THE UNIVERSITY OF MANITOBA

EROSION STUDY OF THE SEINE RIVER DIVERSION

by

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ABSTRACT

The degradation of the Seine River Diversion in the Province of Manitoba has resulted in numerous engineering problems. The purpose of this thesis was to study the erosion of the channel and to assess its present stability.

Data on longitudinal and transversal profiles of the channel has been presented to show the variations of the original bed elevations and cross sectional shape over a nine year period. The relation of width-depth ratio to the percent silt-clay in the perimeter of the channel and a part of its hydraulic geometry at some cross sections are presented and indicate that the original design was far from a stable shape. The channel did not suit the characteristics of self-formed alluvial channels and it progressively adjusted its slope and cross section toward a more stable state. A comparison of alternative designs for the channel has been made with the original design and indicated that the original design slope was much too steep. Stabilizing the present channel by means of gradient control structures has been discussed.

More field measurements have been recommended.

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TABLE OF CONTENTS

TABLE OF CONTENTS - continued

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES - continued

LIST OF FIGURES - continued

LIST OF PHOTOGRAPHS

CHAPTER I

INTRODUCTION

Over the years, disastrous flooding occured along rivers draining ~~the~~ Southern Manitoba. Among others, the Seine River flowing off the eastern escarpment of the former glacial lake Agassiz and draining the lowland Area of Ste-Anne and Ile des Chenes was a particularly troublesome stream. It has a drainage basin of 660 square miles that extends for a distance of nearly sixty miles southeastwards from the junction of the Seine with the Red River in St-Boniface (FIGURE 1.1). Initial reaches of the stream fall fairly rapidly to Ste-Anne, but below Ste-Anne the slopes are milder and the Seine meanders considerably. It was in the region from Ste-Anne to the Winnipeg area that frequent overflow took place over the agricultural lands. In 1955, a review of several flood control proposals for the Seine River was undertaken by the Canada Department of Agriculture, Prairie Farm Rehabilitation Administration (P.F.R.A.) to determine the most feasible scheme that could alleviate the flood situation in the Seine River basin. Careful engineering and economic considerations were later given to their recommended proposal and some alterations were made to produce in 1960 the actual Seine River Diversion. It consists of an excavated earth channel to convey water from the Seine River one mile upstream of Ste-Anne, due West, passing through a reach of the Johnstone Drain and the Manning Canal, discharging into the Red River two miles North of St-Adolphe.

After the diversion was used, diverted floods were very harmful for the stability of the channel and appurtenant structures. The flow caused intensive erosion of the channel bed and gave rise to local sliding of banks. The bed scouring and bank caving have resulted in numerous engineering problems with concrete ford crossings, bridges and transported sediments. The ford crossings have been undermined and consequently failed. Considerable scour occured at bridge piers and abutments resulting in the failure of two bridges. About 90% of the sediments that have been picked up from the channel bed and banks have been transported to the Red River downstream.

The principal objective of this thesis is to explain the regime of the diversion channel supported by descriptive data and photographs. The first part of the study deals with the design procedures and original characteristics of the diversion. Following this, a general discussion is presented on the adjustment of the channel. Analysis is made on the variations of the hydraulic characteristics - width, depth and velocity- with increasing discharges at given cross sections and on the influence of the sediment type on the shape of the channel. In the last part, a comparison of alternative designs for the channel is made with the original design and an investigation as to stabilizing the present channel is presented.

CHAPTER II

ORIGINAL CHANNEL DESIGN

2.1 Design Discharge

The Seine River Diversion was designed to permit the complete diversion of flows during flood stages, allowing the low summer flows to pass down the river. For this purpose, a control dam was constructed across the Seine River a short distance downstream of the diversion entrance. The control offered by this dam is such that during a flood the conduit gates are closed and all the flow is diverted, leaving only local drainage in the river throughout St-Vital and St-Boniface. During periods of low normal flow, the opened gates pass the total flow through the conduits. The conduits and the diversion inlet were designed so that the flow below 180 cfs remains in the river channel to serve the landowners downstream. The layout of the diversion entrance and control structures are shown in PHOTOGRAPHS 2.1 and 2.2.

At the time of the investigation in 1955(3)[1], records of peak flows for the Seine River were available for a 22 year period, 1915 to 1937, at Ste-Anne and for a 14 year

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[1]Numerals in parentheses, thus (3), refer to corresponding items in the list of references.

period, 1942 to 1955, at Prairie Grove gauge located about four miles West of Lorette in the municipality of Tache. The peak flows of the missing five years of record, 1937 to 1941, were estimated by comparison with the Roseau River, a neighbouring stream. The recorded discharges at Ste-Anne were transposed to Prairie Grove and thus, the recorded peak discharges at that station were continuous for a forty year period. During that period, the maximum daily discharge observed was of 2840 cfs. It was expected that the maximum discharge that could have been recorded for the same period of time at the diversion entrance would be lower due to the smaller drainage area. Using the Meyer-Davis formula:

$$Q = 100\, b \sqrt{A}$$

where: Q = peak discharge in cubic feet per second

A = drainage area in square mile

b = coefficient characteristic of the watershed and equal to 1.27

The discharge relative to the drainage area above Ste-Anne was estimated to be 2240 cfs and of the same order of frequency. It was decided to use this discharge as the design flood for the upper reach of the diversion and increase the discharges throughout the length of the waterway due to changes in drainage area and local inflow (FIGURE 2.1).

Excavation works of the channel started in 1958 at the downstream end of the diversion and proceeded in the upstream direction. During the construction of the middle reach, a severe storm generated a flood which reached a peak of 3300 cfs in the Seine River at Ste-Anne. It was therefore decided to redesign the upper reach of the channel with this maximum flow recorded to date with a frequency of exceedence of 3.7% (FIGURE 2.2). The constructed sections downstream were checked to make sure that the channel could safely handle the increased design flow.

2.2 Design Method

For the preliminary design, the waterway from Ste-Anne to the Red River was divided into ten reaches, the length of each being dependent of the prairie slopes. The dimensions of the channel, width and depth were computed according to the Manning's flow formula with a limiting velocity criteria of 4 feet per second for erosion protection:

$$Q = \frac{1.49}{n} AR^{2/3}S^{\frac{1}{2}}$$

where: Q = design discharge

A = cross sectional area of flow

R = hydraulic radius

S = hydraulic gradient

n = coefficient of roughness

It was decided that the channel would be of a trapezoidal section with a 6:1 side slope. Design discharges used for the computation of the water surface profile increase regularly from 3300 to 6700 cfs. The coefficient of roughness, specifically known as Manning's n was estimated to 0.025.

The size of the channel in each reach was computed by using the various prairie slopes as the proposed hydraulic gradient throughout the diversion. On the basis of these foregoing data, nine typical cross sections were designed (FIGURE 2.5). The bed width and depth of the channel were rounded off and adjusted to keep the velocities around 4 feet per second. Rating curves were computed at different intervals to obtain the elevations of the design discharges. These points were joined by a line to give the water surface profile of the design flood throughout the diversion (FIGURE 2.5).

2.3 Designed Characteristics of the Channel

The diversion channel is approximately 22 miles in length and the computed water surface elevations dropped a total of 60 feet from the inlet to the outlet. On the Seine River the 3300 cfs flood flow corresponded to a gauge height of 6.5 feet (FIGURE 2.3) and approximately to a geodetic elevation of 828 feet. For the Red River, these flood conditions were those of the 1950 Spring flood which raised the water surface level to the elevation 768 feet (FIGURE 2.4).

The diversion bed width varied from 80 to 92 feet in the upper stretch of the waterway, and between 50 and 70 feet in the lower reaches. The transition of sections in reach No. 5 (FIGURE 2.5) is due to the change of design discharges after the diversion was constructed up to that point. The average depth of flow varied between 5.8 and 12.2 feet.

Mean velocities between 3.35 and 5.76 feet per second were expected. Dykes were designed to increase the capacity of the floodway and constructed with the excavated earth of the channel. Allowance roads for servicing the canal and appurtenant structures were graded on the dyke top. All cross sections were provided with gently sloped berms layed out at the average prairie level. Their width varies between 15 and 425 feet and serve as floodplain for unexpected high floods. The sides of the channel and berms were grassed for erosion protection.

Two drop structures at the downstream end of the diversion were designed to lower the flow 14 feet into the Red River. They were required to prevent erosion of the St-Adolphe coulée and to prevent the flood waters of the Red River from backing up the channel. The drop structures are of the spillway chute type with an uncontrolled trapezoidal weir. PHOTOGRAPH 2.3 shows these structures as they appeared after construction in 1961.

CHAPTER III

REGIME OF THE CHANNEL

3.1 Field Investigations

In 1963, an erosion investigation was undertaken in the Seine Diversion with a view to assessing the erosion damage that have resulted from subsequent flows. More particularly this was done with a view to assessing the means and steps necessary for the repair of the ford crossings at various locations along the diversion (FIGURE 2.1). Data were obtained for purposes other than a study of the regime of the channel and were for this investigation incomplete, particularly the data on channel roughness, sediment load and water surface level. These incomplete data and, also data obtained in a later investigation have been used to provide a picture of the variations of the longitudinal and transversal profiles of the channel. Useful relationships have also been made to show the interaction of the discharge and sediment type on the channel shape.

The investigation consisted of a level survey of the longitudinal and transversal profiles of the diversion channel and of a channel bed soil sampling and testing. The soil bore holes were advanced with a 4" diameter scoop auger on the channel bottom at elevations as near as possible to the design elevations. Those drilled at bridge sites were advanced with a 4" diameter flight auger before and during the time of construction of the diversion. The description and location of soil logs are shown in FIGURE 3.1. The samples of soil were submitted to laboratory tests for identification and classification purposes. These tests consisted of the determination of physical proprieties and Atterberg limits of the soil and the mechanical analysis of grains. The results of the soil tests are described in TABLES B-1 to B-33 in Appendix B. The cross sections were surveyed at approximatively every half mile along the diversion and their plotting has been superimposed on the as-constructed sections so as to show the cross sectional changes that have resulted by erosion of the channel (FIGURES 3.2A to 3.2E). Their respective positions have been marked on the longitudinal profile and plan view of the channel in FIGURE 3.2. The surveyed and as-constructed channel bed profiles have been plotted to a common datum (FIGURE 3.2) so as to obtain an indication of the variations of the channel bed slope and the degradation of the channel.

In June 1963, a storm in the La Broquerie region generated a flood which reached a recorded peak of 1455.5 cfs at the diversion entrance. This was the first major flood to which the Seine Diversion had been subjected and caused the failure of the ford crossings. The Manitoba Department of Agriculture had these structures repaired for the harvest season but in Spring 1964, they were again destroyed by washing out of the foundation material. PHOTOGRAPH 3.1 shows the ford crossing C6 at Youville Drain as it was after the 1964 flood. The ford crossings were again re-reconstructed in 1965 and yet in the same manner the 1966 Spring flood put them out of use. The rapid degradation of the channel and successive deterioration of ford crossings necessitated the construction of several erosion control structures. In late Autumn 1963, a stone sill as shown in PHOTOGRAPH 2.2 was constructed a short distance downstream of the diversion inlet to re-establish the proper division of flows. After the 1964 Spring flood and in summers 1965-66, various bridge piers were rock rip-rapped. In Winter 1966-67, seven gabion gradient control structures of the type shown in PHOTOGRAPH 3.2 were constructed in the upper reach of the channel (FIGURE 2.1). They were designed for the purpose of diminishing the velocities of flow by progressive reduction of the hydraulic gradient. Three control structures were placed a short distance downstream of ford crossings with a view to providing protection. The various field inspections showed that this reach of the channel became more stable after the installation of these erosion control structures. In lower reaches particularly in the Oak Island Settlement and upstream, the erosion of the channel bed and banks was not controlled and resulted in the failure of the abutments of two bridges in Summer 1969. One of them: B7 is located on the diversion (FIGURE 3.2) and the other one, on the Manning Canal at its confluence with the diversion. PHOTOGRAPH 3.3 shows the situation after failure of the left abutment of this bridge. In Autumn 1969, three other gabion structures were constructed in this section of the channel.

In July and October 1969, another erosion investigation, more particularly with a view to study the regime of the channel, was undertaken. This investigation consisted in a level survey of a total of 46 cross sections of the channel, and of a sediment sampling of the perimeter of 14 of these cross sections. The plotting of the cross sections has been also superimposed on the as-constructed sections to illustrate the changes that have occured in the channel (FIGURES 3.2F to 3.2J). Their respective locations are also shown on the plan view and longitudinal profile of the channel in FIGURE 3.2. Sediment samples were taken from the channel floor and banks. A hand scoop was used to take three to four samples of the surface top inch of sediments across the channel bottom and were combined to give a composite sample of the channel alluvium. In the same way, three samples of sediment deposits were taken separately at different levels from the banks and combined. In the laboratory, size analysis of each composite sample was made and cumulative grain-size curves were plotted (FIGURES B.1 to B.14, Appendix B).

3.2 Flow Metering

From 1962 to 1967, the characteristics of the shape of the channel at stages corresponding to observed discharges were recorded in five metering stations: M1 to M5 (FIGURE 3.2). For each measuring station, the width of the water surface was recorded and the depth and velocity of water were measured at various distances from the bank by the current-meter method. The data and computations made of these measurements are tabulated in FIGURE 3.2. The mean depth has been computed by dividing the cross sectional area of water by the corresponding width of the water surface. The mean velocity is the quotient of discharge divided by the area of water section. The changes in width, depth and velocity in response to changes in discharges were observed to have certain characteristics which apply to many natural rivers and artificial canals. These similarities are described in Section A.4 of Appendix A and, from the current-meter data recorded in the diversion channel these hydraulic characteristics have been analysed at three metering stations in Section 3.6

In Spring 1969, discharge measurements and corresponding gauge heights were recorded at metering station M5 only (TABLE III-1). These data have been also interpreted in Section 3.6.

3.3 Soils

The soil along the diversion route is typical of the Southern Manitoba soils. It consists of highly plastic varved clays of the great Lake Agassiz origin. In sequence of increasing depth, these glacial clays occur as a layer of brown clay locally known as "chocolate clay" and an intermediate stratum of brown-grey clay known locally as "mixed clay". Underlaying these varved clays, a glacial till consisting of silt, sand and gravel is encountered. The upper feet of this material are often mixed with the overlaying layers of clay.

The concentration of silt and clay in sediments deposited on banks was found extremely high; in fact, it ranged between 86.9 and 98.9% (TABLE III-2). In the upstream vicinity of gabion structures, due to the trapping effect of these erosion controls (PHOTOGRAPHS 1B and 2B, PLATE 3.11), greater quantities of sediment deposits were observed on the channel floor. However, it did not seem that the particle sizes were much smaller (S3 to S9, TABLE III-2). In the reach of cross sections S13 to S16, there was visual evidence that erosion has carried on down to a stratum that was either hardpan or gravelly clay (PHOTOGRAPH 3B, PLATE 3.11); coarse grained particles covered the channel floor. It seemed that vegetation has accelerated the deposition of fine silt in sections S18 and S28 (PLATES 3.11 and 3.12). In cross sections S22 and S26, there was a remarkable similarity in the composition of bed and bank sediments. This was certainly due to the effect of the constructed gabion structures in that reach of the channel in Autumn 1969. These structures have raised the water surface level and caused the washing out of fine particles of the bank material that deposited on the channel floor later. Farther downstream, retardation of the flow caused by backwater effects of drop structures D1 and D2 allowed the deposition of fine particules in suspension in a more or less uniform repartition either on banks and on the channel floor (TABLE III-2).

3.4 Degradation of the Channel

The diversion works were completed in 1960 and the first flow in the channel occurred in Spring 1961. The flows intensively eroded the channel bed and banks. For descriptive purposes, the Seine Diversion has been divided into five reaches; the length of each has been chosen upon marked similarities of the adjusted cross sectional pattern of the channel. They are shown along the longitudinal profile of the channel in FIGURE 3.2 and on individual plan view accompanying the plates showing different sections of the channel.

Until 1963, the erosion has been more intensive in the Oak Island Settlement and in the upper reach (FIGURE 3.2) resulting in a progressive reduction of the channel bed slope. The erosion of the inlet control at the confluence of the Seine River and Seine Diversion (PHOTOGRAPH 3.4) has complicated the situation so that the division of flow at that point could not be carried out as was originally conceived. However, it seemed that the installation of gabion structures in Winter 1966-67 has controlled the channel bed degradation in that reach. Their efficiency is distinctly marked in FIGURE 3.2 by a relative drop of 2 feet deep of the average channel bed level downstream of gabion structure G7. In that reach of the diversion, the erosional forces have developed a U shaped channel as shown in FIGURES 3.2A and 3.2F. There were however some islands approximatively 100 yards long made of silt materials that formed in the channel between bridges B2 and B3 as may be seen in PHOTOGRAPH 2A on PLATE 3.2 and in cross section S2 on FIGURE 3.2F. In that same section of the channel, the erosion has carried on down to the glacial till stratum. The depth of scour decreased in 1969 from 8½ to 5 feet at the lower end of the reach, reducing the original bed slope of 0.00012.

In reach No. 2, the bulk of erosion occured more recently (FIGURE 3.2) and the erosive attacks were concentrated on the left (south) side of the channel bed (FIGURE 3.2G). A comparison of the 1963 and 1969 cross sections shows that the U shape was not in 1969 as well determined as it was in 1963. The shifting of the erosion to one side of the channel bed may be due to the Northwestward orientation of the diversion which was found to be perpendicular to the direction of the dominant winds. Perhaps, this orientation is more favorable for the accumulation of snow on the north bank in Winter time. The formation of snow pack can, to a certain extent, protect the north side of the channel against erosion produced by early Spring floods. During field inspections of the channel in May and June 1969, non-excessive velocity of flow were observed in the section that extends up to the ford crossing C4. The stage of flow shown in PHOTOGRAPHS 5 and 6 on PLATE 3.6 corresponded approximatively to the as-constructed channel bed level.

The evidence of greater bed erosion in reach No. 3 (FIGURE 3.2H) appeared to be concomitant with the narrowing and the reduction of the width-depth ratio of the constructed sections of the channel. The initial U shape self-formed section as shown in FIGURE 3.2C and in PHOTOGRAPHS 5A and 6A on PLATE 3.2 has progressively developed toward a more elliptical shape. Both sides of the channel have caved uniformly as shown in FIGURE 3.2H and in PHOTOGRAPHS 8 and 9 on PLATES 3.6 and 3.7. This progressive change of sectional form began with the erosion of a low flow channel as shown in cross sections 22 and 24. The depth of degradation varied in 1969 between 7½ and 10 feet deep. Local slides along the left bank of the channel were observed during the various field trips.

The section of the channel corresponding to reach No. 4 includes that length of the diversion route which passes through the Oak Island Settlement; a low land area of relatively high ground water table level. Until 1963, the erosion was intensive over the entire bed width and gained a reduction of the original bed slope by the removal of a nick in the original profile (FIGURE 3.2). The resurveyed cross sections of the channel in 1969 (FIGURE 3.2I) showed that during the last six year period (1963-69) the south bank of the channel in the Oak Island Settlement recessed of several feet when the northern bank did not show any significant recession. The concentration of the erosive attacks on the south bank and the slumping of bank material into the channel started in 1964 and continued to date. The development of the channel and the progressive caving of the southern bank is visualized through the PHOTOGRAPHS 7A, 8A and 11 (PLATES 3.2 and 3.7) 9A and 12 (PLATES 3.3 and 3.7) 1E and 2E (PLATE 3.10) which show the same section of the channel at different time intervals. PHOTOGRAPHS 3.5 and 3E show a close-up on a local intrusion of ground water through the south bank of the channel in the Oak Island Settlement. These local influx of ground water saturate the bank material which is dried up during summer months. The wetting and drying process associated with the frost action of the Winter and Spring thaw probably changed the properties of the soil making up the channel because the top six inches was completely dessicated and broken up into small cubes with no cohesive propriety. Any flow in the channel even at very low velocities can remove this friable layer. In fact, it has been found in previous investigations [14,23] of the factors influencing the erodibility of streambanks and in a study [1] of the effects of the frost action on Winnipeg clay that changes in moisture content and cycles of freezing and thawing considerably reduce the strength of cohesive soils and their packing including a group of related proprieties such as: porosity, density, structure, and cementing. PHOTOGRAPHS 3.6 and 4E show the effect of this action on the south bank material. Farther downstream in the same numbered reach, at the confluence of the Manning Canal (cross section S32, FIGURE 3.21) there was noticeable shifting of the erosion to the left (south) side of the channel bed only. This cross section readjustment coincided with an increase of the as-constructed channel width. The change of erosional pattern was initiated before 1963 as shown in cross sections 33 and 34 on FIGURE 3.2D and proceeded since then with the addition of sediments on the opposite side (cross sections S34 and S35). This change in the adjustment of the channel form may as well be observed in PHOTOGRAPHS 13, 14 and 15 on PLATE 3.8.

PHOTOGRAPH 3.7 shows an aerial view of the fifth reach of the diversion that extends from halfway between bridges B11 and B12 to the upstream drop-structure D1. In general, along that reach, the degradation of the channel occurred on the left side of the bed only, (FIGURE 3.2J) resulting in the formation of a low flow channel paralleling the toe of the southern bank as shown in PHOTOGRAPHS 17 to 20 on PLATE 3.9. Probably during the recession of floods, the water shifted laterally across the channel and built up by deposition that portion of the base on which it flowed. Several rotational failures occurred along the southern bank (PHOTOGRAPH 3.8). The chunks of soil were then submitted to the erosive action of waters and supplied sediments to the bed and suspended load of the channel.

3.5 Shape of the Channel in Relation to Sediment Type

In 1960-61, S.A. Schumm [16,17,18] investigated the relationship that exists between the percentage of silt-clay in the perimeter of some alluvial streams and the shape of their channels. His investigation is briefly presented in Section A.3 of Appendix A and, from the sediment data collected in the perimeter of the fourteen cross sections along the diversion in October 1969, a comparison is hereafter made with the characteristics of stable channel sections put forward by Schumm. The percentages of silt and clay in banks and channel, S_b and S_c in TABLE III-2, have been taken from the cumulative grain-size curves of each composite sediment sample and the weighted mean values of silt-clay (M) in the perimeter of each cross section have been computed with the formula derived at this effect. The width and depth of the channel have been determined from the 1969 plotted cross sections. The channel depth has been estimated from observations of the depth of scour on banks and measured from the lowest part of the channel to a level representative of the self-formation of the shape of the channel. The short dashed lines in each sampled cross section show the measured width at that section. Calculations of width-depth ratio (F) are presented in TABLE III-2 with all other data on the cross sections and sediment. In FIGURE 3.3 the width-depth ratio (F) has been plotted against

(M) for the fourteen cross sections and the regression line characteristic of stable sections of alluvial stream channels has also been drawn in that figure to show where the fourteen points lie in relation to that line. The scatter and location of points all above the regression line in the zone of aggrading cross sections disagree with the criterion of aggradation and degradation of channels advanced by Schumm. The lack of correlation between (F) and (M) suggests that the constructed sections of the channel with an imposed width to depth ratio were not at all representative of the self-formed section of stable channels in alluvial materials. An investigation in this matter has been made by plotting (FIGURE 3.3) the fourteen values of the computed ratio of top width of the constructed sections of the channel to the corresponding depth (TABLE III-2A) versus the same weighted mean values of percent silt-clay in the surveyed cross sections. The constructed top width is also indicated in each sampled cross section. It may be expected that the sediments carried throughout the mass of flowing water would have been roughly of the same type after construction. From this expectation, one may observe in FIGURE 3.3 that the points representing the present sections of the channel are getting closer to the line characteristic of stable sections of Schumm. This figure shows that any adjustment of the section of the channel toward a stable section under the same character of sediments could be done by decreasing the width to depth ratio; that is, by increasing the depth or decreasing the width or both. The erosion that has occured in the channel so far seems to lead toward such an adjustment.

3.6 Hydraulic Geometry of the Channel

With the current-meter data collected at metering stations M2, M4 and M5 between 1962 and 1967, analysis of variations of width, depth and velocity with increasing discharges have been made separately for each of these measuring sections. The recorded data on water surface width, mean depth and mean velocity have been plotted against discharge on log-log paper and straigth regression lines have been drawn by eye through the various sets of points representing individual year of measurements. Each variable is therefore expressed as a function of discharge "at a section" in the same manner as Leopold and Maddock [9] have done in 1963 for many rivers in America. A brief summary of their investigation is presented in Section A.4. FIGURE 3.4 shows the relations of the variables -W_s, D, V- to discharge at metering station M2. The cross sectional shape of the channel was at that time (1963-64) similar to the cross section No.1 in FIGURE 3.2A. The derived relationship of each variable to discharge is given by the equations:

$$W_s = 25\ Q^{0.16}$$

$$D = 0.23\ Q^{0.39}$$

$$V = 0.17\ Q^{0.44}$$

The values of exponents and coefficients of these equations have been computed from the graphs. The sum of exponents b, f and m and the product of coefficients a, c and k are respectively 0.99 and 0.98. The rate of change of depth with increasing discharges (f=0.39) was practically the same as the mean value of 0.40 computed by Leopold and Maddock for many river cross sections. However, the b value of 0.16 was considerably greater than 0.04 value found on Brandywine Creek (22) and the expected value for any other channel sections with cohesive bank materials. This marked difference is due in large part to the gentle sloping side of the constructed trapezoidal channel. The constructed section has been eroded and now it approaches the approximate shape encountered in cohesive soils. This cross sectional change is likely to reduce the value of the exponent b. The rate of increase of mean velocity with discharges (m=0.44) was fairly high and a straight extrapolation of the regression line gives mean velocities as high as 6 feet per second for discharges of the same order of magnitude as the design discharge. This is indeed an extremely high velocity of water in alluvial channels.

FIGURE 3.5 presents the hydraulic geometry of the channel at metering station M4 for the years 1965 and 1967. It may be seen in this figure that the points representing the 1965 flow characteristics, in the velocity and width to discharge graphs fall in a fairly good alignment. However, the depth to discharge relation is ill-defined and no further analysis of this graph will be pursued. The gabion gradient control structure G2 constructed downstream of bridge B3 (FIGURE 3.2) in Winter 1966-67, created backwater effects through that measuring section and upstream in the channel. This explains why the Spring 1967 current-meter data deviate from the respective lines and are not representative of the natural behaviour of the channel. These structures were designed to reduce the velocities of flow and, by the position of the point representing the 1967 measurement of the velocity in the velocity-discharge graph; this goal is fairly well achieved. For the purpose of studying the regime of the channel under natural conditions, the values of the 1967 measurements will be disregarded. The rate of variation of mean velocities with increasing discharges (m=0.85) was fairly high and the relationship gives water velocities of the order of magnitude of 12 feet per second for discharges even smaller than the design discharge. The eroding power was accordingly extremely high. The water surface breadth increased very rapidly with discharges; its rate of variation (b=0.51) was not for the same reason stated previously characteristic at all of the one encountered in self-formed alluvial channels.

The relation of width, depth and velocity to discharge at metering station M5 is shown in FIGURE 3.6 for the 1962 to 1967 year period. Four regression lines have been drawn through the various sets of points in each graph to show the variation of these relationships from year to year. There is considerable scatter of points about the respective lines and the shifting of their position and inclination indicates that the relation of these variables was not stable throughout the period of record. Part of this instability probably resulted from the scour and temporary fill of the channel in periods of high waters and to the section control made by the rock riprapping of bridge piers in Summers 1964 to 1966. The latter reason explains why the lines drawn through the 1963 plotted points are set off in the graphs. This local interference changed the original conditions of the flow and its hydraulic characteristics so that the measuring section became no longer really representative of the average reach of the channel. For the same discharges under the backwater effects of the constriction, the depth and water surface breadth were increased and mean velocities reduced. The rate of variation of these variables was more particularly different in 1966 and 1967. This probably depends on the changes in configuration of the cross sections due to subsequent riprapping in Summers 1965 and 1966. To same discharges, corresponded in Spring 1967 a higher rate of increase of mean depth and therefore of water surface breadth and a lower rate of variation of velocity than in Spring 1966. The Spring 1969 discharge measurements at that same metering station resulted in a plot of the relation of stage of flow versus discharge in FIGURE 3.7. The break in the curve at 600 cfs flow indicates that the stage-discharge relationship was not yet stable.

The recorded data was insufficient to analyze the hydraulic geometry of the channel in a downstream direction. The discharges having the same frequency of exceedence were not recorded at many metering stations. The condition of constant frequency of discharges at all cross sections is very important for the comparison of the hydraulic characteristics along the length of any channel.

CHAPTER IV

ALTERNATIVE DESIGNS FOR THE ORIGINAL CHANNEL

4.1 Channel Design Methods and Application

The design of stable channels in alluvial materials has been the object of intensive research during the past century and various procedures for designing them have been developed. These methods are categorized as belonging to one of the following design criteria: maximum permissible velocity, critical tractive force and regime theory. The concept of the "stable channel" as defined in Appendix A is the basis of these theories. Each design technique is also summarized in Appendix A. They have been applied to the design of the diversion channel with the original conditions of soil and prairie level in the design route. A trapezoidal section having a 4:1 side slope has been chosen and the same design discharges have been used. It was expected that for the type of soil making up the channel, and taking into account the very low values of side slope encountered in self-formed stable channels in cohesive soils and the investigation made of the stability of river banks in the Winnipeg area[2], a designed bank slope of 4:1 could be stable against sliding at the condition of having a stable channel bed slope. The design procedures for the upper reach of the channel are hereafter explained.

Using the Simons and Albertson's charts (Section A.2, Appendix A) for canals having cohesive bed and banks, the characteristics of the channel are for a discharge of 3300 cfs:

From FIG. A.6, the hydraulic radius	:R	= 9.5	ft
" " A.7, the average depth	:d_A	= 11.0	"
" " A.8, the wet. perimeter	:P	= 127.0	"
" " A.9, the average width	:W	= 115.0	"
" " A.10, the top width	:W_T	= 127.3	"
" " A.11, the area of water	:A	=1200.0	ft^2
from product Wxd_A " "	:A	=1265.0	"
" " PxR ". "	:A	=1208.0	"
the average area of water section	:A_A	=1225.0	"
from continuity equ: $V = Q/A_A$	:V	= 2.7	ft/s
from FIG. A.12, the value of R^2S	:R^2S	= 0.004	

For the designed average and top widths and depth of the water section, the side slope of a trapezoidal channel is 1.12:1. For the selected trapezoidal section having a 4:1 side slope and the same designed average width and depth, the corresponding wetted perimeter and hydraulic radius have been recomputed with the equations:

$$P = b + 2d_A \sqrt{1 + Z^2} \qquad (9)$$

$$R = \frac{A}{P} \qquad (10)$$

where: b = bed width

Z = parameter of the side slope equal to 4

From equation (9), P = 161.5 feet and from equation (10), R = 7.6 feet. With this value of R and $R^2S = 0.004$, the corresponding value of the channel slope was 0.73×10^{-4}. In brief, the redesigned channel characteristics are:

For the average width : $W = 115.0$ ft

for the average depth : $d_A = 11.0$ ft

for the slope : $S = 0.73 \times 10^{-4}$

According to the Blench's regime equations (Section A.2), the calculated channel characteristics are:

For the average width : $W = 121.8$ ft

for the average depth : $d_A = 9.3$ ft

for the slope : $S = 0.105 \times 10^{-4}$

In his equations, the side factor f_s has been estimated to 0.20, the bed factor f_b to 0.90 and the water temperature to 60^oF.

Using the Manning's flow formula: $V = \frac{1.49}{n} R^{2/3} S^{\frac{1}{2}}$ with a predetermined maximum mean velocity as a criterion of stability, the design procedures consisted of the following steps:

a) The average prairie slope: $S = 9.76 \times 10^{-4}$ has been used in the formula as the proposed hydraulic gradient.

b) For the kind of soil involved, the Manning's n has been estimated to 0.025.

c) From TABLE A-1 and FIGURE A.1 for clays having a void ratio of 1.0, a limiting velocity of

2.5 ft/s. has been selected and a correction factor of 1.2 for an expected depth of flow of 8.0 feet has been chosen from FIGURE A.2. The limiting velocity for the design was therefore 3.0 ft/s.

The values of the variables S, n, and V have been substituted into Manning's formula to give a hydraulic radius value of 2.09 feet. The parameter W and d_A of the cross sectional area of flow have been computed according to equation (9) and the following ones:

$$A = \frac{Q}{V} \tag{11}$$

$$P = \frac{A}{R} \tag{12}$$

$$A = (b + Zxd_A)\ d_A \tag{13}$$

From Equation	(11)	$A = 1100.0$ ft^2
" "	(12)	$P = 526.0$ ft
" "	(9) & (13)	$d_A = 2.1$ ft
" "	" "	$b = 508.5$ ft

The channel was found too wide and shallow, the bed width was therefore given a new dimension: b = 80.0 feet. From equation (13) and for the same cross sectional area of flow, the recalculated depth was 9.38 feet. The corresponding values of the wetted perimeter and hydraulic radius were from equations (9) and (10) P = 157.3 feet and R = 7.0 feet. The required channel slope was for the adjusted section equal to 1.9×10^{-4}. To sum up, the redesigned characteristics of the channel are:

For the average width : $W = 117.6$ ft

for the average depth : $d_A = 9.4$ ft

for the slope : $S = 1.9\text{x}10^{-4}$

The first step in designing channels by the method of tractive force consists in selecting an approximate channel section. The estimation of the average width has been made by using the Lacey's wetted perimeter formula (Section A.2) which gives values nearly equal to the top width in wide channels. The average depth of flow has been estimated equal to the hydraulic radius and selected from the Simons and Albertson's charts. The channel slope has been computed according to the Du Boys' tractive force equation (Section A.2) with a limiting unit-tractive force of 0.1 lb/ft^2 obtained from FIGURES A.3, A.4 and A.5. The computed channel characteristics are:

For the average width : $W = 115.9$ ft

for the average depth : $d_A = 9.5$ ft

for the slope : $S = 1.69\text{x}10^{-4}$

The same design procedures have been applied to the design of lower reaches and the characteristics of the redesigned channel have been compared with the original ones. Results are summarized in TABLES IV-1A and IV-1B. The alternative design methods indicated that the original width of the channel was in generally close agreement with the values of the redesigned one. However, the redesigned slopes were by far milder than the original and present ones. This would therefore require drop structures or low check structures to be placed at frequent intervals along the channel in order to reduce the hydraulic gradient. A preliminary investigation in stabilizing the channel by means of low slope control structures has been made in CHAPTER V.

CHAPTER V

POSSIBLE MEANS FOR STABILIZING THE PRESENT CHANNEL

Because of the critical need for an effective control of the degradation of the channel, an attempt has been made to stabilize the channel. In many cases of streambed stabilization [10,11,15,20], bed sills have proven to be effective in controlling channel bed degradation through reduced velocities created by the increase of water surface elevations induced by the sills.

The actual experience with gabion gradient control structures in the Seine River Diversion has shown that these installations have controlled the channel slope since no appreciable degradation has taken place during the two years they have been in use. Their flexibility makes them particularly adaptable to the local scour because the foundation material is generally composed of erodible fine silt and clay. Also, in order to prevent a further reduction in the original ground water table level in the adjacent agricultural lands it is suggested that the water surface slope be controlled by means of a series of sills with small energy loss over each structure rather than using high drop structures that could perform the same intended function. To prevent further degradation and to give the channel a stable slope requires that the height of the crest of transverse bed sills above the actual channel floor be so designed and, the successive stabilization structures be so placed along the channel that the design velocity in the stabilized reach would be equal or smaller than the velocity values in the recommended "stable section" of the channel (TABLES IV-1A and IV-1B). Eventually, sediments will deposit in the pool upstream of structures and create a new gradient equal to the regime slope that terminates at the toe of the next structure upstream. FIGURE 5.1 shows a sketch of the final stage of this stabilized condition.

For a preliminary design of the various distances between structures, the following formula has been used:

$$L = \frac{h}{S_a - S_s}$$

where: L = distance between structures

h = height of structure

S_a = present channel slope

S_s = stable channel slope

According to this formula, computation of spacing and number of three feet high drop structures have been made in TABLE V-1. This preliminary investigation reveals that sixteen low drop structures are required corresponding to an average of about one structure a mile. They may consist of gabion structures, rock sills or reinforced concrete weirs. The decision as to which one to use or a combination of them should be based on the inherent adaptability of each, the accessibility of the channel to equipment and the availability of materials.

The cost of this stabilization system should normally be compared to the cost of a high velocity lined canal. The use of revetments as stabilization means have not been considered here because at first glance, their cost would have been prohibitive.

CHAPTER VI

CONCLUSIONS

The regime study of the Seine Diversion Channel and comparisons made at the same time between its characteristics and those of stable channels in alluvial materials indicates that the channel was far from stable. The channel with its given width, depth and slope was not representative of the "self-formed channel" in cohesive soils which under the same conditions of flow would have been deeper and have had a much milder slope. Its designed average width was reasonably close to the width of the stable channel with the exception of the side slope that was about four times too mild.

In any event, the field investigations showed that the diversion channel progressively adjusted its slope and cross section so as to become more stable. An effective control of the channel bed degradation requires a series of low check structures designed to reduce the hydraulic gradient.

CHAPTER VII

RECOMMENDATIONS

1). In order to properly locate and design the height of the stabilization structures, it is recommended to make field tests to determine the present tractive resistance of the channel material. The test procedure would consist in measuring with a vane borer the in-situs shear strength of the top surface (0-4 in.) of the soil making up the channel. The apparatus proposed by I.S. Dunn[6] in 1959 is recommended in this matter.

2). In second instance, it is recommended to conduct a ground water investigation along the left bank of the channel in the Oak Island Settlement. The purpose of this investigation is to find the relationship that may exist between the amount of bank recession and some characteristics of the bank material and of the ground water flow through the left bank. Several lines of wells perpendicular to this bank would be of particular interest to measuring the level and gradient of the water table, the permeability of the soil and the amount of ground water draining into the channel for different stages of flow in the channel.

3). To know more about the regime of the channel, it is recommended to install gauge recorders in the 1969 surveyed cross sections. Those water markers would serve to define the water surface profile and the hydraulic roughness of the channel at different stages of flow. In about five cross sections well distributed along the channel, sediment load and current-meter measurements should be made at the same time in order to make a complete and accurate analysis of the "hydraulic geometry" of the channel. The present gauging sections are not appropriately located so that the recorded data were good for the purpose of computing discharges only.

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LIST OF REFERENCES

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TABLES

TABLE III-1

SEINE RIVER DIVERSION

1969 DISCHARGE MEASUREMENTS

METERING STATION: M5

DATE	GAUGE HEIGHT (ft)	OBSERVED DISCHARGE (cfs)	DATE	GAUGE HEIGHT (ft)	OBSERVED DISCHARGE (cfs)
13 Apr., 69	8.52	1730	8 May, 69	2.89	285
14	7.25	1220	9	2.48	234
15	6.40	959	10	2.21	200
16	5.88	838	11	1.68	132
17	5.05	668	12	1.55	115
18	4.75	628	13	1.47	105
19	4.15	509	14	1.33	85.8
20	3.92	463	15	1.26	76.8
21	3.40	377	16	1.25	75.6
22	3.07	327	17	1.29	79.3
23	2.88	296	18	1.22	70.8
24	2.67	263	19	1.22	70.8
25	2.64	260	20	1.21	68.4
26	3.72	402	21	1.21	68.4
27	4.35	507	22	1.17	63.8
28	4.32	502	23	1.06	50.4
29	4.50	532	24	0.99	40.9
30	4.50	532	25	0.94	35.4
1 May, 69	4.63	556	26	0.82	24.6
2	4.50	531	27	0.78	21.5
3	4.48	527	28	0.92	33.2
4	4.21	480	29	0.93	34.3
5	4.02	446	30	0.92	34.3
6	3.77	405			
7	3.13	319			

TABLE III-2

SEINE RIVER DIVERSION

CHANNEL AND SEDIMENT CHARACTERISTICS
(1969 survey)

CROSS SECTION No.	SILT-CLAY IN CHANNEL (S_c,%)	SILT-CLAY IN BANKS (S_b,%)	WEIGHTED MEAN SILT-CLAY (M,%)	MEASURED WIDTH (W_B,ft)	MEASURED DEPTH (D_B,ft)	WIDTH-DEPTH RATIO ($F=W_B/D_B$)
S.3	88.3	92.4	88.9	95	7.5	12.7
S.4	74.1	96.9	76.3	110	6.0	18.3
S.6	97.8	95.7	97.6	105	8.0	13.1
S.9	70.5	94.2	73.6	103	7.5	13.7
S.13	60.0	96.1	64.9	115	9.0	12.8
S.16	70.0	90.8	73.3	95	9.0	10.5
S.18	92.5	95.1	93.1	78	11.0	7.1
S.22	97.1	98.0	97.4	86	13.0	6.6
S.26	98.8	98.9	98.8	100	12.5	8.0
S.28	76.0	91.2	78.7	90	10.0	9.0
S.32	96.2	86.9	94.6	108	11.5	9.4
S.37	41.8	98.9	50.7	115	10.5	10.9
S.41	99.8	97.7	99.6	134	12.0	11.2
S.44	98.1	94.6	97.6	142	11.0	12.9

TABLE III-2A

SEINE RIVER DIVERSION

CHANNEL AND SEDIMENT CHARACTERISTICS

CROSS SECTION No. (1969 survey)	CONSTRUCTED TOP WIDTH (W_{tc}, ft)	CONSTRUCTED DEPTH (D_c, ft)	CONSTRUCTED WIDTH-DEPTH RATIO (W_{tc}/D_c)	WEIGHTED MEAN SILT-CLAY (1969 survey) (M, %)
S.3	175	6.0	25.0	88.9
S.4	155	6.5	23.9	76.3
S.6	195	8.4	23.2	97.6
S.9	185	7.8	23.7	94.2
S.13	215	9.8	21.9	96.1
S.16	205	9.0	22.8	93.1
S.18	105	4.9	21.4	93.1
S.22	130	6.5	20.0	97.4
S.26	123	6.5	18.9	98.8
S.28	115	5.8	19.8	78.7
S.32	190	9.2	20.7	94.6
S.37	200	10.0	20.0	50.7
S.41	200	11.5	17.4	99.6
S.44	218	13.0	16.8	97.6

TABLE IV-1A

SEINE RIVER DIVERSION

REDESIGNED CHANNEL CHARACTERISTICS

REACH NO.*	DESIGN DISCHARGE (Q, cfs)	DESIGN METHOD	AVERAGE WIDTH (W, ft)	AVERAGE DEPTH (d_A, ft)	MEAN VELOCITY (V, ft/s)	WTH-DTH RATIO (W/d_A)	CHN. SLOPE ($S\mathrm{x}10^{-4}$)	UNIT-TRAC. FORCE (τ, lb/ft)
1	3300	Sns & Al.'s ch.	115.0	11.0	2.69	10.5	0.73	0.05
		Blench's equat.	121.8	9.3	2.91	13.1	1.05	0.06
		Perm. velocity	117.2	9.4	3.00	12.5	1.90	0.11
		Tract. force	115.9	9.5	2.90	12.6	1.50	0.10
		Recomm. charact.	120.0**	9.5**	2.90	12.6	1.50**	0.08
	3300	Orig. charact.	110.0	5.8	5.15	19.0	10.66	0.39
2, 3, 4, 5, 6, 7	3700	Sns & Al.'s ch.	120.0	11.3	2.79	10.6	0.77	0.05
		Blench's equat.	129.0	9.7	2.95	13.3	1.03	0.06
		Perm. velocity	124.6	9.9	3.00	12.6	1.75	0.11
		Tract. force	123.8	9.8	3.05	12.6	1.63	0.10
		Recomm. charact.	125.0**	10.0**	2.96	12.5	1.00**	0.06
	3720	Orig. charact.	120.2	6.7	4.62	18.0	6.90	0.29

* Numbered Reaches are those taken along the elevation view of the channel in FIGURE 2.5.

** Represents selected values for the average width, depth and channel slope.

TABLE IV-1B

SEINE RIVER DIVERSION

REDESIGNED CHANNEL CHARACTERISTICS

REACH NO.*	DESIGN DISCHARGE (Q, cfs)	DESIGN METHOD	AVERAGE WIDTH (W, ft)	AVERAGE DEPTH (d_A, ft)	MEAN VELOCITY (V, ft/s)	WTH-DTH RATIO (W/d_A)	CHN. SLOPE ($S \times 10^{-4}$)	UNIT-TRAC. FORCE (τ, lb/ft)
8, 9, 10, 11	4100	Sns & Al.'s ch.	135.0	11.5	2.71	11.7	0.67	0.05
		Blench's equat.	135.8	10.1	2.99	13.4	1.01	0.06
		Perm. velocity	131.9	10.4	3.00	12.7	1.65	0.10
		Tract. force	131.0	10.0	3.13	13.1	1.60	0.10
		Recomm. charact.	135.0**	10.5**	2.89	12.8	1.00**	0.06
	4100	Orig. Charact.	97.5	7.3	5.76	13.3	10.00	4.57
12	6200	Sns & Al.'s ch.	170.0	12.8	2.88	13.3	0.63	0.05
		Blench's equat.	167.0	11.5	3.23	14.5	0.95	0.07
		Perm. velocity	168.8	12.2	3.00	13.8	1.34	0.12
		Tract. force	164.4	11.5	3.28	14.3	1.39	0.10
		Recomm. charact.	165.0**	11.5**	3.27	14.4	0.95**	0.06
		Orig. Charact.	129.0	9.7	4.95	13.3	5.30	0.31

* Numbered reaches are those taken along the elevation view of the channel in FIGURE 2.5.

** Represents selected values for the average width, depth and channel slope.

TABLE V-1

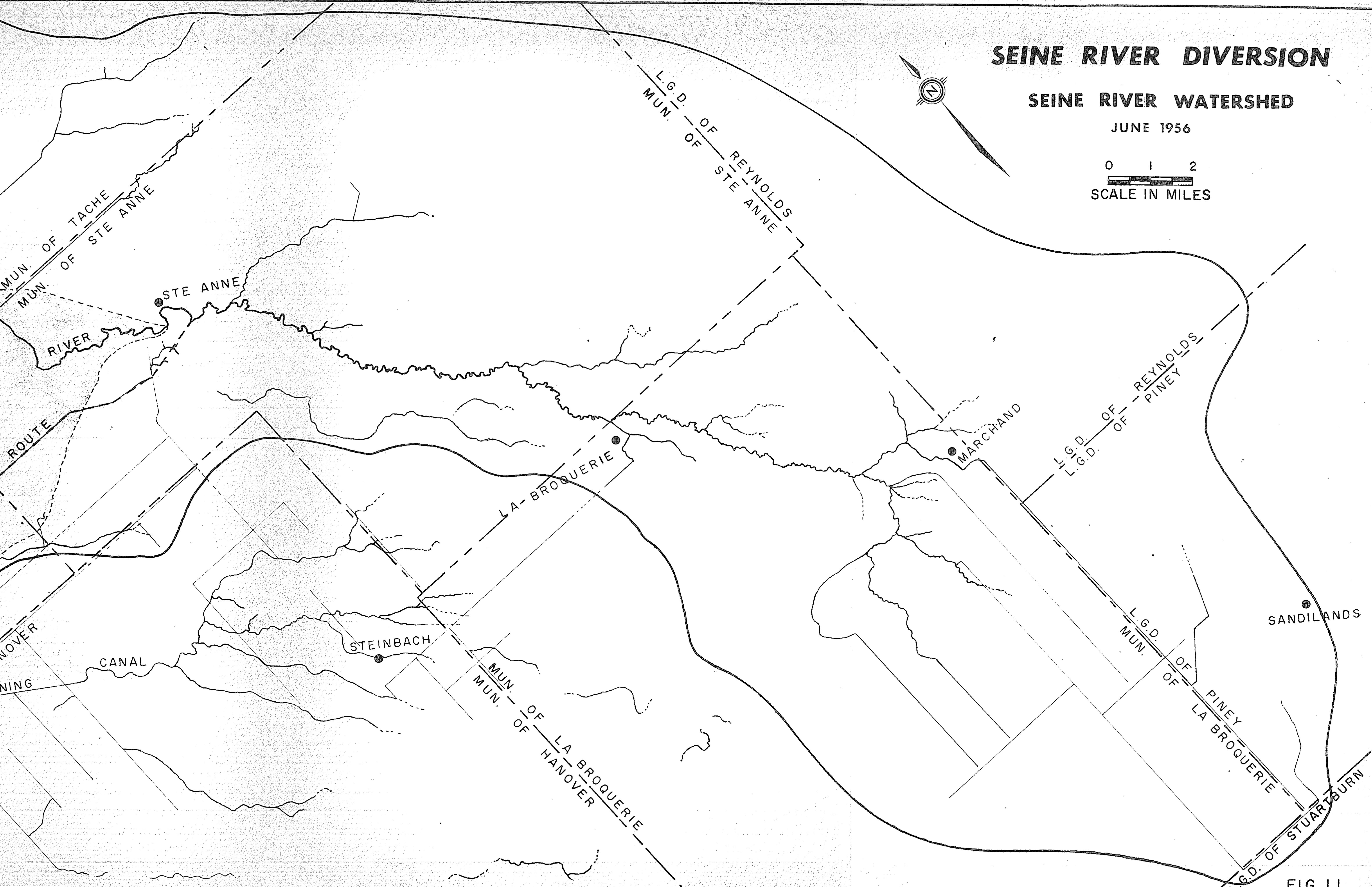
SEINE RIVER DIVERSION

STABILIZED CONDITIONS

REACH NO.*	PRESENT SLOPE (S_ax10-4)	STABLE SLOPE (S_sx10-4)	HEIGHT OF STRUCTURE (h, ft)	DISTANCE BETWEEN STRUCTURES (Lx10^2,ft)	LENGTH OF REACH (lx10^2,ft)	NUMBER OF ST. PER REACH (l/L)
1	9.50	1.50	3.0	37.5	180	5
	5.10	1.00	3.0	73.3	100	1
2	4.20	1.00	3.0	93.8	150	2
	5.30	1.00	3.0	69.8	200	3
3	5.30	1.00	3.0	69.8	200	3
4	2.90	0.95	3.0	150.0	220	2
						Total: 16

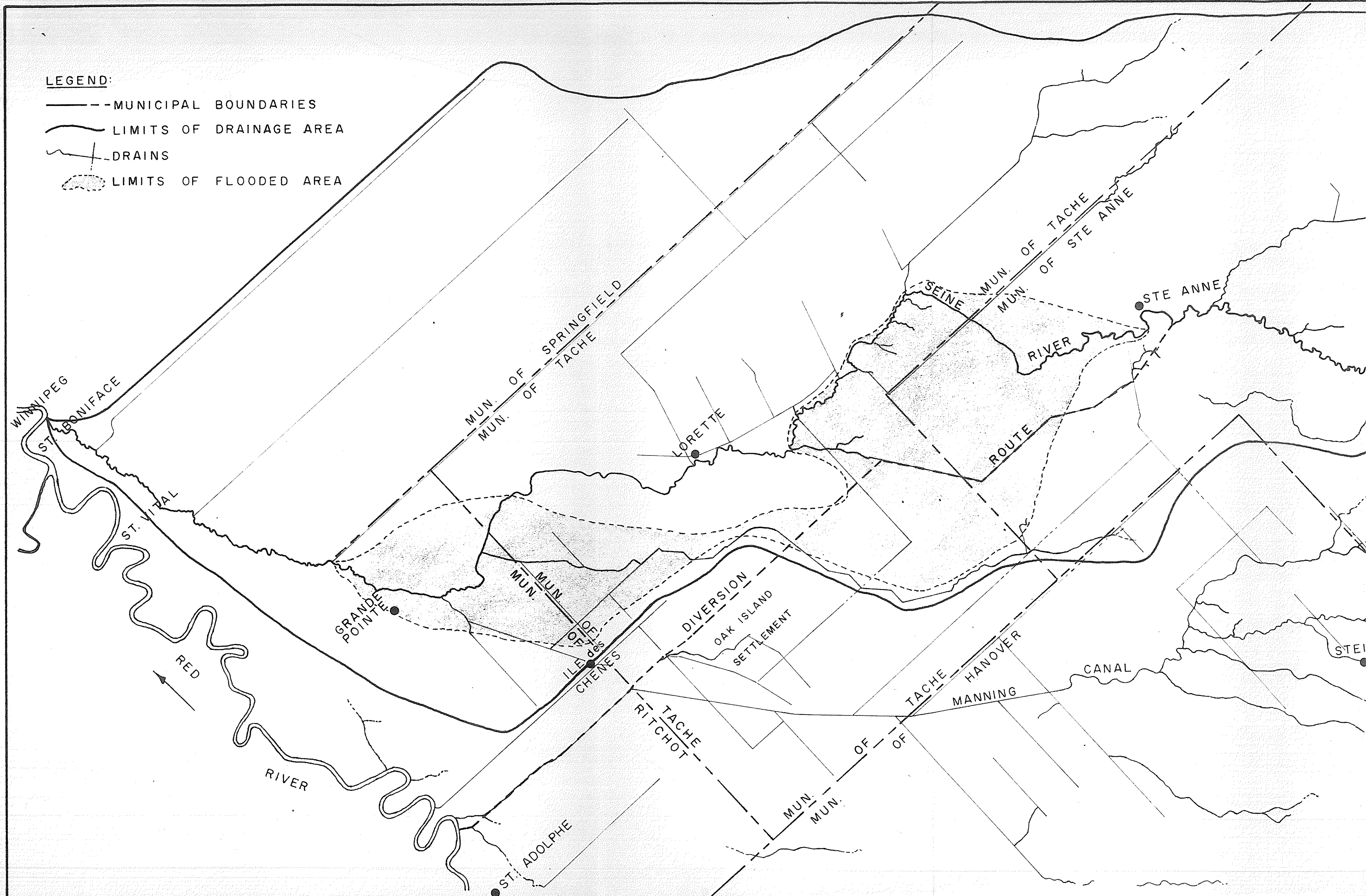
* Numbered reaches are those taken along the Longitudinal Profiles in FIGURE 3.2

FIGURES



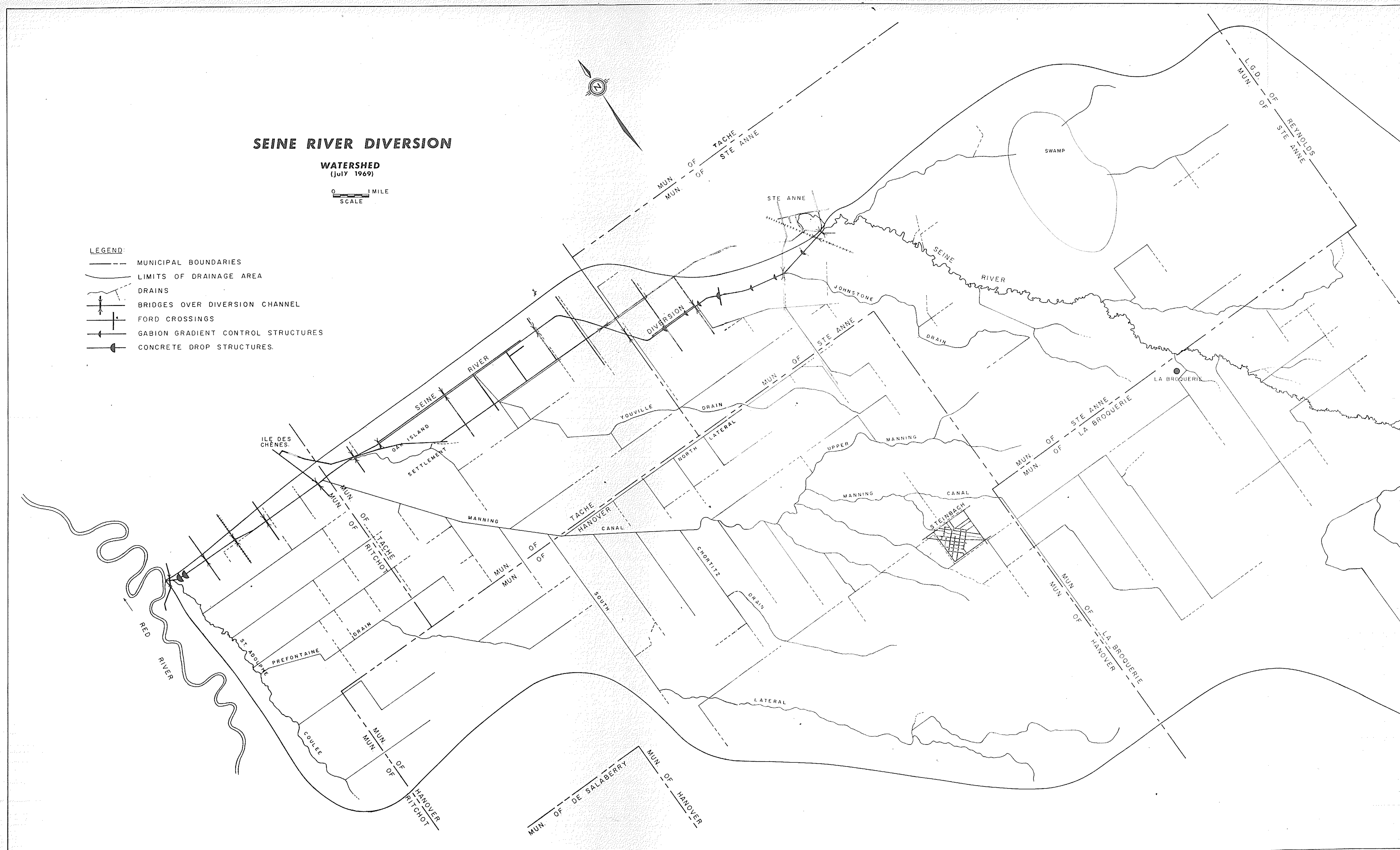
SEINE RIVER DIVERSION
SEINE RIVER WATERSHED
JUNE 1956
N
0 1 2
SCALE IN MILES
L.G.D. OF REYNOLDS
MUN. OF STE ANNE
MUN. OF TACHE
MUN. OF STE ANNE
STE ANNE
RIVER
ROUTE
LA BROQUERIE
L.G.D. OF REYNOLDS
L.G.D. OF PINEY
MARCHAND
L.G.D. OF PINEY
MUN. OF LA BROQUERIE
SANDILANDS
L.G.D. OF STUARTBURN
MUN. OF LA BROQUERIE
MUN. OF HANOVER
STEINBACH
CANAL
NOVER
NING

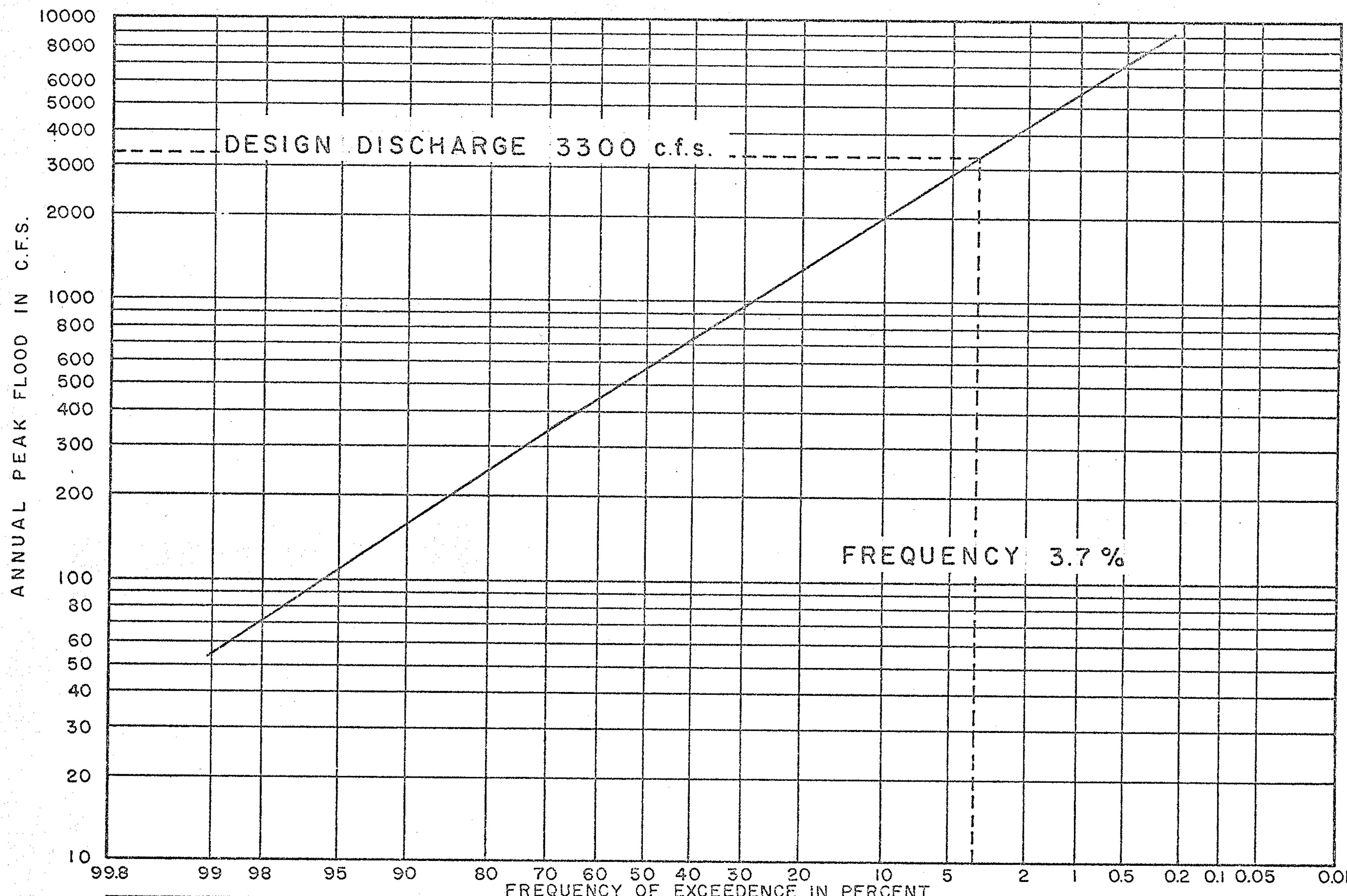
FIG. 1.1


LEGEND:
MUNICIPAL BOUNDARIES
LIMITS OF DRAINAGE AREA
DRAINS
LIMITS OF FLOODED AREA
WINNIPEG
ST. BONIFACE
ST. VITAL
RED RIVER
MUN. OF SPRINGFIELD
MUN. OF TACHE
MUN. OF TACHE
MUN. OF STE ANNE
SEINE RIVER
STE ANNE
ROUTE
LORETTE
GRANDE POINTE
MUN. OF ILE des CHENES
MUN. OF
DIVERSION
OAK ISLAND SETTLEMENT
TACHE
RITCHOT
MUN. OF TACHE
MUN. OF HANOVER
MANNING CANAL
ST. ADOLPHE
STEI


L.G.D. OF REYNOLDS
MUN. OF STE ANNE
L.G.D. OF REYNOLDS
L.G.D. OF PINEY
MARCHAND
MUN. OF LA BROQUERIE
L.G.D. OF PINEY
SANDILANDS
L.G.D. OF STUARTBURN

FIGURE 2.1


SEINE RIVER DIVERSION
WATERSHED
(july 1969)
0 1 MILE
SCALE
LEGEND:
MUNICIPAL BOUNDARIES
LIMITS OF DRAINAGE AREA
DRAINS
BRIDGES OVER DIVERSION CHANNEL
FORD CROSSINGS
GABION GRADIENT CONTROL STRUCTURES
CONCRETE DROP STRUCTURES.
MUN. OF TACHE
MUN. OF STE ANNE
L.G.D. OF REYNOLDS
MUN. OF STE ANNE
SWAMP
STE ANNE
SEINE RIVER
JOHNSTONE
DRAIN
DIVERSION
LA BROQUERIE
MUN. OF STE ANNE
MUN. OF LA BROQUERIE
SEINE RIVER
OAK ISLAND
SETTLEMENT
ILE DES CHÊNES
YOUVILLE DRAIN
NORTH LATERAL
MUN OF STE ANNE
UPPER MANNING
MANNING CANAL
STEINBACH
MANNING
TACHE
HANOVER
CANAL
MUN. OF TACHE
MUN. OF RITCHOT
MUN OF TACHE
MUN OF HANOVER
MUN OF LA BROQUERIE
MUN OF HANOVER
CHORTITZ
DRAIN
SOUTH
ST. ADOLPHE
PREFONTAINE
DRAIN
RED RIVER
COULEE
MUN. OF HANOVER
MUN. OF RITCHOT
LATERAL
MUN. OF DE SALABERRY
MUN OF HANOVER

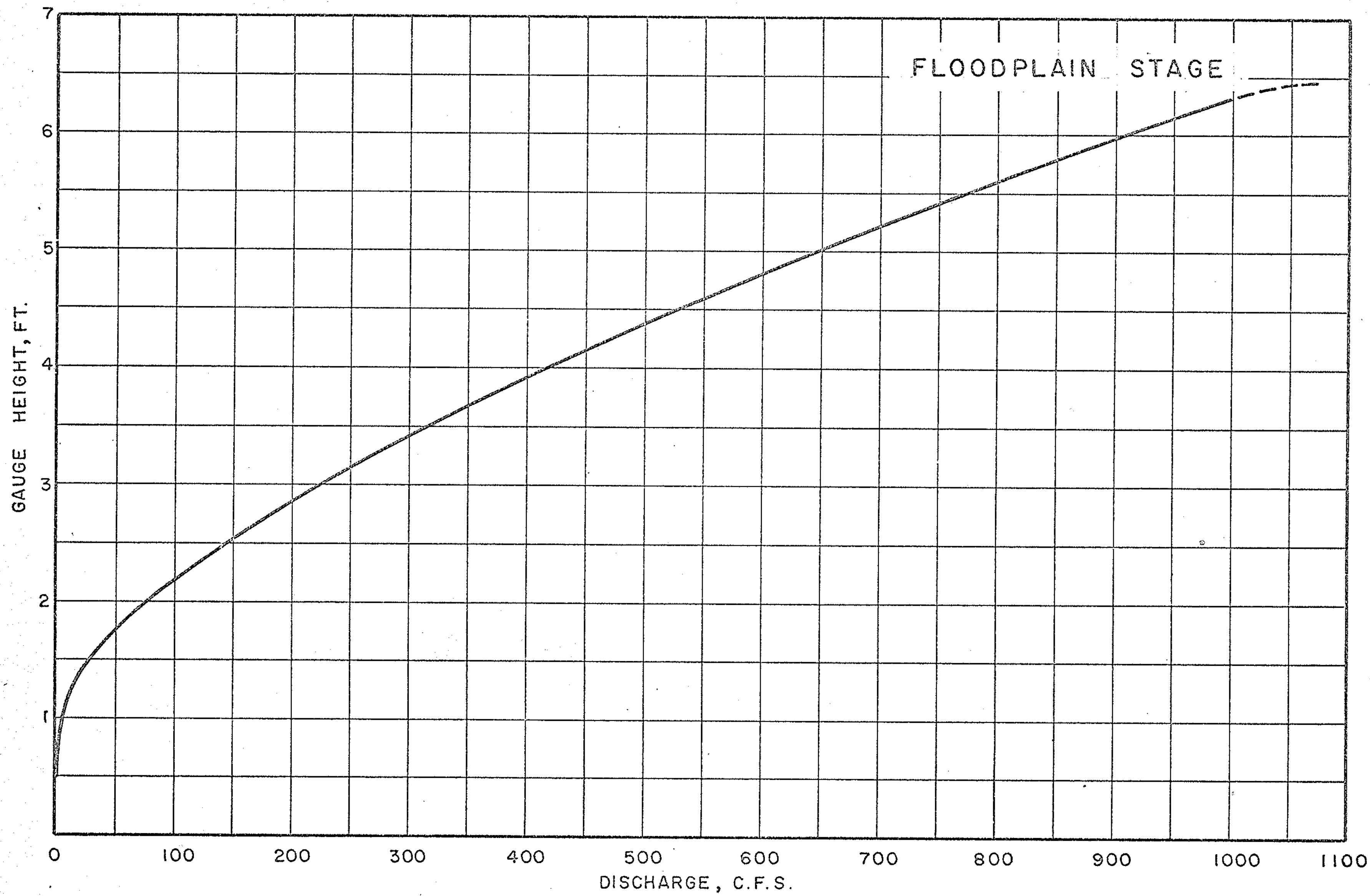


LOCATION: AT SEINE RIVER DIVERSION INLET
DRAINAGE AREA: 310 SQ. MI.
PERIOD OF RECORD: 1915-37, 1955-67.

