THE UNIVERSITY OF MANITOBA

MORPHOLOGY OF THE 8-MILE CHANNEL
LAKE WINNIPEG REGULATION PROJECT

by

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A THESIS

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ABSTRACT

The Lake Winnipeg Regulation Project calls for the dredging of the 8-Mile Channel, a large diversion channel at the north end of Lake Winnipeg. The entrance of this channel passes through a high sand ridge, which may present difficulties in precise assessment of future hydraulic performance. The prediction of the depth-discharge relationship is difficult to ascertain, and this aspect is studied in some detail. Active fluvial processes produce changes in channel morphology and possible increases in channel roughness values. Most reasonable depths for expected flow conditions are obtained. This aspect was studied by utilizing accepted depth-discharge prediction techniques, and a hydraulic model. It appears that bedforms will not fully develop in the lower reaches of the channel, and from this the assumed design roughness value of n = 0.025 appears reasonable. Sand removal, and bed movement from the channel entrance were studied with the aid of a large hydraulic model; recommendations for the construction of rock-filled dykes or slope cuts to alleviate this bed material movement are present.

The alignment of the channel entrance was controlled by rock out-croppings within Playgreen Lake, and this alignment was found to propogate meander tendencies in the lower reaches of the channel. This meandering will probably initiate bank caving in the downstream portion of the channel. Channelization and stabilization by rock removal and spur dyke construction were also studied with the aid of the model, and recommendations are made to control channel meander initiation resulting from the alignment of the channel.

ACKNOWLEDGEMENTS

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A special acknowledgement to my wife Linda, who has continually supported my involvement with the program.

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LIST OF SYMBOLS

Symbol	Definition	Dimensions
A	Cross-section area of channel	L^2
B	Slope of the $V/\sqrt{gDS}$ versus ln y/k relation	none
$C/\ g$	Dimensionless Chezy discharge coefficient equivalent to $8/f = V/\sqrt{gDS}$	none
$C'/\sqrt{g}$	Chezy coefficient for a channel or an equivalent channel having grain roughness boundary	none
D	Average depth of flow	L
d_m	Mean diameter of bed material	L
d_s	Diameter of bed material of which s percent by weight of the sizes is finer, when s is some specific percent	L
	Fall diameter of bed material in Simons and Richardson's analysis	L
D'	The average depth of flow a channel would have for the measured slope and discharge if only an average grain roughness affects the flow, $D' = VD/V'$	L
ΔD	Increase in average depth resulting from the form roughness and wave activity, $D = \Delta D - D'$	L
F	Froude number of the flow, $F = V/\sqrt{gD}$	none
g	Acceleration of gravity	L/T^2
h	Wave height from trough to crest	L
K	Equivalent grain roughness	L
k	General expression for height of the boundary roughness	L
λ	Meander wave length	L

Symbol	Definition	Dimensions
n	Manning's roughness coefficient	none
N_f	Froude number of the flow, $F = V/\sqrt{gD}$	none
Q	Discharge of flow	L^3/T
q	Unit discharge of flow	L^2/T
qs	Unit discharge of sediment	F/T/L
R	Hydraulic radius (area/wetted parimeter)	L
R_b	Hydraulic radius of the bed	L
R_b'	Hydraulic radius of the bed corresponding to grains	L
R_b''	Hydraulic radius of the bed corresponding to bed forms	L
R	Reynolds number, $R = VR/\nu$	none
R_*	Ratio of the Reynolds number to the Chezy discharge coefficient $R/C/\sqrt{g} = V_*D/\nu$ or V_*R/ν	none
S	Channel slope	L/L
S'	Grain-roughness slope	L/L
s	Specific gravity	F/L^3
V	Average velocity based on continuity principle	L/T
U_*	Shear velocity equal to $\sqrt{gRS}$ or $\sqrt{\tau_0/\rho}$	L/T
V_*'	Shear velocity corresponding to grains, equal to $\sqrt{gR_b'S}$	L/T
Vs	Terminal velocity of sediment	L/T
W	Bed width of channel	L
α	Geometric factor	none
ψ'	Parameter used by Einstein	none
ρ_s	Mass density of sediment	F/L^3

Symbol	Definition	Dimensions
ρ_f	Mass density of fluid	F/L^3
ν	Kinetic viscosity of fluid	L^2/T
γ	Specific weight of fluid	F/L^3
γ_s	Specific weight of sediment	F/L^3
γ_f	Specific weight of fluid	F/L^3
ω	Fall velocity of particle in still flow	L/T
$\Delta\gamma_s$	$\Delta\gamma_s = (\gamma_s - \gamma_f)$	F/L^3
$\tau 0$	Shear stress on the boundary equal to RS	F/L^2
τ^0	Stream Power	$F/T/L^2$
τ_0'	Shear stress of the bed, corresponding to grains, equal to R_b' S	F/L^2
τ_0''	Shear stress of the bed, corresponding to bed forms, equal to $R_b''S$	F/L^2
τ_*	Dimensionless shear stress of the bed, corresponding to grain roughness	none
τ_*'	Dimensionless shear stress of the bed, corresponding to bed form roughness	none

CHAPTER I

INTRODUCTION AND CHARACTERISTICS

OF THE

8-MILE CHANNEL

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INTRODUCTION AND CHARACTERISTICS OF THE 8-MILE CHANNEL

1.1 Introduction

The 8-Mile Channel is a diversion channel in Norther Manitoba incorporated into the Nelson River Hydro-Electric Development. The 8-Mile Channel flows North-West from Playgreen Lake to Kiskittogisu Lake. This Channel has been designed for maximum velocities of 4.3 feet per second in the clay portion at 56,000 cubic feet per second, (maximum recorded flood, 1966), and for flows ranging up to 80,000 cfs, the 1/10,000 year flood. Of concern to the designers is the channel entrance, as this portion passes through a large ridge of sand and gravel. The entrance has been widened from 500 feet, to 800 feet, and eventually to 1000 feet to reduce the maximum flow velocities to 2.4 feet per second during the 1966 flood, through this very unstable sand ridge section. During normal operating conditions, 50% duration, the velocities are expected to range between 1-1 1/2 feet per second for this section.

The 8-Mile Channel as designed by Manitoba Hydro is assessed through the use of a large hydraulic model. The basic purpose of the model is to examine the changes in morphology or bed configuration. Also very important in the model study is the recent discovery of large rock outcroppings in the upstream portion of the channel. The rock outcroppings' effect on velocity and meander initiation is examined with the aid of the model.

Several important questions arise from the present channel design:

(1) What will be the volume of sand movement in the 1000 foot wide channel entrance under normal operating conditions?

(2) Will the resistance to flow (channel roughness) change appreciably with sand in motion, and bed forms throughout the lower reaches of the channel within the design range of flows?

(3) Will the eroded sand move easily through the lower clay and higher velocity reaches of the channel?

(4) Will the channel entrance alignment have any effect on the flow in the channel and is meandering to be expected in the downstream portion of the channel because of this alignment?

(5) Will the rock outcroppings have any effects on channel flow and meandering initiation, and if so what possible remedies would be recommended by the use of the model?

1.2 Location

The 8-Mile Channel is located at approximately 54° N. latitude and 98° W. longitude at the outflow end of Lake Winnipeg in the Province of Manitoba. The water in the 8-Mile Channel flows between Playgreen Lake and Kiskittogisu Lake in a north-west direction.

See location plans, Figure 1.1, 1.2 and Photo 1.1.a, and 1.1.b.

1.3 Geology

The land area surrounding the 8-Mile Channel has undergone ice age consequences. The area was at one time at the bottom of glacial Lake Agassiz, subsequently covering the area with deep layers of lacustrian lake bed material interspersed with deposits of sand and gravel eroded by previous glacial movement. The material along the channel route is composed of sands, gravels, clays, and silts. The entrance, or 1000 ft. section is mostly non-cohesive sand, with intermittent layers of gravel and clay. The channel then narrows first to 525', then to a 425' wide section where the material is mostly cohesive clay. Soil log data was obtained, analyzed, and graphically represented in the three dimensional channel soil profile. Figure 1.3.

For the purpose of this study a mean sand size of 0.3 mm. was estimated to be representative of the 1000' channel entrance soil conditions.

The entrance is a ridge of sand and gravel, being eroded at present by lake wave action. Photos 1.2 through 1.3 show the setting of the entrance, while photos 1.4 through 1.5 indicate the type of material in the ridge.

1.4 Model Setup

Many hydraulic problems are so complex that they are virtually insolvable by theory or reference to imperical data. The questions posed have substantial economic importance to warrant the use of a hydraulic model to assess the 8-Mile Channel. It should be noted, that with mobile bed models, the results must be tempered by experience and judgment, as these results are usually qualitative rather than quantitative. The basic purpose of the model is to examine the changes in river morphology or bottom configuration that results from changes in bed load transport, or the establishment of the stable bed forms. Photo 1.5.

Model details concerning choice of scales, layout, operation and instrumentation can be found in Appendix A. Figure 1.4.

1.5 Basic Assumptions

(1) Flow frequency, Figure 1.5

% of time equalled to or exceeded	Q cfs
100	3,500
80	14,000
50	21,000
20	28,000
10	31,000
1	56,000
1/10,000	80,000

(2) All design work by Manitoba Hydro based on backwater studies and Manning's equation

$$V = \frac{1.49}{n} R^{2/3} S^{1/2} \tag{1.1}$$

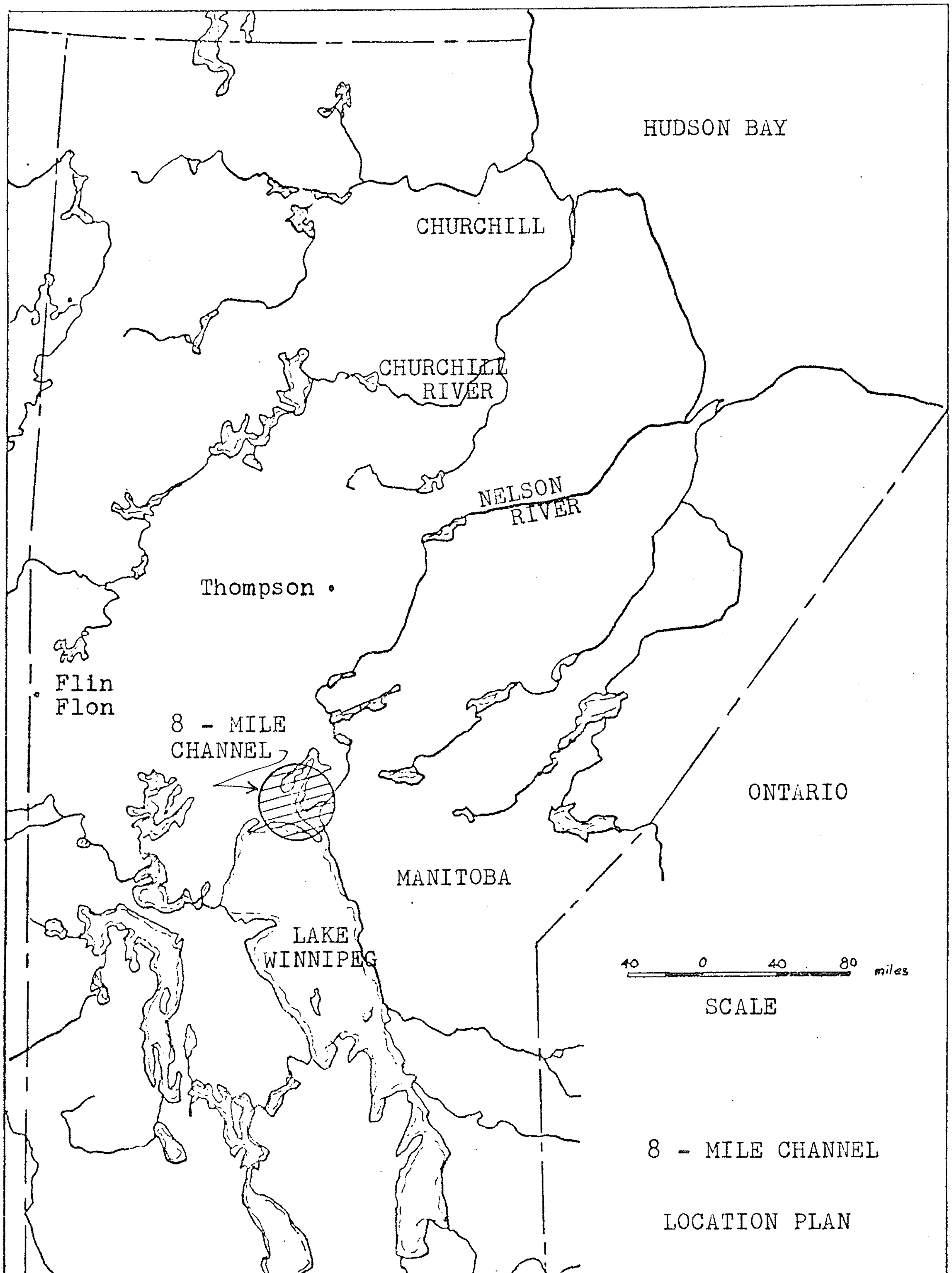
with n = 0.025

s = 0.0001 (channel bed slope)

(3) Maximum design velocity for the maximum recorded flow, 1966,

V max = 4.3 ft./sec.

(4) For the purpose of modelling ease, (i.e., space availability) the model layout is the mirror image of the prototype.



8 - MILE CHANNEL

LOCATION PLAN

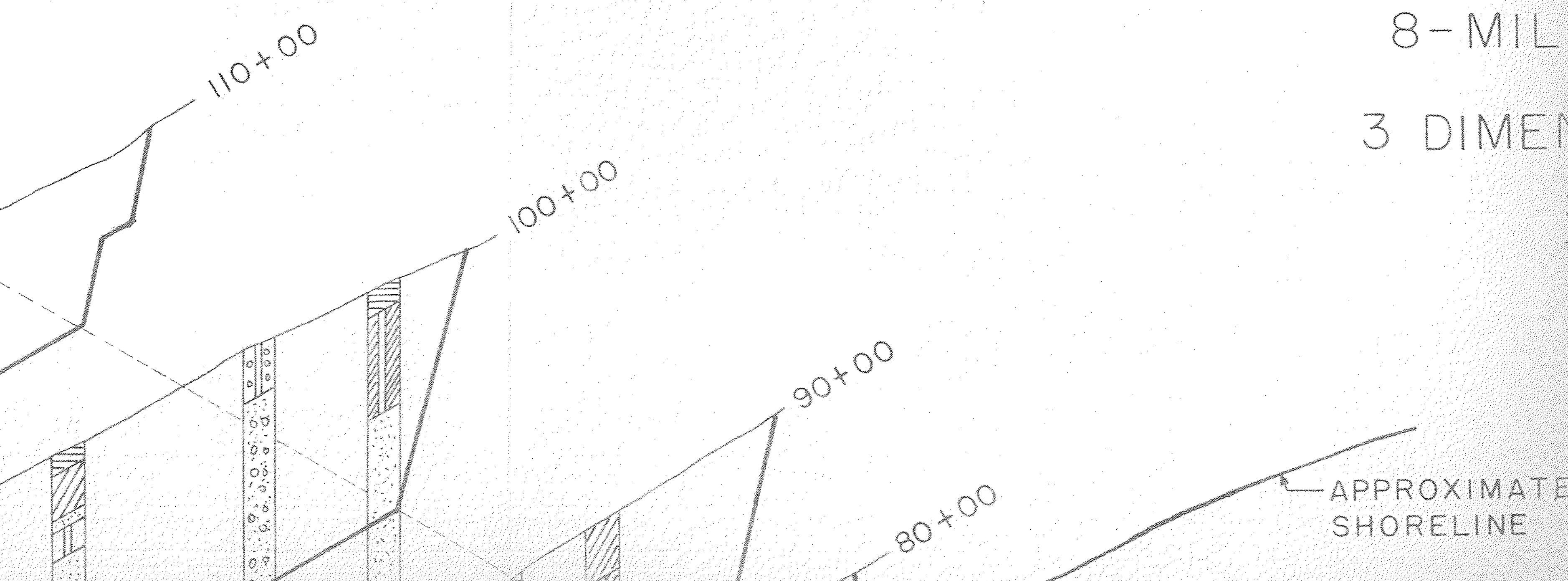
Figure 1.1

8 - MILE CHANNEL

3 - DIMENSIONAL VIEW

FIGURE 1.3

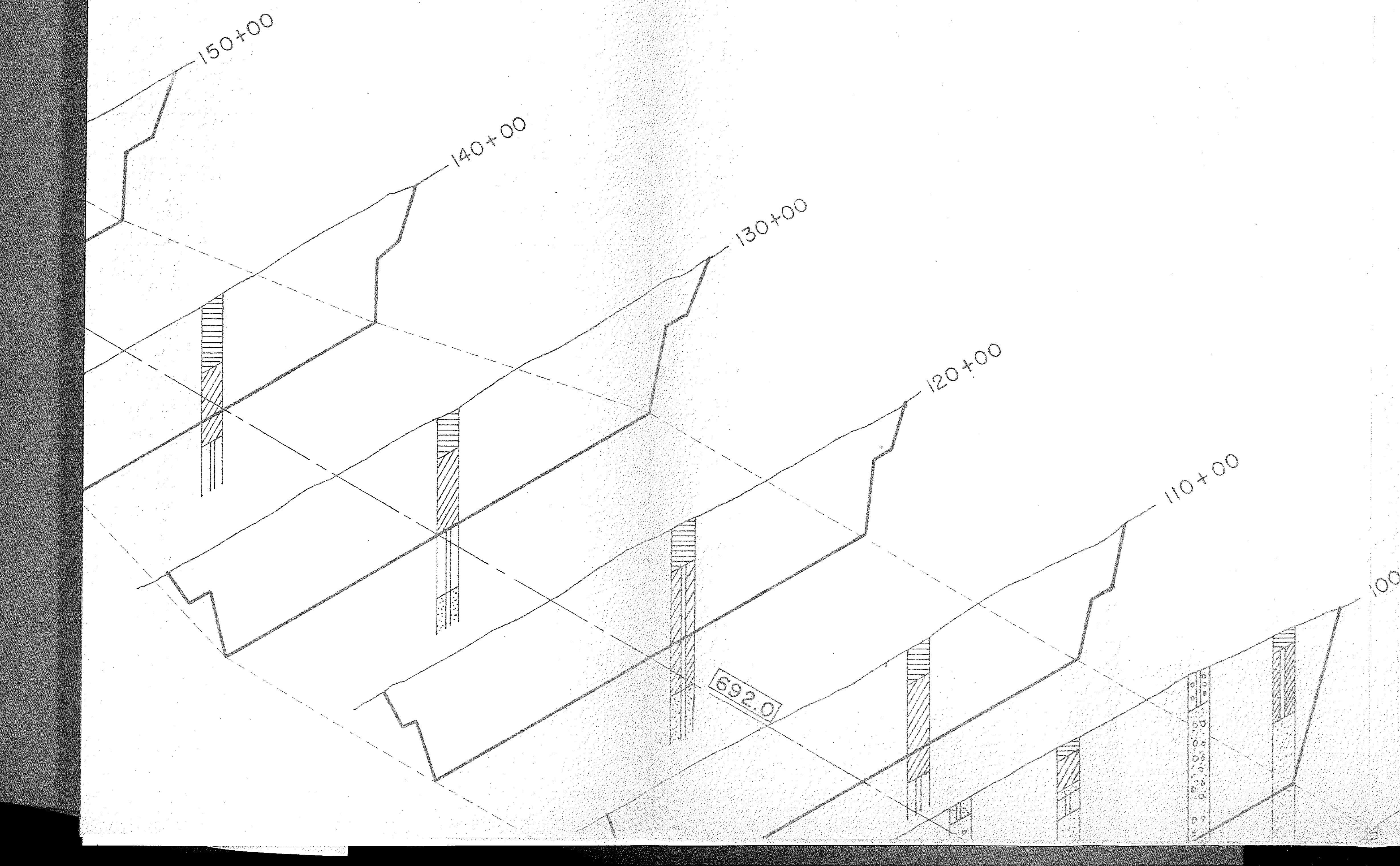
FIGURE 1-3



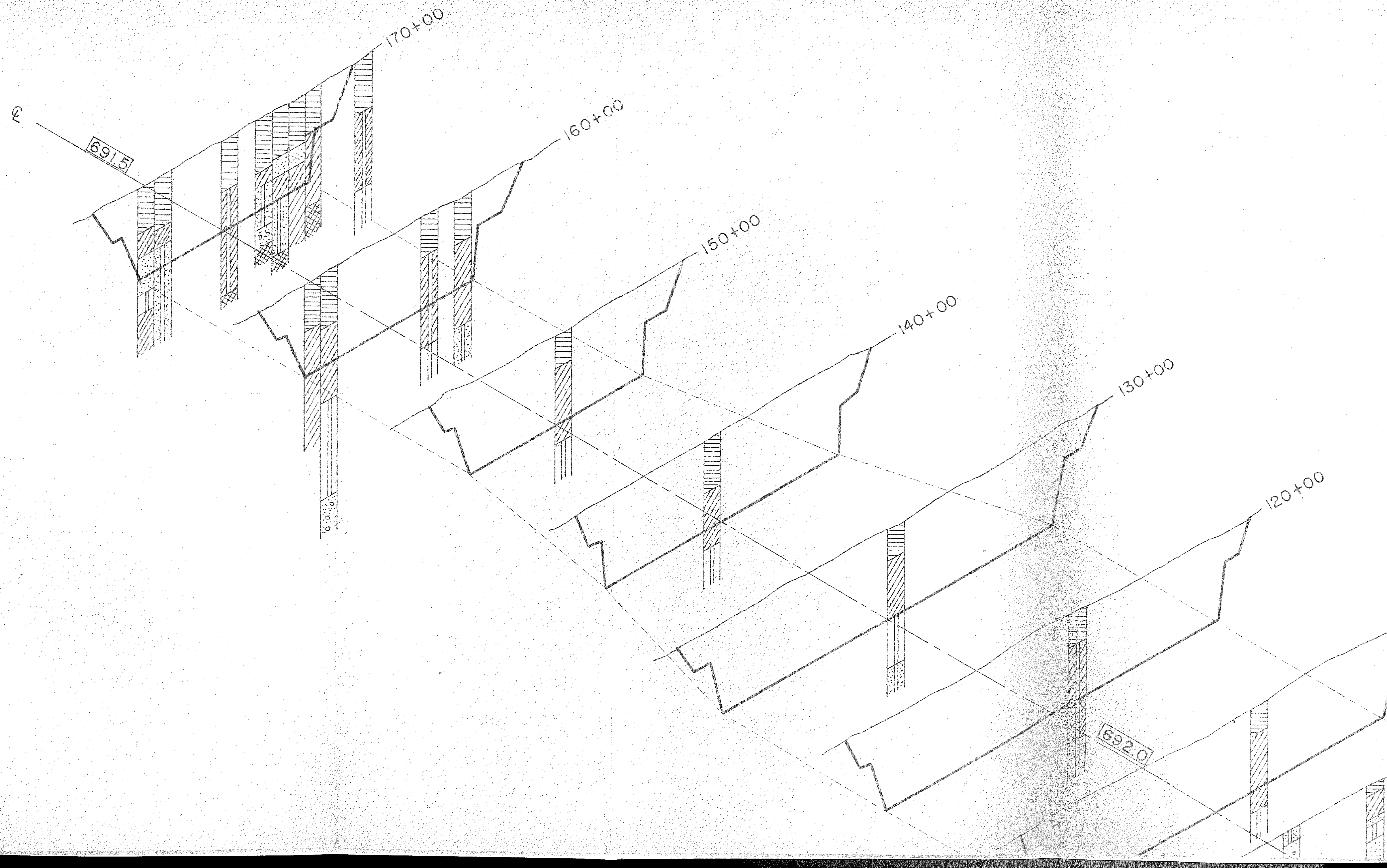
8-MILE CHANNEL

3 DIMENSIONAL VIEW

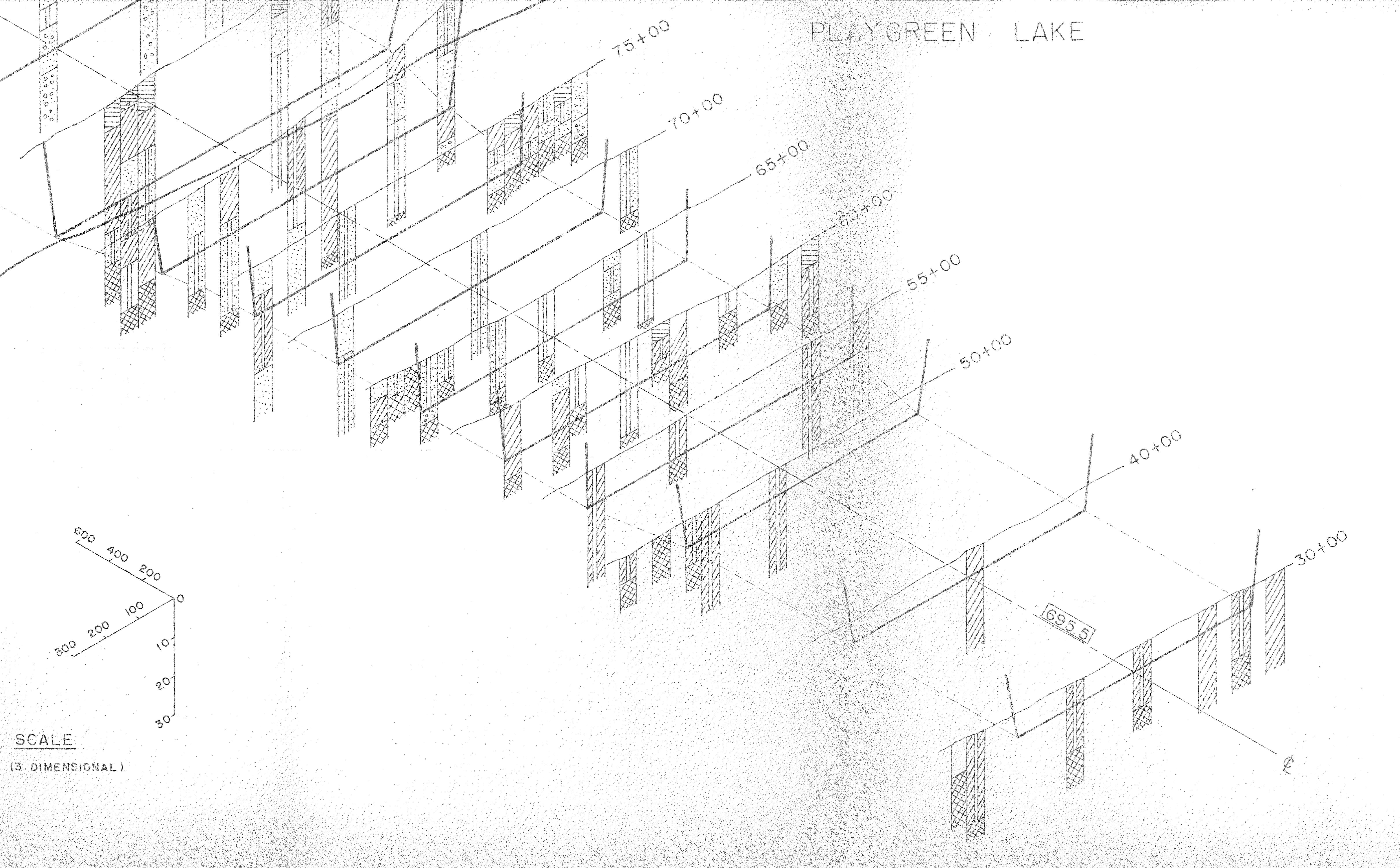
X-SECTIONS
TOPOGRAPHY
DRILL LOGS

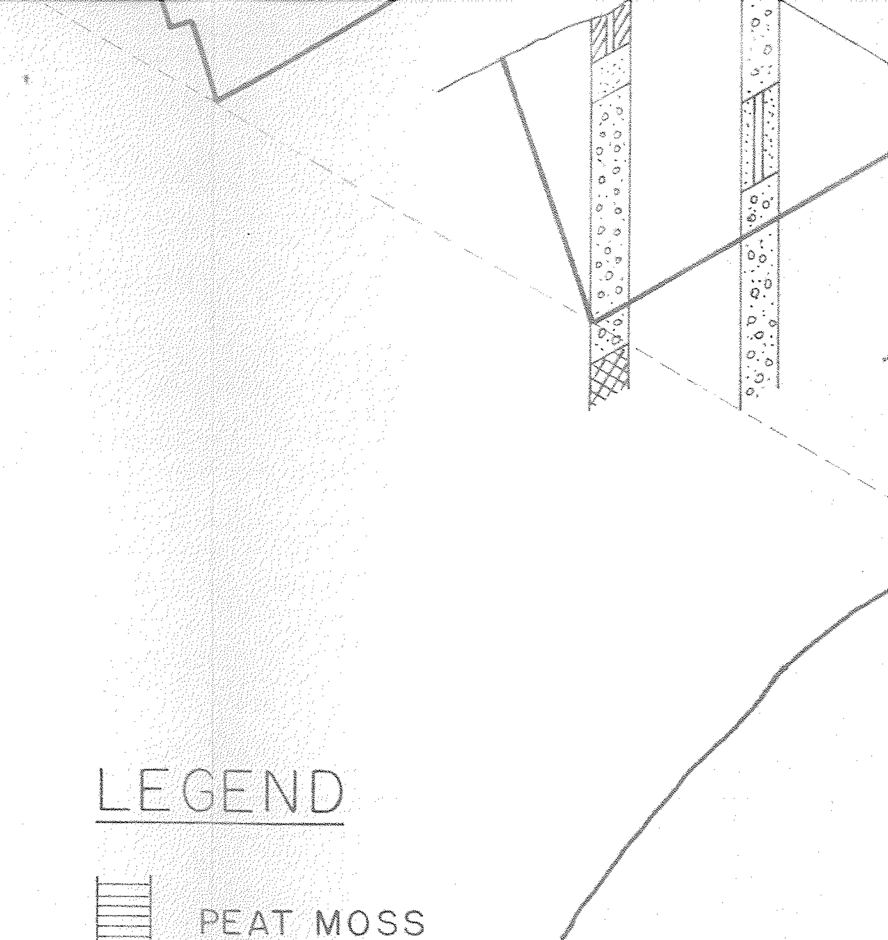


150+00
140+00
130+00
120+00
110+00
692.0



℄
691.5
170+00
160+00
150+00
140+00
130+00
120+00
692.0


PLAYGREEN LAKE
75+00
70+00
65+00
60+00
55+00
50+00
40+00
30+00
695.5
℄
600
400
200
0
100
200
300
10
20
30
SCALE
(3 DIMENSIONAL)



LEGEND

PEAT MOSS

SAND

GRAVEL

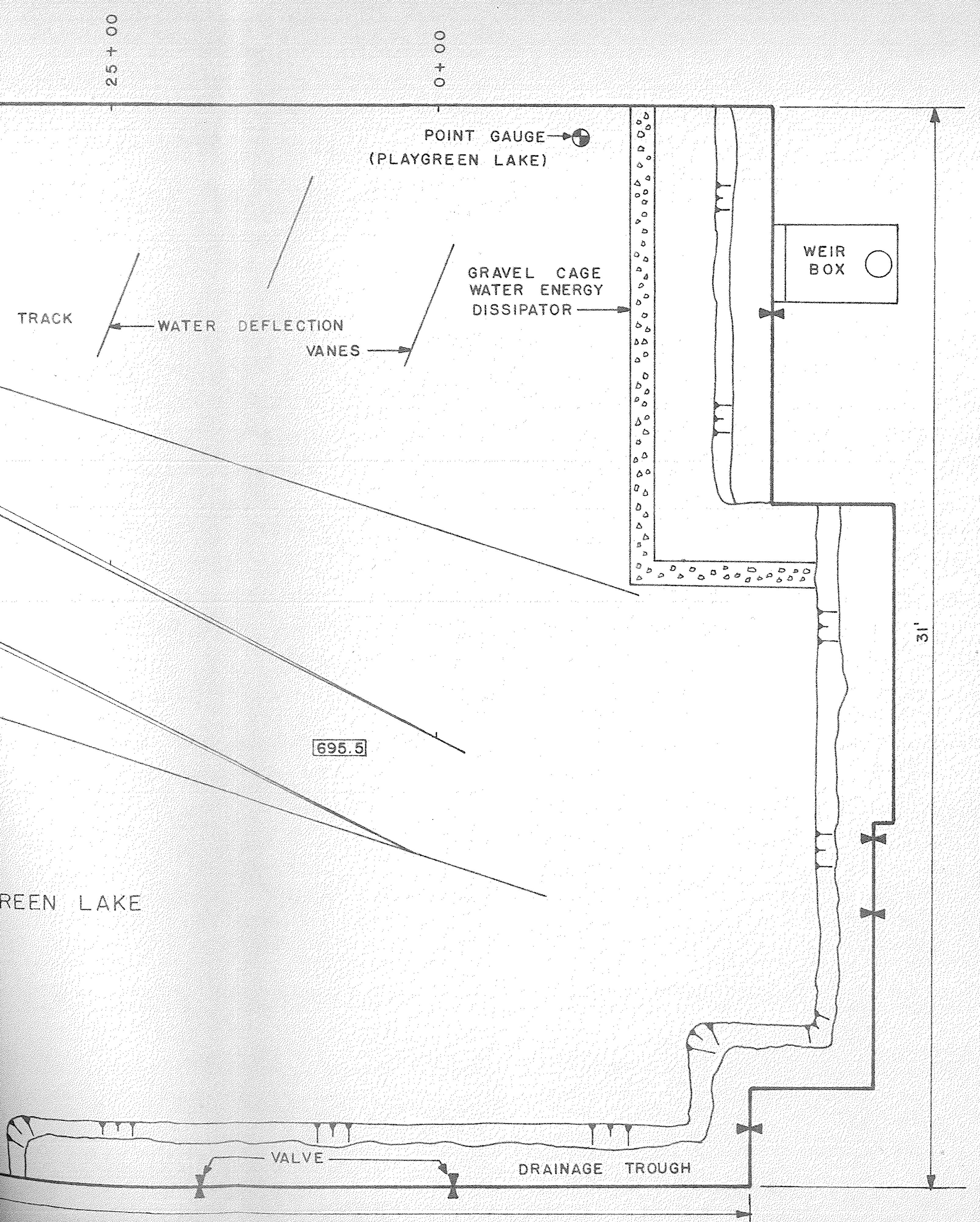
CLAY

SILT

BEDROCK

S

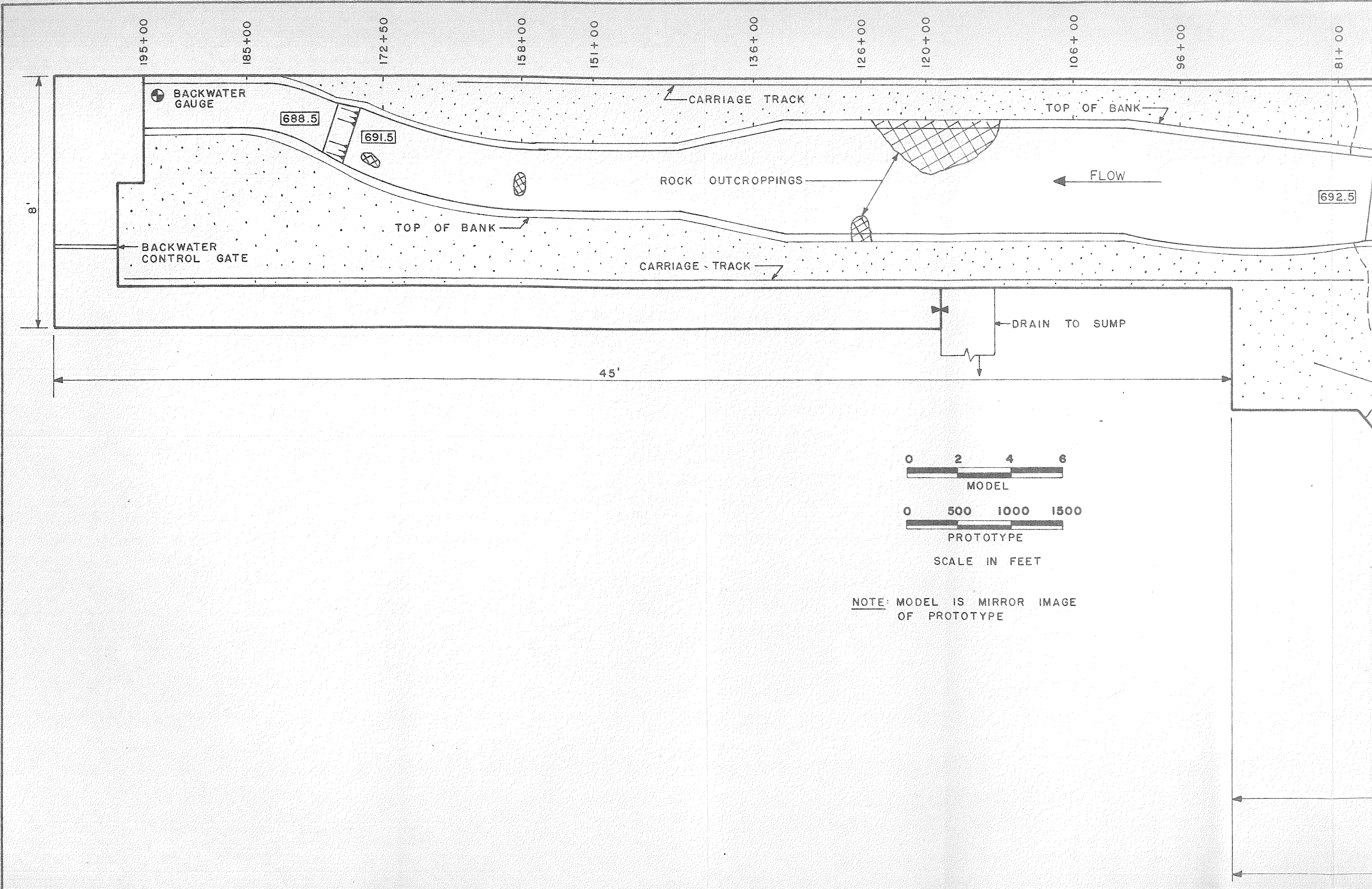
(3



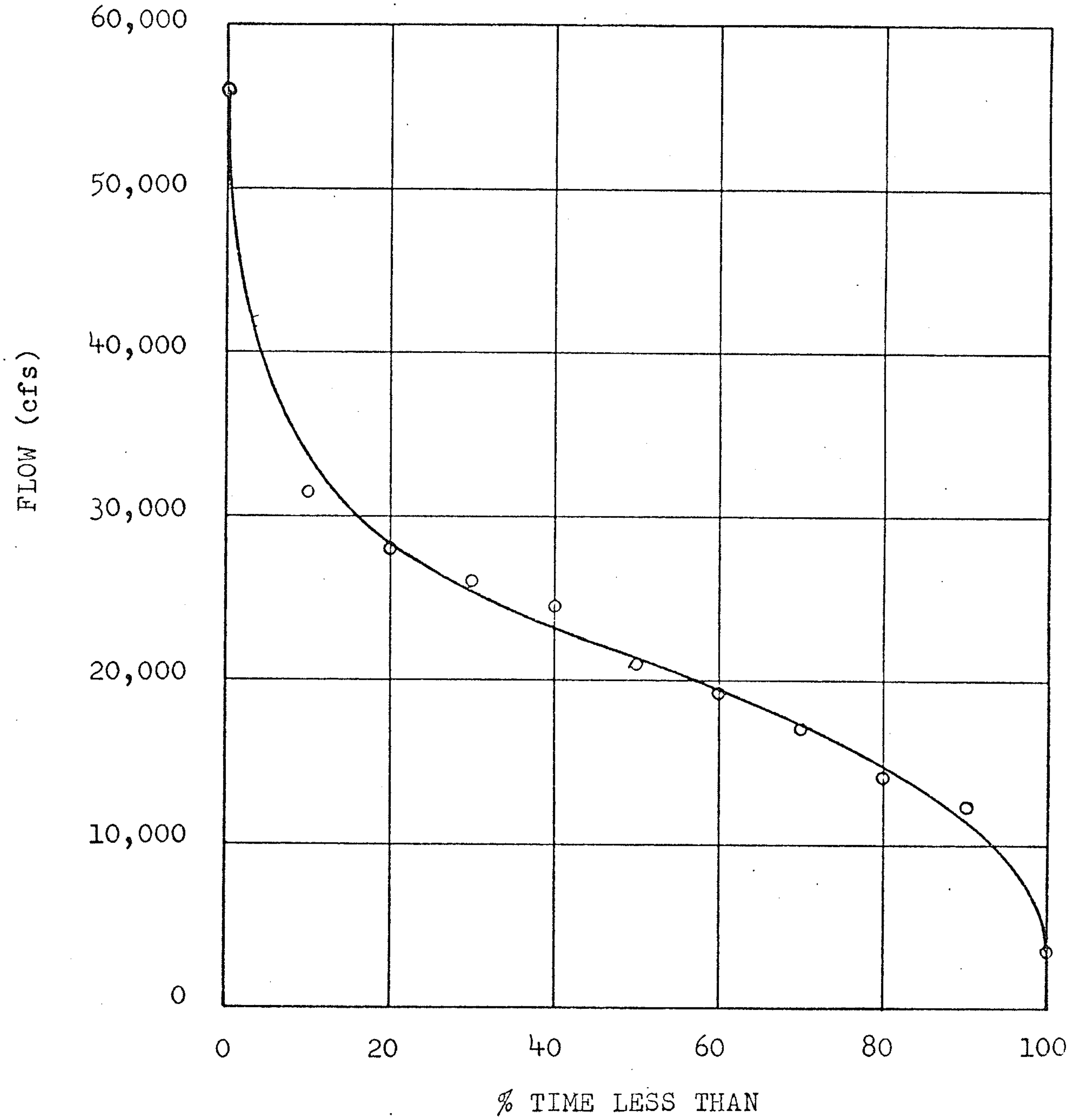
8 - MILE CHANNEL

MODEL LAYOUT

FIGURE 1.4



195+00
185+00
172+50
158+00
151+00
136+00
126+00
120+00
106+00
96+00
81+00
BACKWATER GAUGE
688.5
691.5
CARRIAGE TRACK
TOP OF BANK
ROCK OUTCROPPINGS
FLOW
692.5
8'
TOP OF BANK
BACKWATER CONTROL GATE
CARRIAGE TRACK
DRAIN TO SUMP
45'
0 2 4 6
MODEL
0 500 1000 1500
PROTOTYPE
SCALE IN FEET
NOTE: MODEL IS MIRROR IMAGE OF PROTOTYPE



