manning's n value is difficult for a natural channel without reach specific information and practical experience. The value of n depends on streambed composition, vegetation, channel alignment, channel size and shape, depth of flow, suspended sediment and bed load, and seasonal changes. Recommended Manning's n values, and a method for estimating Manning's n values for both man-made and natural channels has been provided by Chow (1959).

The hydraulic radius (R) is defined as the ratio of the cross sectional flow area to the wetted perimeter. For channels in which the top width is more than 30 times the average depth of flow, depth may be substituted for the hydraulic radius without any appreciable effect on the accuracy of the calculations.

The slope (S) represents the rate energy is dissipated (energy grade line) in order to overcome the resistance to flow caused by the streambed and streambank irregularities. As previously mentioned uniform flow requires that depth and average velocity are constant through the study reach. In order for this to occur energy must be expended at a constant rate through the study reach. Hence the energy grade line, water surface profile, and streambed profile must be parallel. Thus the channel slope is commonly used in place of the slope of the energy gradient when applying the Manning equation.

In the analysis of access conditions at Portage Creek and Indian River, Manning's equation (Equation 3) was combined with the continuity equation (Equation 1) and applied using the concept of unit discharge. The combined equation which expresses total discharge past a cross section in terms of the Manning parameters is shown below:

$$Q = \frac{1.49}{n} R^{.67} S^{.5} A \qquad (4)$$

Unit discharge (q) is the flow rate per foot of channel width. It may be calculated by dividing total discharge at a cross section by the effective top width of the stream at that location.

The cross sectional dimensions of the stream tube that conveys the unit discharge is, by definition, one foot wide and "y" feet deep. The wetted perimeter of the stream tube is one foot, and its cross sectional area is "y" square feet. Thus the hydraulic radius, or ratio of the cross sectional flow area to the wetted perimeter, is "y" feet. Therefore, Manning's equation of continuity for unit discharge may be written as:

$$q = \frac{1.49}{n} S^{.5} y^{1.67} \tag{5}$$

This is the basic equation used to determine the relationships of depth and velocity to unit discharge in Figures 7 and 17. For the specific portions of Indian River and Portage Creek being evaluated both n and S were known (estimated). Thus the first terms in the equation may be viewed as a constant, and rewritten as:

$$q = K y^{1.67} \tag{6}$$

where $K = \frac{1.49}{n} S^{.5}$

This equation can be rewritten to express depth (y) as a function of unit discharge (q).

$$y = \frac{q}{K}^{.6} \tag{7}$$

Thus the depth of flow (y) can readily be determined (estimated) for any unit discharge. And by applying the continuity equation (Equation 1), the corresponding velocity of flow can be determined (estimated for that same unit discharge).

Streambed Stability

The streamflow which causes incipient motion of streambed materials may be estimated using Shields criterion. If the Shields parameter is equal to or greater than 0.047, a sediment particle of diameter d_s will begin to move. The dimensionless Shield's parameter is defined as

$$F^* = \frac{\Psi}{(\psi_s - \psi)\, d_s} \qquad (8)$$

where

F_* = Shield's parameter (dimensionless)

ψ_s = specific weight of sediment particles (lbs/ft³)

ψ = specific weight of water (62.4 lbs/ft³)

d_s = diameter of sediment particle (ft)

Ψ = bed shear stress (lbs/ft²)

with Ψ defined as:

$$\Psi = 1/8\, f \rho V^2 \qquad (9)$$

where

Ψ = bed shear stress (lbs/ft²)

ρ = density of water (1.94 slugs/ft³)

V = velocity of flow (ft/sec)

f = Darcy Weisbach Friction Factor

The Darcy Weisbach Friction Factor can be expressed in terms of Manning's n as:

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

Chezy Eq: $V = C\sqrt{RS}$

chezy $C = \sqrt{\frac{8g}{f}}$

$$f = 116 \frac{n^2}{y^{.33}} \qquad (10)$$

Set Mannings Eq. equal to Chezy Eq.

$$\frac{1.49}{n} R^{2/3} S^{1/2} = \sqrt{\frac{8g}{f}} \, R^{1/2} S^{1/2}$$

$$\frac{1.49}{n} R^{1/6} = \sqrt{\frac{8g}{f}}$$

Substitute y for R

where

- f = Darcy Weisbach Friction Factor
- n = Manning's n
- y = depth of flow (feet)

The above equation can be substituted for the Darcy Weisbach friction factor (f) and bed shear stress defined in terms of Manning's n as:

$$\Psi = \frac{116\, n^2\, \rho\, V^2}{8y^{.33}} \qquad (11)$$

which can be simplified by combining the constant values to

$$\Psi = 28 \frac{n^2 V^2}{y^{.3}} \qquad (12)$$

where

- Ψ = bed shear stress
- n = Manning's n
- V = average velocity of flow determined from Manning's equation
- y = depth of flow determined from Manning's equation

Bed shear stress (Ψ) was determined as a function of unit discharge using Equation 12 and the same Manning equation parameters used to calculate the depth and velocity relationships presented in Figures 7 and 17. The results of these calculations (bed shear stress vs. unit discharge) are not presented in the report since they are an intermediate step in determining streambed stability.

Shield's criterion and Equation 12 for were used to estimate the velocity at which various size streambed particles begin to move. Shields parameter was given a value of 0.047 and the specific weight of streambed material in Portage Creek and Indian River was estimated to be 165-170 lbs/ft^3. Using these values and 62.4 lbs/ft^3 as the specific weight for water, Shield's equation was solved to express the diameter (d_s) of a streambed particle (inches) moved as a function of the bed shear stress.

$$d_s = 2.43\ \Psi \qquad (13)$$

The bed shear stress (Ψ) calculated with Equation 12 was used to determine the diameter of the particle sizes moved as a function of unit discharge. The results from these calculations are presented in Figures 8 and 18 of the report.

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