SEINE RIVER DIVERSION

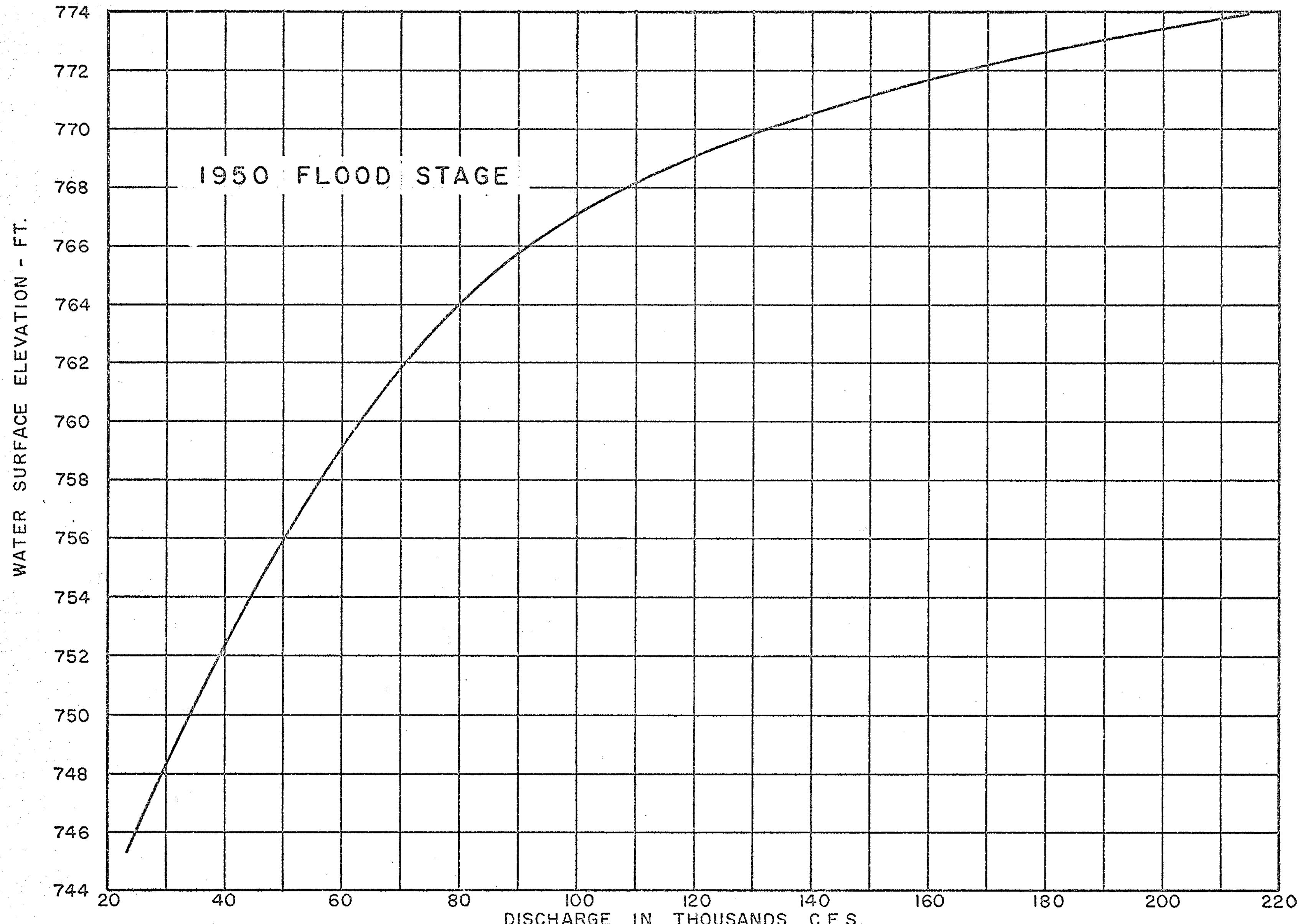
SEINE RIVER FLOOD FREQUENCY CURVE

FIGURE 2.2



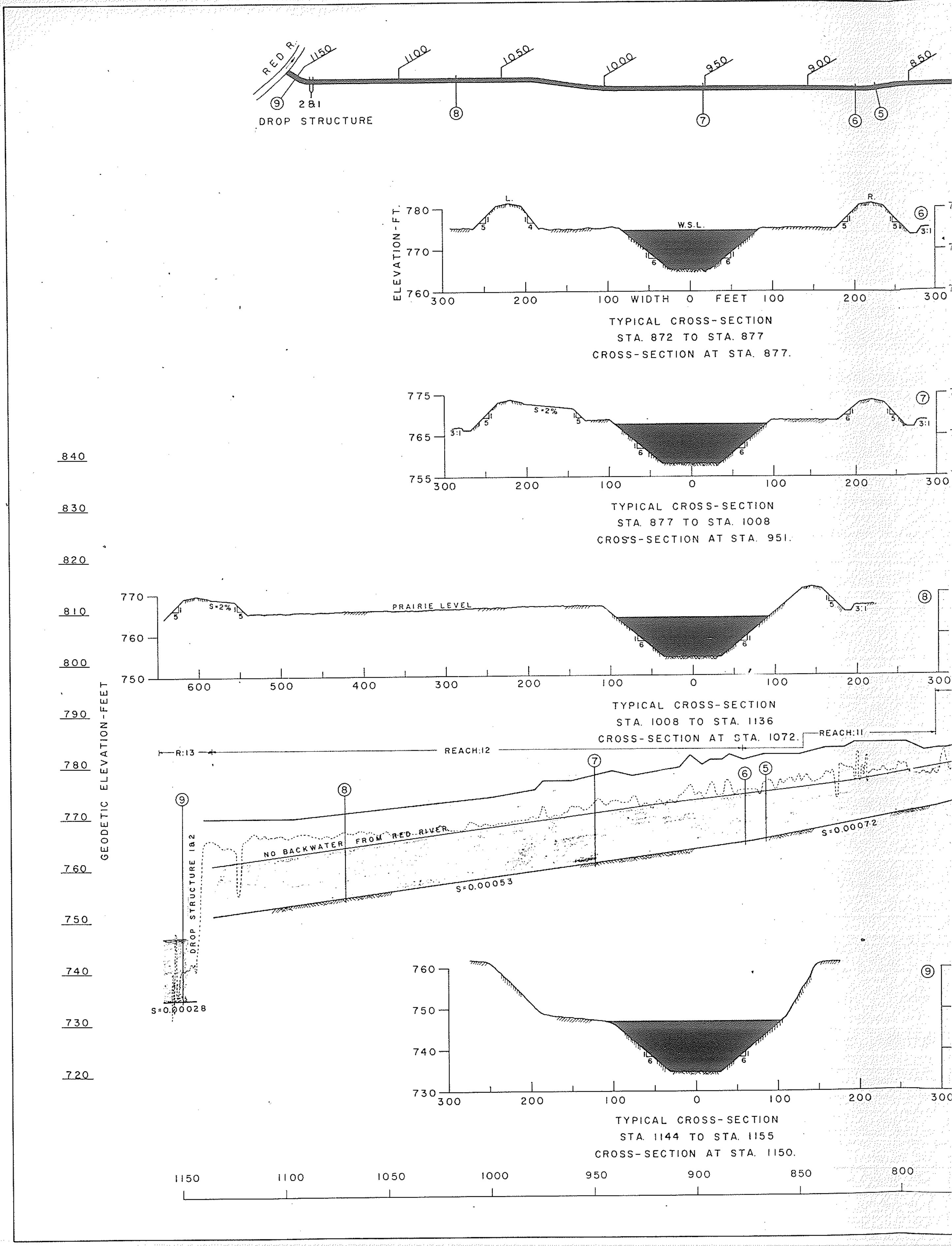
LOCATION	SEINE RIVER DIVERSION
AT SEINE RIVER DIVERSION INLET	SEINE RIVER RATING CURVE

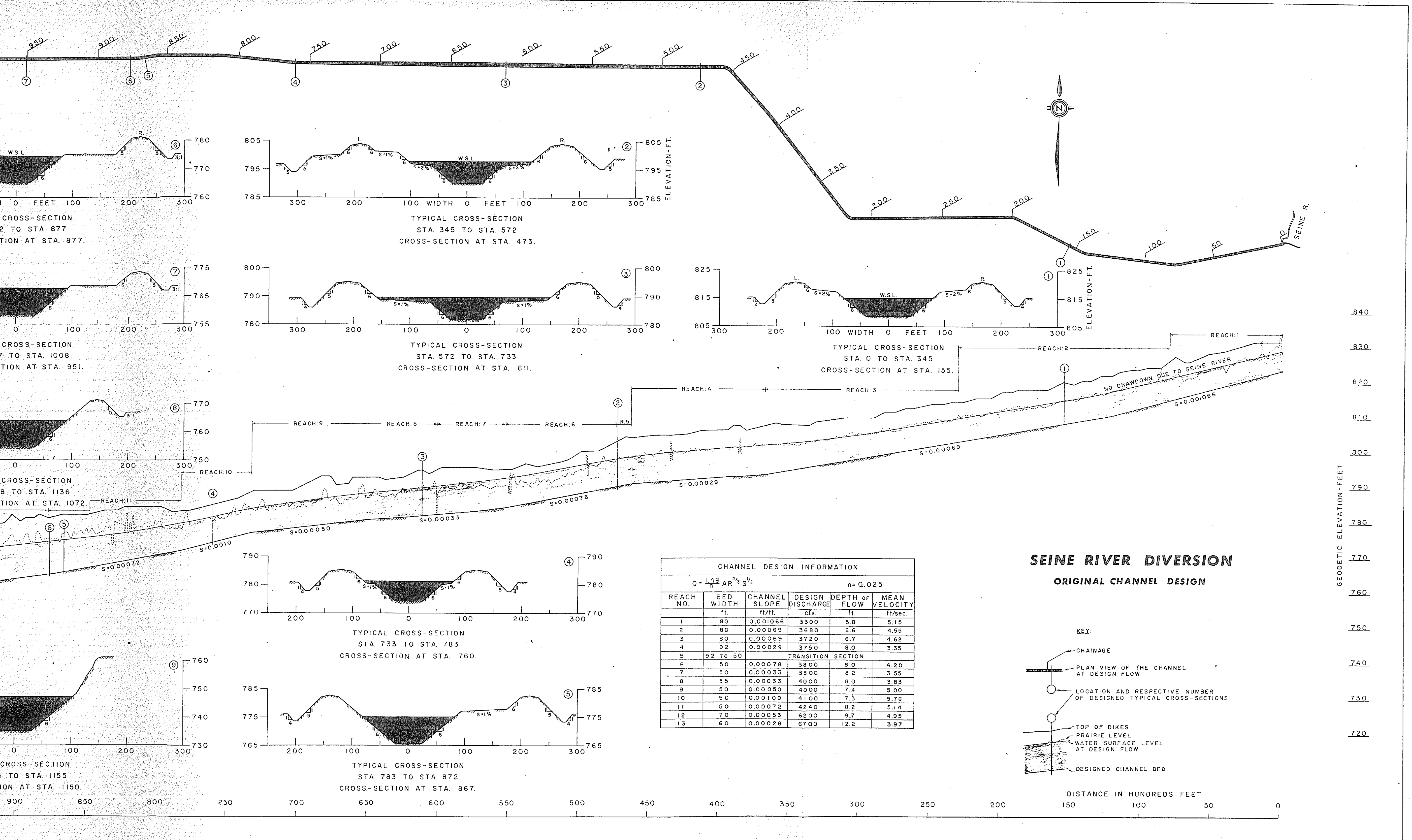
FIGURE 2.3



LOCATION: SEINE RIVER DIVERSION OUTLET.	SEINE RIVER DIVERSION RED RIVER RATING CURVE

FIGURE 2.4


RED R.
1150
1100
1050
1000
950
900
850
9
2&1
DROP STRUCTURE
8
7
6
5
ELEVATION-FT.
780
770
760
300
200
100 WIDTH 0 FEET 100
W.S.L.
L.
R.
3:1
TYPICAL CROSS-SECTION
STA. 872 TO STA. 877
CROSS-SECTION AT STA. 877.
775
765
755
S=2%
TYPICAL CROSS-SECTION
STA. 877 TO STA. 1008
CROSS-SECTION AT STA. 951.
PRAIRIE LEVEL
600
500
400
TYPICAL CROSS-SECTION
STA. 1008 TO STA. 1136
CROSS-SECTION AT STA. 1072.
REACH:11
R:13
REACH:12
GEODETIC ELEVATION-FEET
840
830
820
810
800
790
780
770
760
750
740
730
720
DROP STRUCTURE 1&2
NO BACKWATER FROM RED RIVER
S=0.00053
S=0.00072
S=0.00028
TYPICAL CROSS-SECTION
STA. 1144 TO STA. 1155
CROSS-SECTION AT STA. 1150.
800



CHANNEL DESIGN INFORMATION

$Q = \frac{1.49}{n} A R^{2/3} S^{1/2}$ n= 0.025

REACH NO.	BED WIDTH	CHANNEL SLOPE	DESIGN DISCHARGE	DEPTH of FLOW	MEAN VELOCITY
	ft.	ft/ft.	cfs.	ft.	ft/sec.
1	80	0.001066	3300	5.8	5.15
2	80	0.00069	3680	6.6	4.55
3	80	0.00069	3720	6.7	4.62
4	92	0.00029	3750	8.0	3.35
5	92 TO 50	TRANSITION SECTION			
6	50	0.00078	3800	8.0	4.20
7	50	0.00033	3800	8.2	3.55
8	55	0.00033	4000	8.0	3.83
9	50	0.00050	4000	7.4	5.00
10	50	0.00100	4100	7.3	5.76
11	50	0.00072	4240	8.2	5.14
12	70	0.00053	6200	9.7	4.95
13	60	0.00028	6700	12.2	3.97

FIGURE 2.5

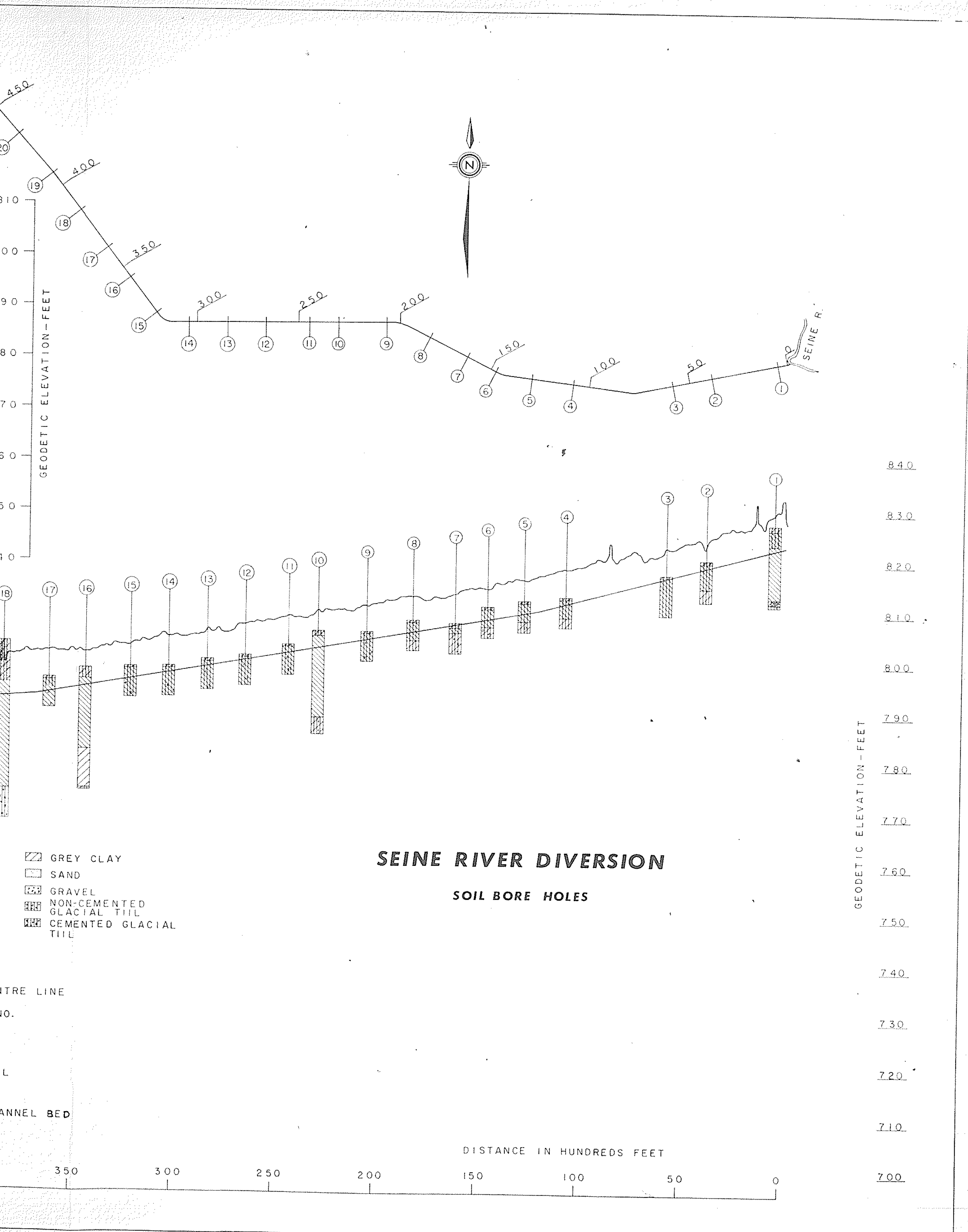
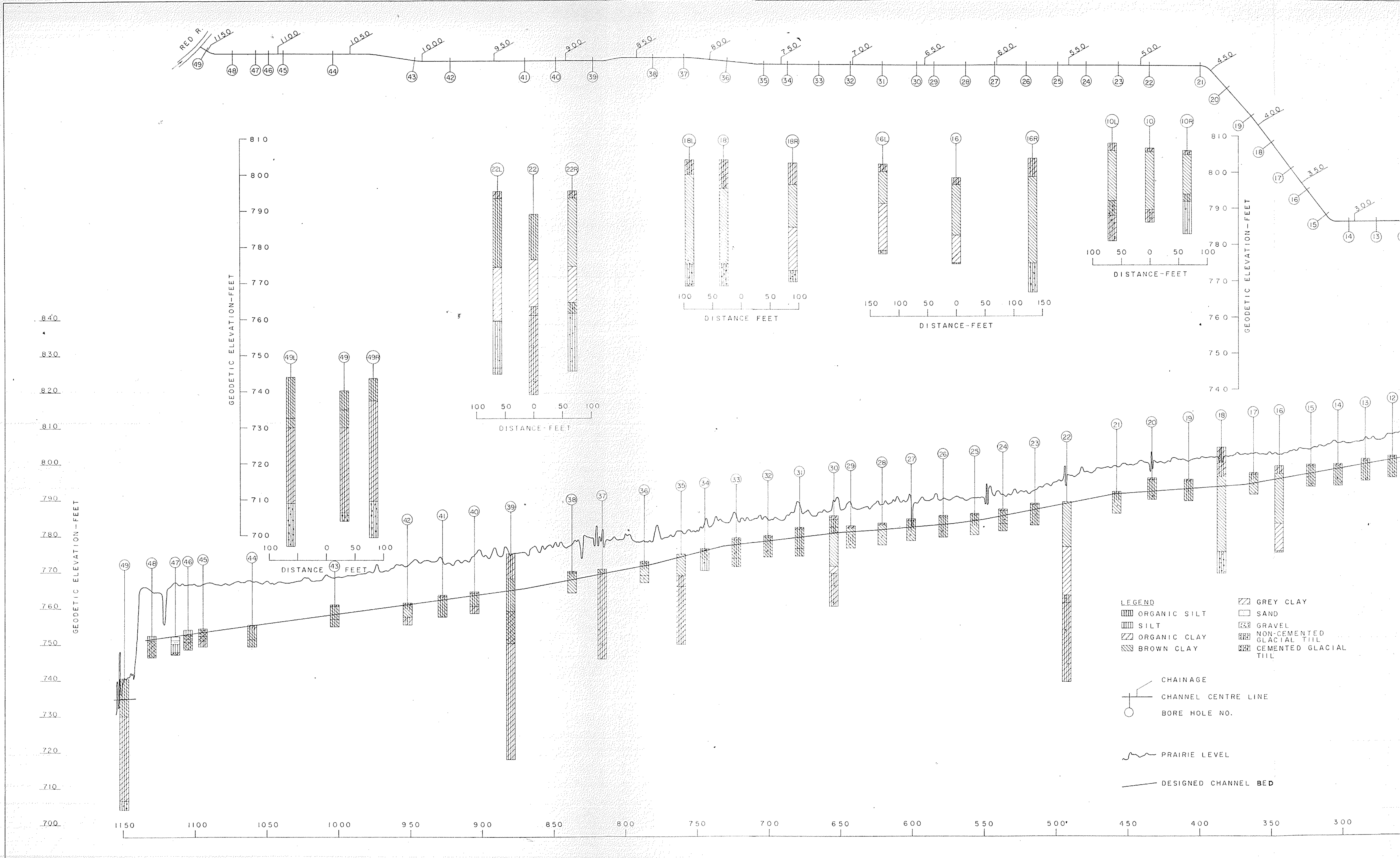
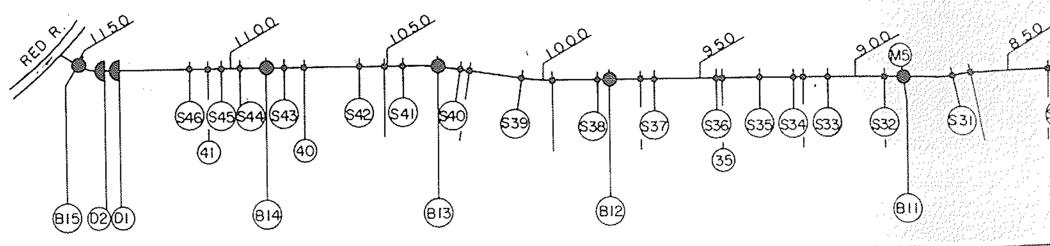

SEINE RIVER DIVERSION
SOIL BORE HOLES
SEINE R.
GREY CLAY
SAND
GRAVEL
NON-CEMENTED GLACIAL TILL
CEMENTED GLACIAL TILL
GEODETIC ELEVATION - FEET
DISTANCE IN HUNDREDS FEET
ANNEL BED

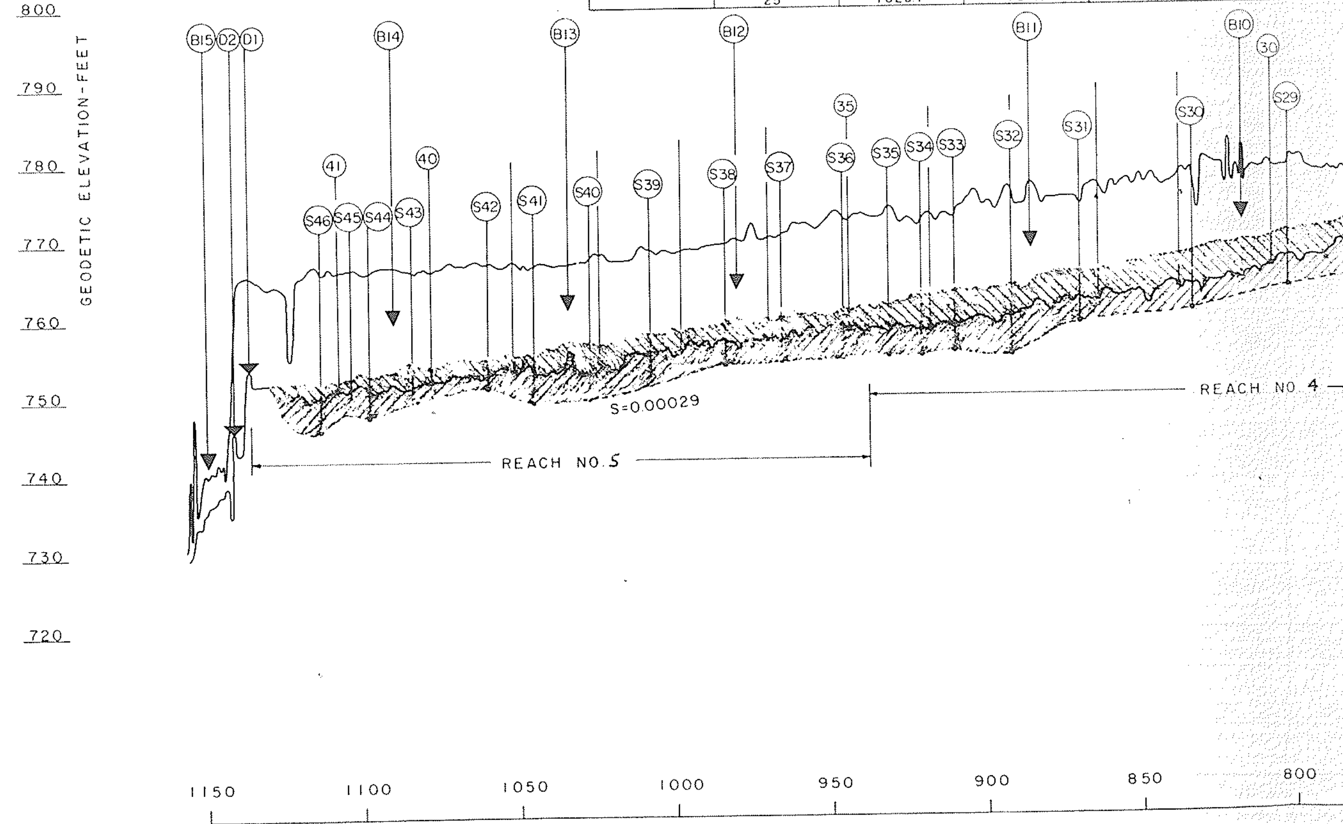
FIGURE 3.1

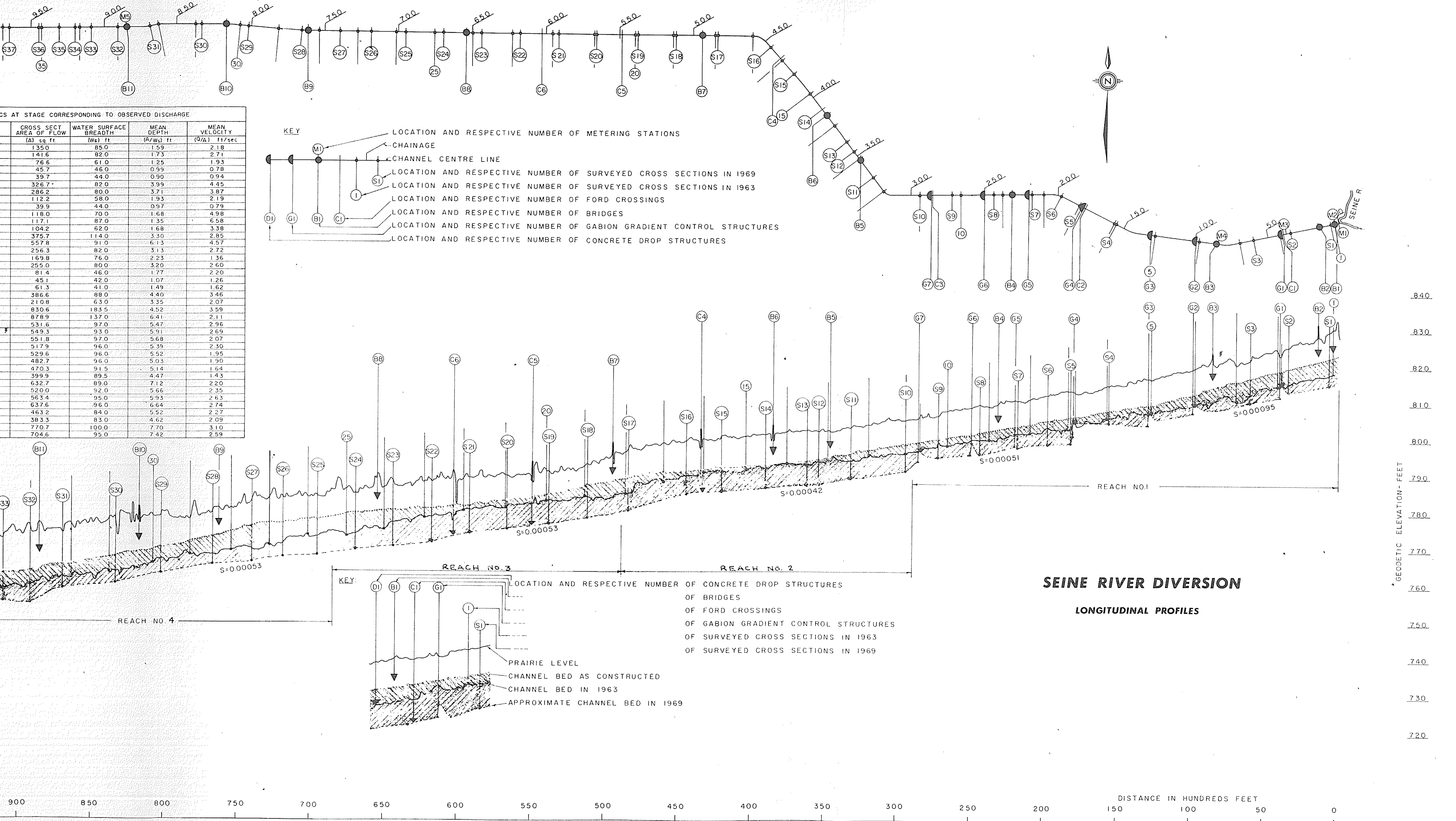

RED R.
LEGEND
ORGANIC SILT
SILT
ORGANIC CLAY
BROWN CLAY
GREY CLAY
SAND
GRAVEL
NON-CEMENTED GLACIAL TILL
CEMENTED GLACIAL TILL
CHAINAGE
CHANNEL CENTRE LINE
BORE HOLE NO.
PRAIRIE LEVEL
DESIGNED CHANNEL BED
GEODETIC ELEVATION-FEET
DISTANCE-FEET



CHANNEL SHAPE CHARACTERISTICS AT STAGE CORRESPONDING TO OBSERVED DISCHARGE

METERING STA. NO.	DATE OF RECORD	DISCHARGE	CROSS SECT AREA OF FLOW	WATER SURFACE BREADTH	MEAN DEPTH
		(Q) cfs	(A) sq ft	(Ws) ft	(A/Ws) ft
1	APR. 19, 1962	294.7	135.0	85.0	1.59
	20	382.3	141.6	82.0	1.73
2	APR 17, 1963	147.9	76.6	61.0	1.25
	MAY, 2	35.6	45.7	46.0	0.99
	JUN. 10	37.3	39.7	44.0	0.90
	27	1455.5	326.7	82.0	3.99
	28	1108.1	286.2	80.0	3.71
	APR. 24, 1964	245.9	112.2	58.0	1.93
3	APR. 30, 1968	31.9	39.9	44.0	0.97
4	APR. 19, 1965	588.3	118.0	70.0	1.68
	20	770.7	117.1	87.0	1.35
	21	352.2	104.2	62.0	1.68
	APR. 25, 1967	1073.9	375.7	114.0	3.30
5	APR. 20, 1962	2549.2	557.8	91.0	6.13
	23	698.1	256.3	82.0	3.13
	26	230.8	169.8	76.0	2.23
	MAY, 29, 1962	662.3	255.0	80.0	3.20
	APR. 17, 1963	178.7	81.4	46.0	1.77
	MAY, 2	56.8	45.1	42.0	1.07
	JUN. 10	99.0	61.3	41.0	1.49
	28	1338.6	386.6	88.0	4.40
	APR. 22, 1965	437.4	210.8	63.0	3.35
	APR. 7, 1966	2983.0	830.6	183.5	4.52
	10	1856.8	878.9	137.0	6.41
	12	1570.9	531.6	97.0	5.47
	13	1475.8	549.3	93.0	5.91
	14	1409.2	551.8	97.0	5.68
	15	1192.6	517.9	96.0	5.39
	16	1033.1	529.6	96.0	5.52
	17	917.5	482.7	96.0	5.03
	18	773.4	470.3	91.5	5.14
	20	570.2	399.9	89.5	4.47
	APR. 10, 1967	1397.3	632.7	89.0	7.12
	11	1223.3	520.0	92.0	5.66
	14	1483.5	563.4	95.0	5.93
	15	1749.9	637.6	96.0	6.64
	17	1054.1	463.2	84.0	5.52
	18	800.0	383.3	83.0	4.62
	24	2390.1	770.7	100.0	7.70
	25	1826.7	704.6	95.0	7.42





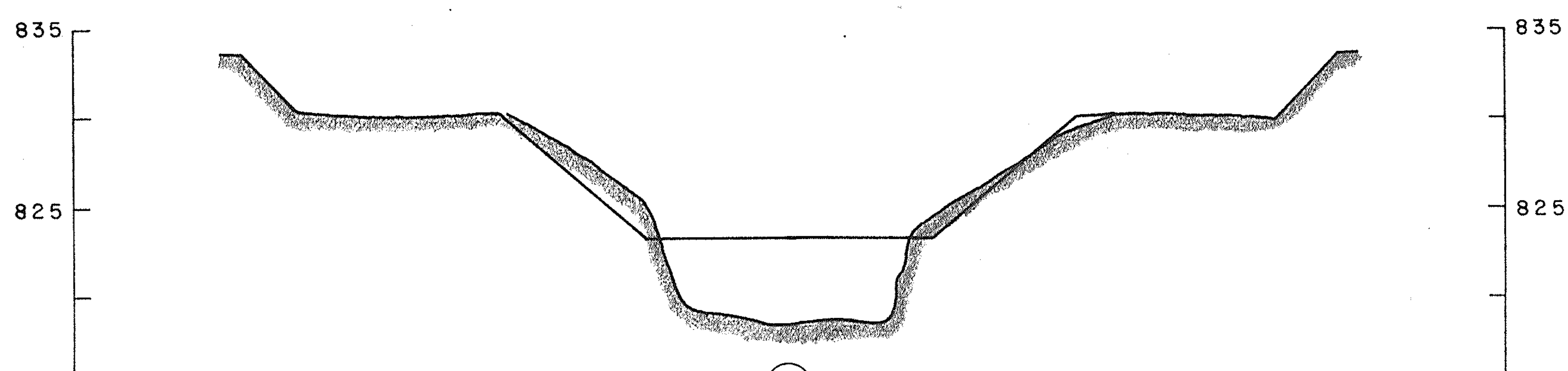
CS AT STAGE CORRESPONDING TO OBSERVED DISCHARGE

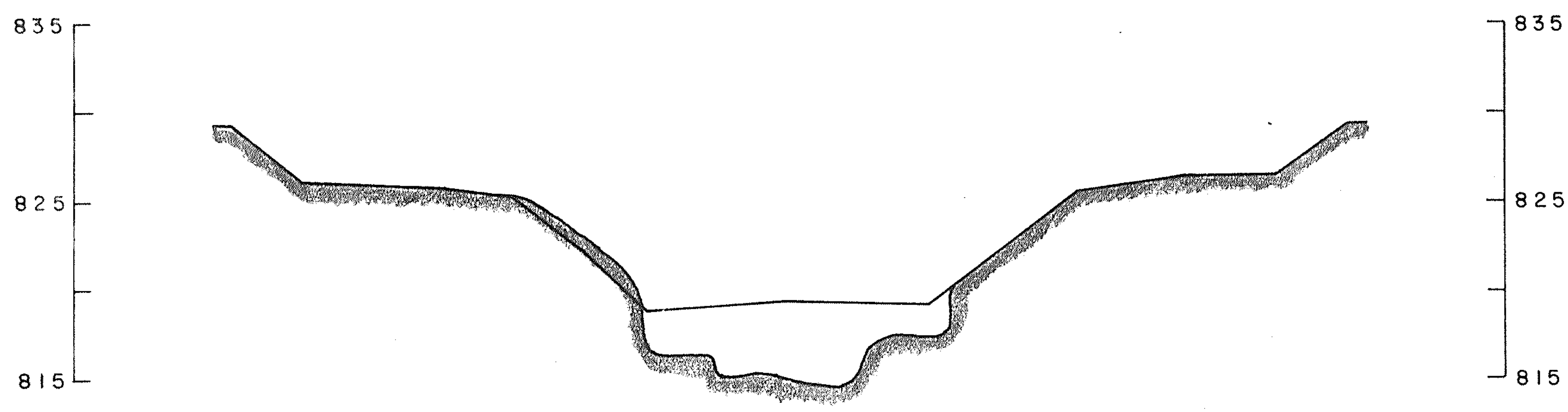
CROSS SECT AREA OF FLOW (A) sq ft	WATER SURFACE BREADTH (Ws) ft	MEAN DEPTH (A/Ws) ft	MEAN VELOCITY (Q/A) ft/sec
135.0	85.0	1.59	2.18
141.6	82.0	1.73	2.71
76.6	61.0	1.25	1.93
45.7	46.0	0.99	0.78
39.7	44.0	0.90	0.94
326.7	82.0	3.99	4.45
286.2	80.0	3.71	3.87
112.2	58.0	1.93	2.19
39.9	44.0	0.97	0.79
118.0	70.0	1.68	4.98
117.1	87.0	1.35	6.58
104.2	62.0	1.68	3.38
375.7	114.0	3.30	2.85
557.8	91.0	6.13	4.57
256.3	82.0	3.13	2.72
169.8	76.0	2.23	1.36
255.0	80.0	3.20	2.60
81.4	46.0	1.77	2.20
45.1	42.0	1.07	1.26
61.3	41.0	1.49	1.62
386.6	88.0	4.40	3.46
210.8	63.0	3.35	2.07
830.6	183.5	4.52	3.59
878.9	137.0	6.41	2.11
531.6	97.0	5.47	2.96
549.3	93.0	5.91	2.69
551.8	97.0	5.68	2.07
517.9	96.0	5.39	2.30
529.6	96.0	5.52	1.95
482.7	96.0	5.03	1.90
470.3	91.5	5.14	1.64
399.9	89.5	4.47	1.43
632.7	89.0	7.12	2.20
520.0	92.0	5.66	2.35
563.4	95.0	5.93	2.63
637.6	96.0	6.64	2.74
463.2	84.0	5.52	2.27
383.3	83.0	4.62	2.09
770.7	100.0	7.70	3.10
704.6	95.0	7.42	2.59

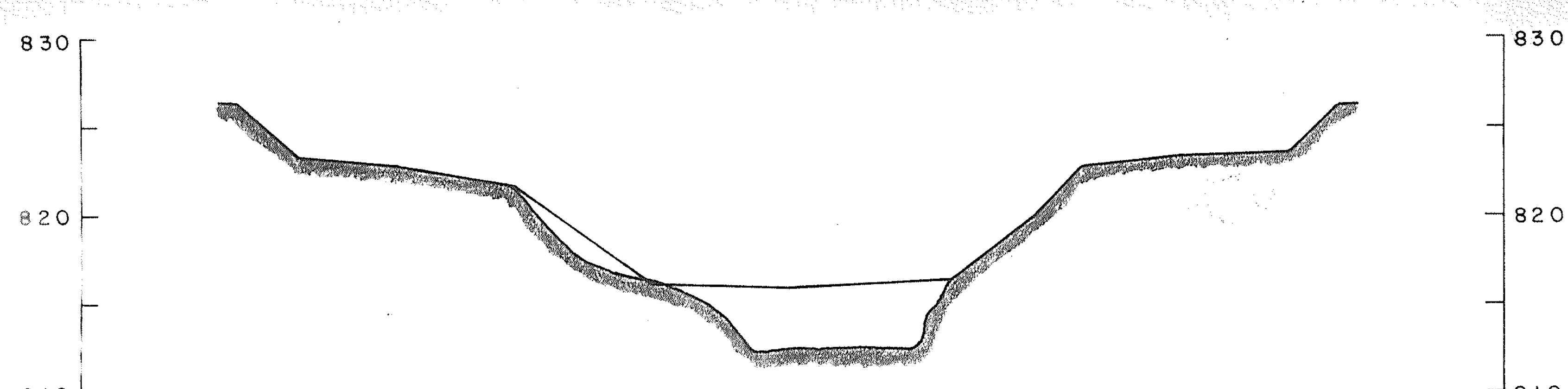
SEINE RIVER DIVERSION

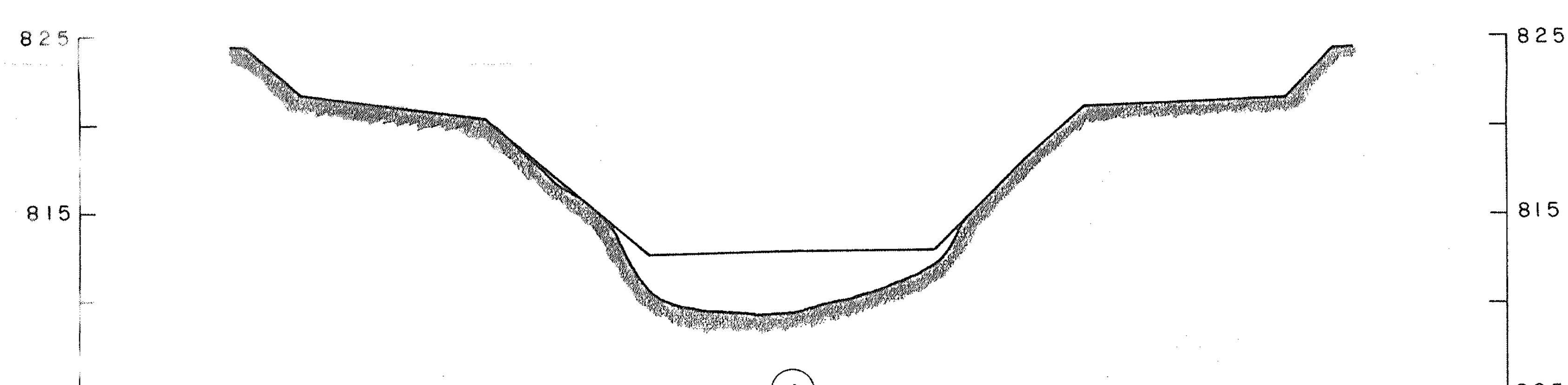
LONGITUDINAL PROFILES

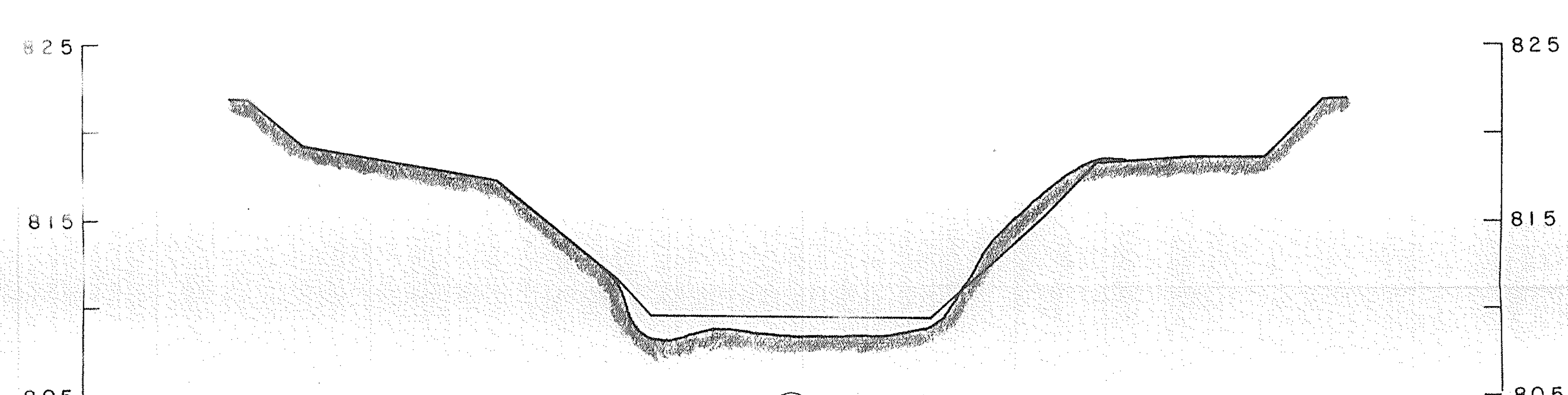
FIGURE 3.2

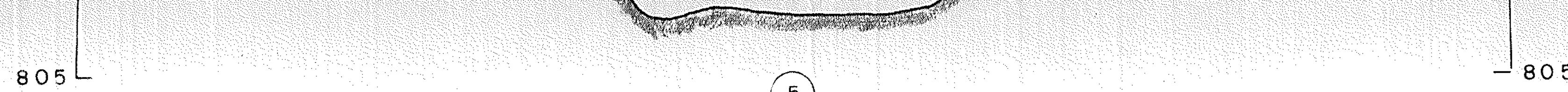

835
825
815
835
825
815
1


835
825
815
835
825
815
2

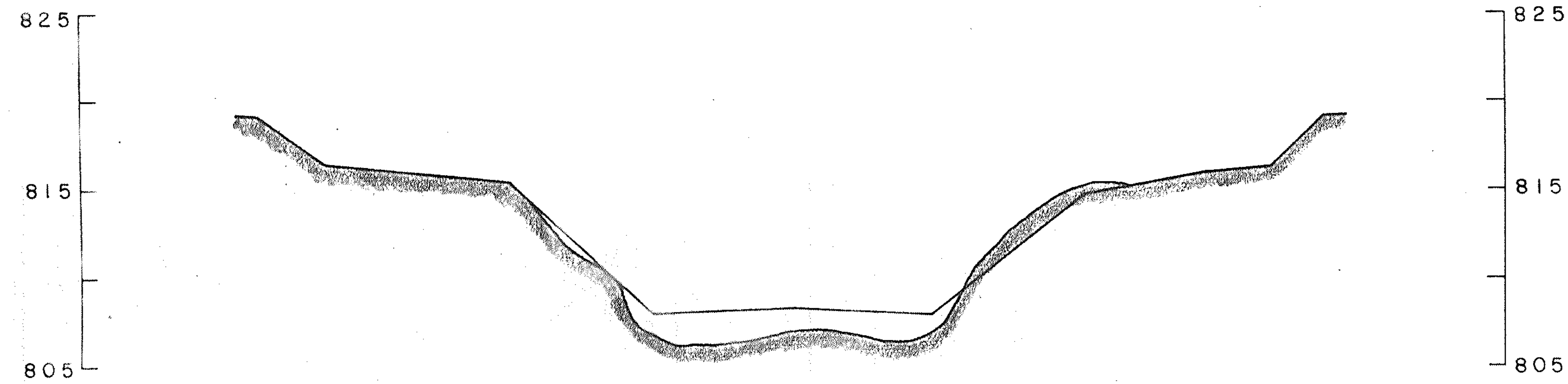

830
820
810
830
820
810
3


825
815
805
825
815
805
4

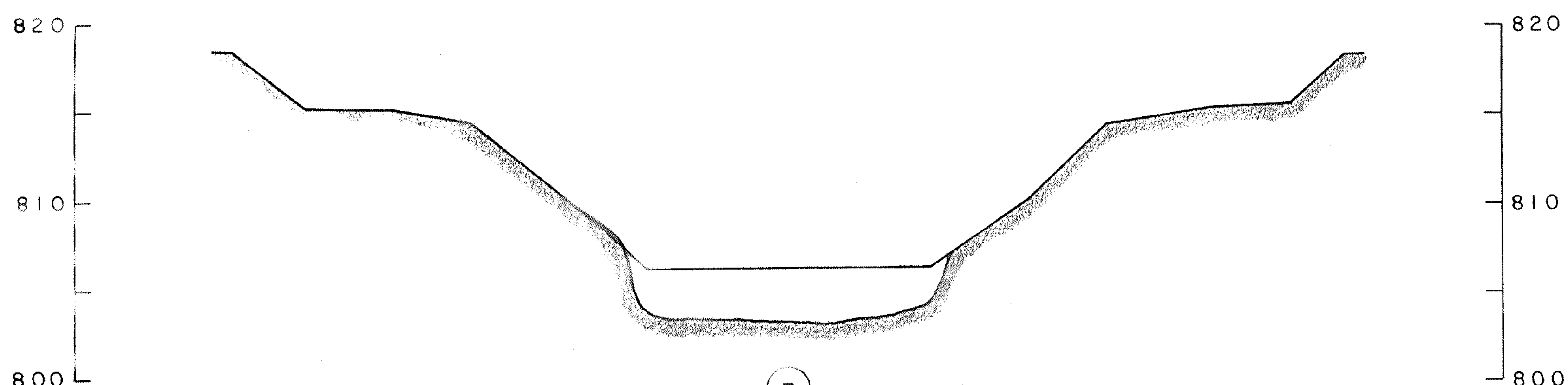

825
815
805
825
815
805
5


805
805

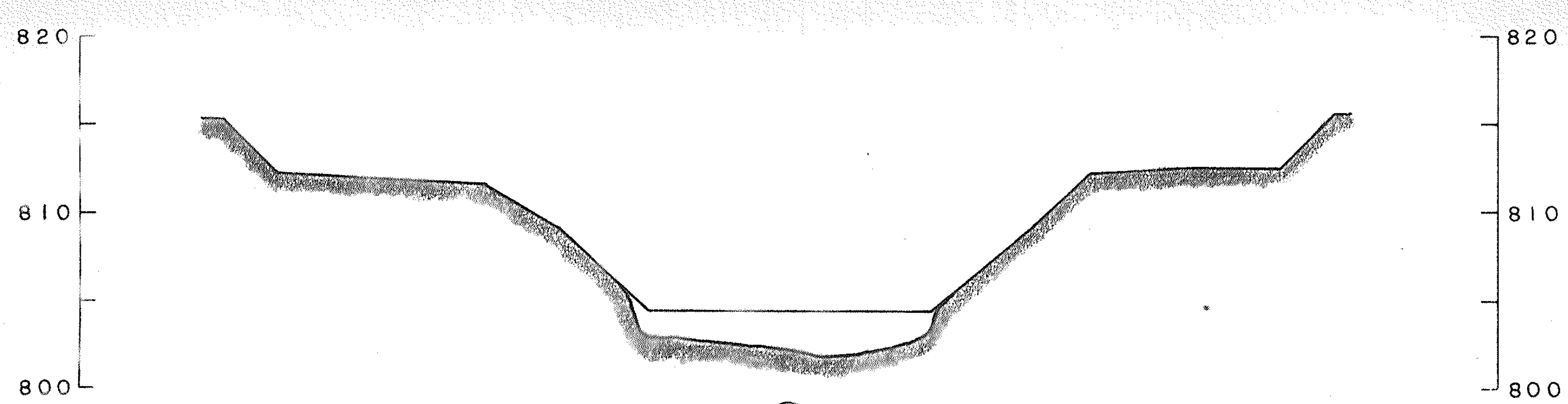
5


825
815
805
825
815
805

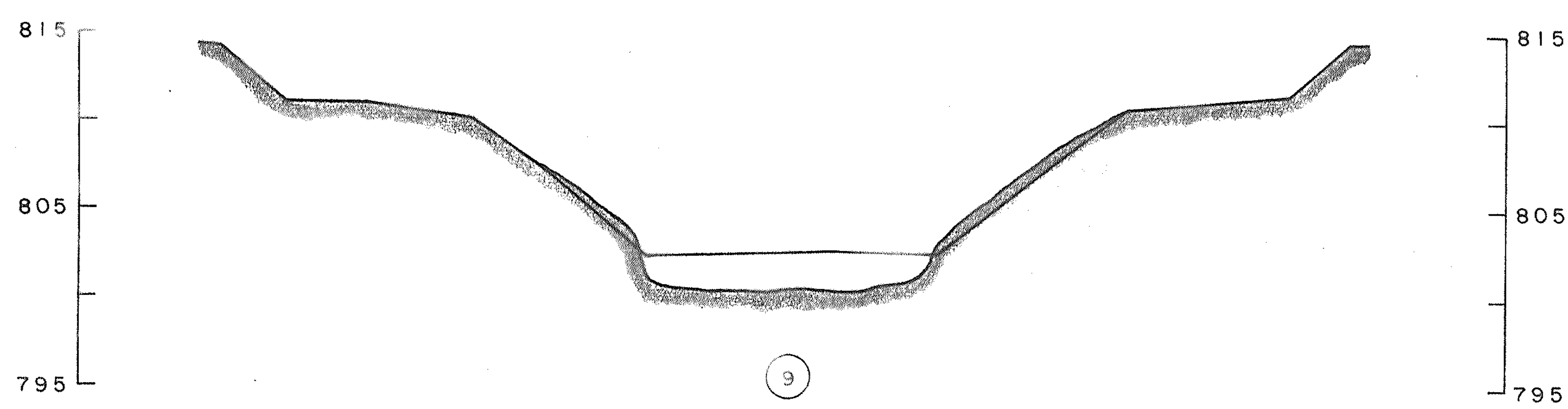
6


820
810
800
820
810
800

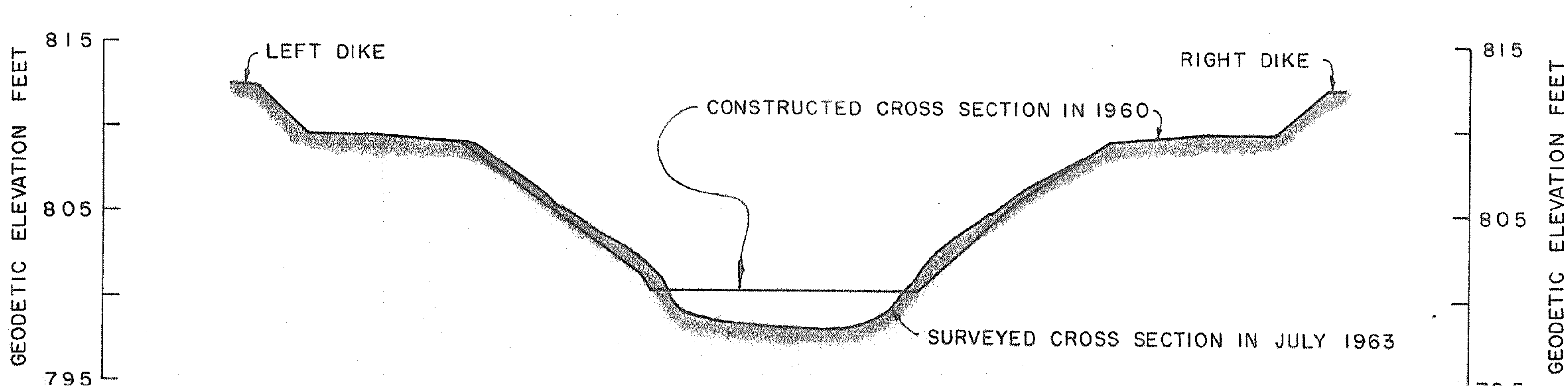
7

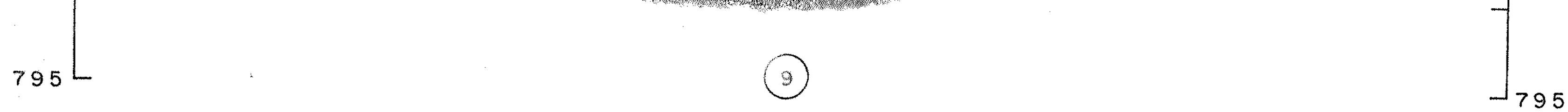

820
810
800
820
810
800

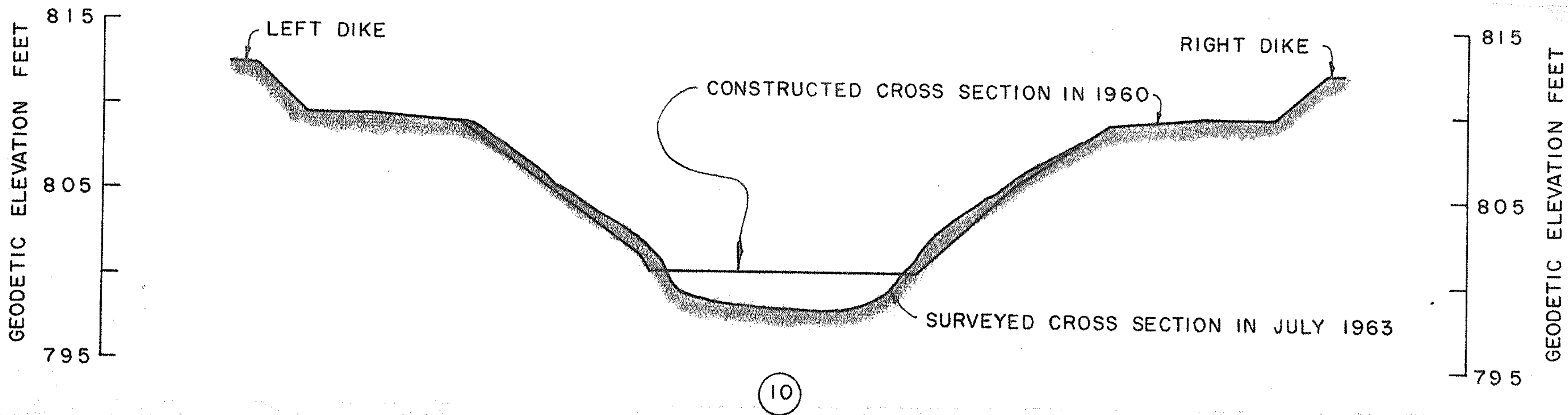
8


815
805
795
815
805
795

9


GEODETIC ELEVATION FEET
815
805
795
LEFT DIKE
RIGHT DIKE
CONSTRUCTED CROSS SECTION IN 1960
SURVEYED CROSS SECTION IN JULY 1963
815
805
GEODETIC ELEVATION FEET