8 - MILE CHANNEL

FLOW DURATION CURVE

Figure 1.5

8-MILE CHANNEL

Photo 1.1

AERIAL PHOTO OF DREDGING IN PROGRESS

Photo 1.1b

Aerial Closeup Photo of
Dredging in Progress

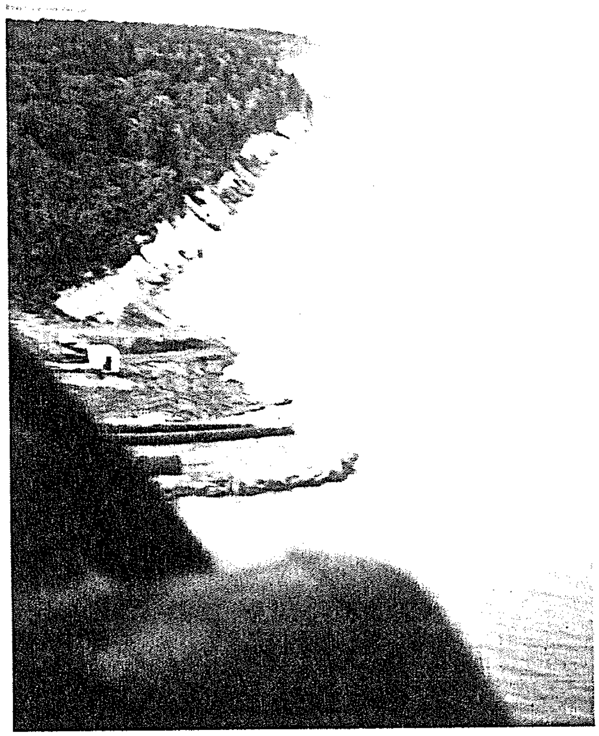


Photo 1.2.a

Sand and Gravel Ridge at the Entrance to the 8-Mile Channel. Sand is moved Northward by Littoral Currents. (Looking North)

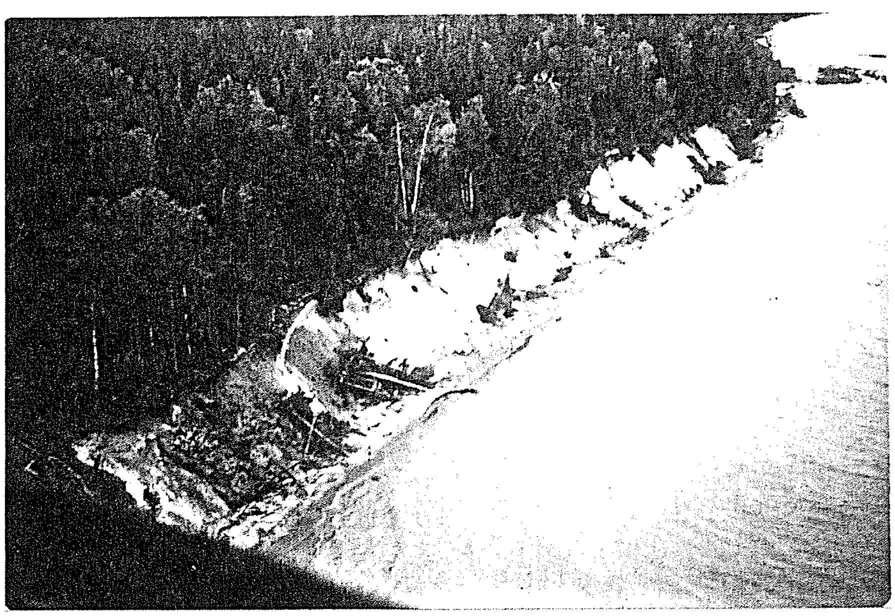


Photo 1.2.b

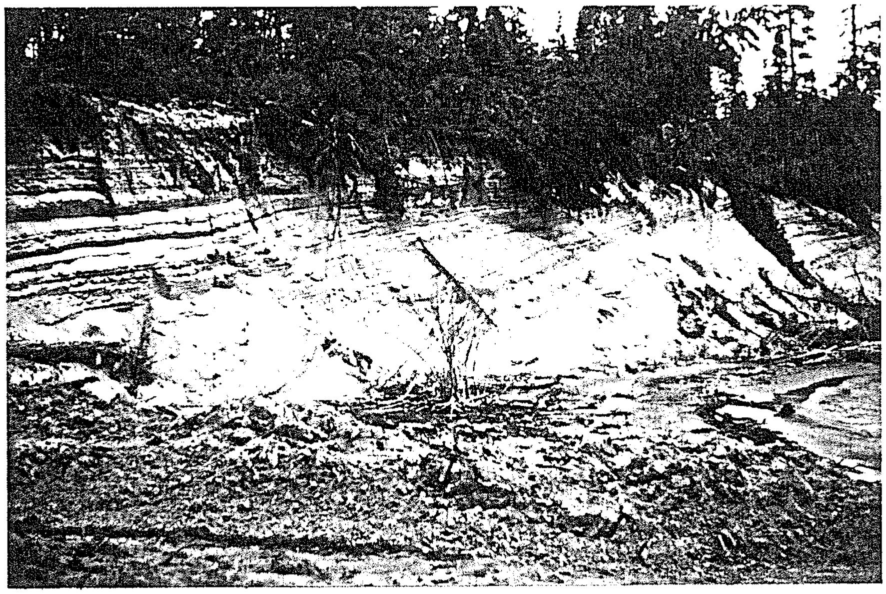


Photo 1.3.a

Stratified Deposit of Fine Sand at
Actively Eroding Bank

Photo 1.3.b

Photo 1.4.a

Pit in the Ridge at the Entrance to the Channel
(looking East)

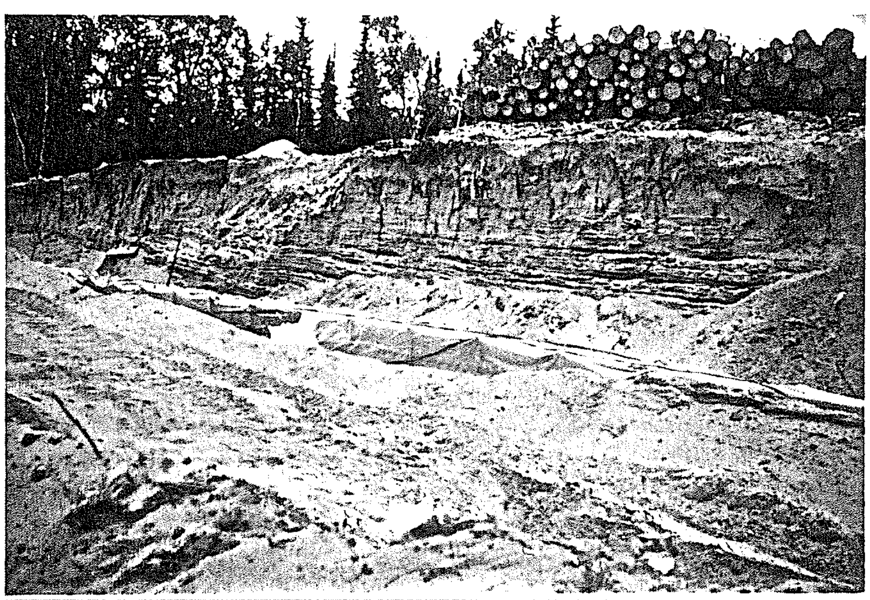
Photo 1.4.b

Sand and Gravel Strata shown in Banks of Above Pit

Photo 1.4.c

Photo of Sand and Gravel
Strata in Banks of Pit

Photo 1.4.d



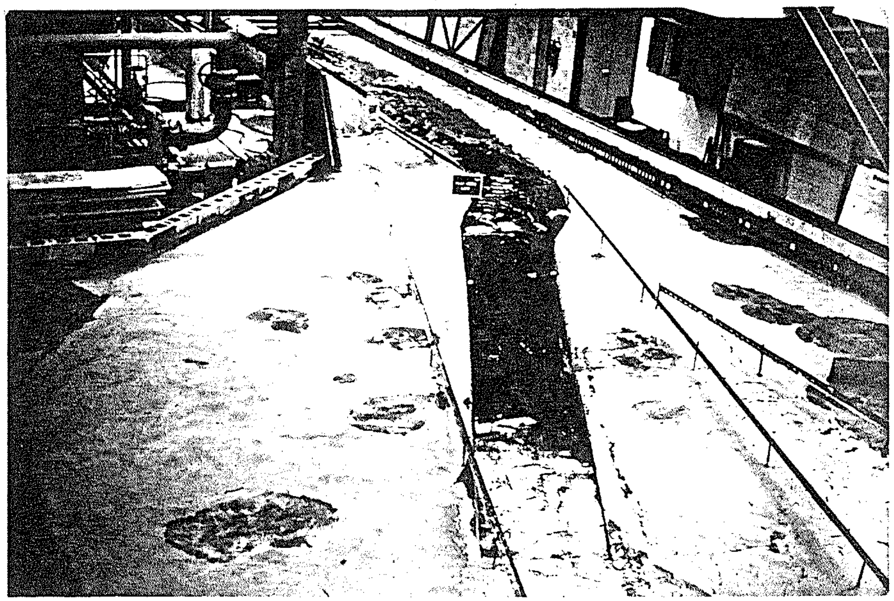


Photo 1.5.a

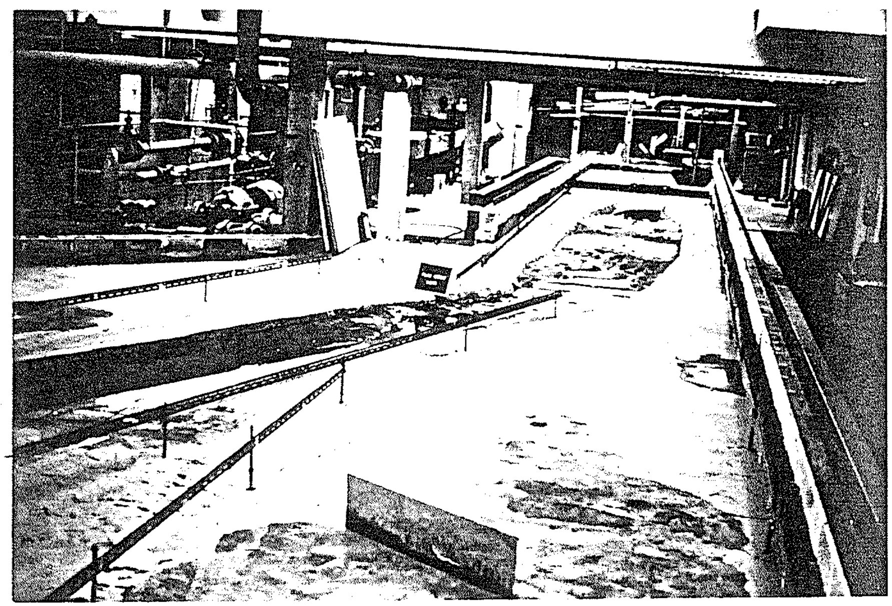


Photo 1.5.b

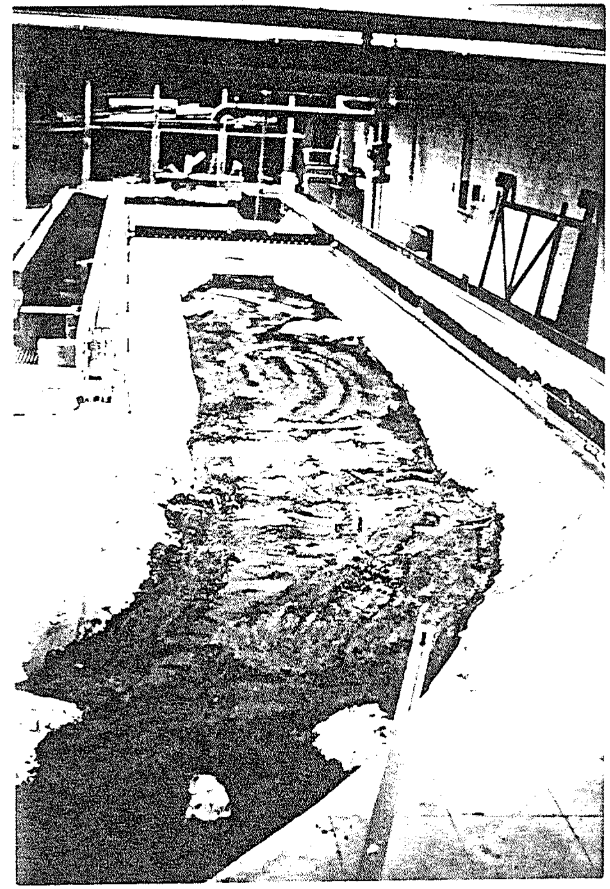


Photo 1.5.c

8-Mile Channel

Moveable Bed Hydraulic Model in Laboratory

CHAPTER II

DEPTH-DISCHARGE PREDICTION

CHAPTER II

DEPTH-DISCHARGE PREDICTION

2.1 Introduction

This chapter deals with the prediction of Depth-Discharge relationships, and the prediction of probable bed forms likely to form in the 8-Mile Channel. The prediction of flow depths for mobile bed channels is one of the most difficult problems in river hydraulics.

The 8-Mile Channel is composed of cohesive and non-cohesive bank and bed material. The upstream portion of the channel has a design width of 1000 feet, and is mostly non-cohesive sand with occasional lenses of gravel and clay. From the data available a rough estimate of mean grain size is determined to be 0.3 mm. The channel width of 1000 feet is maintained for about 6000 feet, until the bed material changes to cohesive clay. The channel is then reduced to a width of 525 ft., then to 425 ft., where a higher range of velocities can be maintained without excessive material movement.

One of the aims of this study is to evaluate future flow depths in the wide 1000 foot section, and in the narrow 425 foot section. The amount of sand supplied to the 425 foot section will be less than its capability for transport. How will this affect the bed forms and roughness of the channel? If the roughness of the channel is increased, then higher depths will be encountered. If the roughness is decreased, higher velocities will result, and more bank and bed erosion will occur than anticipated.

In the prototype, delivery curves for Playgreen Lake and Kiskittogisu Lake control the water level. For the purpose of estimating the possible high water depth limits for both the 1000 foot and 425 foot sections, it is assumed that bed material from the 1000 foot section will be sand which has been transported into the 425 foot section.

With a mobile bed channel, bed forms must be considered when predicting a depth-discharge relationship. Einstein and Barbarrossa (1952) proposed that the resistance to flow in an alluvial channel is no longer only related to grain roughness, which is provided by individual grains of bed material, but intimately related to the form resistance. Bed forms have a significant effect on the flow resistance in a channel. Table 2.1.

2.2 Bed Form Description

In 1966, ASCE attempted to resolve any remaining confusion in describing bed forms by appointing a committee with the task of standardizing the classification of laboratory and natural bed forms. In their report, the ASCE task force (1966, p. 53) proposed the following descriptions and nomenclatures for bed forms in alluvial channels:

(1) Bed Configuration - any array of bed forms, or absence thereof, generated on the bed of an alluvial channel by the flow.

(2) Flat Bed - a bed surface devoid of bed forms.

(3) Bed Form - any deviation, from a flat bed, that is readily detectable by eye or higher than the largest sediment size present in the parent material, generated on the bed of an alluvial channel by flow.

(4) Ripples - small bed forms with wave lengths less than approximately one (1.0) foot and heights less than approximately 0.1 foot.

(5) Bars - bed forms having lengths of the same order as the channel width or greater, and heights comparable to the mean depth of the generating flow.

(6) Dunes - bed forms smaller than bars but larger than ripples that are out of phase with any water surface gravity waves that accompany them.

(7) Transition - a bed configuration consisting of a heterogeneous array of bed forms, primarily low-amplitude ripples or dunes and flat areas.

(8) Antidunes - bed forms that occur in trains and that are in phase with and strongly interact with gravity water-surface waves.

(9) Chutes and Pools - a sediment bed configuration occurring at relatively large slopes and sediment discharges, that consists of large mounds of sediment which form chutes on which the flow is supercritical, connected by pools, in which the flow may be suprcritical or subcritical.

See Figure 2.1.

2.3 Prediction of Bed Forms in the 8-Mile Channel

Engineers in many instances, have designed channels with the use of the Manning Equation to assess flow depths. Usually a constant value of Manning's 'n' has been adopted throughout the entire depth range. More recently, a quantitative approach has been strived for in order to predict probable bed forms in a channel. Various bed forms have been generated in laboratory flumes or observed in natural channels, and measured flow and sediment properties, (velocity, particle size, rate of sediment transport, etc.) are related graphically to the bed forms. Approximate boundaries between bed form regimes can be established on the graphs. Various investigators have proposed graphs relating bed forms to hydraulic properties.

Bed form prediction is confined to the 1000 foot and 425 foot sections of the 8-Mile Channel. In the 1000 foot section, with exception of high floods, the velocities are expected to remain low enough so as to limit the bed formations to ripples or small dunes. However, at the higher flows, 40,000 cfs or greater in the 1000 foot section, and any flows in the 425 foot section, we can expect to observe various bedforms, depending on bed material available at any one location.

The following widely used techniques are used to predict probable bedforms in the '8-Mile Channel':

(1) Albertson et al. (1958)

Refer to Figures 2.2, and 2.3

(a) Figure 2.2 - 'Criteria for Bedforms in Alluvial Channels'

The ordinate is a dimensionless ratio of the shear velocity,

$$U_* = (gRS)^{1/2} \qquad (2.1)$$

to the terminal velocity of the sediment, (V_s).

The abscissa is a special form of the dimensionless Reynold's Number,

$$R = \frac{U_* d}{\nu} \qquad (2.2)$$

where d is a representative diameter of the bed material, and ν is the kinematic viscosity of water.

(b) Figure 2.3 - 'Settling Velocity vs Particle Size' (after Graf et al (1966))

The ordinate is the mean particle diameter, and the abscissa is the settling velocity.

Using Figures 2.2 and 2.3, and the following information:

$Q = 56{,}000$ cfs $\qquad S = 0.0001$

$d_m = 0.3$ mm $= 0.000983$ ft. $\qquad SG = 2.65$

$\nu = 1.4 \times 10^{-5}$ @ 50°

we obtain:

(a) for the <u>1000</u>' section,

$$U_* = (gDS)^{1/2} = 0.24 \text{ '/s}$$

$$R = \frac{U_* d_m}{\nu} = 16.8$$

$$V_s = 40 \text{ mm/s} = 0.13 \text{ '/s}$$

$$\frac{U_*}{V_s} = 1.85$$

From the figure, the bed forms indicated are dunes near the transition zones.

(b) for the 425' section,

$$U_* = (gDS)^{1/2} = 0.295 \text{ '/s}$$

$$R = \frac{U_* d_m}{\nu} = 21.5$$

$$V_s = 0.13 \text{ ft.}$$

$$\frac{U_*}{V_s} = 2.27$$

From the figure, the bed forms indicated are antidunes or plane bed.

(2) Simons et al. (1963)

Refer to Figure 2.4 'Relation of Stream Power and Median Fall Diameter to Bed Form"

The ordinate is the stream power, computed as the product of mean bed shear stress and mean flow velocity,

$$\tau_o = \gamma DS \qquad (2.3)$$

$$\tau_o V = \gamma DSV \qquad (2.4)$$

The abscissa is the median fall diameter of the bed material, d_m.

Using Figure 2.4 and the following information:

$$Q = VA \qquad (2.5)$$

$$A = WD \qquad (2.6)$$

$Q = 56{,}000$ cfs $\qquad S = 0.0001$

$d_m = 0.3$ mm $= 0.000983$ ft. $\qquad \gamma = 62.4$ lb/ft^3

we obtain:

(a) for the 1000' section, D = 18.0'

$$A = WD = 18{,}000 \text{ ft}^2$$

$$V = \frac{Q}{A} = 3.1 \text{ '/s}$$

$$\tau_o V = \gamma DSV = 0.348 \text{ ft lb/s/ft}^2$$

From the figure we find the bed forms indicated are dunes.

(b) for the 425' section, D = 27.0'

$$A = WD = 11{,}500 \text{ ft}^2$$

$$V = \frac{Q}{A} = 4.87 \text{ '/s}$$

$$\tau_o V = \gamma DSV = 0.821 \text{ ft lb/s/ft}^2$$

From the figure, the bed forms indicated are antidunes.

(3) Engelund et al. (1966)

Refer to Figure 2.5 - 'Stability of Various Bed Forms'

The ordinate is the dimensionless ratio of average velocity over the bed shear velocity for the conditions given. The abscissa is the Froude Number,

$$N_f = \frac{V}{(gD)^{1/2}} \tag{2.7}$$

$$\frac{V}{U_*} = \text{ratio} \tag{2.8}$$

Using Figure 2.5, and the following information:

Q = 56,000 cfs   S = 0.0001

We obtain:

(a) for the 1000' section

$$N_f = \frac{V}{(gD)^{1/2}} = 0.13$$

$$\frac{V}{U_*} = 13.0$$

From the figure, the bed forms indicated are dunes.

(b) for the 425' section,

$$N_f = \frac{V}{(gD)^{1/2}} = 0.165$$

$$\frac{V}{U_*} = 16.5$$

From the figure, the bed forms indicated are dunes.

From the previous outlined techniques and the results calculated, it is concluded that at flows of 56,000 cfs, the bed forms will be dunes, or antidunes.

2.4 Depth-Discharge Prediction Techniques

As discussed earlier, many investigators have attempted since Einstein and Barbarrossa, to develop techniques capable of reliable depth-discharge prediction. In this section, several of the more widely accepted methods are analyzed and compared. The following techniques are used:

(1) Einstein and Barbarrossa (1952) Method
(2) Engelund's Method (1966)
(3) Depth-Adjustment, Galay and Cheung (1972)
(4) Manning's Equation (1889)

A brief description of each method, computations and graphical comparison of methods is provided in Appendix B1, and B2.

2.5 Remarks

A graphical comparison, see Figures 2.12, and 2.13, shows clearly the values predicted by the various depth-discharge prediction techniques. The graphs showed:

(1) The Einstein-Barbarrossa Method over predicted the depth

in both upper and lower flow regimes, for an equivalent grain roughness value of K = 0.3 mm. However, a marked decrease in stage for comparable discharges was observed when the K value was 0.2 mm. The k = 0.2 mm curve is the median of all the curves.

(2) The Engelund Method yielded good results in the lower flow regime, but underestimated the depth of flow in the upper flow regime. It should be noted that the range of flows where this prediction was low is far beyond the capacity of the 8-Mile Channel.

(3) The Depth-Adjustment Method produced good results for the entire range of probable discharges.

(4) By using the Manning's equation,

$$V = \frac{1.49}{n} R^{2/3} S^{1/2} \tag{2.9}$$

the roughness factor, n, is a very important parameter in determining the shape of the curve, and does not directly account for bed form configuration. As seen by the two values of n used in the prediction, the value of n = 0.030 produced a curve which came very near to being the mean curve of all the techniques used. In comparison, the value of 'n' which was adopted for the prototype design was n = 0.025.

(5) An important consideration to be evaluated in the assessment of the Depth-Discharge Predictions are the actual observations of bed forms and depths within the hydraulic model.

2.6 Model Observations of Bed Forms and Sand Movement

The hydraulic model is a very useful tool when an estimation of bed forms, major bars, and sand movement is attempted. As was seen from the theoretical bed form prediction techniques, dunes or antidunes are expected to be the predominate bed form. This type of bed form definitely increases the channel roughness factor. Comparison of depth-discharge prediction techniques also proves out the fact that bed forms do increase roughness, therefore increasing depths.

Observations made in the model of bed forms and sand movement downstream were as follows:

(1) At 21,000 cfs, small bedforms were observed on the channel bed in the 1000 ft. section. See Photo 2.6.1. Bed material movement was confined to occasionally observed individual grains moving along the channel bottom. This material was transported right through to the 425 ft. section. No bed forms were observed in the 425 ft. section due to the fact that there was insufficient bed material in the section to have any form. Material moved as sheet flow through the 425' section.

(2) At 40,000 cfs, bedforms were observed in the 1000 ft. section, and were of noticeable height. See Photo 2.6.2. Boils were observed in the channel entrance. Sand movement occurred, and the bed material entered the 425 ft. area and formed travelling ridges, assumed to be dunes or transition type bed configuration. Roughness was increased by observing deeper water for equivalent flows.

(3) At 56,000 cfs, there were definitely defined forms along both sections of the channel. Boils were observed at the channel

entrance. The bed forms were large and considered to vary between dunes and antidunes. See Photo 2.6.3.a. Bed material was readily observed moving along the entire length of the channel, continuously throughout the test time. This material from the 1000 ft. section was transported into the 425 ft. stretch, where bedforms were shaped, though small and infrequent when compared to the channel entrance. These forms were probably antidunes, and were observed to move downstream. See Photo 2.6.3.a., and 2.6.3.b. The roughness factor of the channel was definitely increased by these bed configurations.

(4) At 80,000 cfs, the channel became very unstable because of the increase in flow velocity. Bed forms in the 1000 ft. section were very pronounced. See Photo 2.6.4.a. Boils and eddies were observed at this flow. A considerable amount of bed material was observed moving downstream into and through the 425 ft. section. Bed forms were travelling along the 425 ft. channel bed and seemed to be defined as sheet flow of bed material. Bed material did not cover the entire bed, thus not allowing definite stable bed forms to build within this portion of the channel. The travelling waves of material were formed intermittently in the transition to the 425 ft. section. See photos 2.6.4.b., and 2.6.4.c.

(5) Material in suspension was observed for all flows, but could not be quantified. This material originated in the channel entrance, where severe scour from overbank flow was occurring. This suspended material was carried through the entire length of the model without deposition.

(6) Accurate descriptions of bedforms in the channel were not possible due to the fact that in a hydraulic model bed forms are distorted and not easily recognized. The best observation concerning bed form configuration was that in the 425 ft. section of the channel, there was an insufficient amount of bed material being transported and deposited in the area to form any stable type of bed configuration.

2.7 Conclusions

As discussed before, accurate depth-discharge prediction is a very difficult problem. From model observations and technique comparison, the following conclusions are made:

(1) All depth-discharge prediction techniques except for one trial of Einstein-Barbarrossa (1952), using a K value equal to 0.3 mm, were reasonably close in comparison in the lower flow regime. That is to say, the results for the 50% duration, (21,000 cfs) were within a two foot range, and for the 1% duration, (56,000) were within a three foot range.

The range of results in the 425 foot section was slightly higher, and this can be attributed to the initial assumption that enough bed material was deposited in this section to form stable bed forms. The higher results indicate what conditions might occur in the narrow portion of the channel if indeed enough bed material did line the channel bottom from the 1000 ft. section.

(2) A Manning's n value ranging between n = 0.025 and n = 0.030 is considered suitable.

(3) Predicting mean velocities and subsequent depth-discharge relations in the upper flow regime is very uncertain without actual field data to support the prediction. More reliable methods are required in order to accurately assess upper flow regime parameters.

(4) Flows less than the 1% flood can be accurately estimated when depth prediction techniques are assessed.

(5) Seive analysis is an extremely important factor when using all but the Manning's Equation in the prediction of depth-discharge relations. A thorough soil survey with accurate analysis is required if any prediction methods are relied on for design purposes.

(6) Bed form analysis in a moveable bed hydraulic model is limited to a qualitative rather than a quantitative assessment. Trends and differences can be observed when comparing different segments of the model, and these can be related, with care, to prototype conditions. Roughness factors can be supported from theoretical calculation by observations of changes in the model of different parameters.

CLASSIFICATION OF FLOW REGIME

TABLE 2.1

FLOW REGIME	BED FORM	MODE OF SEDIMENT TRANSPORT	TYPE OF ROUGHNESS	PHASE RELATION BETWEEN BED AND WATER SURFACE
Lower Flow Regime	Ripple Ripples on dunes Dunes	Discrete steps	Form roughness	Out of phase
Transition	Washed out dunes		Variable	
Upper Regime	Plane bed Antidunes Chutes and pools	Continuous	Grain roughness predominates	In phase

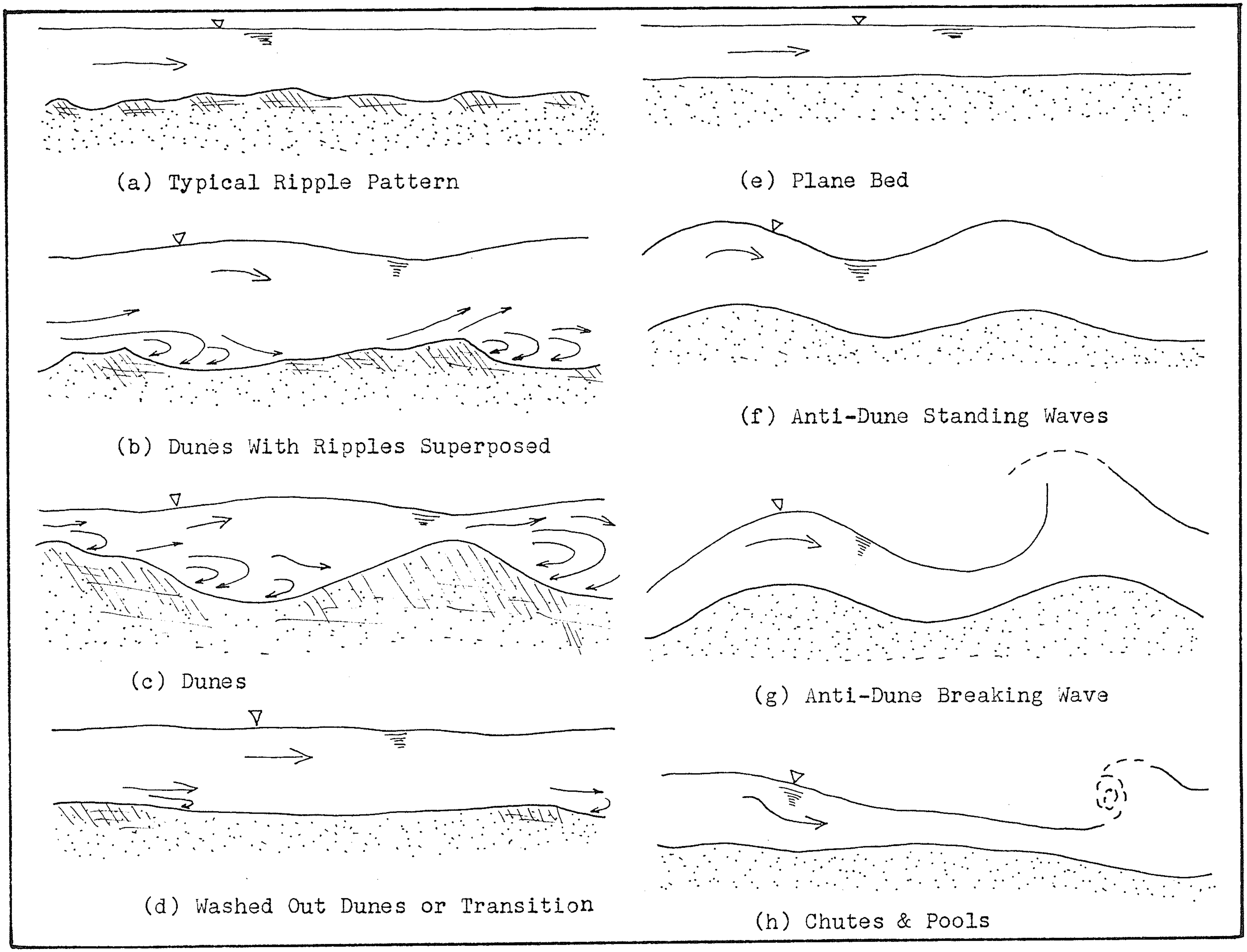
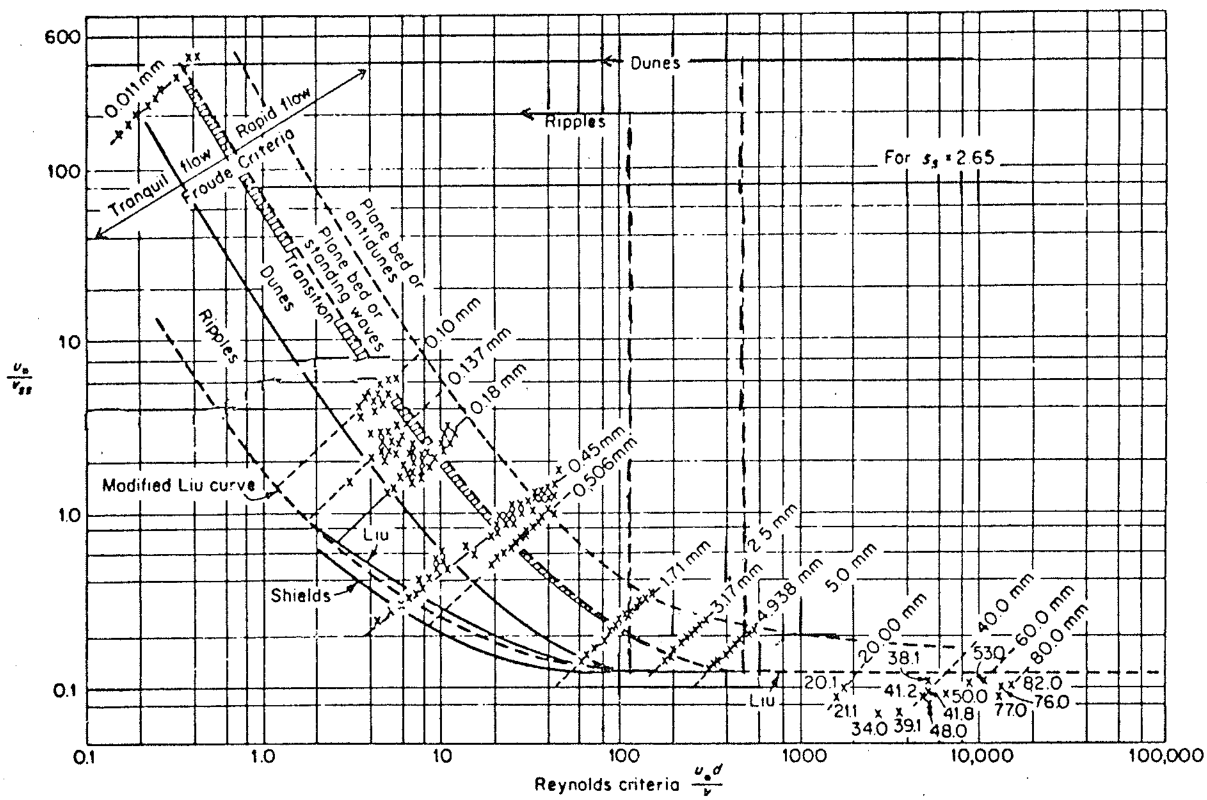
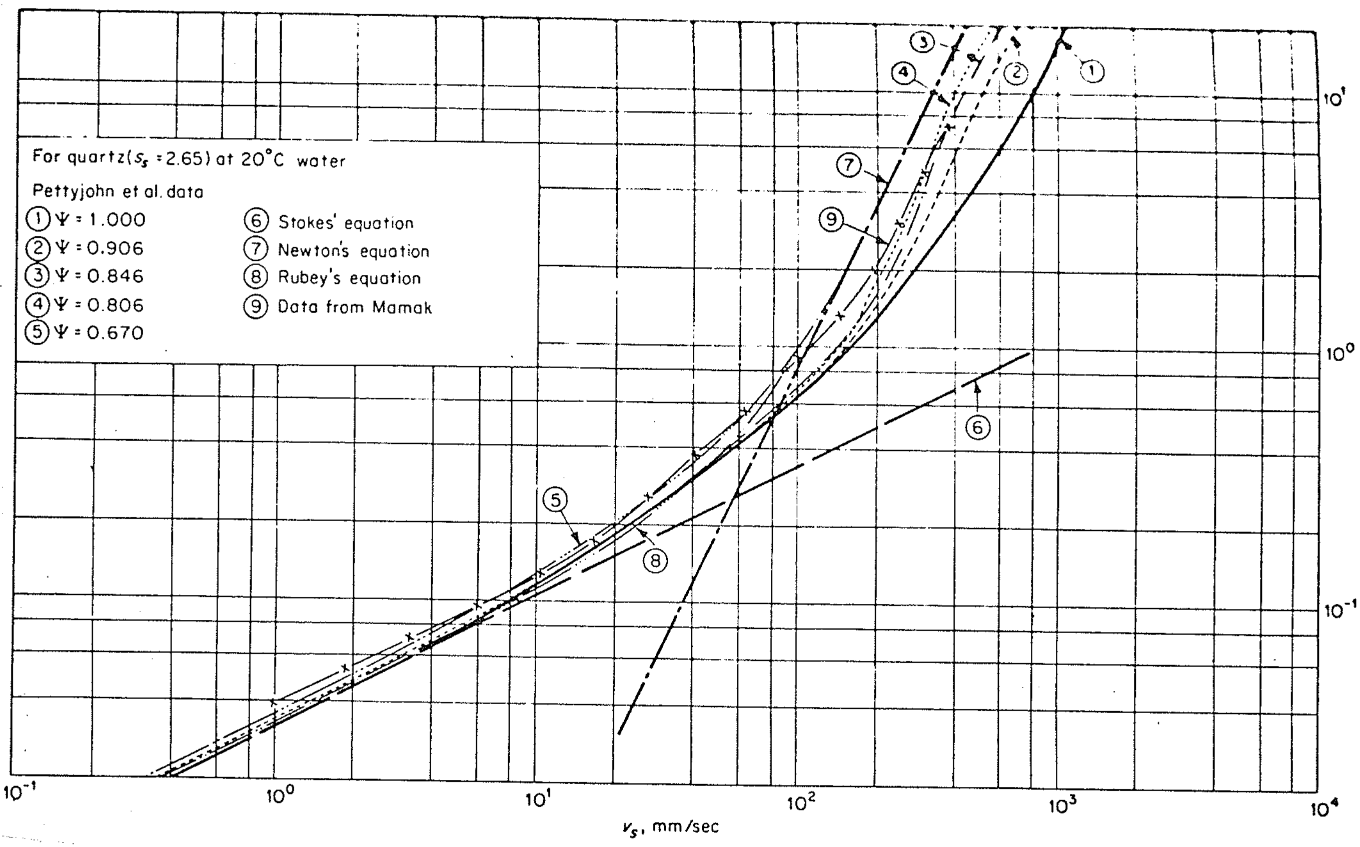


Figure 2.1 Forms of Bed Roughness in Alluvial Channels (Simons and Richardson. 1961)



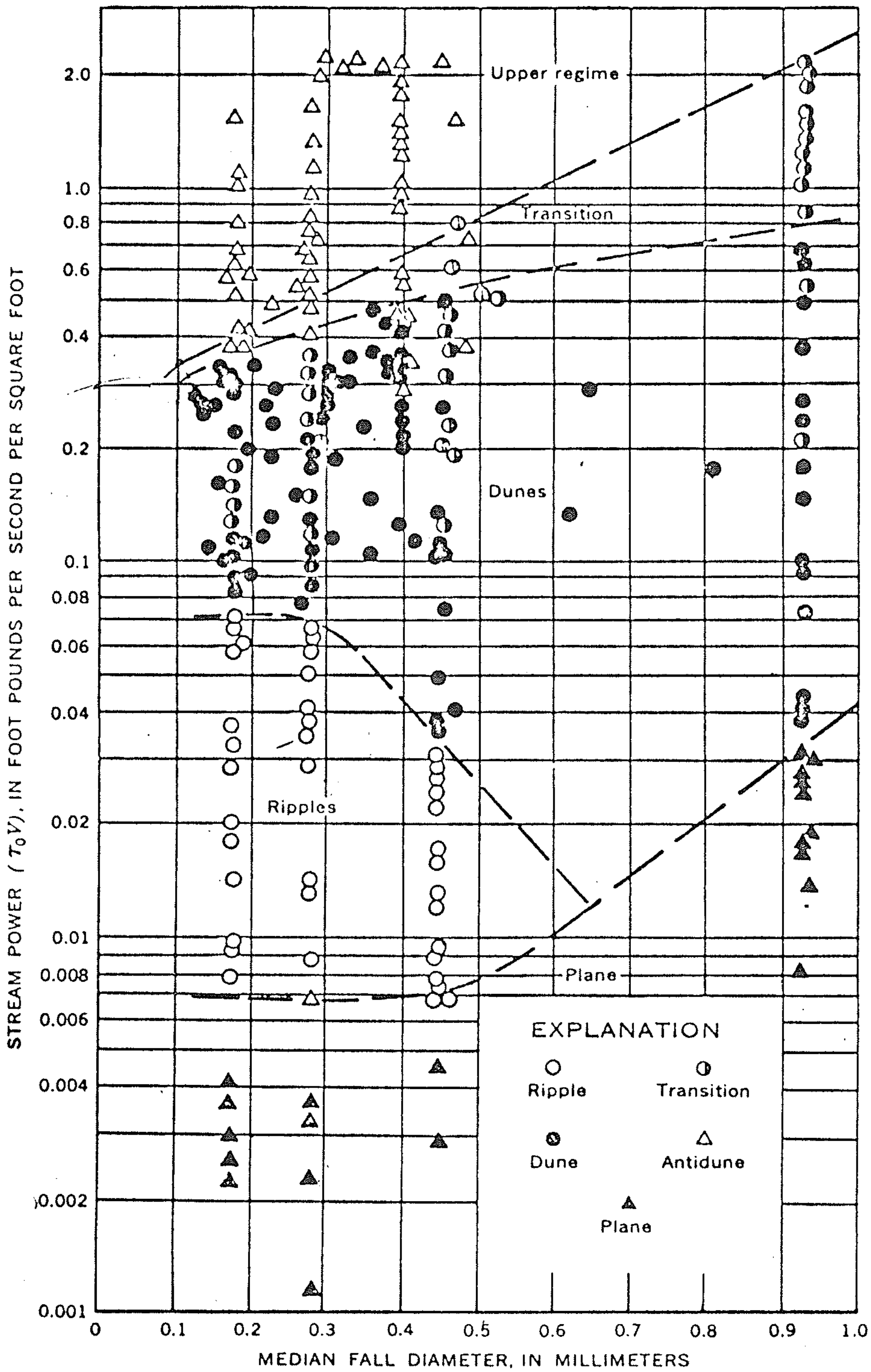
Critieria for Bedforms in Alluvial Channels (after Albertson et al., 1958)

Figure 2.2



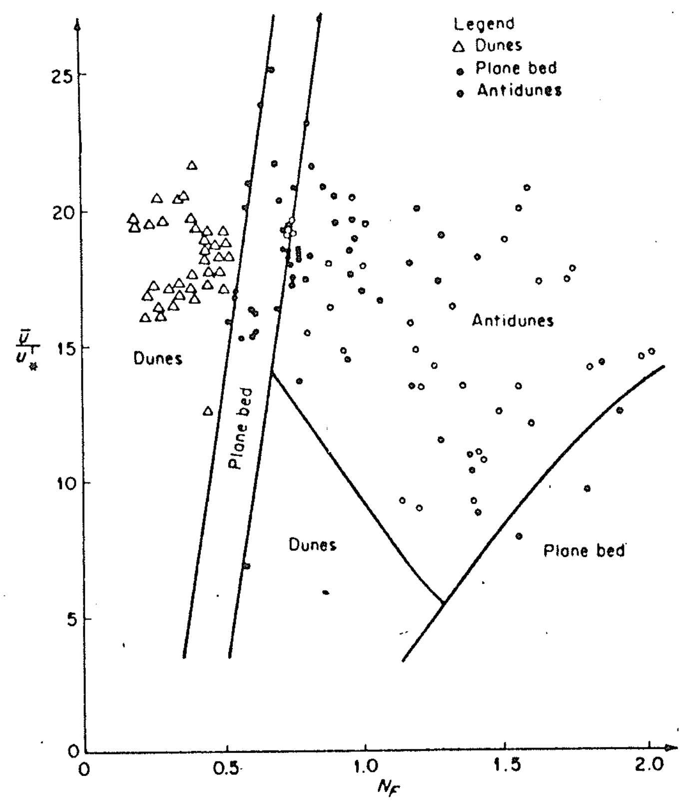
Settling velocity vs. particle diameter; various equations and shape-factor parameters Ψ. [*After* GRAF *et al.* (*1966*).]