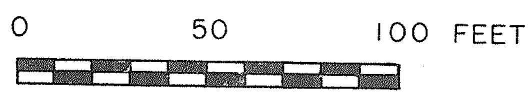




SEINE RIVER DIVERSION

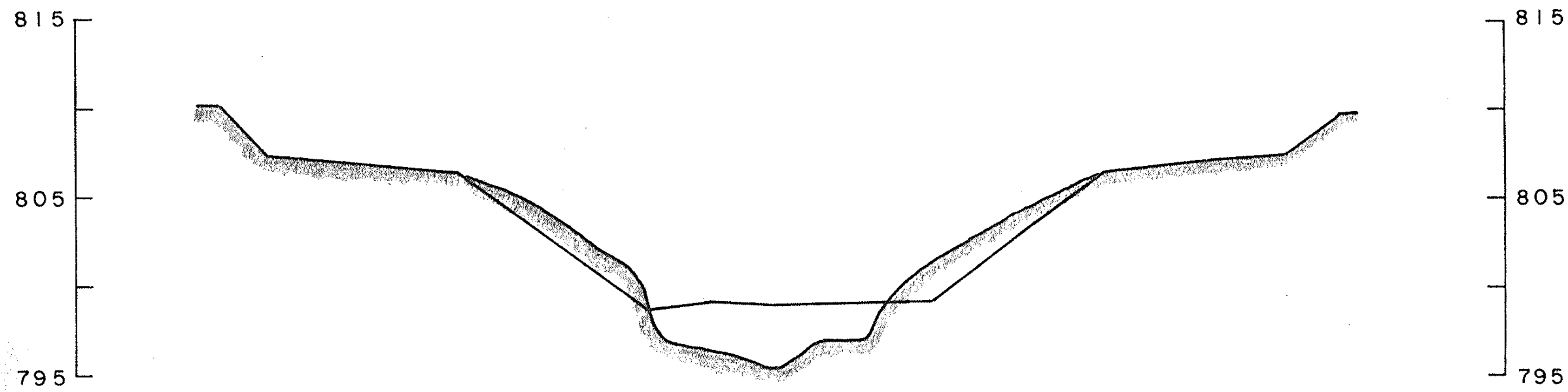
CROSS SECTIONS
IN
REACH NO. I

FOR KEY SEE CROSS SECTION NO. 10

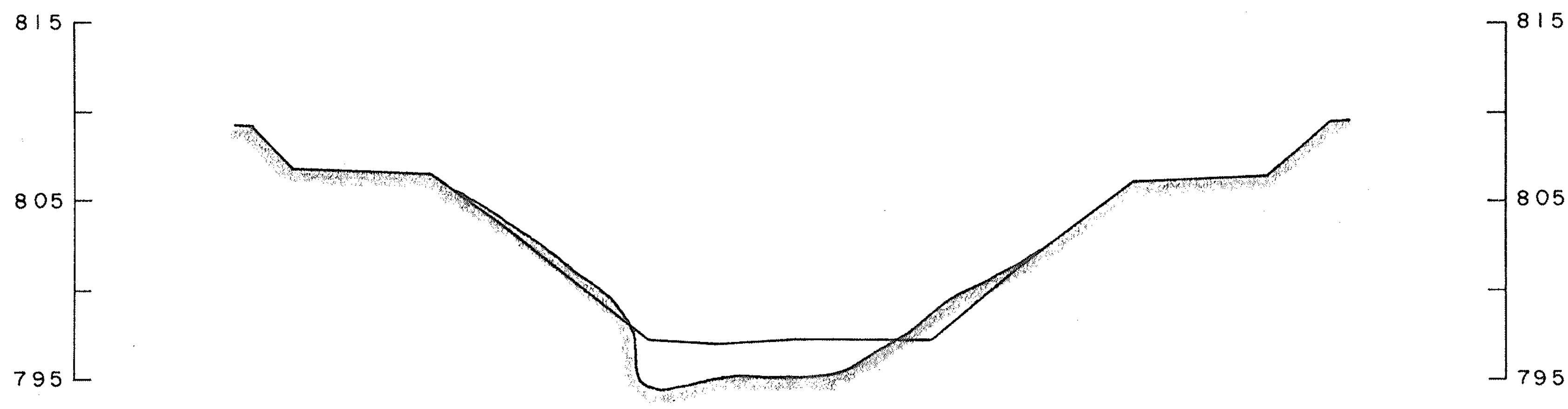


HORIZONTAL SCALE

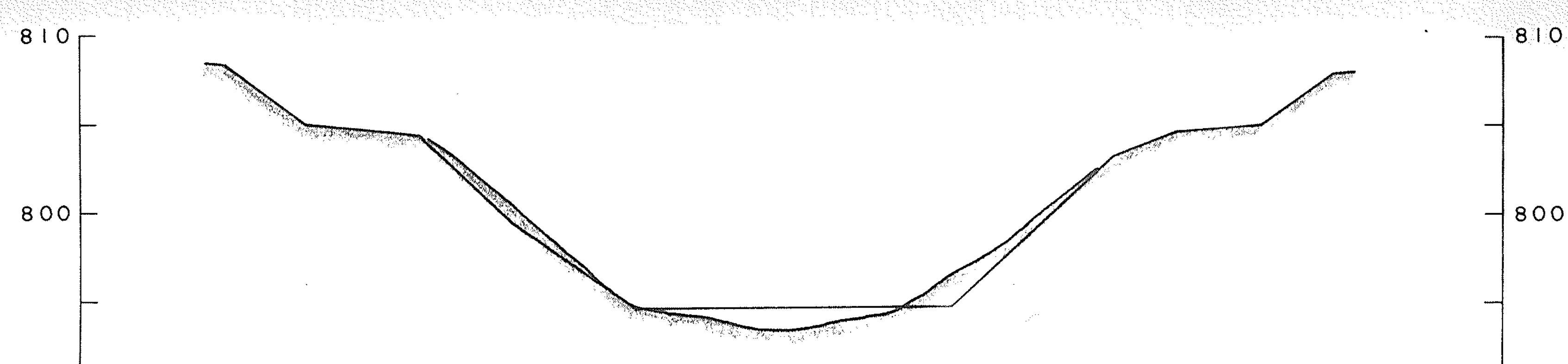
FIGURE 3.2A



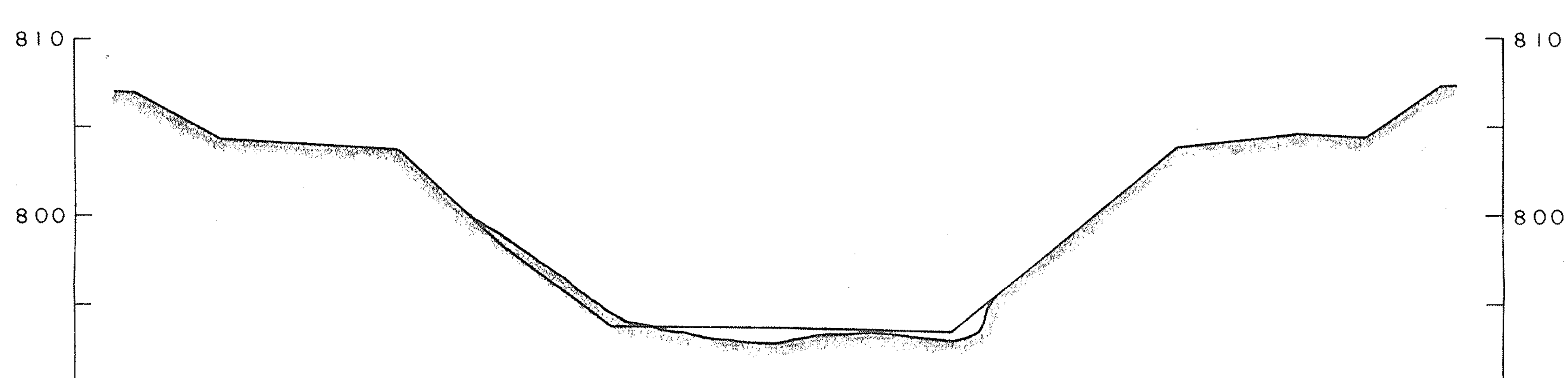
11



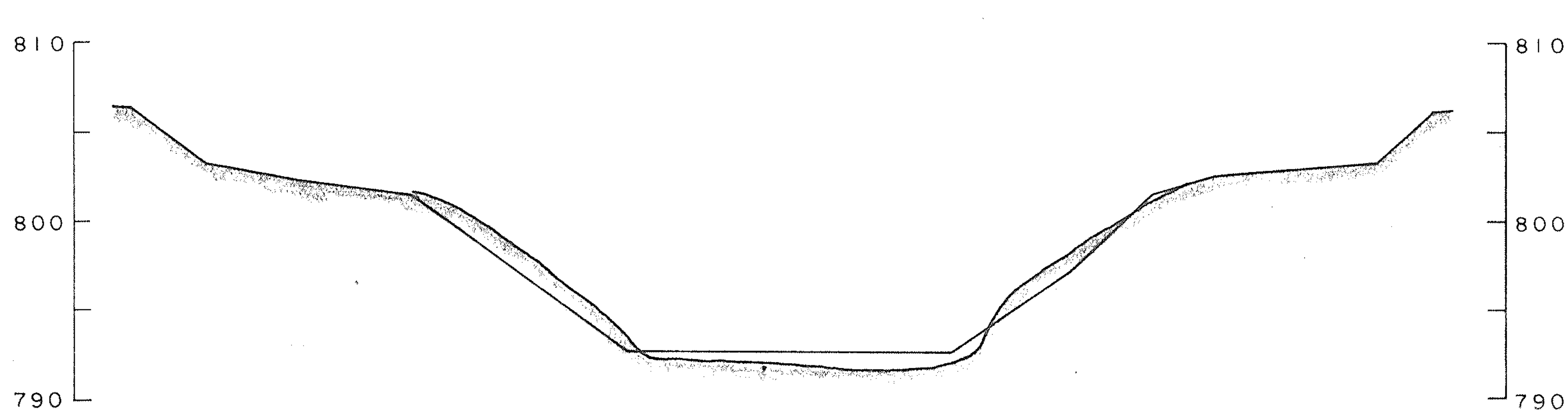
12



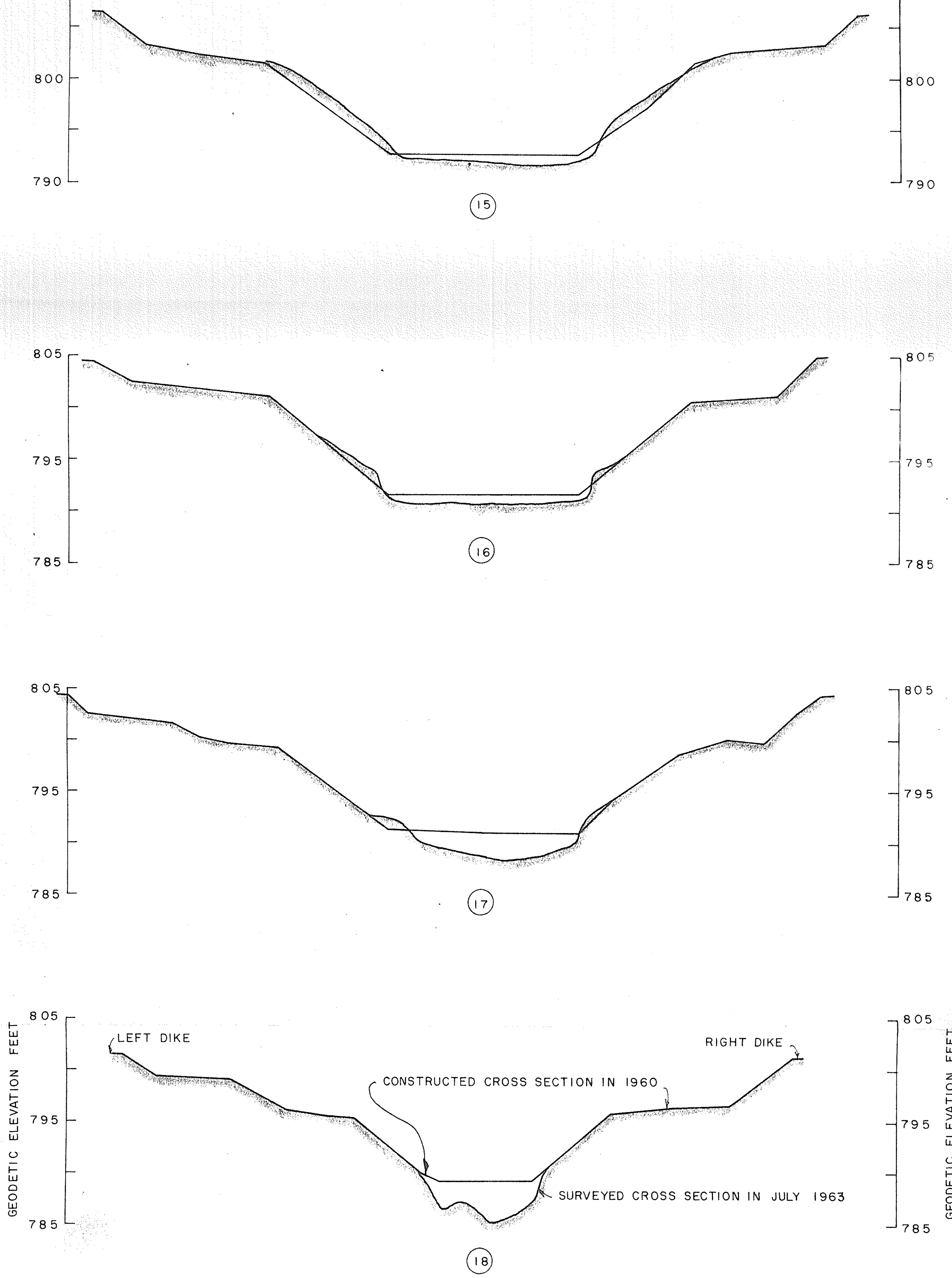
13



14



15



SEINE RIVER DIVERSION

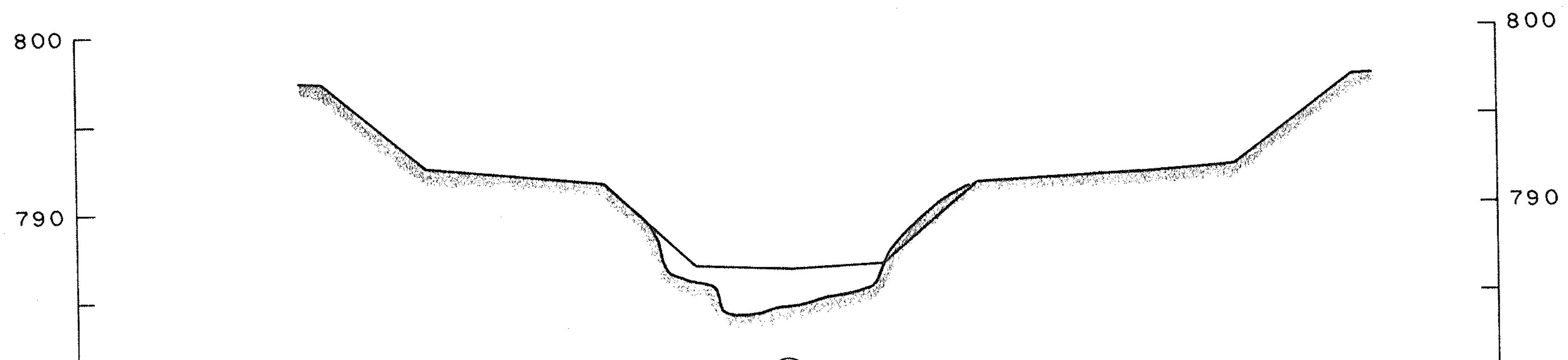
CROSS SECTIONS
IN
REACH NO 2

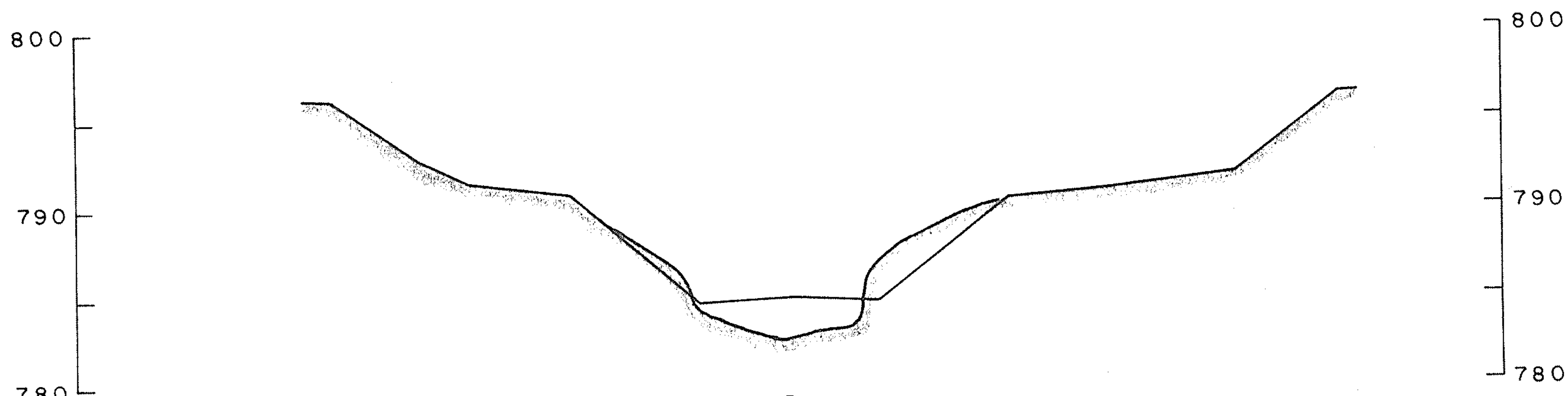
FOR KEY SEE CROSS SECTION NO. 18

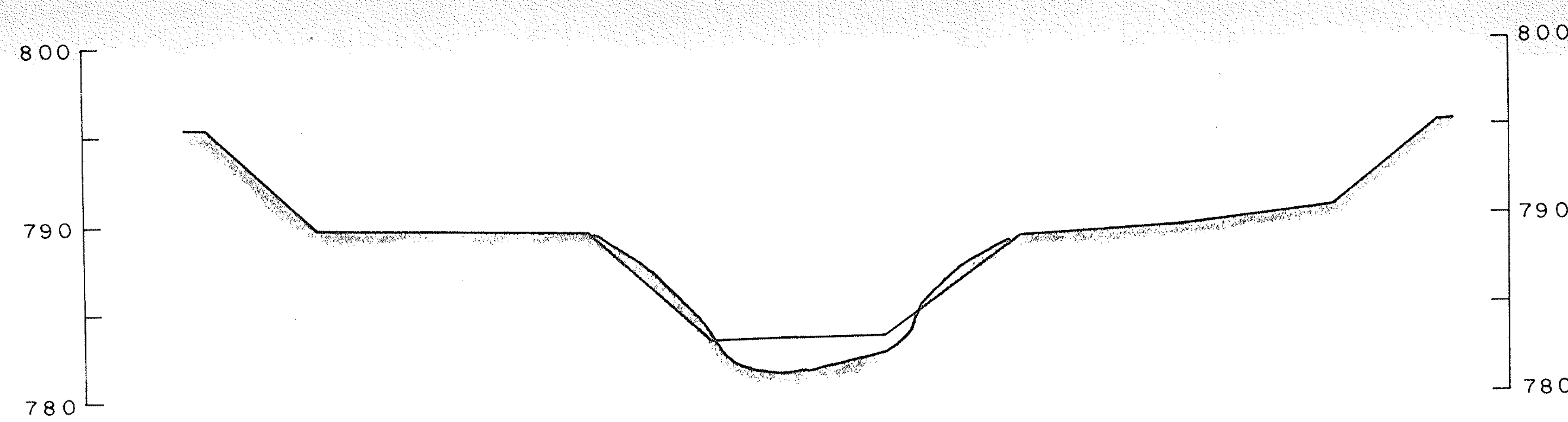
0 50 100 FEET

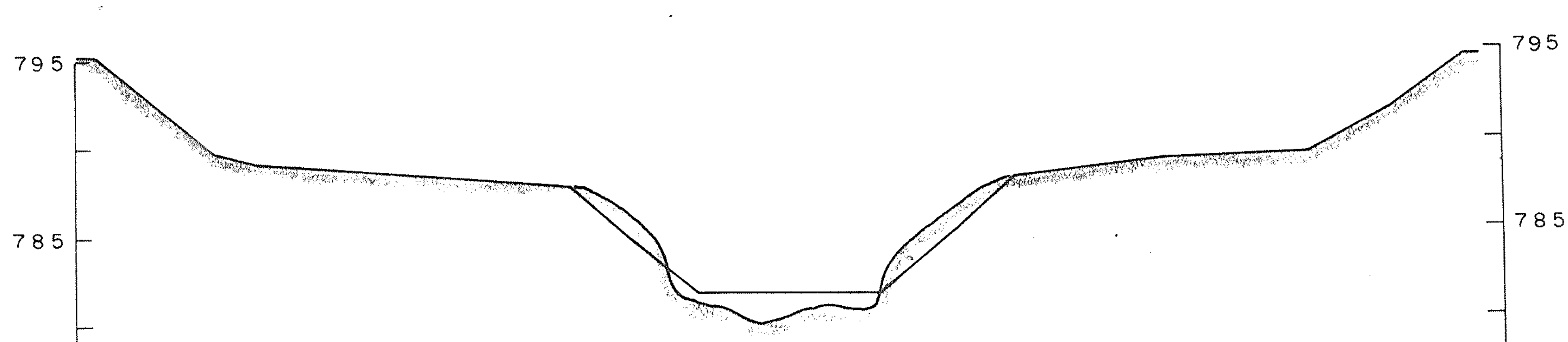
HORIZONTAL SCALE

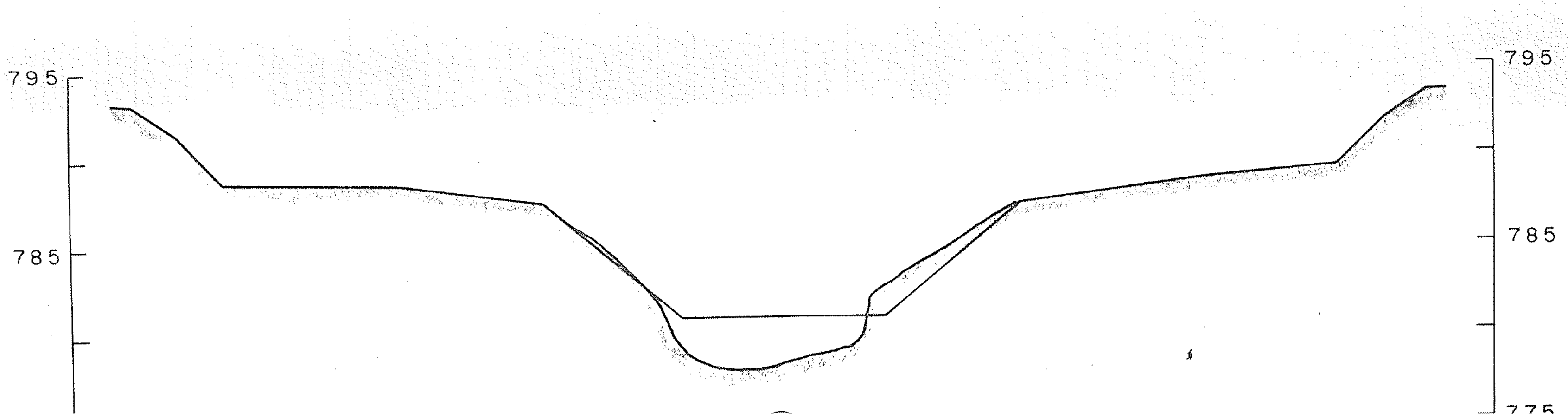
FIGURE 3.2B

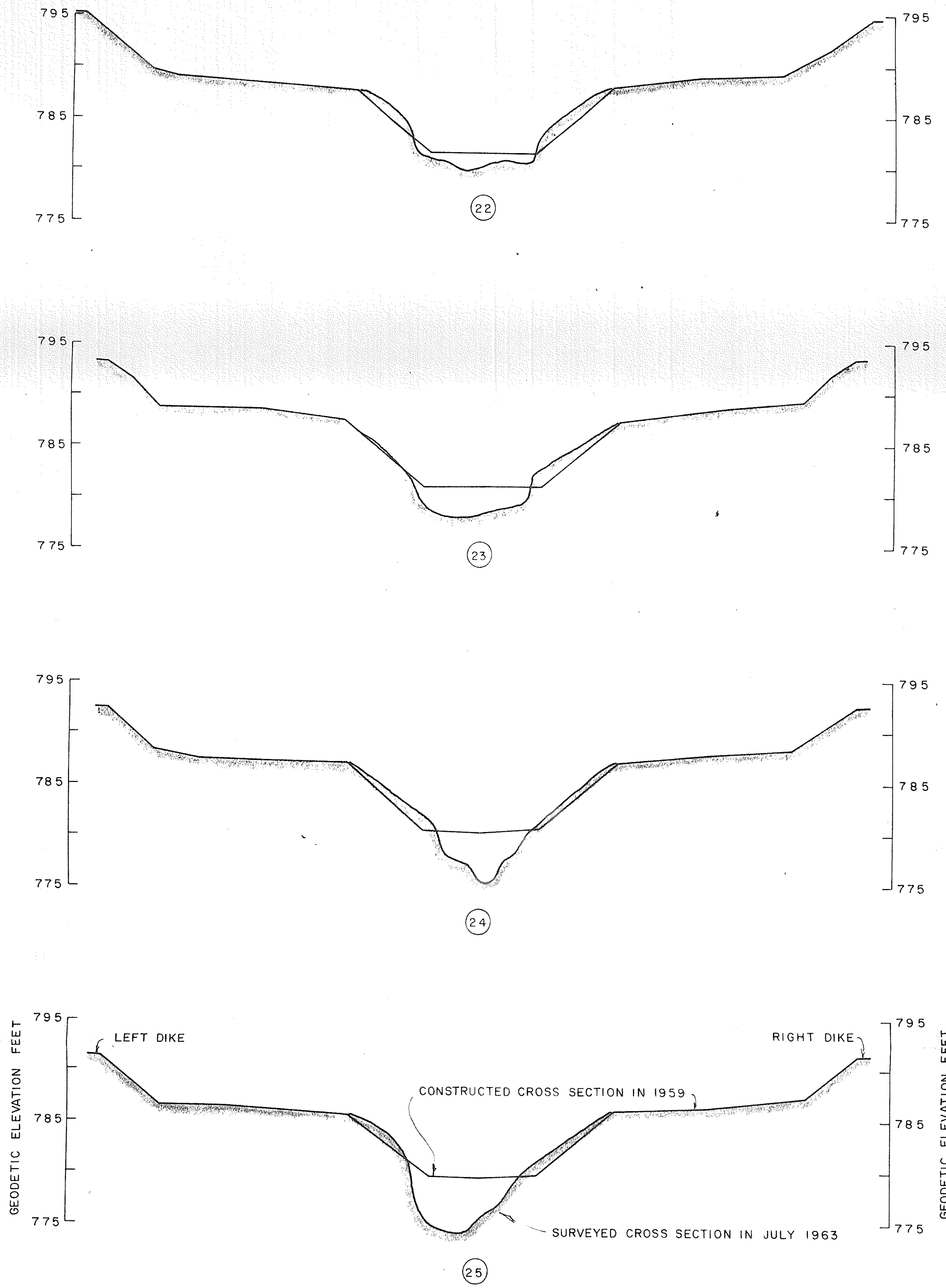

800
790
780
800
790
780
19


800
790
780
800
790
780
20


800
790
780
800
790
780
21


795
785
775
795
785
775
22


795
785
795
785



SEINE RIVER DIVERSION

CROSS SECTIONS
IN
REACH NO. 3

FOR KEY SEE CROSS SECTION NO. 25

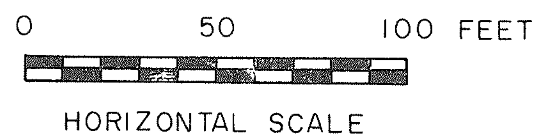
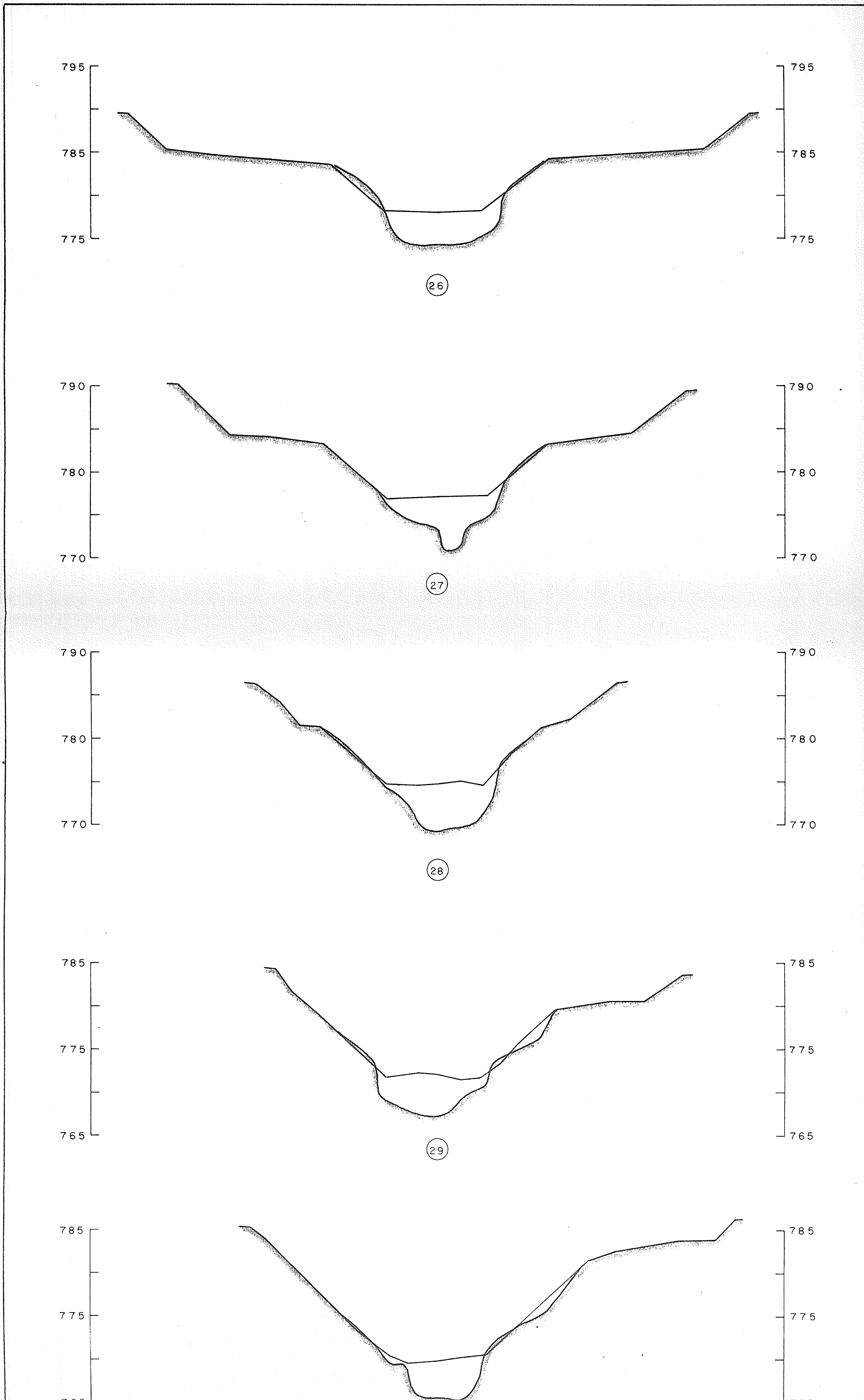
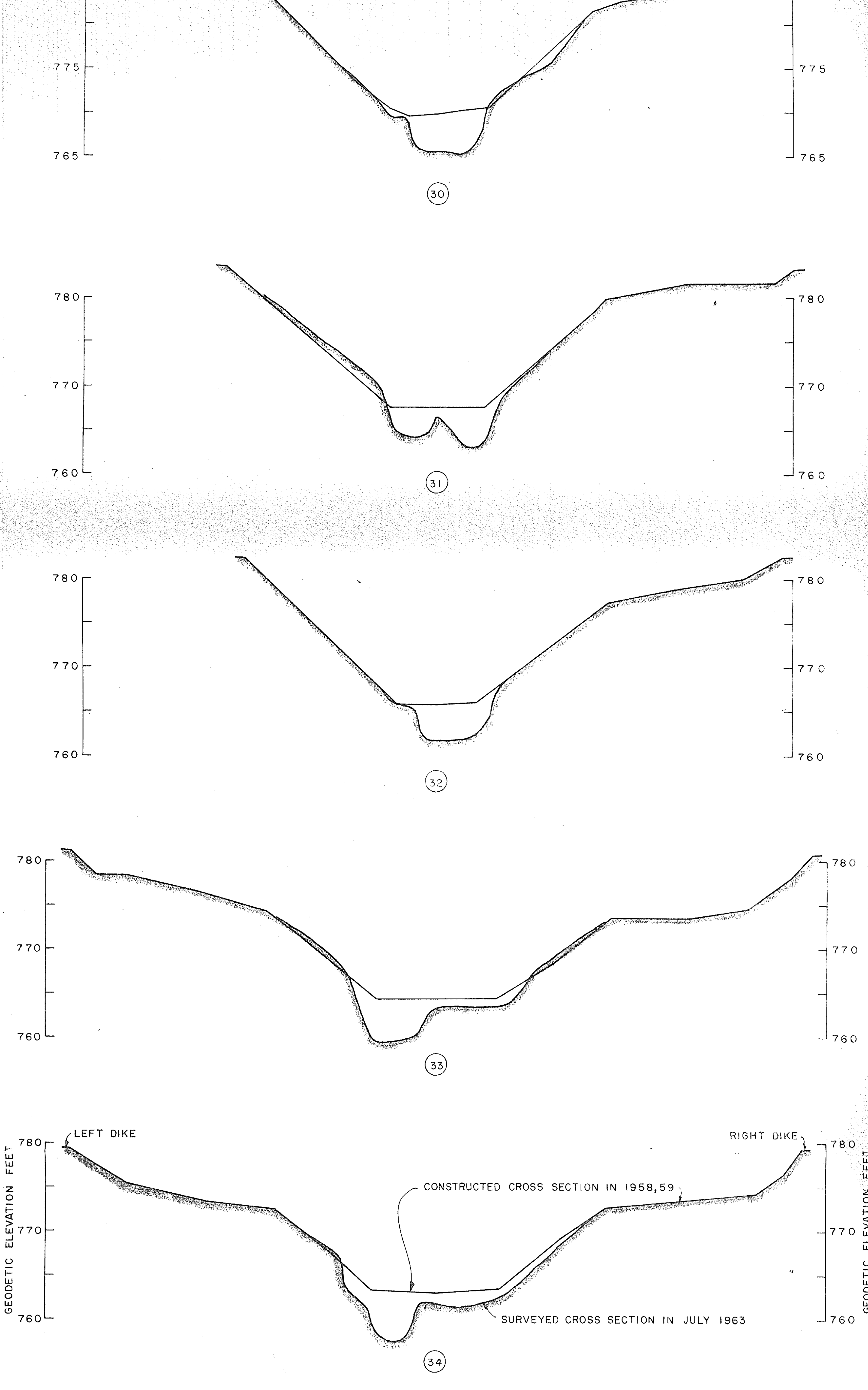


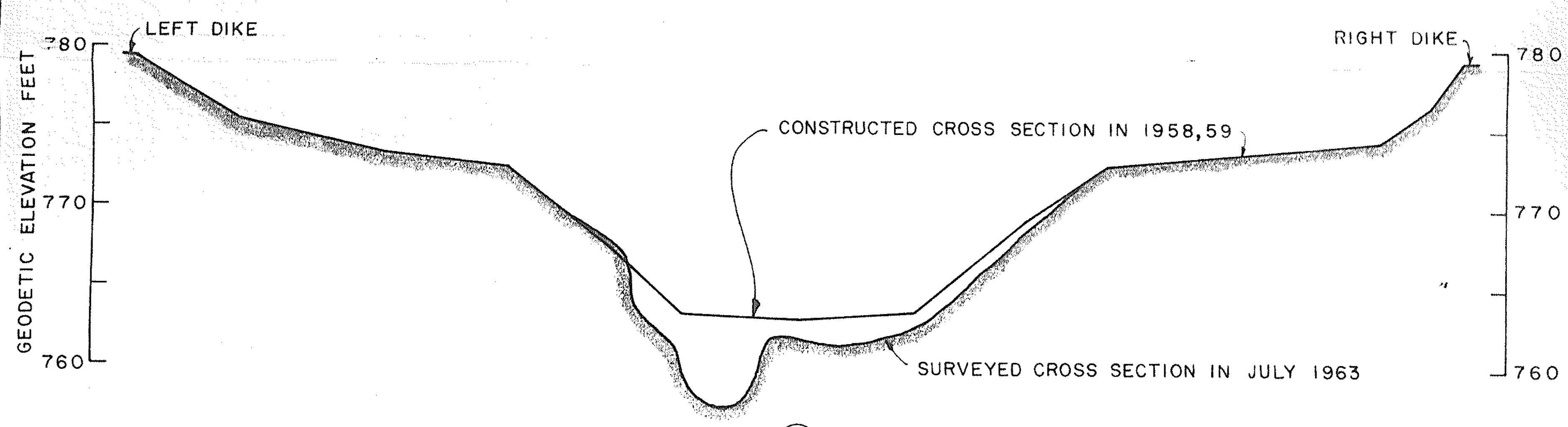
FIGURE 3.2C


795
785
775
26
790
780
770
27
790
780
770
28
785
775
765
29
785
775



SEINE RIVER DIVERSION

CROSS SECTIONS



SEINE RIVER DIVERSION

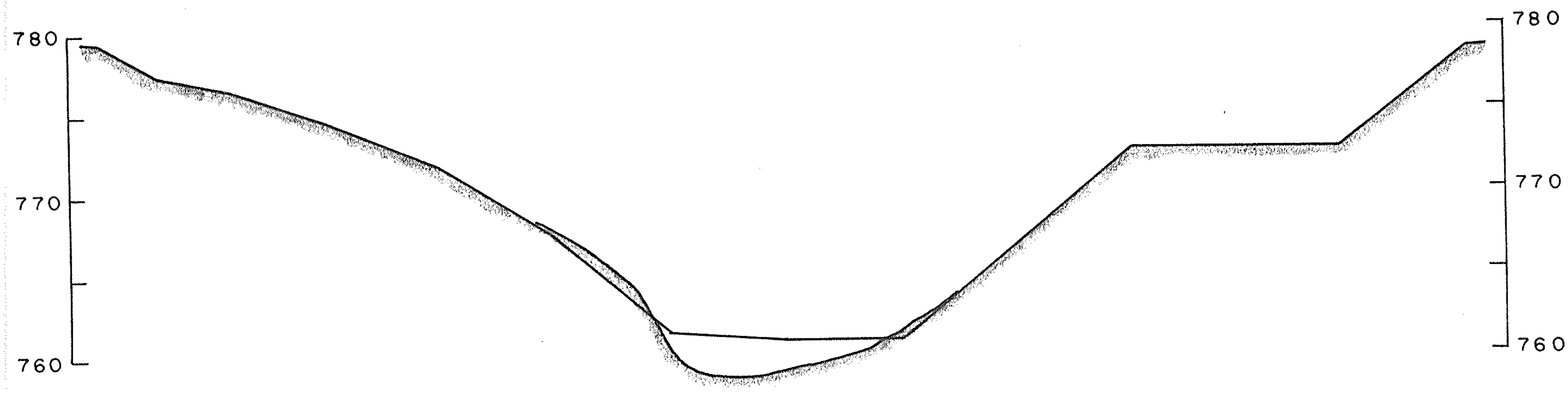
CROSS SECTIONS
IN
REACH NO.4

FOR KEY SEE CROSS SECTION NO. 34

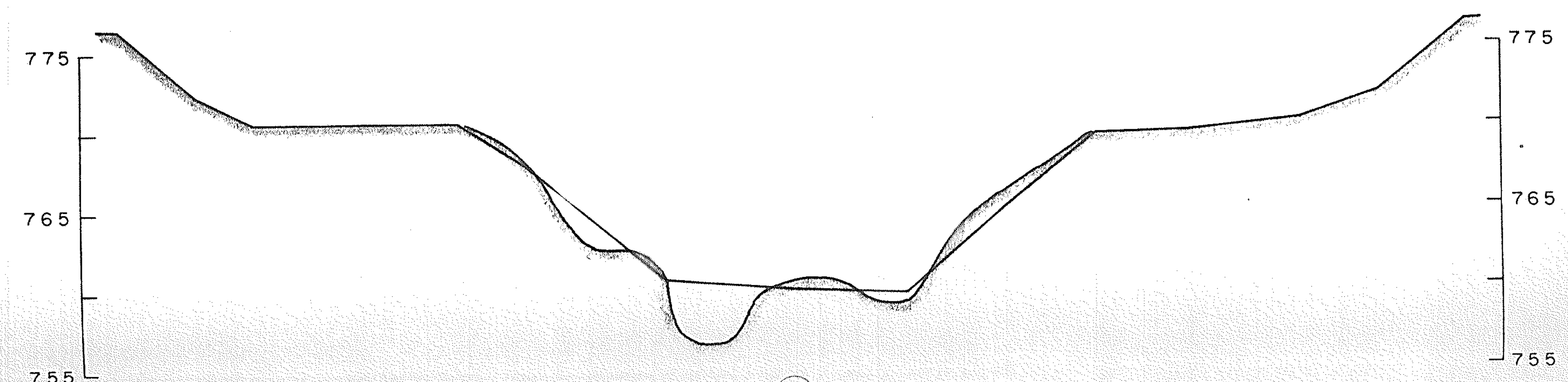
0 50 100 FEET

HORIZONTAL SCALE

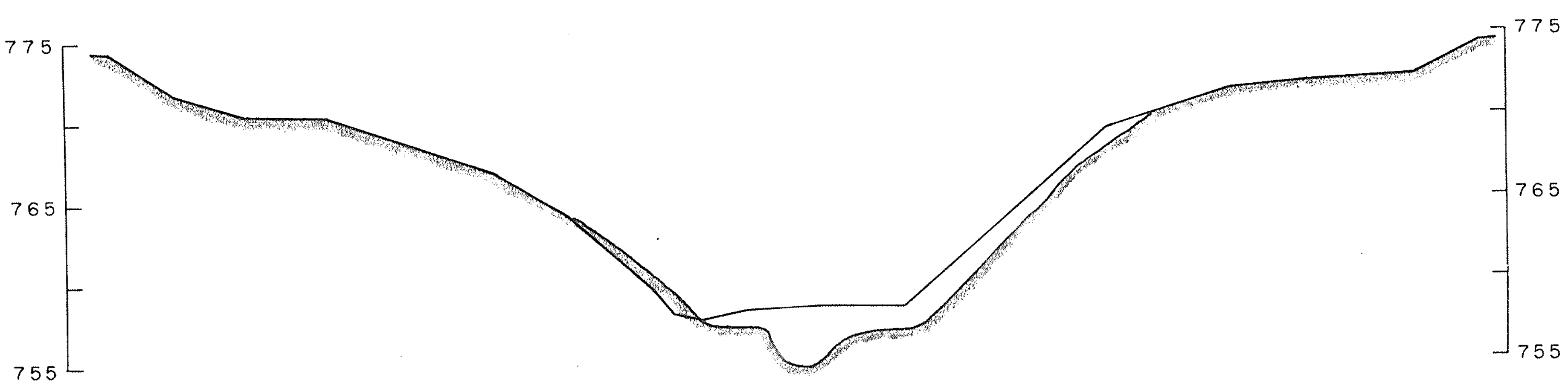
FIGURE 3.2D


780
770
760
780
770
760

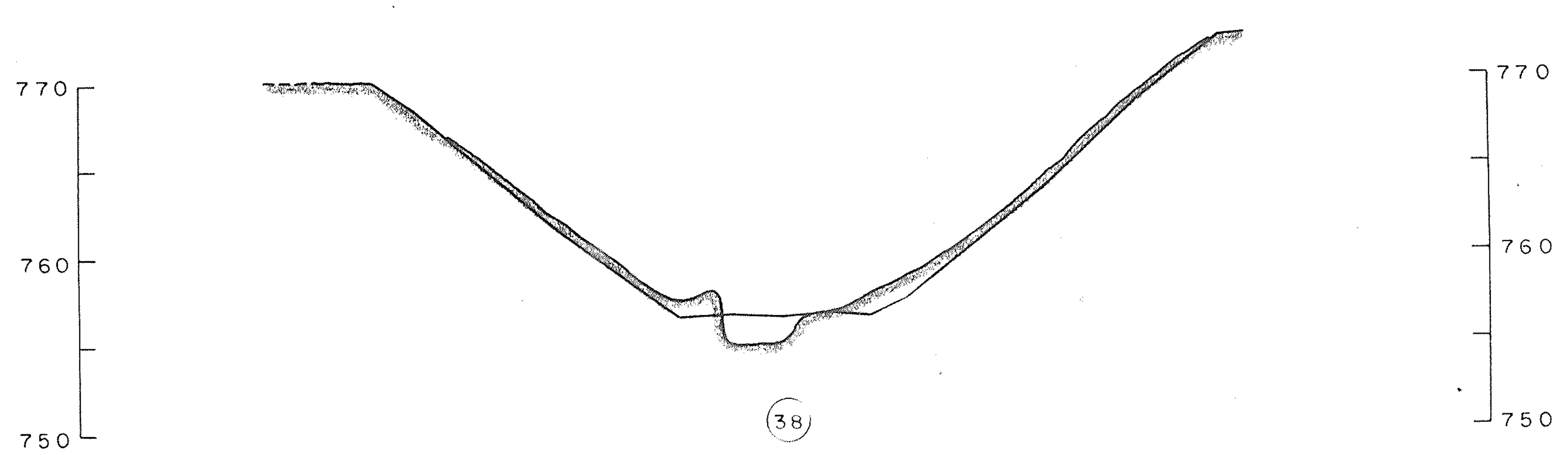
35


775
765
755
775
765
755

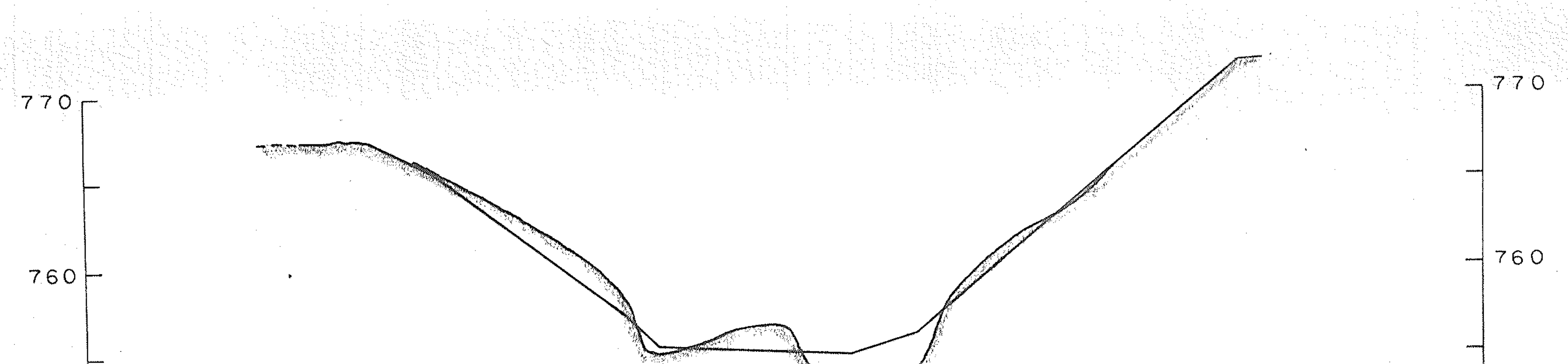
36

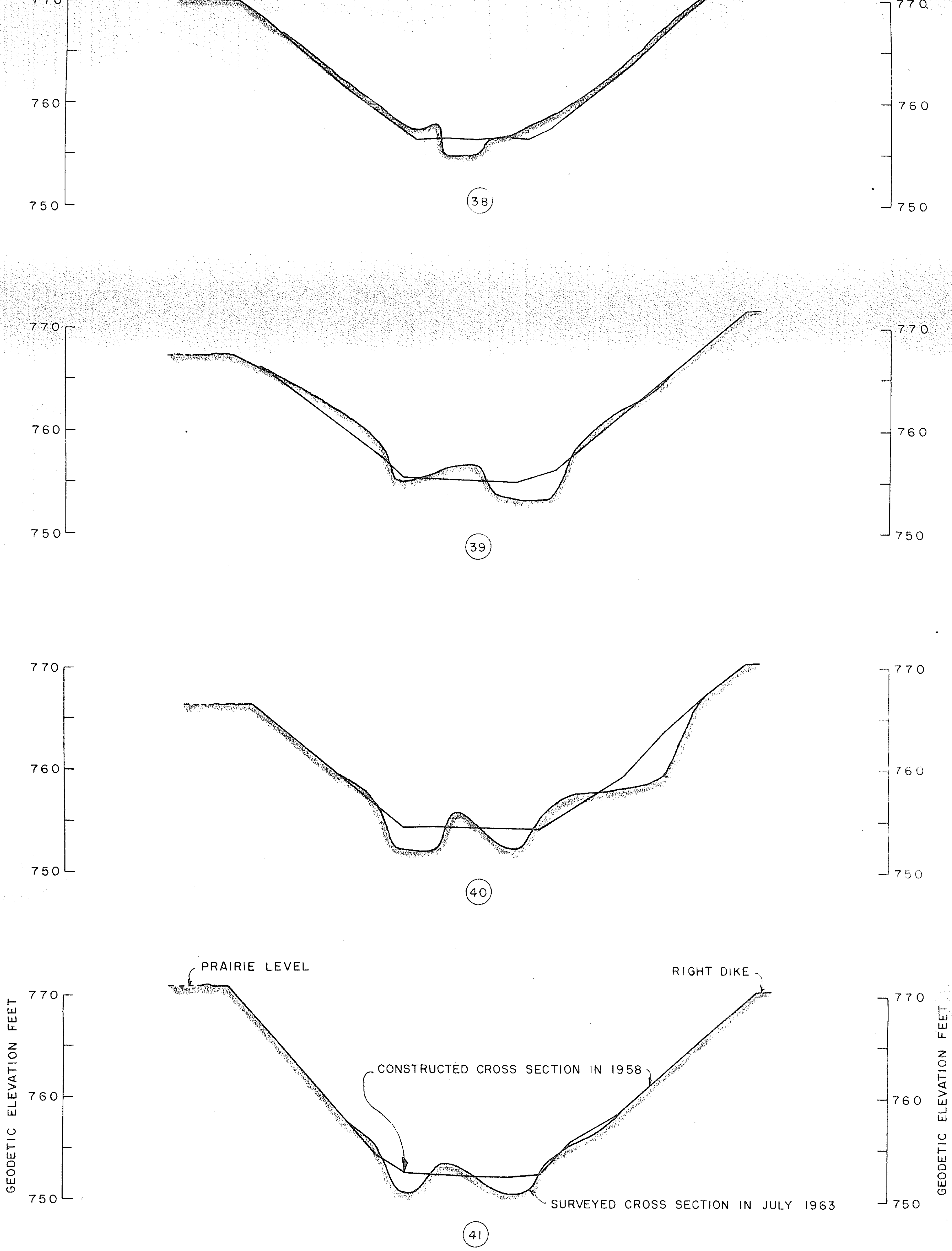

775
765
755
775
765
755

37


770
760
750
770
760
750

38


770
760
770
760



SEINE RIVER DIVERSION

CROSS SECTIONS
IN
REACH NO.5

FOR KEY SEE CROSS SECTION NO. 41

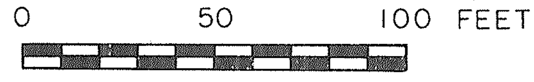
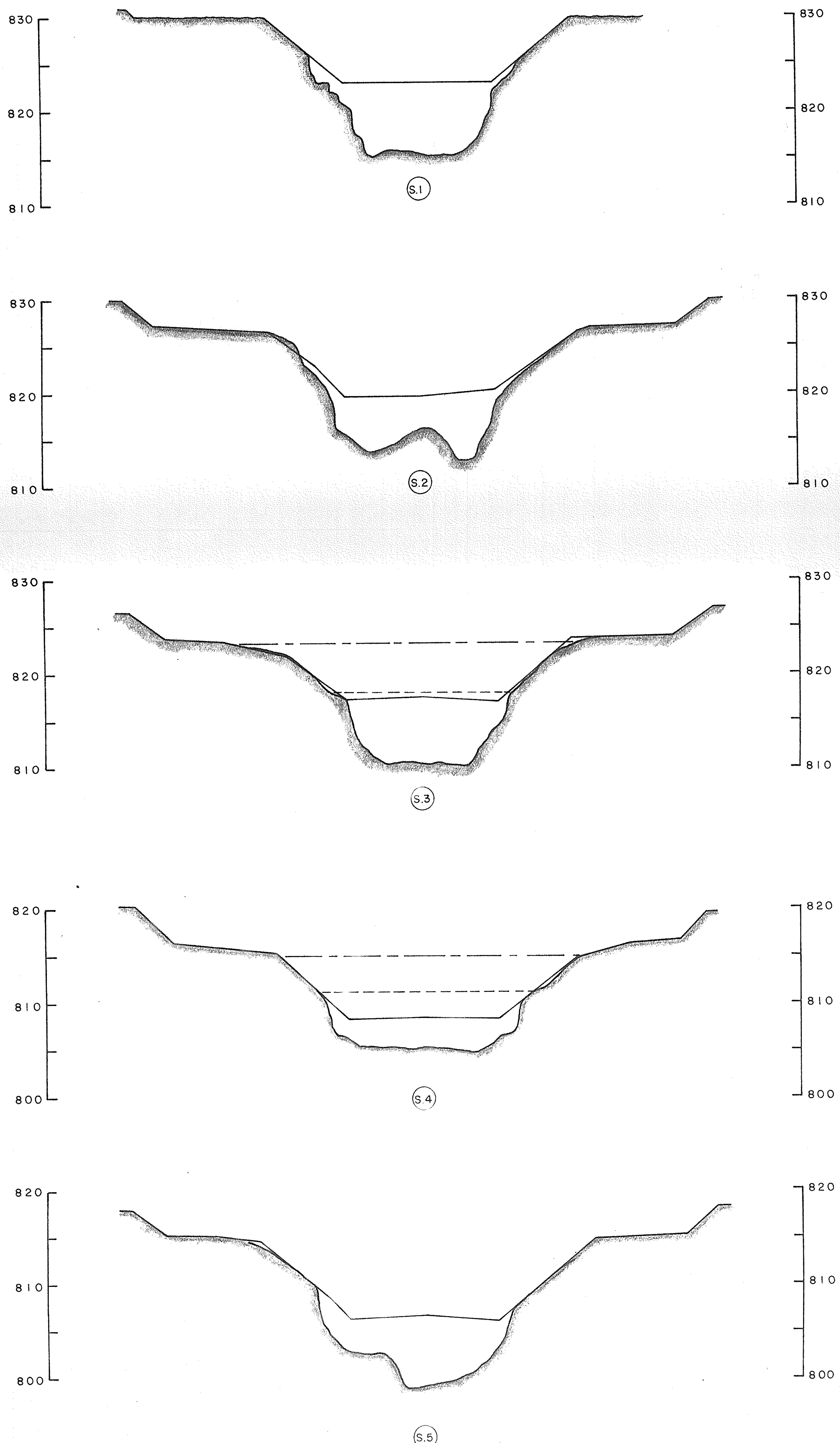


FIGURE 3.2E



830
820
810
830
820
810
S.1
830
820
810
830
820
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S.2
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S.3
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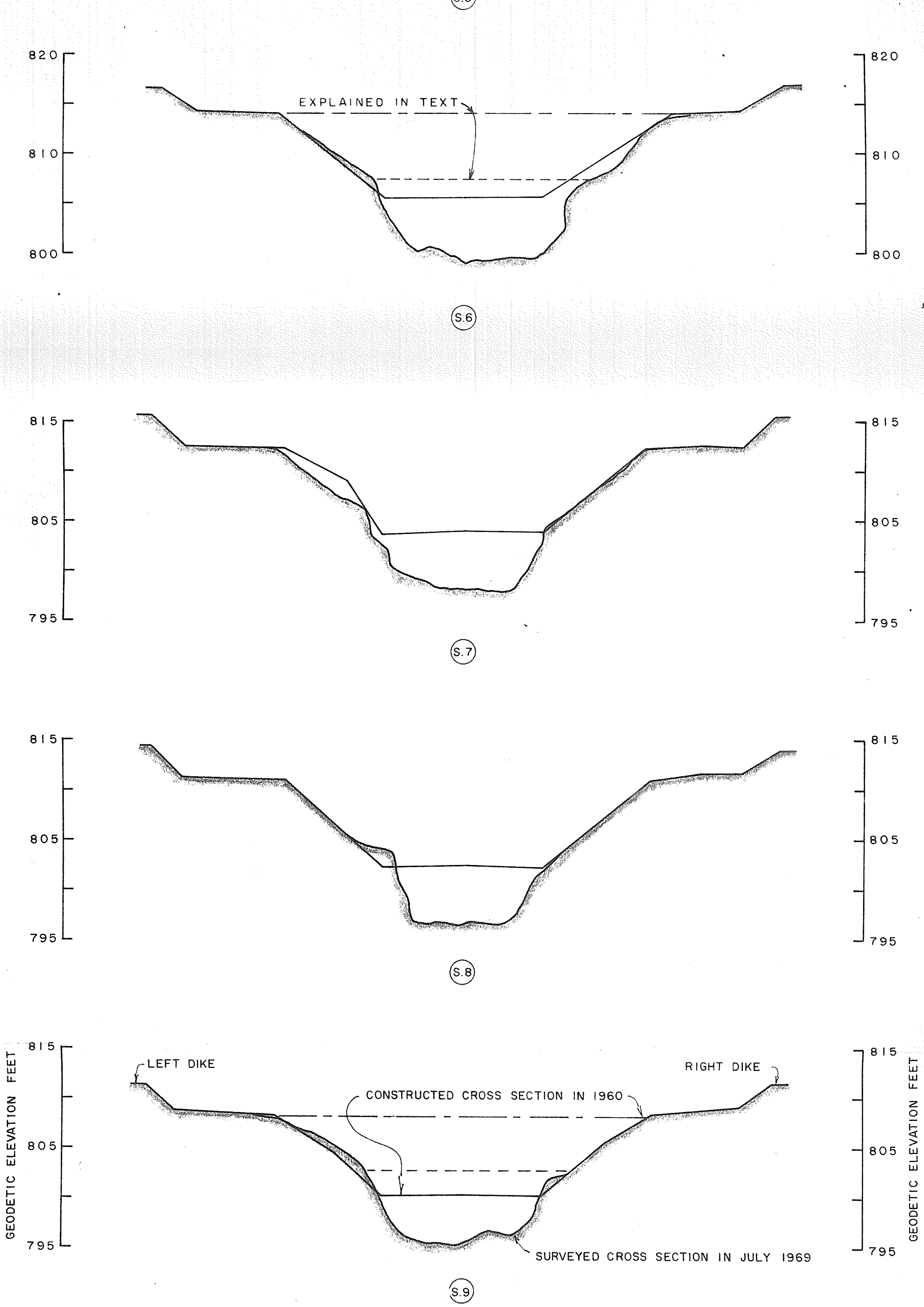
S.4
820
810
800
820
810
800
S.5



SEINE RIVER DIVERSION

CROSS SECTIONS
IN
REACH NO:1
FOR KEY SEE CROSS SECTION NO. S.9

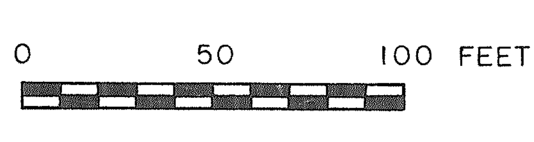
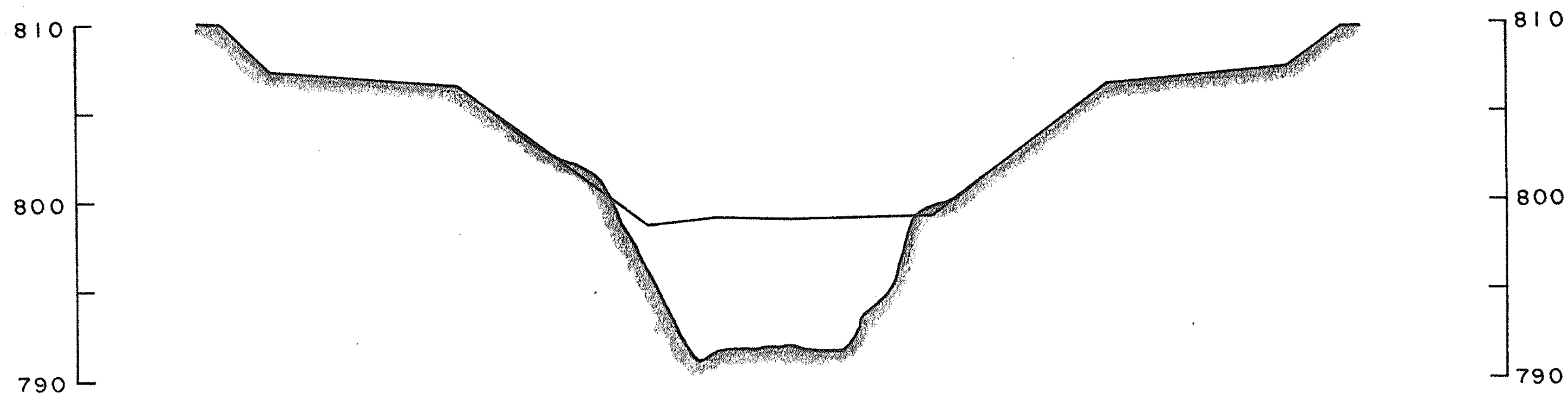
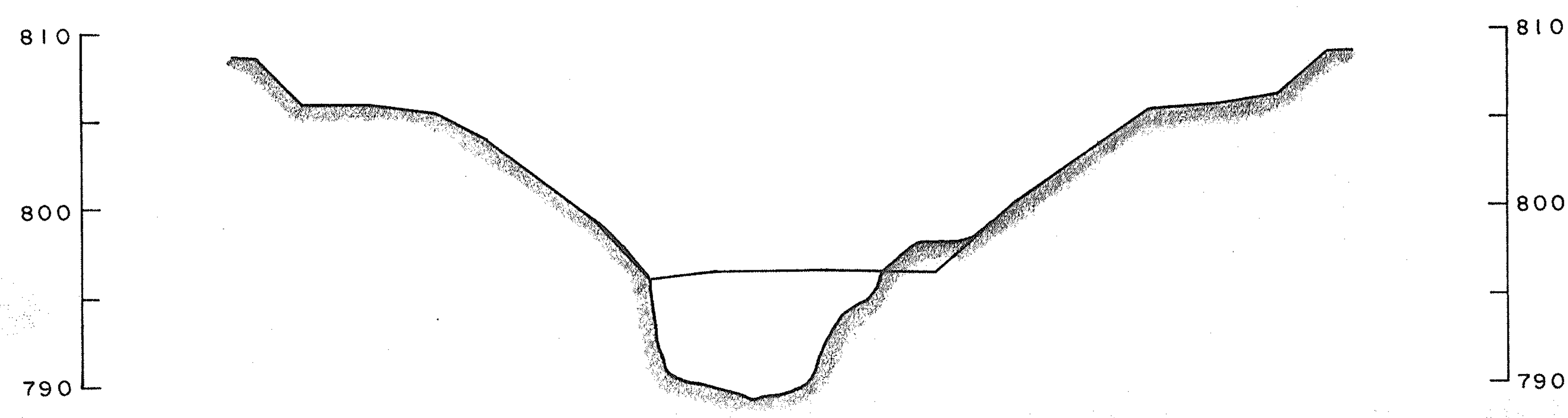


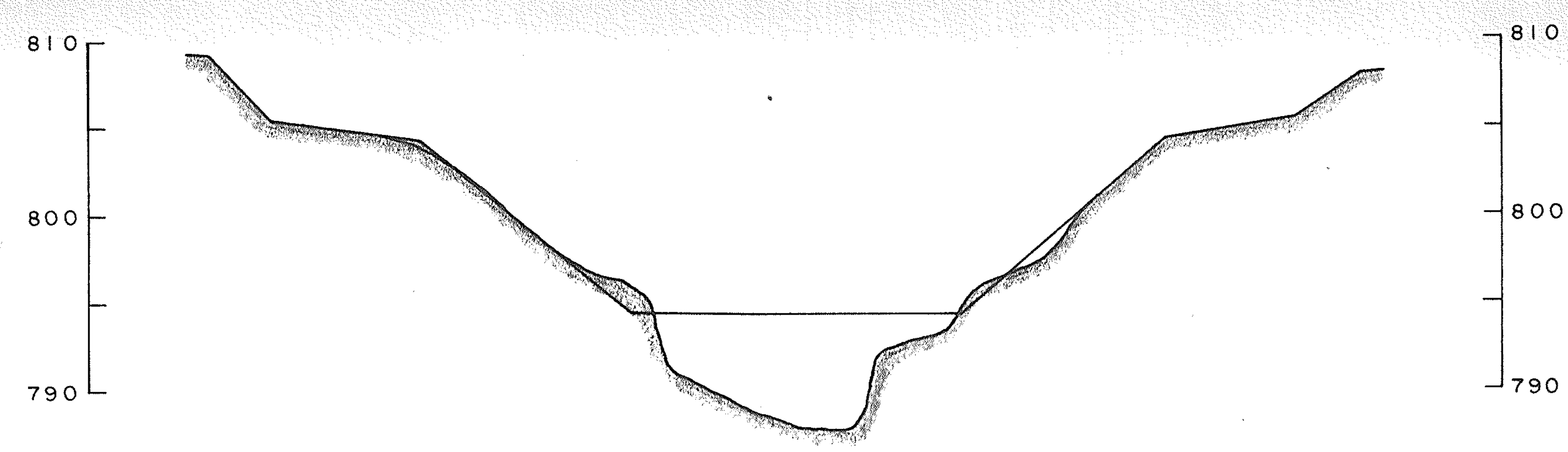
FIGURE 3.2F



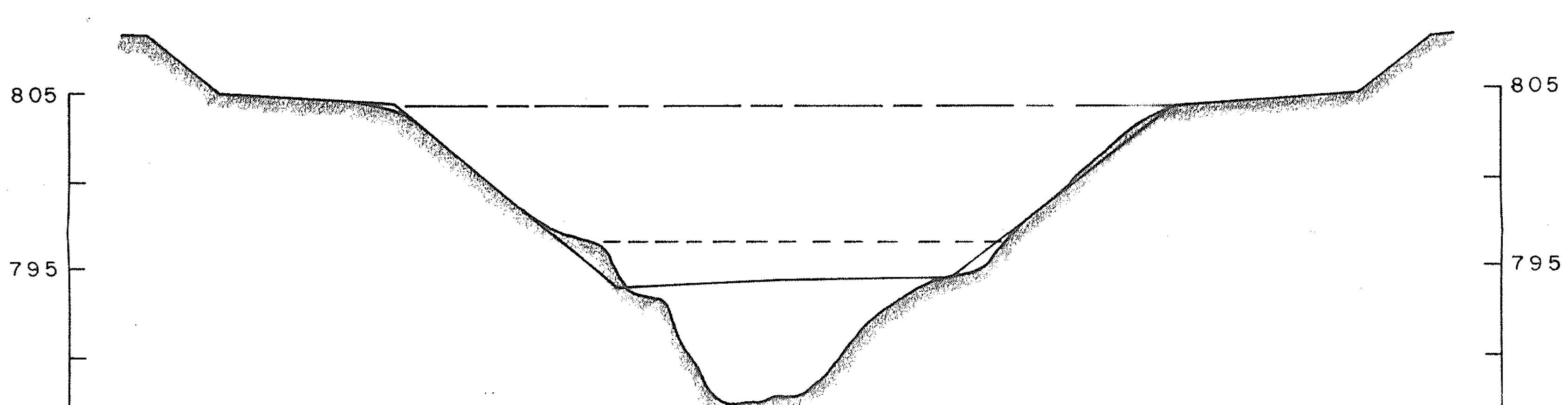
S.10



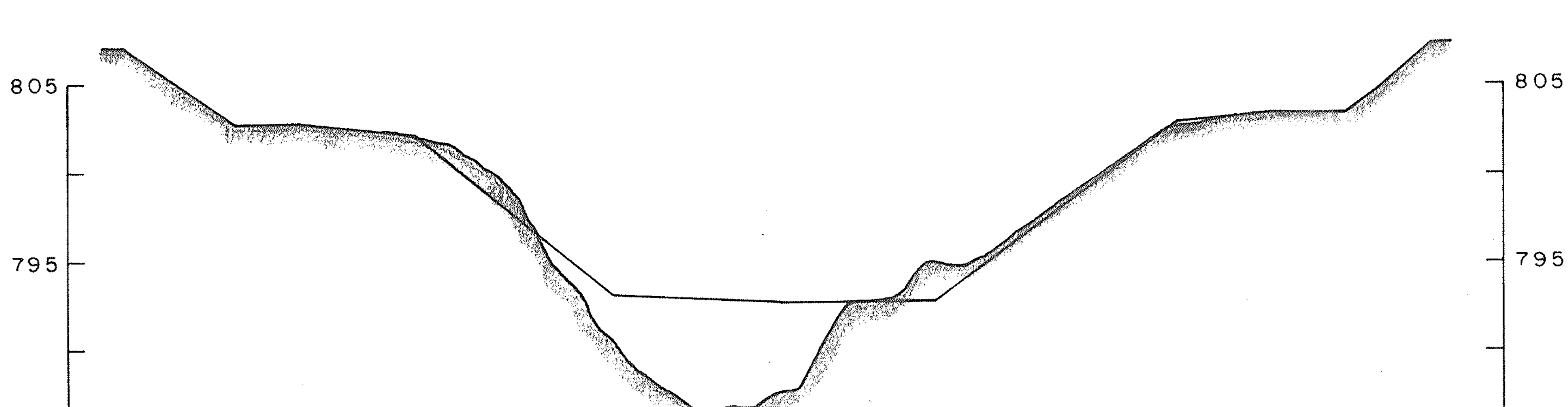
S.11

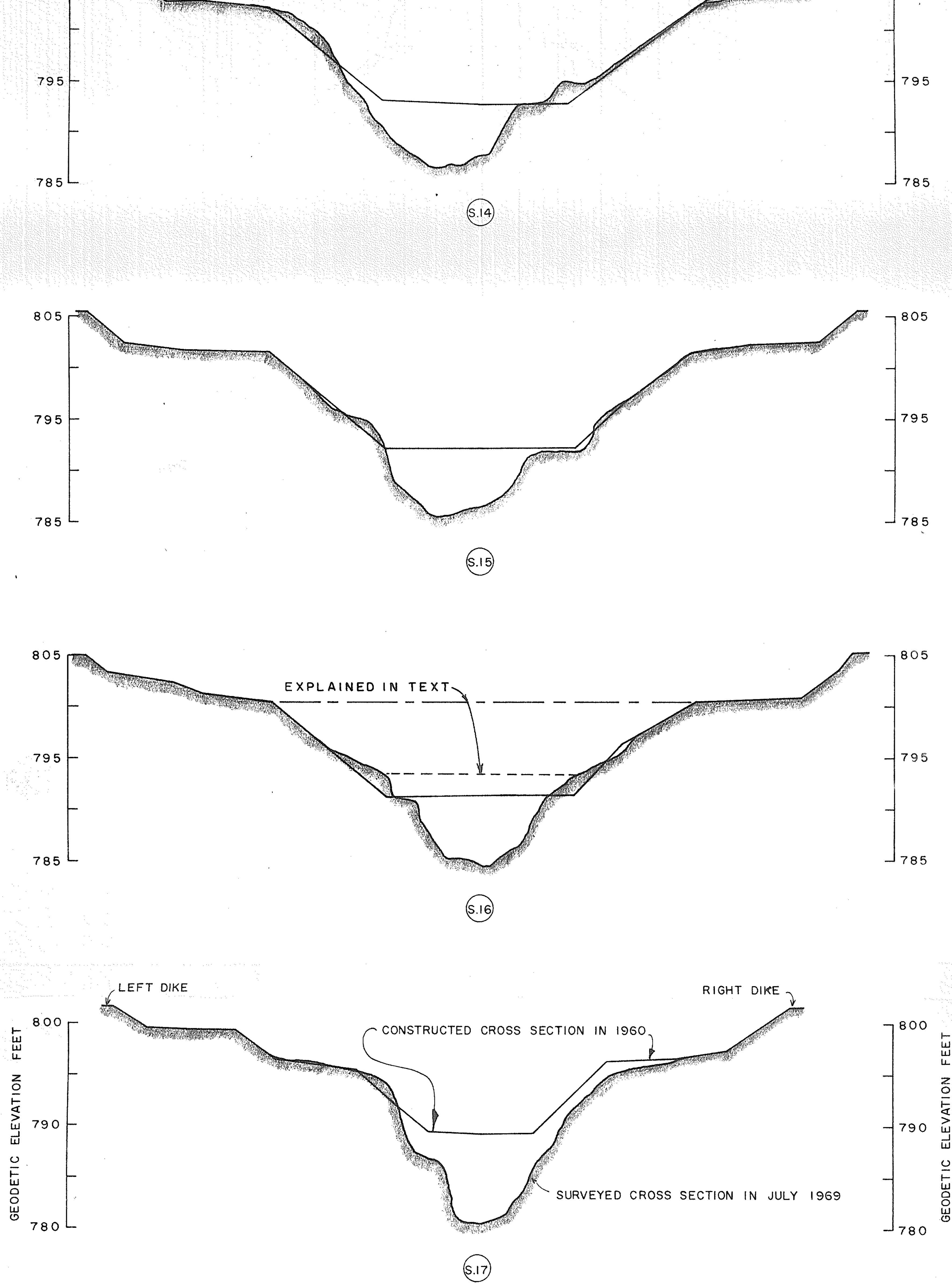


S.12



S.13





SEINE RIVER DIVERSION

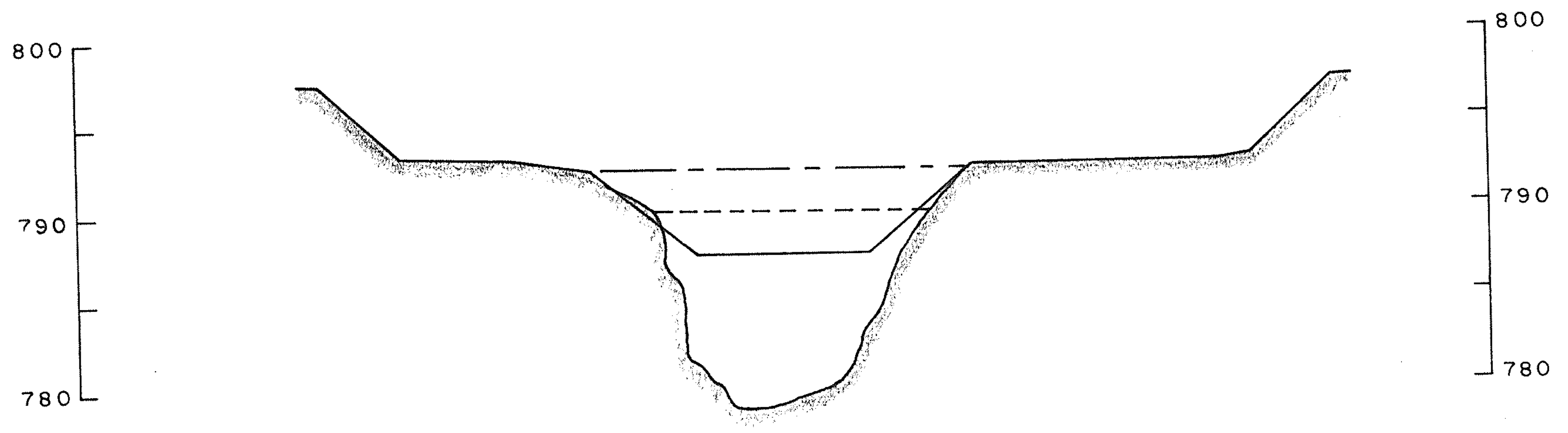
CROSS SECTIONS
IN
REACH NO. 2

FOR KEY SEE CROSS SECTION NO. S17

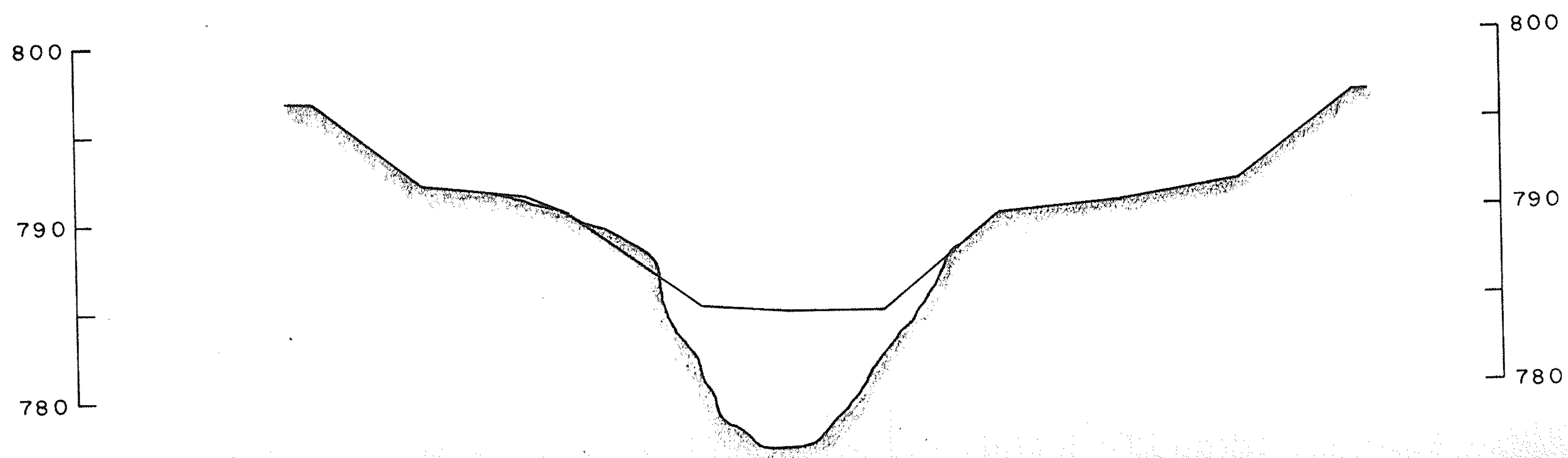
0 50 100 FEET

HORIZONTAL SCALE

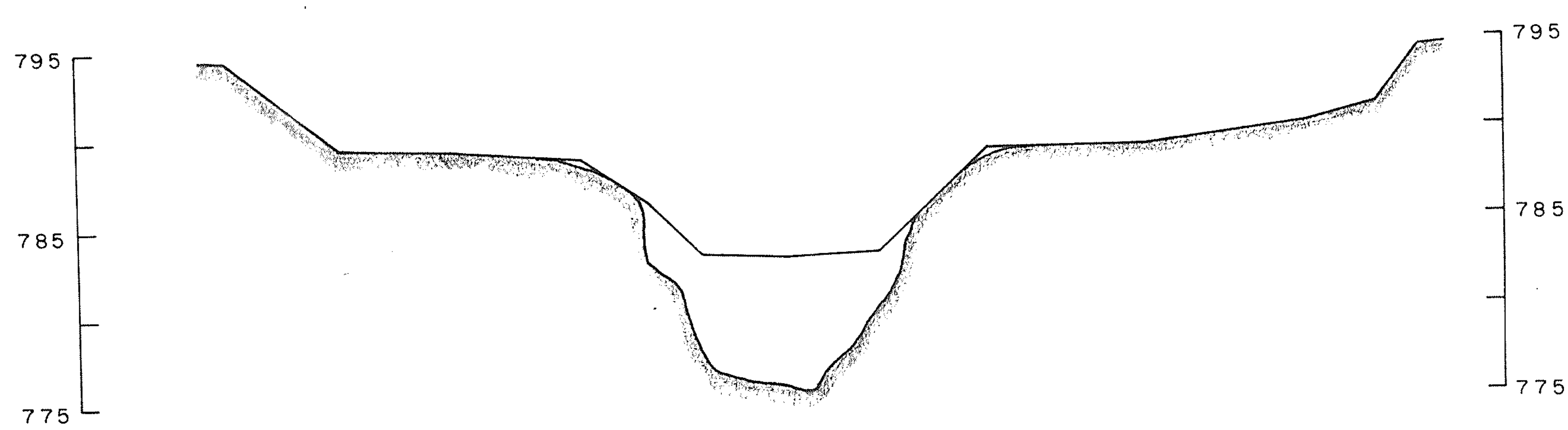
FIGURE 3.2G



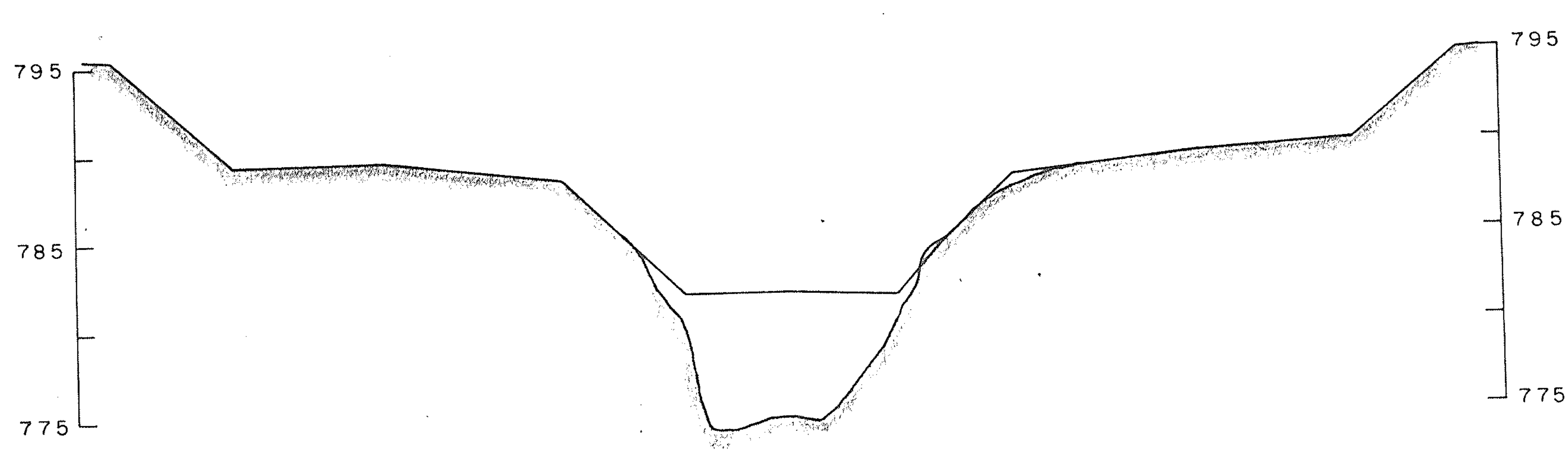
S.18



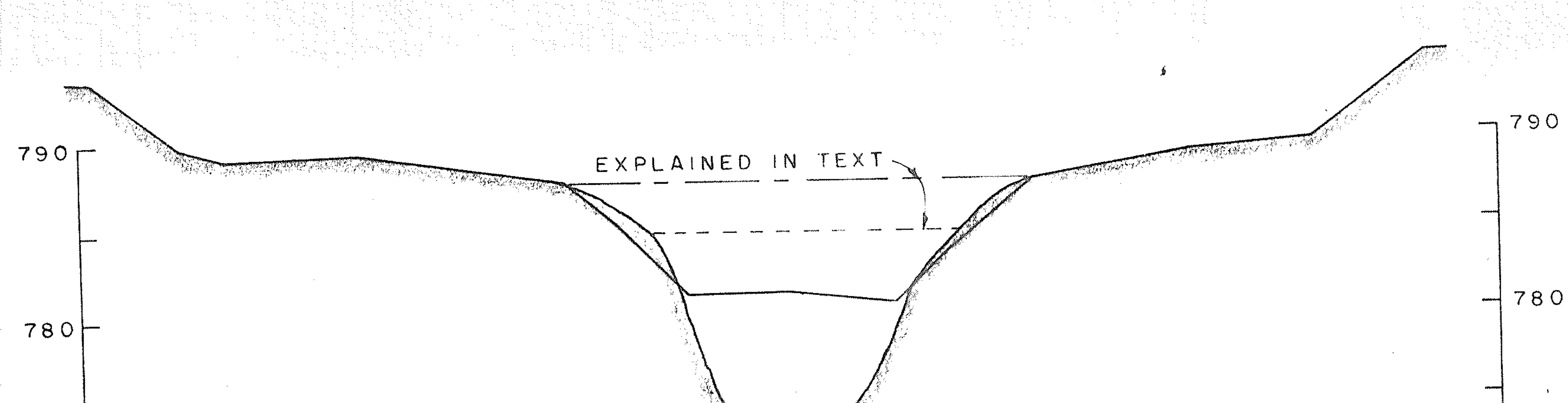
S.19

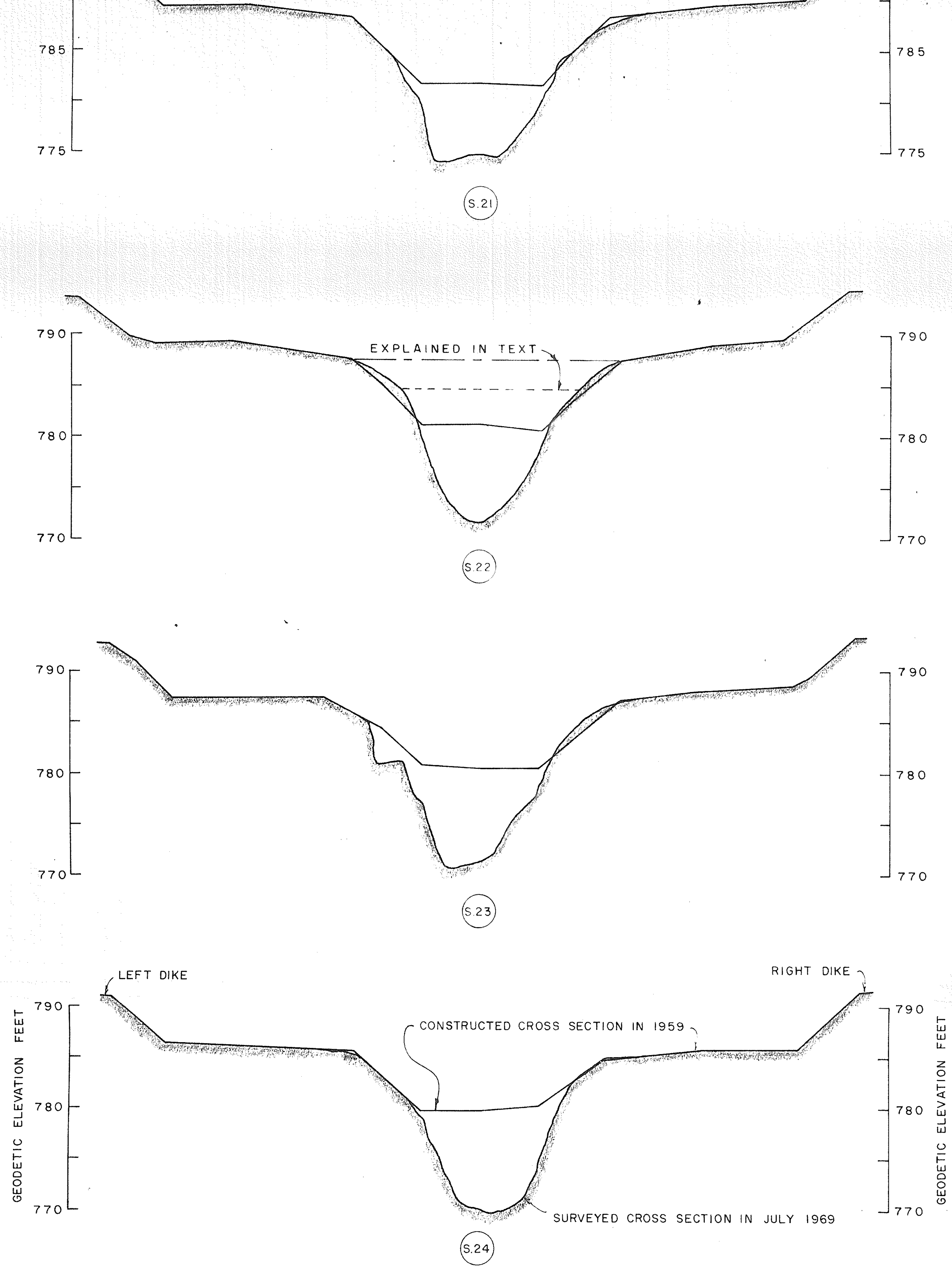


S.20



S.21





SEINE RIVER DIVERSION

CROSS SECTIONS
IN
REACH NO.3

FOR KEY SEE CROSS SECTION NO. S.24

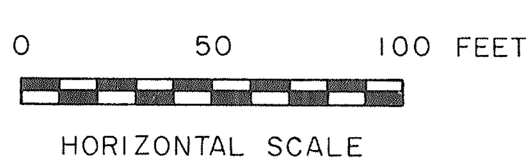
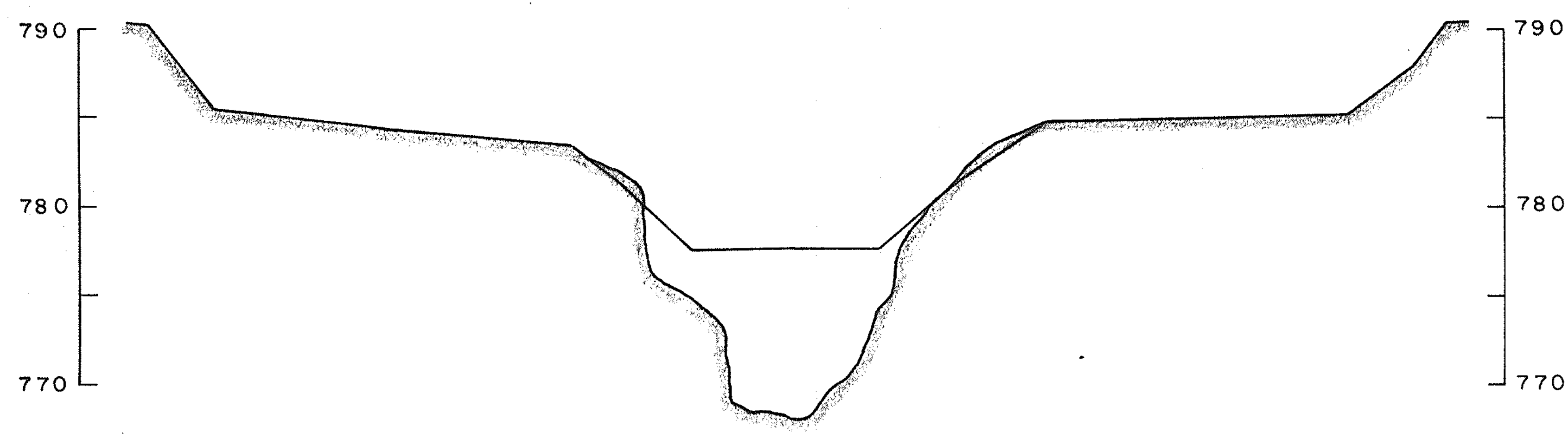
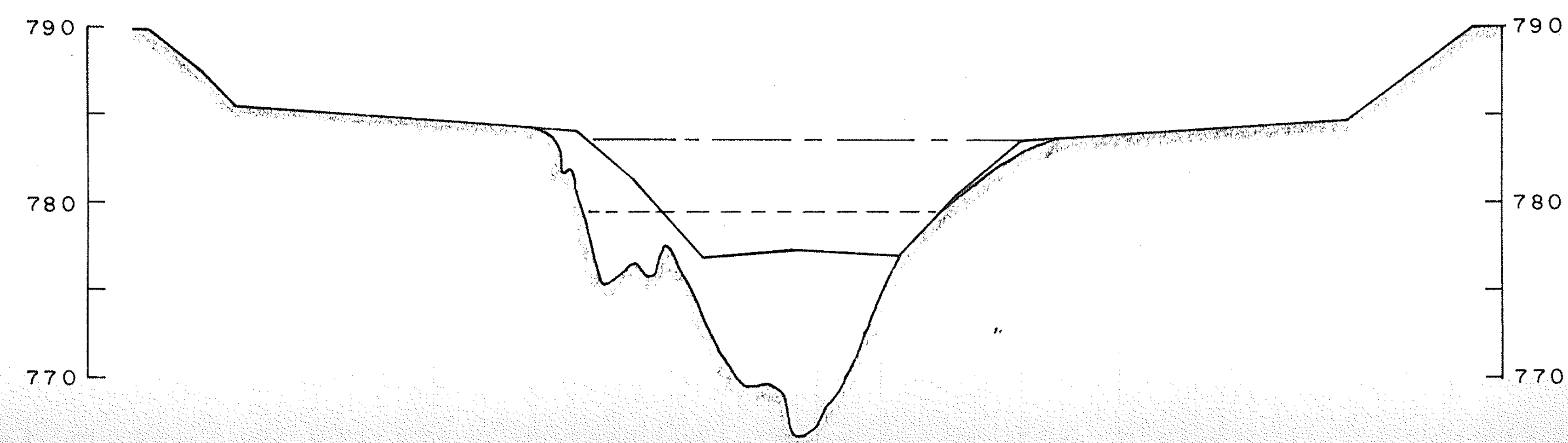


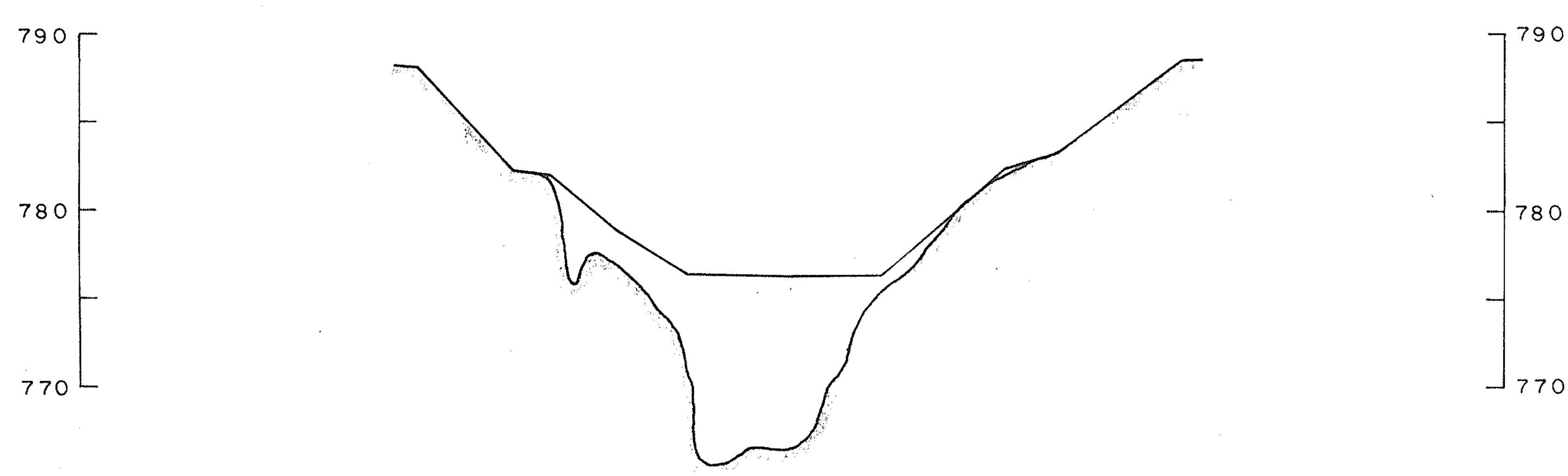
FIGURE 3.2H



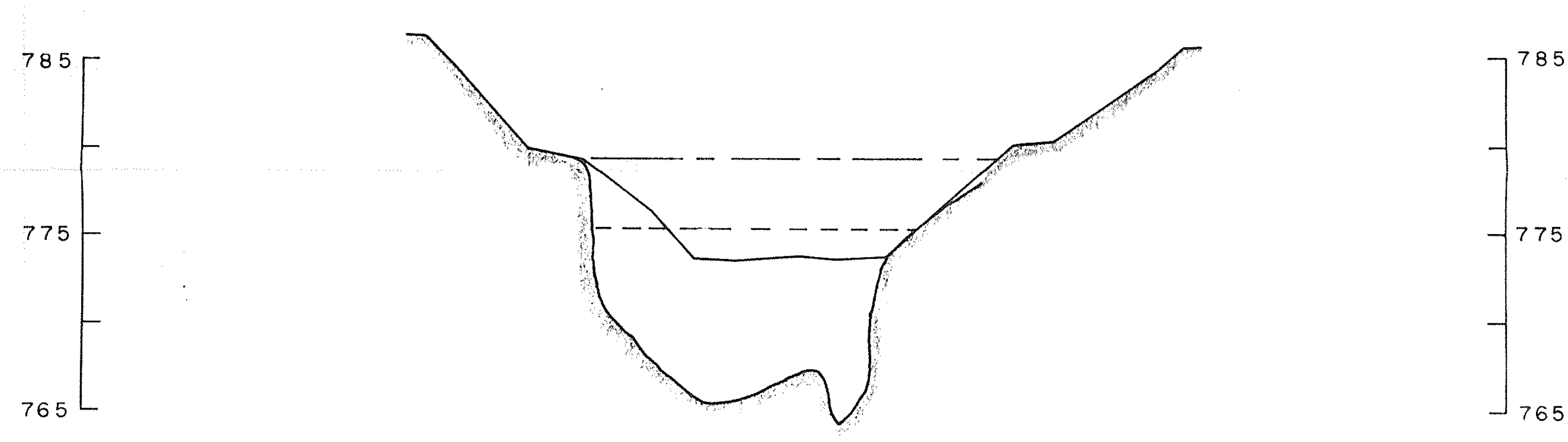
S.25



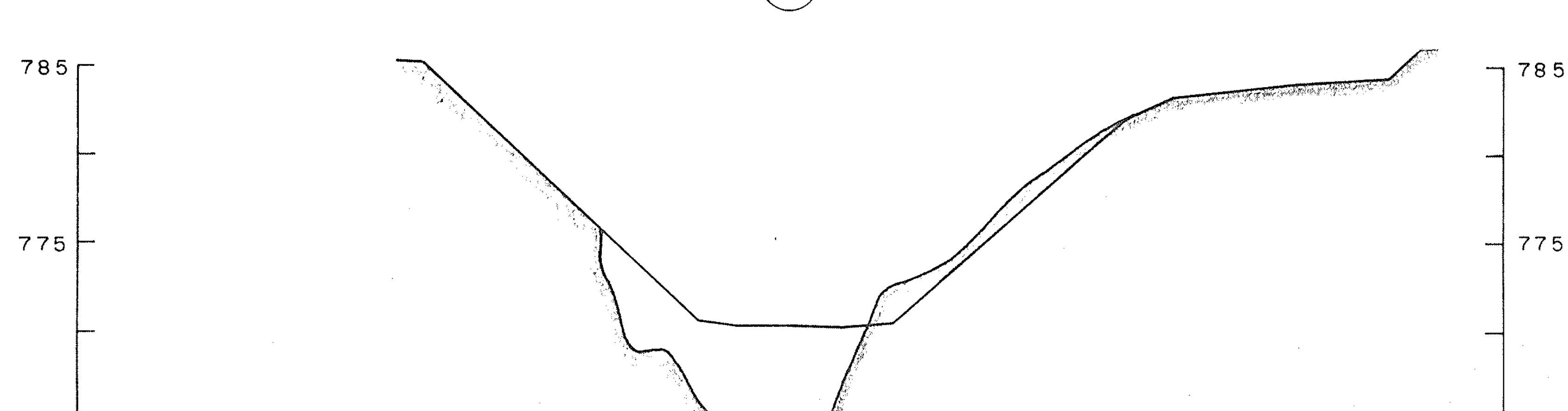
S.26



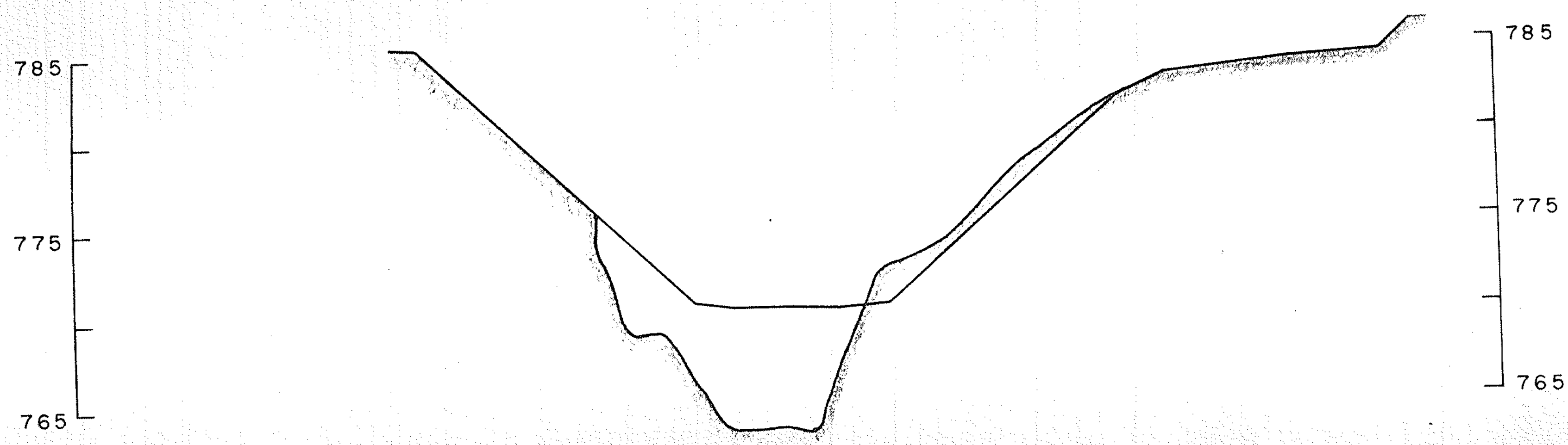
S.27



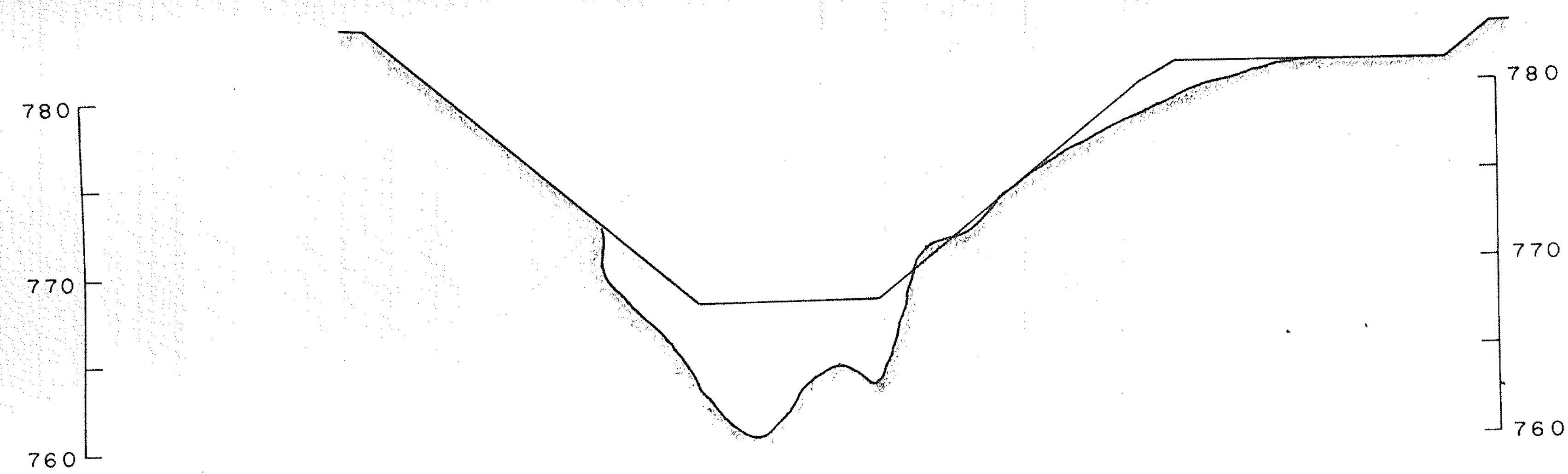
S.28



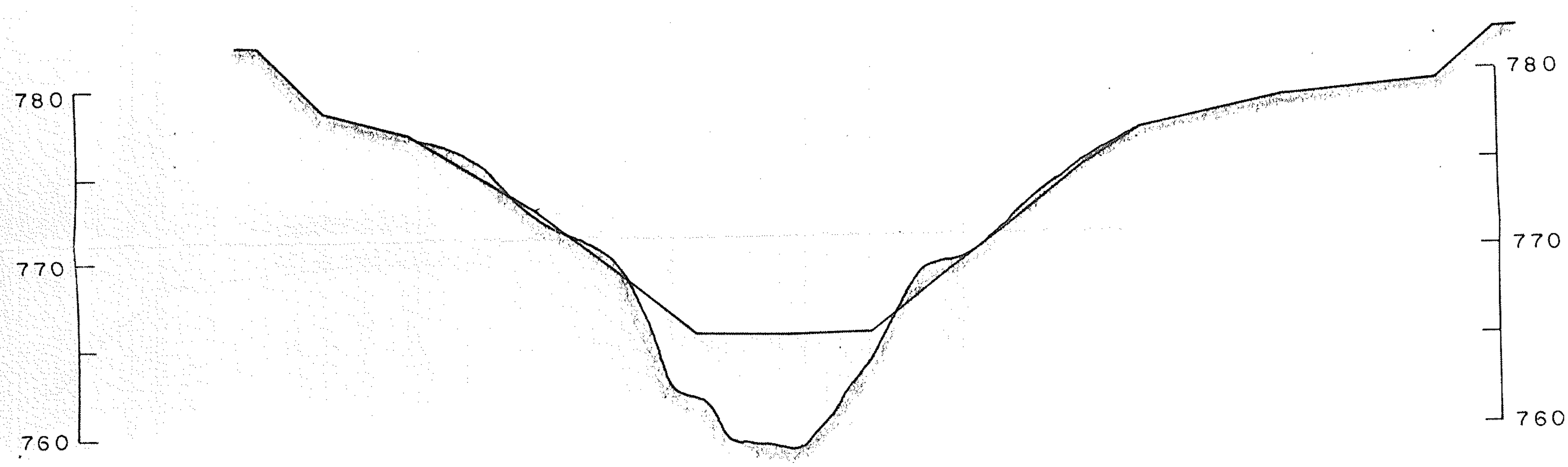
S.28



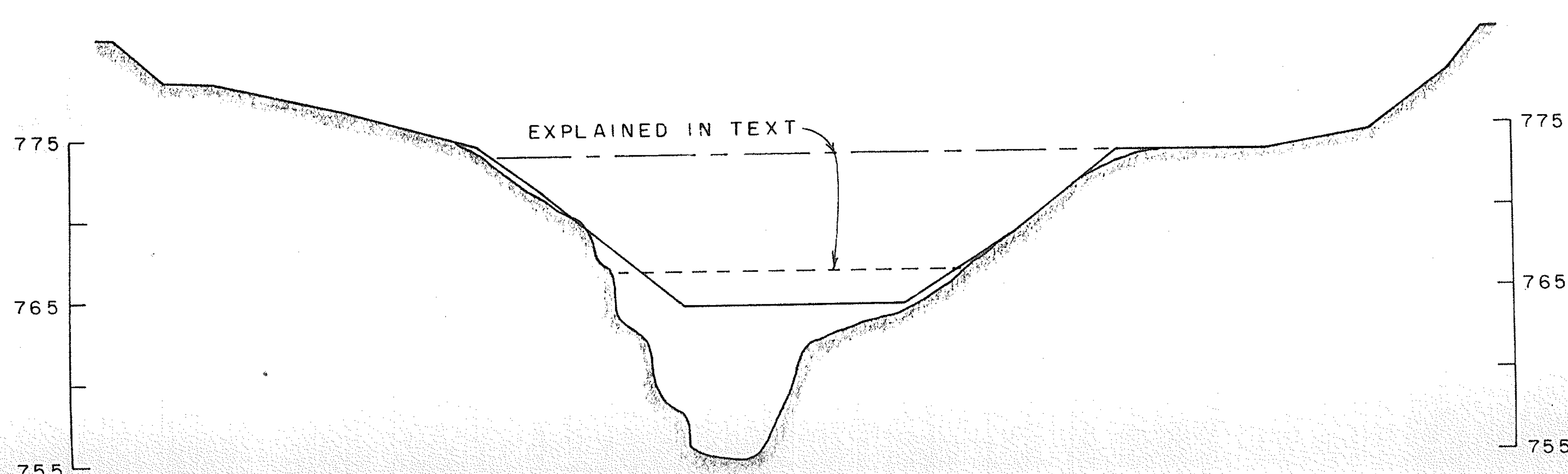
S.29



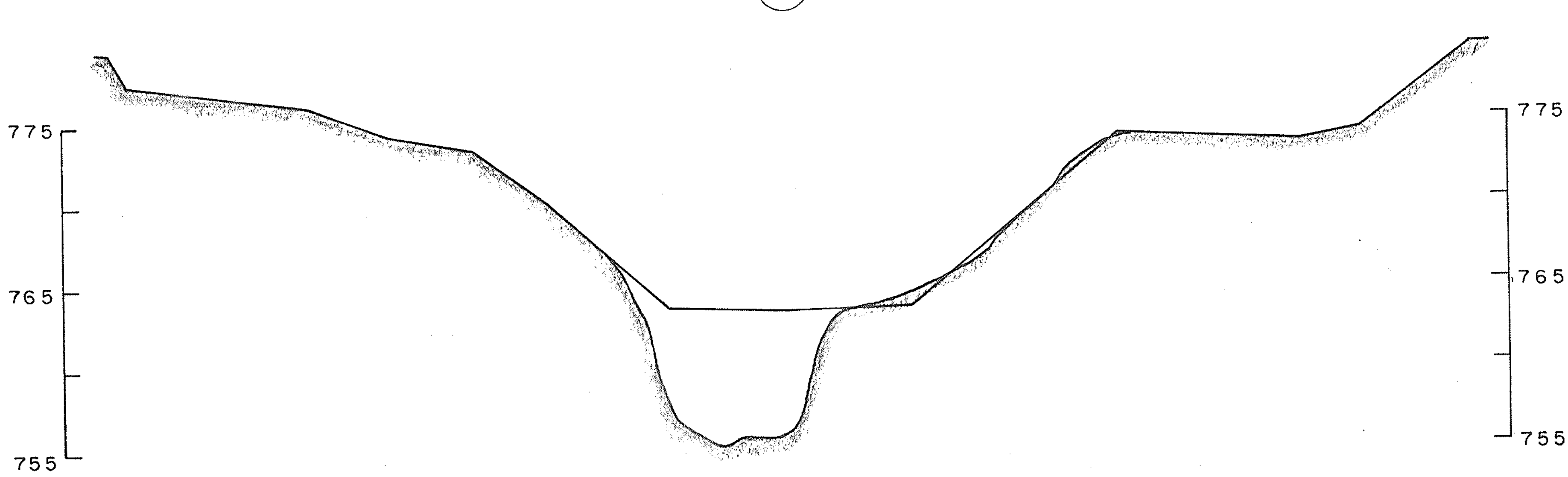
S.30



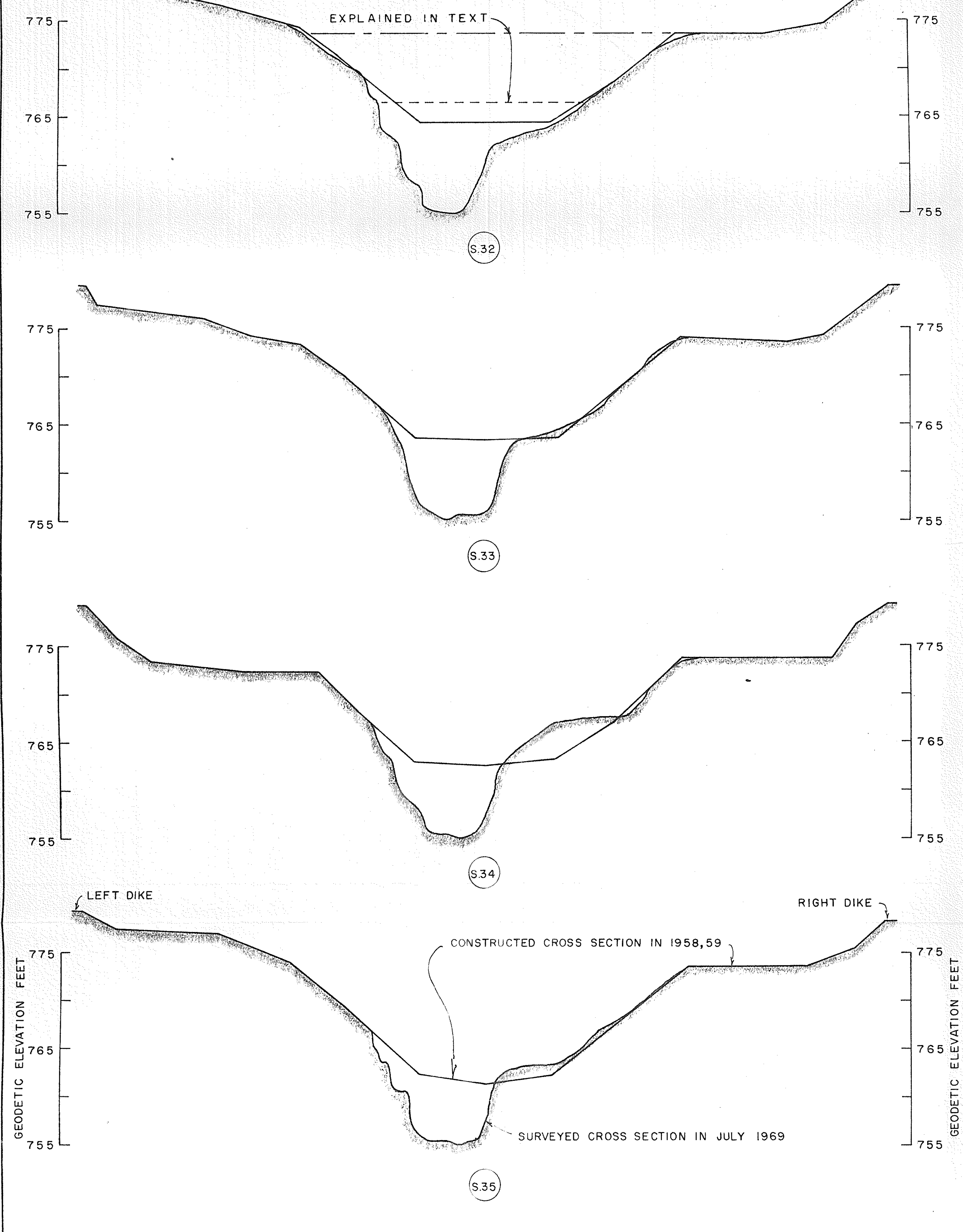
S.31



S.32



S.33



SEINE RIVER DIVERSION

CROSS SECTIONS
IN
REACH NO.4

FOR KEY SEE CROSS SECTION NO. S35

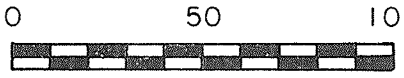
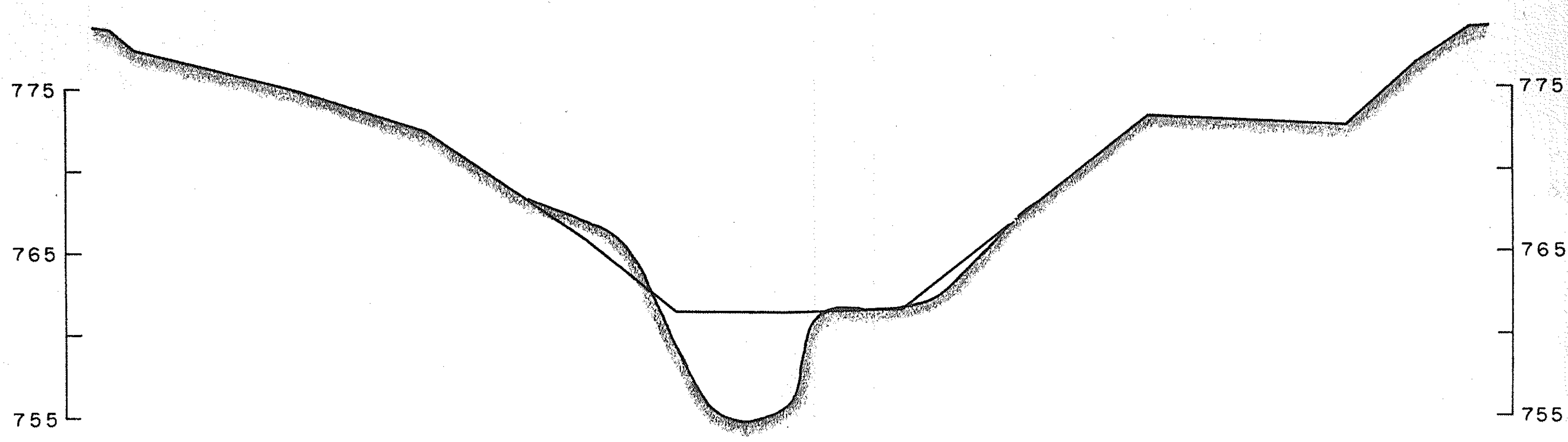
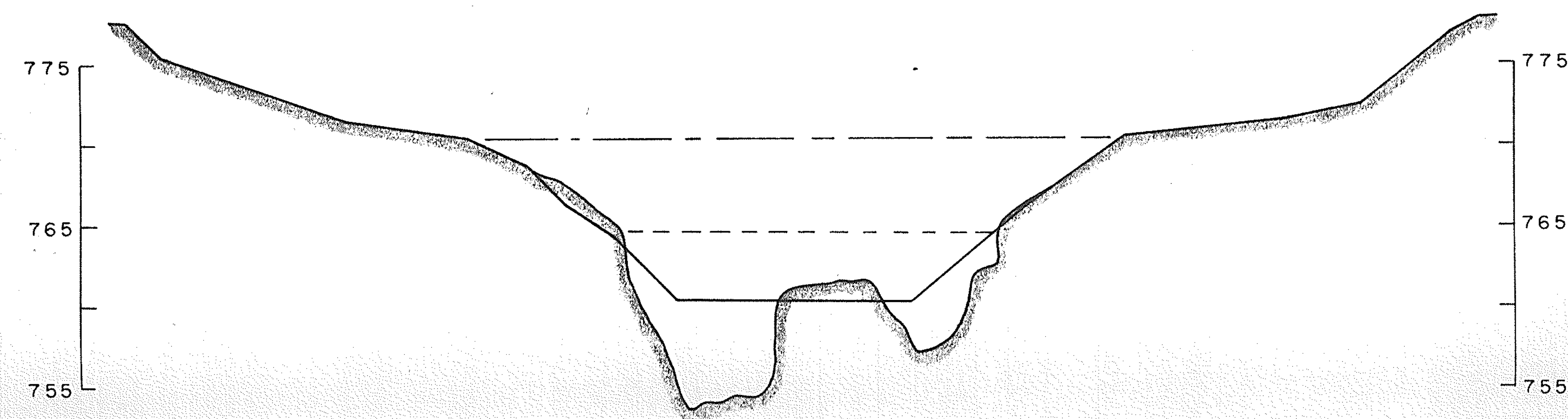


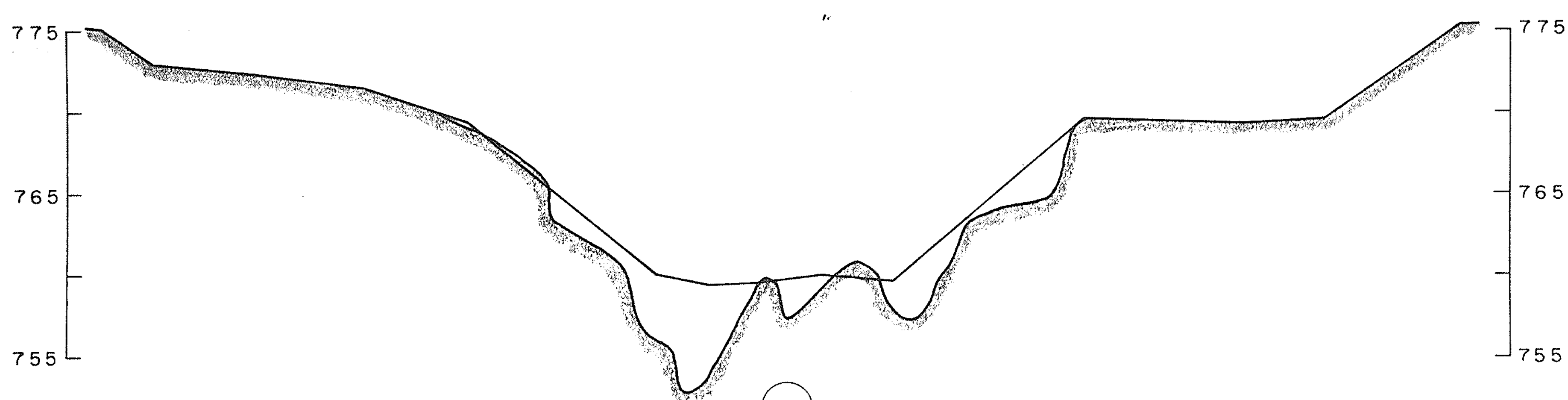
FIGURE 3.21



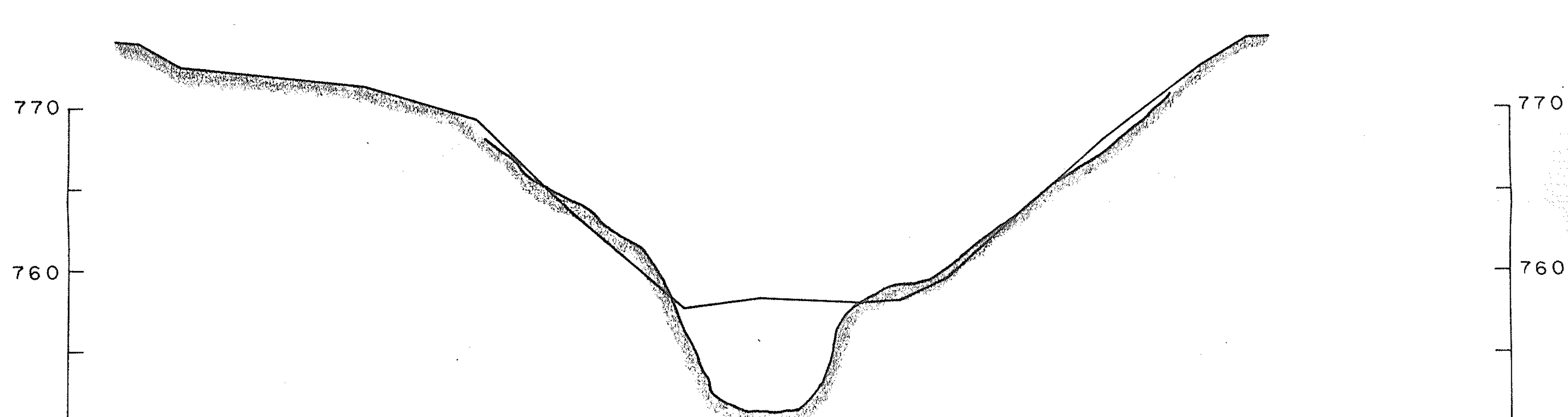
S.36



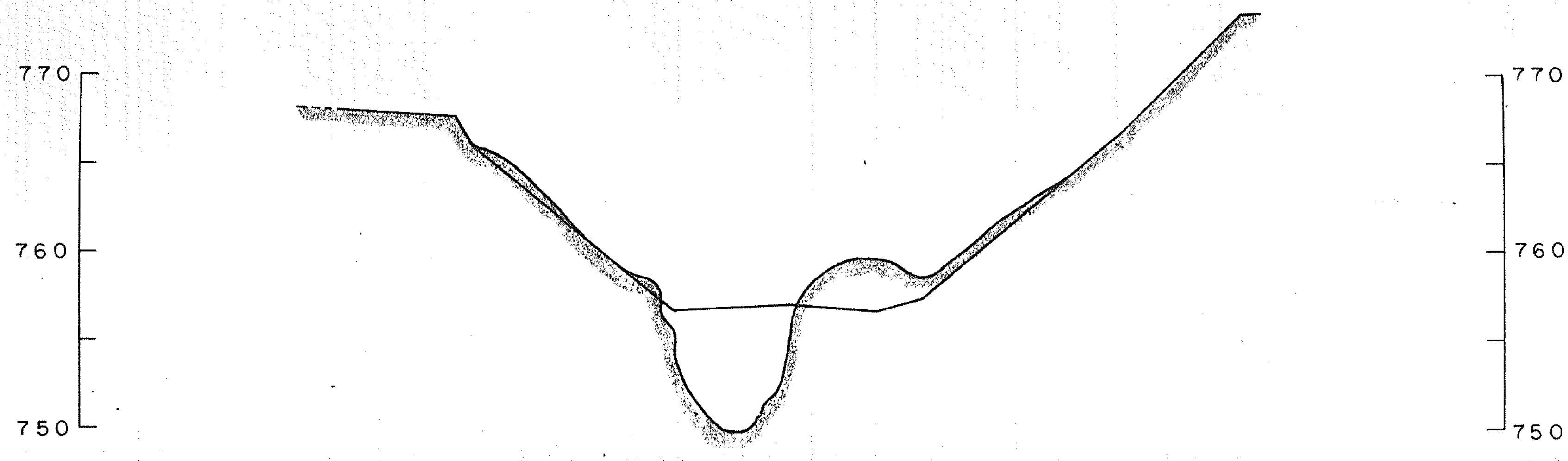
S.37



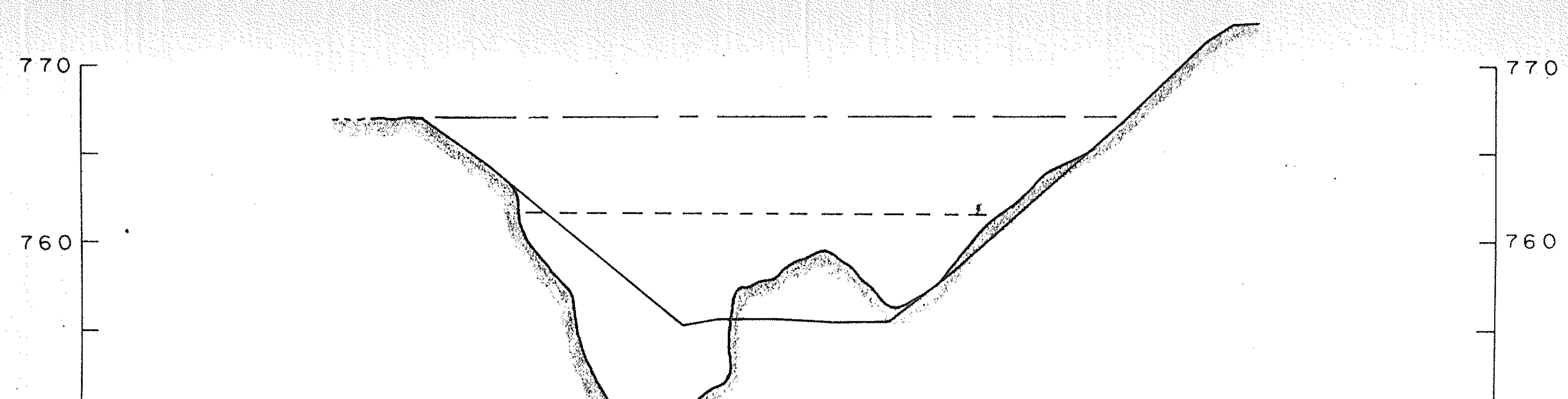
S.38



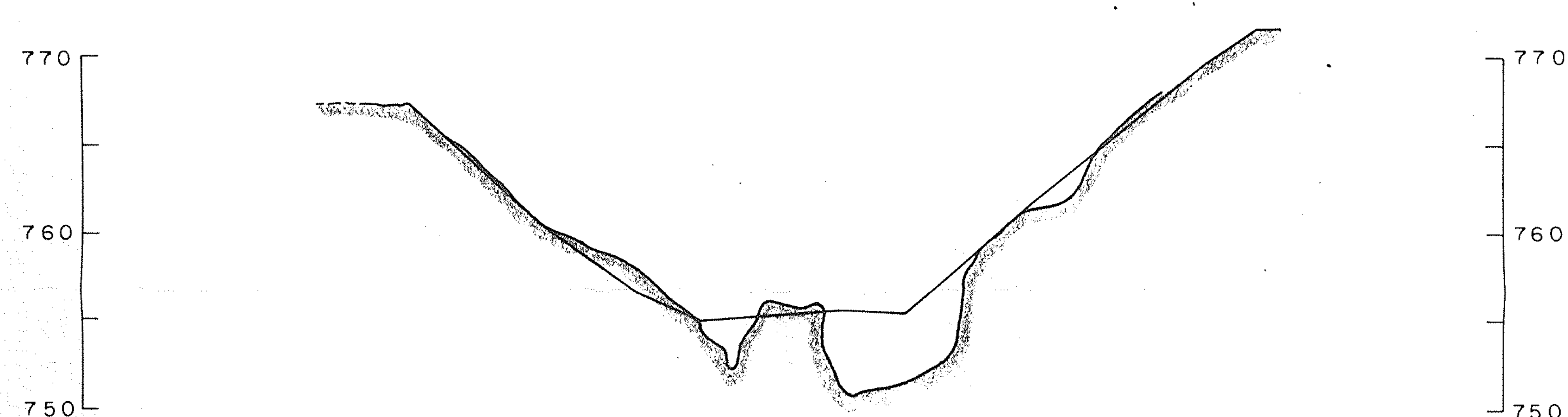
S.39



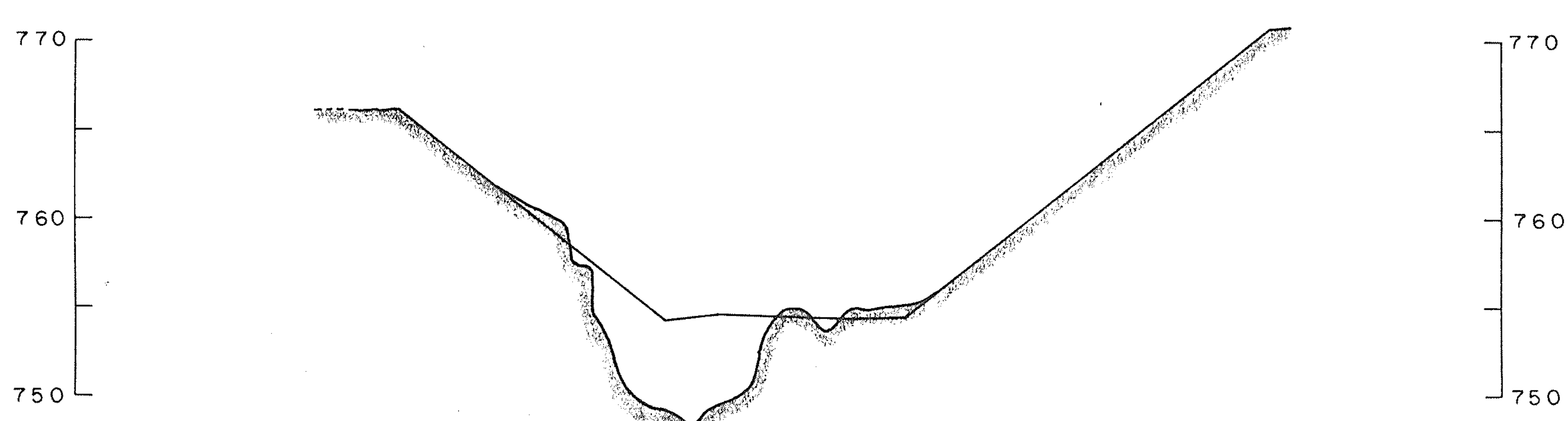
S.40



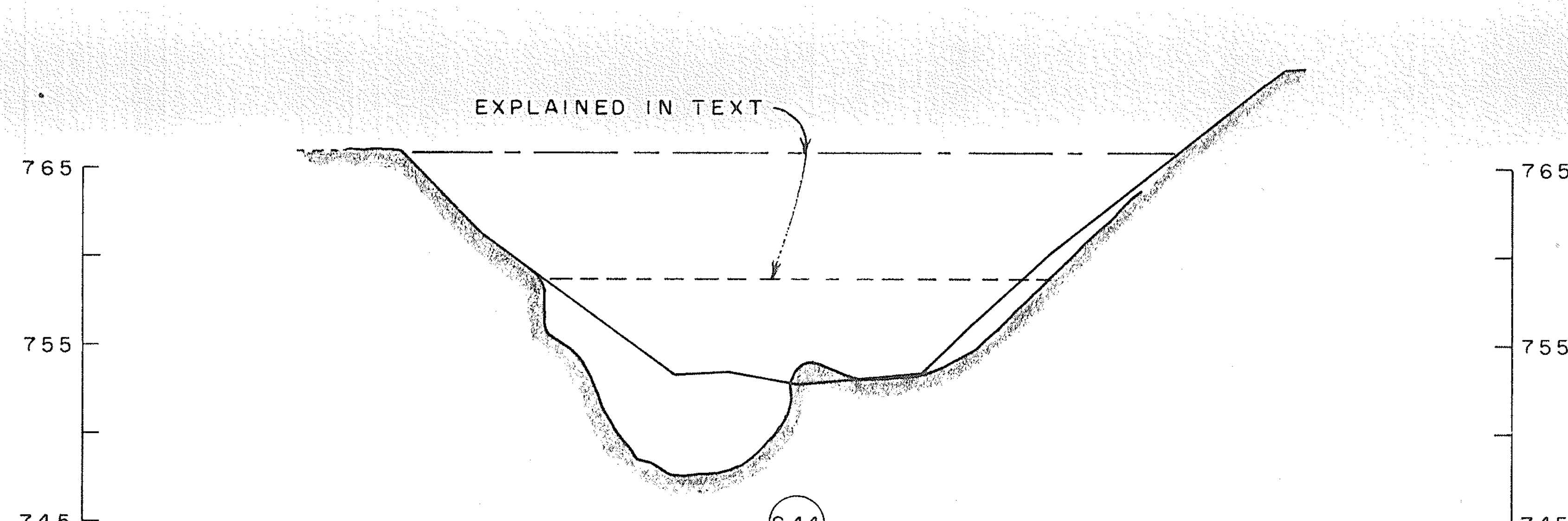
S.41



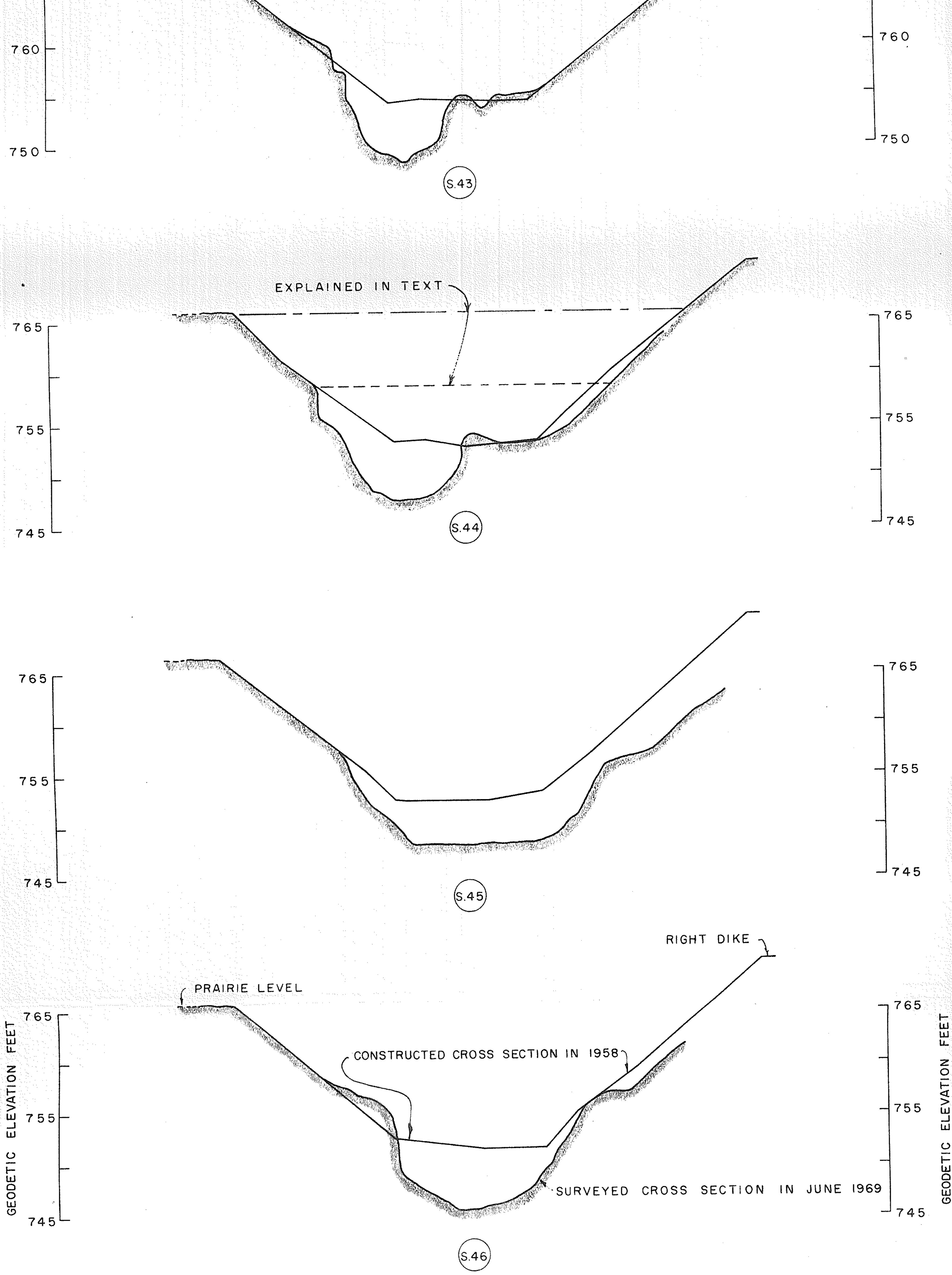
S.42



S.43



S.44



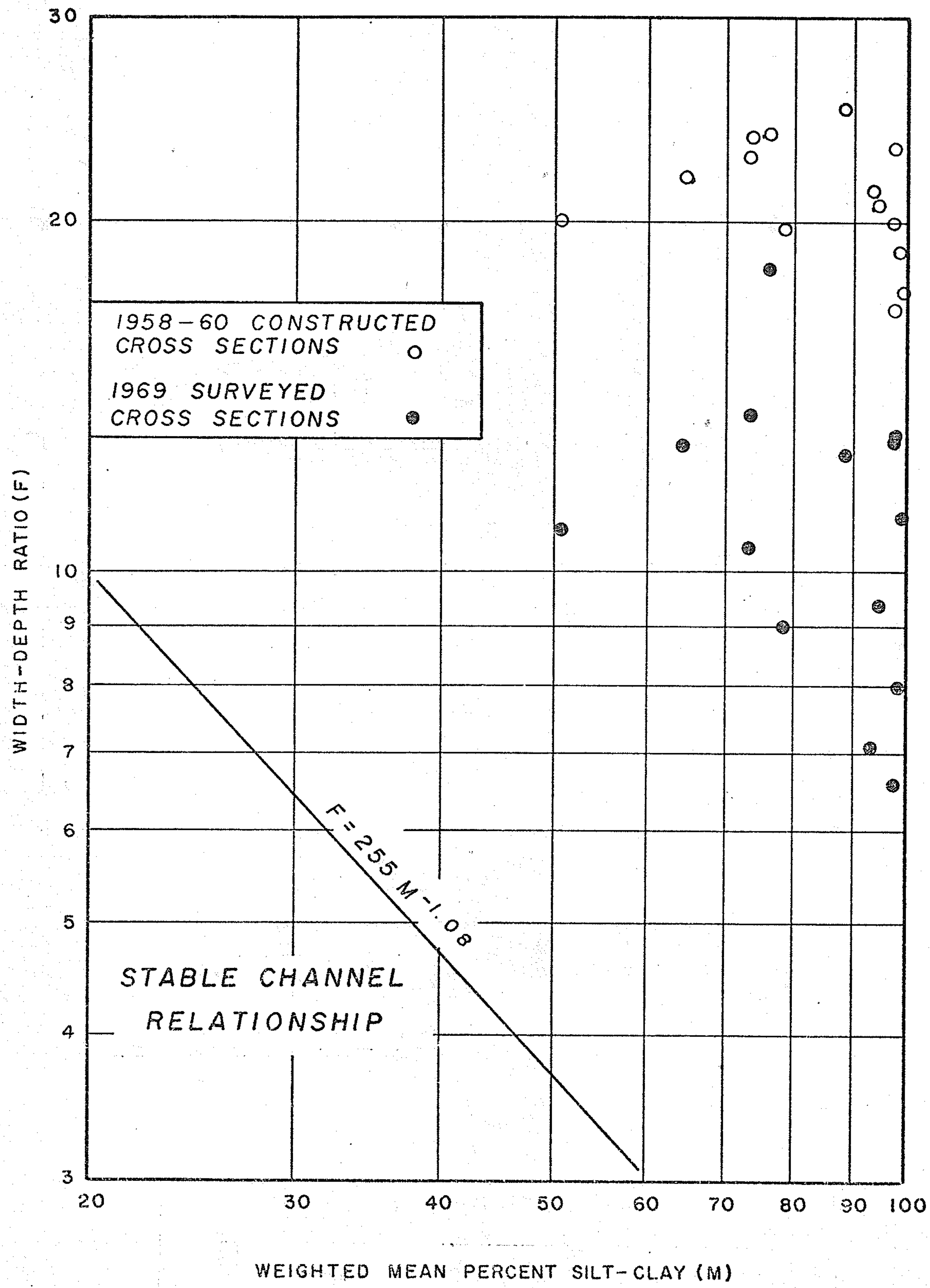
SEINE RIVER DIVERSION

CROSS SECTIONS
IN
REACH NO. 5

FOR KEY SEE CROSS SECTION NO. S.46

HORIZONTAL SCALE

FIGURE 3.2J



SEINE RIVER DIVERSION

RELATION BETWEEN WIDTH DEPTH RATIO AND WEIGHTED MEAN PERCENT SILT CLAY AT DIFFERENT CROSS SECTIONS

FIGURE 3.3

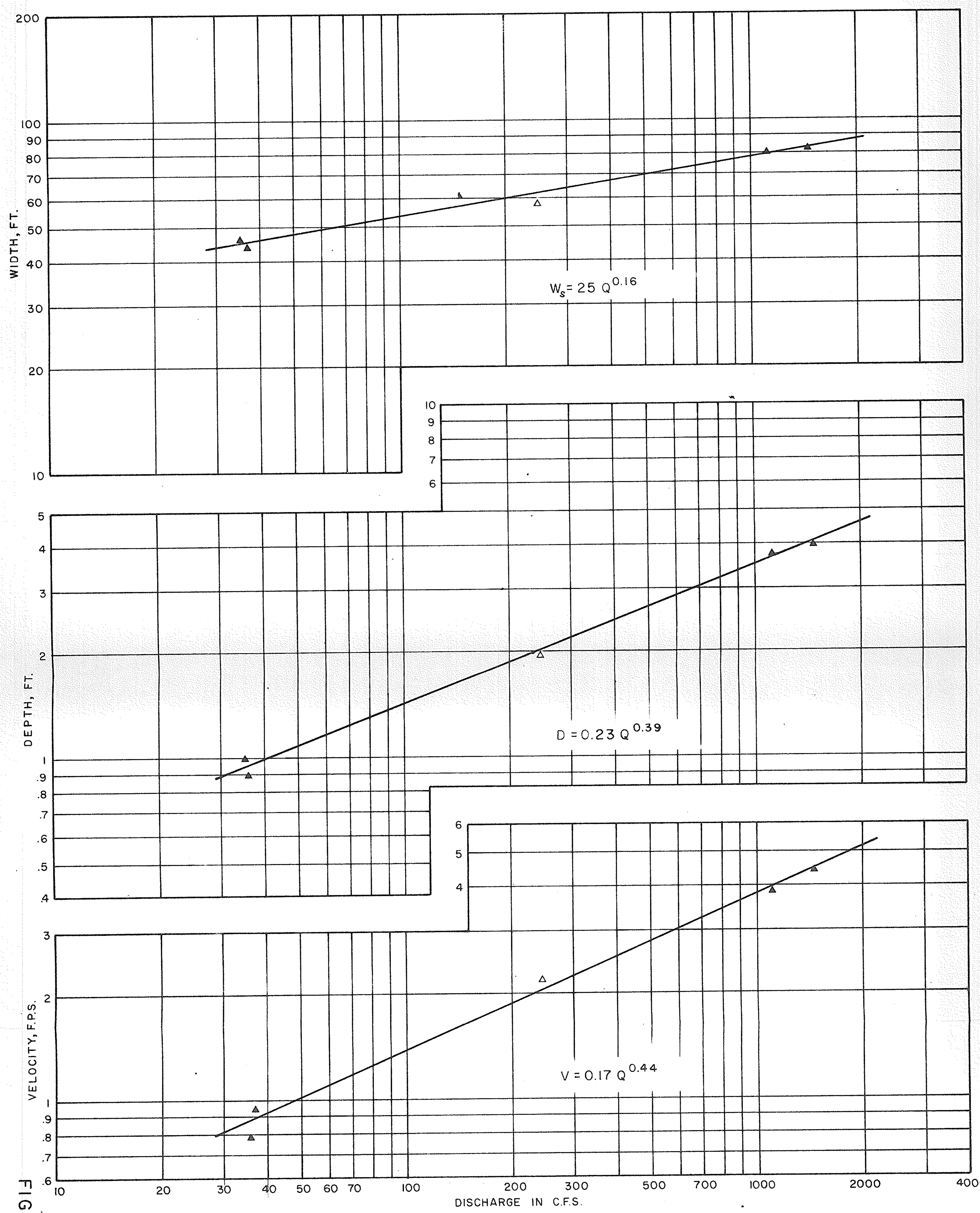


FIGURE 3.4

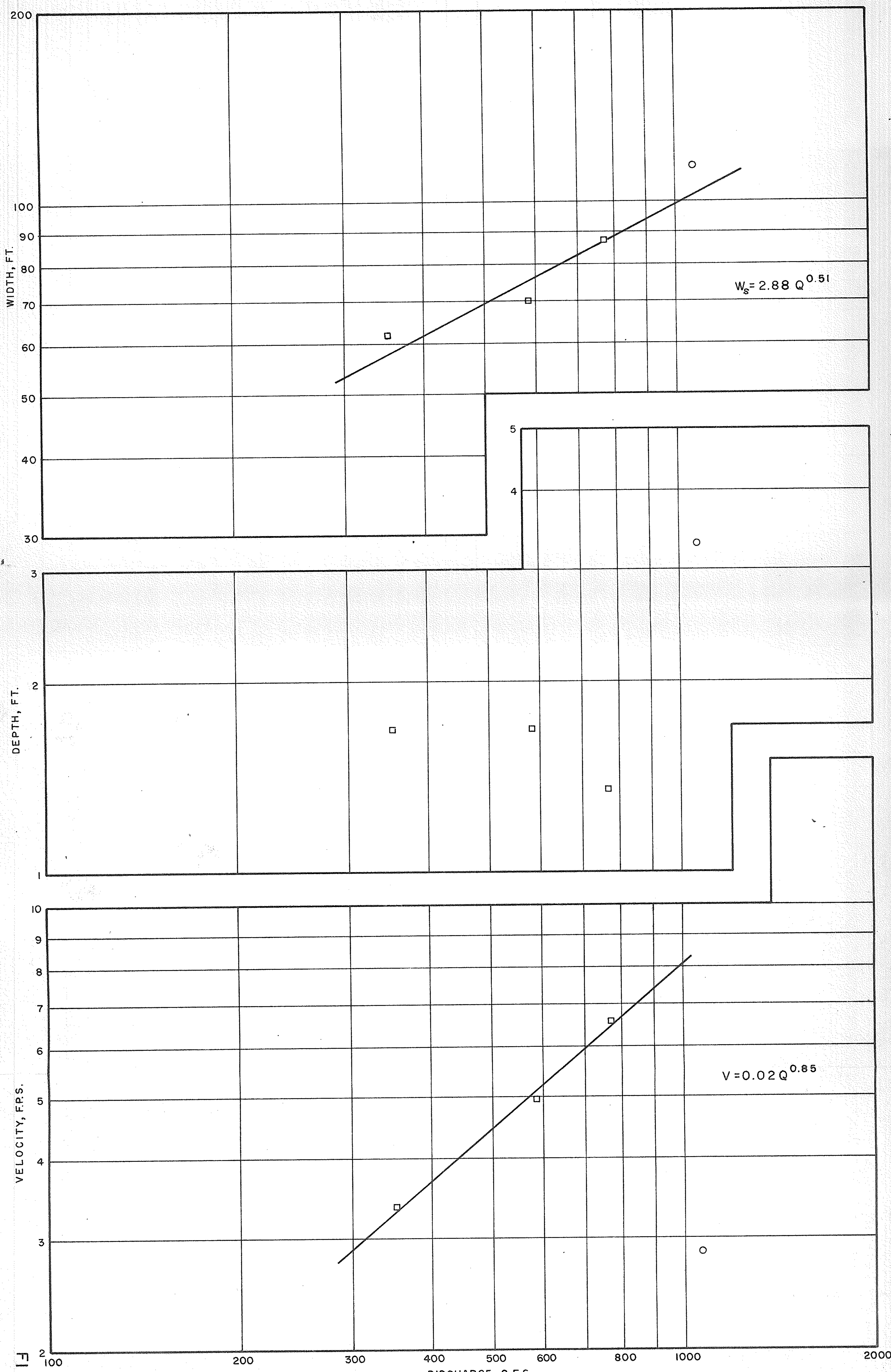
LOCATION: METERING STA. NO. 2

1963 PLOTTING POSITION: ▲

1964 PLOTTING POSITION: △

SEINE RIVER DIVERSION

RELATION OF WIDTH, DEPTH, AND VELOCITY TO DISCHARGE



WIDTH, FT.
200
100
90
80
70
60
50
40
30
$W_S = 2.88\ Q^{0.51}$
DEPTH, FT.
5
4
3
2
1
VELOCITY, F.P.S.
10
9
8
7
6
5
4
3
2
$V = 0.02\ Q^{0.85}$
100
200
300
400
500
600
800
1000
2000
DISCHARGE, C.F.S.