Figure 2.3



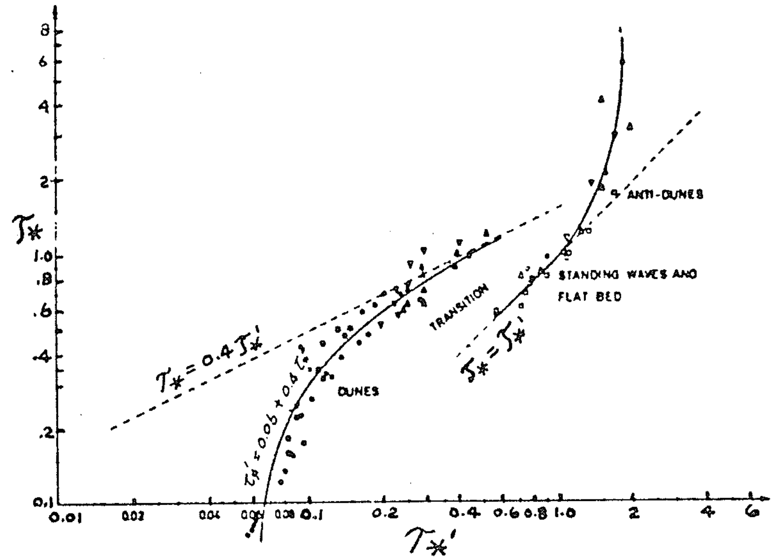
Relation of Stream Power and Median Fall Diameter to Bed Form (after Simons et al., 1963).

Figure 2.4



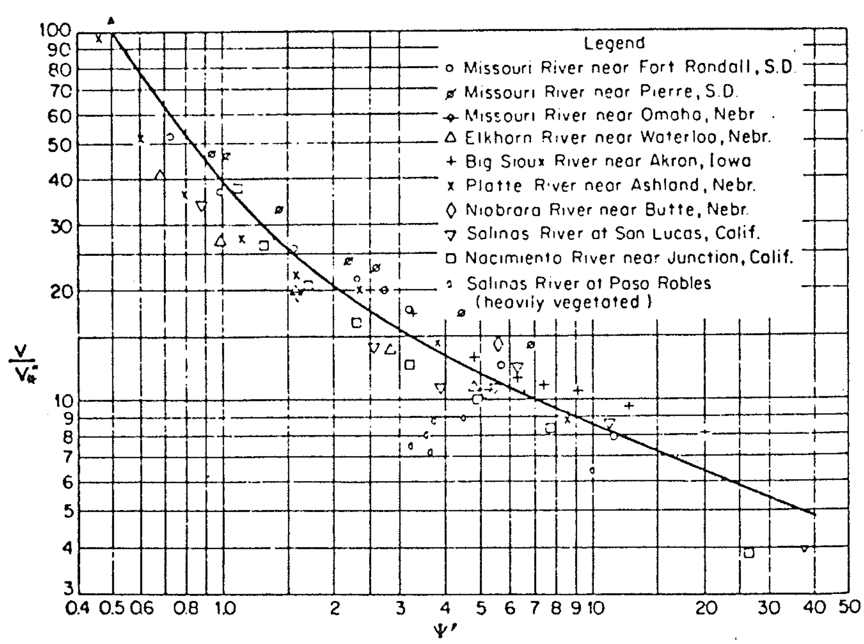
Stability of Various Bed forms (after Engelund et al., 1966).

Figure 2.5



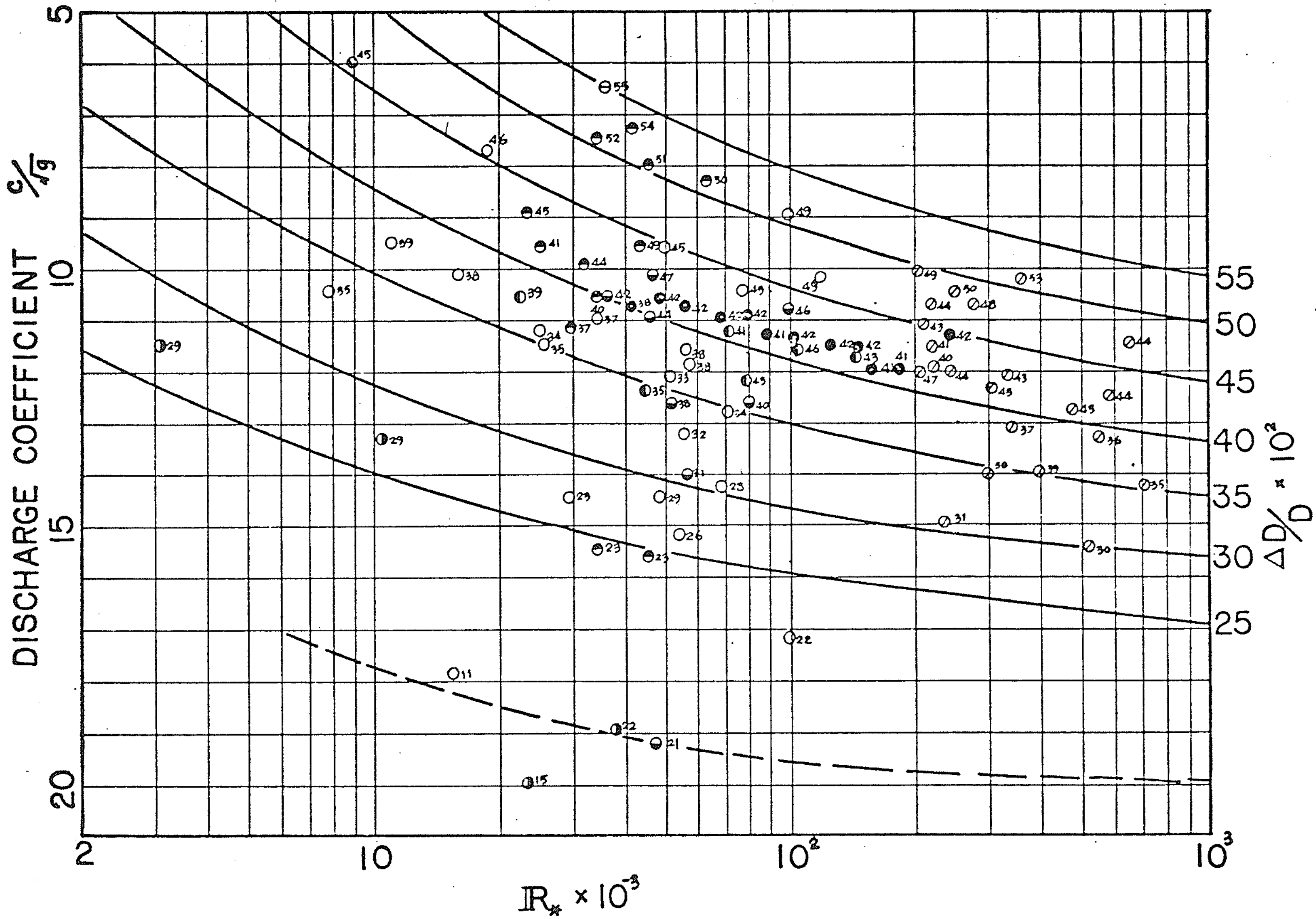
Engelund's Relation Between Normalized Grain Roughness Shear Stress, τ_* and Normalized Total Shear Stress, τ_*'.

Figure 2.6



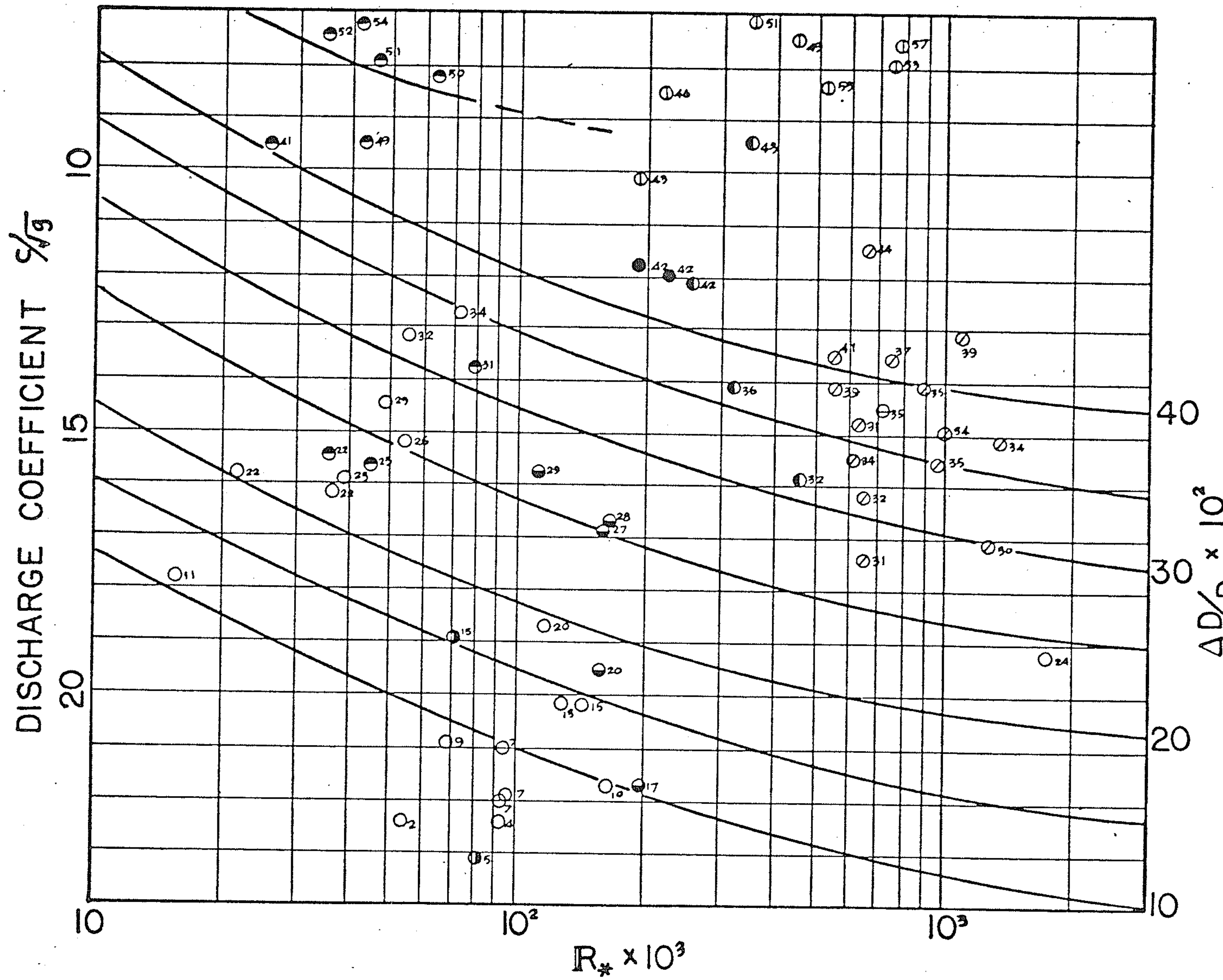
Einstein and Barbarrossa Bar Resistance Curve

Figure 2.7



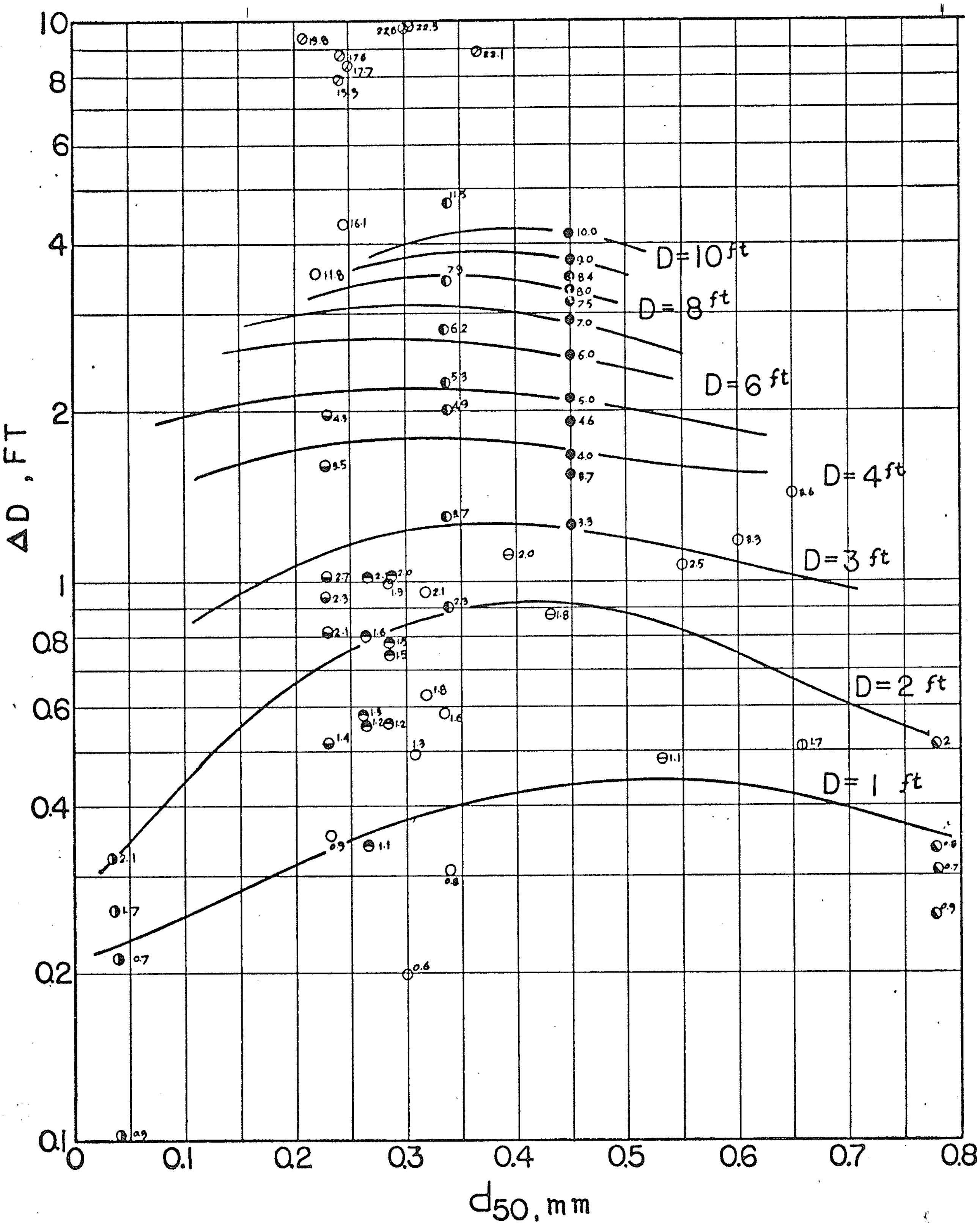
Resistance Diagram Relating $C/\sqrt{g}$, $R*$, and $\Delta D/D$ For The Lower Flow Regime

Figure 2.8



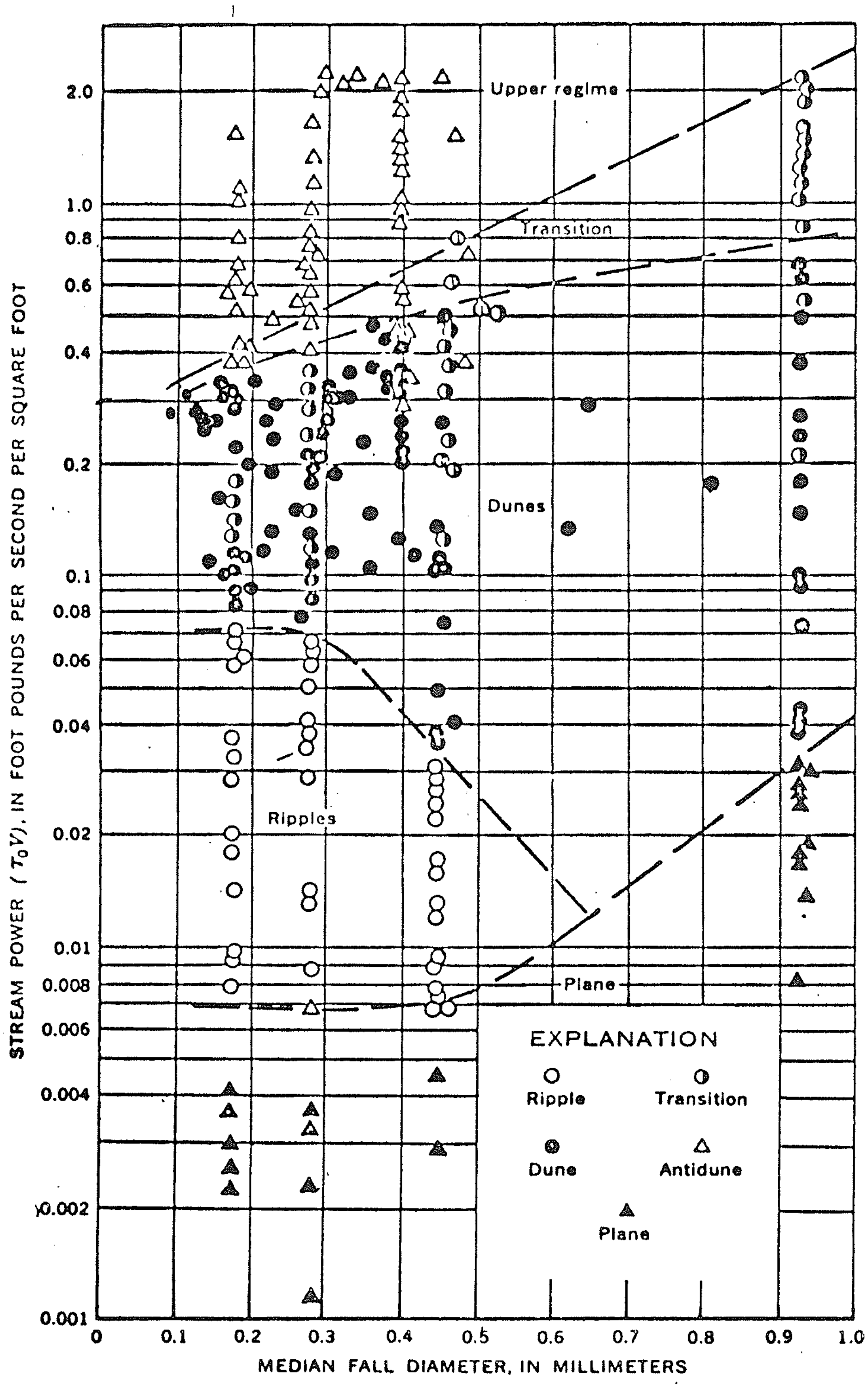
Resistance Diagram Relating C/ g , R* , and D/D For The Upper Flow Regime

Figure 2.9



Relation Between The Depth Adjustment, D ; Sediment Size, d_{50} ; And Depth For The Lower Flow Regime Plotted on Semi-Log Scale

Figure 2.10



Relation of Stream Power and Median
Fall Diameter to Bed Form
(Simons et al., 1963)

Figure 2.11

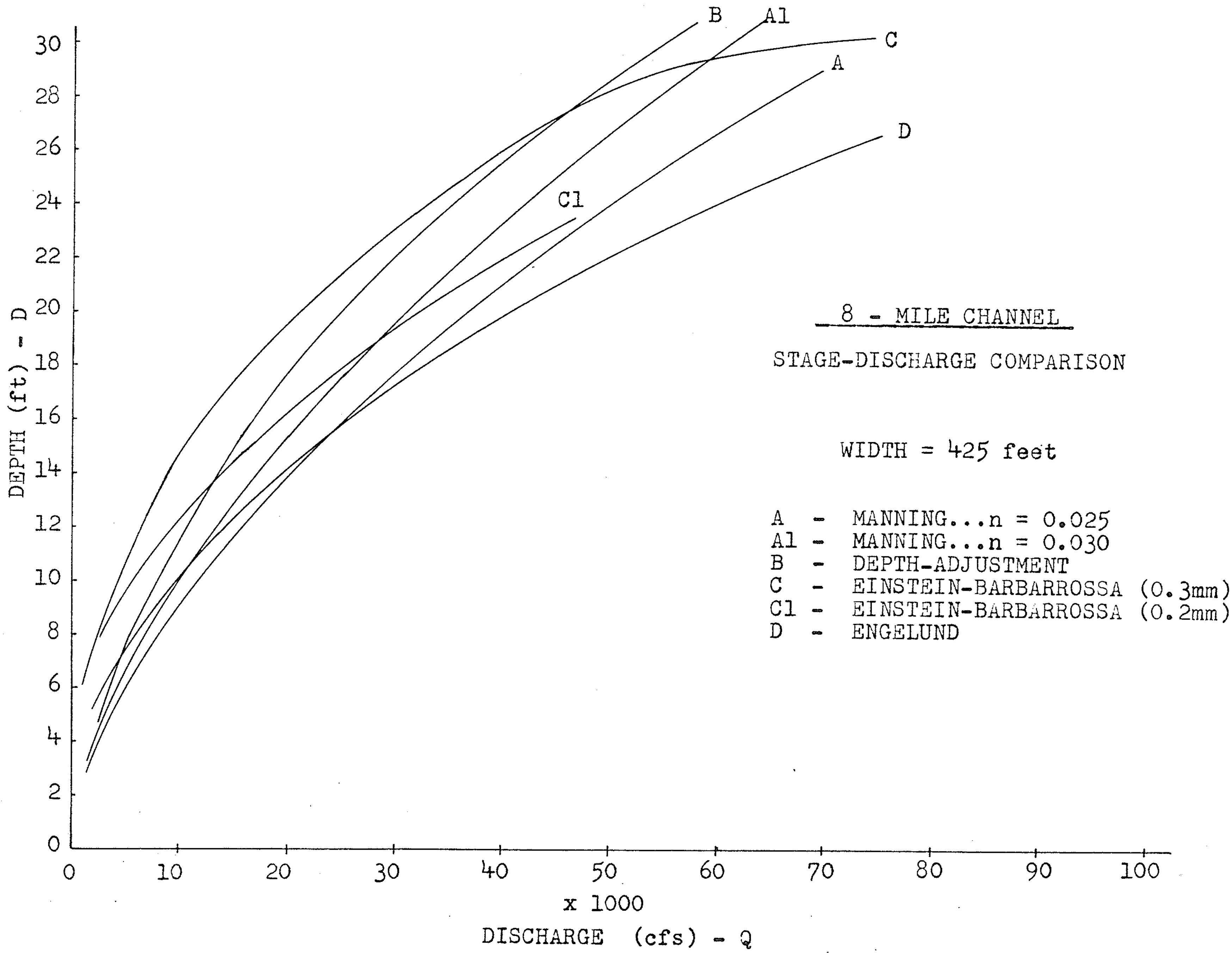
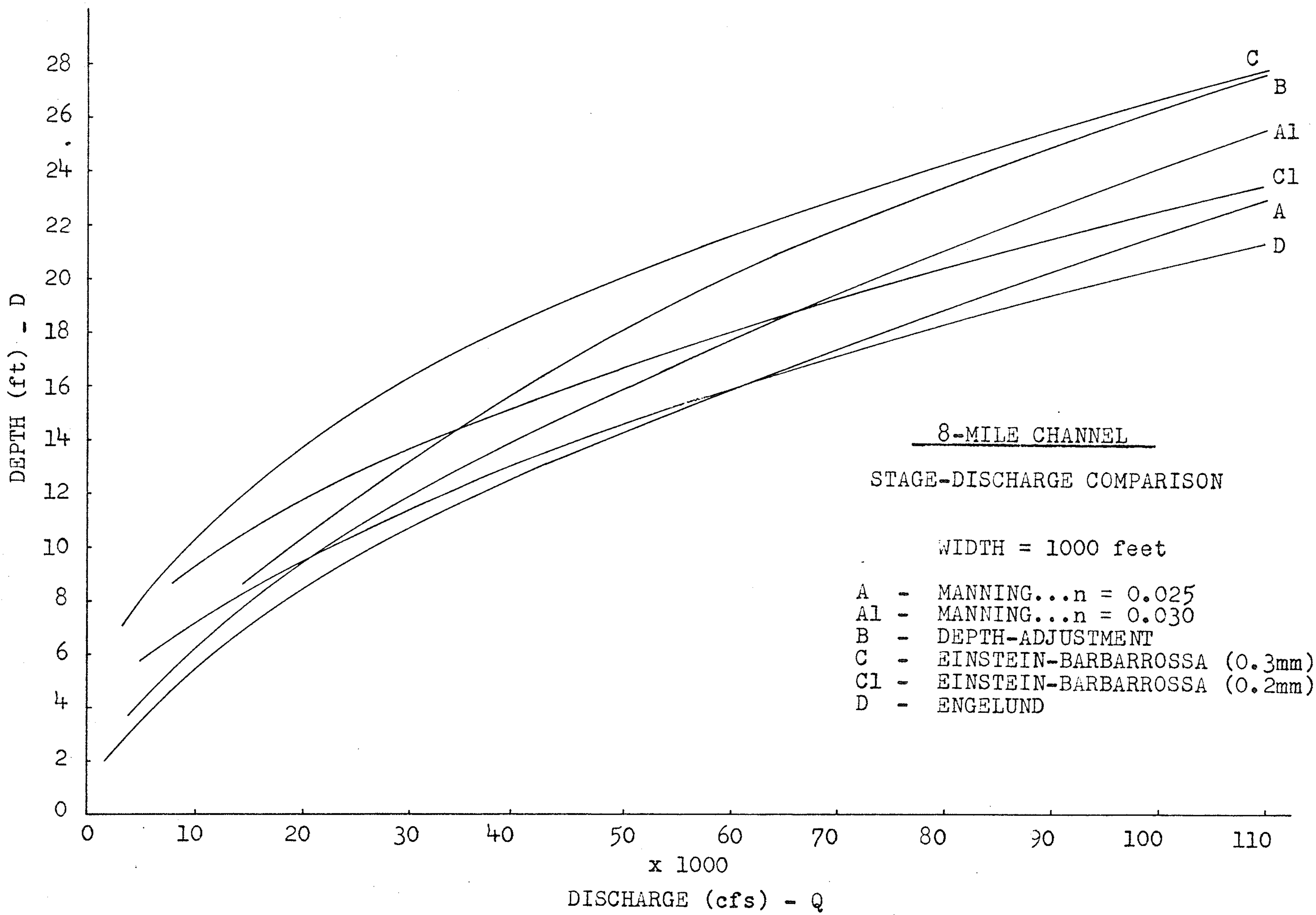
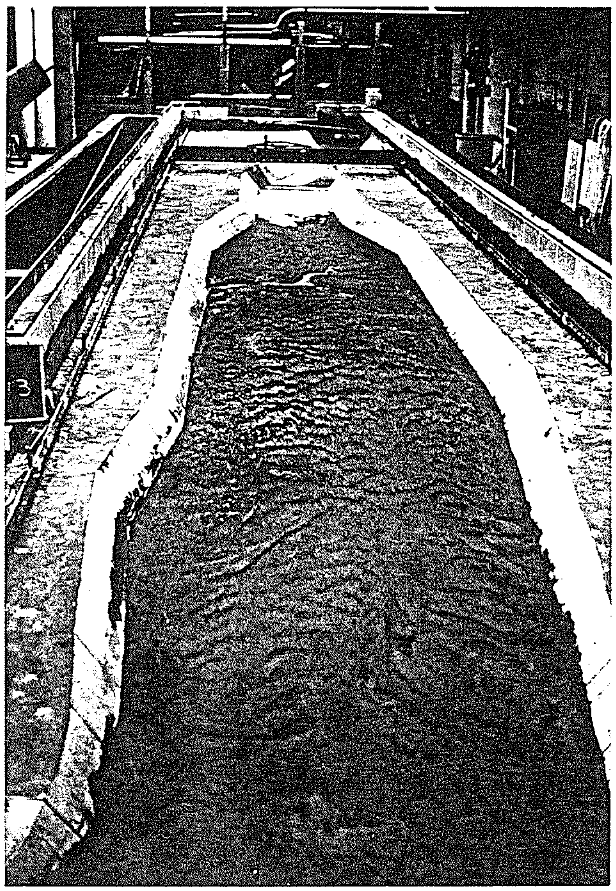

B
A1
C
A
D
C1
8 - MILE CHANNEL
STAGE-DISCHARGE COMPARISON
WIDTH = 425 feet
A - MANNING...n = 0.025
A1 - MANNING...n = 0.030
B - DEPTH-ADJUSTMENT
C - EINSTEIN-BARBARROSSA (0.3mm)
C1 - EINSTEIN-BARBARROSSA (0.2mm)
D - ENGELUND
DEPTH (ft) - D
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
0
10
20
30
40
50
60
70
80
90
100
x 1000
DISCHARGE (cfs) - Q

Figure 2.12

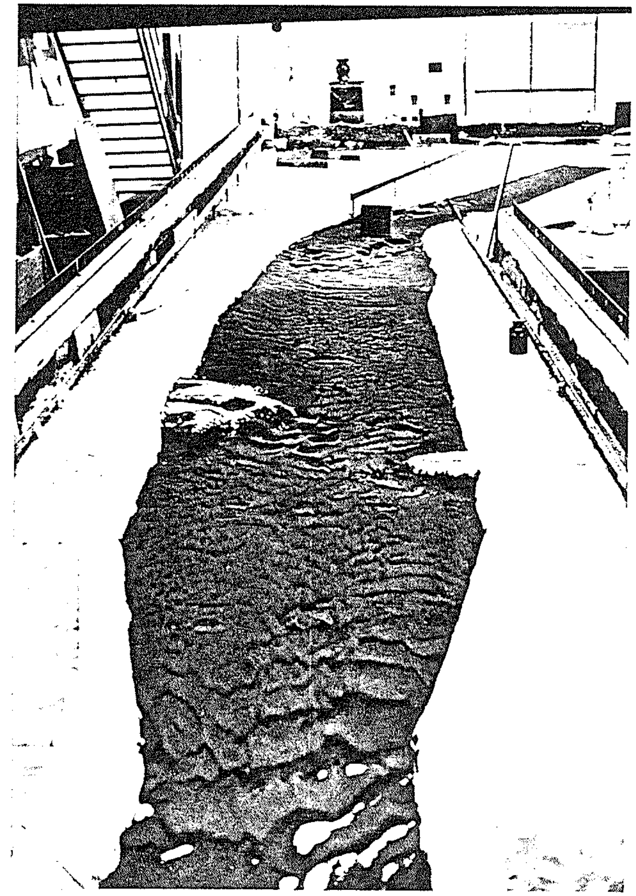


C
B
A1
C1
A
D
DEPTH (ft) - D
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
110
x 1000
DISCHARGE (cfs) - Q
8-MILE CHANNEL
STAGE-DISCHARGE COMPARISON
WIDTH = 1000 feet
A - MANNING...n = 0.025
A1 - MANNING...n = 0.030
B - DEPTH-ADJUSTMENT
C - EINSTEIN-BARBARROSSA (0.3mm)
C1 - EINSTEIN-BARBARROSSA (0.2mm)
D - ENGELUND

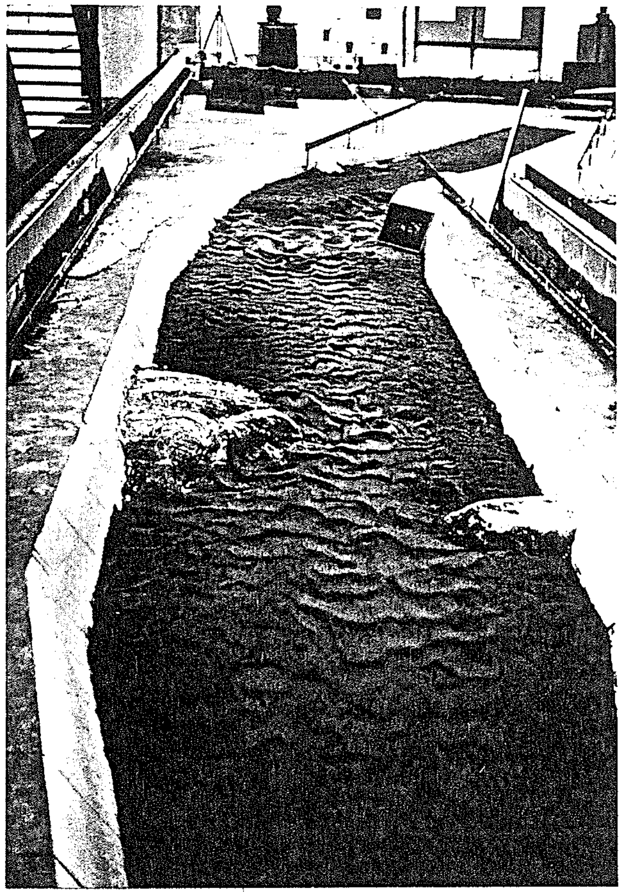
Figure 2.13



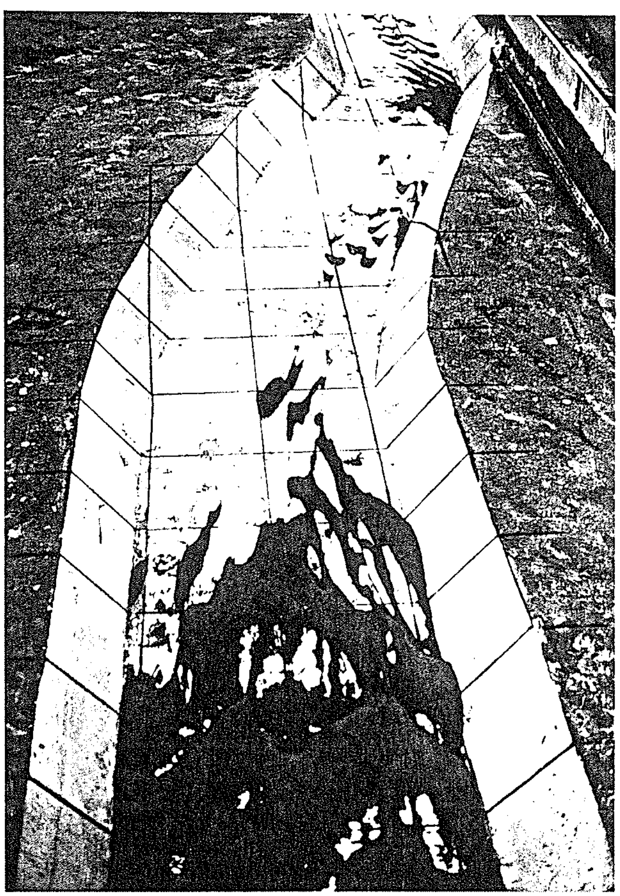
2.6.1 (21,000 cfs)



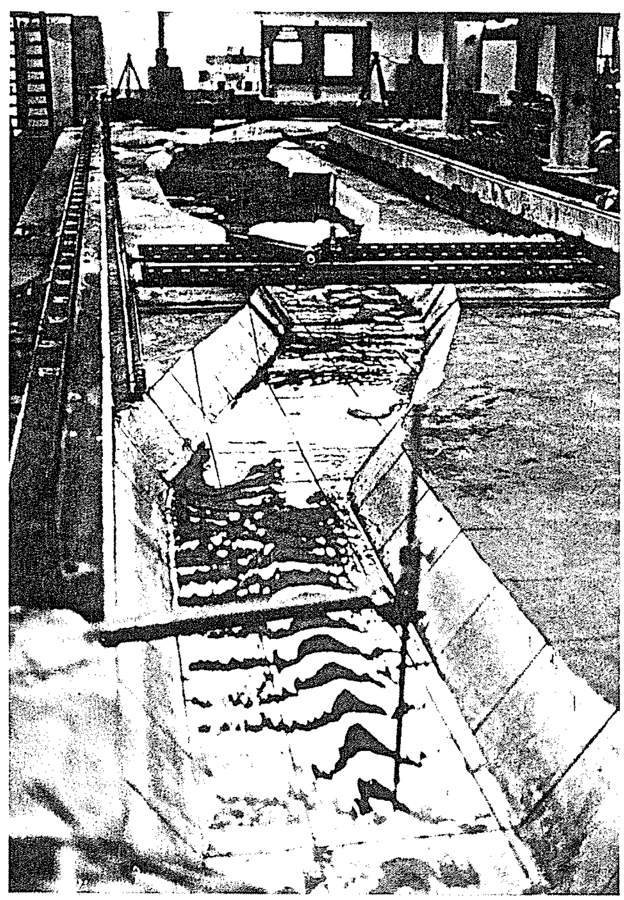
2.6.2 (40,000 cfs)



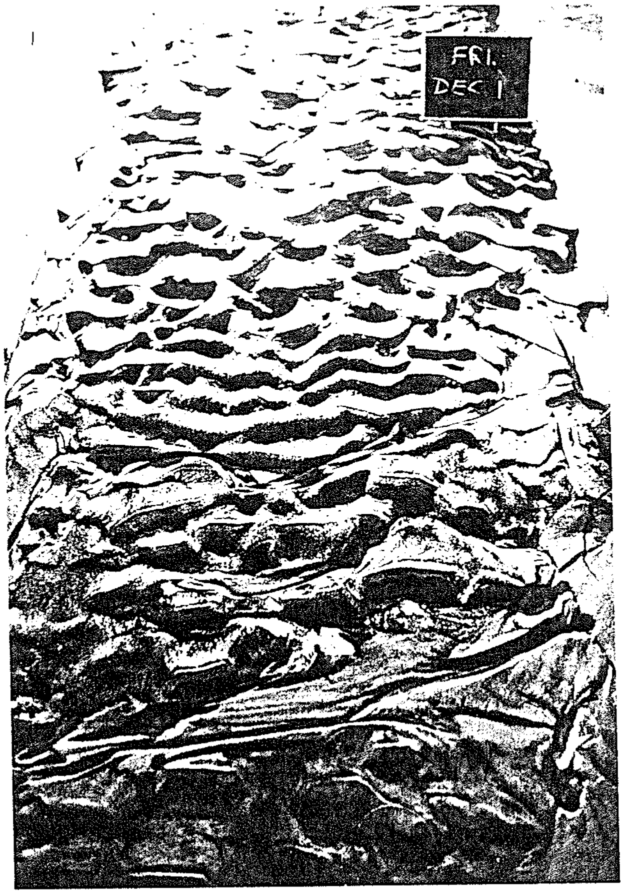
2.6.3.a
(56,000 cfs)



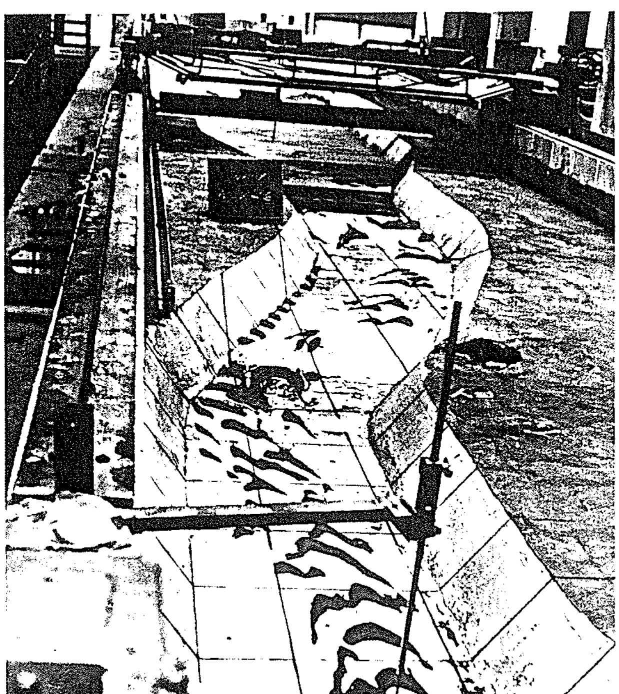
2.6.3.b



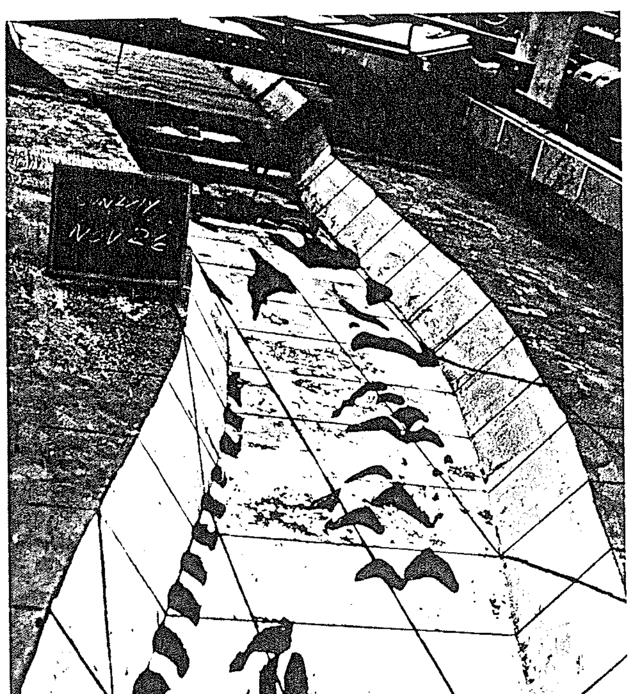
2.6.3.c



2.6.4.a
(80,000 cfs)



2.6.4.b



2.6.4.c

CHAPTER III

BED MOVEMENT IN THE 8-MILE CHANNEL

CHAPTER III

Bed Movement in the 8-Mile Channel

3.1 Introduction

The entrance of the 8-Mile Channel is composed chiefly of sand, with gravel and clay lenses. See Figure 1.3. Of significant importance is the alignment of the channel and flow through this portion. The most important questions raised concerning this 1000 ft. section of the channel are:

(1) Will a large amount of sand be removed from the entrance under the normal range of flows?

(2) Will the resistance to flow (channel roughness) change appreciably with erratic changes in entrance morphology?

(3) Will the alignment of the channel entrance have any effect on the flow in the channel, and is meandering to be expected in the downstream portion of the channel because of this alignment?

(4) Will the rock outcroppings have any effect on channel flow and meandering initiation?

(5) Can the sand movement and meander initiation be controlled by the use of channel stabilization and channelization works?

These important questions are discussed in three parts:

(A) Channel entrance condition (3-A)
(B) Meander initiation condition (3-B)
(C) Possible stabilization and channelization works (Chapter IV)

3.A - CHANNEL ENTRANCE CONDITIONS

3.A.1 Introduction

Natural shoreline processes of wave action, bank erosion, and slumping indicate that under natural conditions this entrance portion of the channel is undergoing constant change. See Photo 1.2. The alignment and water flow variation have very detrimental effects on the entrance in terms of sand movement, scour, degradation and aggradation.