FIGU

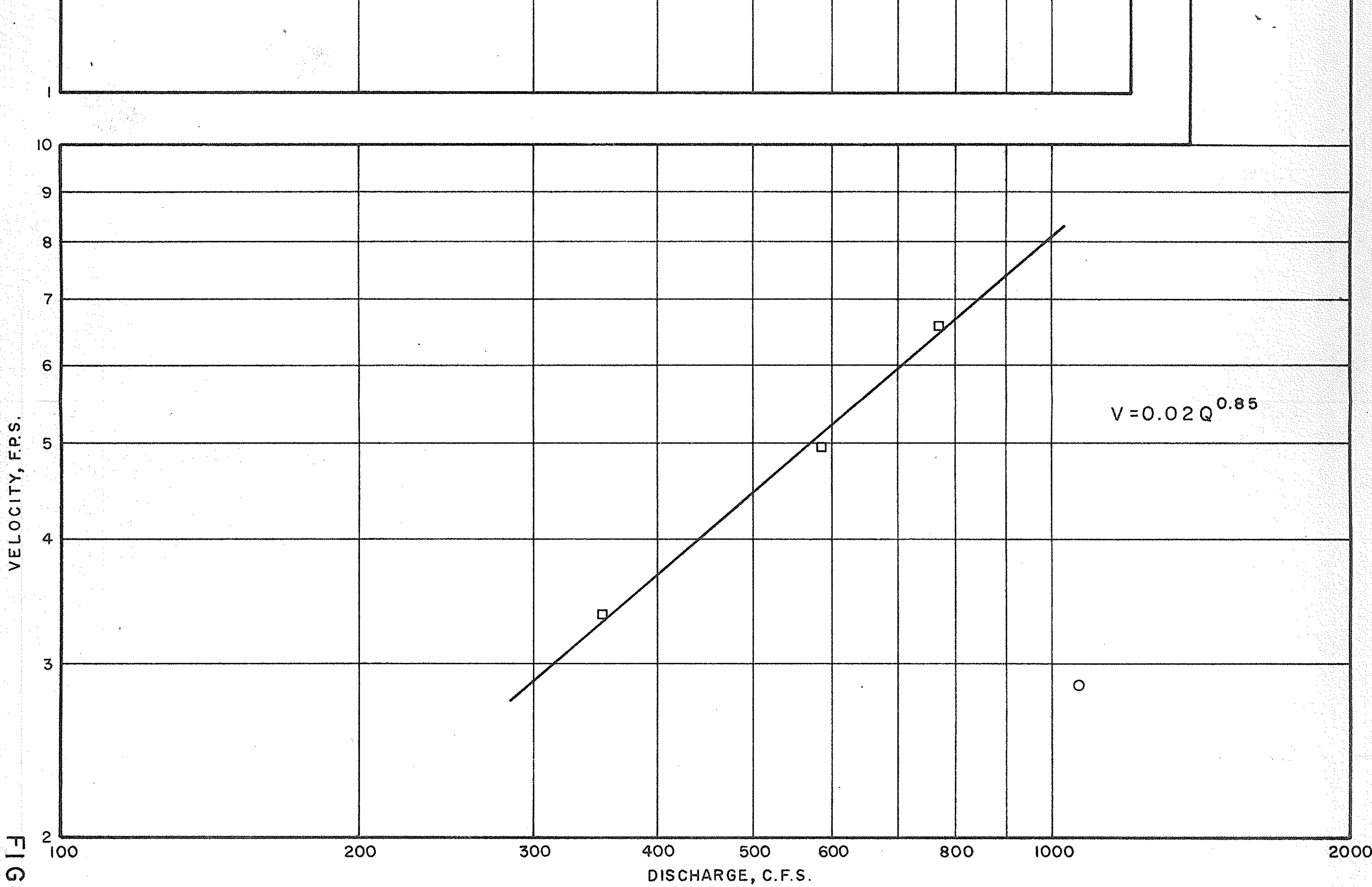


FIGURE 3.5

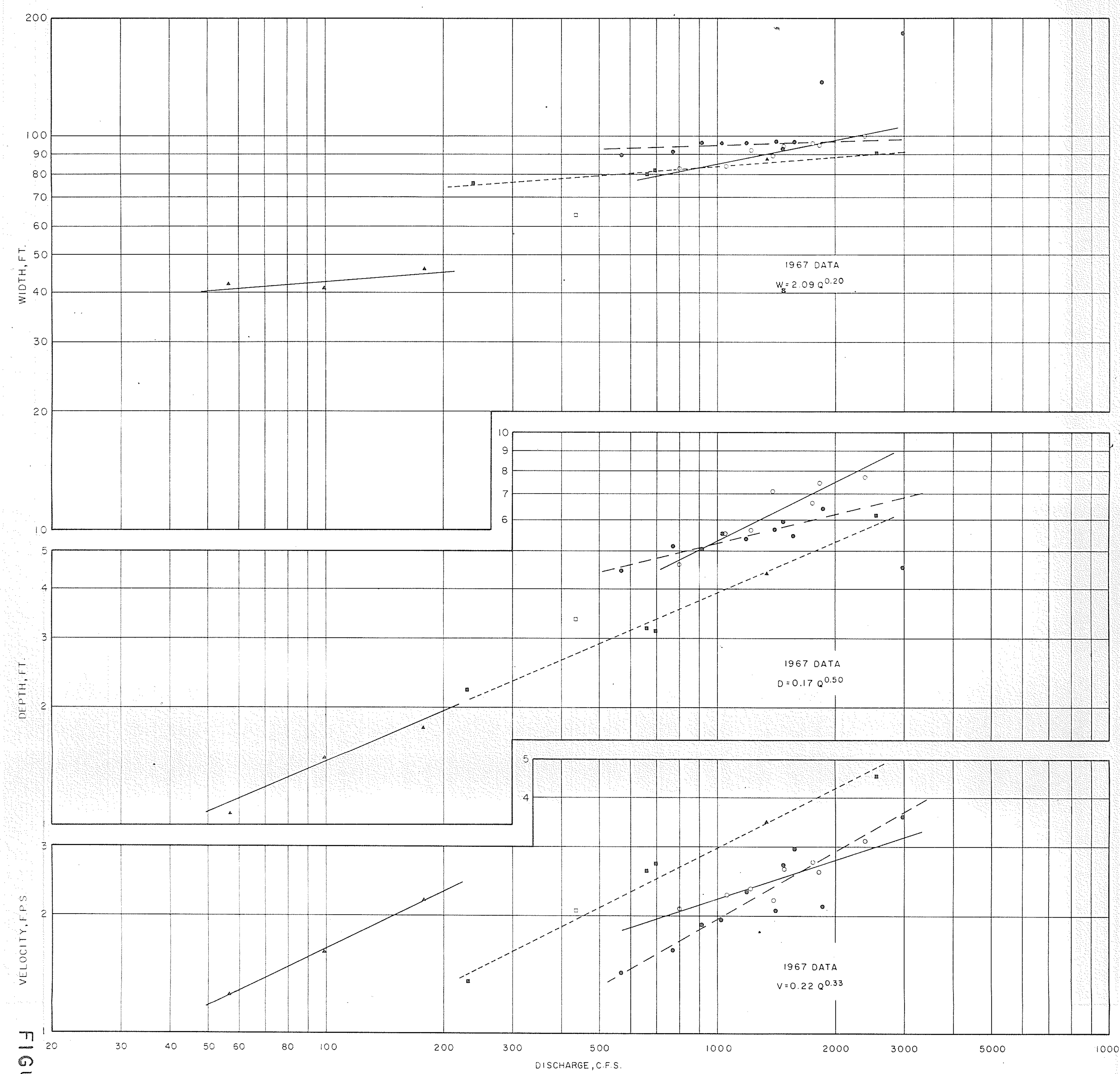
LOCATION: METERING STA. NO. 4

1965 PLOTTING POSITION: □

1967 PLOTTING POSITION: ○

SEINE RIVER DIVERSION

RELATION OF WIDTH, DEPTH, AND VELOCITY TO DISCHARGE



LOCATION: METERING STA. NO. 5

1962 PLOTTING POSITION: ▪

1963 PLOTTING POSITION: ▲

1965 PLOTTING POSITION: □

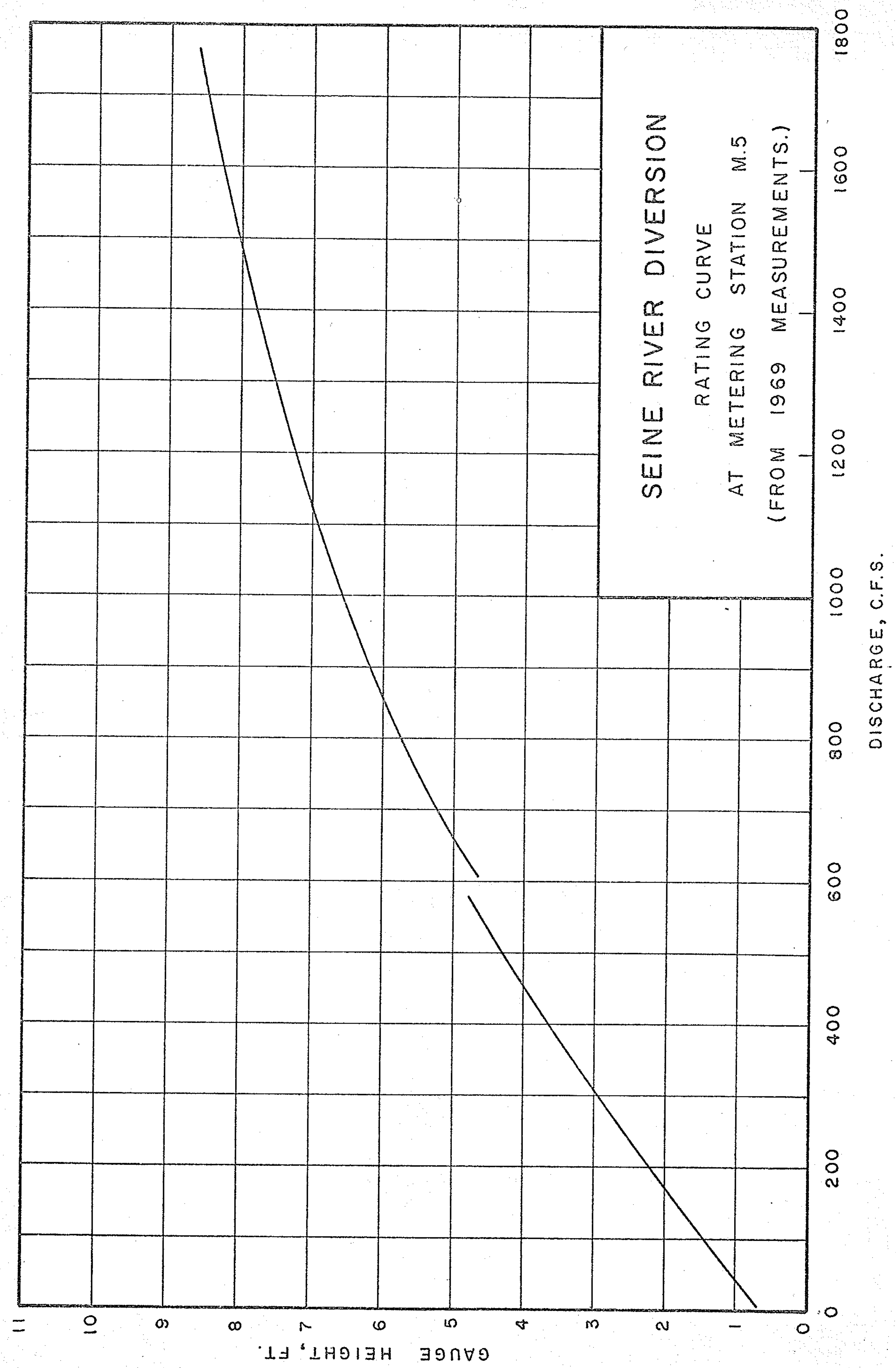
1966 PLOTTING POSITION: •

1967 PLOTTING POSITION: ○

SEINE RIVER DIVERSION

RELATION OF WIDTH, DEPTH, AND VELOCITY TO DISCHARGE

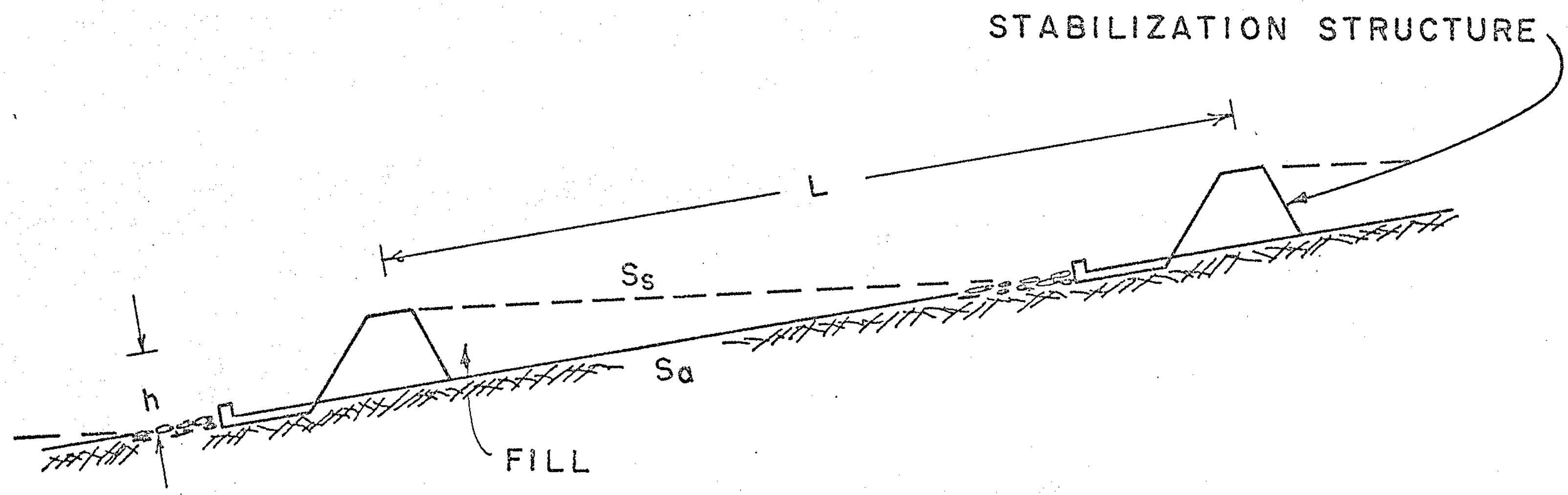
FIGURE 3.6



SEINE RIVER DIVERSION
RATING CURVE
AT METERING STATION M.5
(FROM 1969 MEASUREMENTS.)
DISCHARGE, C.F.S.
GAUGE HEIGHT, FT.
0
200
400
600
800
1000
1200
1400
1600
1800
0
1
2
3
4
5
6
7
8
9
10
11

FIGURE 3.7

$$L = \frac{h}{S_a - S_s} \quad \text{(FOR SMALL SLOPES)}$$



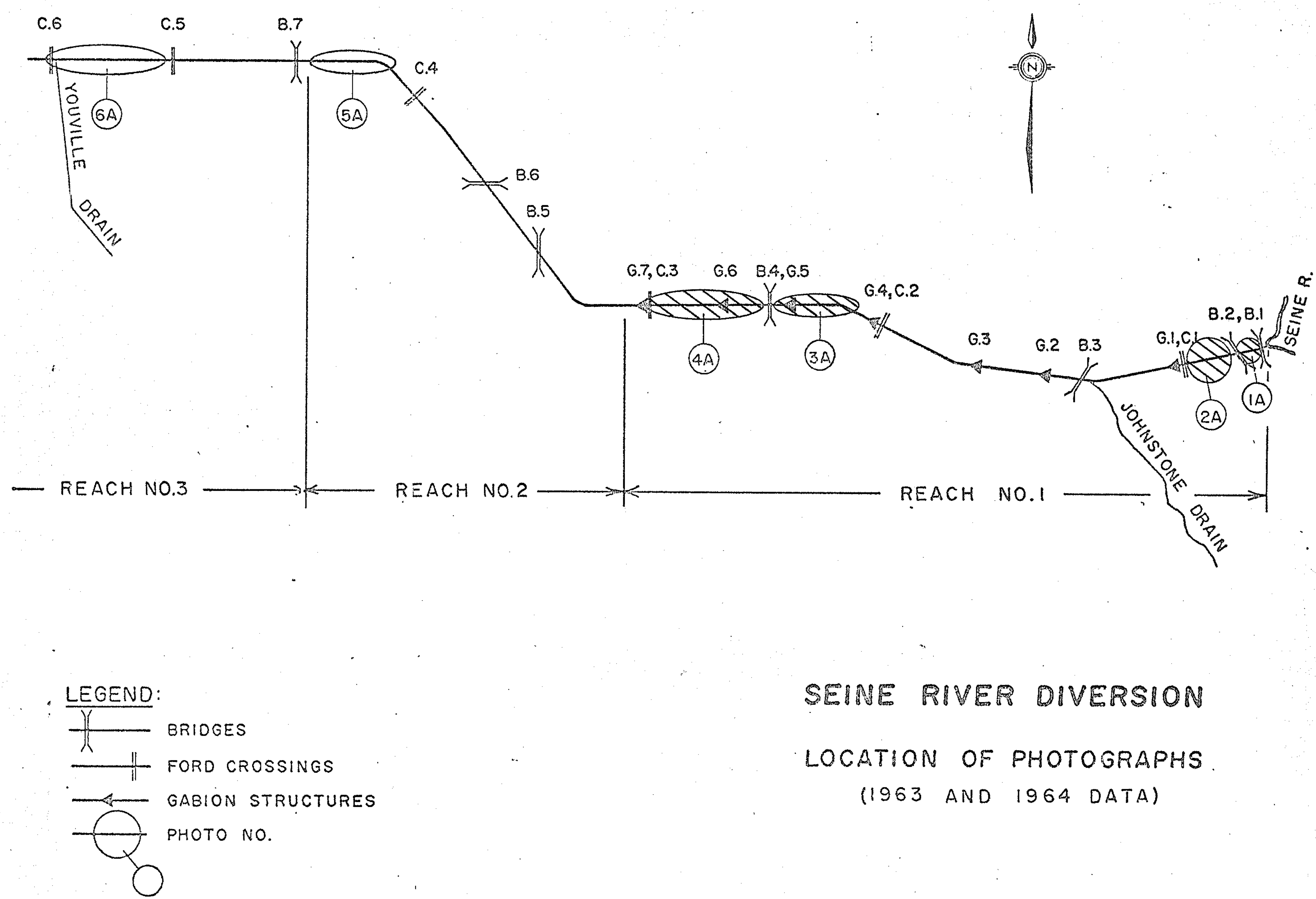
SEINE RIVER DIVERSION

STABILIZATION METHOD

FIGURE 5.1

PHOTOGRAPHS

PLATES



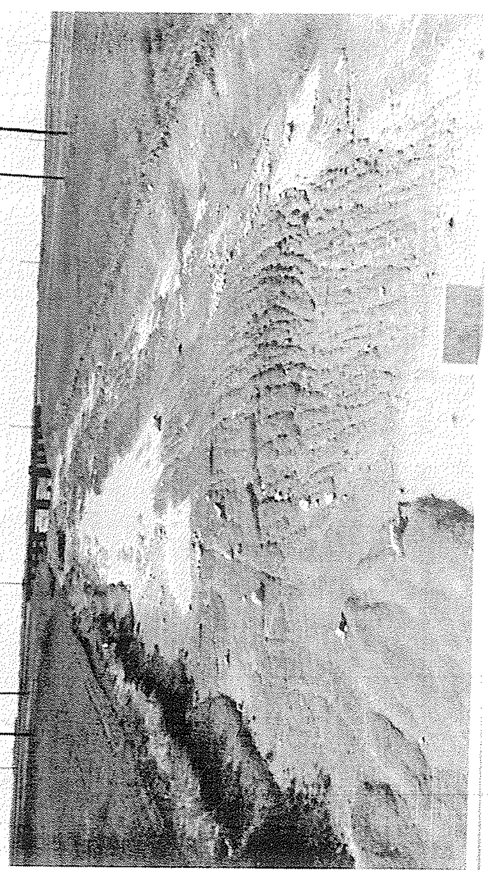
SEINE RIVER DIVERSION

LOCATION OF PHOTOGRAPHS

(1963 AND 1964 DATA)

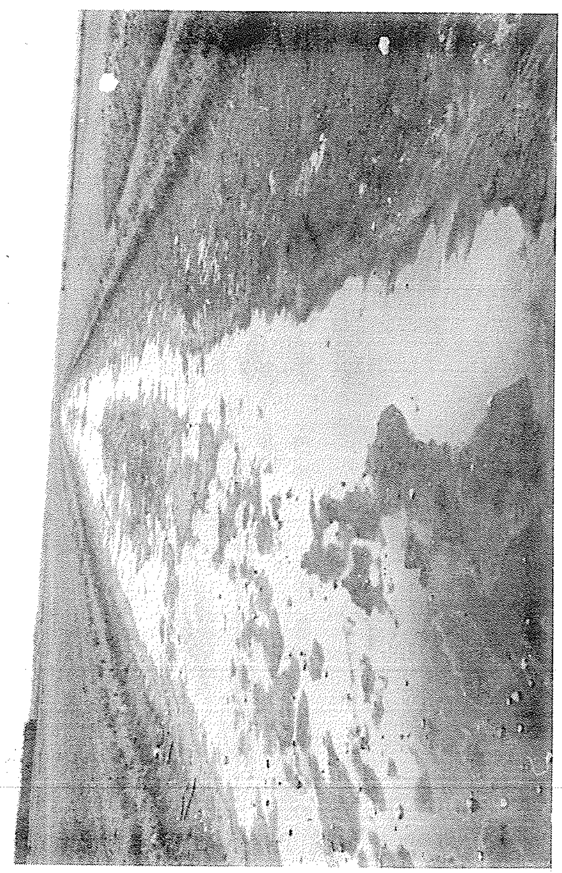
84

55

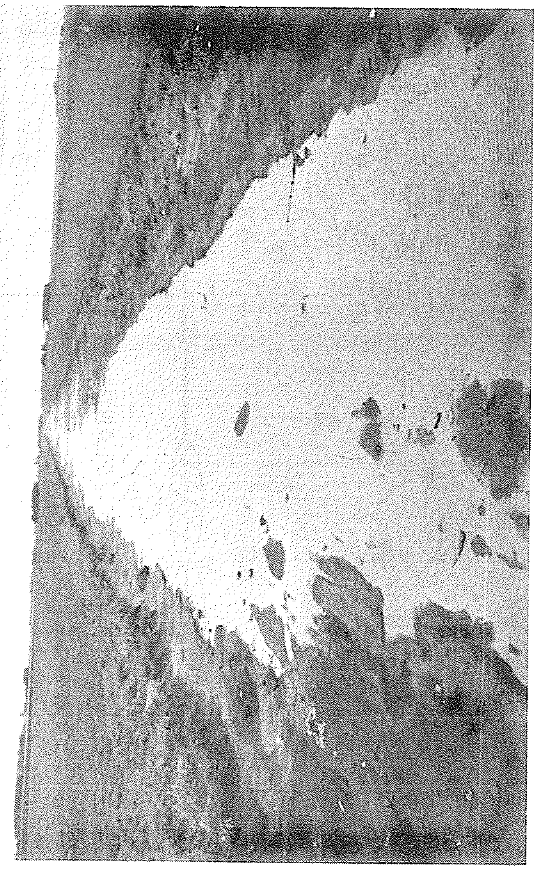


Ph.1A. Sept. 1963

Ph.2A. Sept. 1963



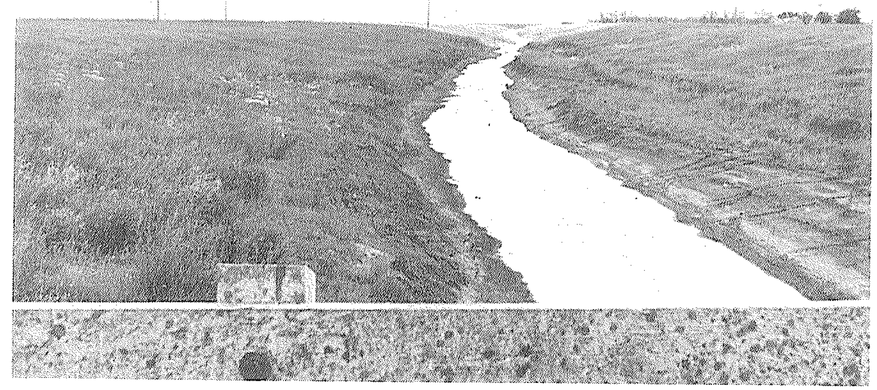
Ph.3A. Sept. 1963



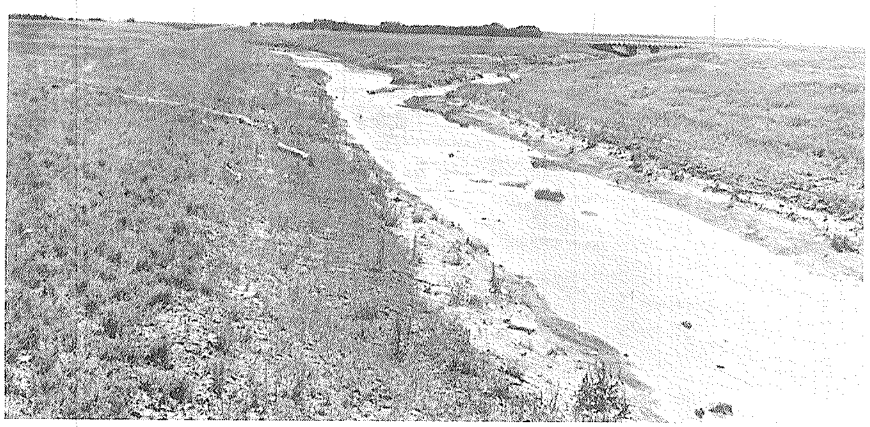
Ph.4A. Sept. 1963

PLATE 3.1

Ph. 9A. June 30, 1964



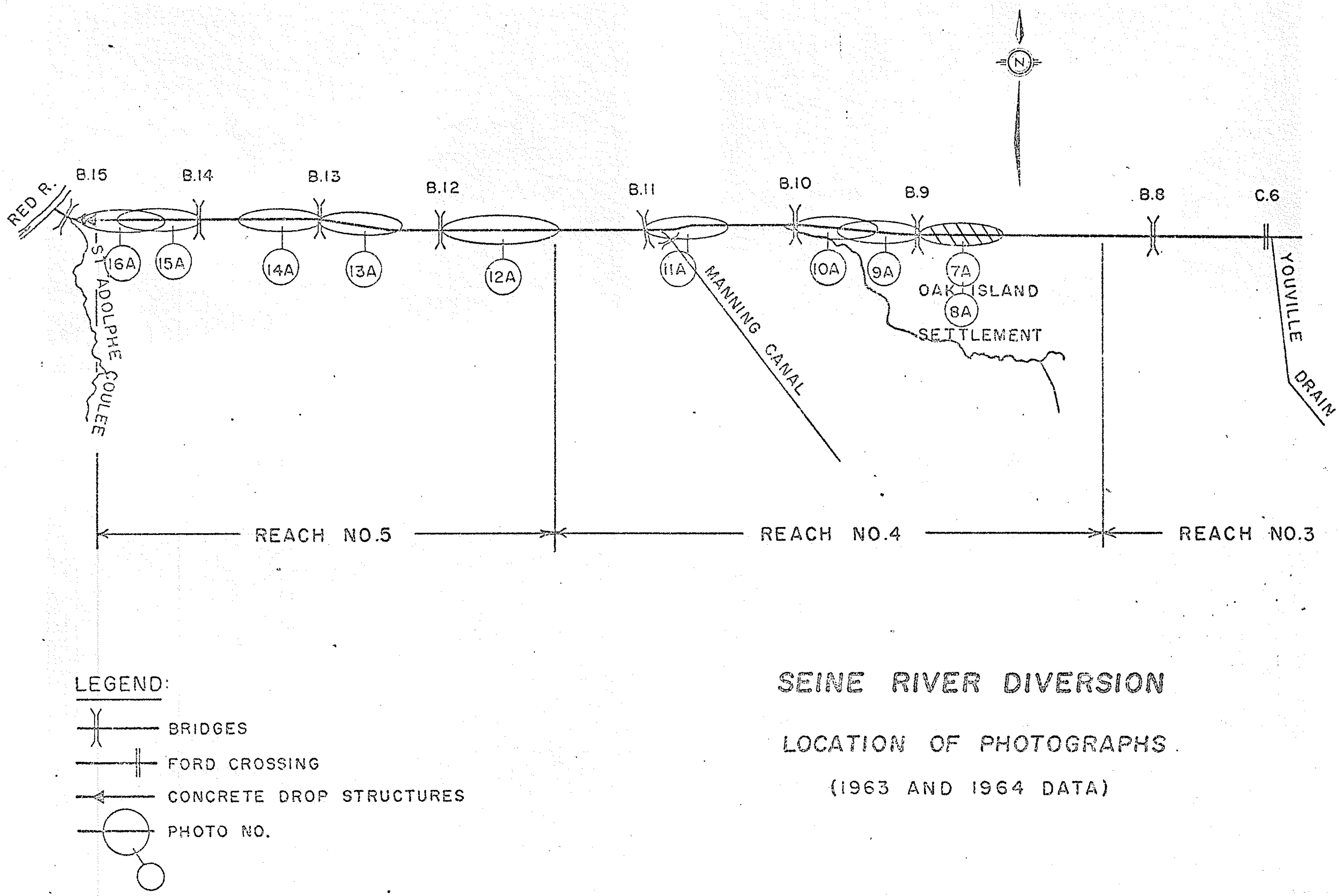
Ph. 10A. June 30, 1964



Ph. 11A. June 30, 1964

Ph. 12A. June 30, 1964

PLATE 3.3

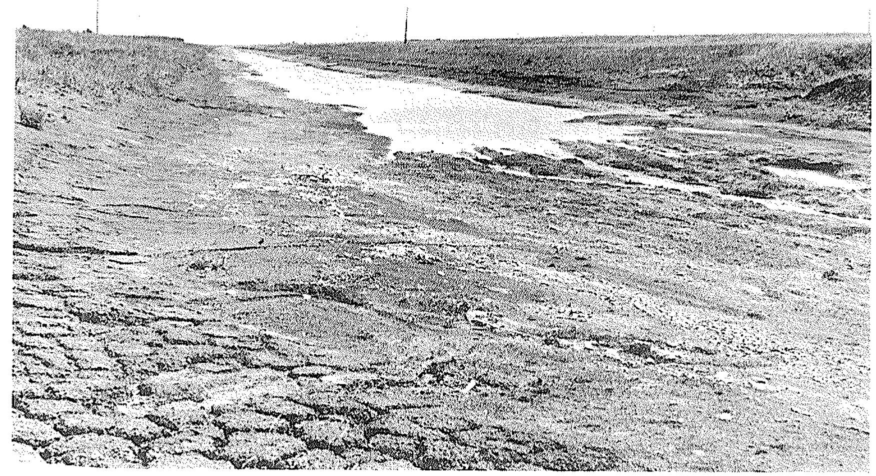


SEINE RIVER DIVERSION

LOCATION OF PHOTOGRAPHS.

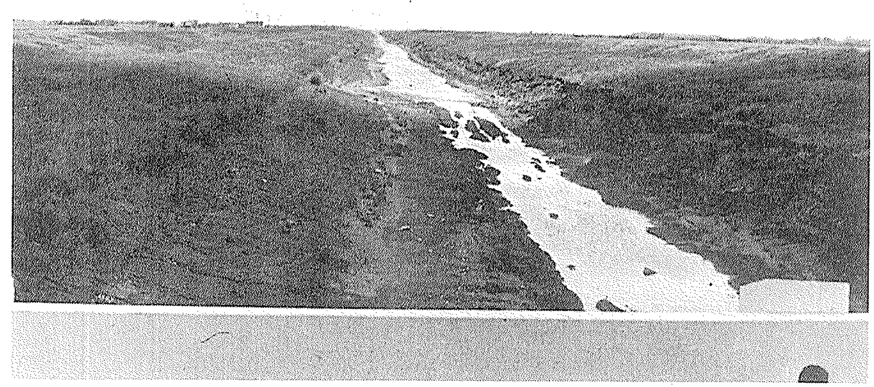
(1963 AND 1964 DATA)

Ph. 5A. Sept. 1963



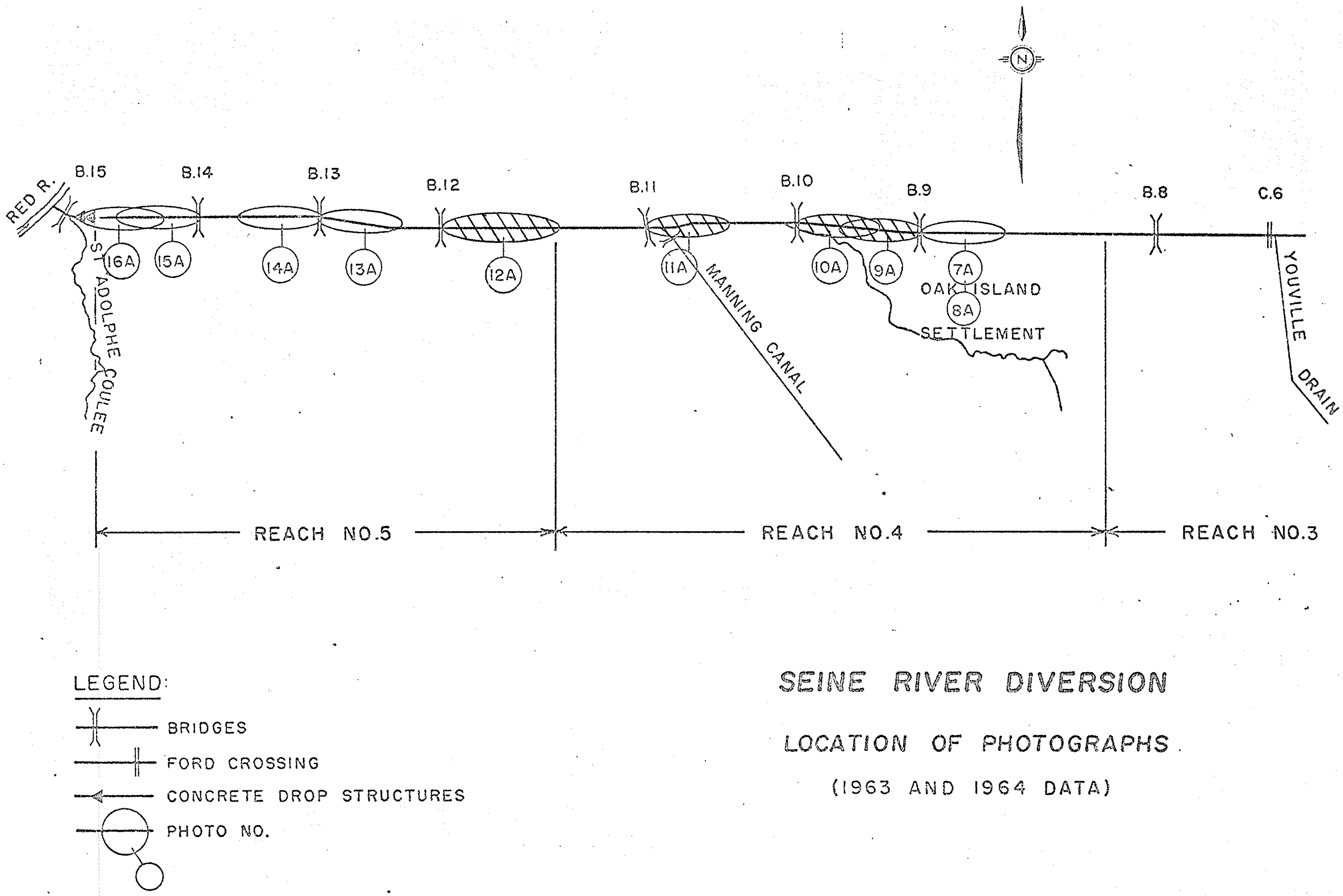
Ph. 6A. June 30, 1964

Ph. 7A. Sept. 1963



Ph. 8A. June 30, 1964

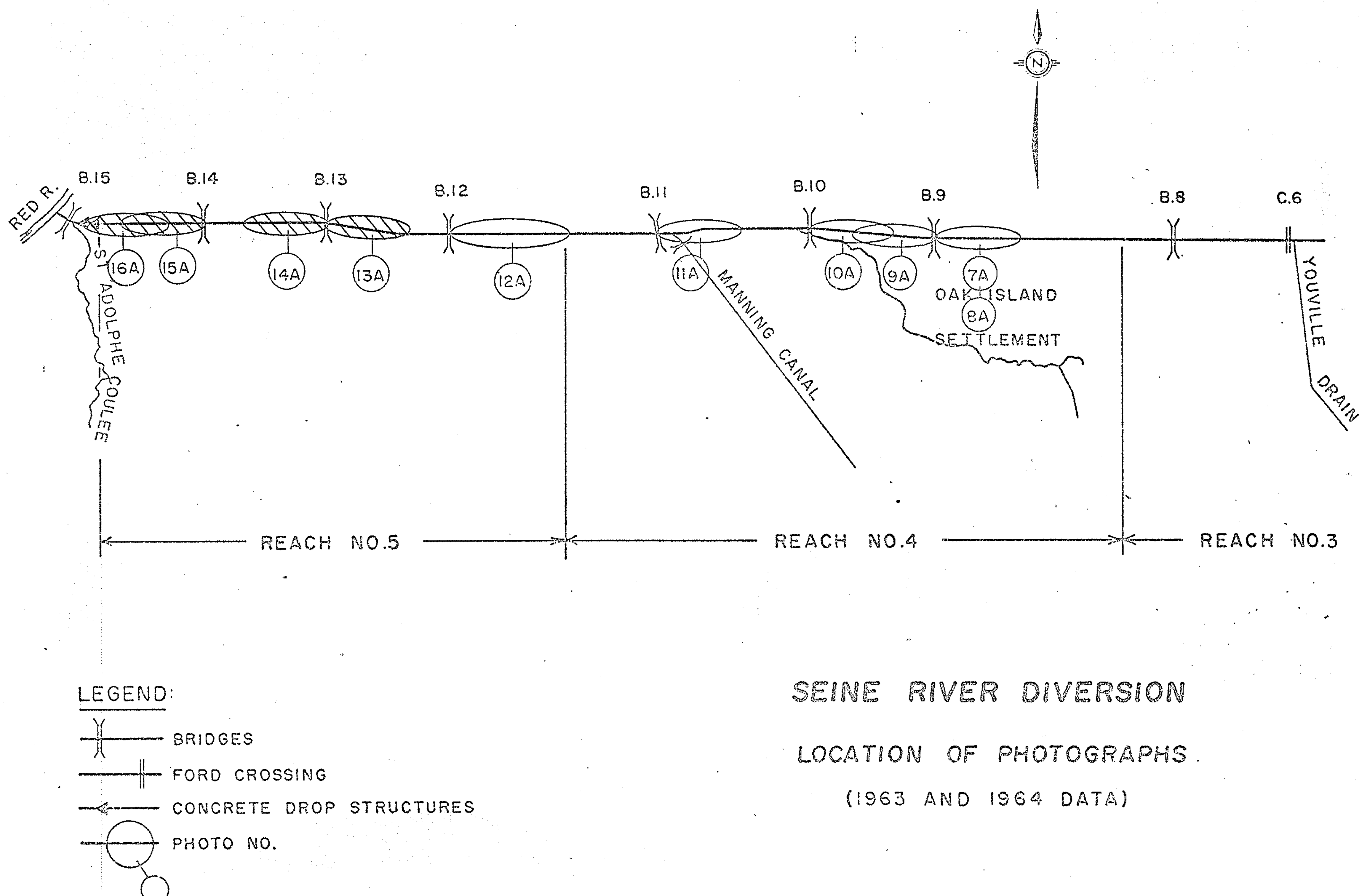
PLATE 3.2



SEINE RIVER DIVERSION

LOCATION OF PHOTOGRAPHS

(1963 AND 1964 DATA)



SEINE RIVER DIVERSION

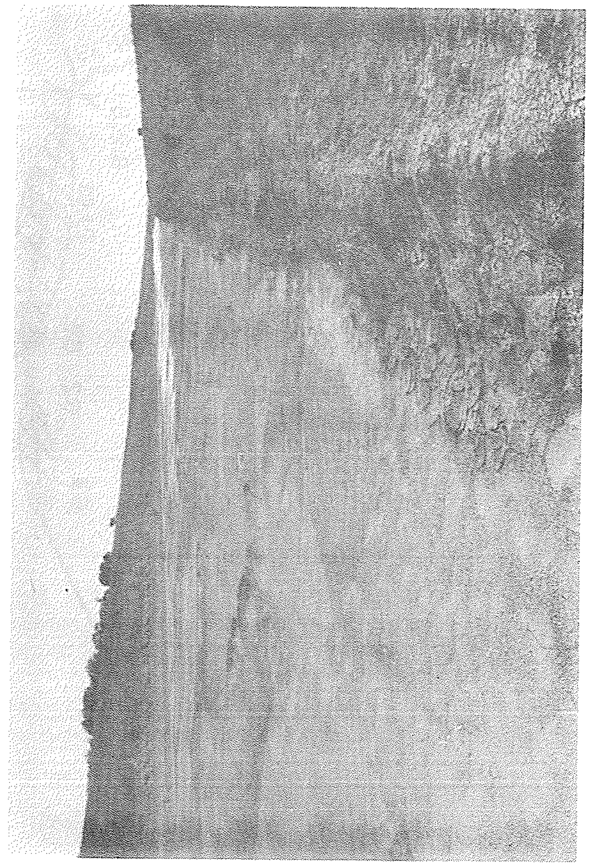
LOCATION OF PHOTOGRAPHS.

(1963 AND 1964 DATA)

Ph.13A. June 30, 1964

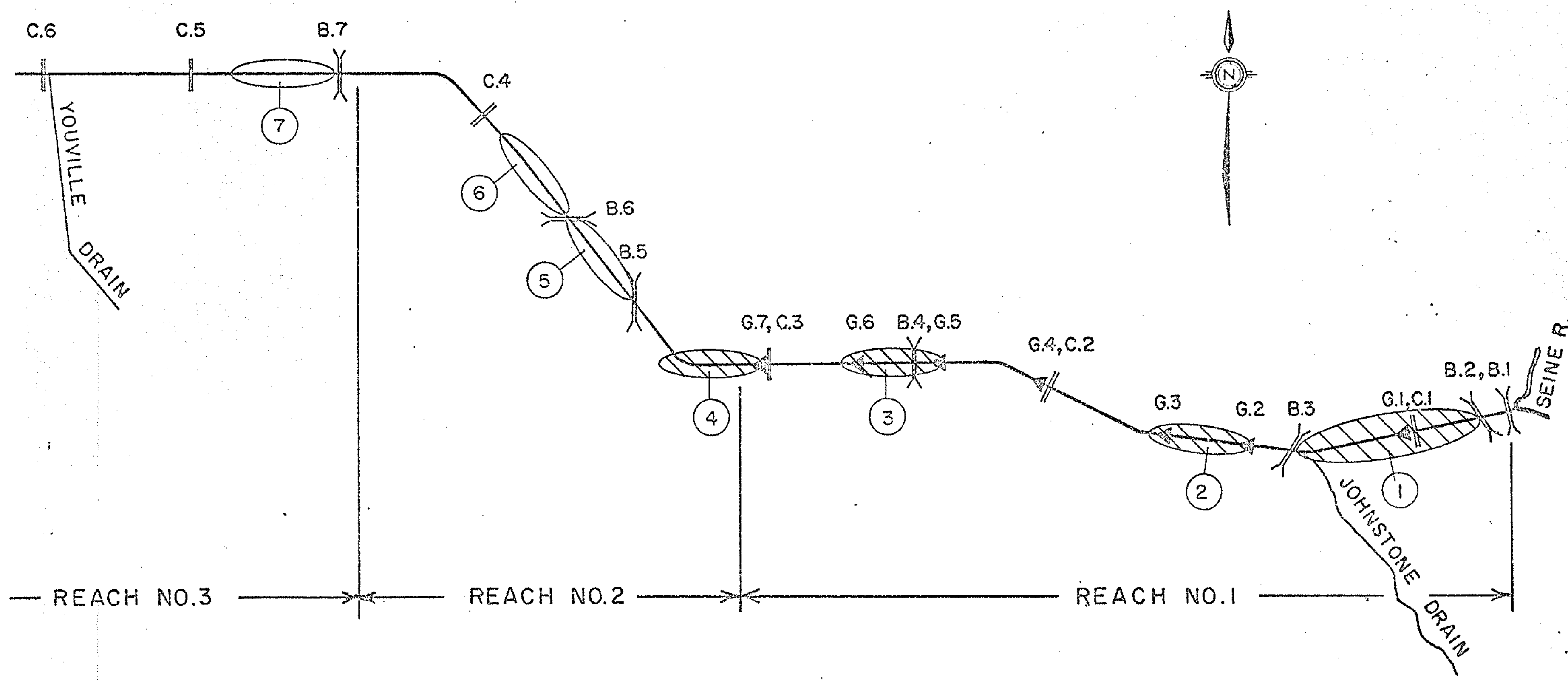
Ph.14A. June 30, 1964

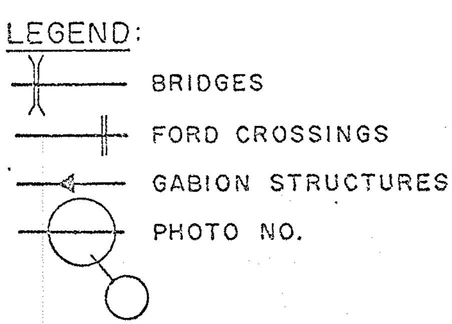
Ph.15A. Sept. 1963



Ph.16A. Sept. 1963

PLATE 3.4

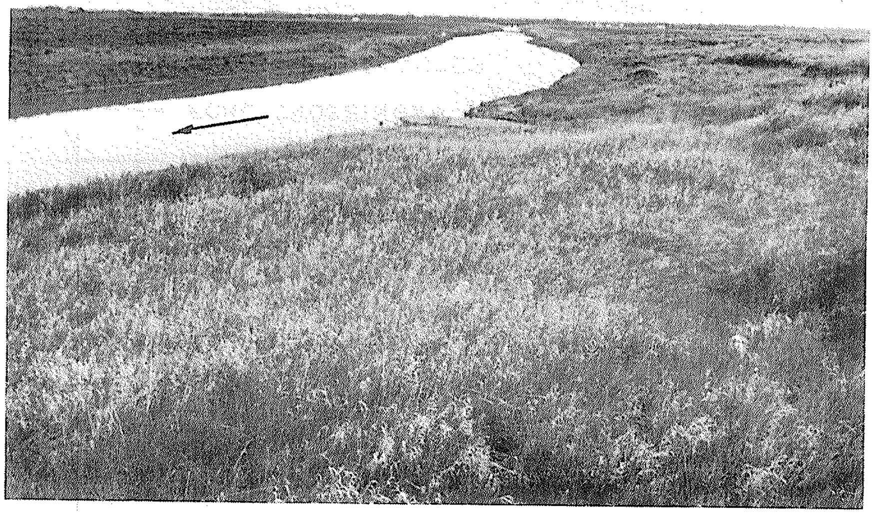




SEINE RIVER DIVERSION

LOCATION OF PHOTOGRAPHS

(1969 DATA)



Ph.1. June 6, 1969

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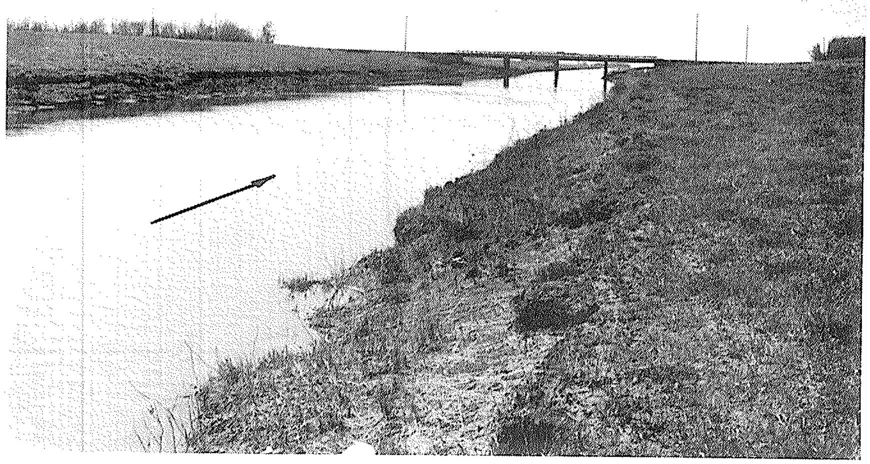

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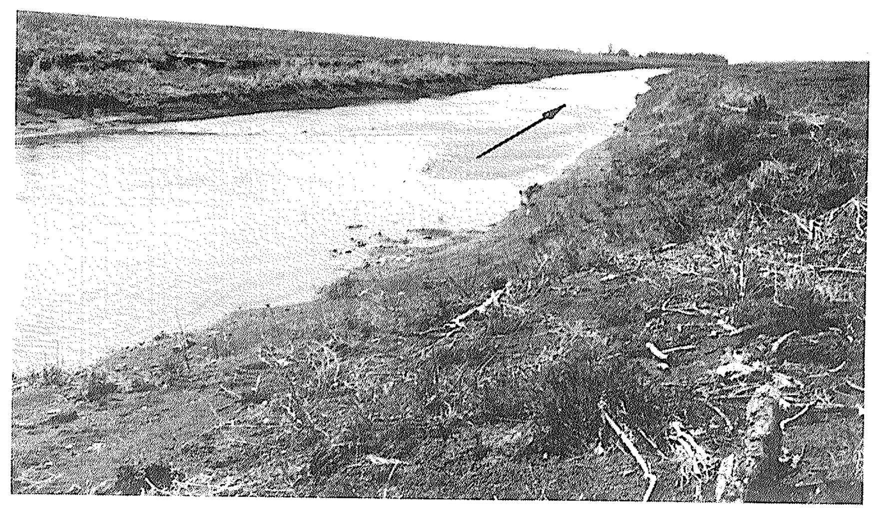
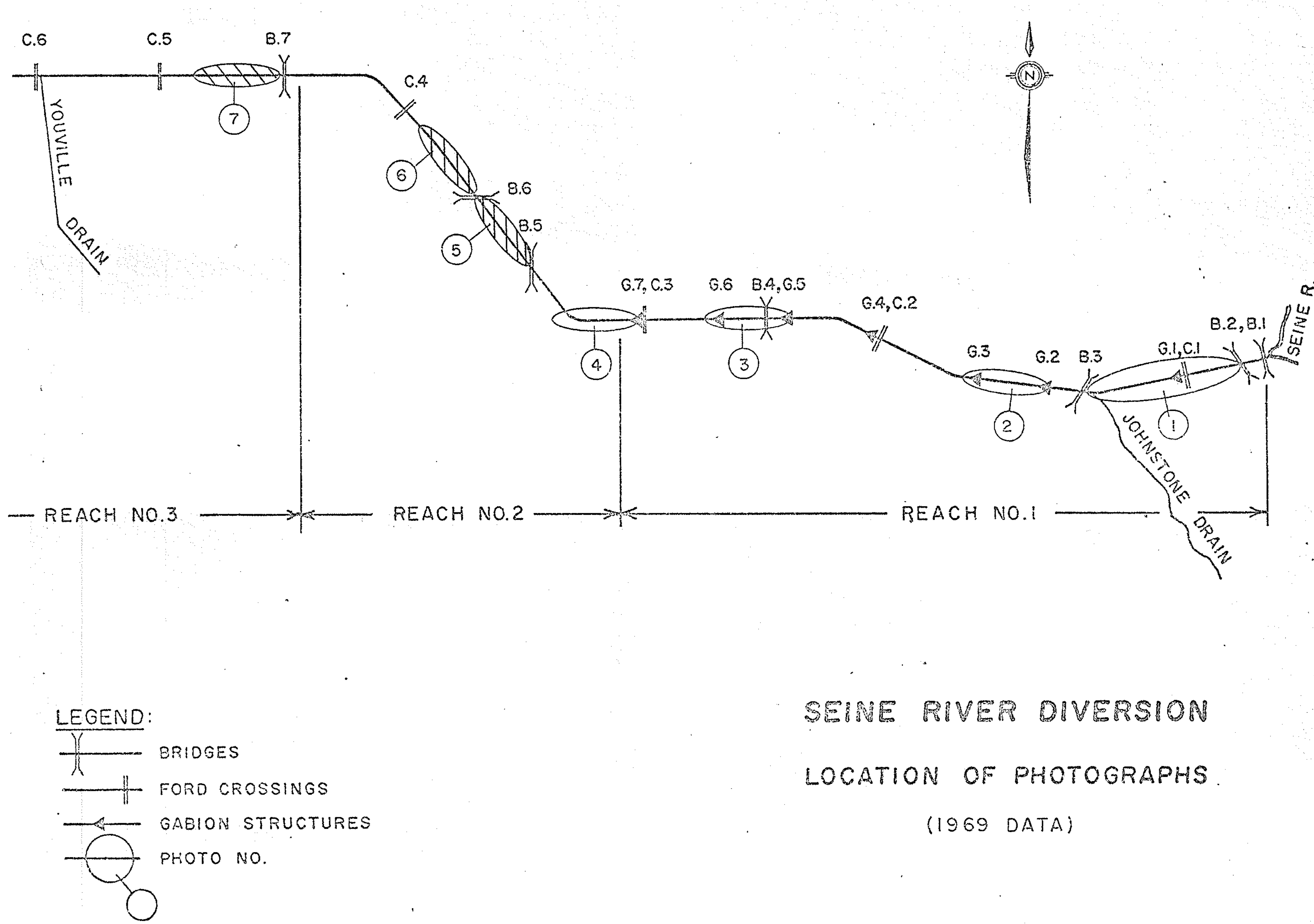


Ph.4. May 13, 1969

PLATE 3.5



SEINE RIVER DIVERSION

LOCATION OF PHOTOGRAPHS

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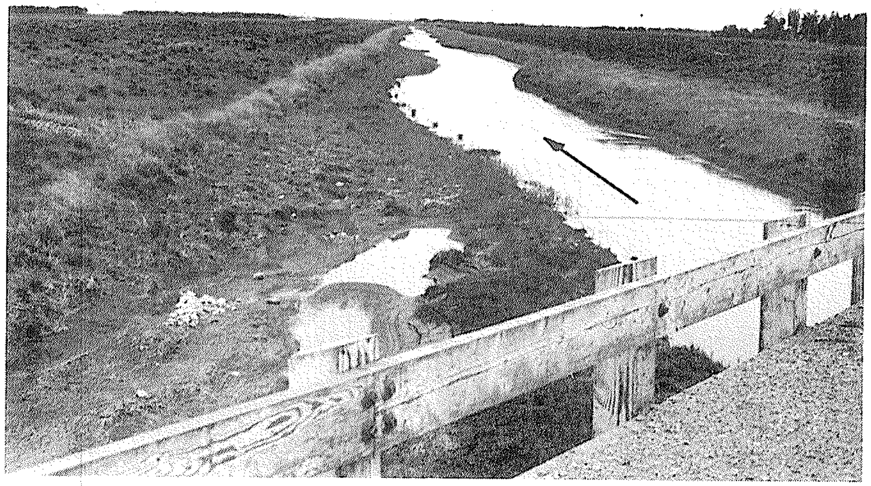

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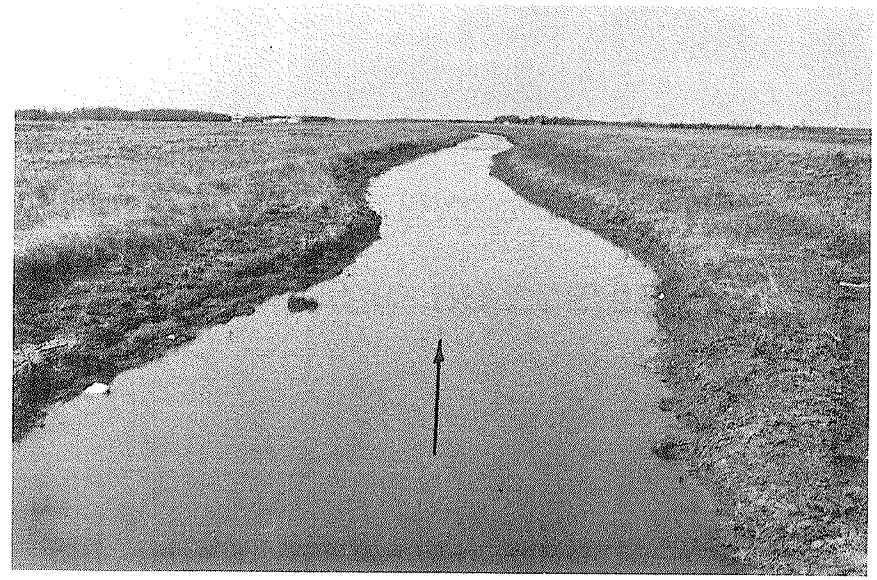

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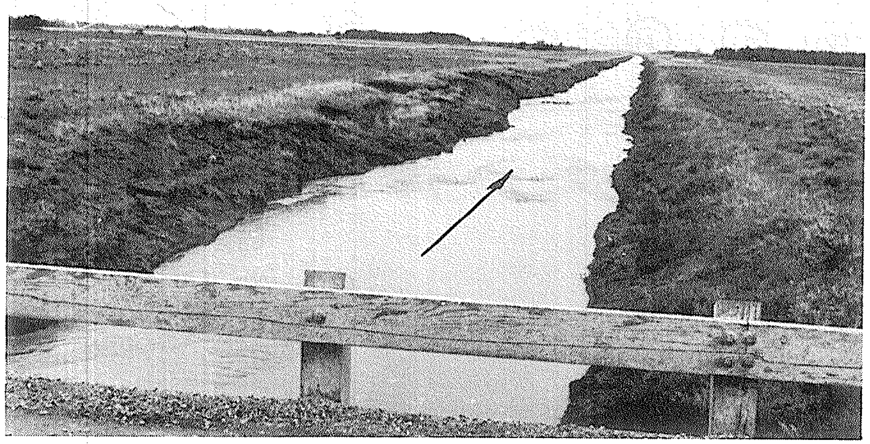