The model study indicates changes to the channel morphology. The testing included discharges between 21,000 cfs and 80,000 cfs, operated for a sufficient length of time for changes to establish themselves.

The direction of water flow approaching the channel is a key factor in the occurring changes. As can be seen from the photographs, and figures included, overbank flow perpendicular to the channel flow direction creates water eddies and increased turbulence. This turbulence consequently produces severe scour initiating at the bank edges, and once the scour has begun, it continues on downstream in varying stages depending on flow condition. This sand movement, and scour varies between slight bank erosion to severe scour patterns which cover the width of the channel. Figure 3.1.

A detailed description of the conditions, with diagrams, and photos can be found in the following figures:

(1) Figure 3.A.1 21,000 cfs
(2) Figure 3.A.2 40,000 cfs

(3) Figure 3.A.3 56,000 cfs

(4) Figure 3.A.4 80,000 cfs

3.A.2 Model Observations

See Figures 3.A.1 → 3.A.4.

3.A.3 Sediment Transport

The question arises as to how much material will be removed from the channel entrance, and what is a fair estimation of channel bed degradation.

Preliminary computations, (Appendix C-1), indicate that a reasonable amount of sand may be removed from the 8-Mile Channel entrance at higher flows, resulting in an approximate rate of degradation of one foot per year. This approximated rate should decrease in time, due to possible paving of the channel bed by gravel lenses, and possible deposition of sand into the entrance by littoral currents in Playgreen Lake.

3.B - CHANNEL MEANDER CONDITIONS

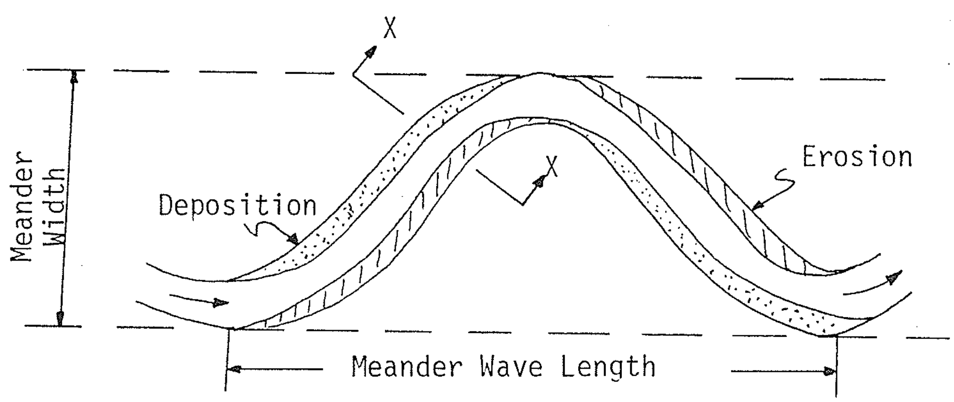
3.B.1 Introduction

The term "meander" is derived from "Maiandras" the Greek name of a winding river in Asia Minor.

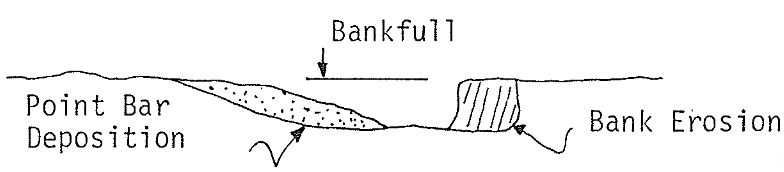
Meandering results from variations in velocities in a x-section, local bank erosion and consequent local overloading and deposition by the river of the heavier sediments which move along the bed.

Nearly all rivers exhibit some tendency to develop a pattern which seem to be proportional to the size of the channel. These curves seem to develop in symmetrical patterns.

Meander wave length is empirically related to the square root of effective or dominant discharge.



PLAN



SECTION X-X

Determining the theoretical meander wavelength of the channel was done by following the relationship developed by G. H. Dury, 1965. The empirical relation $L \propto Q^{0.5}$ between meander wavelength and bankfull discharge has proven to be realistic in estimate because of the data used in the technique. Leopold and Wolman (1957) concluded that bed width is determined directly by discharge, whereas wavelength depends directly on width and thus only indirectly on discharge. Wavelength should range generally from 8-12 times the bed width. Slightly higher ratios are used by practicing engineers when flow is below bankfull (12:1). The technique is proven by statistical connection. The data ranged in magnitude of flows from 0.02 cfs to 1 million cfs on the Missouri River. The sets of data from the author and Leopold and Wolman accord well with each other. Slope and velocity may not be immediately relevant in determining a general equation for wavelength. The basic form of the equation is:

$$L = KQ^{B} \quad (3.B.1)$$

L = wavelength of stream meander in feet

Q = discharge at bankfull capacity

K = coefficient

B = power

The equation used for the 8-Mile Channel and the best fit for the data is:

$$L = 30Q^{0.5} \quad (3.B.2)$$

For the 8-Mile Channel Q was taken as 56,000 cfs, the maximum recorded flood, which occurred in 1966. This gives a meander wavelength of:

$$L = 30Q^{0.5}$$

$$L = 7130 \text{ ft.}$$

Dury's method was checked using the techniques developed by Leopold and Wolman (1960) and Inglish (1947). On closer examination, the Inglis (1947) method produces a very tortuous meander pattern, and was subsequently discarded as Inglis data was for incised rivers and rivers on flood plains, which is not the case of the 8-Mile Channel. The Leopold and Wolman (1960) method produced a wavelength of 7,200 feet, very close to the 7,130 ft. predicted by Dury.

See Appendix C-2 for Leopold & Wolman (1960) meander wavelength technique.

Model observations in the 425 foot section of the channel indicated a channel meander length of approximately 7000 ft.

3.B.2 Model Observations of Meander Conditions

The observation of possible meander patterns in the 8-Mile Channel is one of the most important purposes of the hydraulic model study. Conditions and subsequent patterns can be easily identified through the use of a moveable bed model.

The following questions are examined:

(1) Will meandering occur within the channel due to the present alignment?

(2) Will the channel entrance condition, scour, and bed material movement affect the initiation of channel meander?

(3) Will the presence of rock outcroppings within the channel have any effect on possible channel meander?

These questions are discussed by model observations in:

Figure 3.B.1	21,000 cfs
Figure 3.B.2	40,000 cfs
Figure 3.B.3	56,000 cfs
Figure 3.B.4	80,000 cfs

Note:

(1) Pictures and observations are made from a number of tests at each flow condition.

(2) On the figures, the four main channel outcroppings will be named by their respective station numbers. Rocks 120+00, 126+00, 158+00, and 172+50.

(3) Dye tracings and float observations were made and recorded to establish flow patterns.

(4) The time duration for each test was sufficient to allow any changes to occur (up to 30 hours).

3.2 Conclusions

Channel bed movement is an extremely important consideration in the successful design of a waterway. Changes in channel morphology are easily observable in a moveable bed model study. Care must be taken when directly applying model results to prototype conditions, as moveable bed model studies are more qualitative than quantitative.

The following conclusions are made concerning bed movement and meander in the 8-Mile Channel:

Channel Entrance

Overbank flow from Playgreen Lake will cause bed movement and scour at the channel entrance. As can be seen by Figure 3.1, overbank flow is perpendicular to the main body of flow within the channel. The sudden interaction of these opposing flows produces turbulence, eddies, and water vortexes. The subsequent entrance scour varied between local for the 21,000 cfs flow, to severe at the 80,000 cfs flow. This bed movement causes scour, bed form formation, and consequently increases the channel roughness factor. This increased roughness factor reduces the expected efficiency of the channel.

Bed material did move out of the channel entrance at all flows, and was either deposited in the 1000 ft. section, or transported entirely through the model. Large amounts of sand will be removed from the channel entrance at flows less than the 50% duration flow.

It is recommended that the excavation of material along the north shore between stations 75+00 and 100+00 be omitted from the design. This portion of the north bank was very inefficient in passing flow. Aggradation of material scoured out of the entrance occurred here to a significant amount, and because of channel alignment, very low velocity water, or reverse flow was observed in this section.

The excavation of bed material between stations 76+10 and 78+10 to enable the channel bed to drop 3 feet is impractical. Because of the nature of the bed material in this section, channel alignment and entrance scour, this steep sloped area was either quickly eroded away by water flow, or filled in, leaving behind a much smoother slope transition.

It is recommended that channel entrance works, or bank slope alterations be made to avoid the undesired bed movement out of the channel entrance, if the original design characteristics of the 8-Mile Channel are to be met.

The present alignment of the 8-Mile Channel entrance will initiate a meander within the channel at all flows. Through dye releases, it was observed that the main flow stream entered the channel from Playgreen Lake, along the middle of the channel, and was directed towards the south shoreline. This meander initiation continued on downstream from the entrance.

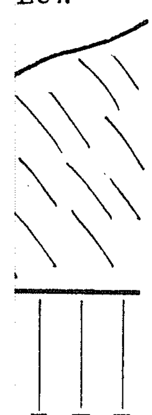
Channel Meander

The 8-Mile Channel will meander under all flow conditions, more readily at higher flows due to increased water velocities and bed movement. A theoretically calculated meander length of 7,100 ft. will be produced in the 8-Mile Channel, 425 ft. section, at flows of 56,000 cfs. This value is supported by observed model meander lengths of 7000 ft.

Present channel alignment will increase meander initiation. Rock outcroppings will increase the meander tendencies at all flows. Conversly, rock outcropping removal will decrease the meander patterns.

Bed roughness will be increased in the locality of rock outcroppings due to increased water velocities resulting from meander trends. Scour along banks in the downstream portion of the channel will be more pronounced due to channel meander, as indicated by velocities observed in the model.

Channelization works (i.e., spur dykes and revetments), are recommended to reduce meandering, thereby curtailing bed and bank erosion.



8 - MILE CHANNEL ENTRANCE CONDITIONS

DISCHARGE : 21,000 cfs

PLAYGREEN LAKE LEVEL : 713.3 feet

KISKITTOGISU LAKE BACKWATER LEVEL : 712.2 feet

DYE RELEASES

SCOUR

DEPOSITION

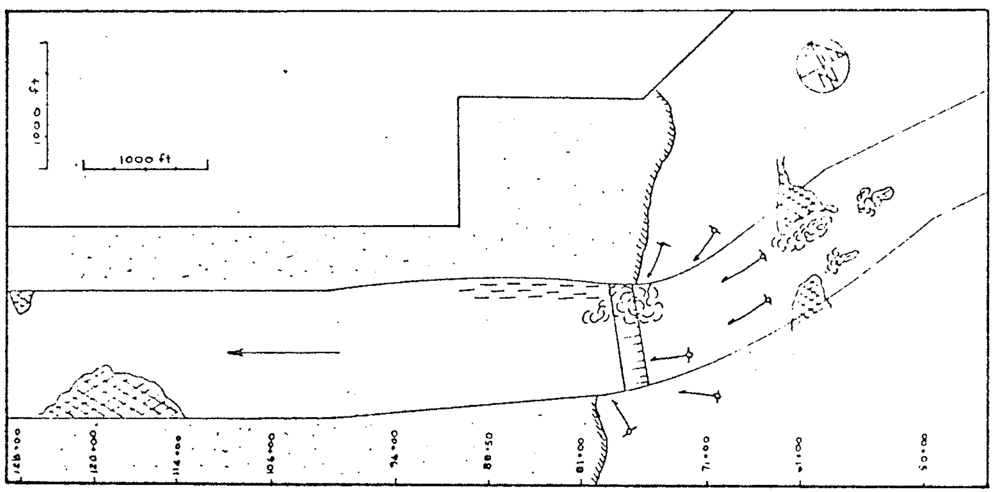


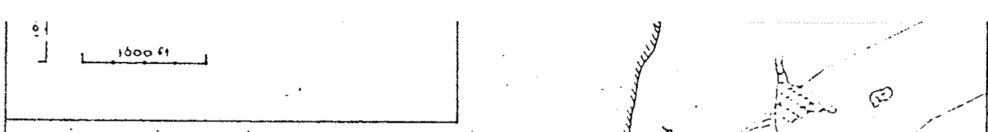
Figure 3.A.1

21,000 cfs.

The rock outcroppings in Playgreen Lake did show evidence of scour immediately around the rocks. This was expected and is not considered to be the cause of any real problems. This scour can be readily seen in photos 3.A.1.a,b, and c.

The over bank flow where the lake water level travels along the shoreline and into the channel showed a slight degree of turbulence when coming in contact with the in-channel flow. The turbulence was observed by releasing dye at various positions outside of the channel banks. This turbulence created eddies and high local velocities, thus causing some bed material to be transported away from the area. This scour due to the 21,000 flow is not severe and is confined to the over-flow area close to the bank, and does not erode downstream. It should be noted that the model has rigid banks and erosion would occur of the bank material to some degree.

It is also observed that scour and bed movement occurred only at the north shore. The scoured material deposited itself directly downstream of the overbank flow along the north shore portion of the channel, in the curved portion of the channel between stations 80+00 and 90+00.



decreased. The water levels were observed to increase due to the rise in bed form roughness.

8 - MILE CHANNEL ENTRANCE CONDITIONS

DISCHARGE : 56,000 cfs

PLAYGREEN LAKE LEVEL : 714.2 feet

KISKITTOGISU LAKE BACKWATER LEVEL : 713.45 feet

DYE RELEASES

SCOUR

DEPOSITION

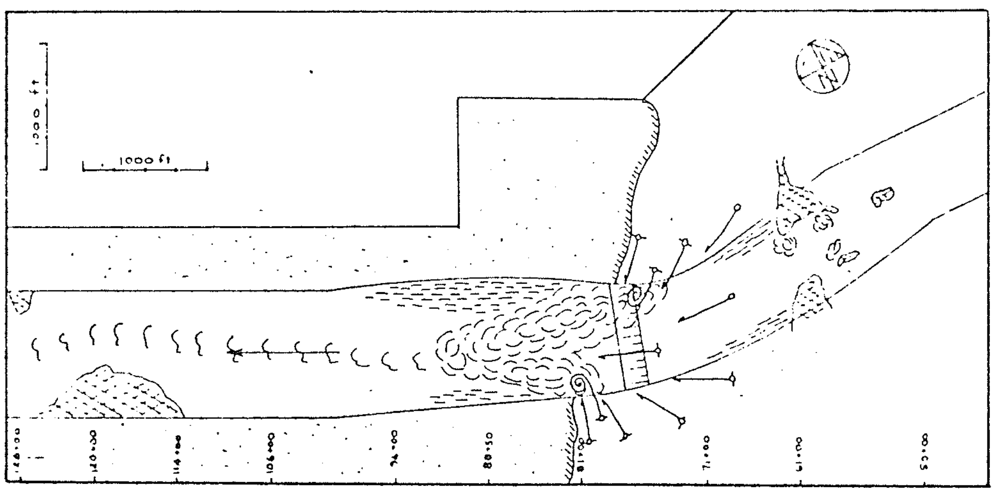


Figure 3.A.3

FIG. 3.A.3

56,000 cfs.

At 56,000 cfs, there was no appreciable scour around the rock outcroppings in the Playgreen Lake portion of the channel, probably due to the fact that the water depths were large. This can be seen in photo 3.A.3.a.

There was, however, a definite increase in water depths due to the rise in bed form roughness. The high flow of 56,000 cfs produced a considerable amount and depth of over-bank flow, coming into perpendicular contact with the main channel flow. Dye releases in the lake showed considerable turbulence when the main channel flow was intercepted. The resulting eddies, vortexes and increased local velocities initiated considerable scour and erosion beginning at the north shore, and continuing on downstream until the 1000 ft. straight section was encountered, where the velocities reached an equilibrium. See photo 3.A.3.b. Scour was also initiated along the south bank and moved towards the center of the channel where large scour holes occurred when the scour pattern from the north bank was contacted. The scoured material from the north shore was deposited along the curved portion of the north bank where the velocities are lower than the rest of the channel. This can be seen in photo 3.A.3.b and 3.A.3.c. The bed elevation was raised up a number of feet in this area, and the water in this curved section was dead water, or water with extremely low velocities.

The entrance conditions produced velocity, and meander patterns undesired in the channel.

8 - MILE CHANNEL ENTRANCE CONDITION

DISCHARGE : 80,000 cfs

PLAYGREEN LAKE LEVEL : 720.9 feet

KISKITTOGISU LAKE BACKWATER LEVEL : 719.9 feet

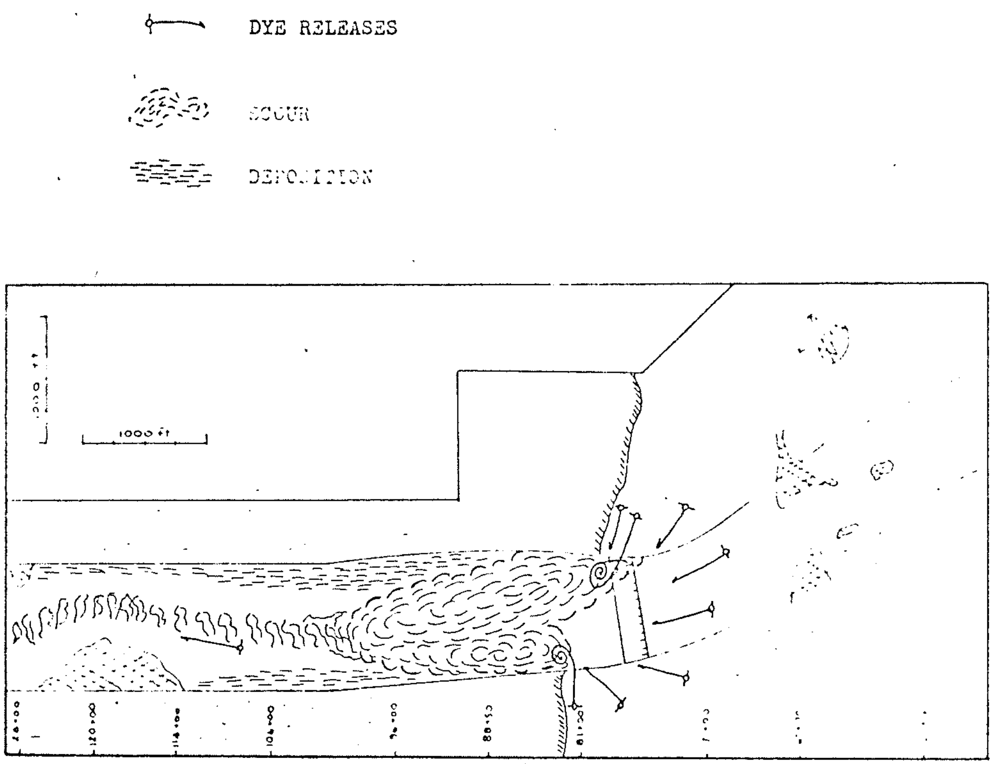


Figure 3.A.4

FIG. 3.A.4

<u>80,000 cfs.</u>

80,000 cfs is the one in ten thousand flood, and therefore the model testing at this flow represents the worst possible condition that could occur. After this flow has run for a number of hours, it is readily observable that severe bed material erosion and degradation will occur along the entire length of the channel.

Due to the high lake levels, the overbank flow from Playgreen Lake into the 8-Mile Channel is very significant. Dye patterns, and observations clearly indicate the severe water turbulence, high local velocities, and surface boils. The high flow produces high velocities, velocities higher than designed for, and the bed material easily moves out of the channel entrance. Erosion occured at both the north and south channel banks, and continued on downstream. The severe scour holes and large bed forms reduced to bedforms where the flow became smooth in the 1000' straight section. See photo 3.A.4.a. The bed movement did occur, however, along the entire length of the 1000 ft section. See photo 3.A.4.b. The main channel flow, contacting the overbank flow perpendicular to the channel produced turbulence enough to cause scour across the entire channel width. The north shore edge eroded first, but the south edge followed soon after until they interacted near the center of the channel. See photo 3.A.4.c. The bed material was scoured down to the bed rock at certain locations in the channel entrance, see photo 3.A.4.c to the left center of the photograph.

Scour at the rock outcroppings in Playgreen was not significant, probably due to the depth of water over the rocks.

The 80,000 cfs flow produced definite channel entrance morphology changes, which had a definite detrimental effect on the hydraulic characteristics of the rest of the channel.

8 - MILE CHANNEL MEANDER CONDITIONS

DISCHARGE : 21,000 cfs

PLAYGREEN LAKE LEVEL : 713.3 feet

KISKITTOGISU LAKE BACKWATER LEVEL : 712.2 feet

DYE RELEASES

MEANDER PATTERN

SCOUR

DEPOSITION

FIG. 3.B.1

21,000 cfs.

At 21,000 cfs, the water depths are small, and consequently, the major portion of the flow is carried around any major rock outcroppings. Observations were made at the following points on the diagram, by tracing dye patterns along the channel.

position (1) channel entrance - water on entering the channel flows along the south bank and continue straight downstream to the first outcroppings.

position (2) at the outcroppings, #120+00 and #126+00, the water is channeled around the rocks, first to north around the rock 120+00, and channeled to the south by rock 126+00, towards the center of the channel. Flow remains fairly straight down the center of the channel until rocks 158+00, and 172+50.

position (3) at rocks 158+00, the water flows around it creating turbulence and scour around the rock, and the main direction of the flow is then diverted south due to rock 172+50.

position (4) at the constriction to 425', and curve in the design of the channel, initiates a meander towards the north bank.

Scour is indicated on plan, at channel entrance, and outcroppings.

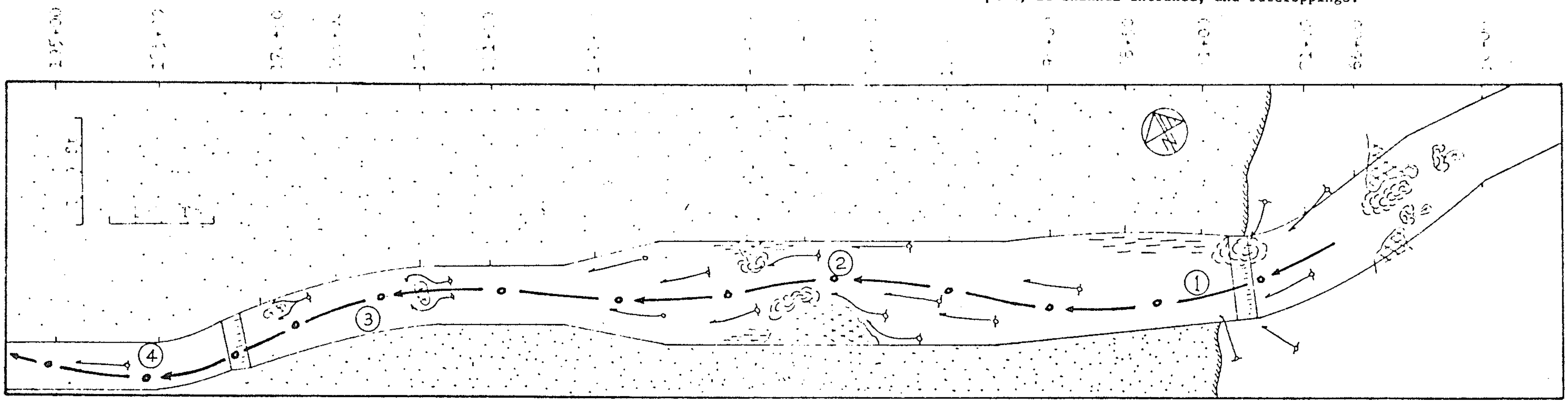


Figure 3.B.1

8 - MILE CHANNEL MEANDER CONDITIONS

DISCHARGE : 40,000 cfs

PLAYGREEN LAKE LEVEL : 713.8 feet

KISKITTOGISU LAKE BACKWATER LEVEL : 712.9 feet

DYE RELEASES

MEANDER PATTERN

SCOUR

DEPOSITION

40,000 cfs

At 40,000 cfs, the flow of water creates a depth of water which flows over the channel rock outcroppings. Dye tracings and float observations were made to establish characteristic flow patterns.

Position (1) at the channel entrance, dead water was observed in the material deposition area along the north shore and the flow was directed towards the south edge of the channel. Photo 3.B.2.a.

Position (2) the main body of flow was observed to wander across the channel towards the north edge where rock 120+00 directed this water at the north shoreline. Velocities were observed to increase in this section. Rock 126+00, and the backwater before it, redirected the water flow towards the south shoreline. Slow water downstream of rock 120+00 prevented this water from coming all the way across the channel and directed the main flow into the transition zone.

Position (3) rock 158+00 showed water turbulence and scour around the rock. The water moving away from rock 158+00 was turbulent with surface ripples, and local velocities were high at the edges. Rock 172+50 redirected the flow to the south side of the channel.

Position (4) the main body of flow entered the 425 foot section along the south portion of the channel, and was observed to meander back across the channel towards the north bank.

Scour was evident at the entrance, and around the outcroppings.

Some material was observed moving downstream.

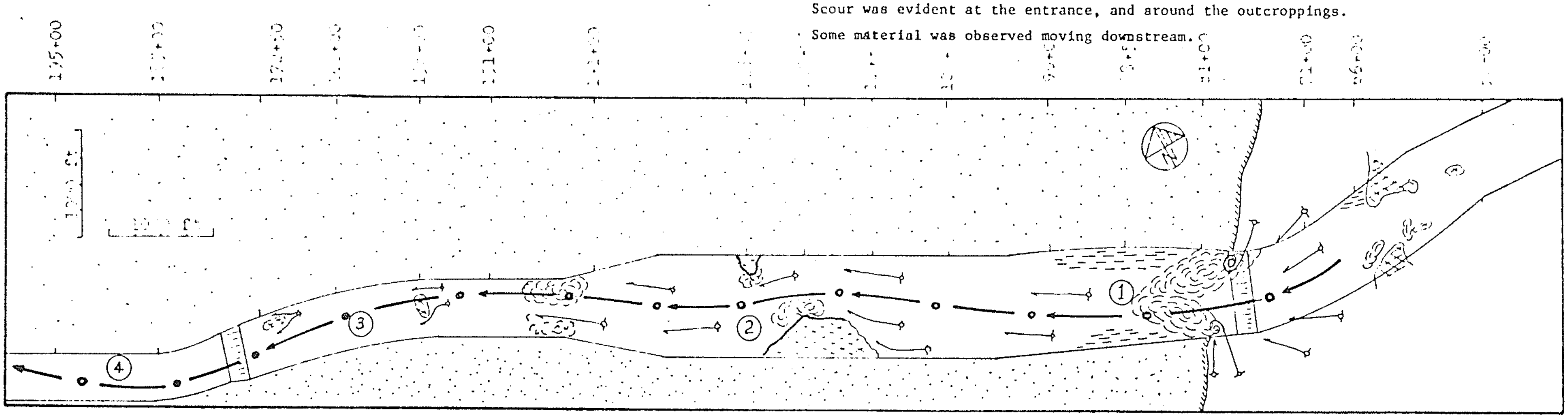


Figure 3.B.2

FIG. 3.B.3

8 - MILE CHANNEL MEANDER CONDITIONS

DISCHARGE : 56,000 cfs

PLAYGREEN LAKE LEVEL : 714.2 feet

KISKITTOGISU LAKE BACKWATER LEVEL : 713.45 feet

DYE RELEASES

MEANDER PATTERN

SCOUR

DEPOSITION

56,000 cfs

At 56,000 cfs, water depths are large, and water velocities are at maximum designed for.

Position (1) slow velocity water area was observed in the entrance where deposition occurred along the north shore of the channel. See photo 3.A.3.b. Scour resulted from high local velocities. These high velocities continued down the channel, moving from the south towards the north.

Position (2) the flow pattern is easily recognized by observing the pattern formed on the bed form configuration. The high velocities in the main flow produce a pattern of meandering bed forms around rocks 120+00, and 126+00. Scour occurred around both these rocks. As in the 40,000 cfs, rock 120+00 directed the main flow to the north, and rock 126+00 redirected the flow towards the south. At 56,000 cfs there is enough water flowing over rock 120+00 to reduce the dead water area downstream of the rock somewhat. The meander pattern was directed across the channel towards the north edge in the transition zone. Material along the north shore was moved out of this section and downstream. See photo 2.6.3.b.

Position (3) rock 158+00 had high local velocities and severe water turbulence downstream of it. Ripples on the water surface were observed, see photo 3.B.3.b. Rock 172+50 produced high local velocities along the north shoreline, and redirected the flow towards the south bank.

Position (4) flow was along the south bank coming into the 425' section, but meandered across the channel towards the north shore. This is readily seen in photo 3.B.3.c.

Scour was observed at the entrance, the rock outcroppings, and along the main stream of flow, or the thalwag of the channel. This bed movement clearly defined the possible meander patterns in the 8-Mile Channel at this 56,000 cfs. See photo 3.B.3.c.

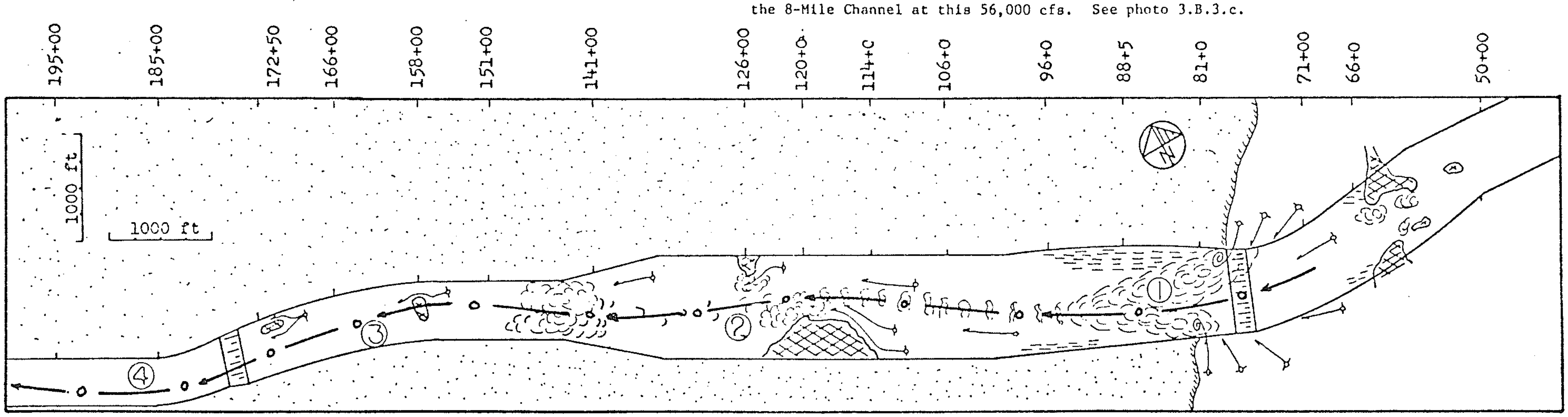


Figure 3.B.3

8 - MILE CHANNEL MEANDER CONDITIONS

DISCHARGE : 80,000 cfs

PLAYGREEN LAKE LEVEL : 720.9 feet

KISKITTOGISU LAKE BACKWATER LEVEL : 719.9 feet

DYE RELEASES

MEANDER PATTERN

SCOUR

DEPOSITION

80,000 cfs

The 80,000 cfs flow is an extreme flood flow and is defined as the maximum probable flow. The channel was not designed to carry this amount of water. This was easily seen by observing the model under this condition.

Position (1) channel entrance scour is seen in photo 3.A.4.c. Deposition and low velocity water is observed along the north shoreline. The main flow is towards the south edge of the channel.

Position (2) the main flow pattern is around the outcroppings and not directly over. The t alwag of the 8-Mile Channel is seen easily by dye releases, and by the pattern of scour, or bed movement in the channel. See photo 3.B.4.a. The main flow is directed north, south and then north again as it enters the transition zone. The bed material on the north side of the channel in the transition zone which is still composed of sand is eroded and transported downstream. See photo 3.B.4.b.

Position (3) rocks 158+00 and 172+50 have high local velocities along the shorelines, which will erode the banks. Turbulence and surface ripples were observed around the rocks. The main flow and bed material are directed from the north side ofthe channel towards the south edge just as it enters the 425 ft. section of channel. See photos 3.B.4.c and d.

Position (4) the main channel flow and moving bed material enters the 425 foot section along the south shoreline and then meanders across the channel towards the north shoreline. This is readily seen in photos 3.B.4.c and 3.B.4.d.

Bed material was observed moving along the channel and continued through to the end of the model.

Considerable scour and bed movement was observed along the entire length of the model.

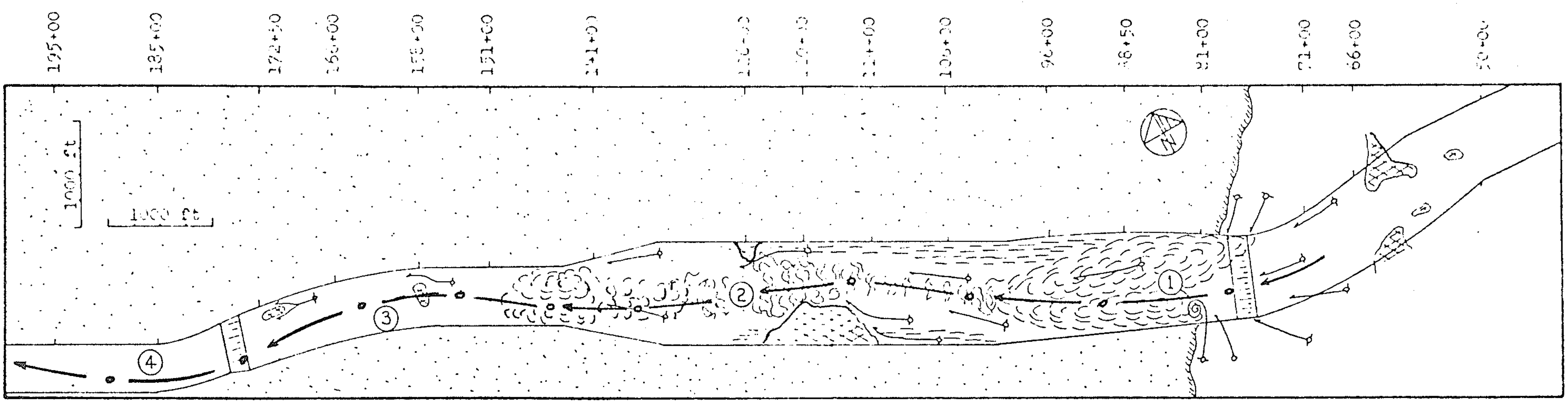


Figure 3.B.4

CHAPTER IV

POSSIBLE STABILIZATION AND CHANNELIZATION WORKS

CHAPTER IV

Possible Stabilization and Channelization Works

4.1 Introduction

Most rivers, if left completely to their own devices, will develop qualities that are at best inconvenient to man and his activities. One of the most common faults is the development of an irregular course which offers high resistance to floods. The remedy is to train the river into a more regular course, usually by confining it to some extent, but without interfering too drastically with the river's own natural inclinations. For protection from erosion and floods, channel realignment, revetments, dykes, groins, levees, retards, and bankheads are employed. In all cases, the availability of local materials and the accessibility of those materials, may be the deciding factors for project feasibility.

As was readily observed in the model, the 8-Mile Channel is very susceptible to scour, bed movement, and meandering. These undesired affects are the result of the following processes:

(1) alignment of the 8-Mile Channel

(2) overbank flow and resulting scour at the entrance to the 8-Mile Channel

(3) increased velocities from the entrance conditions

(4) newly discovered major outcroppings in the 8-Mile Channel

The 8-Mile Channel as designed, will be adversely affected by the resulting conditions, unless preventative measures are taken to reduce the unplanned for alterations.

The dye patterns indicated the direction of the main channel flow. The velocity x-sections and profiles indicated the response to various alterations. Since velocity is the major parameter in bed movement, an accurate comparison of velocities is a good indicator as to the success of a particular channel layout. Photographs were taken at the end of each test to visually compare the channel bed under different conditions.

4.2 Model Observations of Channel Entrance Works

As was seen in Chapter 3.A, the channel entrance conditions were undesirable at all but the low flows, that is 21,000 cfs or less. Flexible rock simulated dykes were built and placed at various positions at the entrance to the 8-Mile Channel. A flow of 56,000 cfs was run for a sufficient length of time to assess the effectiveness of a particular position.

See Figures 4.1 through 4.5 for further observations and comments.

As can be seen by noting these figures, the overbank flow from Playgreen Lake, flowing perpendicular into the main channel flow, caused water turbulence, eddies, and vortexes. Rock dykes were experimented with to establish their effectiveness. It was quickly realized, that by reducing the overbank flow velocity, scour of bed material was reduced to a negligible amount, depending on dyke position used. Rock filled dykes of this size would be very costly to construct, bearing in mind the location and availability of rock fill. An alternative solution to reducing the high overbank flow velocity is to decrease the channel side slopes sufficiently in the scoured area to reduce water turbulence, and allow for a smooth interaction of flows.

Considering that the 8-Mile Channel is being dredged, the additional cost of increasing side slopes would be more feasible than the rock filled dyke construction, as rock is not available in the immediate area. Various side slopes were studied and a side slope of 10:1 was decided on to be the most suitable for model testing. The 10:1 slope was built on both the north and south channel banks, with the shoreline being approximately in the center of the 10:1 zone. From this slope area, a transitional side-slope area was formed to blend in with the 3:1 side slopes. The length and positioning of the 10:1 side slopes, and transition slopes were tested under flows of 40,000 cfs and 80,000 cfs. Observations and comments can be found on Figure 4.6.1, and 4.6.2.

4.3 Model Observations of Meander Reduction

4.3.1 Introduction

As was discussed earlier, channel meandering was initiated by channel alignment, entrance conditions, and rock outcroppings. With channel alignment being a constant in the model, and entrance conditions being observed and improved, the changes to rock out-croppings were studied in order to further reduce the meander.

For the purpose of description ease, the four major rock outcroppings were given the name of the station closest to the rocks' center line. The four rocks are labelled, #120+00, #126+00, #158+00, and #172+50, and will be referred to by these numbers throughout the rest of the discussion.

The model enabled experimentations with various techniques of stabilization and channelization, to control the adverse affects. A number of trials were run with varying degrees of success. These included:

(1) groins or dykes placed into the Playgreen Lake at the channel entrance

(2) spur dykes placed within the channel

(3) various combinations of rock outcroppings removed

(4) entrance side slopes increased from 3:1 to 10:1

In regards to the channel entrance, various works were tested at the 56,000 cfs flow, and upon reaching a final design recommendation, a range of flows was run through to test the effectiveness of the end result.

In regard to bed movement and channel meandering, tests were run under three conditions, at three different flows. The conditions were:

(A) all rock outcroppings removed,

(B) all rock outcroppings in place,

(C) partial removal of outcroppings.

The flows were:

(A) 40,000 cfs,

(B) 56,000 cfs,

(C) 80,000 cfs.

The following observations were made during all phases of testing:

(1) dye patterns,

(2) velocity x-sections, and profiles,

(3) photographs for comparison of bed movement.

Various model runs were tried with rocks #126+00, and #158+00 being altered in position, and spur dykes were placed in the channel at various positions to aid in the reduction of meander patterns. Keeping in mind that velocity is a key factor in bed movement and bank erosion, it was desirable to do a velocity comparison under different conditions. A number of channel x-sections were chosen as representatives of any problem area. Flows of 21,000 cfs, 40,000 cfs, 56,000 cfs, and 80,000 cfs were discharged under various rock conditions. These conditions included the removal of all rock outcroppings below the channel entrance, no rocks removed, or a partial removal of outcroppings.

4.3.2 Actual Model Observations

A large number of tests were run at various flows and under different conditions. For the purpose of this thesis, the flow of 56,000 cfs will be analyzed, with photos, diagrams, and comments made randomly concerning the other range of flows. An analysis of velocities for all flows and conditions is discussed, thereby indicating the actual effectiveness of various layouts.

Figures 4.7 through 4.10 will indicate the effectiveness of the following combinations:

Figure 4.7 no rock outcroppings in the channel

Figure 4.8 all rock outcroppings in the channel

Figure 4.9 rocks #126+00 and #158+00 removed

Figure 4.10 spur dykes in channel position I, and position II

All of the tests were each run a number of times to ensure the results of any one test were not the result of some invalid conditions. The flows were maintained for a sufficient length of time to allow the channel to stabilize itself in regards to bed movement and flow patterns.

4.3.3 Velocity Pattern Comparison of Rock Outcropping Removal

The conditions as analyzed in the previous sections, Figures 4.1 through 4.10, produced definite visual differences in bed movement and meander pattern. In additional to the dye releases and bed movement photographs, velocity patterns were measured at selected stations along the channel. Mean velocities along the centre line of the channel were assessed and compared to the velocity profile calculated by Manitoba Hydro in their channel design. The velocity was directly measured by the use of a Pygmy meter along the channel length. A number of representative x-sections were chosen, and velocities at various points in the x-section were measured under different conditions.

Velocity Profiles

A mean channel velocity, $\overline{V}$, was calculated on computor by using Manning's Equation and the continuity equation:

$$\overline{V} = \frac{1.49}{n} R^{2/3} S^{1/2} \tag{4.1}$$

n = roughness value

R = hydraulic radius

S = slope

$$Q = \overline{V}A \tag{4.2}$$

Q = discharge in c.f.s.

$\overline{V}$ = average velocity of flow

A = cross-sectional area of flow

In order to compare mean velocities for different channel flows in the model, water depths were directly measured, the x-sectional area was determined, and from equation 4.1, a mean flow velocity was calculated. See Appendix D.1 for tabulated velocities from both model and Manitoba Hydro data. Again for the purpose of this thesis, flows of 40,000 cfs, 56,000 cfs, and 80,000 cfs were run through the model with a partial removal of rock outcroppings, (i.e., rocks #126+00 and #158+00 removed). Conditions of no rock, or all rock were not calculated as the author feels one condition indicates the velocity trends to be expected in all other conditions.

A comparison of mean velocities will indicate the closeness of fit that the model conditions simulate as compared to prototype conditions. The model results can also be used to assess the assumptions of channel roughness used by Manitoba Hydro.

A comparison of mean velocities can be found in the following figures:

Figure 4.11 40,000 cfs (rocks #126+00 and #158+00 removed)
Figure 4.12 56,000 cfs "
Figure 4.13 80,000 cfs "

Velocity X-Sections

The comparison of actual model velocities under different conditions indicates clearly the velocity trends to be expected. Although the local channel velocities measured within the model may not be quantitatively accurate, the general trends indicated by modeling various conditions, can be transposed for use in the prototype. That is to say, any inaccuracy of model simulation is kept as a constant during the testing, and results can be related to actual conditions.

Due to the importance of velocity as a parameter in all estimations of bed movement and subsequent channel roughness and meander changes, it was necessary to conduct a wide range of accurate velocity tests. For this reason, velocities were measured a number of times under the same conditions, to alleviate any error. The range of tests involved flows of 40,000, 56,000 and 80,000 cfs being run through the model under various positioning of rock outcroppings within the channel.

By observing Figures 4.14 (40,000 cfs), 4.15 (56,000 cfs), and 4.16 (80,000 cfs), the advantage of rock removal can be seen. Some isolated readings may be questionable, but in general, looking at all discharges, and cross sections, definite trends are observable.

4.4 Conclusions

This chapter has dealt with almost the entire range of tests done on the 8-Mile Channel. For this reason, observations and conclusions are numerous. Conclusions about observations from each test will be presented in point form under the following headings.

A - Channel Entrance Works

B - Meandering Conditions

C - Velocity Comparisons

A - Channel Entrance Works

The hydraulic model of the 8-Mile Channel proved to be invaluable in assessing the effectiveness of channel entrance works.

(1) Rock filled dykes effectively reduce channel entrance scour.

(2) Bed roughness is decreased when dykes are in position.

(3) Rock filled dykes should be pyramid in shape and extend above the water surface.

(4) The dykes should be almost impermeable, and vary in length up to 1800 ft.

(5) Effective reduction of bed movement can be realized by increasing bank slopes to 10:1, as outlined in Figures 4.6.1 and 4.6.2.

(6) Increasing bank slopes in the channel entrance is a more feasible way of reducing bed movement than rock filled dykes.

(7) It is recommended that the entrance slopes be cut back in dredged steps according to dimensions given in Figures 4.6.1 and 4.6.2.

B - Meandering Conditions

The model was invaluable in determining possible meander patterns, and in assessing the effectiveness of various combinations of rock outcropping removal.

(1) No rock outcroppings, is concluded to be the optimum in regards to minimizing channel bed meander. Figure 4.7.

(2) All rock outcroppings in place, proved to be the worst condition of all studied in regards to bed movement and meander initiation. Figure 4.8.

(3) Rocks #126+00 and #158+00 removed, did reduce bed movement and channel meander. Figure 4.9.

(4) Channel spur dykes in place, proved that by locating submerged rock filled dykes in the channel, meandering is reduced. Figure 4.10.

(5) Channel bed meander will occur to some degree at all flows, regardless of what rock outcropping removal recommendations are implemented.

(6) Removal of rocks #126+00 and #158+00 is recommended if original design hydraulic characteristics are to be maintained.

(7) Bed movement, and thalweg development are definite indicators as to the path of a channel meander.

(8) A moveable bed model study of meander conditions should be incorporated into all channel design procedures where a large capital expenditure is required.

C - Velocity Comparisons

The model was invaluable in studying local velocity patterns.

(1) Mean velocities calculated using model water depths, showed a good correlation with mean velocities calculated by Manitoba Hydro. See Table 4.1.

(2) The closeness of average velocities indicate that the model of the 8-Mile Channel adequately reproduced prototype conditions of roughness.

(3) For all flow conditions studied, local velocities were lowest when the channel had no rock outcroppings.

(4) Local velocities were the greatest when all rock outcroppings were in place.

(5) Removal of rocks #126+00 and #158+00 reduced local velocities, reduced probable bank erosion around rock #158+00, and reduced channel meander in the 1000 ft. section.

(6) Measured local velocities in the model can qualitatively indicate trends to be expected in the prototype.

(7) Local velocities measured in the 425 ft. and 1000 ft. sections were higher than the calculated mean velocities by 1.0 ft/sec (max.) and 0.6 ft/sec (max.) respectively.

(8) Bank slopes and materials should be designed using expected local velocities rather than mean flow velocities.

(9) Under the present conditions, bank protection will be required within the 8-Mile Channel to prevent bank erosion, which in turn would alter expected hydraulic characteristics, and aid in channel meander initiation.

VELOCITY COMPARISONS

TABLE 4.1

FLOW	WIDTH	HYDRO $\overline{V}$ (ft/sec) no rocks	HYDRO $\overline{V}$ (ft/sec) partial	MODEL $\overline{V}$ partial	MODEL V (local) partial
56,000 cfs.	1000 ft.	2.4	2.4 - 2.9	2.2 - 2.6	2.2 - 3.8
56,000	425	4.3	4.2 - 4.4	4.1 - 4.4	4.1 - 6.2

8 - MILE CHANNEL ENTRANCE CONDITIONS

DISCHARGE : 56,000 cfs

PLAYGREEN LAKE LEVEL : 714.2 feet

KISKITTOGISU LAKE BACKWATER LEVEL : 713.45 feet

DYE RELEASES

STONE FILLED DYKES

SCOUR

DEPOSITION

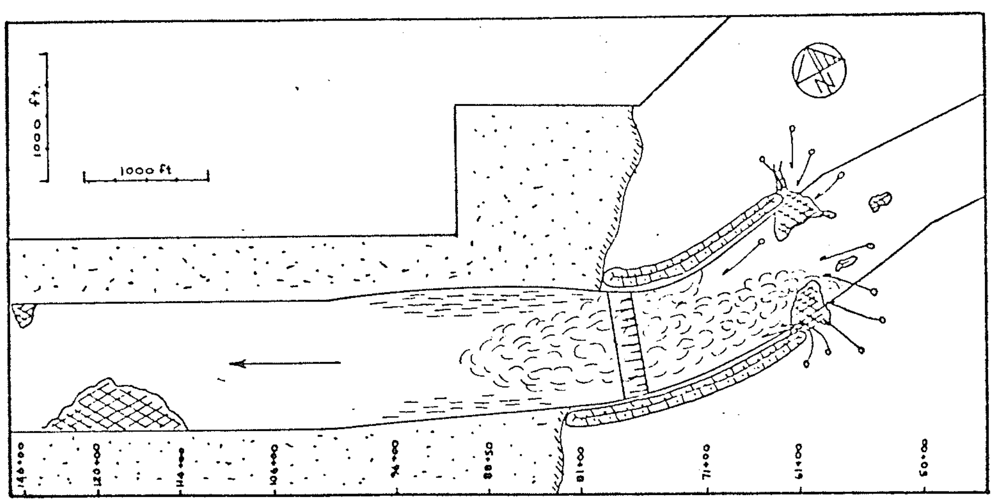


Figure 4.1

Position 1 56,000 cfs

The dykes were built out into Playgreen Lake, parallel and on the top of the bank of the channel. The dykes were continued along the top of the bank until the rock outcroppings in the lake were reached. The tops of the dykes were above the water surface, but the dykes were not completely impervious, some water did seep between the joints. The dykes were pyramid in shape.

After 18 hours of running time, the dykes produced very undesired effects. The channelization of the flow within the dyke confine increased the mean velocity considerably, and produced violent eddies within the channel. This increased velocity was sufficient enough to erode the bed, and scour the material down to the bed rack. This can readily be seen in photos 4.1.a and 4.1.b. The scour holes and bed movement was mainly within the center of the channel, but did scour some material at the north shore. Large bedforms were predominate in the channel, and were reduced before the 1000 ft. straight section was reached, at approximately station 96+00.

8 - MILE CHANNEL ENTRANCE CONDITIONS

DISCHARGE : 56,000 cfs

PLAYGREEN LAKE LEVEL : 714.2 feet

KISKITTOGISU LAKE BACKWATER LEVEL : 713.45 feet

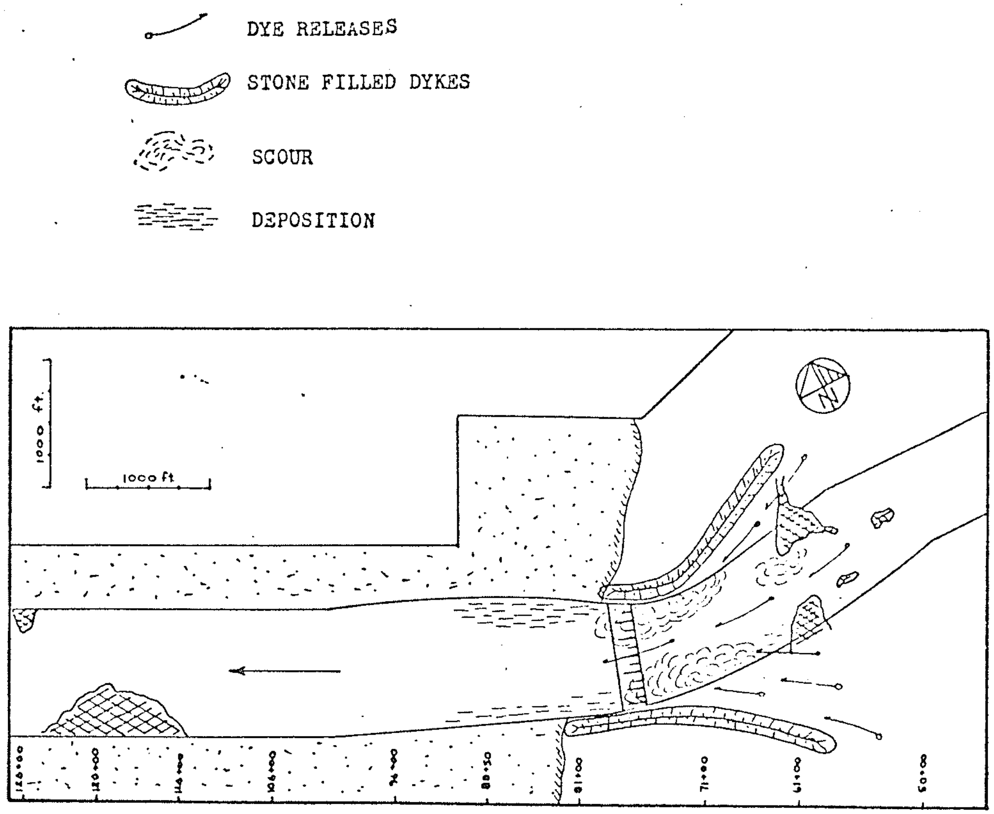
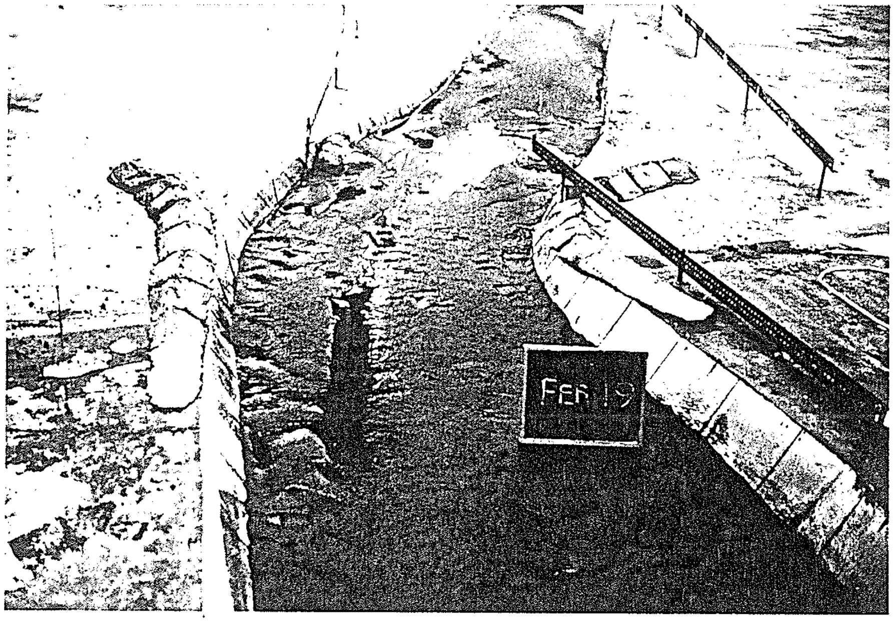


Figure 4.2

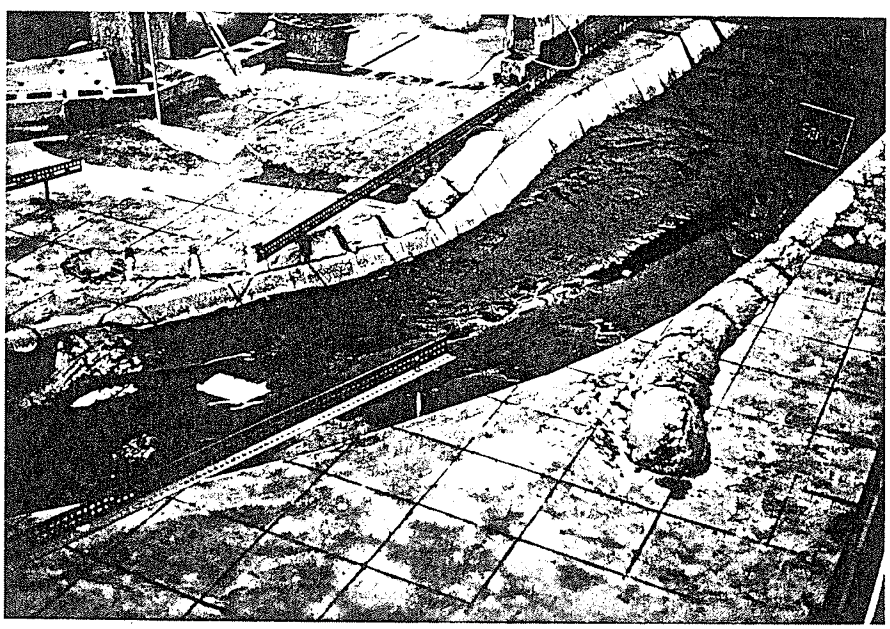
Position II 56,000 cfs

The dykes were againbuilt out into Playgreen Lake, but were angled away at an approximate 45° angle along the south edge, and at a 30° angle along the north edge. The dykes were gently curved, not straight as the stating of an angle would indicate.

After 19 hours of running time, it was observed that this dyke position certainly decreased the amount of bed movement and scour in the channel. The over bank flow from the lake into the channel was not perpendicular but was gradually 'eased' into the main channel flow. Thusly there was very little turbulence, eddy currents, and velocity increase. However, there was some local scour immediately against the channel edges, where the dyke became parallel to the edge of the channel. This was not considered severe, and did not migrate downstream as previously described. The mean velocity was kept low, and a large amount of bed movement did not occur in the channel, as only ripples appeared in the channel entrance. All scour was reduced by station 80+00. See photos 4.2.a and 4.2.b.



4.3.a



4.3.b

8 - MILE CHANNEL ENTRANCE CONDITIONS

DISCHARGE : 56,000 cfs

PLAYGREEN LAKE LEVEL : 714.2 feet

KISKITTOGISU LAKE BACKWATER LEVEL : 713.45 feet

DYE RELEASES

STONE FILLED DYKES

SCOUR

DEPOSITION

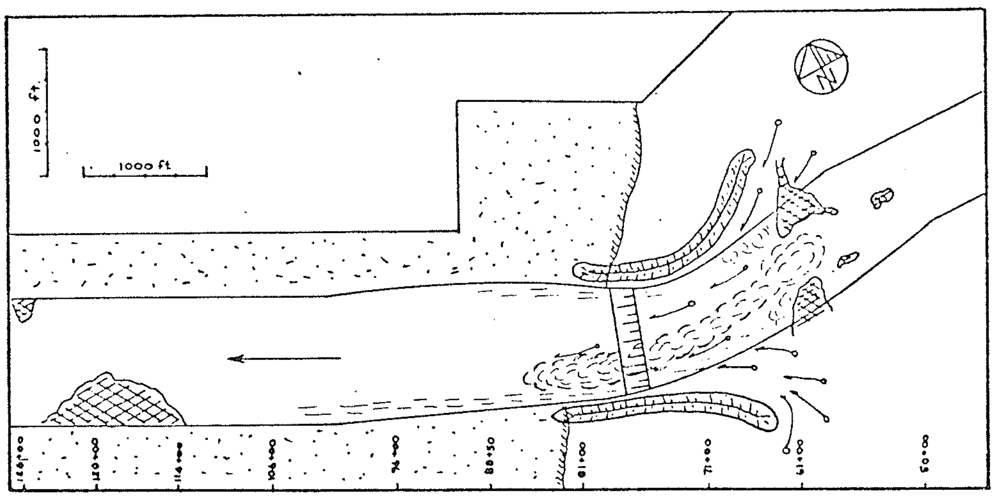


Figure 4.3

Position III 56,000 cfs

The dykes were again built out into Playgreen Lake, with the north dyke being placed further out, closer to the edge and then curved away at approximately 45°. The south side dyke was reduced in length to 500 ft. and gently curved away almost immediately as it protruded into Playgreen Lake.

After 18 hours of running time this position was observed to be the one which had least ill effects on the channel. The overbank flow was not perpendicul anywhere along the dyked area, and there were no scour holes in the channel entranc The flow was observed to be very uniform, and straight. The bed was not disturbed very much as the velocities were kept low enough to stop all scour and severe bed movement. As can be seen in photo 4.3.a, there was a definite main line of flow which did tend to erode a definite line of bed movement down the channel. This line would indicate the channel talwag. There were no bed forms observed in the entrance, and consequently, the channel bed remained stable in the entrance under these conditions. There was however, increased scour around the outcropping in the center of the channel furthest out into the lake. See photo 4.3.a and 4.3.b for pooled water area.

8 - MILE CHANNEL ENTRANCE CONDITIONS

DISCHARGE : 56,000 cfs

PLAYGREEN LAKE LEVEL : 714.2 feet

KISKITTOGISU LAKE BACKWATER LEVEL : 713.45 feet

DYE RELEASES

STONE FILLED DYKES

SCOUR

DEPOSITION

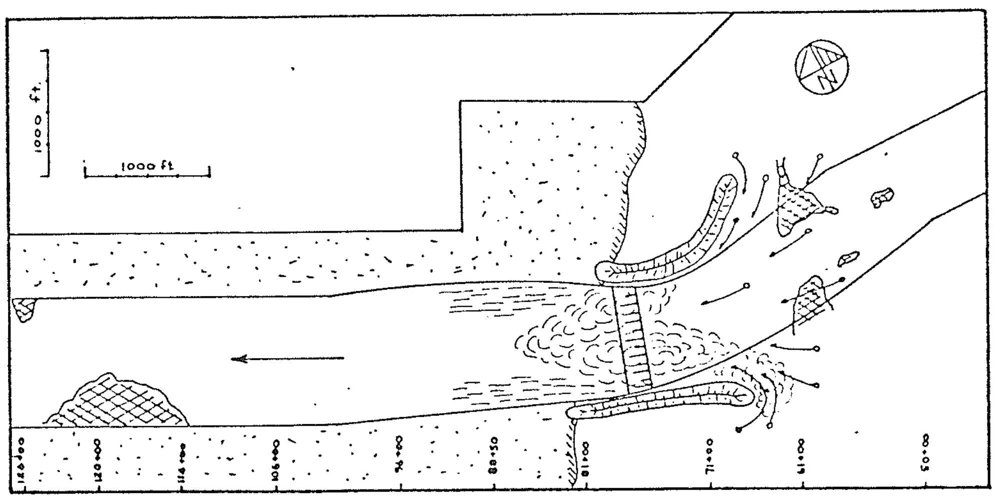


Figure 4.4

Position IV 56,000 cfs

This position was basically the same as III, except the south dyke was reduced about 300 ft. in length and brought closer to the channel edge. A reduction in cost could be obtained using this position.

After the normal running time of 18 hours, severe reaction occurred to this dyke orientation. Overbank flow from the lake was perpendicular over the bank edge, and resulted in turbulence, and violent eddies which created large scour holes in the channel. These scour holes migrated downstream and towards the center of the channel. See photo 4.4.a and 4.4.b. The south edge was relatively unaffected by this change. Some material was placed at the leading toes of the dykes, and on the north dyke was observed to be eroded and moved out by the turbulence of the water. The channel erosion and scour was reduced to minor ripples by station 91+00.

8 - MILE CHANNEL ENTRANCE CONDITIONS

DISCHARGE : 56,000 cfs

PLAYGREEN LAKE LEVEL : 714.2 feet

KISKITTOGISU LAKE BACKWATER LEVEL : 713.45 feet

DYE RELEASES

ROCK FILLED DYKES

SCOUR

DEPOSITION

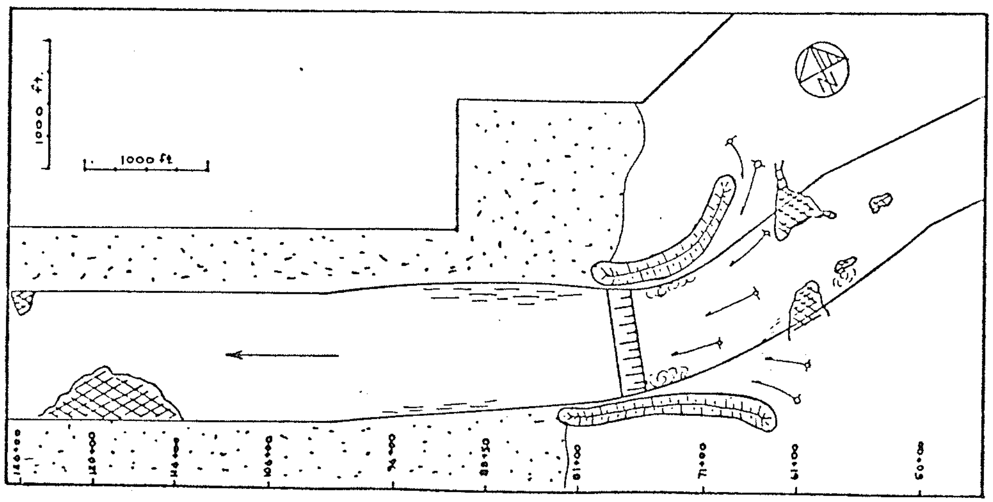
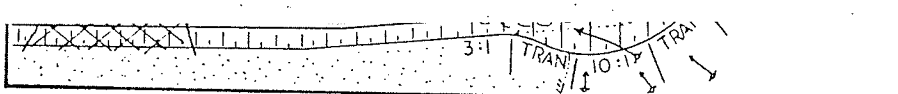


Figure 4.5



Position V 56,000 cfs

The north was left untouched as its position seemed the most advantageous. The south dyke was lengthened and curved further out from the edge of the channel cut. After 18 hours of running this position proved to be the most suitable for minimizing channel entrance altercations.

There was no perpendicular overbank flow, and thus turbulence and water eddies were negligible. The flow velocity was kept low and no bed movement or scour occured in the entrance. Only slight ripples occurred randomly in the channel. See photos 4.5.a and 4.5.b. Scour or movement of material at toes of dykes was minimal, and no scour was observed along the north or south banks.

Flows of 21,000 cfs, 40,000 cfs, and 80,000 cfs were run through this particular setup, and the same results were observed as the 56,000 cfs; no severe bed movement that could increase the channel roughness.

8 - MILE CHANNEL ENTRANCE CONDITIONS

DISCHARGE : 40,000 cfs.

PLAYGREEN LAKE LEVEL : 713.8 feet

KISKITTOGISU LAKE BACKWATER LEVEL : 712.9 feet

DEPOSITION

SCOUR

DYE RELEASES

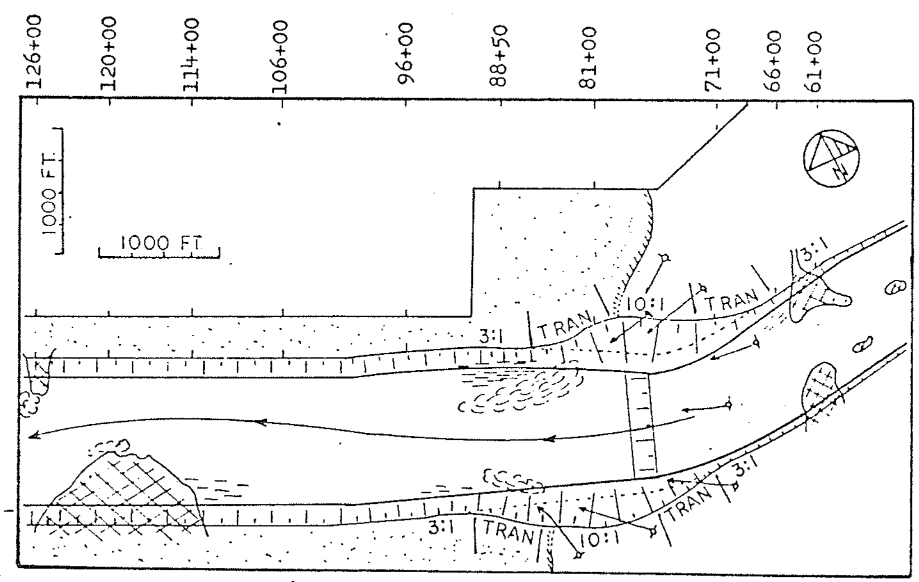


Figure 4.6.2

40,000 cfs

Figure 4.6.2

Side slopes were built into both north and south channel banks as in first test, but the transition zone length was extended along both banks to hopefully elleviate all scour problems. North slope positions were:

Station 66+00 - end 3:1 slope, and begin transition zone
Station 72+50 - end transition zone and begin 10:1 slope
Station 79+00 - end 10:1 slope and begin transition zone
Station 86+00 - end transition zone and continue on with 3:1 slope

South slope positions were:

Station 71+00 - end 3:1 slope and begin transition zone
Station 75+50 - end transition zone and begin 10:1 slope
Station 85+00 - end 10:1 slope and begin transition zone
Station 90+00 - end transition zone and continue on with 3:1 slope

After 10 hours of running time the following observations were made:

(1) dye releases from the south lake side of the channel indicated that the interaction of flows was a smooth process, and turbulence and eddies were minor;

(2) scour along the south bank was minimal except for some minor local scour against the bank in the transition zone at station 85+00. See figure and photos 4.1.6.a. to 4.1.6.c.

(3) dye releases from the north side of the channel indicated that the interaction of flow was relatively smooth, except for the transition zone returning to the 3:1 side slopes. In an attempt to completely eliminate bed movement along the north bank, the transition zone was extended 200 ft., however, reconstruction of the transition zone did not result in a smooth transition of slope, but rather a step-like slope change. The dye releases in this particular area, around station 84+00, indicated same turbulence and eddies.

(4) due to the abrupt change in slope in the transition zone, scour and bed movement did occur at station 84+00, and was carried out in the direction of the main channel flow, and reduced in approximately 500 feet, to smooth bed configuration.

(5) bed movement along the channel downstream was reduced to minor bed movement, and the meandering was not as significant as the test before.

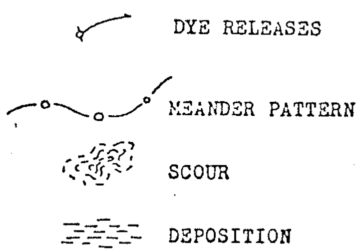
(6) velocities were lower in the channel entrance and 1000 ft. section when compared to test in figure 4.6.1.

8 - MILE CHANNEL MEANDER CONDITIONS

DISCHARGE : 56,000 cfs

PLAYGREEN LAKE LEVEL : 714.2 feet

KISKITTOGISU LAKE BACKWATER LEVEL : 713.45 feet



56,000 cfs

Figure 4.7

The condition of no rock outcroppings was the criteria used in the original design of the channel. An analysis of dye patterns and bed movement trends under this condition is very useful when comparing other layouts. As can be seen from the dye releases marked on the diagram, the flow entered the channel from all directions in the lake. The main flow of water was then directed towards the south bank due to the channel alignment. Low velocities were observed near the north shore where the bank is concave to the channel. The main flow lines then gradually wandered towards the north edge, with contact being in the transition zone. This contact was reflected in the fact that due to the higher water velocity of the main flow, bed material was eroded from thenorth side of the channel. The flow then was redirected across the channel towards the south shore where it entered the 425' section. Once in the 425' section, it meandered across the channel to the north shoreline. This phenomenon can be easily identified by looking at photos 4.7. From the diagrams and photos, a definite meander pattern could be seen developing by observing the talwag of the flow. In this condition of no rock outcroppings, the least obvious meander was formed.

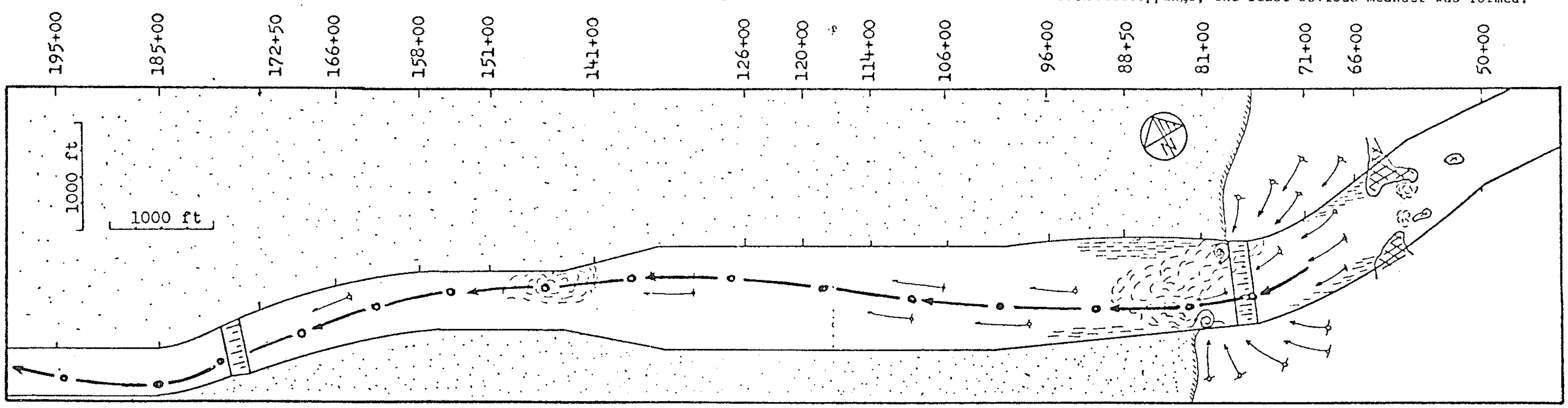


Figure 4.7

8 - MILE CHANNEL MEANDER CONDITIONS

DISCHARGE : 56,000 cfs

PLAYGREEN LAKE LEVEL : 714.2 feet

KISKITTOGISU LAKE BACKWATER LEVEL : 713.45 feet

DYE RELEASES

MEANDER PATTERN

SCOUR

DEPOSITION

56,000 cfs

Figure 4.8

The condition of no rock outcroppings removed is the most important one. For until the decision to remove some rock is made, the results of this test will indicate the conditions which are likely to occur in the channel. With the advent of the large outcroppings being within the channel, a definite meander pattern can be observed, by the release of dye, and the examination of the pattern of erosion induced by the main flow lines or talwag of the channel. The channel entrance conditions are the same for this test as for the test with no rock outcroppings.

The main flow pattern is directed into the south side of the channel at the entrance, and as before, begins to wander towards the north shoreline. Rock #120+00 is of significant size, and acts as a submerged spur dyke within the channel. The result of this, is that the main body of flow is channeled at the north shore, around this large rock. This can be readily seen in the diagram and on photos 4.8.a through 4.8.c. Rock #126+00 also acts as a submerged dyke, and redirects the main body flow back across the channel to the south side. The water is then channeled into the transition zone towards the north shore line, because of the 'dead water' laying behind rock 120+00. Because of the channel constriction due to the rocks, the main flow velocity is higher than designed for, and consequently a talwag is eroded into the channel bed around the rocks. Scour occurs along the north shore in the transition zone. The water is directed around and towards the south edge by both rocks 158+00 and 172+50, where it enters the 425' section along the south bank. As before, the water then wanders towards the north side of the channel. Scour is expected due to high local velocities, around rocks 158+00 and 172+50.

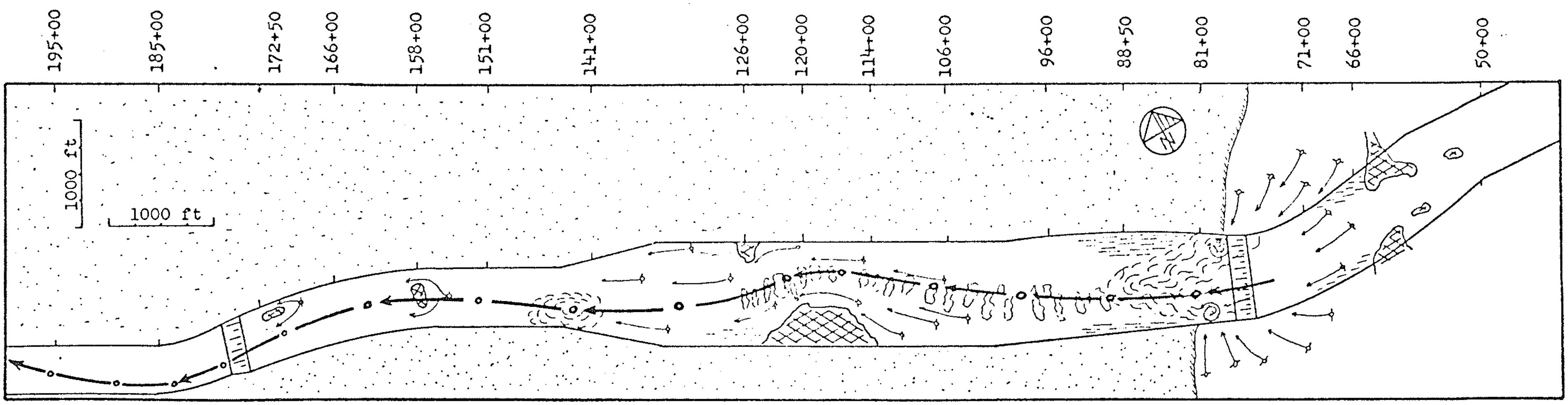


Figure 4.8

8 - MILE CHANNEL MEANDER CONDITIONS

DISCHARGE : 56,000 cfs

PLAYGREEN LAKE LEVEL : 714.2 feet

KISKITTOGISU LAKE BACKWATER LEVEL : 713.45

DYE RELEASES

MEANDER PATTERN

SCOUR

DEPOSITION

56,000 cfs

Figure 4.10

This last trial involves the in-channel placement of spur dykes immediately downstream of rock #120+00. The reason for placement is that the scour around rock #120+00 and the subsequent meander pattern that was developed was undesired from a design point of view. The spur dykes were placed approximately 500 ft., and 1200 ft. downstream of rock #120+00 protruding perpendicularly out from the south bank approximately 250 ft. into the channel flow. Two spur dyke heights were tried; height I placing the top of the dyke above the water level; height II placing the top of the dyke approximately one half of the flow depth. Obvious differences were apparent.

With dyke protruding above the water level, the entire channel flow was diverted into the remaining x-section. This contraction resulted in a much higher mean velocity, and severe channel bed movement and scour did occur. See photos 4.10.a thru 4.10.c. This scour definitely increased the channel roughness

With dyke only one half of flow depth, very favourable results were found. Some of the channel flow was allowed to pass over the dyke, but the main flow was still channelized as desired in the transition zone. Some local scour occurred around rock #120+00 but nowhere as apparent as with the dykes above the water surface. As a result of the dyke placement, the meander pattern was reduced and the flow was aligned straight into the transition zone. Scour did occur in the transition zone, but over the entire channel x-section rather than along the north shore, and not at a high rate. The meander conditions for the rest of the channel were the same as for the other tests. See photos 4.10.d thru 4.10.f.

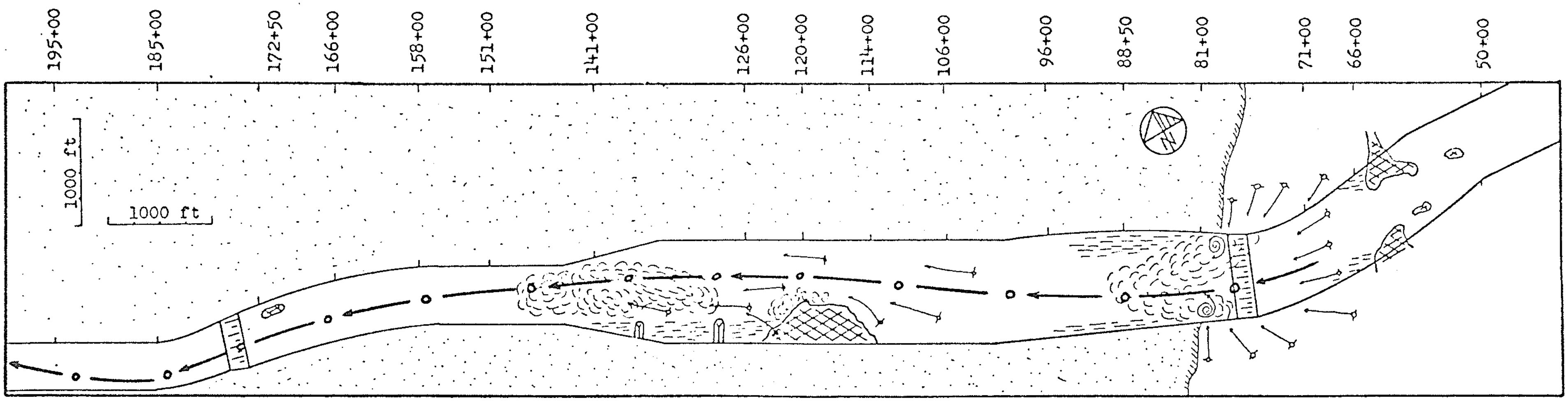


FIGURE 4.10

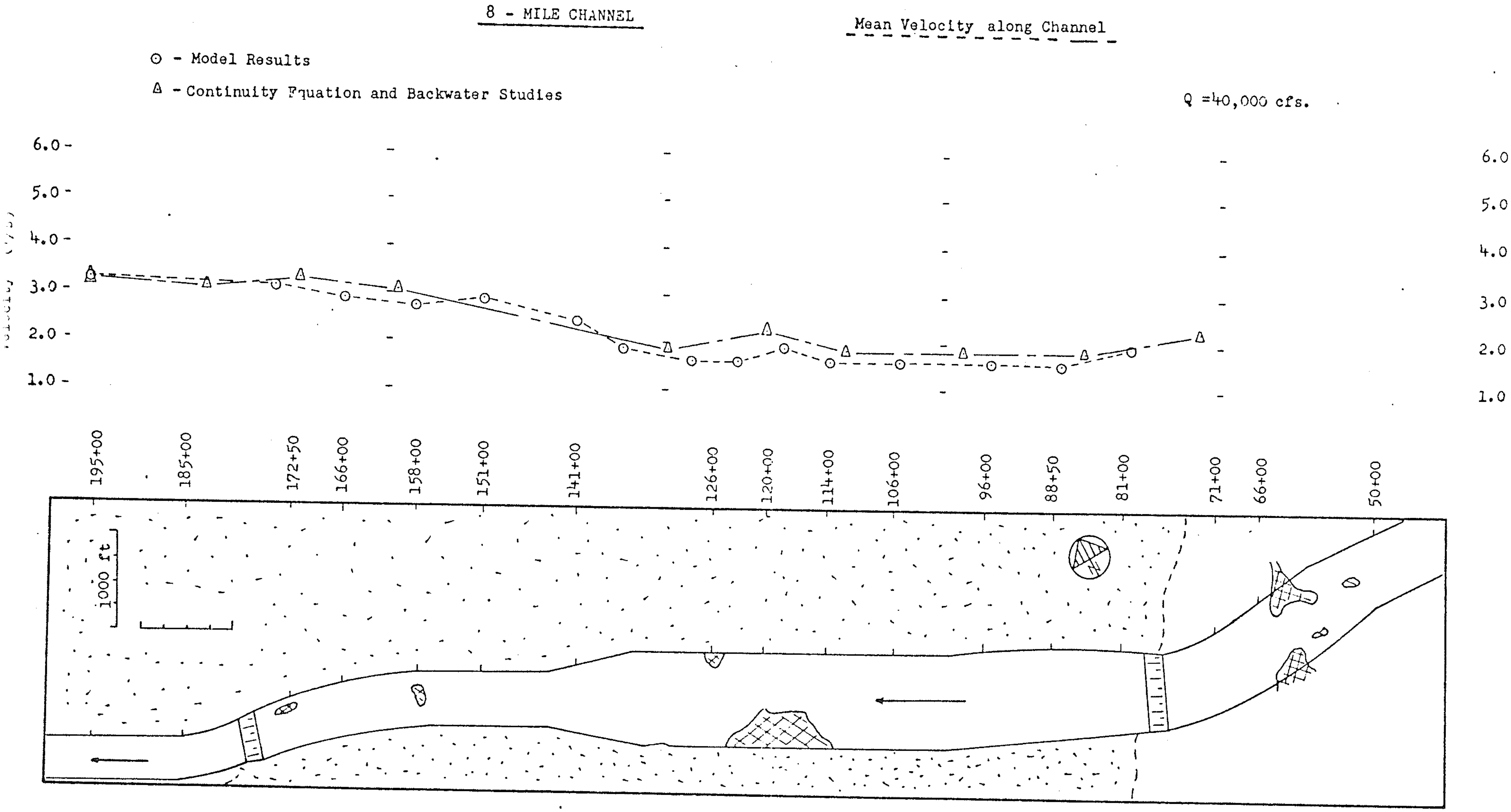

8 - MILE CHANNEL
Mean Velocity along Channel
⊙ - Model Results
Δ - Continuity Equation and Backwater Studies
Q =40,000 cfs.
6.0
5.0
4.0
3.0
2.0
1.0
195+00
185+00
172+50
166+00
158+00
151+00
141+00
126+00
120+00
114+00
106+00
96+00
88+50
81+00
71+00
66+00
50+00
1000 ft

Figure 4.11

8 - MILE CHANNEL

Moan Velocity along Channel

⊙ - Model Results

Δ - Continuity Equation and Backwater Studies

Q = 56,000 cfs.