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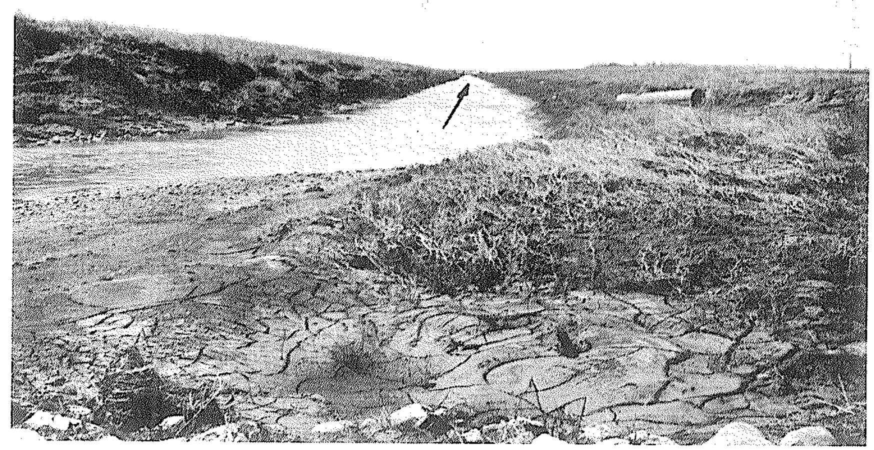

Ph.8. June 6, 1969

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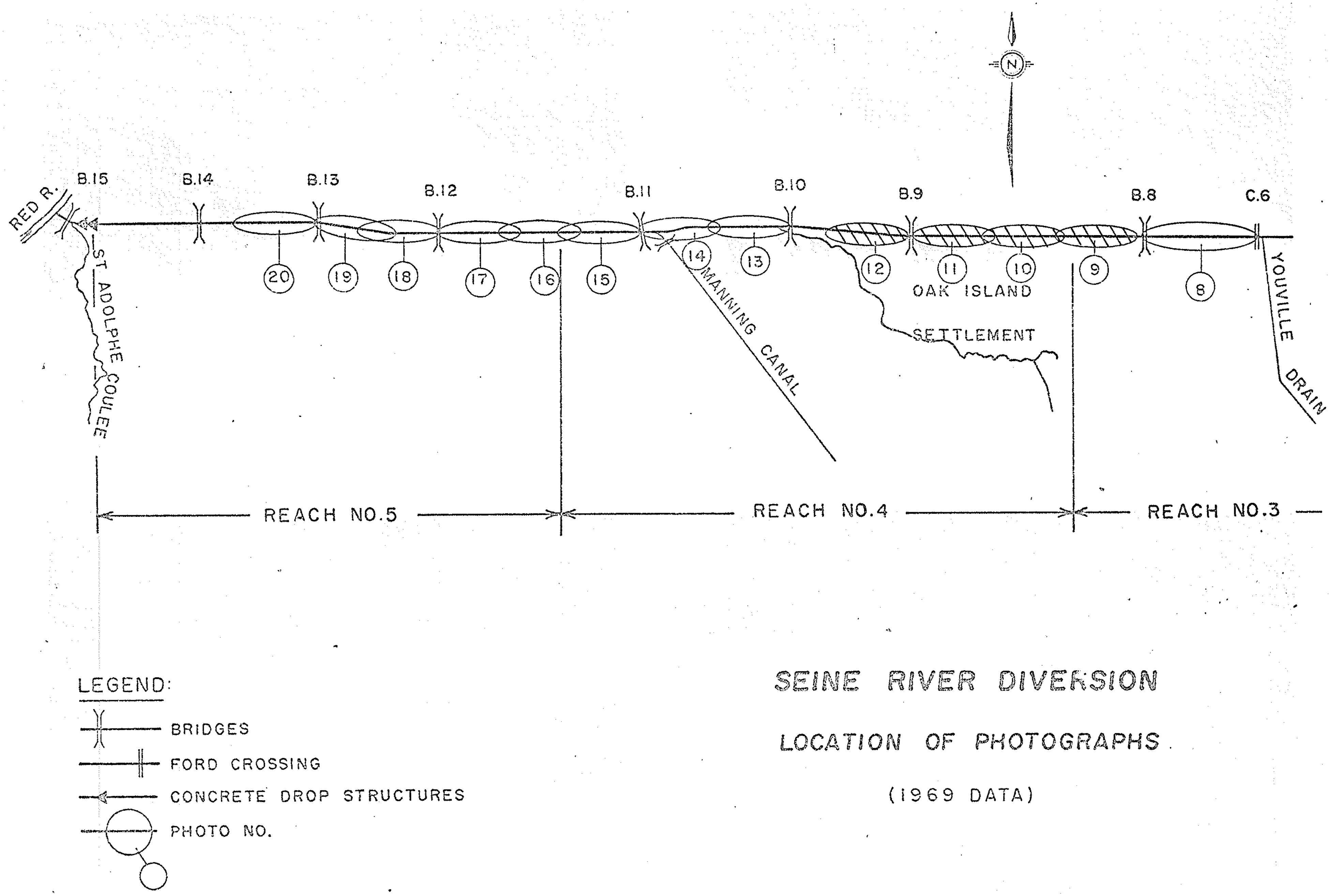

SEINE RIVER DIVERSION

LOCATION OF PHOTOGRAPHS

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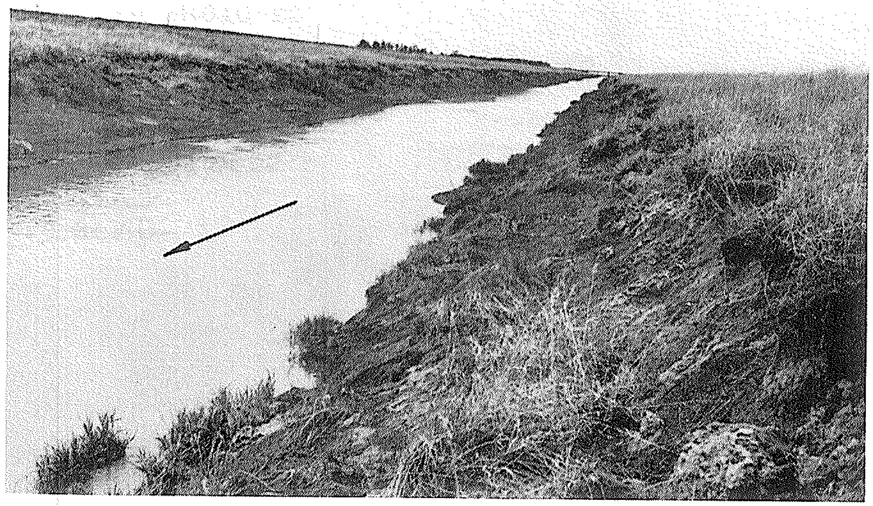

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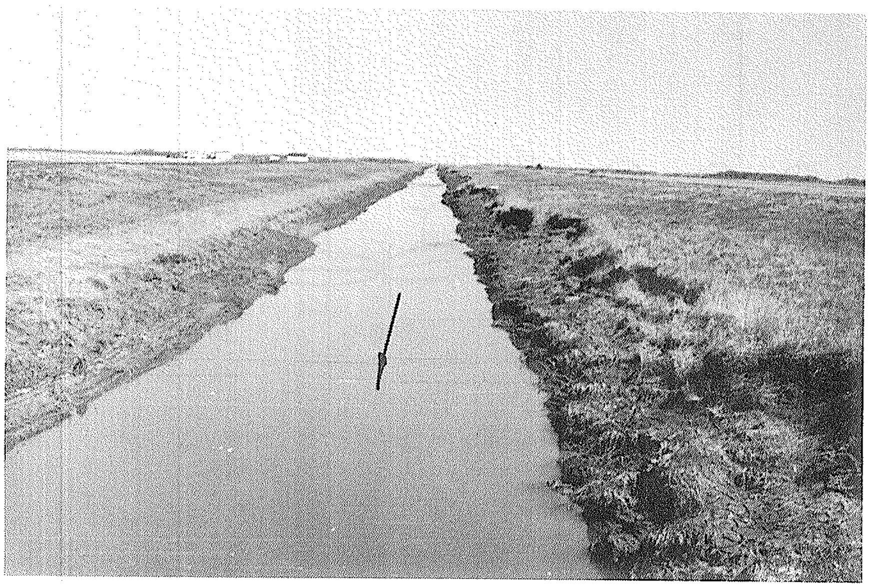
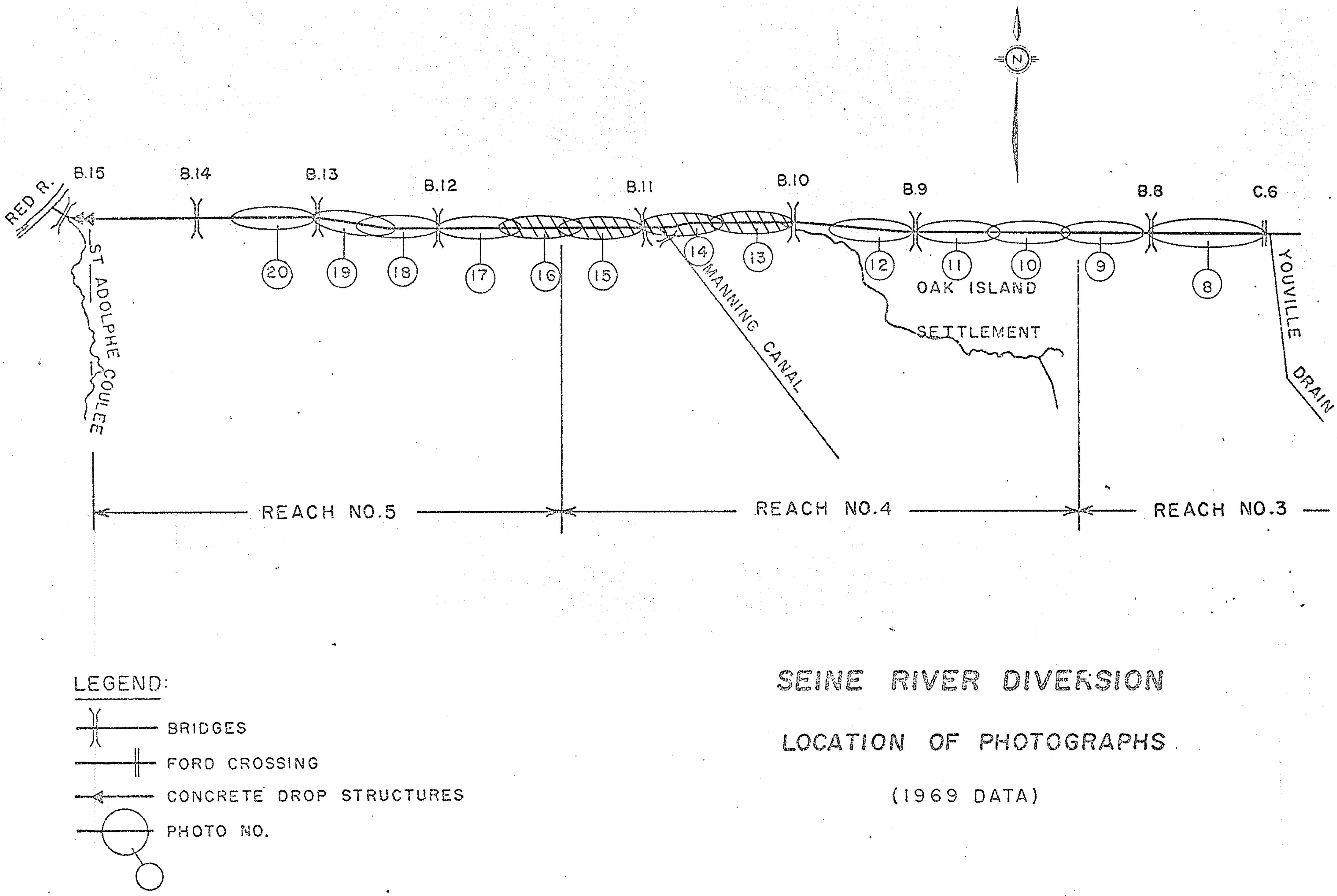


Ph.11. May 13, 1969

Ph.12. May 13, 1969

PLATE 3.7



SEINE RIVER DIVERSION

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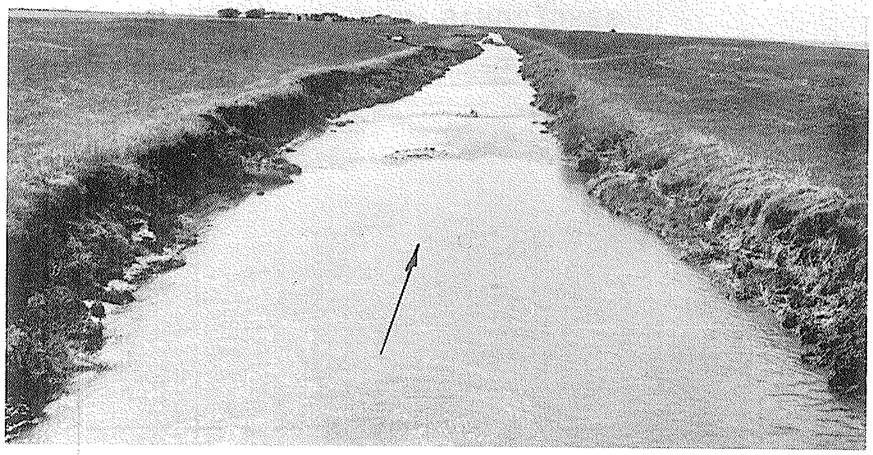

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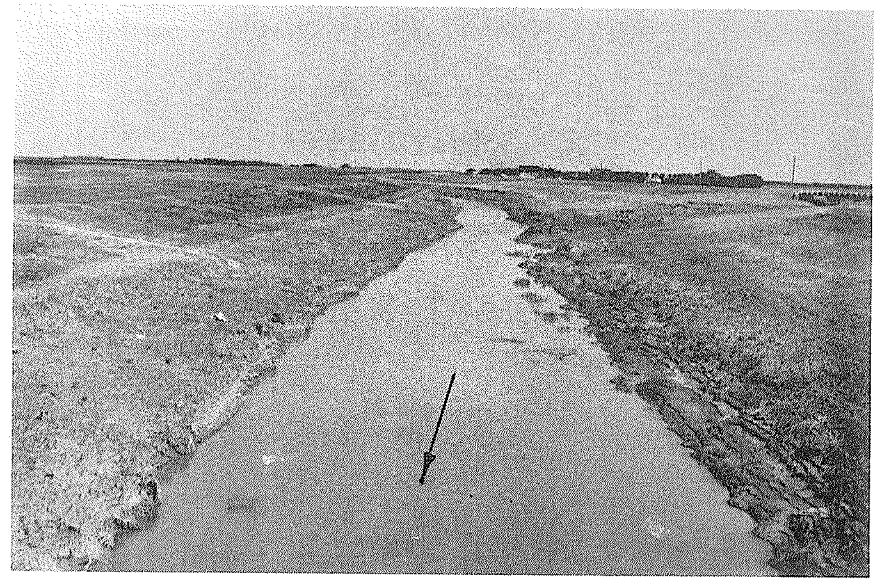

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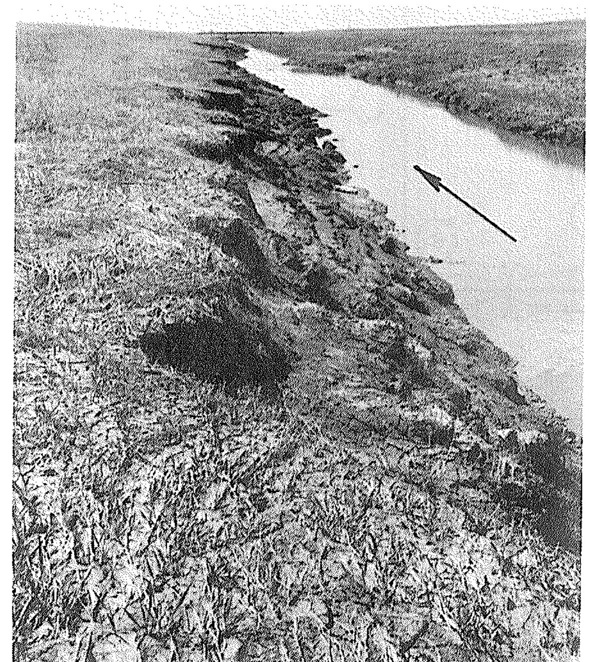
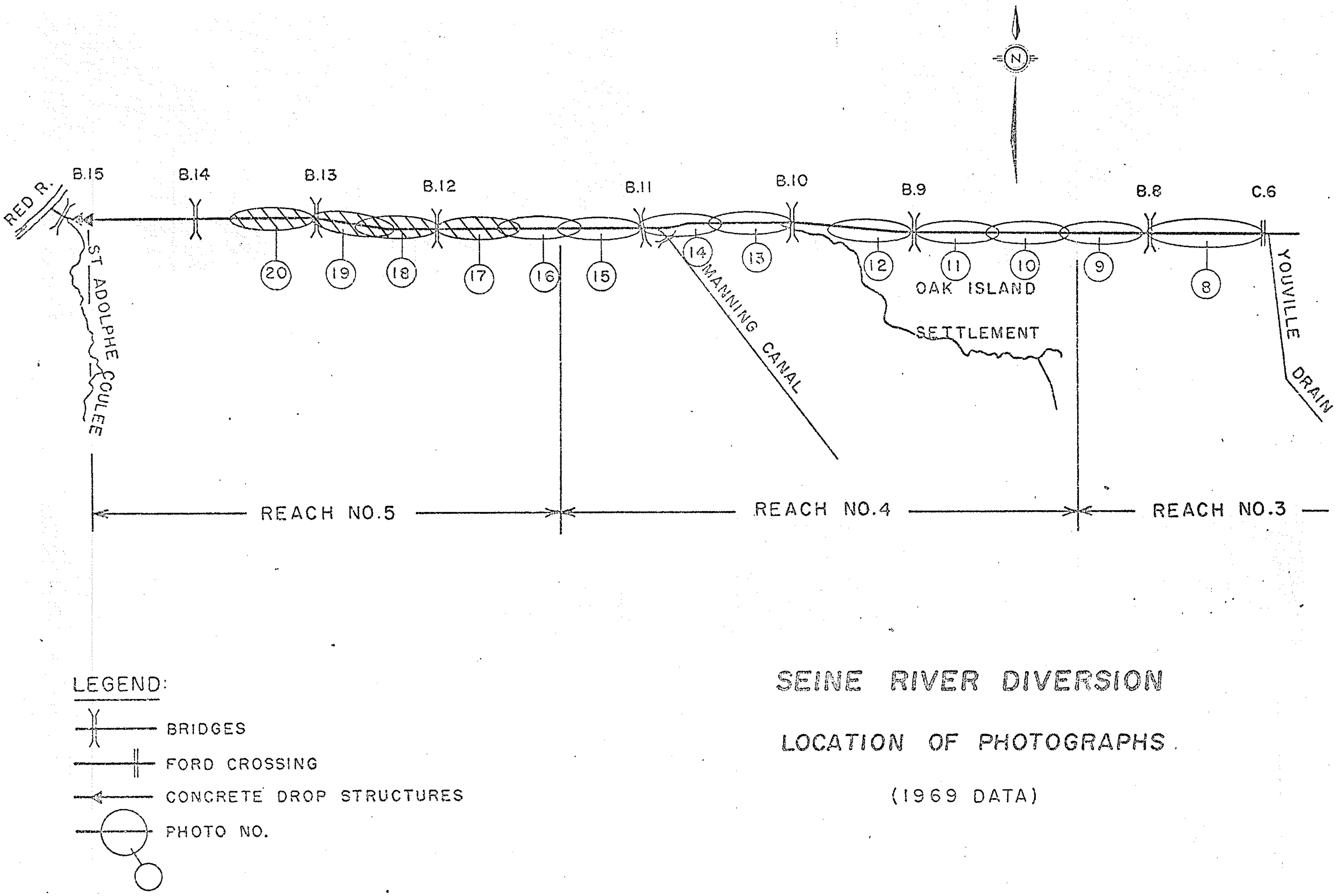


Ph.16. May 17, 1969

PLATE 3.8



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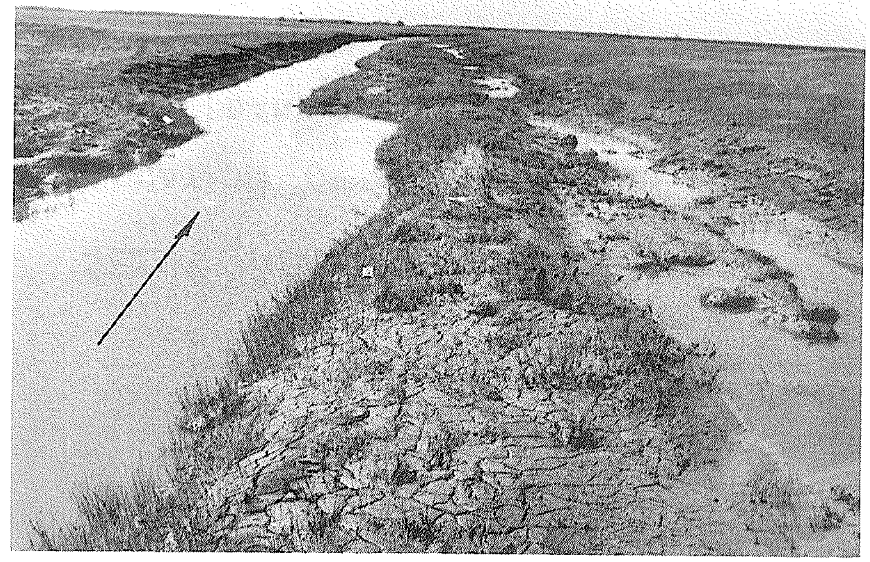

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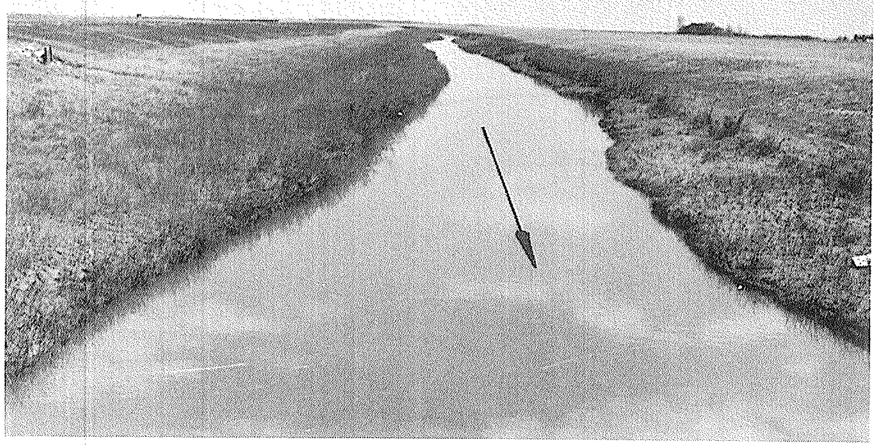

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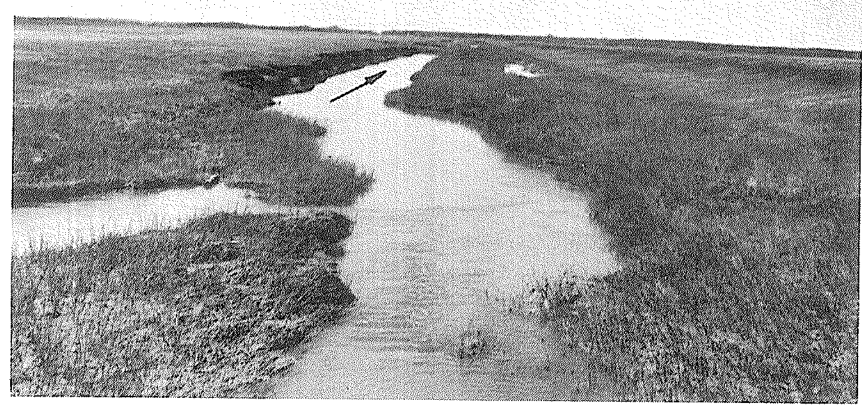
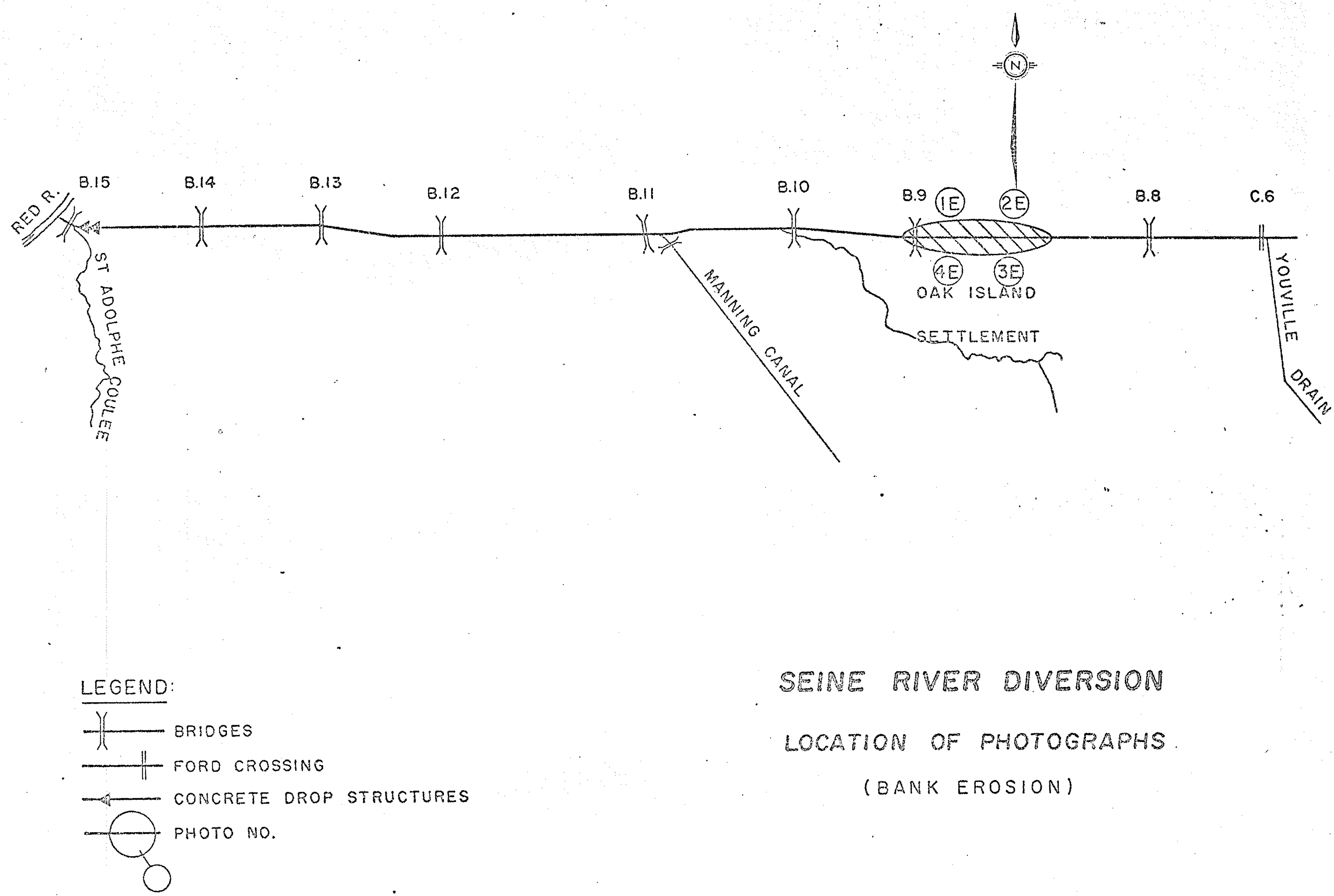


Ph. 20. May 17, 1969

PLATE 3.9



SEINE RIVER DIVERSION

LOCATION OF PHOTOGRAPHS

(BANK EROSION)

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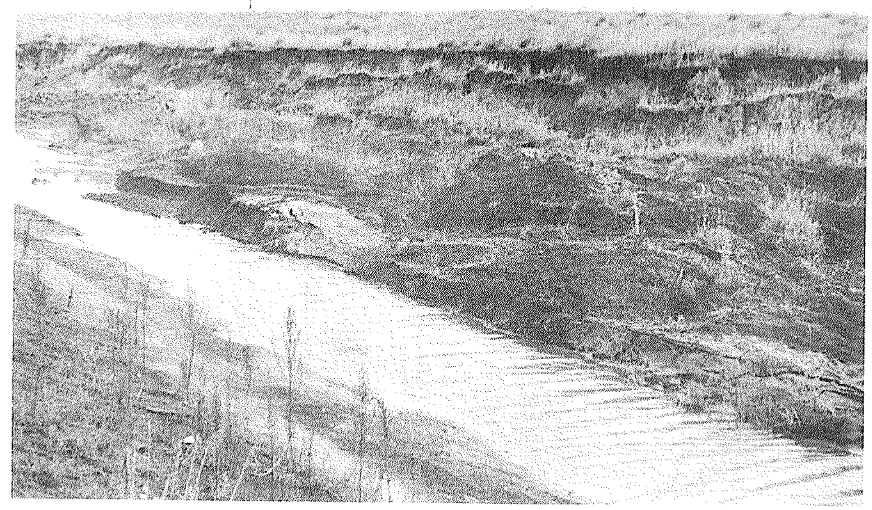
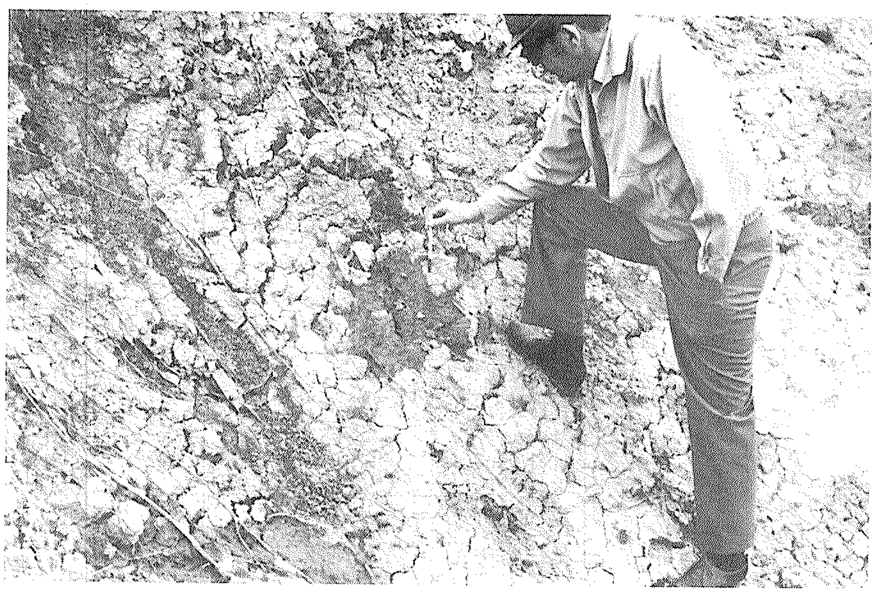


Ph. 2E. Oct., 1968



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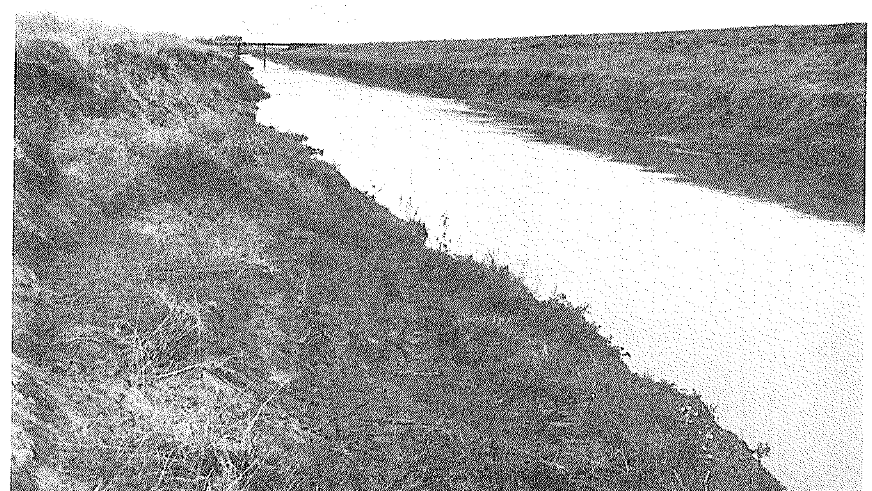
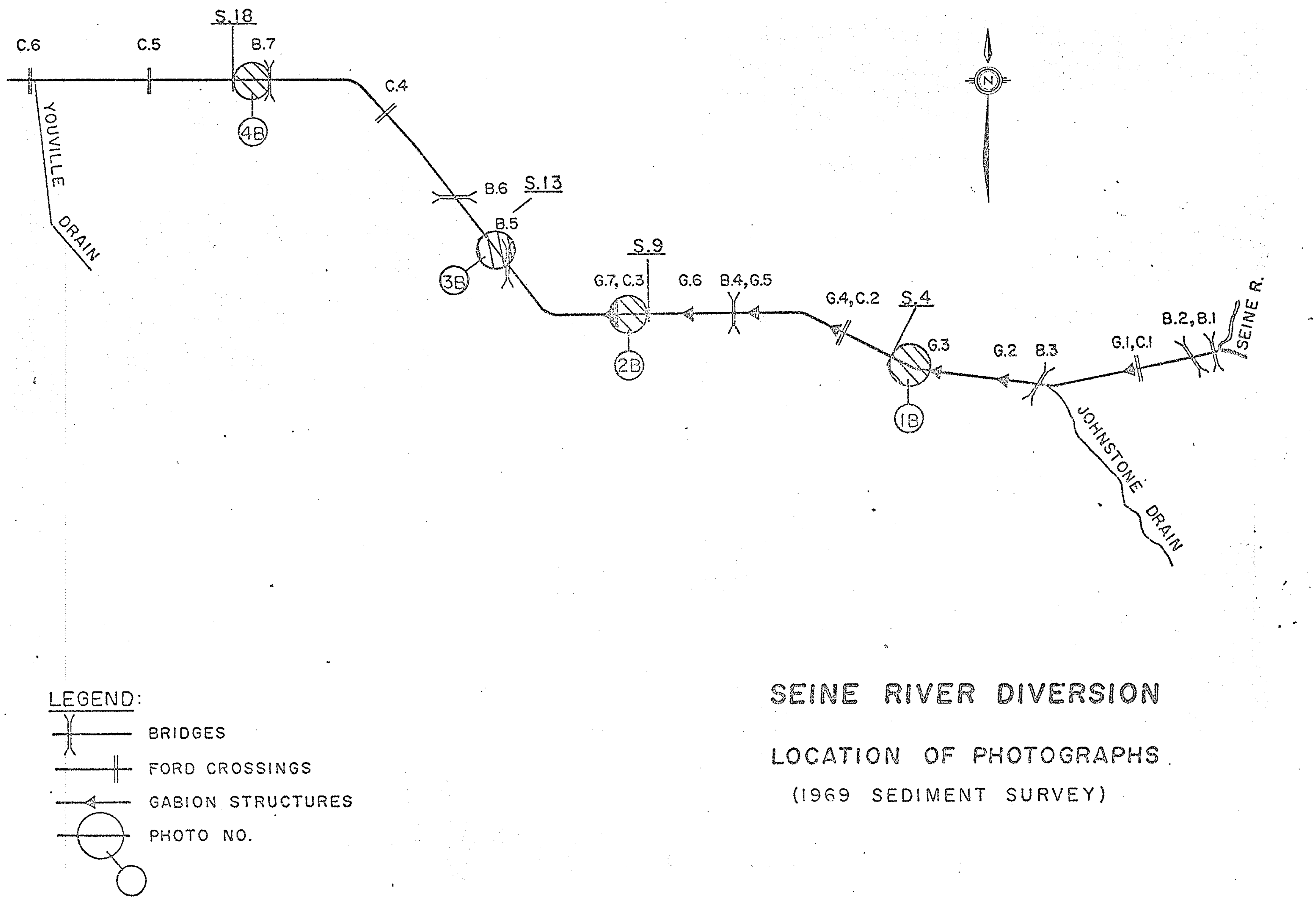


Ph. 4E. June 6, 1969

TYPICAL BANK EROSION IN THE OAK ISLAND SETTLEMENT

PLATE 3.10

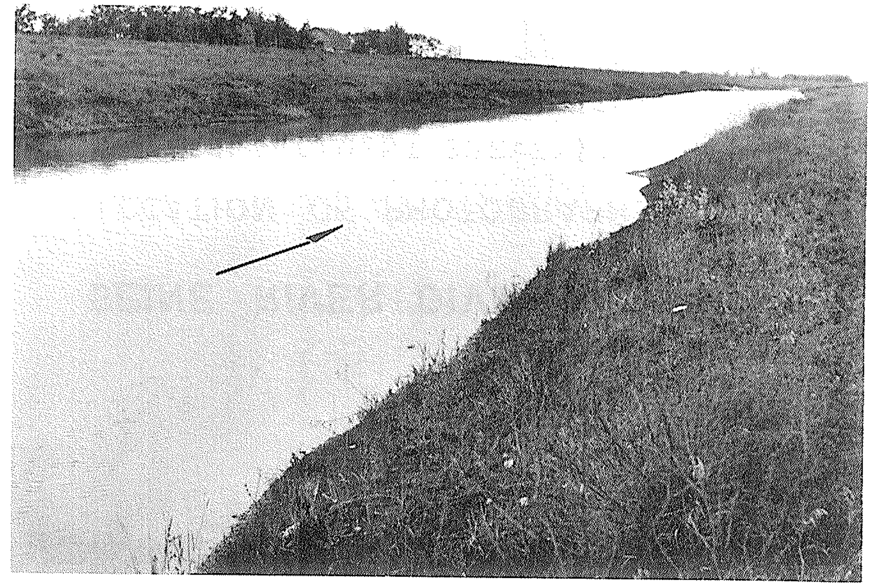


SEINE RIVER DIVERSION

LOCATION OF PHOTOGRAPHS

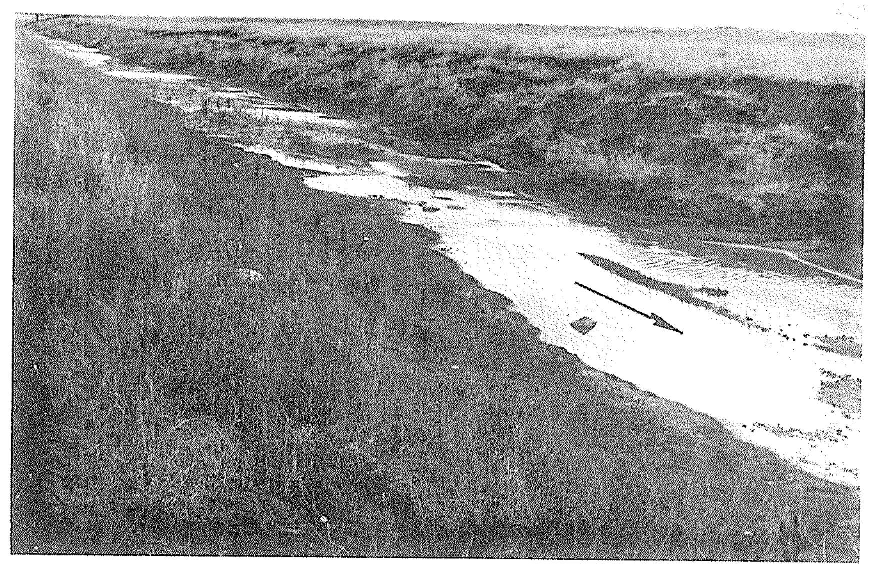
(1969 SEDIMENT SURVEY)

Ph. 1B. Oct. 6, 1969



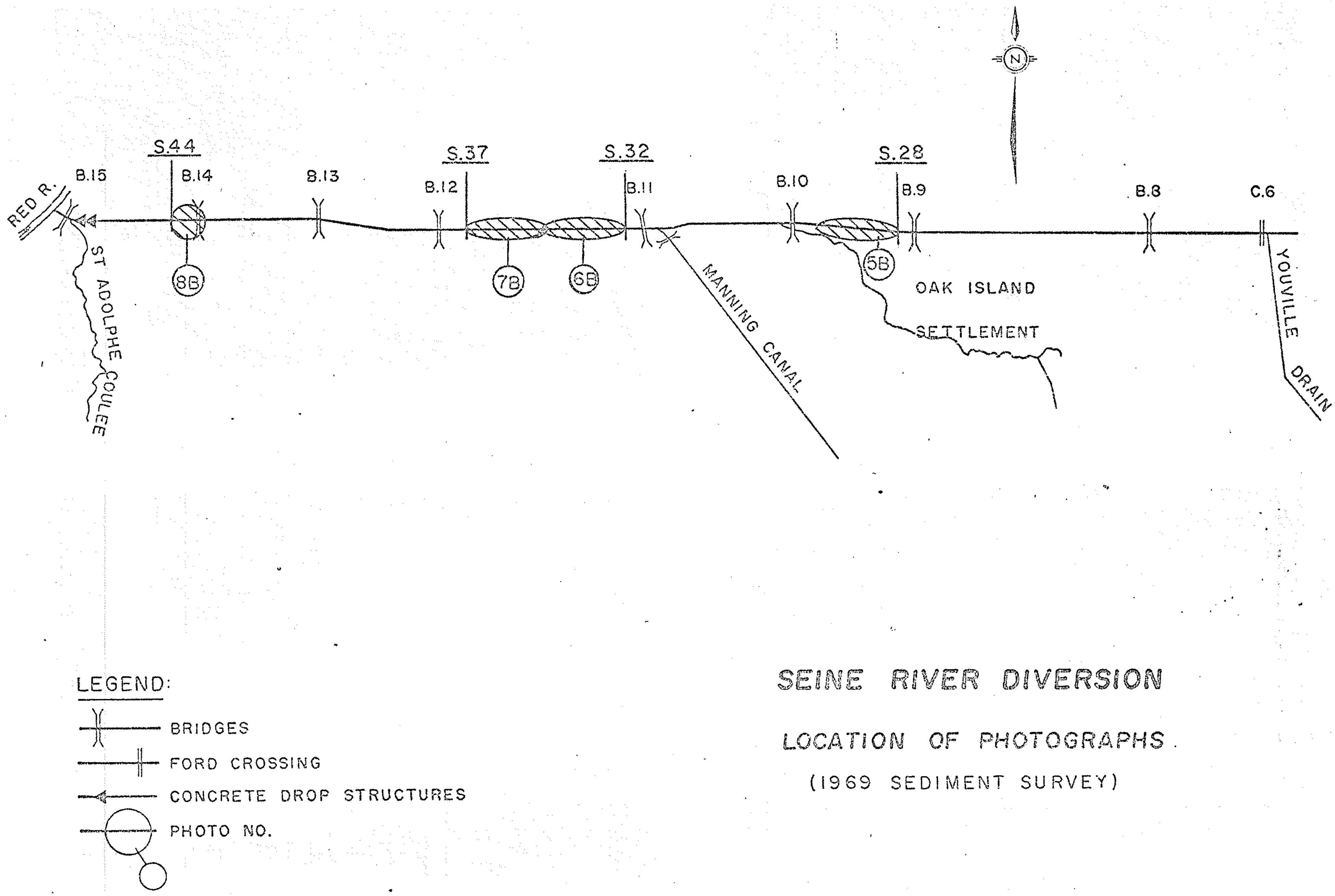
Ph. 2B. Oct. 6, 1969

Ph. 3B. Oct. 6, 1969



Ph. 4B. Oct. 6, 1969

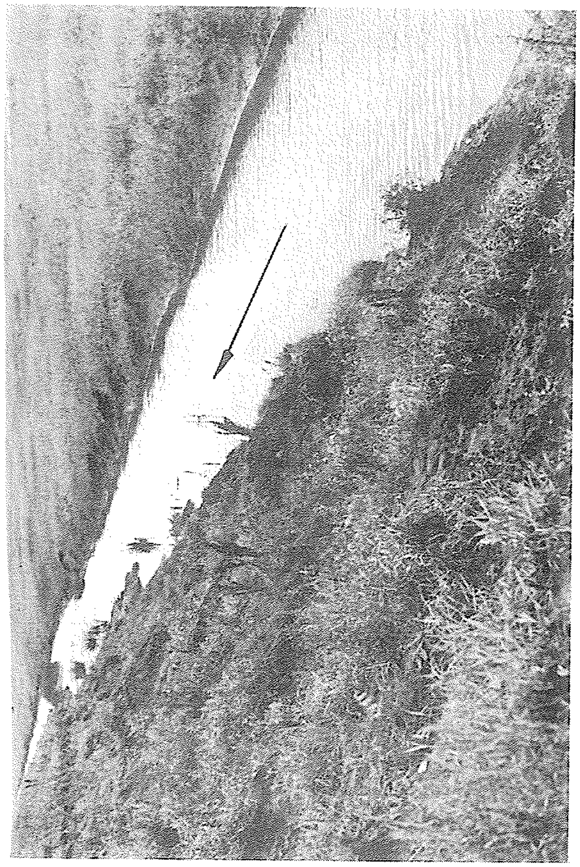
PLATE 3.11



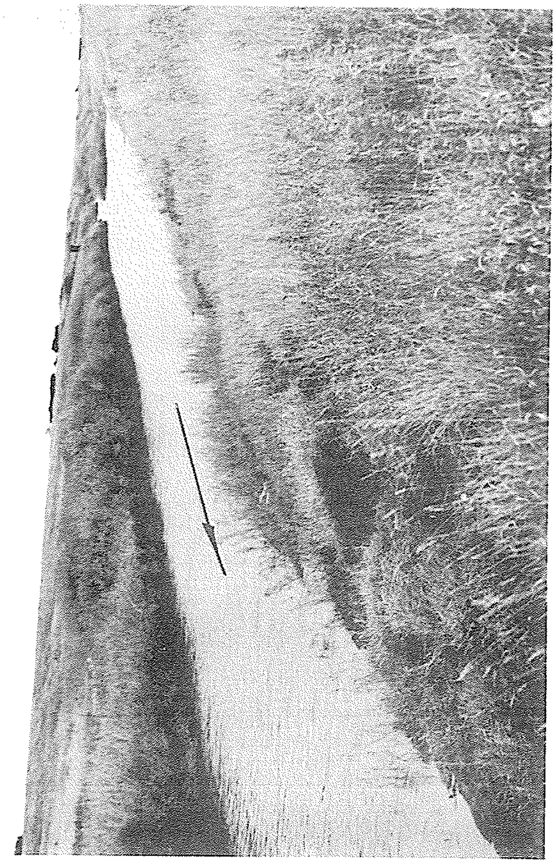
SEINE RIVER DIVERSION

LOCATION OF PHOTOGRAPHS

(1969 SEDIMENT SURVEY)



Ph. 6B. Oct. 6, 1969



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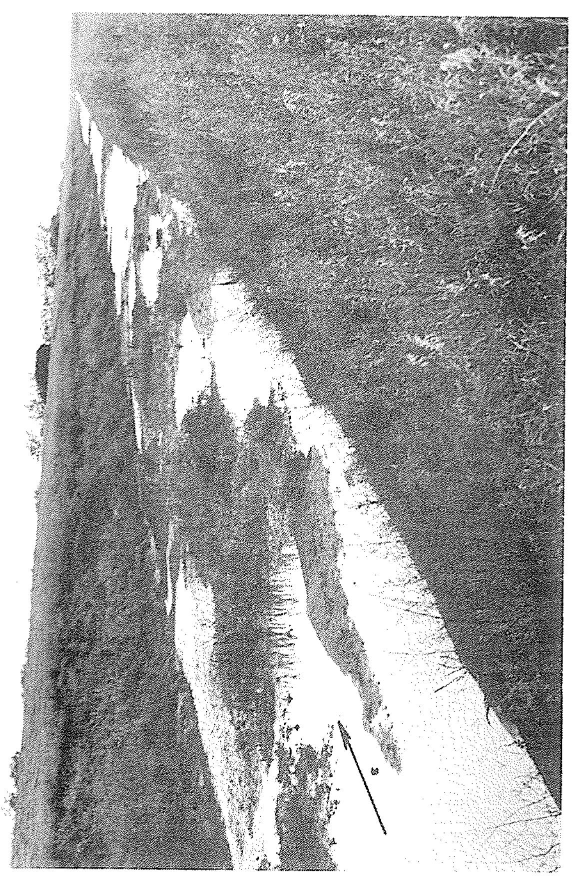


Ph. 5B. Oct. 6, 1969

Ph. 7B. Oct. 6, 1969

PLATE 3.12

Appendix A

STABLE CHANNEL CONCEPTS

A.1 CONCEPT OF THE STABLE CHANNEL

The definition of a stable channel in alluvial materials is associated with the concept of graded streams and canals in regime. In 1948 J.H. Mackin[13] gave a definition of the graded stream that was later revised and applied to the regime canal by L.B. Leopold and T. Maddock Jr. In summary it is:

"A river or a canal in regime is one in which, over a period of years, the slope and channel characteristics: width, depth and roughness are delicately adjusted to provide, with the available discharge, just the velocity required for the transportation of the load supplied to it"

The regime canal is a system in equilibrium and has a stable channel; that is, over a period of years, its bed and banks are not scoured by the moving water and objectionable deposits of sediment do not occur in it.

A.2 STABLE CHANNEL DESIGN THEORIES

PERMISSIBLE VELOCITY THEORY

The permissible velocity design procedure consists of designing the channel for the maximum velocity which the alluvial material can withstand without movement of the granular particles. The limiting velocity will prevent severe

TABLE A-1

MAXIMUM PERMISSIBLE CANAL VELOCITIES

Material	n	Clear water		Water transporting colloidal silts	
		V, fps	τ_0, lb/ft²	V, fps	τ_0, lb/ft²
Fine sand, colloidal	0.020	1.50	0.027	2.50	0.075
Sandy loam, noncolloidal	0.020	1.75	0.037	2.50	0.075
Silt loam, noncolloidal	0.020	2.00	0.048	3.00	0.11
Alluvial silts, noncolloidal	0.020	2.00	0.048	3.50	0.15
Ordinary firm loam	0.020	2.50	0.075	3.50	0.15
Volcanic ash	0.020	2.50	0.075	3.50	0.15
Stiff clay, very colloidal	0.025	3.75	0.26	5.00	0.46
Alluvial silts, colloidal	0.025	3.75	0.26	5.00	0.46
Shales and hardpans	0.025	6.00	0.67	6.00	0.67
Fine gravel	0.020	2.50	0.075	5.00	0.32
Graded loam to cobbles when noncolloidal	0.030	3.75	0.38	5.00	0.66
Graded silts to cobbles when colloidal	0.030	4.00	0.43	5.50	0.80
Coarse gravel, noncolloidal	0.025	4.00	0.30	6.00	0.67
Cobbles and shingles	0.035	5.00	0.91	5.50	1.10

Source: Ven Te Chow[5].

erosion of the channel; its values have been recorded in straight channels constructed in different kinds of soil. TABLE A-1 shows the permissible canal velocities recommended by S. Fortier and F.C. Scobey(7) and the corresponding unit-tractive force values converted by the U.S. Bureau of Reclamation. FIGURES A.1 and A.2 show the curves based on the U.S.S.R. data of permissible velocities for cohesive soils and the appropriate correction factor taking account of the effect of the depth of flow.

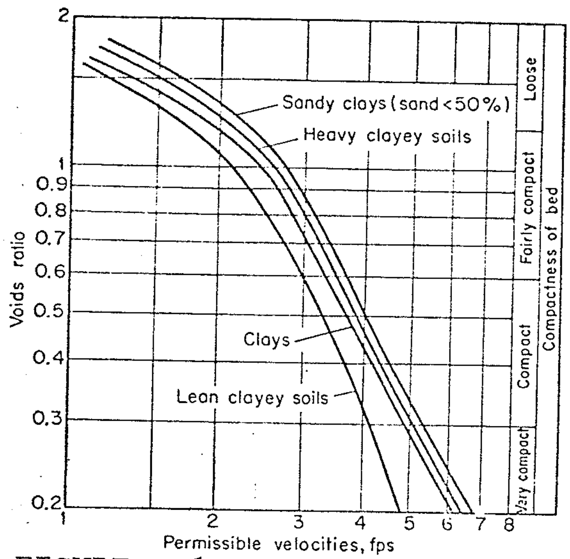


FIGURE A.1 - Curves showing U.S.S.R. data on permissible velocities for cohesive soils. Source: V.T. Chow(5)

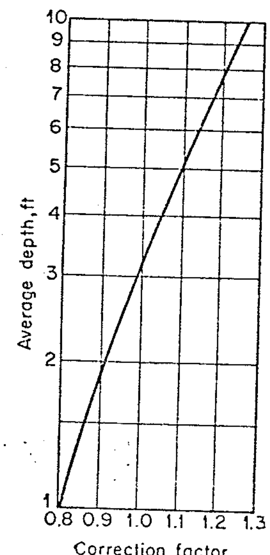


FIGURE A.2 - Curves showing U.S.S.R. corrections of permissible velocity for cohesive and non-cohesive materials. Source: V.T. Chow(5)

TRACTIVE FORCE THEORY

The tractive force design theory is formulated on the basis that stability of bank and bed material is a function of the ability of the banks and bed to resist erosion resulting from the drag force exerted on them by the moving water. In uniform flow, the tractive force is equal to the effective component of the gravity force acting on the body of water parallel to the channel bottom. Its maximum value in wide channels is given by the Du Boys' tractive force equation:

$$\tau = \gamma DS \qquad (1)$$

where: γ = specific weight of water

D = depth of flow in the channel

S = slope of the channel.

Curves plotted in FIGURE A.3 relating the permissible unit-tractive force to the void ratio of cohesive materials are those obtained from conversion of U.S.S.R. data on safe limiting velocities. Many investigators have made studies

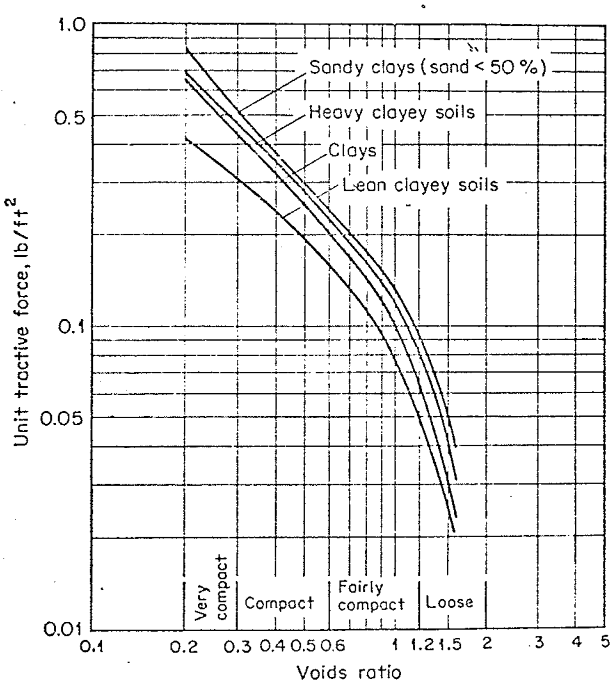


FIGURE A.3 - Permissible unit-tractive force for canals in cohesive materials.
Source: V.T. Chow(5)

involving field observations, flume tests and shear tests in specially designed apparatus to measure the scour resistance of cohesive soils related to their physical proprieties. Among others, E.T. Smerdon and R.P. Beasley[21] after a series of flume tests correlated the critical tractive force causing noticeable bed degradation to the soil proprieties such as: plasticity index, dispersion ratio, mean particle size and percent of clay. The relations of critical tractive force versus plasticity index and percent clay are presented in FIGURES A.4 and A.5.

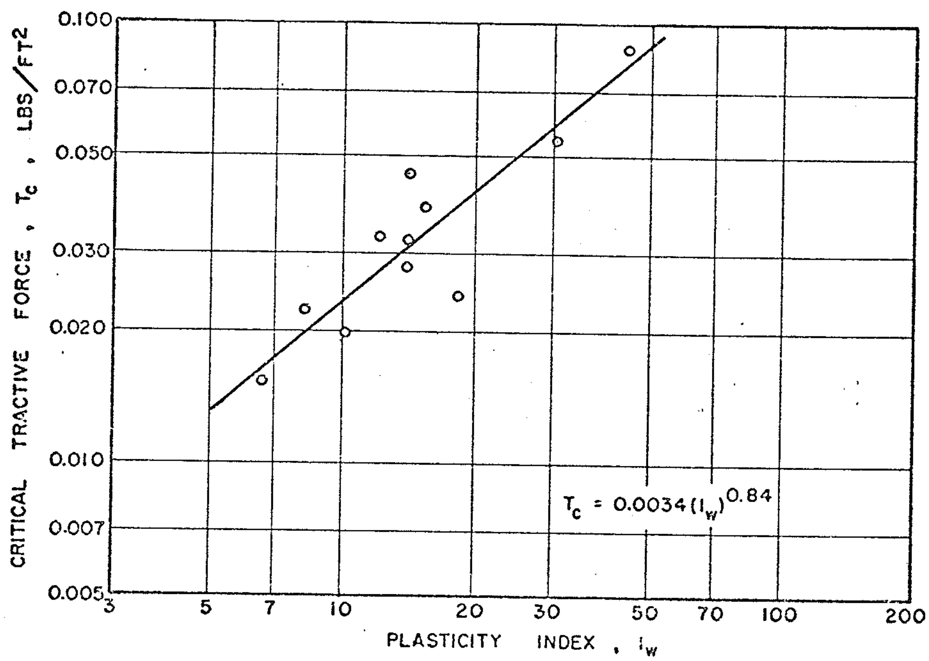


FIGURE A.4 - Critical Tractive Force versus Plasticity index, after Smerdon and Beasley[21].

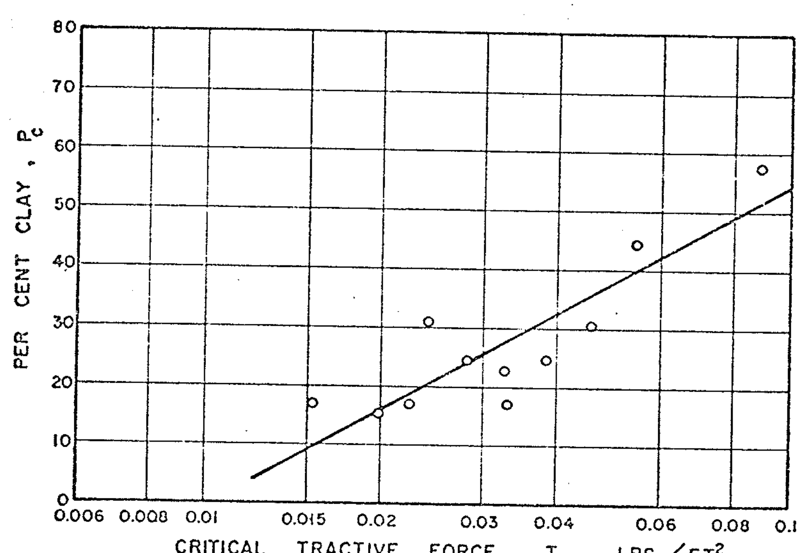


FIGURE A.5 - Critical Tractive Force versus Percent Clay, after Smerdon and Beasley[21].

REGIME THEORY

The regime theory originated with the analysis of stable irrigation canals in India and was introduced by R.G. Kennedy in 1895 when he presented his empirical equation for the "critical" mean velocity. In 1919, E.S. Lindley[12] verbally expressed the regime theory:

"When an artificial canal is used to convey silty water, both bed and banks scour or fill, changing depth, gradient and width, until a stage of balance is attained at which the channel is said to be in regime".

The development of the modern regime theory is, however, due to G. Lacey[8] when in 1929 he published his regime equations based on measurements of channel characteristics made on reaches of Indian canals that had achieved a stable cross section. These equations are:

$$V = 1.15\sqrt{f\ R} \qquad (2)$$

$$P = 2.67\ Q^{\frac{1}{2}} \qquad (3)$$

$$S = \frac{f^{5/3}}{1788\ Q^{1/6}} \qquad (4)$$

where:
- V = mean velocity
- R = hydraulic radius
- P = wetted perimeter
- Q = discharge
- f = silt factor.

These equations were later modified and improved by several individuals, namely C.C. Inglis and T. Blench. Blench[4] separated the effect of the sides and bed of the channel by means of the side and bed factors. His regime equations are:

$$W = \sqrt{\frac{f_b\ Q}{f_s}} \tag{5}$$

$$d_A = \sqrt[3]{\frac{f_s\ Q}{f_b^{2}}} \tag{6}$$

$$S = \frac{f_b^{5/6} f_s^{1/12}}{\frac{3.63}{\nu^{\frac{1}{4}}}\ g\ Q^{1/6}} \tag{7}$$

where: W = average width

d_A = Average depth

f_b = bed factor depending of bed sediments

f_s = side factor depending on bank material

ν = kinematic viscosity

g = acceleration due to gravity.

More recently, D.B. Simons and M.L. Albertson[19] presented several relations based on field data obtained from canal studies in India, Pakistan and the Western United-States. Reproduction of several of these graphs are shown in FIGURES A.6 through A.12.

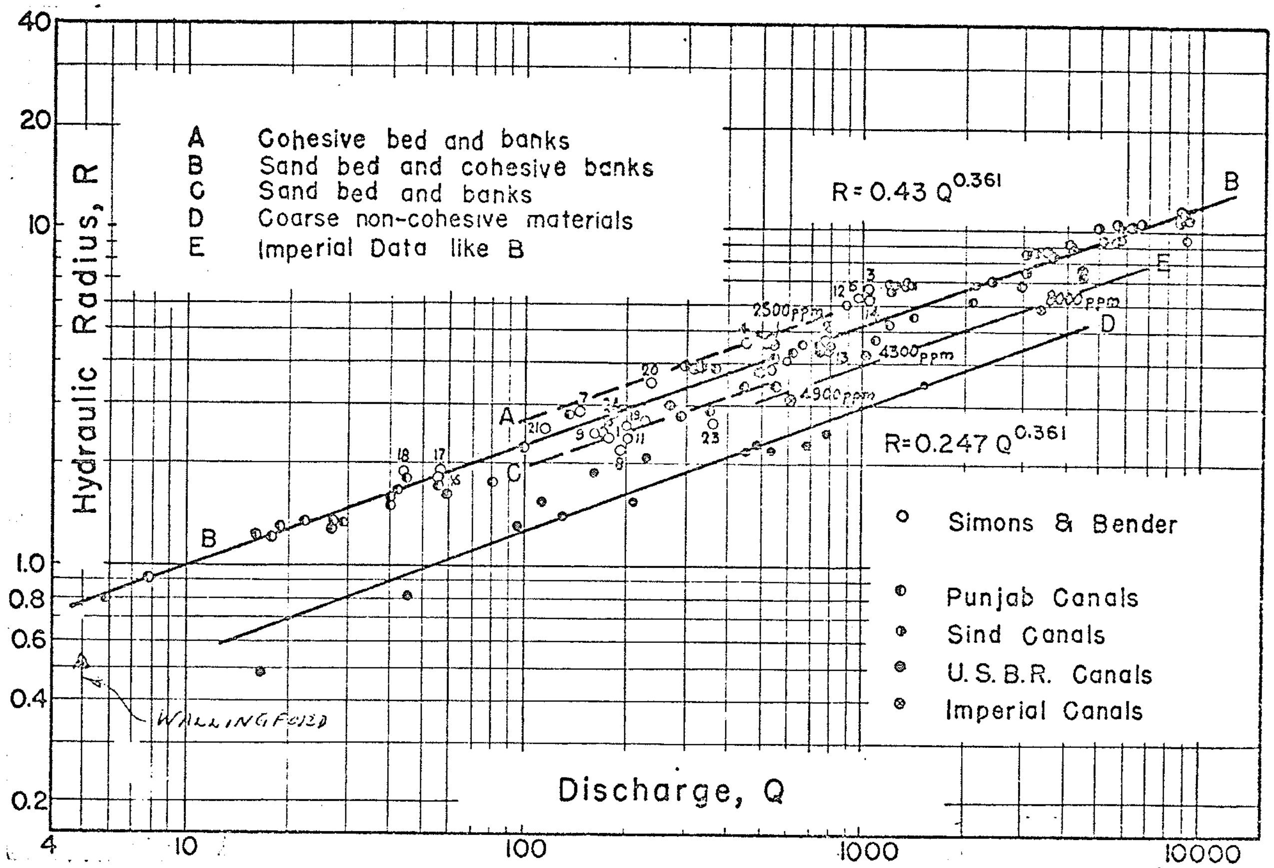


FIGURE A.6 - Variation of R with Q and Type of Channel.

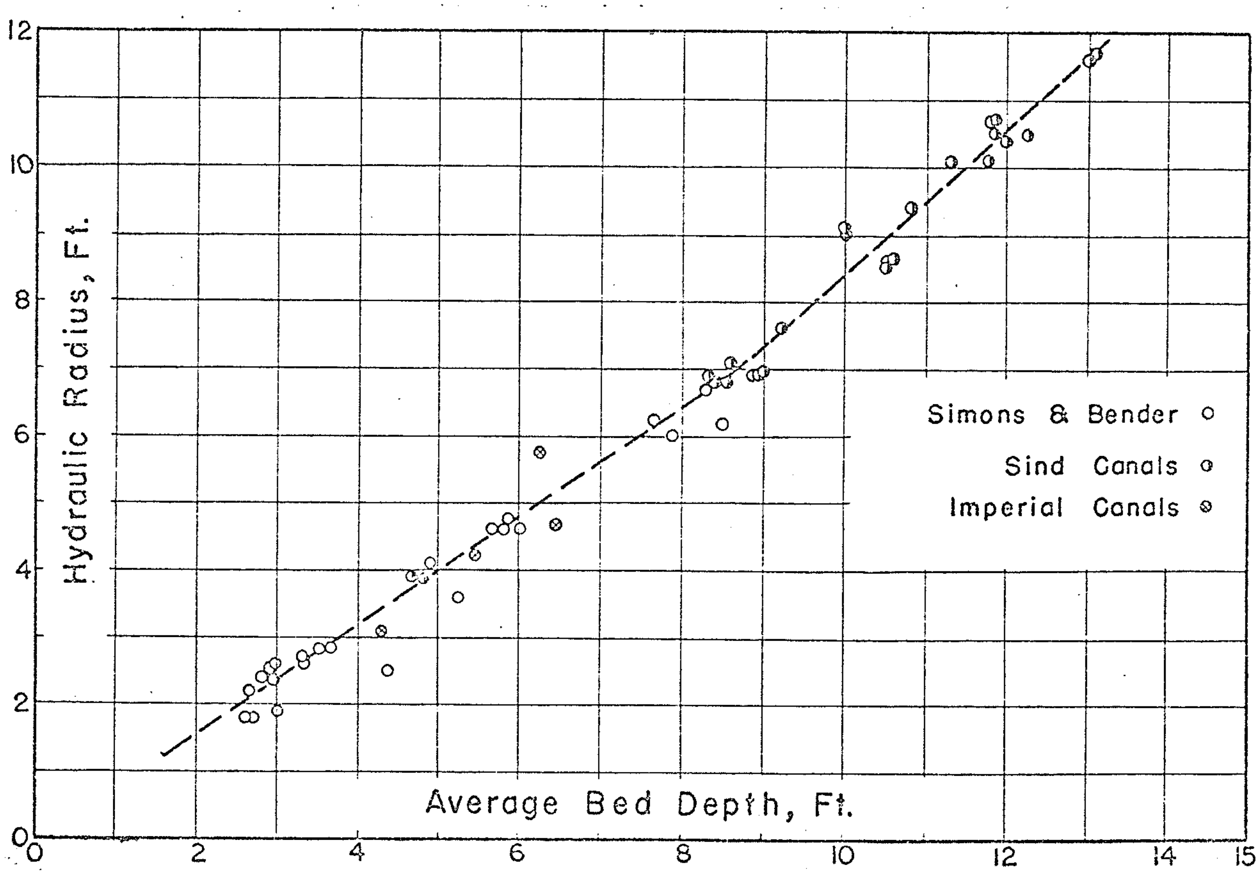


FIGURE A.7 - Variation of R with d_A.