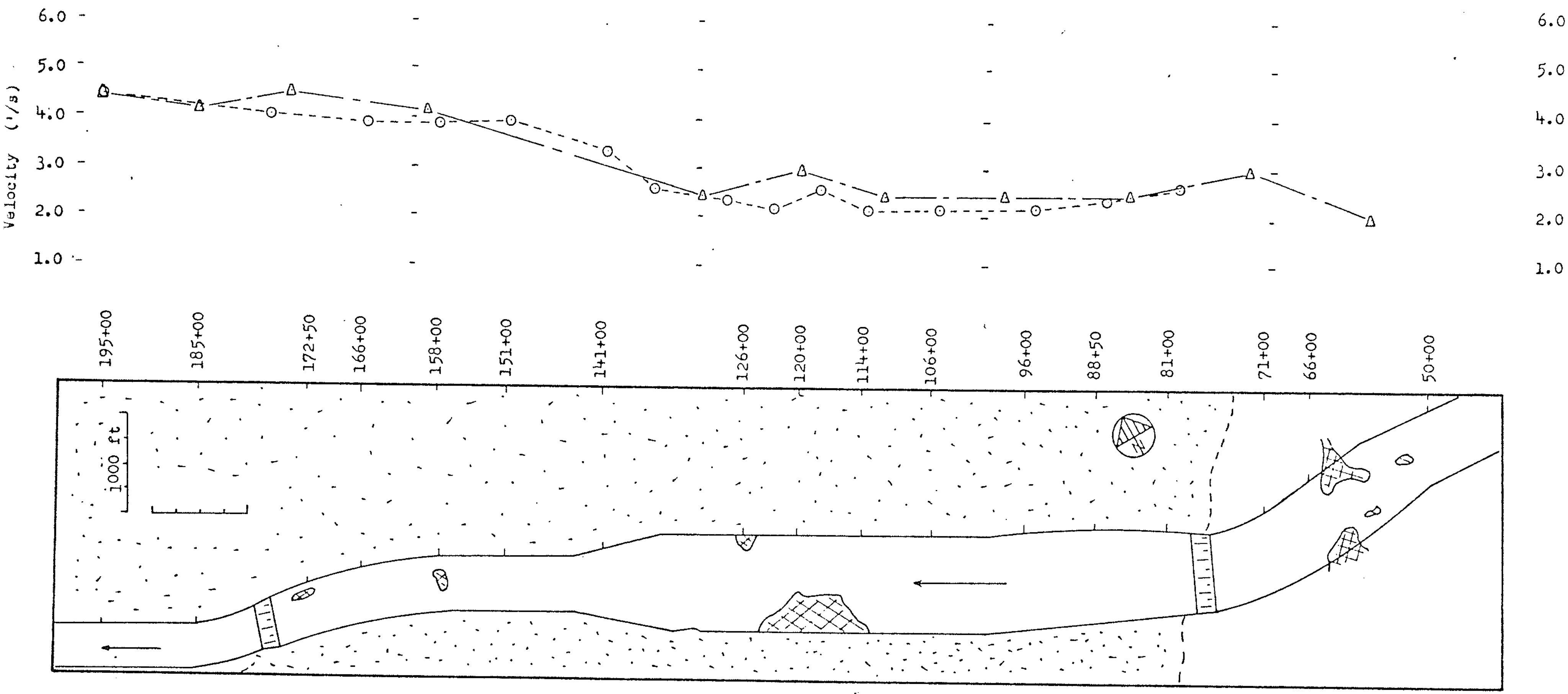


Figure 4.12

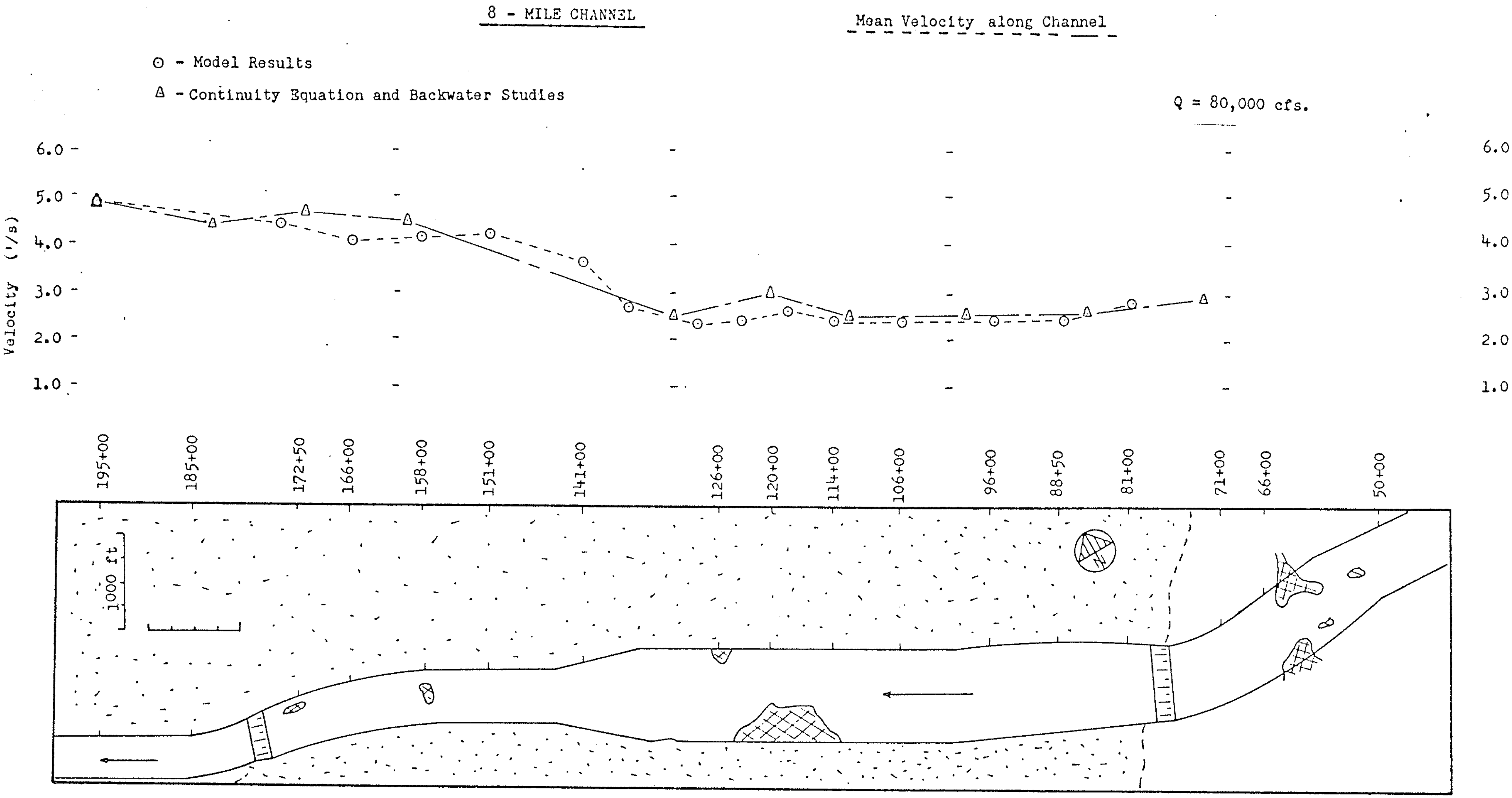

8 - MILE CHANNEL
Mean Velocity along Channel
⊙ - Model Results
Δ - Continuity Equation and Backwater Studies
Q = 80,000 cfs.
Velocity ('/s)
6.0
5.0
4.0
3.0
2.0
1.0
195+00
185+00
172+50
166+00
158+00
151+00
141+00
126+00
120+00
114+00
106+00
96+00
88+50
81+00
71+00
66+00
50+00
1000 ft

Figure 4.13

8 - MILE CHANNEL   Velocity X - Sections

△ - No Rock Outcroppings D/S of 80+00

□ - All Rock Outcroppings D/S of 80+00

⊙ - Rocks #126+00 & #158+00 Removed

Q = 40,000 cfs

W = 1,000 ft.

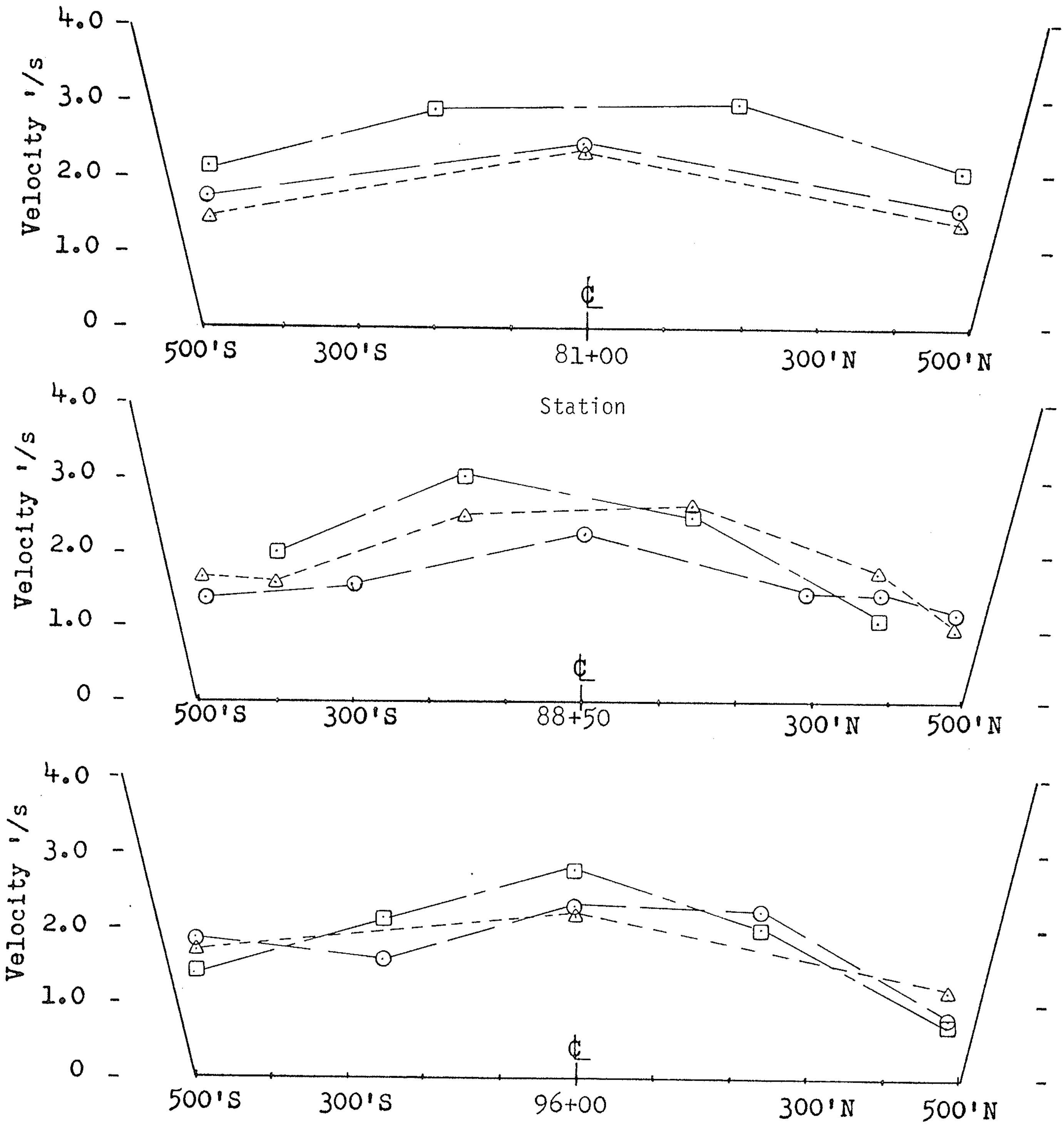


Figure 4.14.a

8 - MILE CHANNEL

Velocity X - Sections

△ - No Rock Outcroppings D/S of 80+00

□ - All Rock Outcroppings D/S of 80+00

⊙ - Rocks #126+00 & #158+00 Removed

Q = 40,000 cfs

W = 1,000 ft.

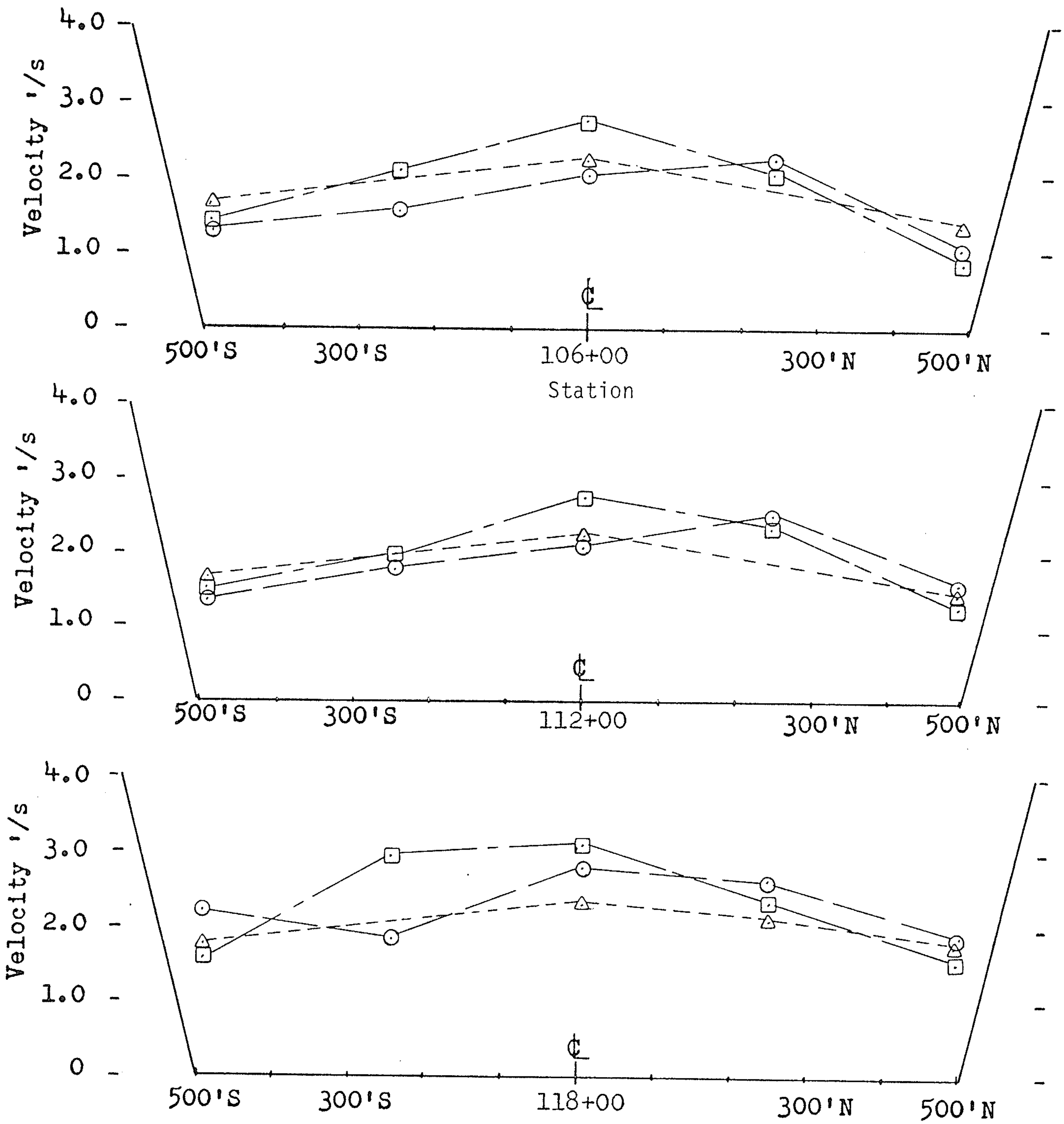


Figure 4.14.b

8 - MILE CHANNEL

Velocity X - Sections

△ - No Rock Outcroppings D/S of 80+00

⊡ - All Rock Outcroppings D/S of 80+00

⊙ - Rocks #126+00 & #158+00 Removed

Q = 40,000 cfs

W = 1,000 ft.

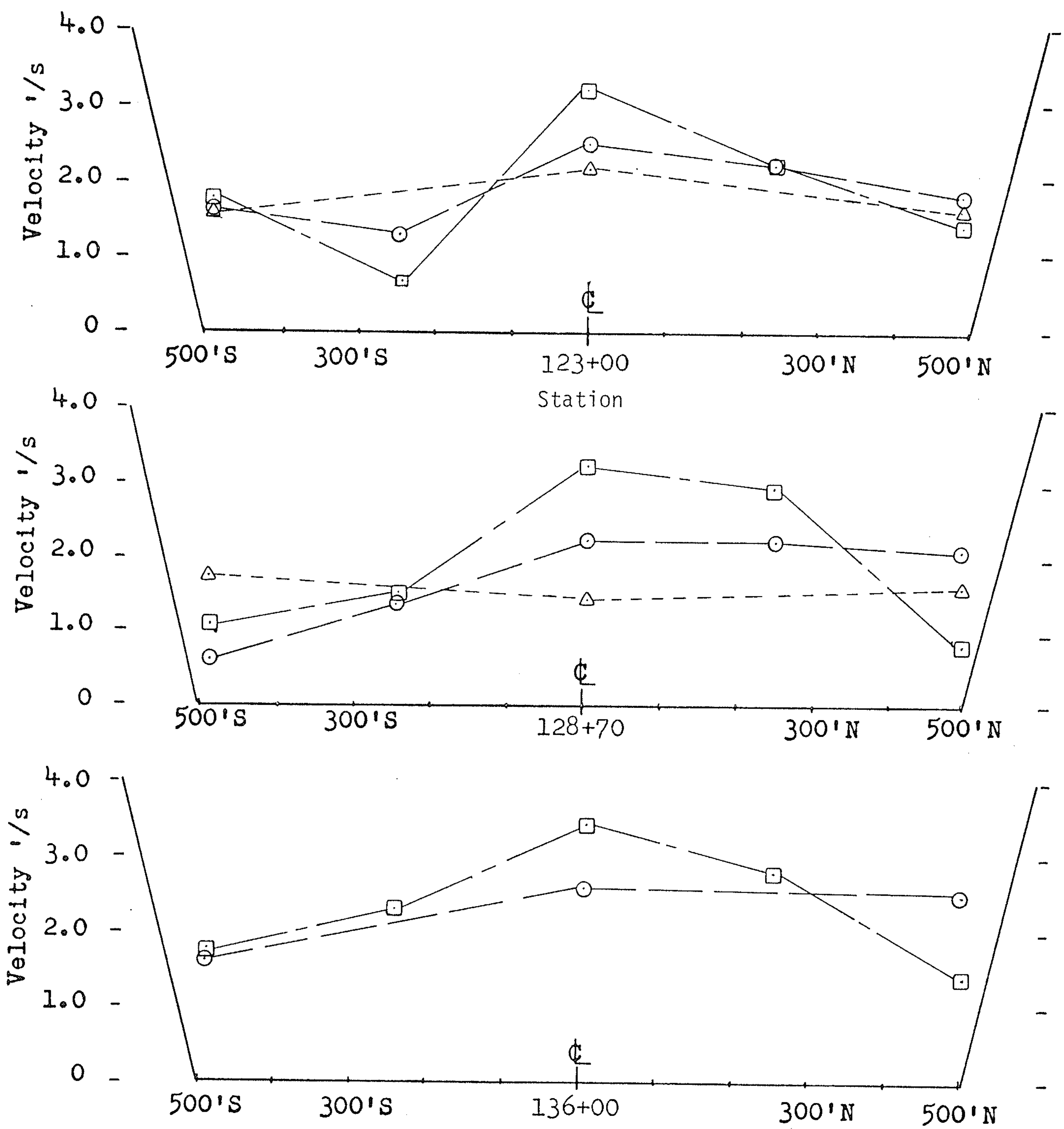


Figure 4.14.c

8 - Mile Channel

Velocity X - Sections

△ - No Rock Outcroppings D/S of 80+00

☐ - All Rock Outcroppings D/S of 80+00

⊙ - Rocks #126+00 & #158+00 Removed

Q = 40,000 cfs

W = 525 ft.

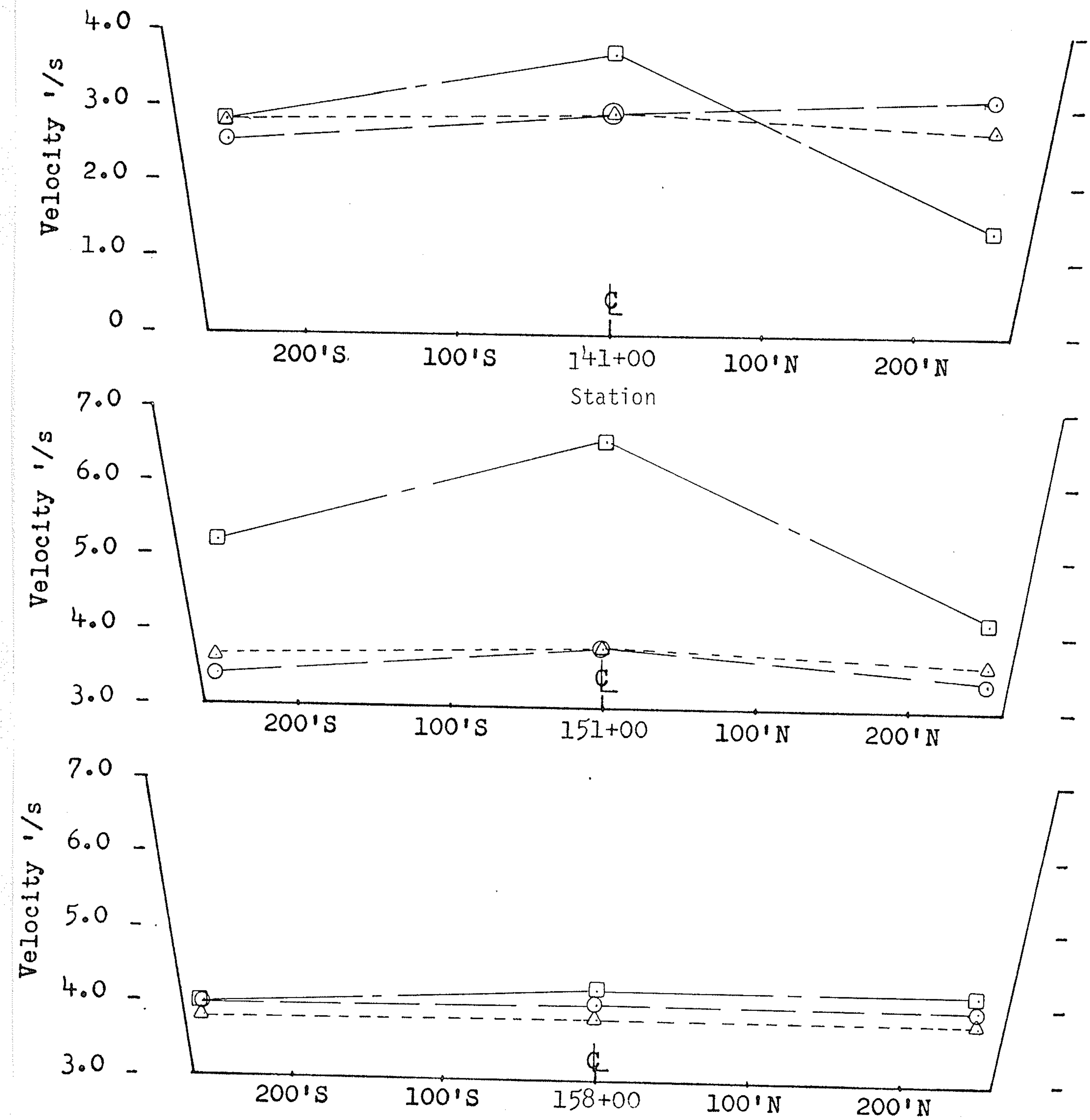


Figure 4.14.d

8 - Mile Channel

Velocity X - Sections

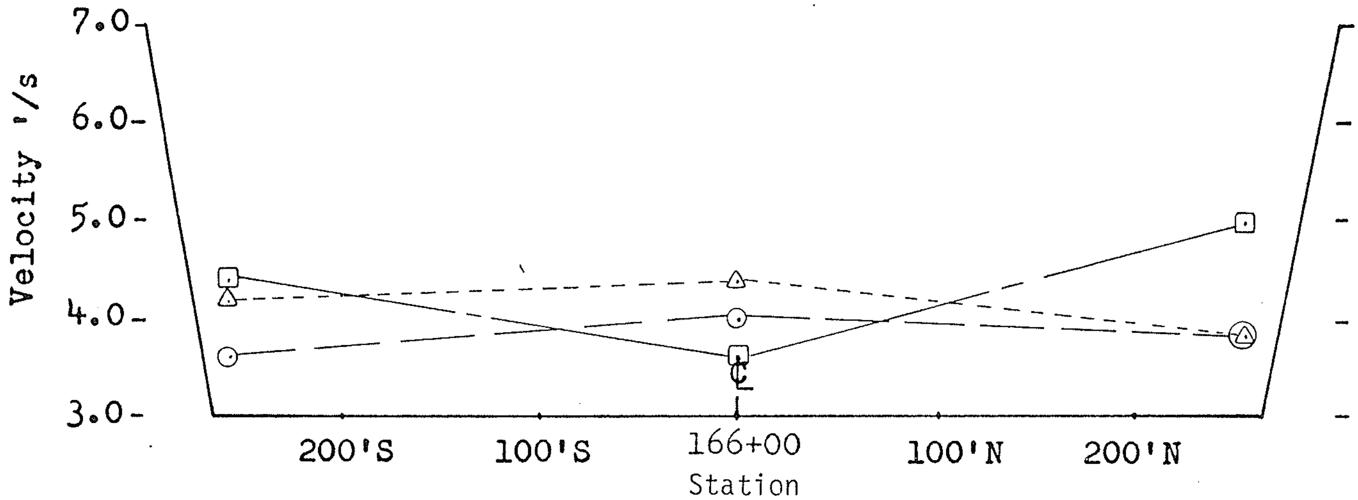
△ - No Rock Outcroppings D/S of 80+00

□ - All Rock Outcroppings D/S of 80+00

○ - Rocks #126+00 & #158+00 Removed

Q = 40,000cfs

W = 525 ft.



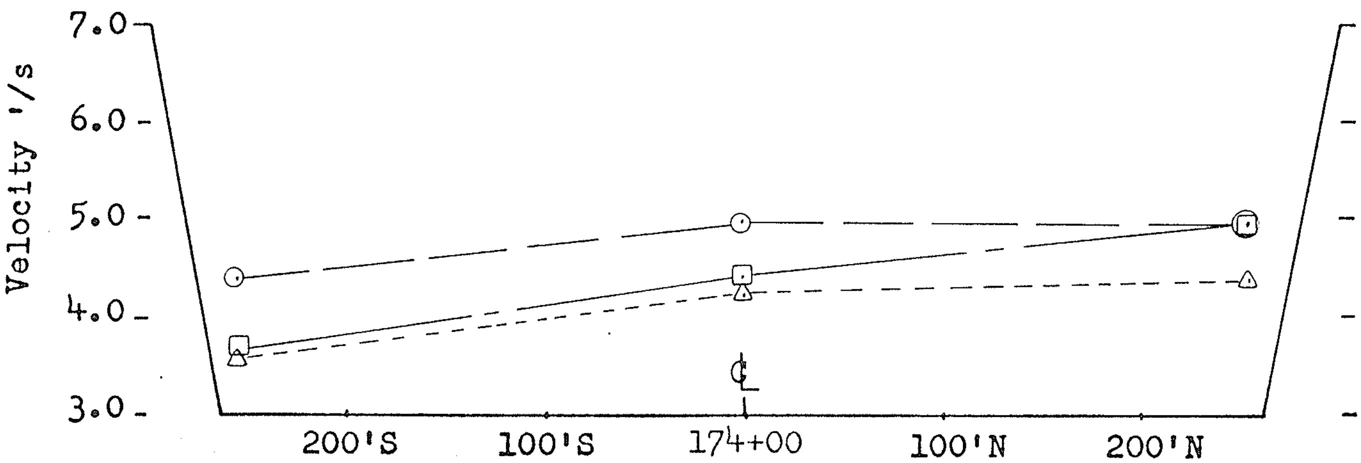


Figure 4.14.e

8 - Mile Channel   Velocity X - Sections

△ - No Rock Outcroppings D/S of 80+00   Q = 40,000 cfs

☐ - All Rock Outcroppings D/S of 80+00   W = 425 ft.

⊙ - Rocks #126+00 & #158+00 Removed

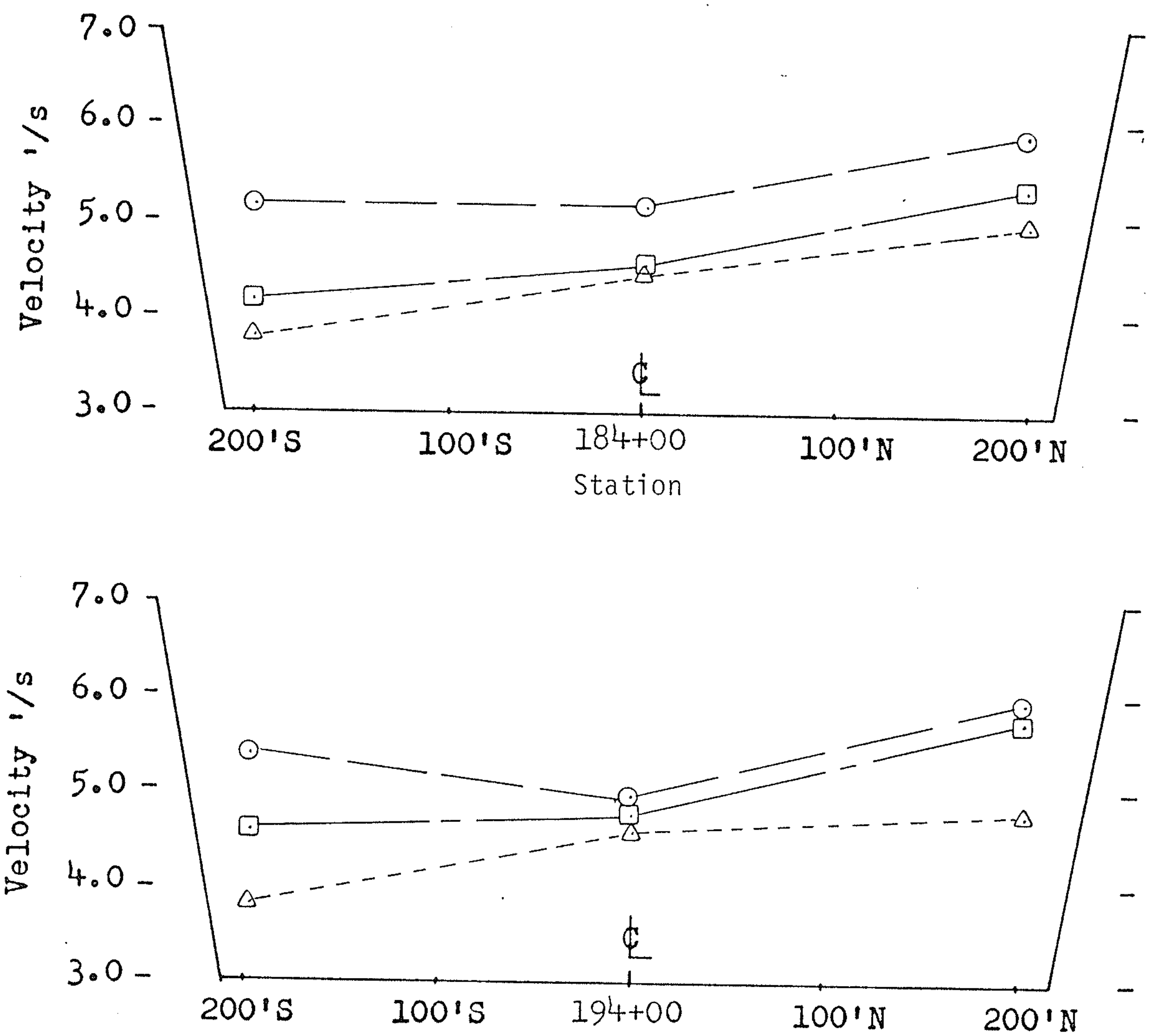


Figure 4.14.f

8 - MILE CHANNEL   Velocity X - Sections

△ - No Rock Outcroppings D/S of 80+00   Q = 56,000 cfs

⊡ - All Rock Outcroppings D/S of 80+00   W = 1,000 ft.

⊙ - Rocks #126+00 & #158+00 Removed

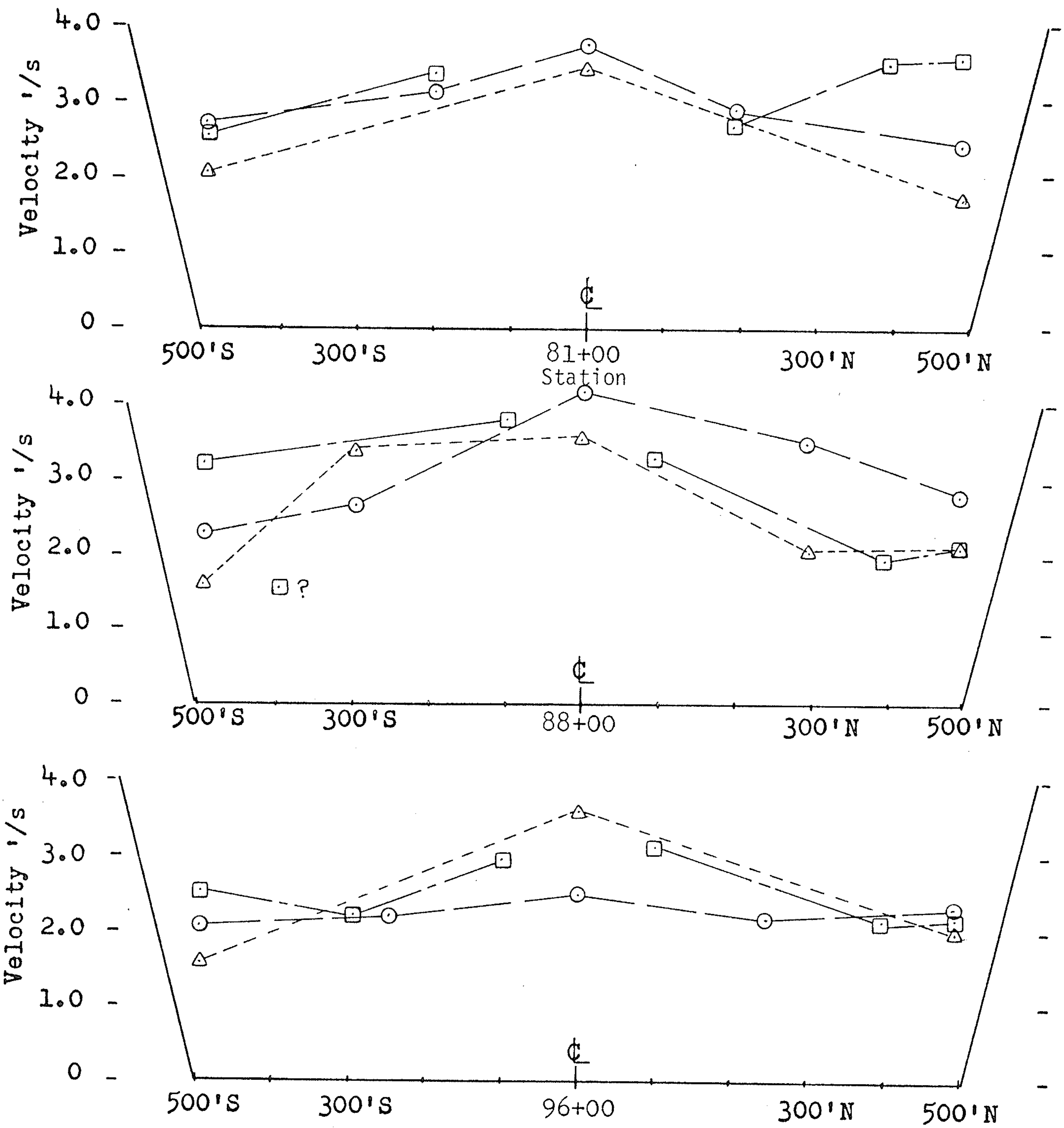


Figure 4.15.a

8 - MILE CHANNEL   Velocity X - Sections

△ - No Rock Outcroppings D/S of 80+00   Q = 56,000 cfs

□ - All Rock Outcroppings D/S of 80+00   W = 1,000 ft.

⊙ - Rocks #126+00 & #158+00 Removed

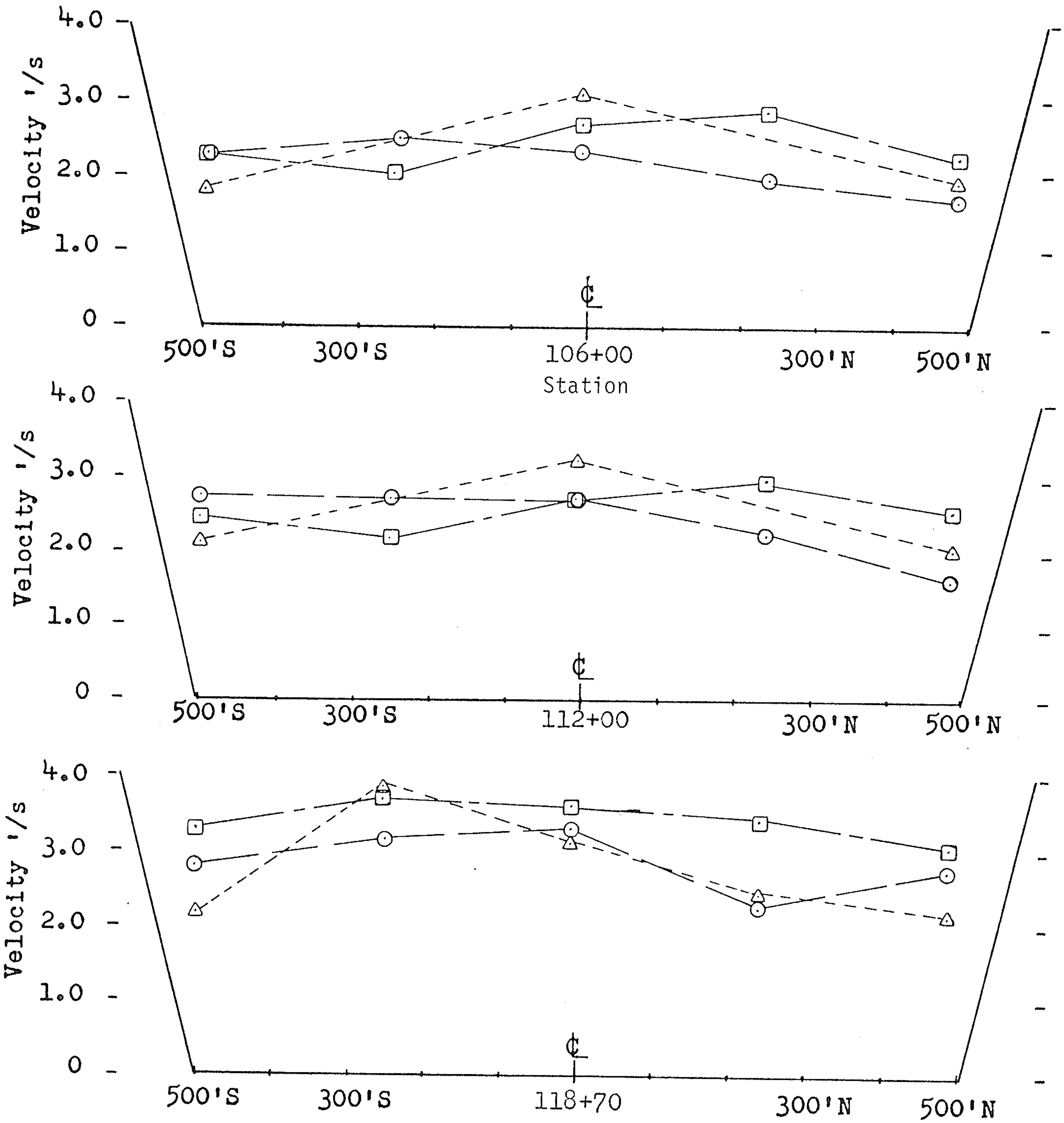


Figure 4.15.b

8 - MILE CHANNEL   Velocity X - Sections

△ - No Rock Outcroppings D/S of 80+00   Q = 56,000 cfs

⊡ - All Rock Outcroppings D/S of 80+00   W = 1,000 ft.

⊙ - Rocks #126+00 & #158+00 Removed

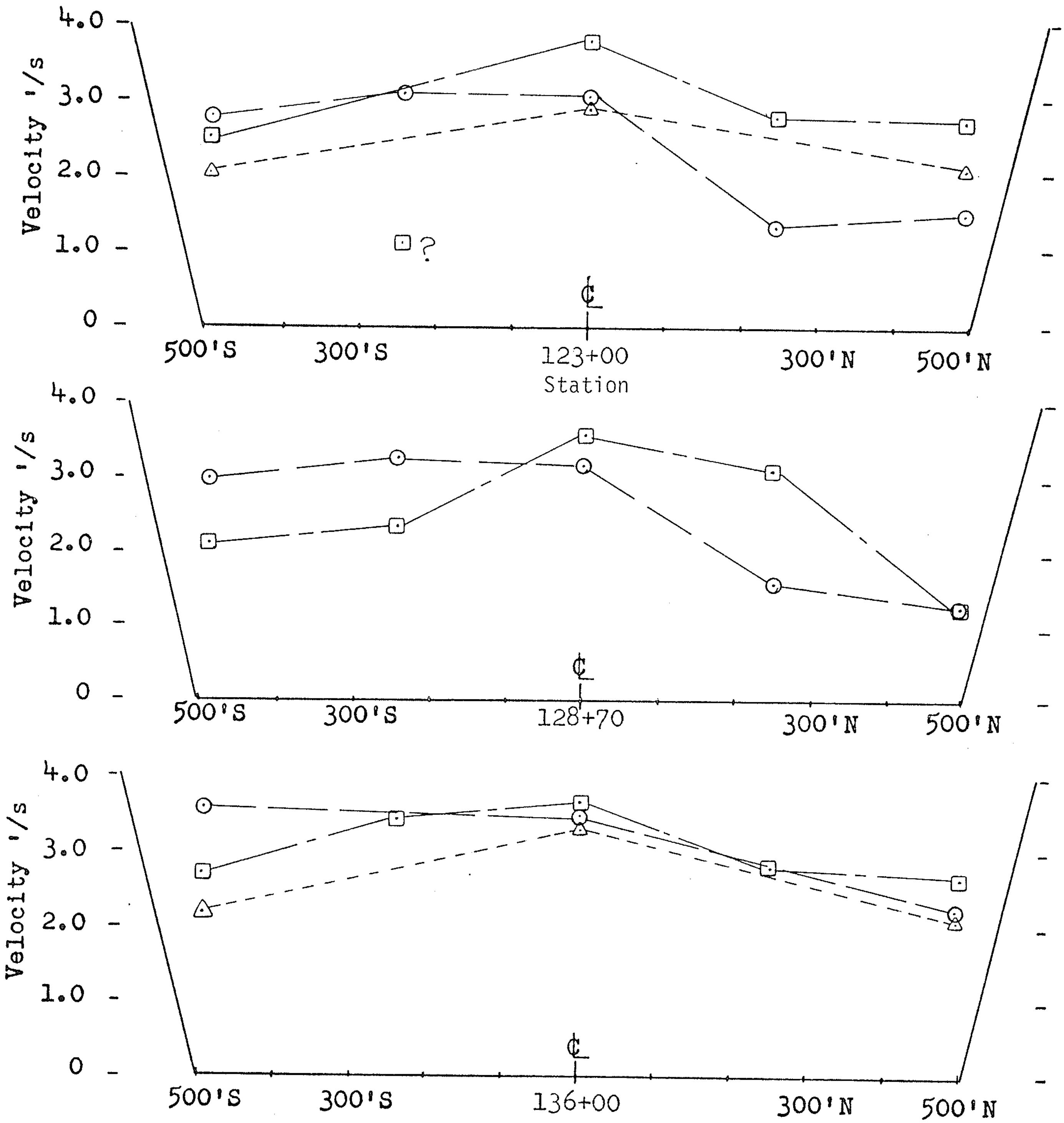


Figure 4.15.c

8 - Mile Channel

Velocity X - Sections

△ - No Rock Outcroppings D/S of 80+00

□ - All Rock Outcroppings D/S of 80+00

⊙ - Rocks #126+00 & #158+00 Removed

Q = 56,000 cfs

W = 525 ft.