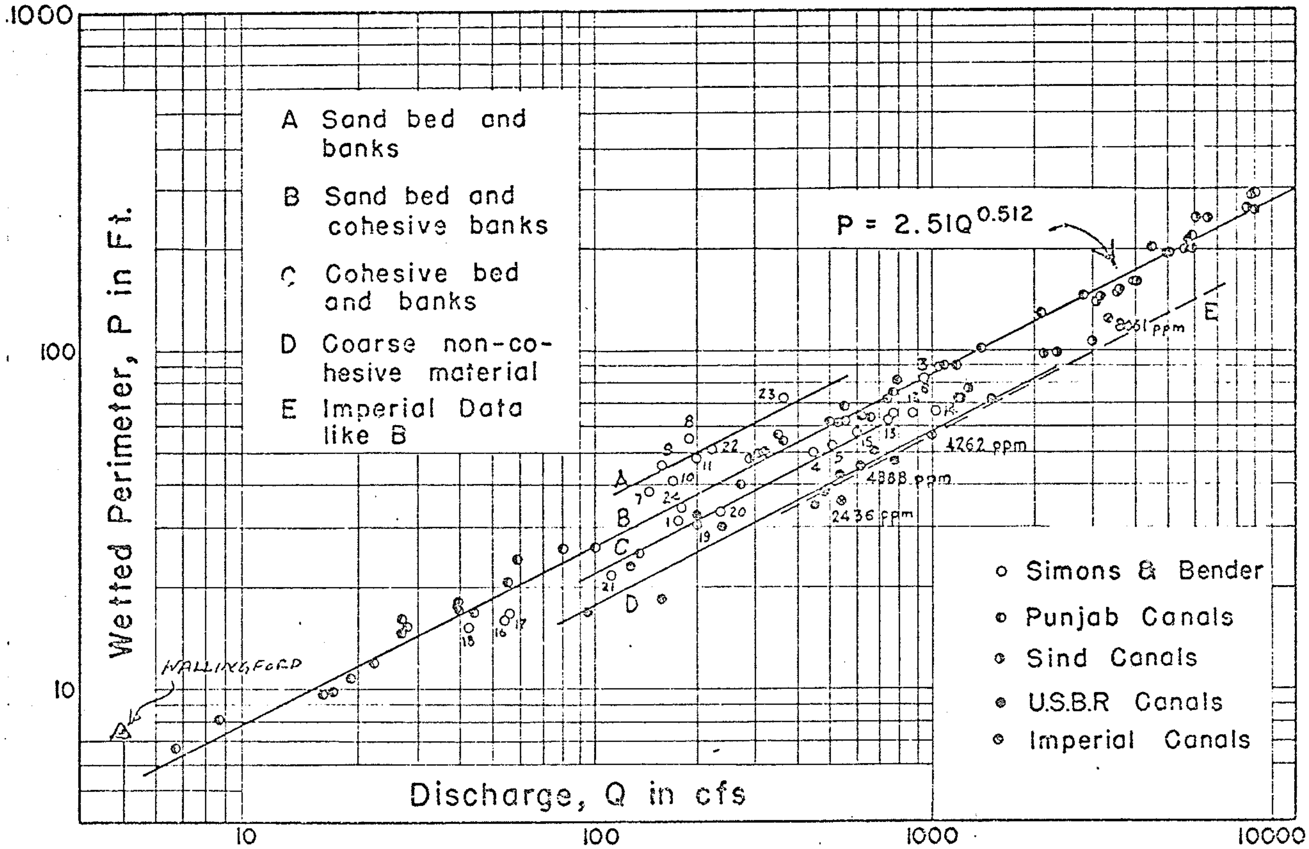


FIGURE A.8 - Variation of P with Q and Type of Channel.

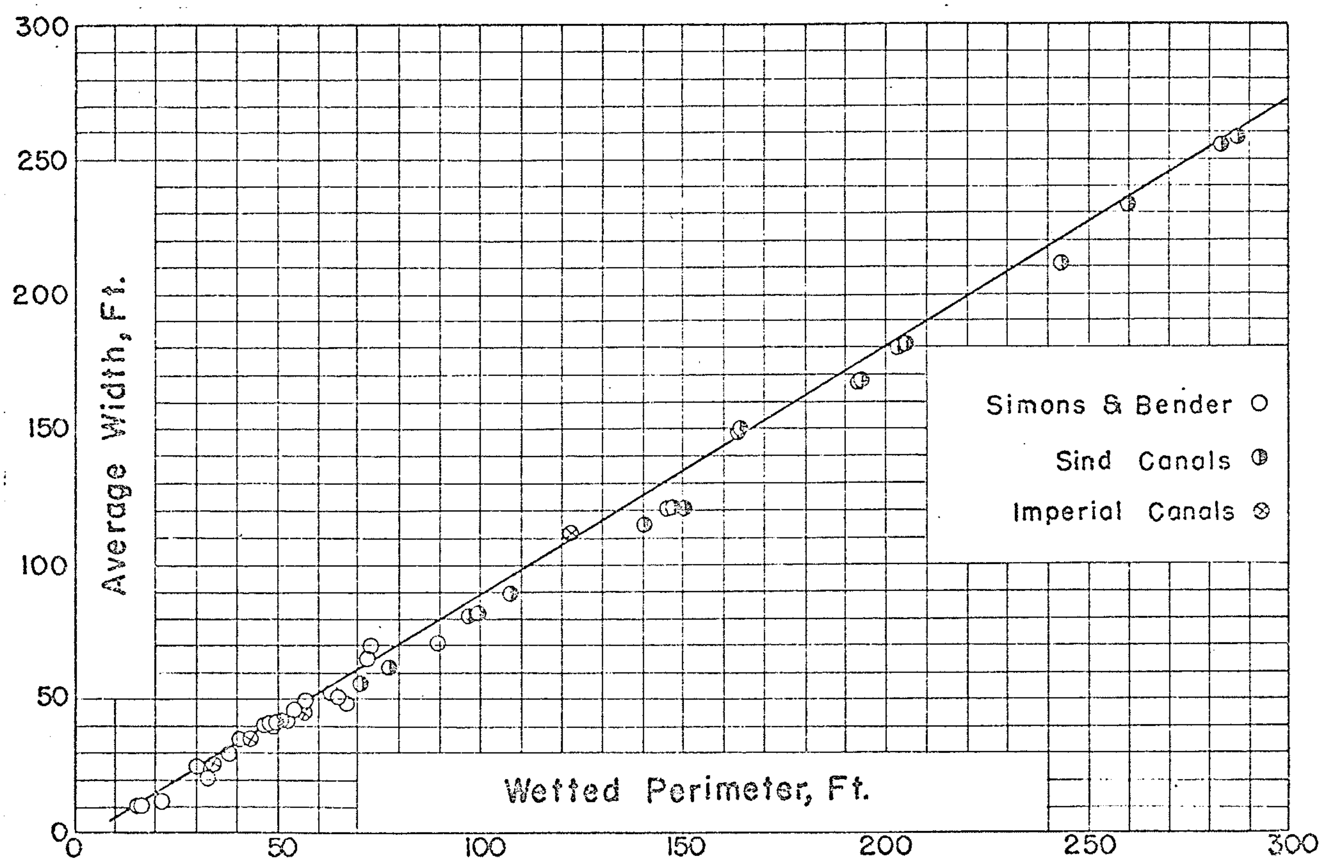


FIGURE A.9 - Variation of W with P.

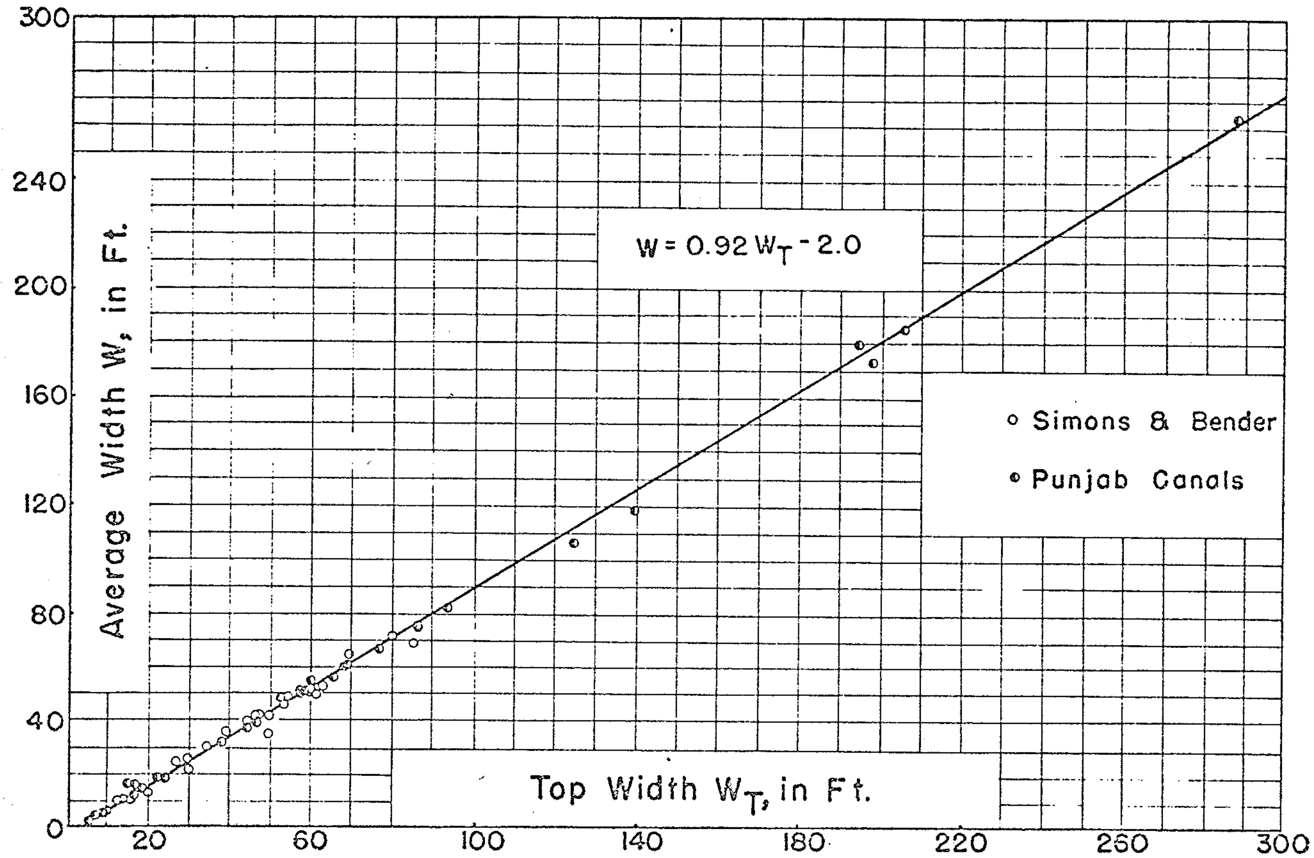


FIGURE A.10 - Variation of W with W_T.

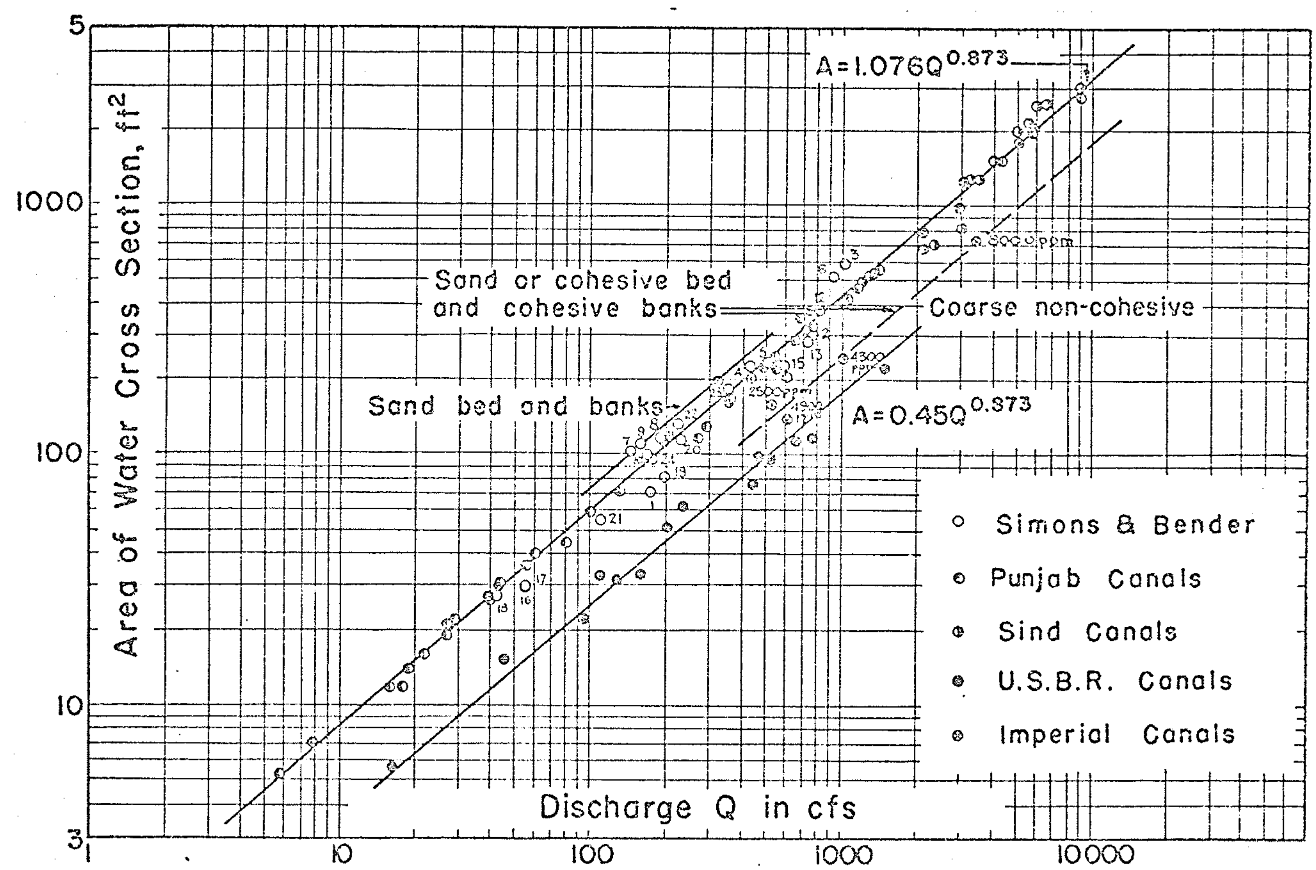


FIGURE A.11 - Variation of A with Q and Type of Channel.

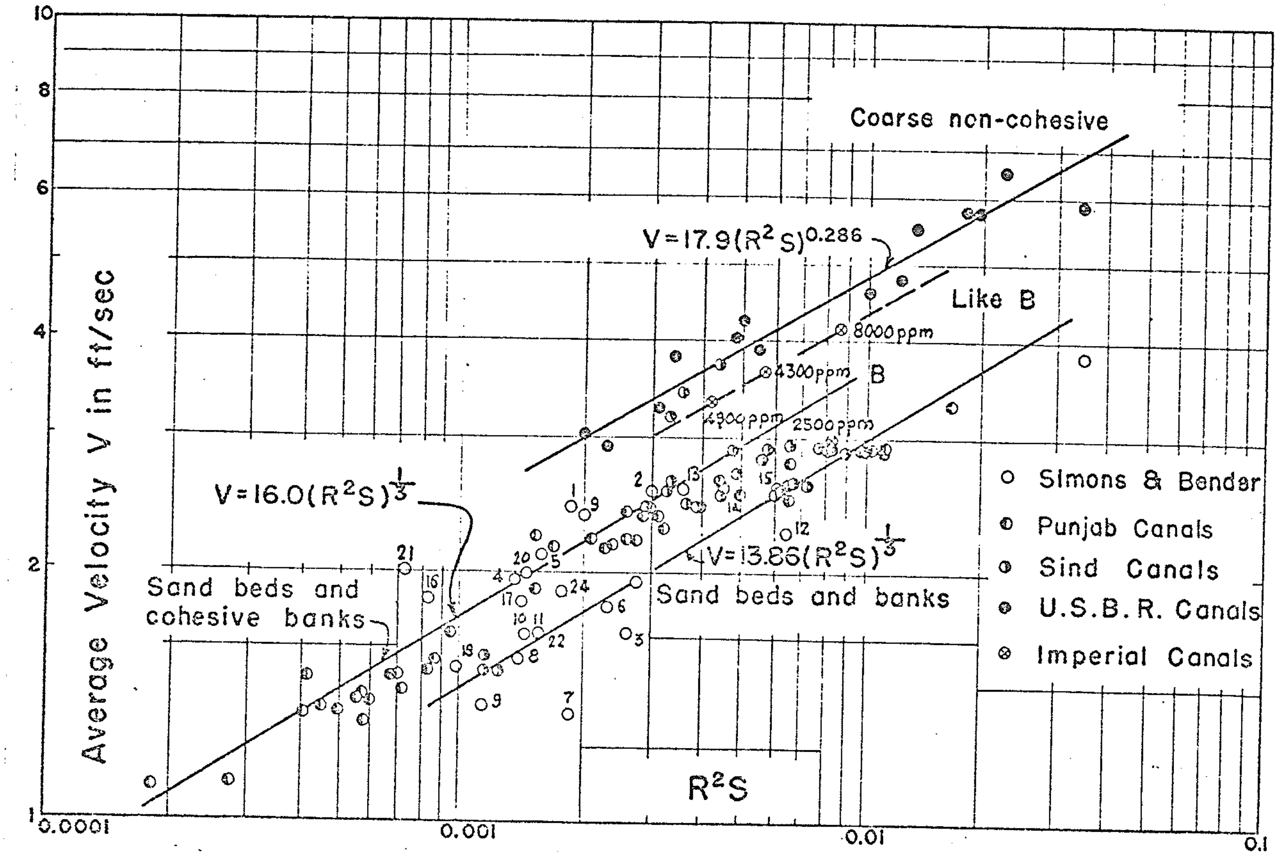


FIGURE A. 12 - Variation of V with R^2S and Type of Channel.

(Reproduction of these graphs have been made from Simons and Albertson(19).)

A.3 SCHUMM'S CONCEPTS OF THE SHAPE OF ALLUVIAL CHANNELS IN RELATION TO SEDIMENT TYPE

In investigating rivers of the Great Plains in United-States, S.A. Schumm found that the type of sediment encountered on the bed and banks of alluvial channels exerted a control on the cross sectional form. In his study of channel development in 1960-61[16,17,18], he selected a large range of streams in different climatic regions and areas in which difference in lithology within the drainage basin did not affect the stream and collected data on sediment character and channel shape at many cross sections that were ultimately determined to be stable or actively being aggraded or eroded. He stressed the importance of the effect of sediment type on channel shape and demonstrated the relationship that exists between the shape of stable cross sections expressed as a width-depth ratio (F) and the weighted mean percent silt-clay composing the perimeter of the channel. The weighted mean percent silt-clay is designated by (M) and calculated as follows:

$$M = \frac{S_c x W_B + S_b x 2D_B}{W_B + 2D_B} \qquad (8)$$

where: S_c = percentage of silt and clay in the channel alluvium

S_b = percentage of silt and clay in bank alluvium

D_B = channel depth

W_B = channel width

In his equation the channel depth is defined as the measured depth to the lowest part of the channel from the edge of the first terrace or bank above the channel floor or the upper limit of deposition of erosion along the sides. The channel

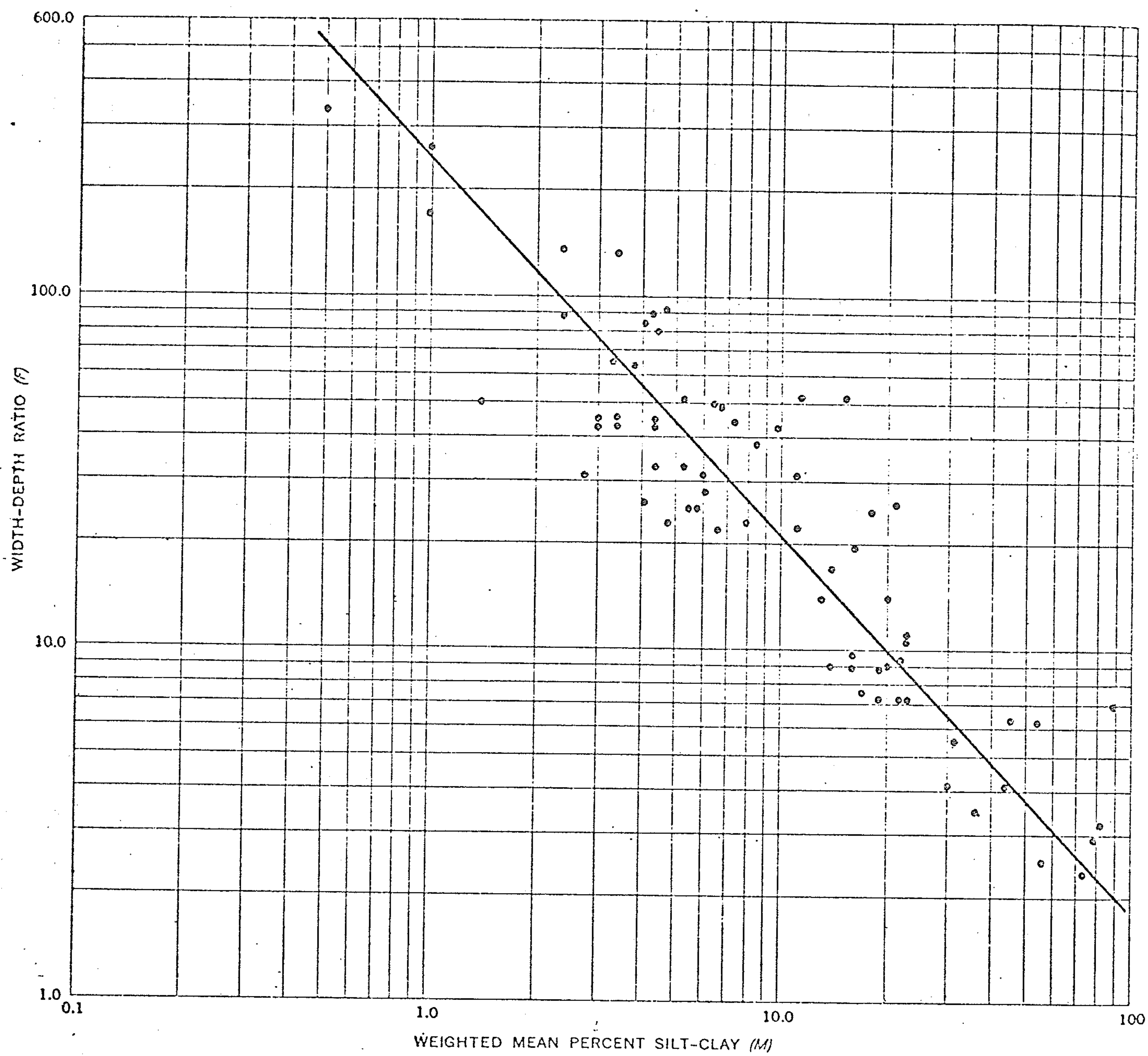


FIGURE A.13 - Relation of Width-depth ratio to Weighted Mean Percent Silt-clay for Stable Cross sections, after S.A. Schumm(16) width is the measured distance from one edge of a bank to the corresponding elevation on the opposite side, at a distance above the channel floor determined by the channel depth. The correlation between the values of width-depth ratio and the weighted mean values for the percent silt-clay in the channel and banks of stable alluvial stream channels is shown in FIGURE A.13. The regression line was determined graphically and bears the following equation: $F = 255\ M^{-1.08}$. The correlation shows that channels containing little silt-clay are relatively wide and shallow; whereas, those composed predominantly of silt-clay are relatively narrow and deep. Streams develop a channel form that is consistent with erodibility of the bed and bank material and the velocity and shear distributions. Soils containing a fair amount of silt and clay are cohesive and tend to resist erosion; hence, channels in this type of alluvium are observed to be deep and narrow since they can withstand high shear and the cohesiveness of the soil prevent bank sliding. On the other hand, there is little or no cohesion

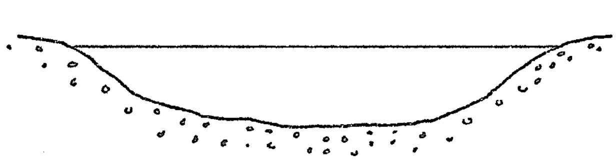


FIGURE A.14 - Typical Channel Cross section in Granular Soils

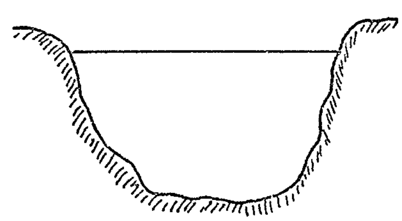


FIGURE A.15 - Typical Channel Cross Section in Cohesive Soils.

in sandy and gravel materials; therefore, these soils are easily eroded and the loose grains are removed immediately.

Channels in granular soils are relatively wide and shallow. The angle of repose of grains is important in determining the shape of these channels. FIGURES A.14 and A.15 show the typical shape of channels both in cohesive and non-cohesive soils.

Schumm also investigated the erosional and deposition process of unstable streams in the study areas and compared the channel and sediment characteristics with those of stable sections. The mean values of F and M for the cross sections determined as aggrading plotted all above the regression line characteristic of stable sections and those values for degrading cross sections plotted below the same line. It has been suggested that the relation between the mean values of width-depth ratio and percent silt-clay may be used as a criterion of channel stability. Aggrading channels plot well above the regression line; whereas, degrading channels plot below the line.

A.4 LEOPOLD AND MADDOCK'S CONCEPTS OF THE HYDRAULIC GEOMETRY OF STREAM CHANNELS

The velocity, width and depth of flowing water were observed to change as the discharge increases at any cross section of a river. The graph of these variables as function of the discharge "at a section" constitutes a part of what L.B. Leopold and T. Maddock Jr.(9) called the "Hydraulic Geometry" of stream channels. They plot as straight lines on logarithmic paper as shown in FIGURE A.16 and generally increase with increasing discharges as simple power functions expressed

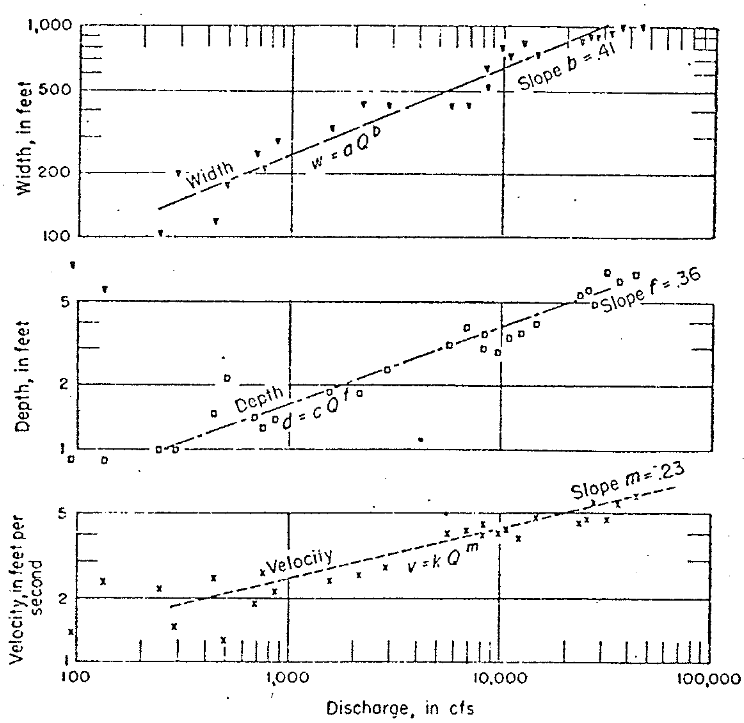


FIGURE A.16 - Relation of Width, Depth and Velocity to Discharge, after Leopold and Maddock.(9)

mathematically by:

$$W_s = a\ Q^b$$

$$D = c\ Q^f$$

$$V = K\ Q^m$$

where: W_s = water surface width

D = mean depth equal to A/W_s

V = mean velocity equal to Q/A

a, c, k, b, f, m = numerical constants.

The relationships between these constants are:

$$ack = 1.0$$

$$b+f+m = 1.0$$

The constants a, c and k represent the intercepts of the lines describing the relationship of variations in discharge to width, depth and velocity and are respectively the value of W_s, D and V at discharge of unity. The constants b, f and m are the slopes of the three lines on the graph and their sum must equal unity. They represent the relative rate of increase of width, depth and velocity with increasing discharges; they are therefore determined by the shape of the channel, the slope of the water surface and the roughness of the wetted perimeter. Their values essentially describe the geometry of the channel and resistance to erosion associated with the composition of the bed and banks material, and the transported load. Many analysis of river cross sections have been made for a large varieties of Rivers in the Great Plains and the Southwest of United States; they have provided a clear indication of the average values of the exponents in these equations. Each of these values at a section averages:

$$b = 0.26$$

$$f = 0.40$$

$$m = 0.34$$

These mean values are presented such that one may visualize the relative order of magnitude of these exponents. It does not imply that the values of b, f and m at a particular cross section of a stream should be closely similar. The type of soils encountered in the perimeter of the channel exerts a marked influence on the cross sectional form. In fact, a wide "dish-shaped" channel as shown in FIGURE A.14 has a rapid rate of increase in width with increasing discharges and therefore, a high value of the exponent b. On the other hand, a "box-like" channel with straight sides such as encountered in cohesive soils (FIGURE A.15), has a low value for b and a relatively high value for f. The values for $b = 0.04$, $f = 0.40$ and $m = 0.52$ at a station on Brandywine Creek(22) with cohesive bank material are an example of this influence. Analysis of variations in width, mean depth and mean velocity with mean annual discharge as discharges increase in the downstream direction have been made for various river systems through United States and for irrigation canals in India in order to determine how these variables change along the length of stream channels. These relationships were derived from measuring stations within the river basin and are shown in FIGURE A.17.

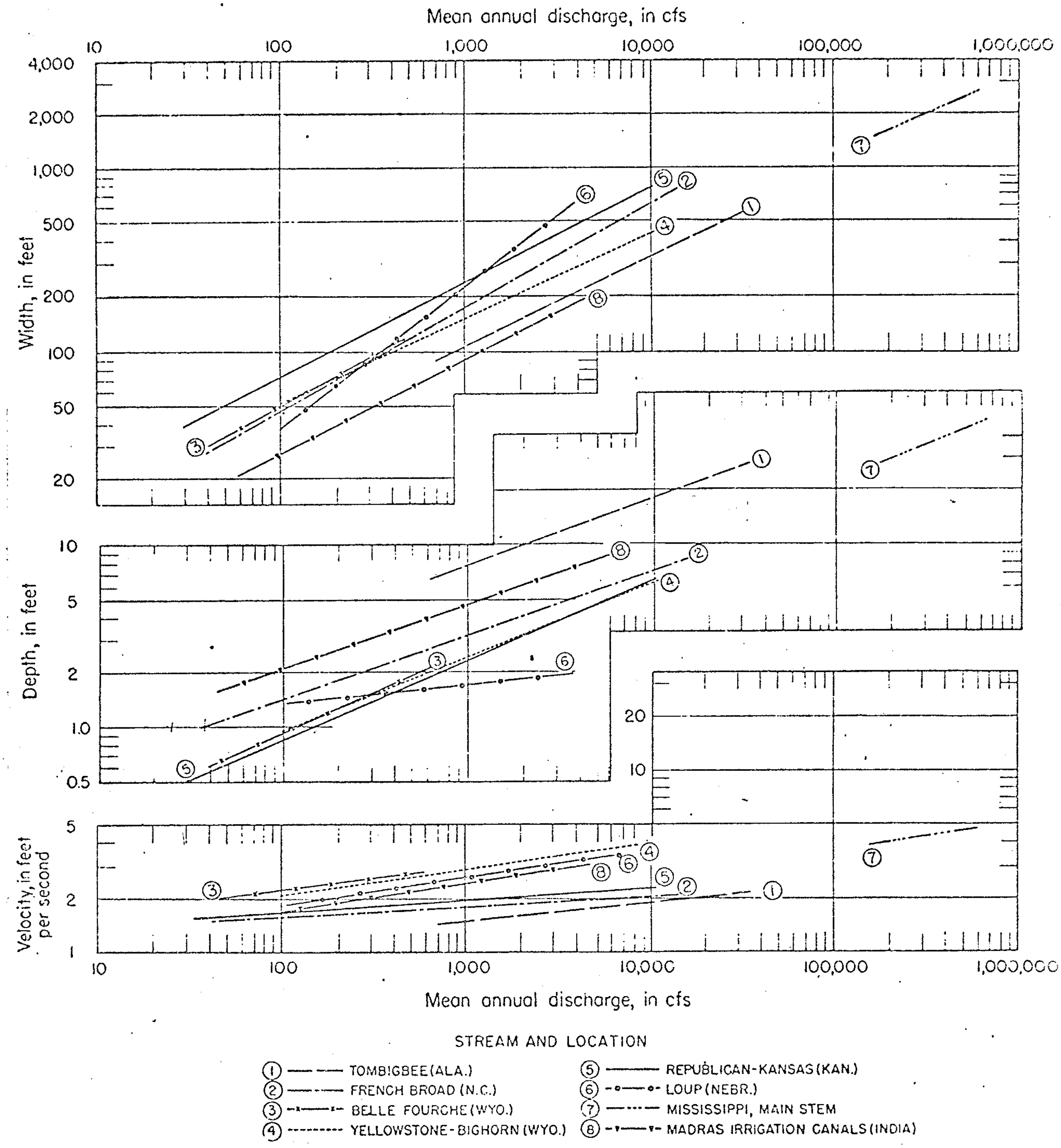


FIGURE A.17 - Width, Depth and Velocity in Relation to Mean Annual Discharge as Discharge Increases Downstream in Various River and canal Systems, after Leopold and Maddock(9).

From these curves it may be seen that there is considerable similarity in the slope of the lines among the various river channels and unlined irrigation canals. The average values of the exponents of the power functions describing these relations for river basins studied are:

$b = 0.50$

$f = 0.40$

$m = 0.10$

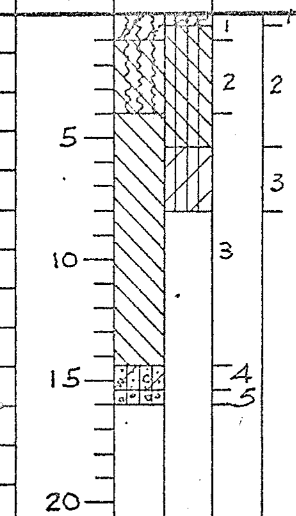
It may be concluded from the analysis made by Leopold and Maddock of the hydraulic geometry of stream channels at a section and in a downstream direction that for discharges of equal frequency, the mean width increases more rapidly than the mean depth ($b > f$) in a downstream direction and therefore, the width to depth ratio increases. Concomitant to the increased rate of change of width downstream, the rate at which the mean velocity increases is reduced ($m = 0.10 < m = 0.34$). This important conclusion drawn from the analysis of hydraulic characteristics of various river systems will be a useful tool in determining the characteristics of the redesigned channel in CHAPTER IV.

Appendix B

SOIL AND SEDIMENT DATA

TABLE B-1

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
828.00	5	46.0													
	10	58.0													
821.41	4	47.1	2.74	1.33	97.5	73.2	108.0	76	24	0	0	0	99	29	70
	6	59.3	2.74	1.68	96.5	63.7	101.4	76	23	1	0	0	106	25	81



Layer No. 1: Organic, moist, soft, dark grey clayed silt.
Layer No. 2: Organic, moist, soft, brown clayed silt with light and dark brown silty pockets.
Layer No. 3: Moist, soft, plastic brown clay with light and dark grey and brown silt pockets.
Layer No. 4: Moist, soft, grey clayed silt with large light and dark brown and grey silt and sand pockets. 2" diam. stones.
Layer No. 5: Wet, stiff, grey non-cemented glacial till.
Layer No. 1: Organic, dark grey clayed silt.
Layer No. 2: Moist, stiff, brown silty clay with grey and brown silt pockets.
Layer No. 3: Moist, soft, grey silty clay with light and dark grey silt pockets.

TEST HOLE NO. 1 AND 2
LOCATION AT STA. 5+00
57' S. of ℄ AT STA. 38+76
HOLE ADVANCED BY 4" ∅ Sc. Aug.
DATE Aug. 31, 1960 Sept 9, 63

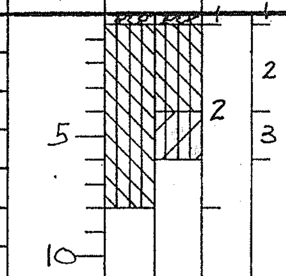
LEGEND:
Organic silt
Silt
Organic clay
Brown clay
Grey clay
Sand
Gravel
Non-cemented glacial till
Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

TABLE B-2

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
817.97	4	58.9	2.72	1.74	91.9	64.5	102.3	93	7	0	0	0			
813.55	2	49.8	2.74	1.46	93.2	69.6	104.1	89	10	1	0	0			
	4	57.4	2.74	1.67	94.0	64.2	101.1	87	13	0	0	0			

DEPTH, ft | SOIL PROFILE | LAYER NO.



Layer No. 1: Organic, moist, soft, dark grey clayed silt.
Layer No. 2: Moist, soft, brown silty clay with grey and brown silt pockets.

Layer No. 1: Organic, moist, soft, dark grey clayed silt.
Layer No. 2: Moist, soft, brown silty clay with grey and brown silt pockets.
Layer No. 3: Moist, soft grey silty clay with light and dark grey silt pockets.

TEST HOLE NO. 3 AND 4
LOCATION 34' S. of ℄ AT ST. 58+14
48' S. of ℄ AT ST. 108+00
HOLE ADVANCED BY 4" ⌀ Sc. Aug.
DATE Sept. 9, 1963.

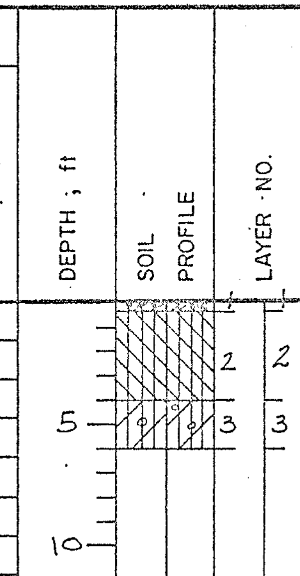
LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

B4

TABLE B-3

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
812.64															
811.45	2	33.4	2.74	1.26	72.4	75.6	101.0	74	22	2	2	0			
	4	55.0	2.74	1.91	79.0	58.6	90.9	84	15	1	0	0			



Layer No. 1: Organic moist, soft, dark grey clayed silt.
Layer No. 2: Moist, soft, brown silty clay with grey and brown silt pockets.
Layer No. 3: Moist, soft, grey silty clay with light and dark grey silt pockets.
Some stones max. 1" diam.

Layer No. 1: Organic, moist, soft, dark grey clayed silt.
Layer No. 2: Moist, soft, brown silt clay with grey and brown silt pockets.
Layer No. 3: Moist, soft, grey silty clay with light & dark grey silt pockets.
Some stones max. ½" diam.

TEST HOLE NO. 5 AND 6
LOCATION 53'S. of ℄ AT ST. 128+41
56'S. of ℄ AT ST. 146+90
HOLE ADVANCED BY 4" ⌀ Sc. Aug.
DATE SEPT. 10 & 11, 1963.

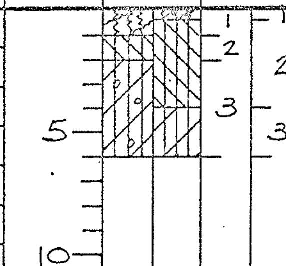
LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

TABLE B-4

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
808.28	4	53.9	2.74	1.57	94.5	66.5	102.2	78	21	1	0	0	111	27	84
808.94															

DEPTH, ft — SOIL PROFILE — LAYER NO.



Layer No. 1: Organic, moist, dense, grey clayed silty sand.
Layer No. 2: Moist, soft, brown silty clay with grey and brown silt pockets. Some stones max. 1" diam.
Layer No. 3: Moist, soft, grey silty clay with light & dark silt pockets.

Layer No. 1: Organic, moist, soft, dark grey clayed silt.
Layer No. 2: Moist, soft, brown silty clay with grey and brown silt pockets.
Layer No. 3: Moist, soft, grey silty clay with light & drak grey silt pockets.

TEST HOLE NO. 7 AND 8
LOCATION 18' S. of ℄ AT ST. 162+61
3' S. of ℄ AT ST. 183+23
HOLE ADVANCED BY 4"⌀ Sc. Aug.
DATE SEPT. 11 & 12, 1963.

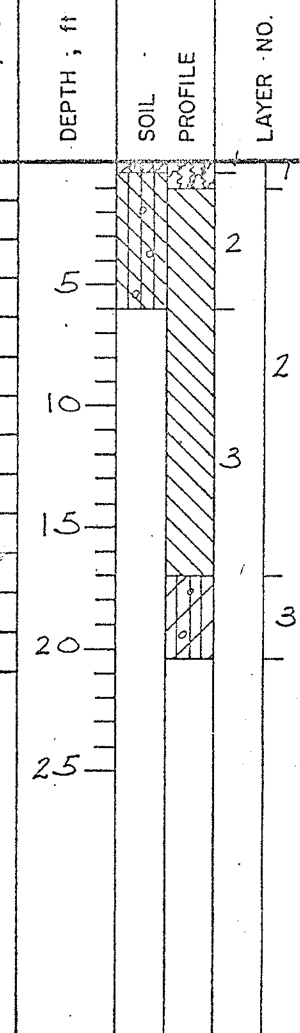
LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

B5

TABLE B-5

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
806.65	4	52.8	2.74	1.47	98	72.4	110.7								
806.63	3	54.1	2.70												
	5	55.1	2.70	1.60	93.1	64.8	101.0								
	8	50.9													
	10	50.0		1.44	93.8	69.1	103.7	94	5	1					
	13	46.7													
	15	20.0				110.3	132.3	27	35	13	7	18	23	13	10



Layer No. 1: Organic, moist, soft, dark grey clayed silt.
Layer No. 2: Moist, soft, brown silty clay with grey and brown silt pockets. Some stones max. 1" diam.

Layer No. 1: Organic, moist, dark grey clayed silt.
Layer No. 2: Moist, soft, brown clay with light & drak grey and brown silt pockets.
Layer No. 3: Moist, dense, light grey clayed silt. Some stones max. 2" diam.

TEST HOLE NO. 9 AND 10
LOCATION 49' S of ℄ AT ST. 206+15 in ℄ AT STA. 230+00
HOLE ADVANCED BY 4"⌀ Sc. & FL. AUG.
DATE SEPT. 12, 63 & AUG. 23, 60.

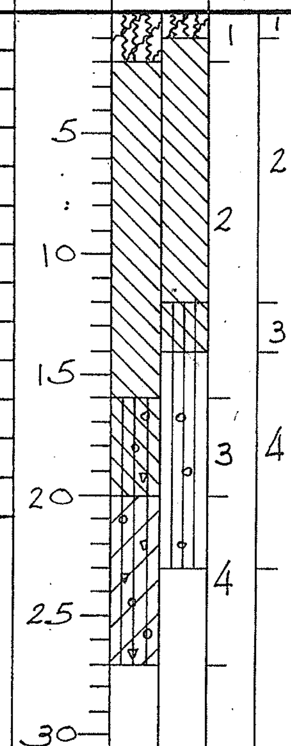
LEGEND:
Organic silt
Silt
Organic clay
Brown clay
Grey clay
Sand
Gravel
Non-cemented glacial till
Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

B6

TABLE B-6

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
808.13	3	36.5													
	4	47.5	2.70	1.316	97.4	72.4	106.8	95	4	1	0	0	111	41	70
	7	50.2													
	9	57.9		1.575	99.2	65.4	103.2	97	2	1	0	0	106	39	67
	12	53.6													
	14	31.3		1.045	80.8	82.4	108.2								
805.93	3	49.5													
	5	56.9	2.70	1.574	97.6	65.5	102.8								
	8	54.4													
	10	51.7		1.417	98.6	69.9	106.0								



Layer No. 1: Organic, dark grey clayed silt.
Layer No. 2: Moist, soft, brown clay with light and dark brown and grey silt pockets.
Layer No. 3: Moist, soft, dense, brown clayed silt. Some stones max. 1" diam.
Layer No. 4: Dry, dense, light grey clayed silt. Some stones max. 1" diam.

Layer No. 1: Organic, moist, dark grey clayed silt.
Layer No. 2: Moist, soft, brown clay with light & dark grey and brown silt pockets.
Layer No. 3: Moist, soft, brown clayed silt. Some stones max. 1" diam.
Layer No. 4: Moist, dense, light brown silt. Small stones max. ¼" diam.

TEST HOLE NO. 10L AND 10R.
LOCATION 65' S. of ℄ AT ST. 230+00
65' N of ℄ AT ST. 230+00
HOLE ADVANCED BY 4" ⌀ FL. AUG.
DATE AUGUST 23, 1960.

LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

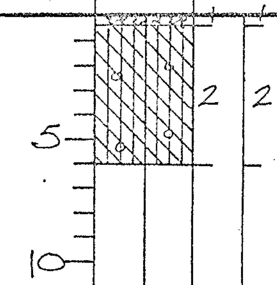
THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

B7

TABLE B-7

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
803.82	4	52.0	2.74	1.50	94.5	68.2	103.6	84	15	1	0	0			
801.73															

DEPTH, ft | SOIL PROFILE | LAYER NO.



Layer No. 1: Organic, moist, grey clayed sandy silt.
Layer No. 2: Moist, soft, brown silty clay with grey & brown silt pockets. Some stones max. 1" diam.

Layer No. 1: Moist, varved, brown clayed silt.
Layer No. 2: Moist, soft, brown silty clay with grey & brown silt pockets. Some stones max. $\frac{1}{4}$" diam.

TEST HOLE NO. 11 AND 12

LOCATION 46' S. of ℄ AT ST. 244+72
42' S of ℄ AT ST. 266+02

HOLE ADVANCED BY 4" ⌀ Sc. Aug.

DATE SEPT. 12, 1963.

LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

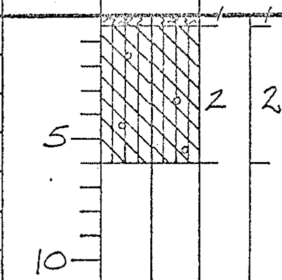
THE SEINE RIVER DIVERSION

LABORATORY SOIL TESTS

B8

TABLE B-8

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
800.83	4	54.7	2.74	1.54	97.0	67.4	104.1	86	14	0	0				
779.50															



Layer No. 1: Organic, moist, dark grey clayed silt.
Layer No. 2: Moist, soft, brown, silty clay with grey & brown silt pockets.
Some stones max. 1" diam.

Layer No. 1: Organic, moist, varved, dark clayed sandy silt.
Layer No. 2: Moist, soft, brown silty clay with grey & brown silt pockets.
Some stones max. ½" diam.

TEST HOLE NO. 13 AND 14
LOCATION 42' S. of ℄ AT ST. 284+87
42' S of ℄ AT ST. 303+82
HOLE ADVANCED BY 4"φ Sc. Aug.
DATE SEPT. 13, 1963.

LEGEND:
Organic silt
Silt
Organic clay
Brown clay
Grey clay
Sand
Gravel
Non-cemented glacial till
Cemented glacial till

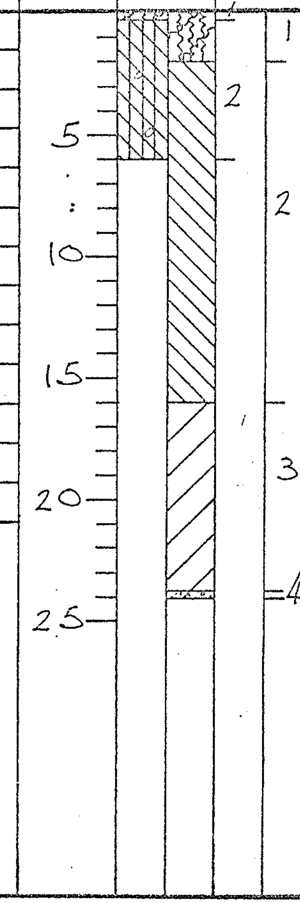
THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

B9

TABLE B-9

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
779.38	4	52.0	2.74	1.450	98.5	69.8	106.1	82	17	1	0	0	95	21	74
798.87	3	40.9													
	5	47.4													
	8	53.4													
	10	51.5	2.70	1.452	95.9	68.8	104.2								
	13	59.4													
	15	51.8		1.333	94.9	69.0	104.8	95	0	1	0	0	98	33	65
	18	51.2													
	20	49.8		1.395	96.7	70.4	105.5								
	22	46.6													

DEPTH, ft | SOIL PROFILE | LAYER NO.



Layer No. 1: Organic, moist, dark grey clayed silt.
Layer No. 2: Moist, soft, brown silty clay with grey & brown silt pockets. Some stones max. ½" diam.

Layer No. 1: Organic, soft, dark grey clayed silt.
Layer No. 2: Moist, soft, plastic, brown clay with light grey & dark brown silt pockets.
Layer No. 3: Moist, soft, plastic, grey clay with light grey silt pockets.
Layer No. 4: Moist, stiff, grey clayed silt with small stones.

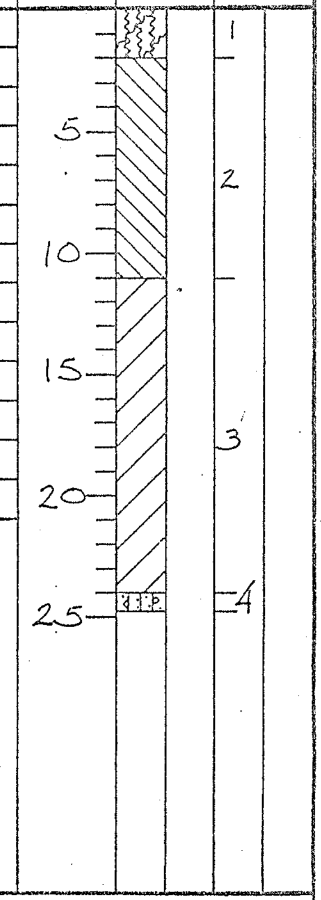
TEST HOLE NO. 15 AND 16
LOCATION 58' S. of ℄ at St. 322+26 in ℄ at St. 344+50
HOLE ADVANCED BY 4" ⌀ Sc. & Fl. Aug.
DATE Sept. 13, 63 & July 28, 60.

LEGEND:
Organic silt
Silt
Organic clay
Brown clay
Grey clay
Sand
Gravel
Non-cemented glacial till
Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

TABLE B-10

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
802.64	3	42.8													
	5	42.6													
	8	56.9													
	10	51.8	2.70	1.439	97.5	69.5	105.5								
	12	53.4													
	15	53.6		1.482	98.0	58.2	104.8	100	0	0	0	0	92	35	57
	18	53.4													
	20	48.9		1.368	96.6	71.3	106.1								



Layer No. 1: Organic, moist, soft, dark grey clayed silt.
Layer No. 2: Moist, soft, brown clay with light grey silt pockets.
Layer No. 3: Moist, soft, plastic, grey clay with large light & dark grey silt pockets.
Layer No. 4: Moist, stiff, light grey glacial till. Small stones max. 3/8" diam.

TEST HOLE NO. 16 L
LOCATION 130' S. of ℄ at St. 344+50
HOLE ADVANCED BY 4" ∅ FL. AUG.
DATE JULY 28, 1960.

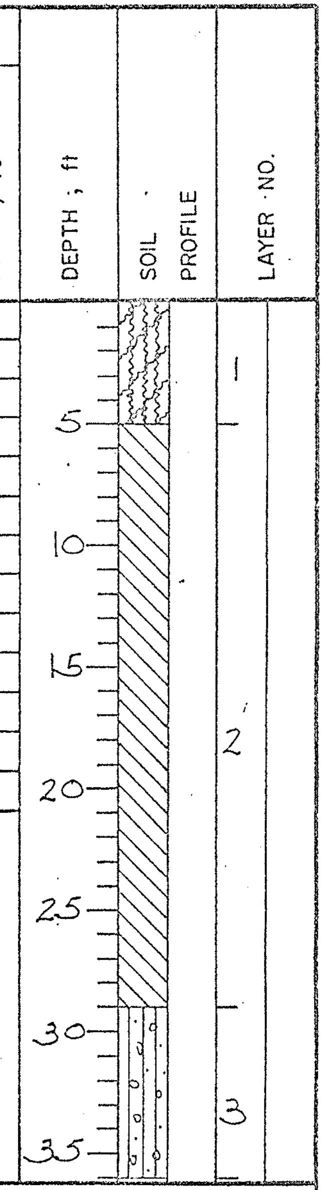
LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

B 12

TABLE B-11

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
804.0	6	37.6													
	7	38.4													
	9	46.1													
	10	50.9	2.70	1.424	96.7	69.4	104.8								
	14	56.7													
	15	53.8		1.512	96.0	67.0	103.0	91	9	0	0	0	108	34	74
	18	56.6													
	20	53.7													
	22	48.8													
	25	49.6		1.395	95.8	70.1	104.8								



Layer No. 1: Organic, moist, soft, dark grey clayed silt.
Layer No. 2: Moist, soft, brown clay with light brown silt pockets.
Layer No. 3: Moist, light brown non-cemented glacial till. Small stones 3/8" diam.

TEST HOLE NO. 16 R
LOCATION 130' N. of ℄ AT ST. 344+50
HOLE ADVANCED BY 4" FL. AUG.
DATE JULY 30, 1960.

LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

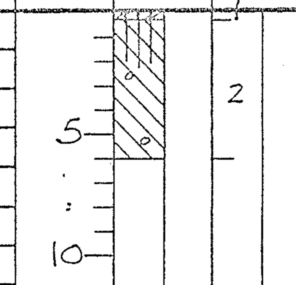
THE SEINE RIVER DIVERSION

LABORATORY SOIL TESTS

TABLE B-12

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
796.95	2"	43.1	2.70	1.372	84.9	71.0	101.7	73.0	27.0	0	0	0	95	23	72
	2	45.7	2.68	1.381	88.4	70.3	102.3	82.5	17.5	0	0	0	89	22	67
	4	50.4	2.70	1.402	97.0	70.3	105.7	83.0	17.0	0	0	0	99	23	76

DEPTH, ft — SOIL PROFILE — LAYER NO.



Layer No. 1: Organic, varved, moist, grey clayed sandy silt.
Layer No. 2: Moist, soft, brown silty clay with grey & brown silt pockets.
Some stones max. ½" diam.

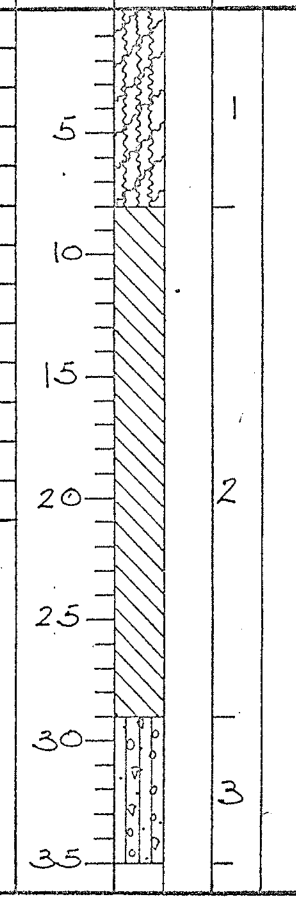
TEST HOLE NO. 17
LOCATION 60' S. of ℄ at St. 362+84
HOLE ADVANCED BY 4"⌀ Sc. Aug.
DATE Sept. 13, 1963.

LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

TABLE B-13

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
804.67	5	34.8													
	8	39.9													
	10	34.8	2.70	1.040	90.0	82.4	111.1								
	12	46.6													
	15	49.1													
	18	57.9													
	20	46.5		1.368	92.0	71.1	104.2	100	0	0	0	0	98	33	65
	23	51.8													
	25	39.5		1.168	91.0	77.4	108.0								
	29	29.2													
	30	24.2		0.649	100.0	102.0	126.7								
	30	11.5		0.312	100.0	128.0	143.5								



Layer No. 1: Organic, moist, soft, dark grey clayed silt.
Layer No. 2: Moist, soft, brown clay with light grey silt pockets.
Layer No. 3: Moist, soft, light brown glacial till. Small stones max. 1/4" diam.

TEST HOLE NO. 18
LOCATION 30' S. of ℄ AT ST. 385+10
HOLE ADVANCED BY 4" ⌀ FL. AUG.
DATE JULY 30, 1960.

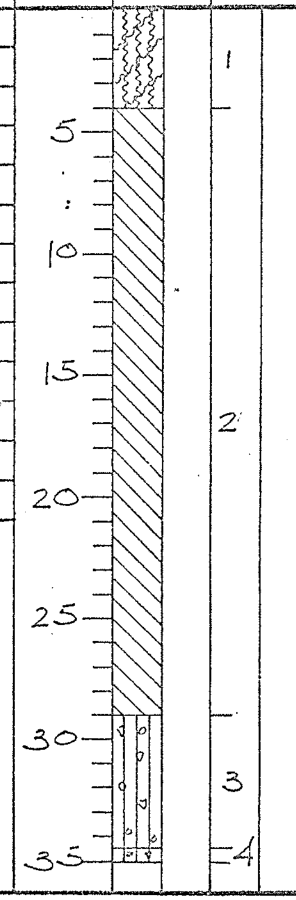
LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

B 14

TABLE B-14

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
803.92	3	38.4													
	5	32.5													
	8	45.1													
	10	47.0	2.70	1.408	90.7	70.5	103.6								
	13	52.7													
	15	51.3													
	18	56.0													
	20	46.2		1.368	91.6	71.3	104.2	97	2	1	0	0	97	33	64
	22	50.6													
	25	51.1		1.424	96.7	59.4	104.8								



Layer No. 1: Organic, moist, soft, dark grey clayed silt.
Layer No. 2: Moist, soft, brown clay with small pockets of gypsum.
Layer No. 3: Moist, stiff, light brown glacial till. Stones max. 1" diam.
Layer No. 4: Cemented glacial till.

TEST HOLE NO. 18 L
LOCATION 90' S. of ℄ AT ST. 385+10
HOLE ADVANCED BY 4"⌀ FL. AUG.
DATE JULY 30, 1960.

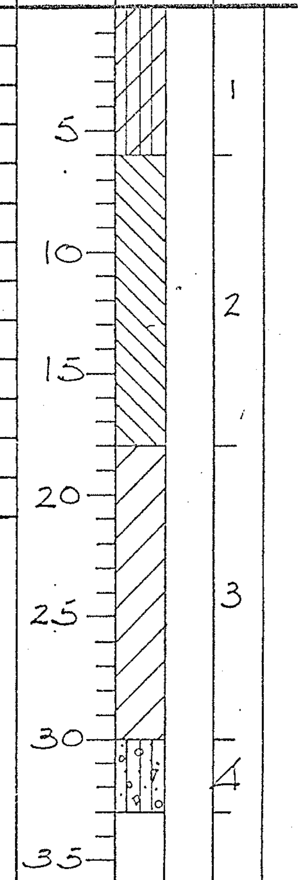
LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

B16

TABLE B-15

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
803.13	3	38.7													
	5	33.9													
	8	45.1													
	10	43.3	2.70	1.264	93.0	74.9	107.3	92	7	1	0	0	97	31	66
	12	49.9													
	15	52.9		1.452	98.4	68.5	104.8								
	18	54.5													
	20	53.8		1.490	97.3	67.4	103.6								
	22	57.0													
	25	47.7		1.315	97.4	72.2	106.7	99	0	1	0	0	94	33	61
	27	39.8													
	30	7.4													



Layer No. 1: Moist, stiff, dark grey clayed silt. Small stones max. ¼" diam.
Layer No. 2: Moist, soft, medium brown clay with light & dark grey silt pockets.
Layer No. 3: Moist, soft, plastic, grey clay with light & dark brown silt pockets.
Layer No. 4: Moist, stiff, brown glacial till. Limestone chips max. 3/4" diam.

TEST HOLE NO. 18R
LOCATION 90' N. of ℄ at St. 385+10
HOLE ADVANCED BY 4" Fl. Aug.
DATE July 30, 1960.

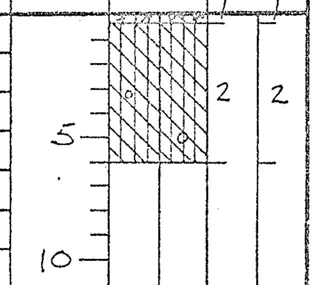
LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

TABLE B-16

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
795.23	2	49.0	2.70	1.592	83.0	65.0	97.9	80	20	0	0	0	100	24	76
	4	52.2	2.70	1.472	96.8	68.4	104.1	78	22	0	0	0			
795.66	4	50.7	2.74	1.38	100.	71.8	108.1	76	22	1	1	0	96	21	75

DEPTH, ft | SOIL PROFILE | LAYER NO.



Layer No. 1: Organic, moist, grey clayed sandy silt.
Layer No. 2: Moist, soft, brown silty clay with grey & brown silt pockets. Some stones max. 3/4" diam.

Layer No. 1: Organic, moist, dark grey clayed silt.
Layer No. 2: Moist, soft, brown silty clay with grey & brown silt pockets. Some stones max. 1" diam.

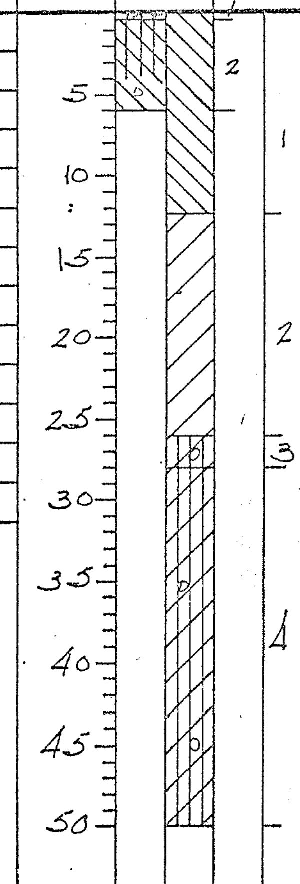
TEST HOLE NO. 19 AND 20
LOCATION 55' S. of ℄ AT ST. 408+09
60' S. of ℄ AT ST. 433+63
HOLE ADVANCED BY 4"⌀ Sc. Aug.
DATE Sept. 16, 1963.

LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

TABLE B-17

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
791.83	2"	47.4	2.70	1.395	91.8	70.0	103.3	68.5	31.5	0	0	0	101	24	77
	2	51.3	2.75	1.490	95.2	69.1	104.5	79.0	21.0	0	0	0	91	22	69
	4	54.8	2.70	1.578	93.7	65.4	101.2	86.5	13.5	0	0	0			
789.07	2.5	44.3													
	5	47.5	2.70	1.357	94.4	71.4	105.3								
	8	51.0													
	10	52.8		1.552	91.8	66.1	101.0	97	2	1	0	0	104	37	67
	13	54.6													
	15	59.6		1.810	88.9	59.9	95.6								
	18	62.4													
	20	61.3		1.724	95.9	61.8	99.7	99	0.5	0.5	0	0	104	38	66
	23	51.1													



Layer No. 1: Organic, moist, dark grey clayed silt.
Layer No. 2: Moist, soft, brown silty clay with grey & brown silt pockets. Some stones max. ½" diam.

Layer No. 1: Moist, soft, plastic, brown silty clay with light and dark grey and brown silt pockets. Pockets of gypsum.
Layer No. 2: Moist, soft, plastic grey clay with light and dark brown and grey silt pockets.
Layer No. 3: Moist, soft, grey clayed silt Stones max. 2" diam. Free water at depth equal 5½'.

TEST HOLE NO. 21 AND 22
LOCATION 27'S. of ℄ AT ST. 458+73 IN ℄ AT ST. 493+97
HOLE ADVANCED BY 4" ⌀ Sc. & Fl. Aug.
DATE SEPT. 16, 1963 & AUG. 22, 60.

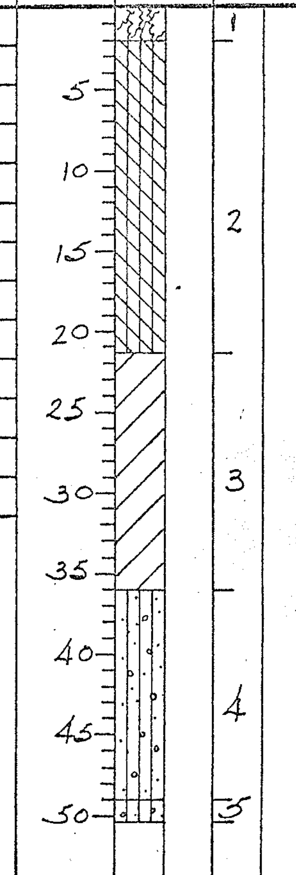
LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

TABLE B-18

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
795.37	2.5	34.0													
	6	44.0													
	9	47.7	2.70	1.638	94.1	71.1	105.0	74	25	1	0	0	98	38	60
	12	50.5													
	14	49.4													
	17	49.2													
	19	51.8		1.420	92.8	67.2	102.0								
	22	58.8													
	24	57.1		1.624	94.9	64.2	100.9								
	27	62.7													
	29	57.6		1.937	80.3	57.4	90.5	98	1	1	0	0	98	36	62
	32	46.7													

DEPTH, ft | SOIL PROFILE | LAYER NO.