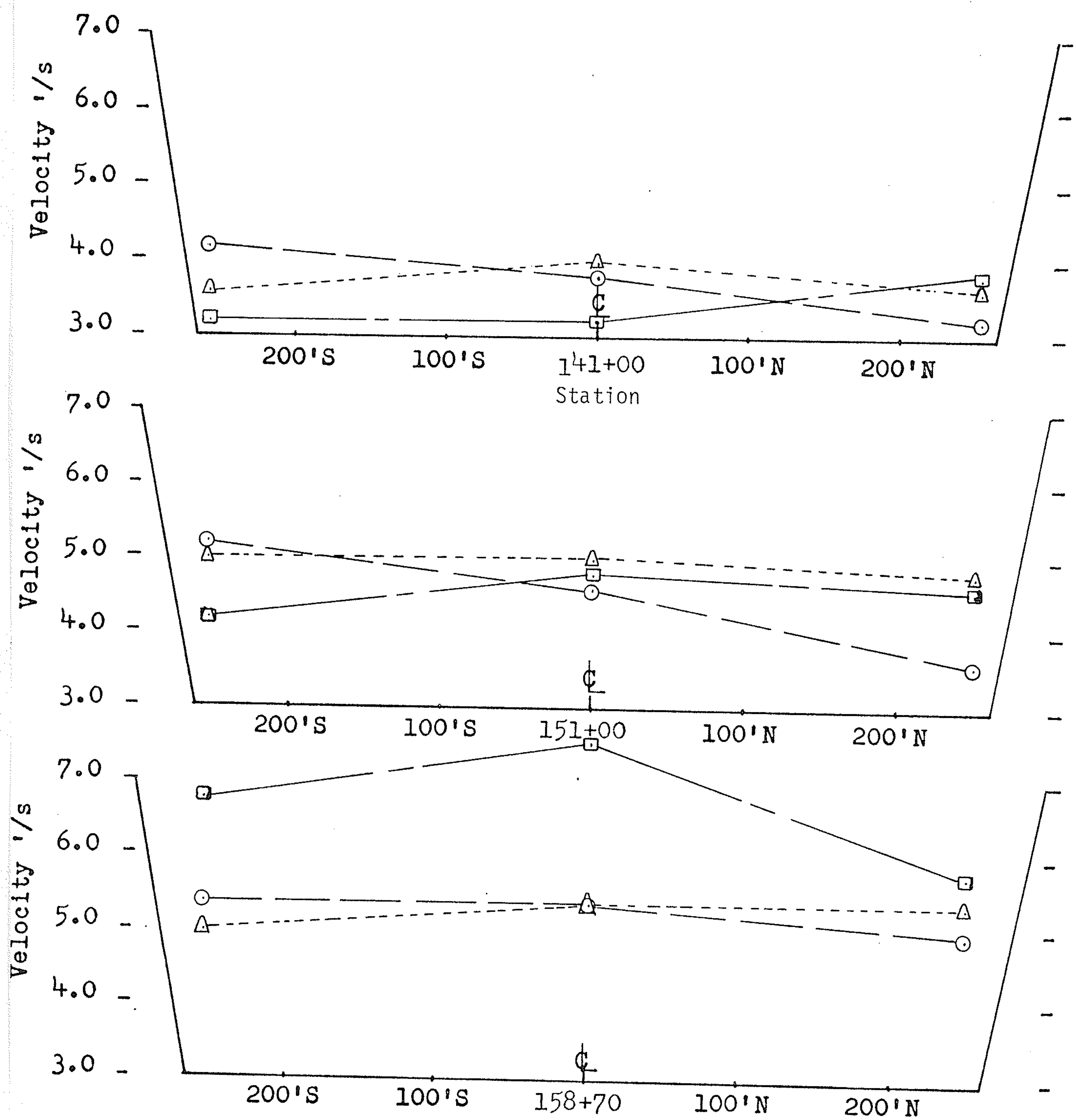


Figure 4.15.d

8 - Mile Channel

Velocity X - Sections

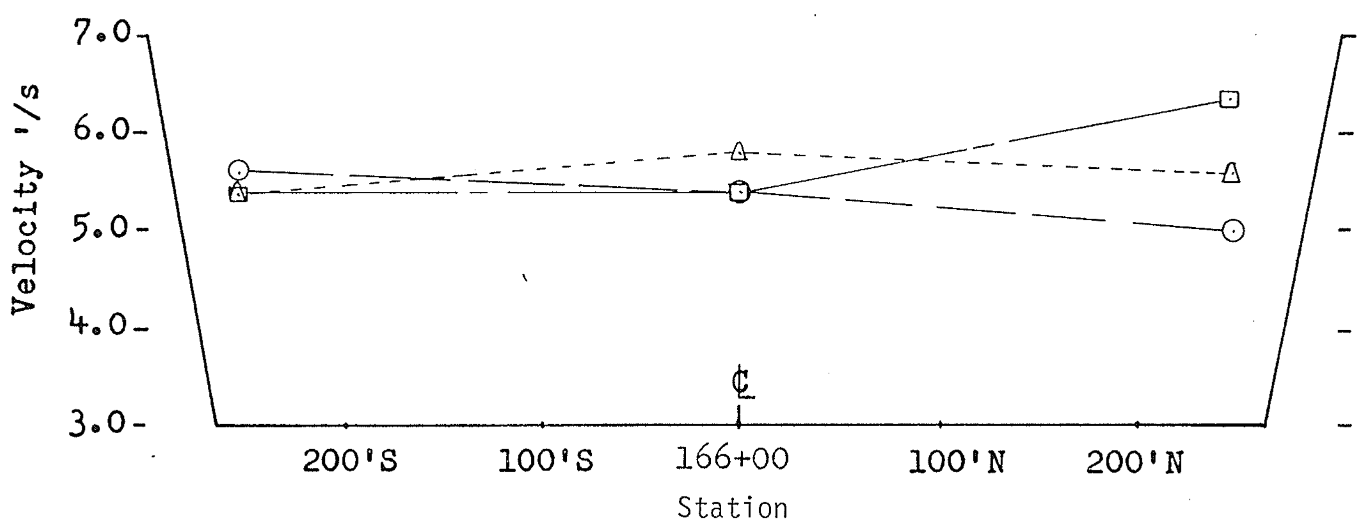
△ - No Rock Outcroppings D/S of 80+00

☐ - All Rock Outcroppings D/S of 80+00

⊙ - Rocks #126+00 & #158+00 Removed

Q = 56,000cfs

W = 525 ft.



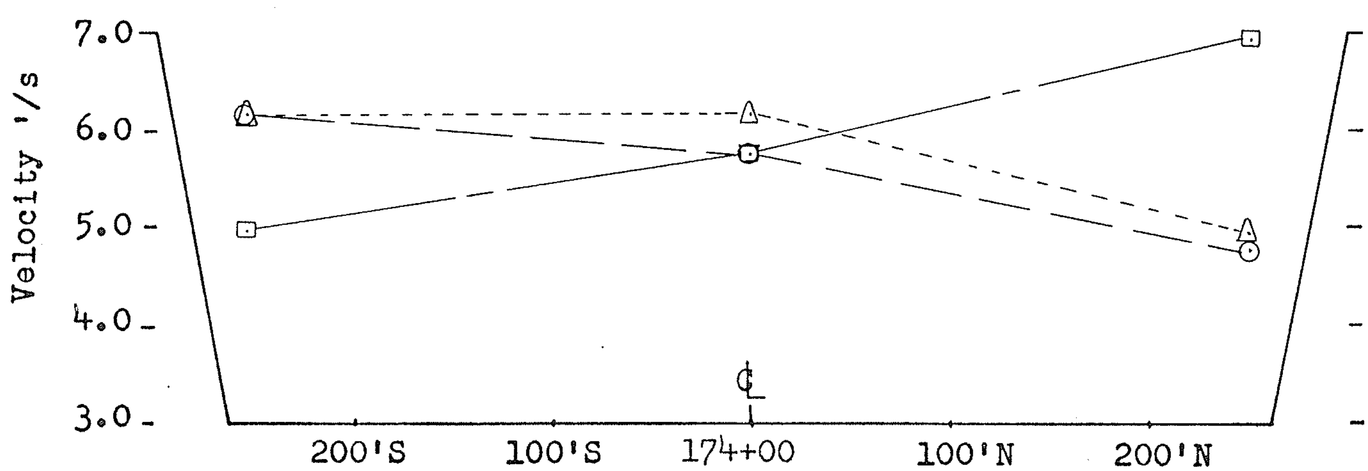


Figure 4.15.e

8 - Mile Channel

Velocity X - Sections

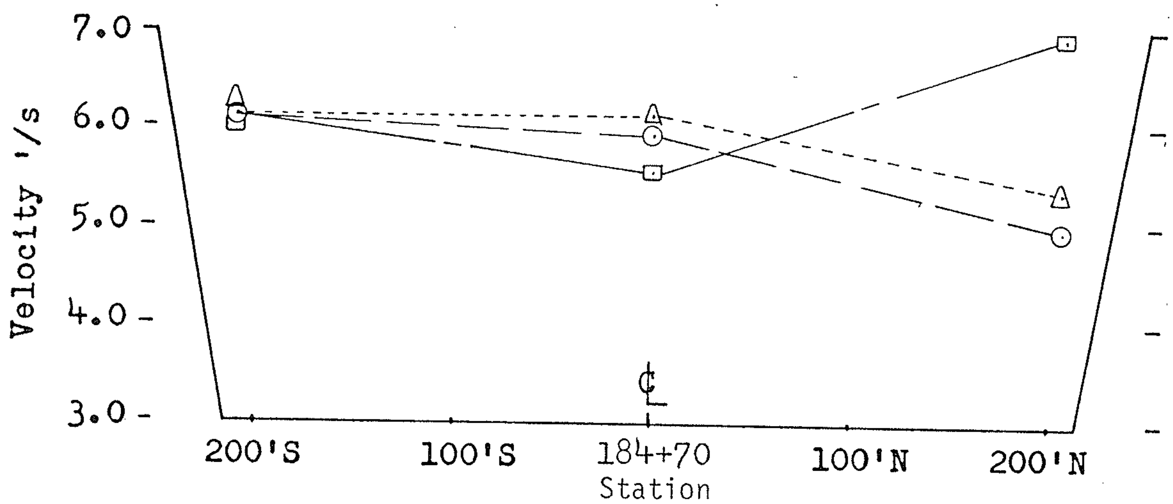
△ - No Rock Outcroppings D/S of 80+00

⊡ - All Rock Outcroppings D/S of 80+00

⊙ - Rocks #126+00 & #158+00 Removed

Q = 56,000cfs

W = 425 ft.



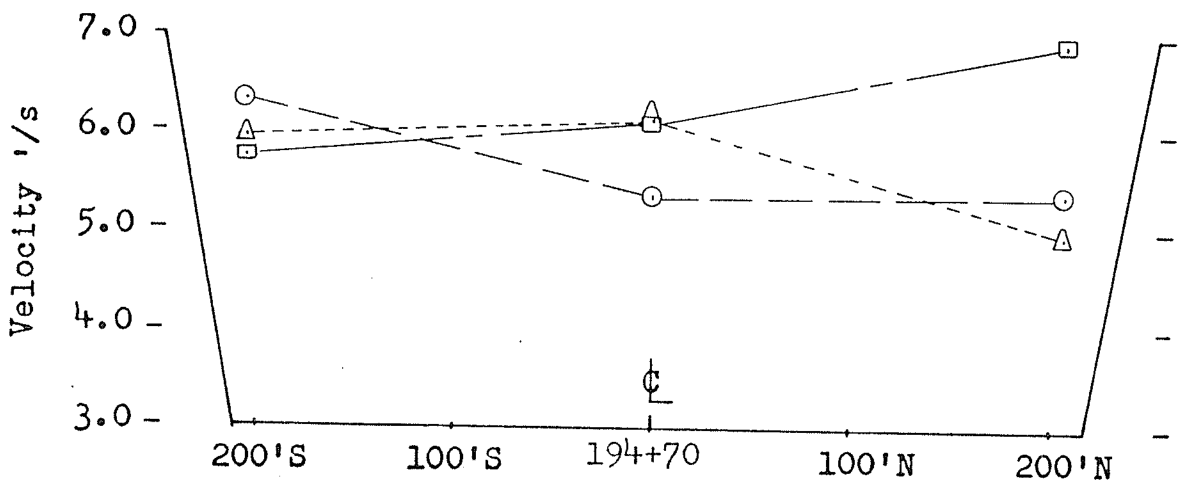


Figure 4.15.f

8 - MILE CHANNEL

Velocity X - Sections

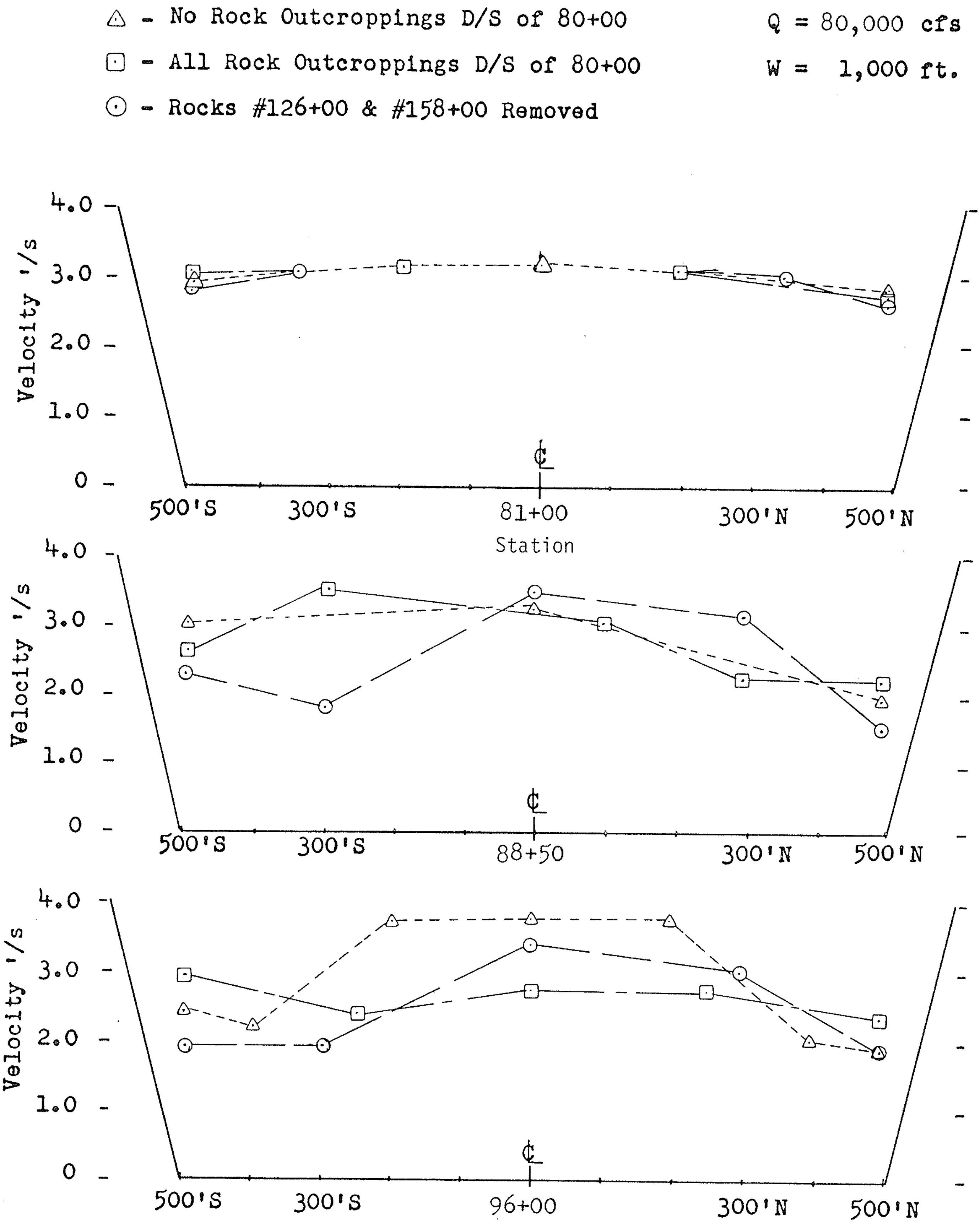


Figure 4.16.a

8 - MILE CHANNEL   Velocity X - Sections

△ - No Rock Outcroppings D/S of 80+00

⊡ - All Rock Outcroppings D/S of 80+00

⊙ - Rocks #126+00 & #158+00 Removed

Q = 80,000 cfs

W = 1,000 ft.

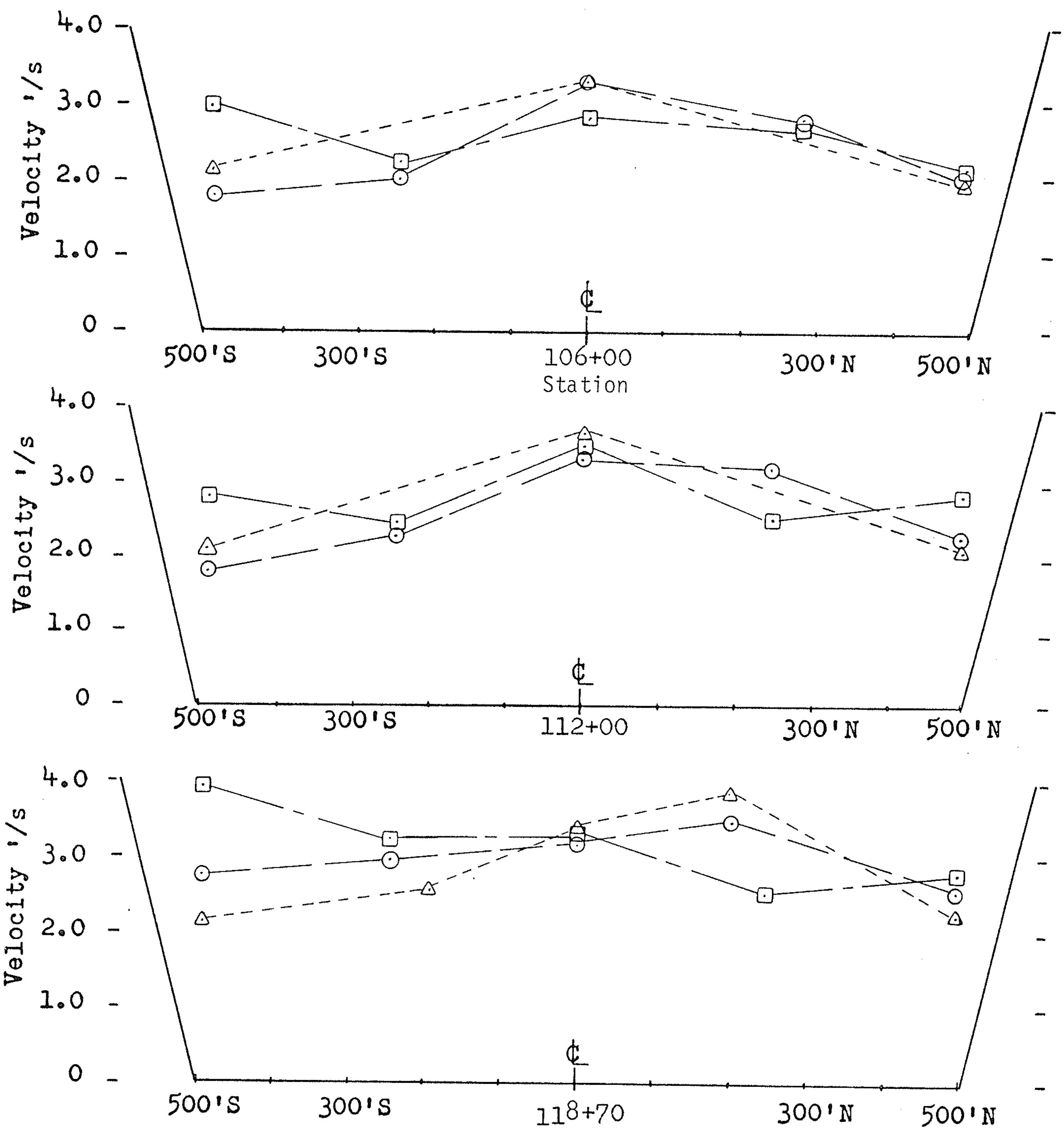


Figure 4.16.b

8 - MILE CHANNEL Velocity X - Sections

△ - No Rock Outcroppings D/S of 80+00

⊡ - All Rock Outcroppings D/S of 80+00

⊙ - Rocks #126+00 & #158+00 Removed

Q = 80,000 cfs

W = 1,000 ft.

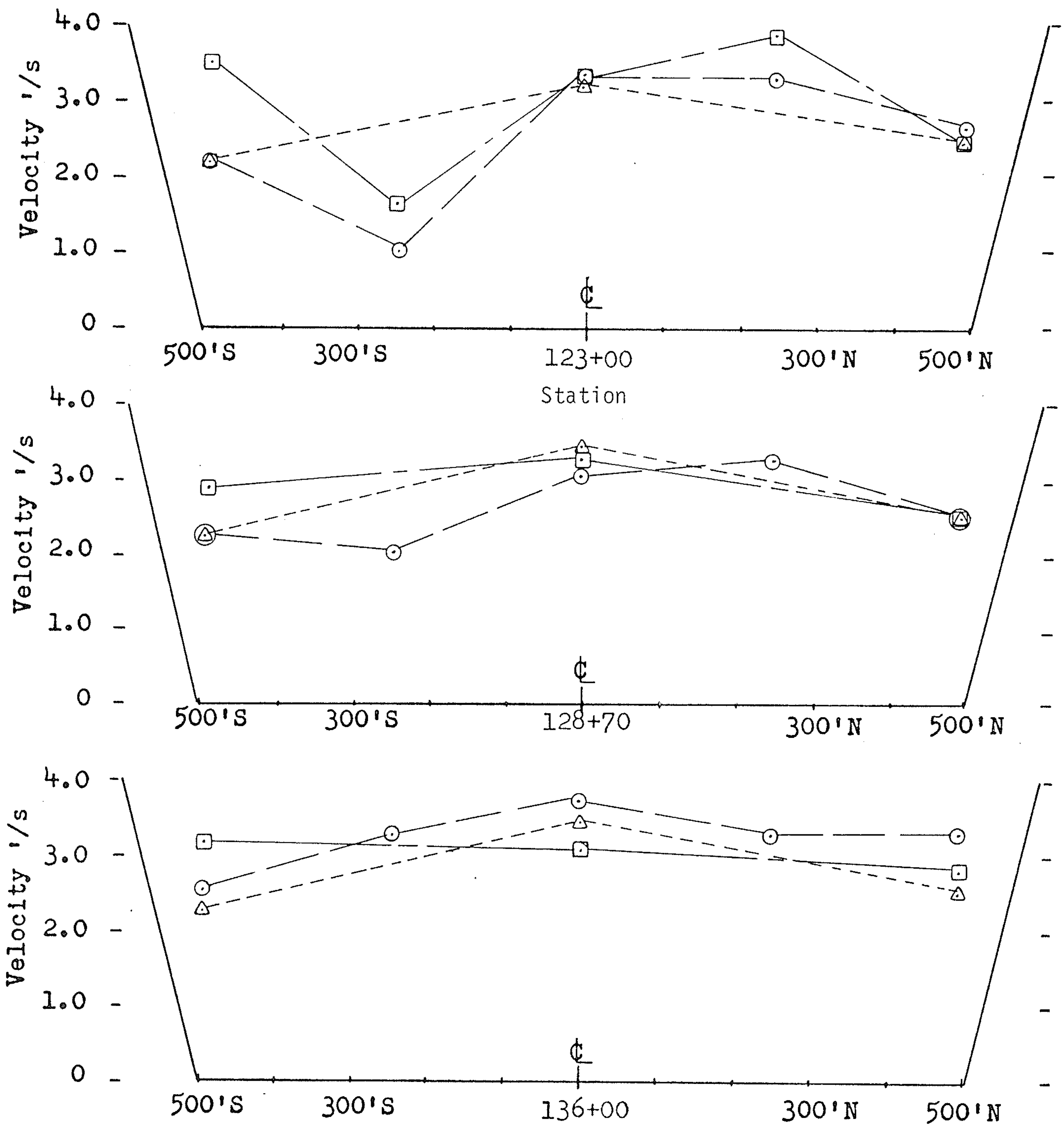


Figure 4.16.c

8 - Mile Channel

Velocity X - Sections

△ - No Rock Outcroppings D/S of 80+00

⊡ - All Rock Outcroppings D/S of 80+00

⊙ - Rocks #126+00 & #158+00 Removed

Q = 80,000 cfs

W = 525 ft.

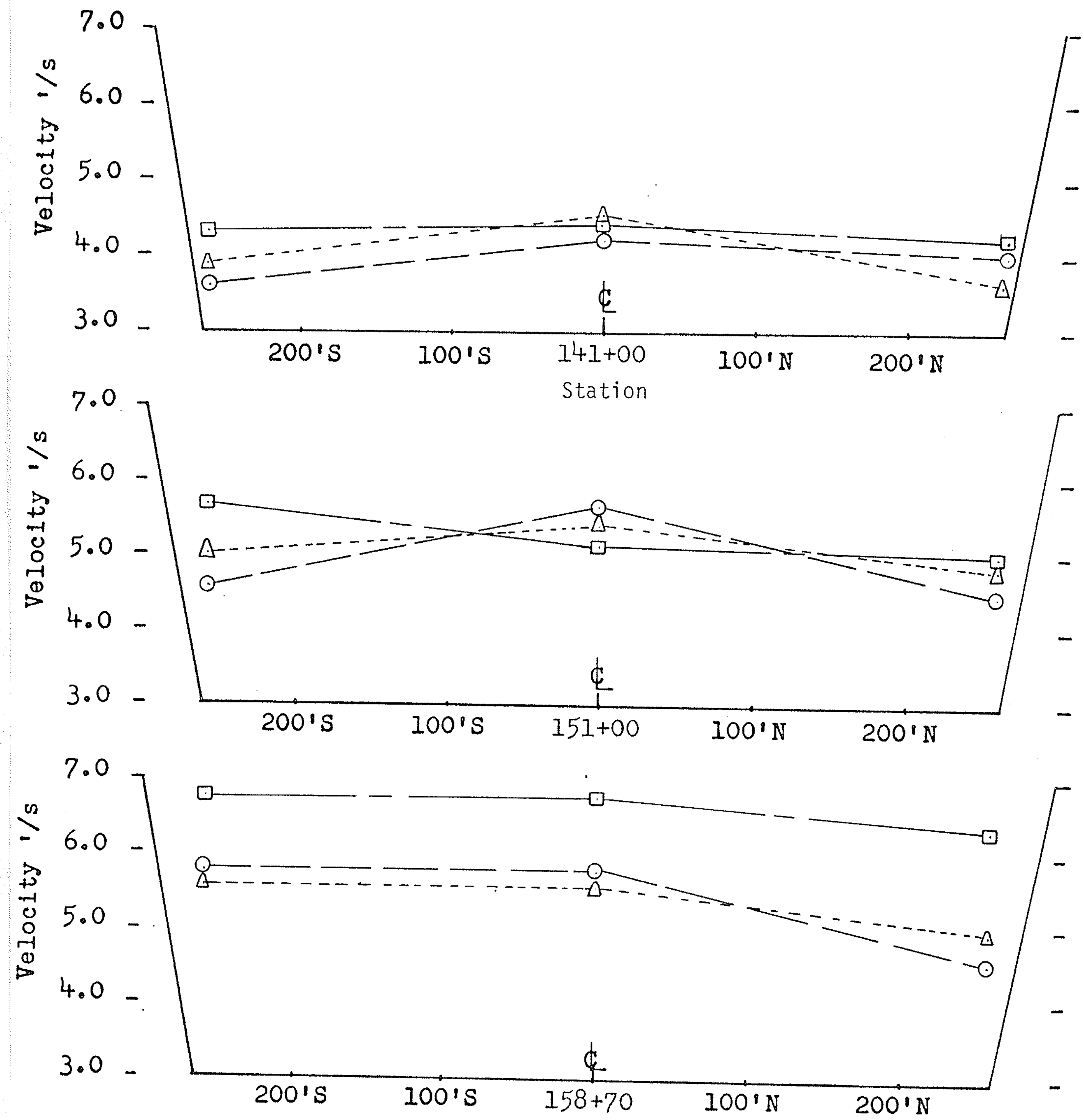


Figure 4.16.d

8 - Mile Channel

Velocity X - Sections

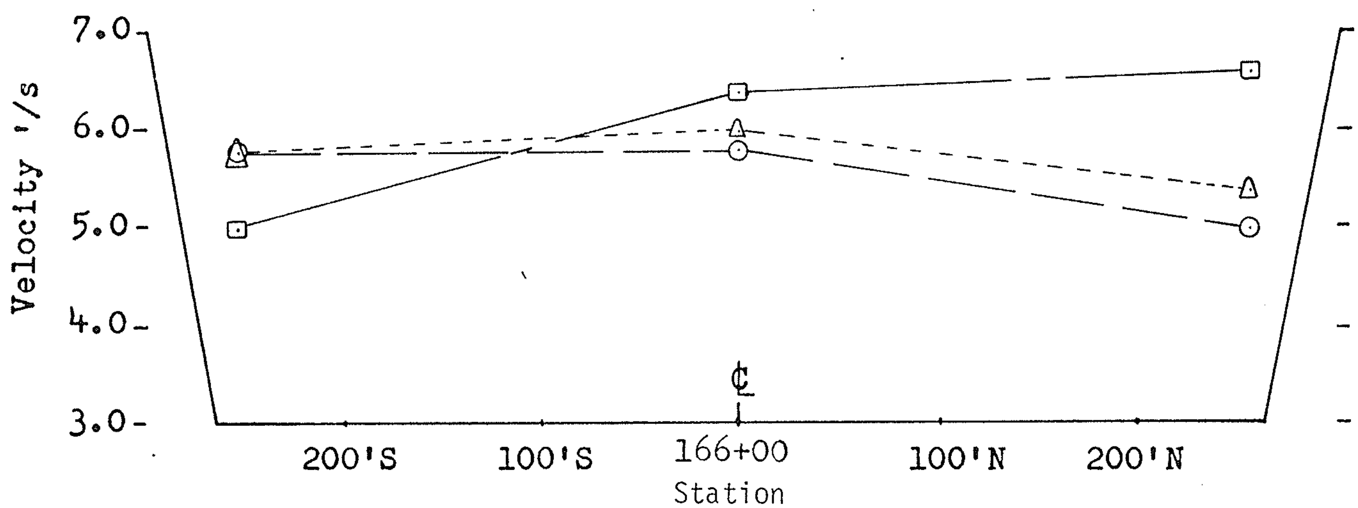
△ - No Rock Outcroppings D/S of 80+00

⊡ - All Rock Outcroppings D/S of 80+00

⊙ - Rocks #126+00 & #158+00 Removed

Q = 80,000cfs

W = 525 ft.



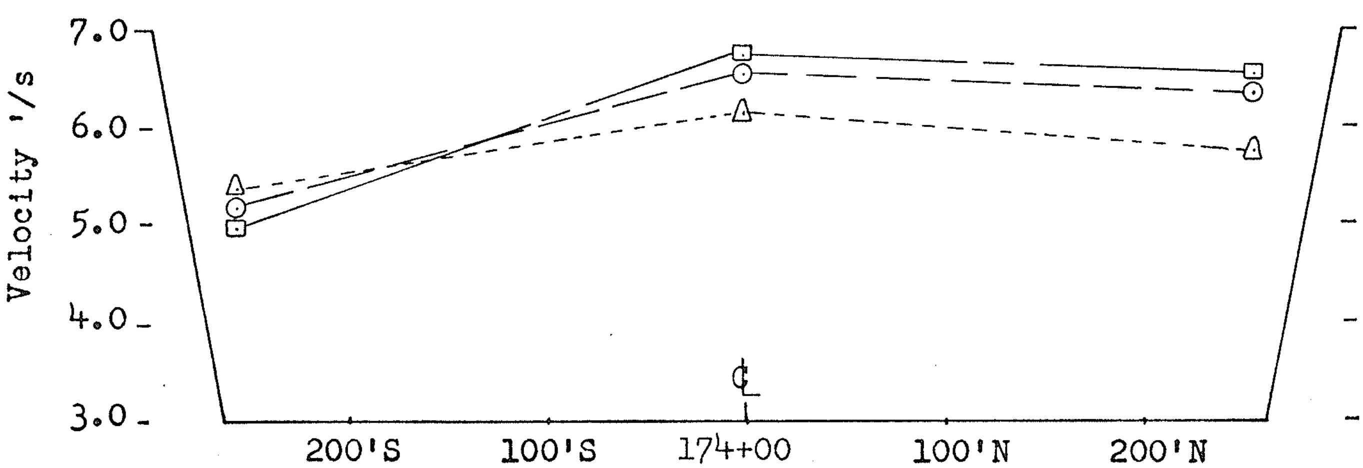


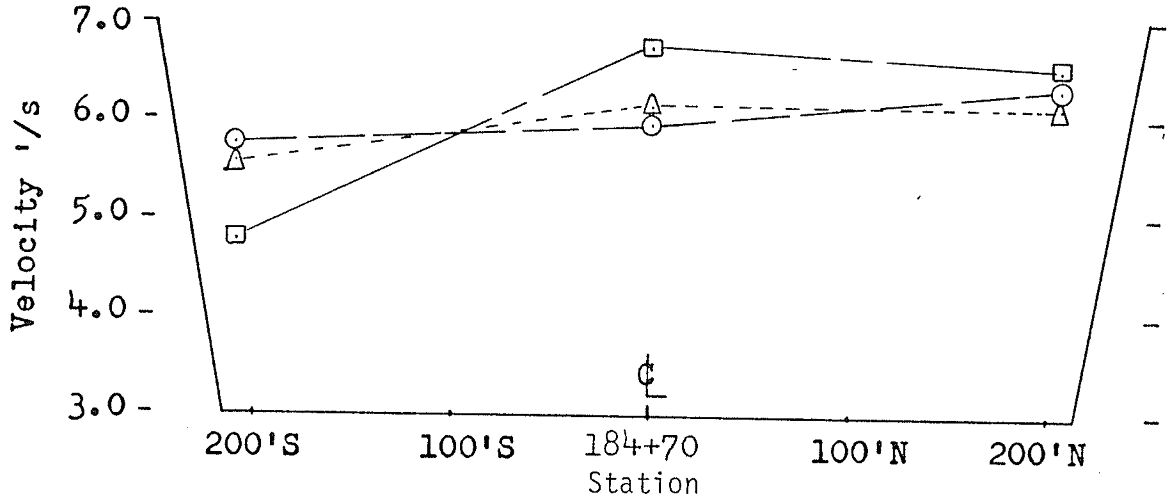
Figure 4.16.e

8 - Mile Channel Velocity X - Sections

△ - No Rock Outcroppings D/S of 80+00 Q = 80,000cfs

⊡ - All Rock Outcroppings D/S of 80+00 W = 425 ft.

⊙ - Rocks #126+00 & #158+00 Removed



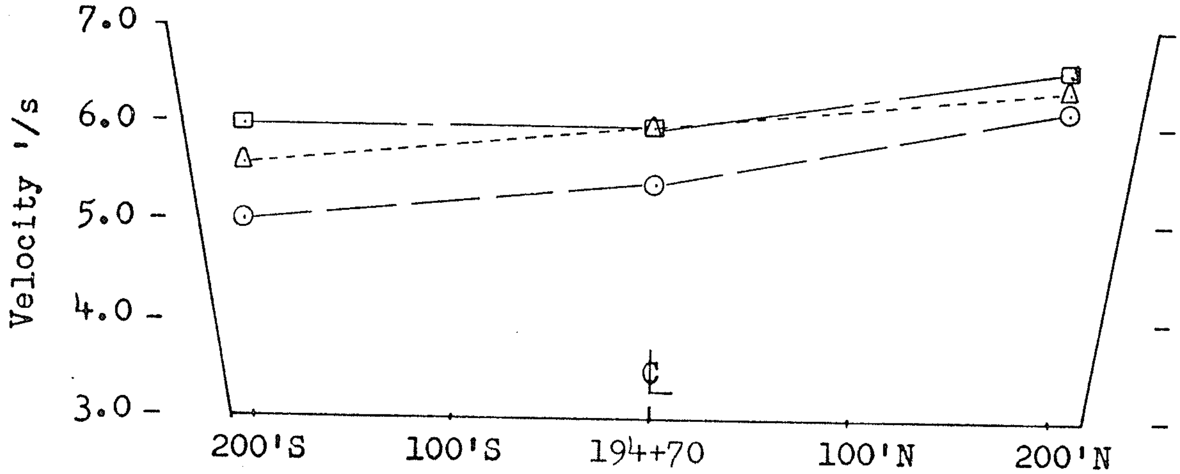


Figure 4.16.f

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This thesis has dealt with a number of different topics relating to the 8-Mile Channel. For this reason, conclusions and recommendations are numerous, and will be presented in point form where possible under the following headings:

A - Depth-Discharge Prediction

B - Channel Entrance

C - Channel Meander

D - Channel Stabilization

5.2 Conclusions

The 8-Mile Channel hydraulic model study provided information about bed movement and channel meander, not obtainable by theoretical calculations alone.

A - Depth-Discharge Prediction

Accurate depth-discharge prediction is a very difficult problem. For technique comparison and model observations, the following conclusions are made:

(1) All stage-discharge prediction techniques evaluated provided comparable results in the lower flow regime for the 1000 foot section of the channel.

(2) The range of results for the 425 foot section was slightly higher than original assumption of n = 0.025, and this can be attributed to the initial assumption that enough bed material was deposited in this section to form stable bed forms.

(3) From model observation of bed movement, insufficient bed material was available in the 425 foot section to form stable sand bed forms.

(4) A Manning's n value ranging between n = 0.025 and n = 0.030 is considered to be the most reliable prediction when all techniques are compared.

(5) Predicting mean velocities and subsequent stage-discharge relationships in the upper flow regime should be done with caution when actual field data to support the prediction is unavailable.

(6) Bed form analysis in a hydraulic model of this type is limited to a qualitative rather than a quantitative nature.

(7) The sudden interaction of the opposing flows in the 8-Mile Channel entrance produced turbulence, eddies, and water vortexes. The resulting bed movement produced bed configurations which increased the channel roughness factor thus reducing expected efficiency of water conveyance.

B - Channel Entrance

(1) The model shows that overbank flow from Playgreen Lake into the main stream flow of the 8-Mile Channel will cause scour and bed movement in the channel entrance. The scour and bed movement occurred at the 50% flow

(21,000 cfs) and was magnified as the flow was increased.

(2) The sudden interaction of the opposing flows in the 8-Mile Channel entrance produced turbulence, eddies, and water vortexes. The resulting bed movement produced bed configurations which increased the channel roughness factor, thus reducing expected efficiency of water conveyance.

(3) Bed material, mostly sand, will be transported out of the channel entrance at all flows, and deposited in the 1000 foot section, or transported entirely through the channel to Kiskittogisu Lake.

(4) At continued flows of 21,000 cfs or greater, the rate of degradation of the sand bed would be approximately one foot per year.

(5) This approximated rate of sand movement should decrease with time, due to possible paving of the channel bed by gravel lenses.

C - Channel Meander

(1) Channel meander will occur at all flows, and more readily at sustained higher flows due to increased water velocities and bed movement.

(2) A meander length of approximately 7000 ft. can be expected in the 425 ft. section of the channel at flows of 56,000 cfs (the maximum recorded). Model observation of length was approximately 7000 ft., while two theoretical approximations of 7100 ft. and 7200 ft. were calculated.

(3) Channel meander will be increased in the downstream portion of the channel at all flows due to the rise in channel bedrock outcroppings.

(4) Bed roughness will be increased in the locality of the rock outcroppings due to increased water velocities resulting from meander trends.

(5) Scour along the banks will be more pronounced due to channel meander in the 525 ft. transition zone, and 425 ft. section.

D - <u>Channel Stabilization</u>

(1) Channelization works in the form of spur dykes, revetments, and bank slope alterations will decrease bed movement and channel meandering.

5.3 Recommendations

The 8-Mile Channel moveable bed hydraulic model enabled research to be conducted with various channelization and stabilization works. From the numerous tests conducted, the following recommendations are made:

A - <u>Depth-Discharge Prediction</u>

(1) It is recommended that further studies be undertaken in relation to stage-discharge prediction in the upper flow regime.

B - <u>Channel Entrance</u>

(1) It is recommended that <u>either</u> of the following be adopted in the construction of the <u>8-Mile Channel entrance</u> to

reduce the water turbulence, high local velocities and subsequent scour, bed movement, and increase in bed roughness factors:

(A) Rock filled dykes, almost impermeable, constructed from the shoreline of Playgreen Lake, out into the lake, length and position as shown in Position V, Figure 4.5. Dykes are to be pyramid in shape, and extend above expected water levels in Playgreen Lake.

Availability and transport of rock fill would probably be economically unfeasible, therefore recommendation (B) is highly favoured.

(B) Channel entrance bank slopes be cut back to approximately a 10:1 slope with transition slope zones, length and positions as shown in Figure 4.6. Slopes may be dredged in steps as the overbank flow will smooth out the step slopes.

C - Channel Meander

(1) In order to reduce channel meandering it is recommended that rocks #126+00, and #158+00 be removed completely. Removal of these two rock outcroppings, #126+00, and #158+00 will reduce bed movement and channel meander in the 1000 ft., and 525 ft. transition zone. Bank scour will then be reduced in these areas.

(2) It is recommended that the dredge removal of material in the following areas be eliminated:

(A) Excavation of material along the north shore between stations 75+00 and 100+00 be omitted from the design.

This portion of the north bank was very ineffective in passing flow. Aggradation of material scoured out of the entrance occurred here to a significant amount, and because of channel alignment, very low velocity water, or reverse flow was observed in this section.

(B) Excavation of material to design bed elevation along the south bank directly downstream of the large rock outcropping, #120+00 be omitted. The material in this section should be dredged down only to elevation of rock 120+00, and this continued until the transition zone area is reached. Tests indicate that the main flow of the channel will be aligned much better for entrance into the 525 ft. transition section, and bank scour due to meander will be reduced.

An alternative to the removal of this material would be the construction of two rock filled spur dykes, length and position as shown in Figure 4.10. Both dykes realign the main flow into the 525 ft. section, and reduce bank scour associated with the meander pattern.

(3) It is recommended that bank protection be provided in the transition zone area along the banks around station 145+00, and along the banks in the areas adjacent to rocks #158+00 and 172+50. The meander pattern and velocity increase in these areas make revetments sensible recommendations.

(4) It is recommended that bank protection be provided around station 182+00 along the south bank in the transition

zone of 525 ft. to 425 ft. It is necessary here, as bank scour due to higher velocities is compounded by the fact that a natural meander curve occurs at this location.

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APPENDIX A

MODEL DETAILS

MODEL DETAILS

A.1 Basic Principles

In order to have similitude we must have more than geometric similiarity. Similarity may be defined as a known and usually limited correspondence between the behavior of the model and the prototype, with or without geometric similarity. Usually it is impossible to satisfy all the conditions for complete similarity. Therefore, we often simplify the problem to the interplay between two major forces and develop a set of transfer ratios which are used to predict prototype behavior from model results. The design of a moveable bed river model is often more an art than a science, and it requires a substantial amount of experience and judgment to apply their results.

In order to complete similitude it requires that the two systems, model and prototype, be geometrically, kinematically and dynamically similar.

Geometric similarity. Exists if the ratios of all linear dimensions are equal. It is indenendent of motion of any kind and involves only similarity in form.

Kinematic similarity. This is similarity of motion. If ratios of components of velocity at all similar points in geometrically similar systems are equal, the status of motion are kinematically similar.

Dynamic similarity. This requires that the ratios of forces in geometrically and kinematically similar systems must be the same.

A.2 8-Mile Channel Model Design

(a) Factors which influenced choice of scales

(1) similitude laws
(2) available space
(3) available discharge
(4) available bed material
(5) type of problem (influences vertical distortion)

On consideration of these factors a distorted scale of horizontal 1:250, and vertical 1:60, and bed material composed of crushed walnut shells, was chosen.

(b) Scale ratios based on Froude Relationship

Length ratio $\frac{X_2}{X_1} = Xr$

height ratio $\frac{Y_2}{Y_1} = Yr$

undistorted model $Xr = Yr$

distorted model $Xr \neq Yr$

*subscript:
1 denotes model
2 denotes prototype

ratio	undistorted	distorted	scales
horizontal	Xr	Xr	1:250
vertical	Yr	Yr	1:60
area	Xr^2	$XrYr$	1:15,000
volume	Xr^3	Xr^2Yr	-
velocity	$Yr^{1/2}$	$Yr^{1/2}$	1:7.74
discharge	$Xr^{5/2}$	$XrYr^{3/2}$	1:116,000
time	$Xr^{1/2}$	$Xr/Yr^{1/2}$	1:32.3
roughness	$Xr^{1/6}$	$Yr^{2/3}/Xr^{1/2}$	-

(c) Layout of model

See figure 1.4, and photos 1.5.a and 1.5.b.

(d) Operation and instrumentation of model

1) discharge is controlled by recirculating water through a centrifugal pump and sump system. The actual discharge is controlled by a valve into a six-foot weir box with a rated V-notch wier.

Q field	Q model	Height (rating curve)	Height (wier box)
80,000 cfs	0.689 cfs	0.568 ft.	(0.768 ft.
56,000	0.483	0.493	0.693
40,000	0.345	0.432	0.632
21,000	0.181	0.333	0.533

2) depth - depths are controlled by the use of a downstream gate, and the water surface is measured by a point gauge at the downstream end, corresponding to values from back water curves obtained from Manitoba Hydro. The Playgreen Lake or upstream lake elevation is checked by the use of a point gauge, to check the closeness of the model condition to the prototype.

Lake Levels

Q	Playgreen Lake	PL gauge	model end 425' section	425' gauge
80,000 cfs	720.9 ft.	1.509	719.9	0.784
56,000	714.2	1.396	713.45	0.693
40,000	713.8	1.389	712.9	0.666
21,000	713.3	1.382	712.2	0.655

Depths in channel are determined by point gauge on moveable track car.

3) velocities - are measured by Pigmy current meter.

4) flow patterns - are measured by dye releases, or float observations.

5) In a given test the model is operated for sufficient time to allow conditions to become constant.

APPENDIX B-1

DESCRIPTIONS

OF

STAGE-DISCHARGE PREDICTION TECHNIQUES

It should be noted here that 2 values for the equivalent grain roughness were used.

$k = 0.3$ mm & $k = 0.2$ mm

It was suspected that a slight difference would produce noticeable changes in the shape of the curve.

B-1.2 Engelund's Method (1966). A new approach was proposed by Engelund (1966). He adopted Carnot's formula for expansion loss in closed conduits to express the flow resistance due to bed forms:

$$S'' = \frac{\alpha V^2}{8gL} \left(\frac{h}{D}\right)^2 \qquad \text{B1.4}$$

where h and L are the wave height - from trough to crest, and wave length of the bed form. α, geometric factor depends on L, h and the depth D, S" is based on Einstein and Barbarossa's assumption that

$$S = S' + S'' \qquad \text{B1.5}$$

in which the energy gradient, S, consisting of two components S' and S", the grain roughness and the bed form roughness, respectively. Then, Engelund introduced the dimensionless shear stress and its components into the analysis

$$\tau_* = \tau_*' + \tau_*'' \qquad \text{B1.6}$$

in which $$\tau_* = \frac{\tau}{\gamma(s-1)\, d_s} = \frac{DS}{(s-1)\, d_s} \qquad \text{B1.7}$$

$$\tau_*' = \frac{DS'}{(s-1)\, d_s} \qquad \text{B1.8}$$

and $$\tau_*'' = \frac{F^2}{8} \frac{\alpha^2}{(s-1)\, d_s \lambda} \qquad \text{B1.9}$$

where γ is the specific weight of the fluid, s specific gravity of the sediment, λ the scale ratio for different streams, and F the Froude number. The relation suggested by Engelund and Hansen (1967) was verified by plotting the data reported by Guy, Simons and Richardson (1966) in Figure 2.7.

The value of τ_*' can be calculated by the relation of

$$\tau_*' = \frac{DS'}{(s-1)\ d_s} = \frac{D'S}{(s-1)\ d_s} \qquad \text{B1.10}$$

with D' determined by the logarithmic resistance formula suggested by Engelund

$$\frac{V}{\sqrt{gD'S}} = 6 + 2.5\ \ln \frac{D'}{2\ D_{65}} \qquad \text{B1.11}$$

B-1.3 Depth-Adjustment, Galay & Cheung (1972)

A concept of determining the resistance to flow based upon adjusting the measured depth to an equivalent depth in a channel having grain roughness was introduced by Simons and Richardson (1966). By utilizing the foregoing concept, based on the analysis of field data from different investigators, a complete depth-discharge technique is developed.

The resistance to flow and the average velocity are evaluated by adjusting the measured depth D to the adjusted D' which the channel would have for the same slope, discharge and average grain roughness. The continuity will be

$$q = V'D' = VD \qquad \text{B1.12}$$

where q is the discharge per unit width, and V' the mean velocity of the equivalent plane bed channel, defined as

$$V' = C'/\sqrt{g}\ \sqrt{gD'S} \qquad B1.13$$

Considering the diagram of the effect of bed configuration on resistance to flow studied by Simons and Richardson (1966), the points for ripples and dunes fall below the average roughness of plane bed. The adjusted depth D' can be determined by finding the difference necessary to adjust the ripple and dune form roughness to average grain roughness line so that

$$D' = D - \Delta D \qquad B1.14$$

in which ΔD is the increment in depth resulting from the form roughness. This difference, ΔD, between the measured depth and adjusted depth is a measure of the effect of the form roughness on resistance to flow. Therefore, ΔD is small for plane bed and antidunes, relatively large for ripples and dunes and varies from large to small value in transition zone.

In order to determine the average grain roughness over a plane bed with appreciable bed material, the Von Karman-Prandtl equation of velocity distribution near rough boundary of two dimension flow is adopted.

$$\frac{v_y}{V_*} = A \ln \frac{y}{k} + B \qquad B1.15$$

and by integrating

$$V = V_* \left[A \ln \left(\frac{D}{k}\right) + (B-A)\right] \qquad B1.16$$

From the studies of the velocity profiles, Simons and Richardson (1966) proposed the constants A and B were equal, with a value of 3.2 and the roughness height k was approximately equal to the d_{85} size of the bed material, that is

$$\frac{V}{V_*} = 3.2 \ln \left(\frac{D}{d_{85}}\right) \quad \text{B1.17}$$

in which $V_* = \sqrt{gDS}$ B1.18

and $\frac{V}{V_*} = \frac{C'}{\sqrt{g}}$ B1.19

From equation 4.1 and 4.2

$$D' = \frac{VD}{V'} \quad \text{B1.20}$$

$$V' = C'/\sqrt{g} \ \sqrt{gD'S} \quad \text{B1.21}$$

Then $D' = (VD/C' \ \sqrt{gs}/\sqrt{g})^{2/3}$ B1.22

and $\Delta D = D - \left(\frac{VD}{C'/\sqrt{g} \ \sqrt{gs}}\right)^{2/3}$ B1.23

Application

To present the usefulness of this approach, resistance diagrams correlating Chezy's discharge coefficient $C/\sqrt{g}$ and the ratio of the Reynolds number to this coefficient R_*, $R_* = V_*D/\nu$, for different values of $\Delta D/D$ were developed in Figure 2.8 and Figure 2.9.

By applying the preceding relations to a relatively straight and regular alluvial channel with known slope and sediment size d_{50}, the average velocity may be determined as follows:

(1) From known values of d_{50} and S, a selected value of D, obtain ΔD from Figure 2.10.

(2) Compute $V_* = \sqrt{gDS}$, $\Delta D/d$, and $R_* = V_*D/\nu$

(3) Enter the values of $\Delta D/D$ and R_* in resistance diagram (Figure 2.8) and read the value of $C/\sqrt{g}$.

(4) Calculate the average velocity to be expected in the lower flow regime

$$V = V_* \, C/\sqrt{g} \qquad \text{B1.24}$$

(5) Determine the bed form by entering the stream power $\tau_0 V$ and the known value of median fall diameter from Simons and Richardson's criterion for bed form in Figure 2.11. If the flow is not in the lower flow regime, the estimate of V should not be allowed.

B-1.4 Manning's Equation

Manning in 1889 proposed a formulae which was later modified to its present well known form:

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

n = Manning's roughness coefficient
R = hydraulic radius
S = slope of channel
V = mean velocity

This formulae, and velocity produced, depends on the velocity distribution which is related to turbulence generated at the boundaries. The value of Manning's 'n' is of great importance and can be reasonably evaluated using the following procedure (Cowan 1956)

$$n = (n0 + n1 + n2 + n3 + n5)m5$$

n = final roughness coefficient
n0 = material involved
n1 = degree of irregularity of surface
n2 = variations in channel x-section
n3 = relative effect of obstructions
n4 = vegetation
m5 = degree of meandering

The values for these factors are listed in Table B.1. Typical values for Manning's n are shown in Table B2, for various types of channels.

(a) For the 8-Mile Channel (1000' section)

$$n = (n0 + n1 + n2 + n3 + n4)m5$$

n0 = 0.024 for straight channel in sand or fine gravel
n1 = 0.005 for good dredged channel
n2 = 0.000 gradual variation
n3 = 0.000 not considering rock out-crops
n4 = 0.001 for minor vegetation growth
m5 = 1.00 for minor meander
n = 0.030

(b) For 8-Mile Channel (425' section)

n0 = 0.020 for straight channel in earth
n1 = 0.005 for good dredged channel
n2 = 0.000 gradual variation
n3 = 0.000 not considering outcroppings
n4 = 0.001 minor vegetation
m5 = 1.0 for minor meander
n = 0.026

n = 0.025 was adopted instead of n = 0.026, as this value was used by Manitoba Hydro, and a comparison is helpful.

Thus for Manning's Equation, two values of channel roughness were used in predicting a stage-discharge curve.

n = 0.025
n = 0.030

Comparing these values for the 8-Mile Channel to Table B.2, the range varied between 0.025 → 0.033 for a dredged channel, uniform, straight, with little or nor vegetation.

VALUES FOR COMPUTATION OF MANNING'S 'n'

TABLE B.1

Channel conditions			Values
Material involved	Earth Rock cut Fine gravel Coarse gravel	n_0	0.020 0.025 0.024 0.028
Degree of irregularity	Smooth Minor Moderate Severe	n_1	0.000 0.005 0.010 0.020
Variations of channel cross section	Gradual Alternating occasionally Alternating frequently	n_2	0.000 0.005 0.010-0.015
Relative effect of obstructions	Negligible Minor Appreciable Severe	n_3	0.000 0.010-0.015 0.020-0.030 0.040-0.060
Vegetation	Low Medium High Very high	n_4	0.005-0.010 0.010-0.025 0.025-0.050 0.050-0.100
Degree of meandering	Minor Appreciable Severe	m_5	1.000 1.150 1.300

VALUES FOR ROUGHNESS COEFFICIENT 'n'

TABLE B.2

Type of channel and description	Minimum	Normal	Maximum
A. Excavated or Dredged			
a. Earth, straight and uniform			
1. Clean, recently completed	0.016	0.018	0.020
2. Clean, after weathering	0.018	0.022	0.025
3. Gravel, uniform section, clean	0.022	0.025	0.030
4. With short grass, few weeds	0.022	0.027	0.033
b. Earth, winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.028	0.030	0.035
5. Stony bottom and weedy banks	0.025	0.035	0.040
6. Cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline-excavated or dredged			
1. No vegetation	0.025	0.028	0.033
2. Light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. Smooth and uniform	0.025	0.035	0.040
2. Jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2. Clean bottom, brush on sides	0.040	0.050	0.120
3. Same, highest stage of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140
B. Natural Streams			
B-1. Minor streams (top width at flood stage 100 ft.)			
a. Streams on plain			
1. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050

TABLE B.2 (continued)

Type of channel and description	Minimum	Normal	Maximum
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
1. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070
B-2. Flood plains			
a. Pasture, no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
b. Cultivated areas			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees, in winter	0.035	0.050	0.060
3. Light brush and tress, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. Dense willows, summer, straight	0.110	0.150	0.200
2. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. Same as above, but with heavy growth of sprouts	0.050	0.060	0.080

TABLE B.2 (continued)

Type of channel and description	Minimum	Normal	Maximum
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5. Same as above, but with flood stage reaching branches	0.100	0.120	0.160
B-3. Major streams (top width at flood stage 100 ft.) The n value is less than that for minor streams of similar description, because banks offer less effective resistance.			
a. Regular section with no boulders or brush.	0.025	---	0.060
b. Irregular and rough section	0.035	---	0.100

APPENDIX B-2

DATA AND COMPUTATIONS

OF

STAGE-DISCHARGE PREDICTION TECHNIQUES

1 - EINSTEIN AND BARBARROSSA METHOD (1952)

$$Vel. = \frac{7.66\ (gS)^{\frac{1}{2}}\ (R')^{2/3}}{K^{1/6}} \qquad \Psi' = \frac{1.68\ D_{35}}{R'S}$$

S = 0.0001 $\qquad$ $R = R' + R''$ $\qquad$ D_{35} = 0.3 mm = .000983 ft. $\qquad$ K = 0.3 mm = .000983 ft.

W = 1000 ft. $\qquad$ $R'' = \frac{(V'')^2}{gS}$

No.	R' (ft)	$(R')^{2/3}$	VEL ('/s)	Ψ'	V/V" fig. 2.6	V"	R"	R (ft)	A (ft^2)	Q (cfs)
1	0.1	0.316	0.433	165.0	3.0	0.148	6.9	7.0	7,000	3,100
2	0.5	0.707	0.988	33.0	5.3	0.186	10.8	11.3	11,300	11,100
3	1.0	1.00	1.40	16.5	7.0	0.200	12.4	13.4	13,400	18,800
4	2.0	1.59	2.23	8.5	9.4	0.237	17.4	19.4	19,400	43,200
5	3.0	2.08	2.92	5.5	12.0	0.243	18.4	21.4	21,000	62,500
6	4.0	2.52	3.53	4.13	13.5	0.261	21.1	25.1	25,100	88,700
7	5.0	2.93	4.10	3.30	15.0	0.274	23.3	28.3	28,300	116,000
8	6.0	3.31.	4.64	2.75	17.0	0.274	23.3	29.3	29,300	136,000
9	7.0	3.66	5.13	2.34	18.0	0.285	25.2	32.2	32,200	165,000
10	8.0	4.00	5.60	2.06	21.0	0.267	22.2	30.2	30,200	169,000

1 - EINSTEIN AND BARBARROSSA METHOD (1952)

$$\text{Vel.} = \frac{7.66\ (gS)^{\frac{1}{2}}\ (R')^{2/3}}{K^{1/6}} \qquad \Psi' = \frac{1.68\ D_{35}}{R'S}$$

$S = 0.0001$ $\quad R = R' + R''$ $\quad D_{35} = .3$ mm $= .000983$ ft. $\quad K = .3$ mm $= .000983$ ft.

$W = 425$ ft. $\quad R'' = \dfrac{(V'')^2}{gS}$

No.	R' (ft)	$(R')^{2/3}$	VEL ('/s)	Ψ'	V/V" fig. 2.6	V"	R"	R (ft)	A (ft^2)	Q (cfs)
1	0.1	0.316	0.433	165.0	3.0	0.148	6.9	7.0	2,980	1,320
2	0.5	0.707	0.988	33.0	5.3	0.186	10.8	11.3	4,810	4,750
3	1.0	1.000	1.40	16.5	7.0	0.200	12.4	13.4	5,700	7,980
4	2.0	1.59	2.23	8.5	9.4	0.237	17.4	19.4	8,250	18,400
5	3.0	2.08	2.92	5.5	12.0	0.243	18.4	21.4	9,100	26,500
6	4.0	2.52	3.53	4.13	13.5	0.261	21.1	25.1	10,600	37,600
7	5.0	2.93	4.10	3.3	15.0	0.274	23.3	28.3	12,000	49,200
8	6.0	3.31	4.64	2.75	17.0	0.274	23.3	29.3	12,500	57,900
9	7.0	3.66	5.13	2.34	18.0	0.285	25.2	32.2	13,700	70,300
10	8.0	4.00	5.60	2.06	21.0	0.267	22.2	30.2	12,700	71,500
11	9.0	4.33	6.06	1.82	22.0	0.275	23.5	32.5	13,800	83,700
12	10.0	4.65	6.52	1.65	23.5	0.277	23.8	33.8	14,400	94,000
13	12.0	5.25	7.36	1.37	27.5	0.267	22.2	34.2	14,500	107,000

1 - EINSTEIN AND BARBARROSSA METHOD (1952)

$$Vel. = \frac{7.66\ (gS)^{1/2}\ (R')^{2/3}}{K^{1/6}} \qquad \Psi' = \frac{1.68\ D_{35}}{R'S}$$

$S = 0.0001$ $\quad R = R' + R''$ $\quad D_{35} = .2\ mm = 0.000655$ ft. $\quad K = .2\ mm = 0.000655$ ft.

$W = 1000$ ft. $\quad R'' = \frac{(V'')^2}{gS}$

No.	R' (ft)	$(R')^{2/3}$	VEL ('/s)	Ψ'	V/V" fig. 2.6	V"	R"	R (ft)	A (ft^2)	Q (cfs)
1	1.0	1.0	1.48	11.0	8.4	0.176	9.63	10.6	10,600	15,800
2	2.0	1.59	2.35	5.5	12.0	0.196	11.9	13.9	13,900	32,700
3	3.0	2.08	3.08	3.67	14.0	0.220	15.0	18.0	18,000	55,500
4	4.0	2.52	3.74	2.75	17.0	0.220	15.0	19.0	19,000	71,100
5	5.0	2.93	4.34	2.2	18.5	0.235	17.1	22.1	22,100	96,000
6	6.0	3.31	4.90	1.83	22.0	0.223	15.5	21.5	21,500	105,000
7	7.0	3.66	5.42	1.57	24.0	0.226	15.9	22.9	22,900	124,000
8	8.0	4.00	5.92	1.38	27.5	0.215	14.4	22.4	22,400	133,000
9	9.0	4.34	6.43	1.22	33.0	0.195	11.8	20.8	20,800	134,000
10	10.0	4.65	6.88	1.10	38.0	0.181	10.2	20.2	20,200	139,000
11	15.0	6.10	9.03	0.734	59.0	0.153	7.27	22.3	22,300	201,000
12	20.0	7.40	10.95	0.550	88.0	0.125	4.85	24.9	24,900	273,000

1 - EINSTEIN AND BARBARROSSA METHOD (1952)

$$\text{Vel.} = \frac{7.66\,(gS)^{\frac{1}{2}}\,(R')^{2/3}}{K^{1/6}} \qquad \Psi' = \frac{1.68\,D_{35}}{R'S}$$

$S = 0.0001$ $\quad R = R' + R''$ $\quad D_{35} = .2$ mm $= .000655$ ft. $\quad K = .2$ mm $= .000655$ ft.

$W = 425$ ft. $\quad R'' = \dfrac{(V'')^2}{gS}$

No.	R' (ft)	$(R')^{2/3}$	VEL ('/s)	Ψ'	V/V'' fig. 2.6	V''	R''	R (ft)	A (ft²)	Q (cfs)
1	1.0	1.0	1.48	11.0	8.4	0.176	9.63	10.6	4,520	6,700
2	2.0	1.59	2.35	5.5	12.0	0.196	11.9	13.9	5,900	13,900
3	3.0	2.08	3.08	3.67	14.0	0.220	15.0	18.0	7,650	23,600
4	4.0	2.52	3.74	2.75	17.0	0.220	15.0	19.0	8,080	30,200
5	5.0	2.93	4.34	2.2	18.5	0.235	17.1	22.1	9,400	40,800
6	6.0	3.31	4.90	1.83	22.0	0.223	15.5	21.5	9,150	44,800
7	7.0	3.66	5.42	1.57	24.0	0.226	15.9	22.9	9,740	52,900
8	8.0	4.00	5.92	1.38	27.5	0.215	14.4	22.4	9,520	56,400
9	9.0	4.34	6.43	1.22	33.0	0.195	11.8	20.8	8,850	56,900
10	10.0	4.65	6.88	1.10	38.0	0.181	10.2	20.2	8,600	59,100
11	15.0	6.10	9.03	0.734	59.0	0.153	7.27	22.3	9,480	85,600
12	20.0	7.40	10.95	0.550	88.0	0.125	4.85	24.9	10,600	116,000

2 - ENGELUND'S METHOD (1966)

$S = 0.0001 \qquad s = 2.65$

$W = 1000$ ft.

$$T^{*\prime} = \frac{D' \times S}{(s-1)d_s} \qquad \frac{VEL}{gD'S} = 6 + 2.5 \ln \frac{D'}{2d_{65}}$$

$d_{65} = .6$ mm $= 0.00197$ ft. $\quad d_s = .3$ mm $= 0.000983$ ft.

No.	D' (ft)	VEL ('/s)	T*'	T* fig. 2-7	D (ft)	A (ft^2)	Q (cfs)
1	1	1.13	0.0616	0.392	6.37	6,370	7,170
2	2	1.73	0.123	0.397	6.45	6,450	11,200
3	3	2.22	0.185	0.559	9.07	9,070	20,100
4	4	2.65	0.246	0.683	11.08	11,100	29,300
5	5	3.03	0.308	0.787	12.78	12,800	38,700
6	6	3.38	0.370	0.880	14.3	14,300	48,300
7	7	3.71	0.431	0.963	15.6	15,600	58,000
8	8	4.02	0.493	1.04	16.9	16,900	67,900
9	9	4.31	0.554	1.11	18.1	18,100	77,800
10	10	4.59	0.616	1.18	19.1	19,100	87,900
11	11	4.86	0.678	1.24	20.2	20,200	98,100
12	12	5.12	0.739	1.30	21.2	21,200	108,000
13	13	5.37	0.801	1.36	22.1	22,100	119,000
14	14	5.61	0.862	1.42	23.0	23,000	129,000
15	15	5.85	0.924	1.47	33.9	33,900	140,000
16	16	6.08	0.986	1.52	24.7	24,700	150,000
17	17	6.30	1.05	1.57	25.5	25,500	161,000
18	18	6.52	1.11	1.62	26.3	26,300	171,000
19	19	6.73	1.17	1.67	27.1	27,100	182,000
20	20	6.94	1.23	1.71	27.8	27,800	193,000
21	21	7.14	1.29	1.76	28.5	28,500	204,000

2 - ENGELUND'S METHOD (1966)

$$T^{*\prime} = \frac{D' \times S}{(s-1)d_s} \qquad \frac{VEL}{gD'S} = 6 + 2.5 \ln \frac{D'}{2d_{65}}$$

S = 0.0001 s = 2.65

W = 425 ft.

d_{65} = .6 mm = 0.00197 ft. d_s = .3 mm = 0.000983 ft.

No.	D' (ft)	VEL ('/s)	T*'	T* fig. 2-7	D (ft)	A (ft^2)	Q (cfs)
1	1	1.13	0.0616	0.392	6.37	2,710	3,050
2	2	1.73	0.123	0.397	6.45	2,740	4,750
3	3	2.22	0.185	0.559	9.07	3,850	8,560
4	4	2.65	0.246	0.683	11.08	4,710	12,500
5	5	3.03	0.308	0.787	12.78	5,440	16,500
6	6	3.38	0.370	0.880	14.3	6,090	20,500
7	7	3.71	0.431	0.963	15.6	6,630	24,700
8	8	4.02	0.493	1.04	16.9	7,190	28,800
9	9	4.31	0.554	1.11	18.1	7,700	33,100
10	10	4.59	0.616	1.18	19.1	8,130	37,400
11	11	4.86	0.678	1.24	20.2	8,590	41,700
12	12	5.12	0.739	1.30	21.2	9,010	46,000
13	13	5.37	0.801	1.36	22.1	9,390	50,400
14	14	5.61	0.862	1.42	23.0	9,780	54,900
15	15	5.85	0.924	1.47	33.9	10,200	59,300
16	16	6.08	0.986	1.52	24.7	10,500	63,800
17	17	6.30	1.05	1.57	25.5	10,800	68,300
18	18	6.52	1.11	1.62	26.3	11,200	72,800
19	19	6.73	1.17	1.67	27.1	11,500	77,300
20	20	6.94	1.23	1.71	27.8	11,800	81,900
21	21	7.14	1.29	1.76	28.5	12,100	86,500

3 - DEPTH ADJUSTMENT METHOD

$V^* = (gDS)^{1/2}$ $R^* = \frac{V^*D}{\nu}$ $V = V^* \frac{c}{(g)^{1/2}}$

S = 0.0001

W = 1000 ft.

D_{50} = 0.3 mm = 0.000983 ft.

$\nu = 1.4 \times 10^{-5}$ @ 50^o

No.	ΔD fig. 2.10	D (ft)	$\Delta D/D$	V^*	R^* $\times 10^{-3}$	$c/\sqrt{g}$ fig. 2.8	VEL ('/s)	A (ft^2)	Q (cfs)
1	0.4	1	0.40	0.0567	4.02	6.3	0.357	1,000	357
2	2.2	5	0.44	0.127	45.1	9.5	1.21	5,000	6,000
3	4.3	10	0.43	0.180	128	10.2	1.84	10,000	18,400
4	5.5	12	0.46	0.197	168	10.7	2.11	12,000	25,300
5	6.9	15	0.46	0.219	233	11.0	2.41	15,000	36,200
6	8.5	18	0.47	0.241	308	11.0	2.65	18,000	47,700
7	8.8	20	0.44	0.254	361	11.7	2.97	20,000	59,400
8	10.5	25	0.42	0.283	502	12.6	3.57	25,000	89,500
9	11.0	30	0.37	0.311	663	13.8	4.29	30,000	128,700

3 - DEPTH ADJUSTMENT METHOD

$S = 0.0001$

$W = 425$ ft.

$V^* = (gDS)^{\frac{1}{2}}$ $R^* = \frac{V^*D}{\nu}$ $V = V^* \frac{c}{(g)^{\frac{1}{2}}}$

$D_{50} = 0.3$ mm $= 0.000983$ ft.

$\nu = 1.4 \times 10^{-5}$ @ 50^{o}

No.	ΔD fig. 2.10	D (ft)	$\Delta D/D$	V^*	R^* $\times 10^{-3}$	$c/\sqrt{g}$ fig. 2.8	VEL ('/s)	A (ft^2)	Q (cfs)
1	0.4	1	0.40	0.0567	4.02	6.3	0.357	425	152
2	2.2	5	0.44	0.127	45.1	9.5	1.21	2,120	2,570
3	4.3	10	0.43	0.180	128	10.2	1.84	4,250	7,830
4	5.5	12	0.46	0.197	168	10.7	2.11	5,100	10,800
5	6.9	15	0.46	0.219	233	11.0	2.41	6,370	15,400
6	8.5	18	0.47	0.241	308	11.0	2.65	7,650	20,300
7	8.8	20	0.44	0.254	361	11.7	2.97	8,500	25,300
8	10.5	25	0.42	0.283	502	12.6	3.57	10,600	37,900
9	11.0	30	0.37	0.311	663	13.8	4.29	12,800	54,700

4 - MANNING'S EQUATION

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

$$Q = V \times A$$

$$S = 0.0001$$

$$W = 1000 \text{ ft.}$$

$$n = 0.025$$

No.	D (ft)	VEL. ('/s)	A (ft^2)	Q (cfs)
1	2	0.95	2,000	1,890
2	4	1.50	4,000	6,010
3	6	1.97	6,000	11,800
4	8	2.39	8,000	19,100
5	10	2.77	10,000	27,700
6	12	3.13	12,000	37,500
7	14	3.47	14,000	48,500
8	16	3.79	16,000	60,600
9	18	4.10	18,000	73,800
10	20	4.40	20,000	87,900
11	22	4.68	22,000	103,000
12	24	4.96	24,000	119,000
13	26	5.24	26,000	136,000
14	28	5.50	28,000	154,000
15	30	5.76	30,000	172,000
16	32	6.01	32,000	192,000

4 - MANNING'S EQUATION

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

$$Q = V \times A$$

$$S = 0.0001$$

$$W = 425 \text{ ft.}$$

$$n = 0.025$$

No.	D (ft)	VEL. ('/s)	A (ft^2)	Q (cfs)
1	2	0.95	850	804
2	4	1.50	1,700	2,550
3	6	1.97	2,550	5,020
4	8	2.39	3,400	8,110
5	10	2.77	4,250	11,800
6	12	3.13	5,100	15,900
7	14	3.47	5,950	20,600
8	16	3.79	6,800	25,800
9	18	4.10	7,650	31,300
10	20	4.40	8,500	37,400
11	22	4.68	9,350	43,800
12	24	4.96	10,200	50,600
13	26	5.24	11,050	57,900
14	28	5.50	11,900	65,500
15	30	5.76	12,750	73,500
16	32	6.10	13,600	81,800

4 - MANNING'S EQUATION

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

$$Q = V \times A$$

$$S = 0.0001$$

$$W = 1000 \text{ ft.}$$

$$n = 0.030$$

No.	$D_{(ft)}$	VEL. ('/s)	$A_{(ft^2)}$	$Q_{(cfs)}$
1	2	0.79	2,000	1,580
2	4	1.25	4,000	5,000
3	6	1.64	6,000	9,850
4	8	1.99	8,000	15,900
5	10	2.31	10,000	23,100
6	12	2.61	12,000	31,300
7	14	2.89	14,000	40,400
8	16	3.16	16,000	50,500
9	18	3.41	18,000	61,500
10	20	3.66	20,000	73,300
11	22	3.90	22,000	85,900
12	24	4.14	24,000	99,300
13	26	4.36	26,000	113,000
14	28	4.58	28,000	128,000
15	30	4.80	30,000	144,000
16	32	5.01	32,000	160,000

4 - MANNING'S EQUATION

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

$$Q = V \times A$$

$$S = 0.0001$$

$$W = 425 \text{ ft.}$$

$$n = 0.030$$

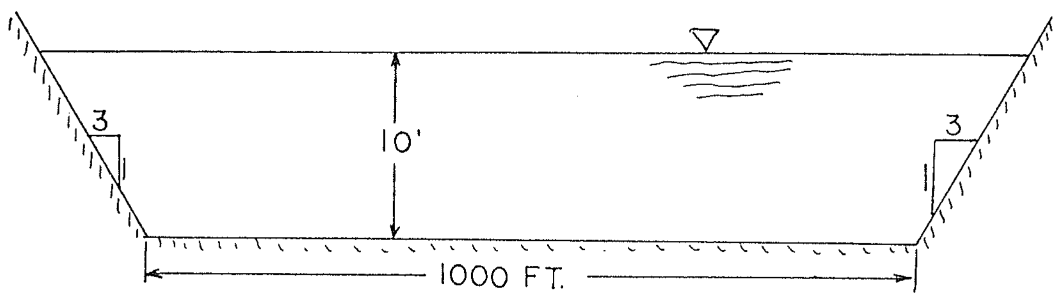
No.	D (ft)	VEL. ('/s)	A (ft^2)	Q (cfs)
1	2	0.79	850	670
2	4	1.25	1,700	2,130
3	6	1.64	2,550	4,180
4	8	1.99	3,400	6,760
5	10	2.31	4,250	9,810
6	12	2.61	5,100	13,300
7	14	2.89	5,950	17,200
8	16	3.16	6,800	21,500
9	18	3.41	7,650	26,100
10	20	3.66	8,500	31,100
11	22	3.90	9,350	36,500
12	24	4.14	10,200	42,200
13	26	4.36	11,050	48,200
14	28	4.58	11,900	54,600
15	30	4.80	12,750	61,200
16	32	5.01	13,600	68,200

APPENDIX C-1

8-MILE CHANNEL ENTRANCE
SEDIMENT TRANSPORT CAPABILITIES

8-MILE CHANNEL ENTRANCE
SEDIMENT TRANSPORT CAPABILITIES

Entrance Channel



50% duration flow Q = 21,000 cfs

Slope = 0.0001 D = 10 feet

Material = predominately sand with some gravel lenses

D_m = 0.30 - 0.60 mm.

Sediment Transport

For channels with sand beds, Colby's charts may be used to estimate the bed material transport. See figure C-1.

qs = 1.7 tons/day/foot

or

qs = 1,700 tons/day

If this material is moved out in block form, the entrance, which may be 1000 feet wide and 5000 feet long the degradation rate would be:

$$1{,}700 \text{ tons/day/feet} \quad \frac{1}{1000 \text{ ft.} \times 5000 \text{ ft.}} \times \frac{2000 \text{ \#/ton}}{100 \text{ \#/cu.ft.}}$$

= 0.0068 ft/day or 2.5 feet/year.

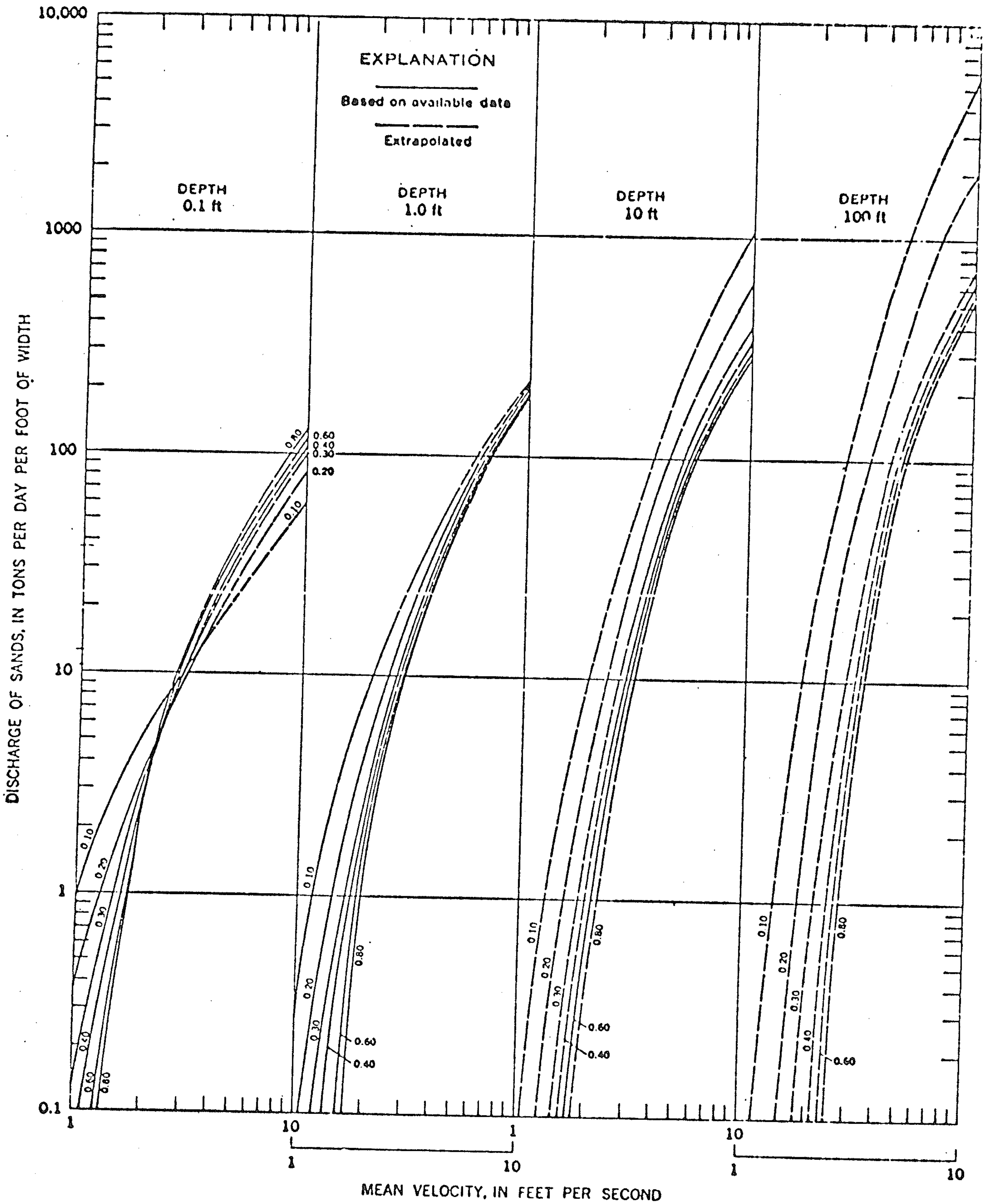
The actual rate of degradation of the entrance would probably be less than two and one half feet per year, (say one foot per year) for the following reasons:

(1) gravel lenses may begin to pave the bottom of the channel;

(2) rate of degradation will decrease with time due to a flattening of channel slope;

(3) north wind conditions may induce littorial currents to deposit sand into the entrance.

The actual rate and extent of degradation is difficult to predict with confidence.



BED - MATERIAL LOAD CHART
(AFTER COLBY, 1964)

Figure C.1

APPENDIX C-2

MEANDER WAVELENGTH

Meander Wavelength (Leopold & Woliman) 1960

meander length = λ

$$\lambda = 10.9\ (w)^{1.01} \qquad \text{(C-2.1)}$$

Lacey width approximation (Regime Theory)

$$w = 2.6\ Q^{0.5} \qquad \text{(C-2.2)}$$

Using Q = 56,000 cfs

$$w = 2.6\ Q^{0.5}$$

$$w = 615'$$

$$\lambda = 10.9\ (w)^{1.01}$$

$$\lambda = 7200\ \text{ft.}$$

Note: Almost exactly the same as Dury, (7130 ft.)

APPENDIX D-1

MEAN VELOCITIES

MEAN VELOCITY DATA FROM MANITOBA HYDRO

*Using Continuity Equation and Backwater Studies

STATION	WATER LEVEL	$\overline{V}$	ROCK	DISCHARGE
41+00	712.37 ft.	0.5 '/s	Partial	21,000 cfs
57+00	712.35	0.8	"	"
73+00	712.32	1.3	"	"
86+00	712.32	1.0	"	"
99+00	712.31	1.0	"	"
112+00	712.31	1.0	"	"
120+00	712.29	1.3	"	"
132+00	712.30	1.0	"	"
160+00	712.23	1.7	"	"
172+50	712.21	1.8	"	"
182+00	712.20	1.7	Partial	21,000 cfs
41+00	713.36	0.9	Partial	40,000 cfs
57+00	713.32	1.5	"	"
73+00	713.22	2.3	"	"
86+00	713.23	1.8	"	"
99+00	713.20	1.8	"	"
112+00	713.18	1.8	"	"
120+00	713.13	2.3	"	"
132+00	713.14	1.8	"	"
160+00	712.94	3.1	"	"
172+50	712.85	3.3	"	"
182+00	712.83	3.1	Partial	40,000 cfs
41+00	714.37	1.1	Partial	56,000 cfs
57+00	714.30	1.9	"	"
73+00	714.14	3.0	"	"
86+00	714.15	2.4	"	"
99+00	714.11	2.4	"	"
112+00	714.08	2.4	"	"
120+00	713.99	3.0	"	"
132+00	713.81	2.4	"	"
160+00	713.65	4.2	"	"
172+50	713.49	4.5	"	"
182+00	713.45	4.2	Partial	56,000 cfs
41+00	720.72	1.1	Partial	80,000 cfs
57+00	720.67	1.8	"	"
73+00	720.53	2.9	"	"
86+00	720.53	2.6	"	"
99+00	720.50	2.6	"	"
112+00	720.47	2.5	"	"
120+00	720.40	3.0	"	"
132+00	720.42	2.5	"	"
160+00	720.06	4.5	"	"
172+50	719.93	4.7	"	"
182+00	719.90	4.4	Partial	80,000 cfs

8-MILE CHANNEL

MODEL MEAN VELOCITY CALCULATIONS

*126+00 }
158+00 } removed

Q = 40,000 cfs

Station (model)	Distance ft.	Water Level ft.	Depth ft.	Area ft^2	$\overline{V}$ '/s
BZ_4	194+70	712.9	24.6	12,330	3.25
BV	175+20	713.1	21.6	12,720	3,14
BS	166+20	714.9	23.3	13,830	2.88
BP	158+70	715.2	24.5	14,680	2.72
BM	151+20	714.9	23.1	13,710	2.91
$BI_{630'}$	141+20	715.3	23.4	16,400	2.44
$BG_{860'}$	136+20	715.3	23.4	21,800	1.84
BD	128+70	715.3	23.3	24,920	1.60
BB	123+20	715.3	23.3	24,720	1.62
A	118+70	715.3	23.2	21,360	1.87
C	113+70	715.3	23.2	24,900	1.61
F	106+20	215.2	23.0	24,580	1.63
J	96+00	715.3	23.0	24,580	1.63
M	88+50	715.6	23.2	24,900	1.61
$P_{880'}$	81+00	714.6	22.1	20,915	1.92

8-MILE CHANNEL

MODEL MEAN VELOCITY CALCULATIONS

*126+00 }
158+00 } removed

Q = 56,000 cfs

Station (model)	Distance ft.	Water Level ft.	Depth ft.	Area $ft.^2$	$\overline{V}$ '/s
BZ_4	194+70	713.45	25.2	12,690	4.40
BV	174+20	713.9	22.4	13,280	4.12
BS	166+20	715.6	24.0	14,320	3.90
BP	158+70	715.9	24.2	14,480	3.87
BM	151+20	715.7	23.9	14,370	3.90
$BI_{630'}$	141+20	715.7	23.8	16,700	3.35
$BG_{860'}$	136+20	715.8	23.9	22,250	2.52
BD	128+70	715.8	23.8	24,200	2.32
BB	123+20	715.9	23.9	25,170	2.20
A	118+70	715.9	23.8	22,010	2.54
C	113+70	715.9	23.8	25,550	2.19
F	106+20	715.8	23.6	25,170	2.22
J	96+00	716.0	23.7	25,220	2.22
M	88+50	715.2	22.8	24,320	2.30
$P_{880'}$	81+00	715.3	22.8	21,700	2.58