Layer No. 1: Organic, moist, dark grey clayed silt.
Layer No. 2: Moist, soft, brown silty clay with light and dark grey & brown silt pockets.
Layer No. 3: Moist, soft, plastic, grey clay with light and dark grey & brown silt pockets.
Layer No. 4: Moist, dense, grey silty sand. Stones 2" diam.
Layer No. 5: Grey silty sand and gravel. Stones $\frac{1}{4}$" diam.

TEST HOLE NO. 22 L
LOCATION 65' S. of ℄ at St. 493+97
HOLE ADVANCED BY 4" ∅ FL. AUG.
DATE AUGUST 23, 1960.

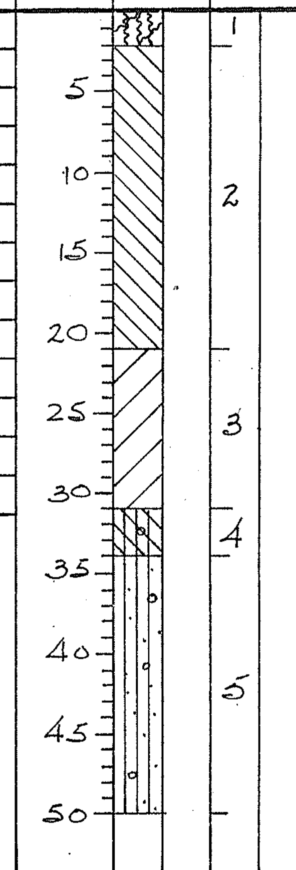
LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

THE SEINE RIVER DIVERSION

LABORATORY SOIL TESTS

TABLE B-19

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
795.37	2.5	32.6													
	8	48.9													
	10	48.5	2.70	1.405	93.1	69.9	103.8	94	5	1	0	0	99	35	64
	13	46.8													
	15	56.7		1.587	96.6	64.9	101.7	98	1	1	0	0	104	35	69
	18	60.7													
	20	55.7		1.738	86.4	55.7	96.2								
	23	60.2													
	25	62.3		0.592	100	66.8	108.4	99	0.5	0.5			98	36	62
	31.5	20.9													



Layer No. 1: Organic, moist, soft, dark grey clayed silt.
Layer No. 2: Moist, soft, brown clay with light and dark grey & brown silt pockets.
Layer No. 3: Moist, soft, plastic, grey clay with light and dark grey & brown silt pockets.
Layer No. 4: Moist, soft, light brown clayed silt. Stones ½" diam.
Layer No. 5: Wet soft, grey silt and sand. Stones 2" diam. Free water at depth equal to 11.5'.

TEST HOLE NO. 22 R
LOCATION 65' N. of ℄ at St. 493+97
HOLE ADVANCED BY 4" ⌀ Fl. Auger
DATE August 22, 1960.

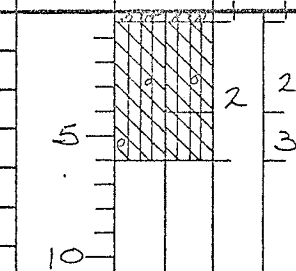
LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

TABLE B-20

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
788.53	2	45.8	2.74	1.33	94.5	73.7	107.4								
	4	49.5	2.70	1.52	88.0	65.6	98.0	88	11	1	0	0			
787.04															

DEPTH, ft · SOIL PROFILE · LAYER NO.



Layer No. 1: Organic, moist, soft, dark grey clayed silt.
Layer No. 2: Moist, soft, brown silty clay with grey and brown silt pockets. Some stones max. 3/4" diam.

Layer No. 1: Organic, moist, dark grey clayed silt.
Layer No. 2: Moist, brown clayed silt with large grey and brown silt pockets. Iron oxide concentrations and stains. Some stones max. ½" diam.
Layer No. 3: Moist, soft, brown silty clay with grey and brown silt pockets.

TEST HOLE NO. 23 AND 24
LOCATION 37' S. of ℄ AT ST. 515+23
38' S. of ℄ AT ST. 537+71
HOLE ADVANCED BY 4" ⌀ Sc. AUGER
DATE SEPT. 16, 1963.

LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

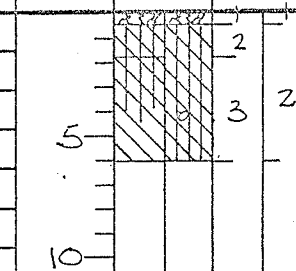
THE SEINE RIVER DIVERSION

LABORATORY SOIL TESTS

TABLE B-21

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
785.87	2"	48.8	2.70	1.41	93.5	70.2	104.2								
	4	50.8	2.74	1.50	93.0	69.0	104.0	90	10	0	0				
785.26															

DEPTH, ft | SOIL PROFILE | LAYER NO.



Layer No. 1: Organic, moist, light and dark grey clayed silt.
Layer No. 2: Moist, soft, brown varved clayed silt with grey brown silt pockets.
Layer No. 3: Moist, soft, brown silty clay with grey and brown silt pockets. Iron oxide concentrations and stains.

Layer No. 1: Organic, moist, light and dark grey clayed silt.
Layer No. 2: Moist, soft, brown silty clay with grey sand brown silt pockets. Some stones max. ½" diam. Iron oxide concentrations and stains.

TEST HOLE NO. 25 AND 26
LOCATION 28' N. of ℄ at St. 557+57
39' N of ℄ at St. 579+57
HOLE ADVANCED BY 4" ⌀ Sc. Auger
DATE Sept. 17, 1963.

LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

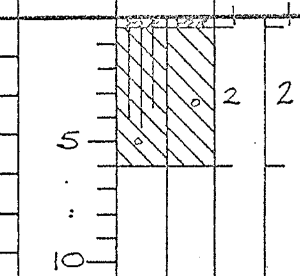
THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

B23

TABLE B-22

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, ÷200-40, %	SAND, ÷40-10, %	STONE, ÷10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
784.32	4	59.1	2.74	1.630	99.7	65.1	103.6	82	18	0	0	0			
783.02	2"	44.0	2.70	1.303	90.9	73.1	105.2	90	10	0	0	0	94	23	71
	2	63.2	2.75	1.849	93.9	60.3	98.4	92	8	0	0	0	100	24	76
	4	59.2	2.70	1.690	94.3	62.8	100.0	81.5	18.5	0	0	0			

DEPTH, ft — SOIL PROFILE — LAYER NO.



Layer No. 1: Organic, moist, light and dark grey clayed silt.
Layer No. 2: Moist, soft, brown silty clay with grey and brown silt pockets. Some stones max. ¼" diam.

Layer No. 1: Organic, moist, light and dark grey clayed silt.
Layer No. 2: Moist, soft, brown silty clay with grey and brown silt pockets. Some stones max. ½" diam.

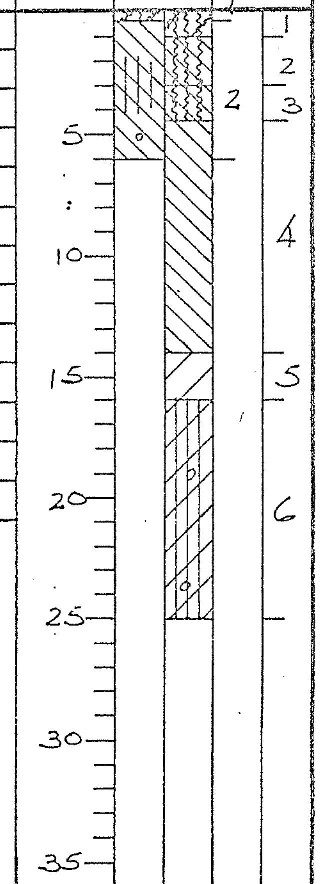
TEST HOLE NO. 27 AND 28
LOCATION 37' N. of ℄ AT ST. 601+57
38' N. of ℄ AT ST. 621+68
HOLE ADVANCED BY 4" ⌀ Sc. AUGER
DATE SEPT. 17 AND 18, 1963.

LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

TABLE B-23

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
782.25	2"	35.6	2.70	1.122	85.3	79.4	107.4	83	17	0	0	0	106	21	85
	2	54.4	2.70	1.448	97.8	68.9	105.1	78.5	21.5	0	0	0			
	4	57.6	2.70	1.582	98.3	65.2	102.7	86.5	13.5	0	0	0	106	24	82
785.20	5	32.6													
	10	50.9													
	15	34.0													
	15.5	61.4													
	20	58.9													
	25	58.9													



Layer No. 1: Organic, moist, light and dark grey clayed silt.
Layer No. 2: Moist, soft, brown silty clay with brown and grey silt pockets. Some stones max. ½" diam.

Layer No. 1: Organic, moist, soft, dark grey clayed silt.
Layer No. 2: Organic, moist, soft, brown clayed silt.
Layer No. 3: Organic, moist, soft, brown clayed silt with light and dark grey & brown silt pockets.
Layer No. 4: Moist, soft, plastic, brown clay with light and dark grey & brown silt pockets. Pockets of gypsum.
Layer No. 5: Moist, soft, plastic, grey clay (6): M,s,p, grey silty clay

TEST HOLE NO. 29 AND 30
LOCATION 37' N. of E AT ST. 643+57 AT ST. 655+57
HOLE ADVANCED BY 4" ⌀ Sc. AUGER
DATE SEPT. 18, 1963 & AUG. 30, 60

LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

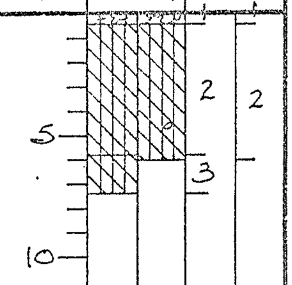
THE SEINE RIVER DIVERSION

LABORATORY SOIL TESTS

TABLE B-24

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
781.92	2"							20	80	0	0	0			
	2	29.6	2.70	0.876	91.7	90.1	116.6	31	69	0	0	0	46	17	29
	4	40.8	2.70	1.160	94.7	77.8	109.5	51.5	46	0.8	1.7	0	70	21	49
	6	55.3	2.70	1.533	97.8	66.6	103.4	86.5	13.5	0	0	0	111	27	84

DEPTH, ft | SOIL PROFILE | LAYER NO.



Layer No. 1: Organic, moist, dark grey clayed silt.
Layer No. 2: Moist, soft, brown clayed silt with grey and brown silt pockets. Iron oxide concentrations and stains.
Layer No. 3: Moist, soft, brown silty clay with grey and brown silt pockets.

Layer No. 1: Organic, moist, dark grey clayed silt.
Layer No. 2: Moist, stiff, brown silty clay with grey and brown silt pockets. Stones max. ¼" diam.

TEST HOLE NO. 31 AND 32
LOCATION 37' N. of ℄ at St. 679+69
36' N. of ℄ at St. 701+57
HOLE ADVANCED BY 4" ⌀ Sc. AUGER
DATE SEPT. 18, 1963.

LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

TABLE B-25

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
779.15	2"							45	55	0	0	0			
	2	29.6	2.70	0.857	93.0	90.8	117.5	41	59	0	0	0	57	18	39
	4	32.7	2.70	0.906	97.0	88.5	117.3	36	64	0	0	0	44	16	28
	6	51.6	2.72	1.410	99.5	70.3	106.5	80.5	19.5	0	0	0	96	24	72
776.03	2"	35.8	2.72	1.037	93.4	83.3	113.0	36.5	63.5	0	0	0			
	2	33.5	2.70	0.939	96.9	87.1	116.2	30.5	69.5	0	0	0	43	15	28
	4	29.8	2.70	0.880	91.4	89.8	116.3	12	88	0	0	0	42	18	24

DEPTH, ft	SOIL PROFILE	LAYER NO.
5, 10		2, 3 / 2

Layer No. 1: Organic, moist, light and dark grey clayed silt.
Layer No. 2: Moist, soft, brown clayed silt with large grey and brown silt pockets and layers. Some stones max. $\frac{1}{4}$" diam. Iron oxide concentrations & stains.
Layer No. 3: Moist, soft, brown silty clay with grey and brown silt pockets.

Layer No. 1: Organic, moist, soft, light and grey clayed silt.
Layer No. 2: Moist, soft, brown clayed silt with grey and brown silt pockets. Some stones max. $\frac{1}{4}$" diam. Iron oxide concentrations and stains.

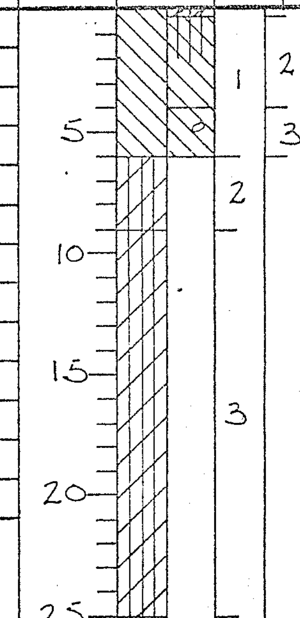
TEST HOLE NO. 33 AND 34
LOCATION 37' N. of ℄ AT ST. 723+57
26' N. of ℄ AT ST. 745+57
HOLE ADVANCED BY 4" ∅ SC. AUGER
DATE SEPT. 19, 1963.

LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

TABLE B-26

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
774.50	5	53.3													
	10	54.1													
	15	50.9													
	20	52.6													
	25	57.2													
772.68	2"	18.3	2.72	0.844	59.9	97.3	109.1	38	62	0	0	0			
	2	49.9	2.70	1.350	100.0	71.9	107.7	82.5	17.5	0	0	0	99	24	75
	4	57.7	2.72	1.555	98.7	66.5	104.0	84.5	15.5	0	0	0	97	23	74



Layer No. 1: Moist, soft, plastic, brown clay with light and dark grey and brown silt pockets. Pockets of gypsum.
Layer No. 2: Moist, soft, plastic, grey silty clay with large light and dark brown silt pockets.
Layer No. 3: Moist, soft, plastic, grey silty clay with light and dark brown and grey silt pockets.

Layer No. 1: Moist, soft, light and dark grey clayed silt.
Layer No. 2: Moist, soft, brown clayed silt with grey and brown silt pockets.
Layer No. 3: Moist, soft, brown silty clay with grey & brown silt pockets. Stones ½" diam.

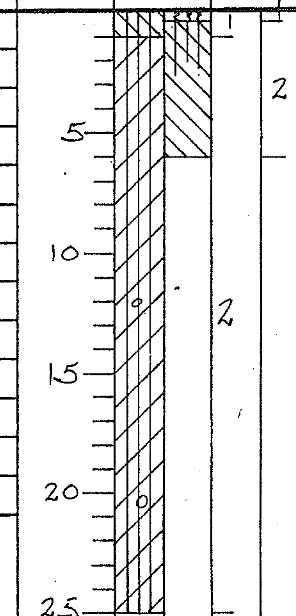
TEST HOLE NO. 35 AND 36
LOCATION AT ST. 762+00
29' N. of ℄ AT ST. 787+57
HOLE ADVANCED BY 4" ∅ Sc. AUGER
DATE AUGUST 29, 1960 & SEPT. 19, 63.

LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

TABLE B-27

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
770.50	5	59.7													
	10	52.6													
	15	60.6													
	20	48.3													
	25	60.4													
769.83	2"	27.2	2.70	0.728	100.0	97.7	124.3	64.4	35.6	0	0	0			
	2	42.8	2.72	1.242	93.3	75.8	108.0	85	15	0	0	0	106	26	80
	4	52.8	2.72	1.439	100.0	69.8	106.5	84	16	0	0	0	100	22	78



Layer No. 1: Moist, soft, plastic, brown clayed silt with light and dark brown silt pockets.
Layer No. 2: Moist, soft, plastic, grey silty clay with light and dark brown & grey silt pockets. Stones max. 3" diam.

Layer No. 1: Organic, moist, stiff, dark silty clay.
Layer No. 2: Moist, stiff, brown silty clay with grey and brown silt pockets.

(Description of Soil Log No. 39, not available).

TEST HOLE NO. 37 AND 38
LOCATION AT ST. 817+40
30' N. of ℄ AT ST. 838+88
HOLE ADVANCED BY 4"⌀ Sc. AUGER
DATE AUG. 29, 1960 & SEPT. 19, 63.

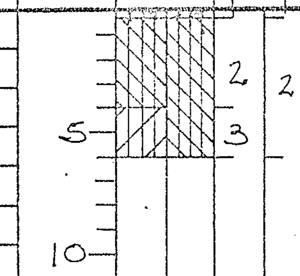
LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

TABLE B-28

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, ÷200-40, %	SAND, ÷40-10, %	STONE, ÷10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
764.33	2"	49.7	2.74	1.50	90.5	68.7	102.8	82	18	0	0	0			
	4	51.2	2.70	1.44	98.0	69.5	105.1	74	26	0	0	0			
763.40															

DEPTH, ft — SOIL PROFILE — LAYER NO.



Layer No. 1: Organic, moist, soft, light and dark grey clayed silt.
Layer No. 2: Moist, soft, brown silty clay with grey and brown silt pockets.
Layer No. 3: Moist, soft, grey silty clay with light dark grey silt pockets.

Layer No. 1: Organic, moist, soft, light and dark grey clayed silt.
Layer No. 2: Moist, soft, brown silty clay with grey and brown silt pockets.

TEST HOLE NO. 40 AND 41
LOCATION 30' N. of ℄ AT St. 906+88
15' N. of ℄ AT St. 928+88
HOLE ADVANCED BY 4" ⌀ Sc. AUGER
DATE SEPT. 20, 1963.

LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

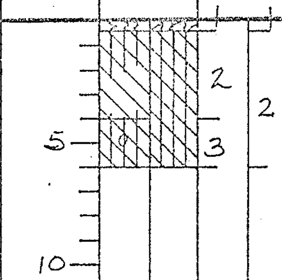
THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

B2.9

TABLE B-29

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
761.31	2	51.2	2.70	1.42	97.4	69.6	105.2	83	17	0	0	0			
	4	56.5	2.74	1.57	98.6	66.7	104.4	76	24	0	0	0			
760.69	4	51.1	2.74	1.50	93.2	68.5	103.4	82	18	0	0	0			

DEPTH, ft | SOIL PROFILE | LAYER NO.



Layer No. 1: Organic, varved, light and dark grey clayed silt.
Layer No. 2: Moist, soft, brown silty clay with grey and brown silt pockets.
Layer No. 3: Moist, soft, grey silty clay with light and dark grey silt pockets. Some stones max. ½" diam.

Layer No. 1: Organic, moist, light and dark clayed silt.
Layer No. 2: Moist, soft, brown silty clay with grey and brown silt pockets.

TEST HOLE NO. 42 AND 43
LOCATION 40' N. of ℄ at St. 953+27
13' N. of ℄ at St. 1004+81
HOLE ADVANCED BY 4" ⌀ Sc. AUGER
DATE SEPT. 20, 23, 1963

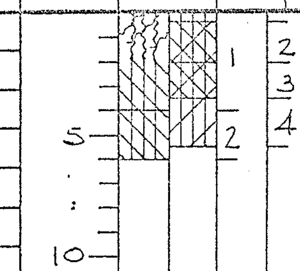
LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

B30

TABLE B-30

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
755.20	2	44.3	2.74	1.29	94.1	74.8	108.0	63	36	1	0	0			
754.36	0	52.8	2.74	1.86	77.4	59.6	91.0	66	33	1	0	0			
	2	38.4	2.74	1.24	84.6	76.2	105.4	73	25	1	1	0			
	4	38.6	2.74	1.18	89.5	78.5	108.7	72	26	2	0	0			



Layer No. 1: Organic, moist, light and dark clayed silt.
Layer No. 2: Moist, soft, brown silty clay with grey and brown silt pockets.

Layer No. 1: Frozen dark grey silt.
Layer No. 2: Moist, soft, grey and brown clayed silt. Pockets of dark grey organic material.
Layer No. 3: Moist, stiff, greyish brown silty clay. Pockets of organic material. Brown silt pockets.
Layer No. 4: Moist, stiff, dark grey silty clay. High silt content. Pockets of dark grey organic material.

TEST HOLE NO. 44 AND 45
LOCATION 5' N. of ℄ AT ST. 1061+88
4' N. of ℄ AT ST. 1096+58
HOLE ADVANCED BY 4" ⌀ Sc. AUGER
DATE NOV. 5 AND DEC. 13, 1963.

LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

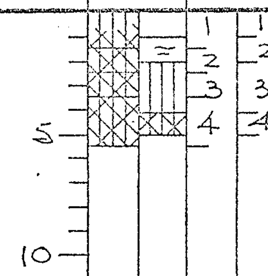
THE SEINE RIVER DIVERSION

LABORATORY SOIL TESTS

TABLE B-31

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
753.84	5'							58	40	2	0	0			
	2	42.3	2.74	1.31	88.4	74.1	105.6	64	35	1	0	0			
	4	46.9	2.70	1.68	75.6	63.0	92.5	65	31	1	1	0			
751.91															

DEPTH, ft — SOIL PROFILE — LAYER NO.



Layer No. 1: Frozen dark grey silt.
Layer No. 2: Moist, soft, plastic, dark greyish brown silty clay. High silt content. Pockets of dark grey organic material.
Layer No. 3: Moist, stiff, greyish brown silty clay. Pockets of dark grey organic material.
Layer No. 4: Moist, stiff, dark grey silty clay. High silt content. Organic material.

Layer No. 1: Ice. (2): Water
Layer No. 3: Wet, soft, dark grey silt.
Layer No. 4: Moist, stiff, greyish brown silty clay. Pockets of dark grey organic material.

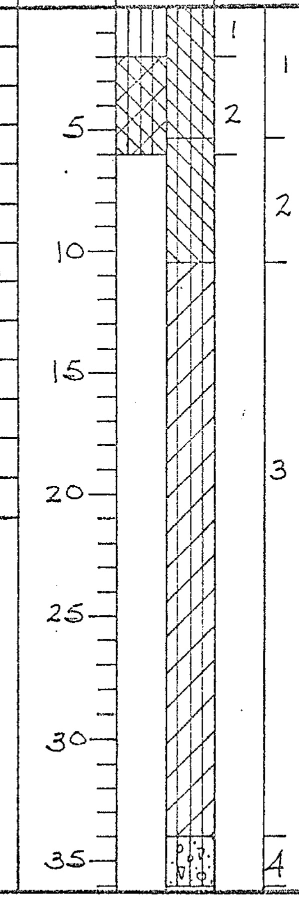
TEST HOLE NO. 46 AND 47
LOCATION 10' S. of ℄ AT ST. 1106+47
3' S. of ℄ AT ST. 1115+35
HOLE ADVANCED BY 4" ⌀ SC. AUGER
DATE DECEMBER 12, 1963.

LEGEND:
- Organic silt
- Silt
- Organic clay
- Brown clay
- Grey clay
- Sand
- Gravel
- Non-cemented glacial till
- Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

TABLE B-32

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
752.25	6"	42.0	2.70	1.290	88.5	73.9	104.9	51	44	3	2	0			
	2	49.8	2.74	1.380	98.3	71.0	106.1	78	22	0	0	0			
	4	52.1	2.74	1.470	97.0	69.4	105.8	78	22	0	0	0			
740.55	6	44.0	2.76	1.185	100			52	29	7	12		89	23	66
	11	43.0	2.72	1.170	100			60	39	1	0		85	21	64
	19	63.0	2.76	1.720	100			73	24	3	0		97	24	73
	24	71.0	2.75	2.120	100										
	28	58.0	2.67	1.540	100			66	32	2	0		75	18	57
	34	9.0	2.65	0.325	81			52	30	18	0		19	11	8



Layer No. 1: Frozen dark grey silt.
Layer No. 2: Moist, stiff, greyish brown silty clay. Large and small light brown and grey silt pockets.

Layer No. 1: Moist, soft, dark brown silty clay. Some small stones.
Layer No. 2: Moist, stiff, brown silty clay with light and dark, grey and brown silt pockets. Some stones max. ¼" diam.
Layer No. 3: Moist, soft, medium plastic, grey silty clay with light and dark grey silt pockets.
Layer No. 4: Moist, loose, grey non-cemented glacial till.

TEST HOLE NO. 48 AND 49
LOCATION 11'S of ℄ AT ST. 1131+86
35'N. of ℄ AT ST. 1151+00
HOLE ADVANCED BY 4" ⌀ Sc Aug. & Spl. T.
DATE DEC. 11, & OCT. 7, 1963

LEGEND:
Organic silt
Silt
Organic clay
Brown clay
Grey clay
Sand
Gravel
Non-cemented glacial till
Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

B33

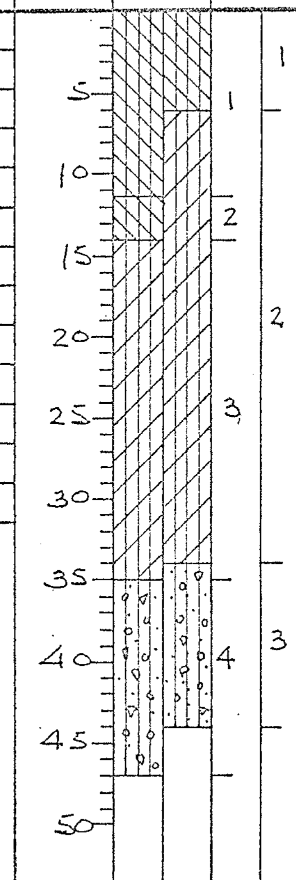
TABLE B-33

ELEVATION of TOP of HOLE, ft.	DEPTH, ft.	MOISTURE CONTENT, %	SPECIFIC GRAVITY	VOID RATIO	DEGREE of SATURATION, %	DRY DENSITY p.c.f.	MOIST DENSITY p.c.f.	GRAIN SIZE DISTRIBUTION: CLAY, %	SILT, %	SAND, +200-40, %	SAND, +40-10, %	STONE, +10, %	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
743.89	4	35	2.72	1.04	93			47	46	7	0	0	85	26	59
	9	37	2.72	1.05	97			52	42	6	0	0	82	24	58
	14	54	2.72	1.48	100			77	20	3	0	0	89	20	69
	19	54	2.79	1.51	100										
	24	61	2.72	1.71	100			80	16	4	0	0	90	24	66
	39	2	2.72					11	52	29	8	0	19	12	7
743.66	4	28	2.69					44	49	7	0	0	80	19	61
	9	48	2.72	1.32	100			73	24	3	0	0	96	22	74
	14	59	2.75	1.67	100										
	19	56	2.75	1.57	100			78	20	2	0	0	102	24	78
	24	64	2.75	1.78	100										

Layer No. 1: Moist, medium dark brown silty clay. Odd small stones.
Layer No. 2: Moist, medium, brown silty clay with light and dark, grey and brown silt pockets.
Layer No. 3: Moist, medium plastic, grey silty clay with light and dark grey silt pockets.
Layer No. 4: Non-cemented glacial till.

Layer No. 1: Slightly moist, stiff, dark brown silty clay with some small stones.
Layer No. 2: Moist, medium plastic, grey silty clay with light and dark grey silt pockets.
Layer No. 3: Moist, loose, grey non-cemented glacial till. Water under artesian pressure coming out of the hole.

DEPTH, ft | SOIL PROFILE | LAYER NO.

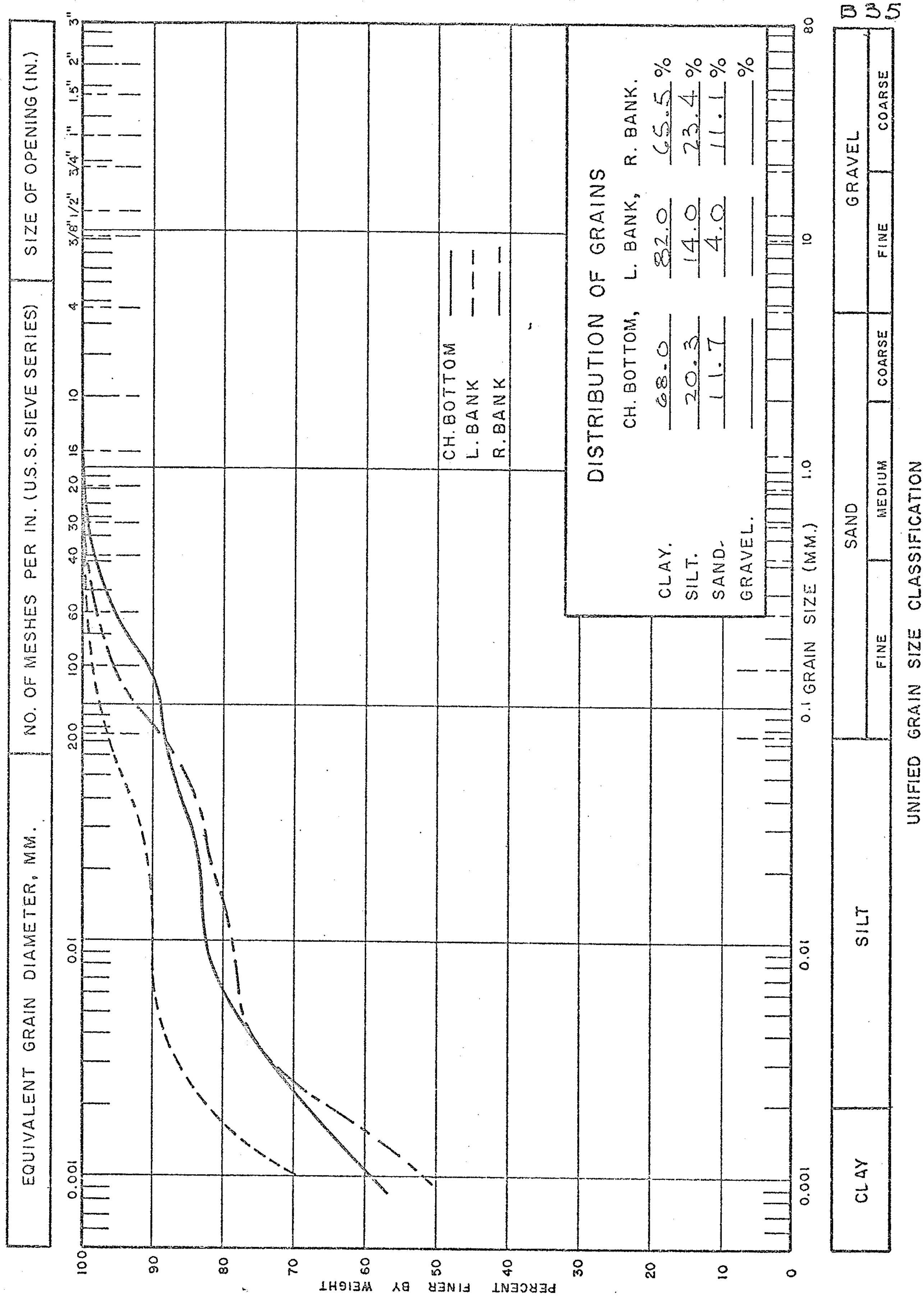


TEST HOLE NO. 49 L AND 49 R
LOCATION 60' S. of ℄ AT ST. 1151+00
85' N. of ℄ AT ST. 1151+00
HOLE ADVANCED BY 2" ⌀ SPL. TUBE
DATE OCTOBER 9, & 8, 1963.

LEGEND:
Organic silt
Silt
Organic clay
Brown clay
Grey clay
Sand
Gravel
Non-cemented glacial till
Cemented glacial till

THE SEINE RIVER DIVERSION
LABORATORY SOIL TESTS

B 34



CROSS SECTION NO. S.3

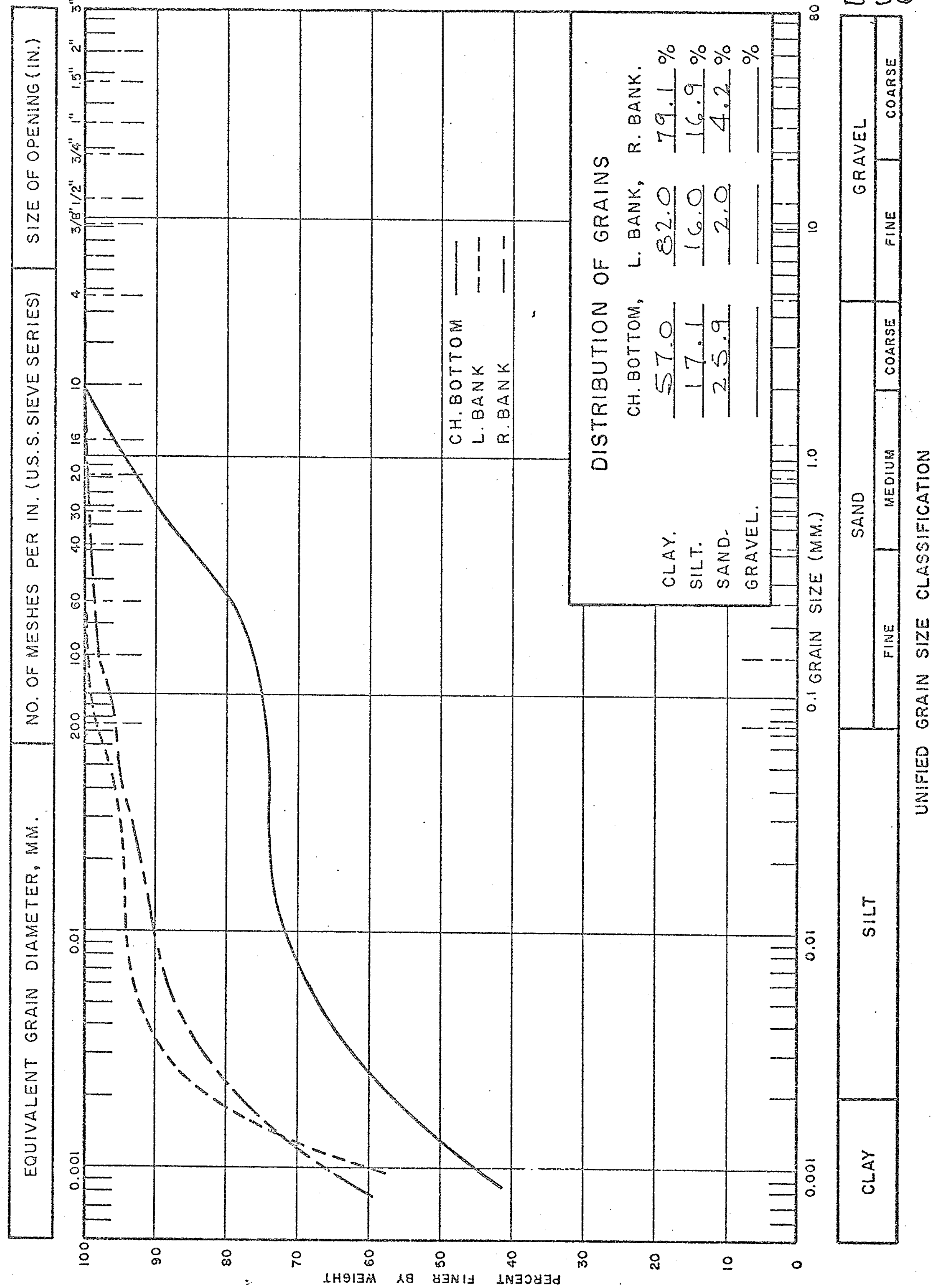
DATE. October 6, 1969

SEINE RIVER DIVERSION

MECHANICAL ANALYSIS
OF SEDIMENTS

FIGURE B.1

B36



	CH. BOTTOM,	L. BANK,	R. BANK.
CLAY.	57.0	82.0	79.1 %
SILT.	17.1	16.0	16.9 %
SAND.	25.9	2.0	4.2 %
GRAVEL.			%

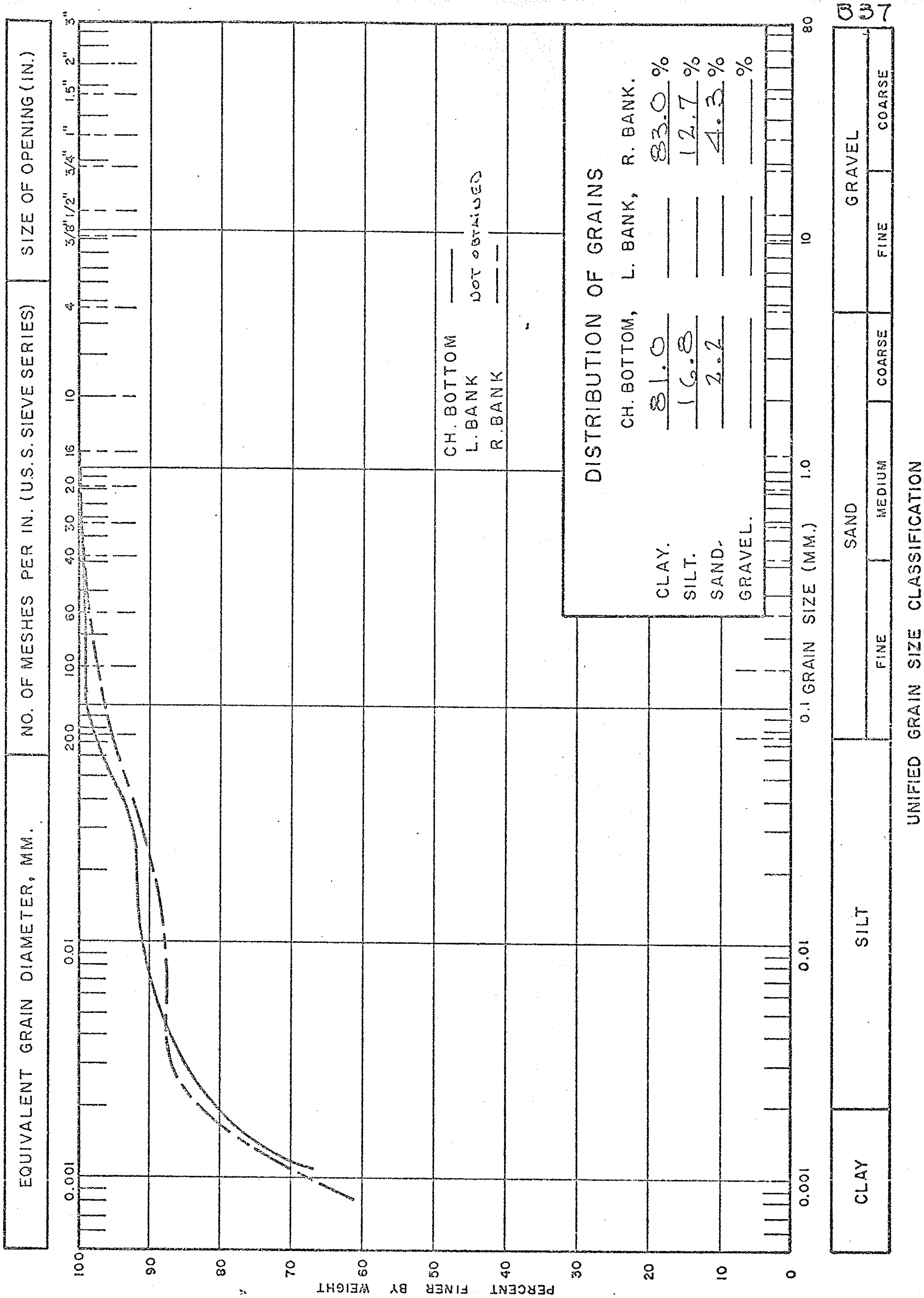
CROSS SECTION NO. S.4

DATE OCTOBER 6, 1969

SEINE RIVER DIVERSION

MECHANICAL ANALYSIS OF SEDIMENTS

FIGURE B2



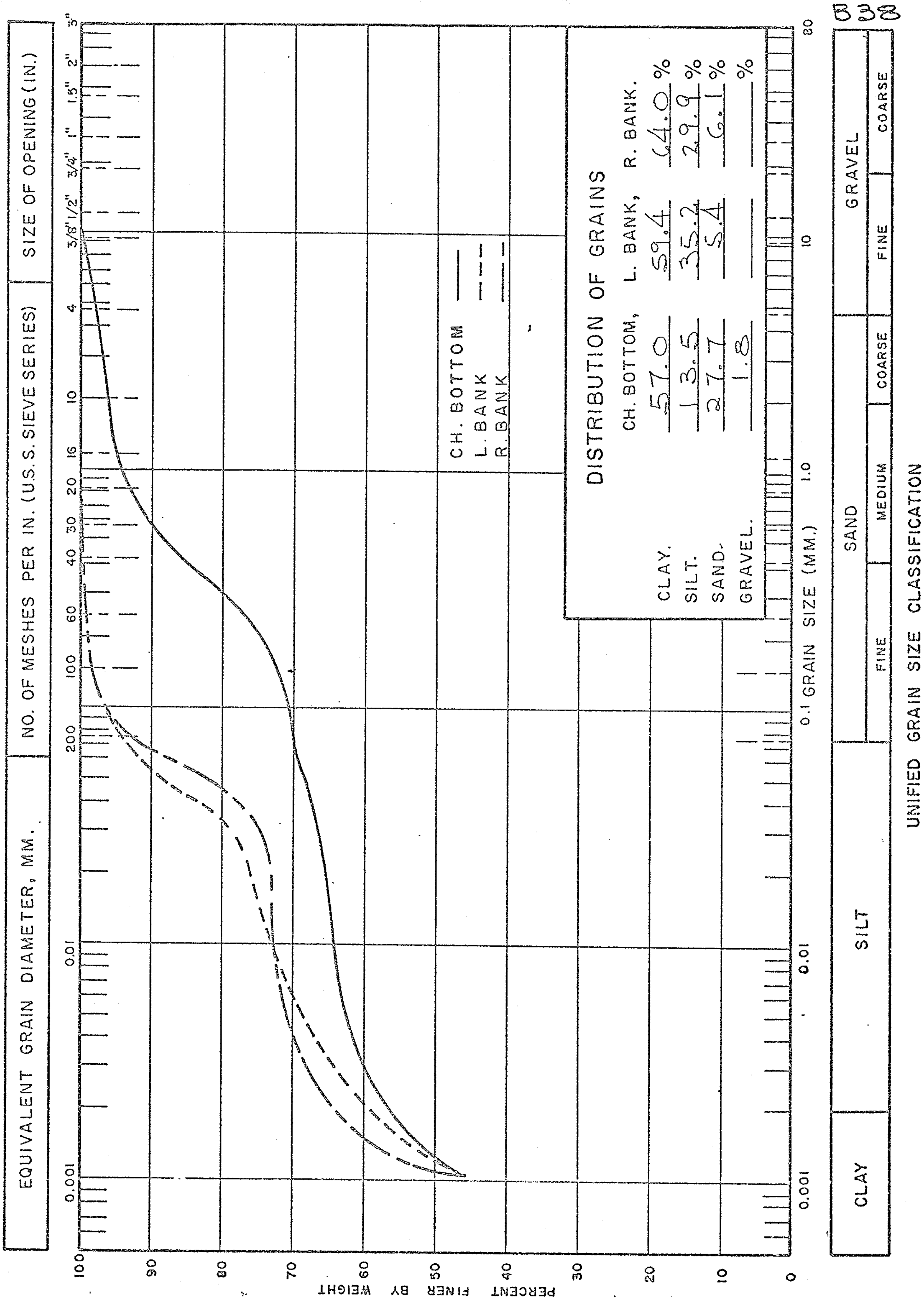
CROSS SECTION NO. S.6

DATE. OCTOBER 6, 1969

SEINE RIVER DIVERSION

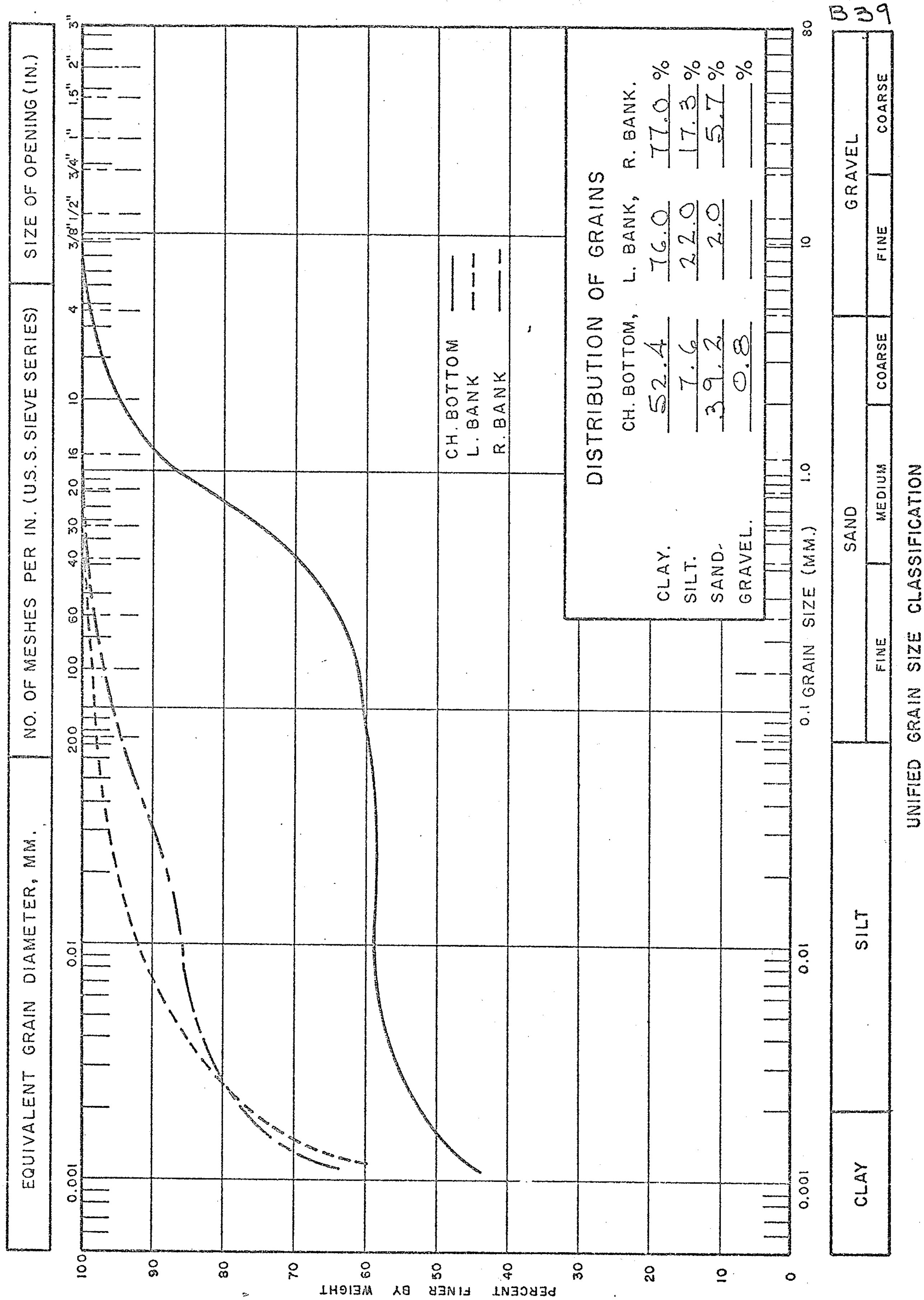
MECHANICAL ANALYSIS OF SEDIMENTS

FIGURE B3



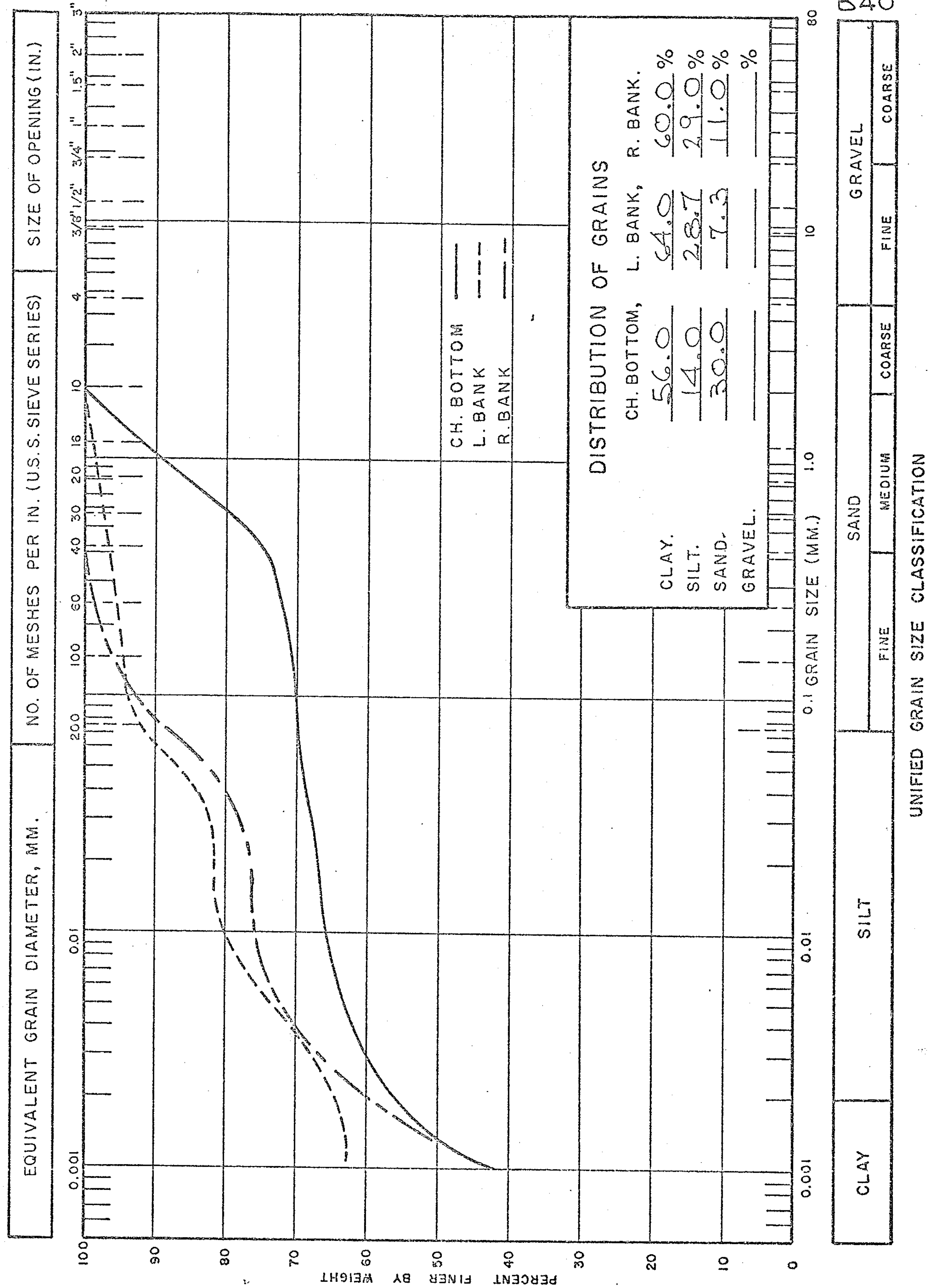
CROSS SECTION NO. S.9 DATE. OCTOBER 6, 1969	SEINE RIVER DIVERSION MECHANICAL ANALYSIS OF SEDIMENTS

B39



CROSS SECTION NO. S.13 DATE. OCTOBER 6, 1969	SEINE RIVER DIVERSION MECHANICAL ANALYSIS OF SEDIMENTS

FIGURE B5



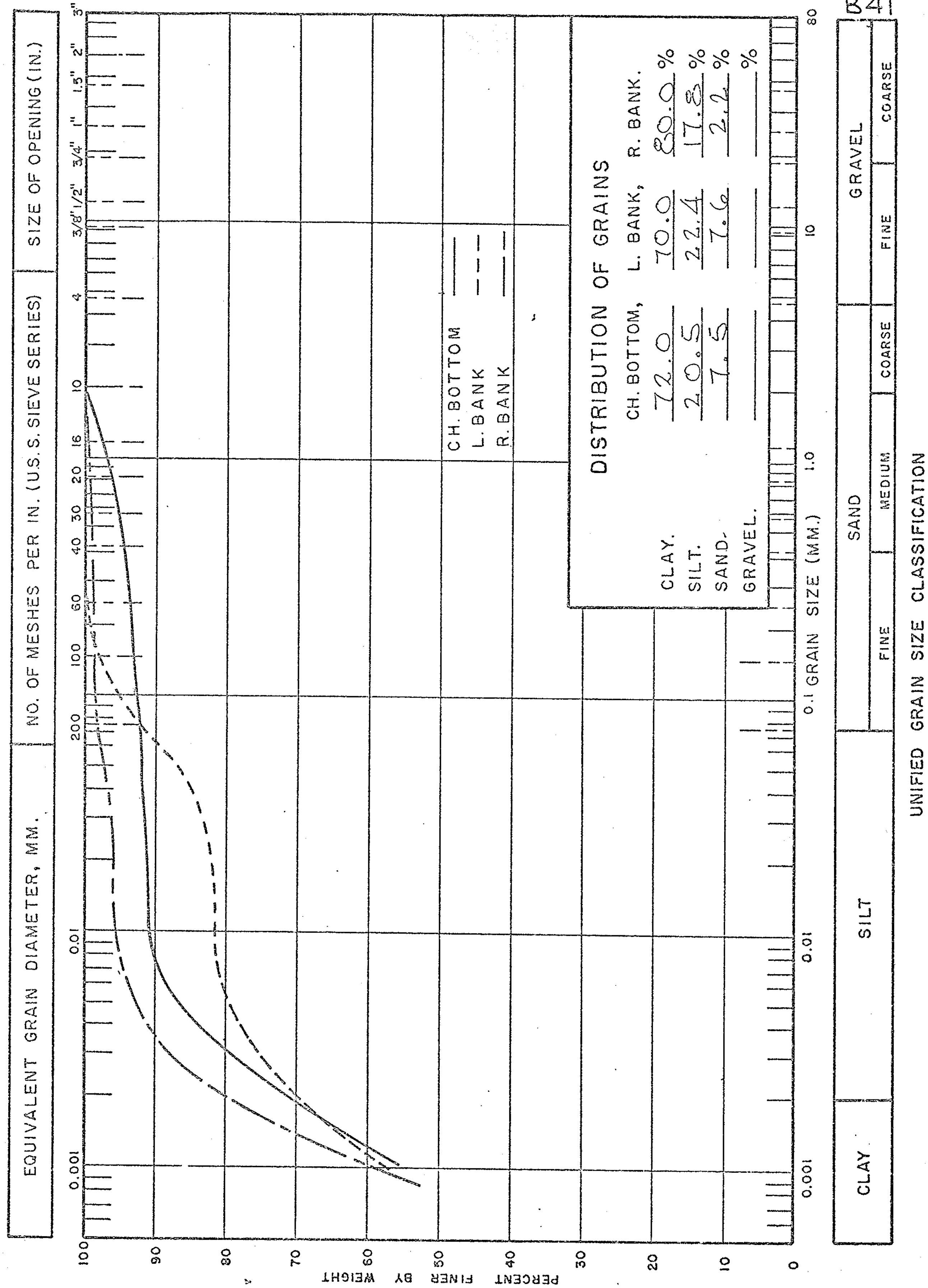
CROSS SECTION NO. S.16

DATE. October 6, 1965

SEINE RIVER DIVERSION

MECHANICAL ANALYSIS OF SEDIMENTS

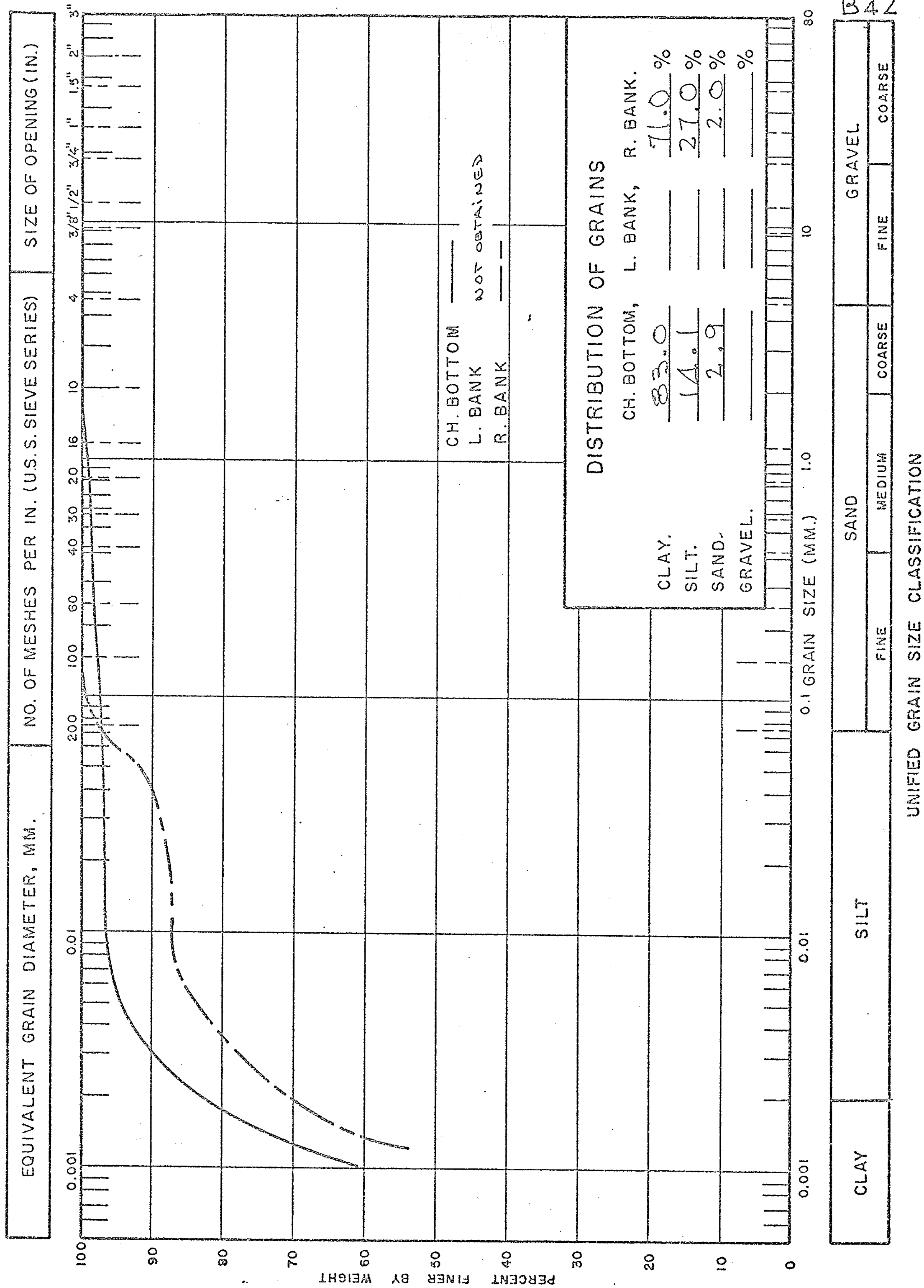
FIGURE B.6



CROSS SECTION NO. S. 18 DATE. OCTOBER 6, 1969	SEINE RIVER DIVERSION MECHANICAL ANALYSIS OF SEDIMENTS

FIGURE B.7

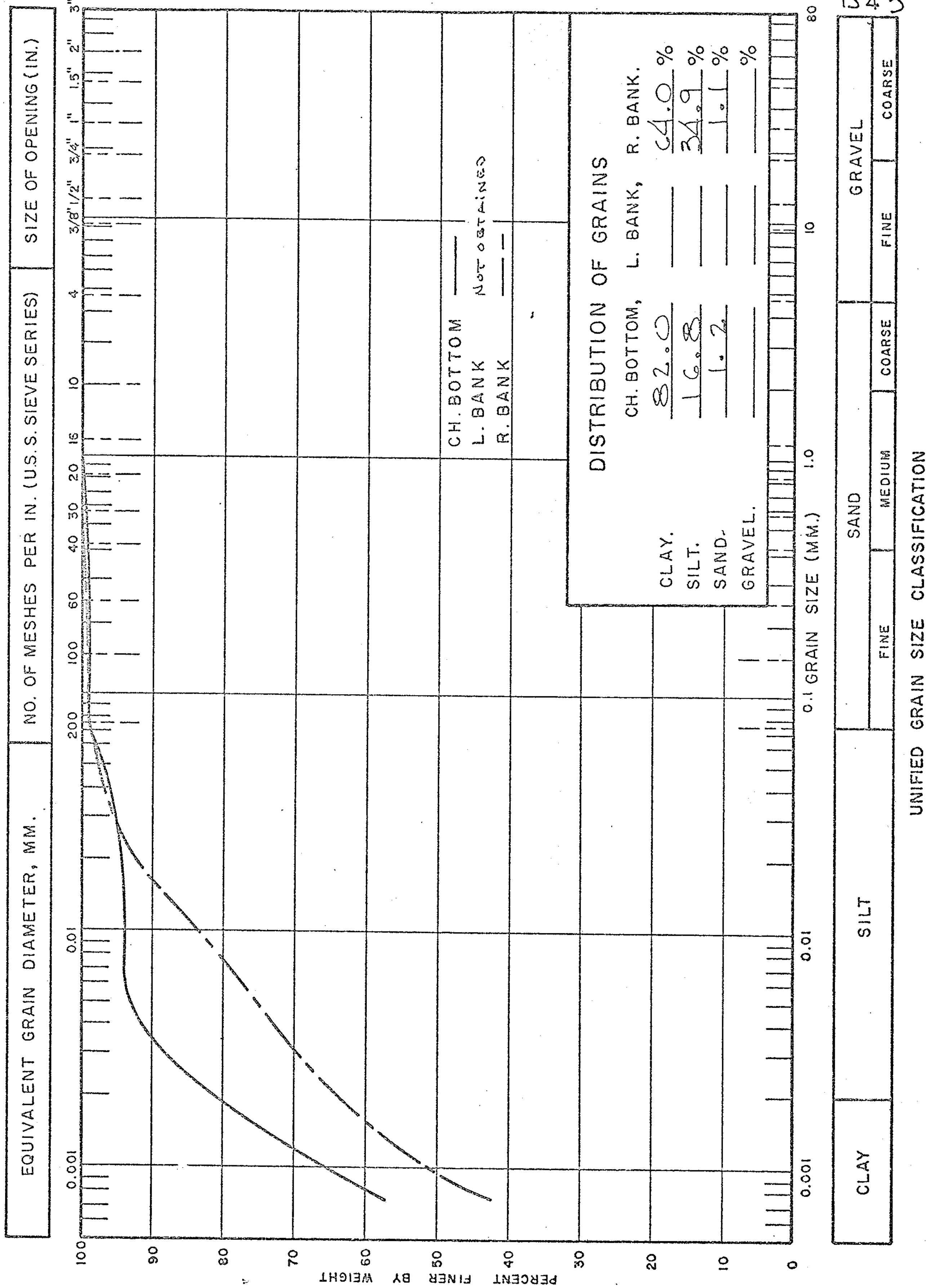
B42



CROSS SECTION NO. S.22 DATE OCTOBER 6, 1969	SEINE RIVER DIVERSION MECHANICAL ANALYSIS OF SEDIMENTS

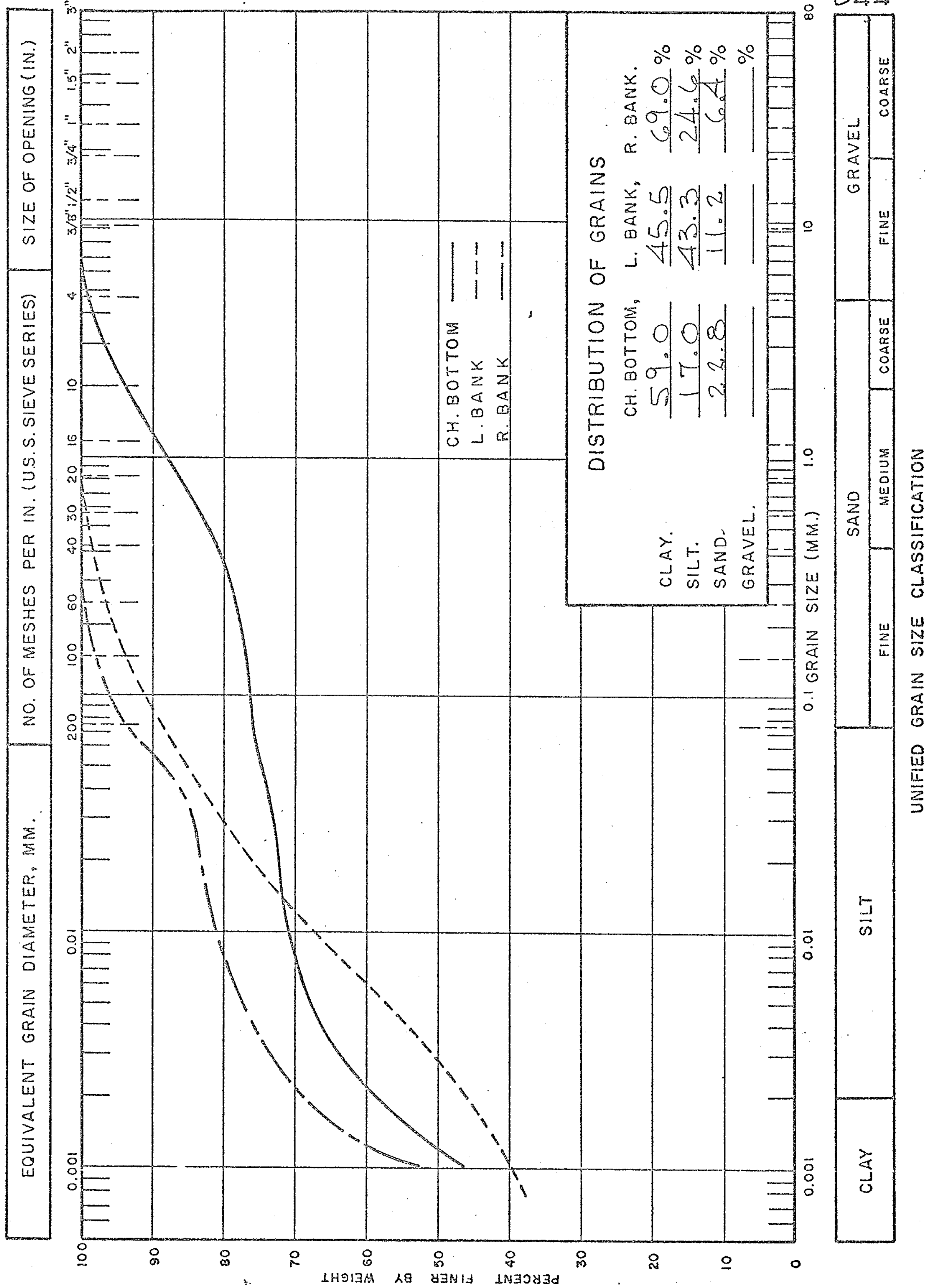
FIGURE B 9

B43



CROSS SECTION NO. S.26 DATE. OCTOBER 6, 1969	SEINE RIVER DIVERSION MECHANICAL ANALYSIS OF SEDIMENTS

FIGURE B 9



	CH. BOTTOM,	L. BANK,	R. BANK.
CLAY.	59.0	45.5	69.0 %
SILT.	17.0	43.3	24.6 %
SAND.	22.8	11.2	6.4 %
GRAVEL.			%

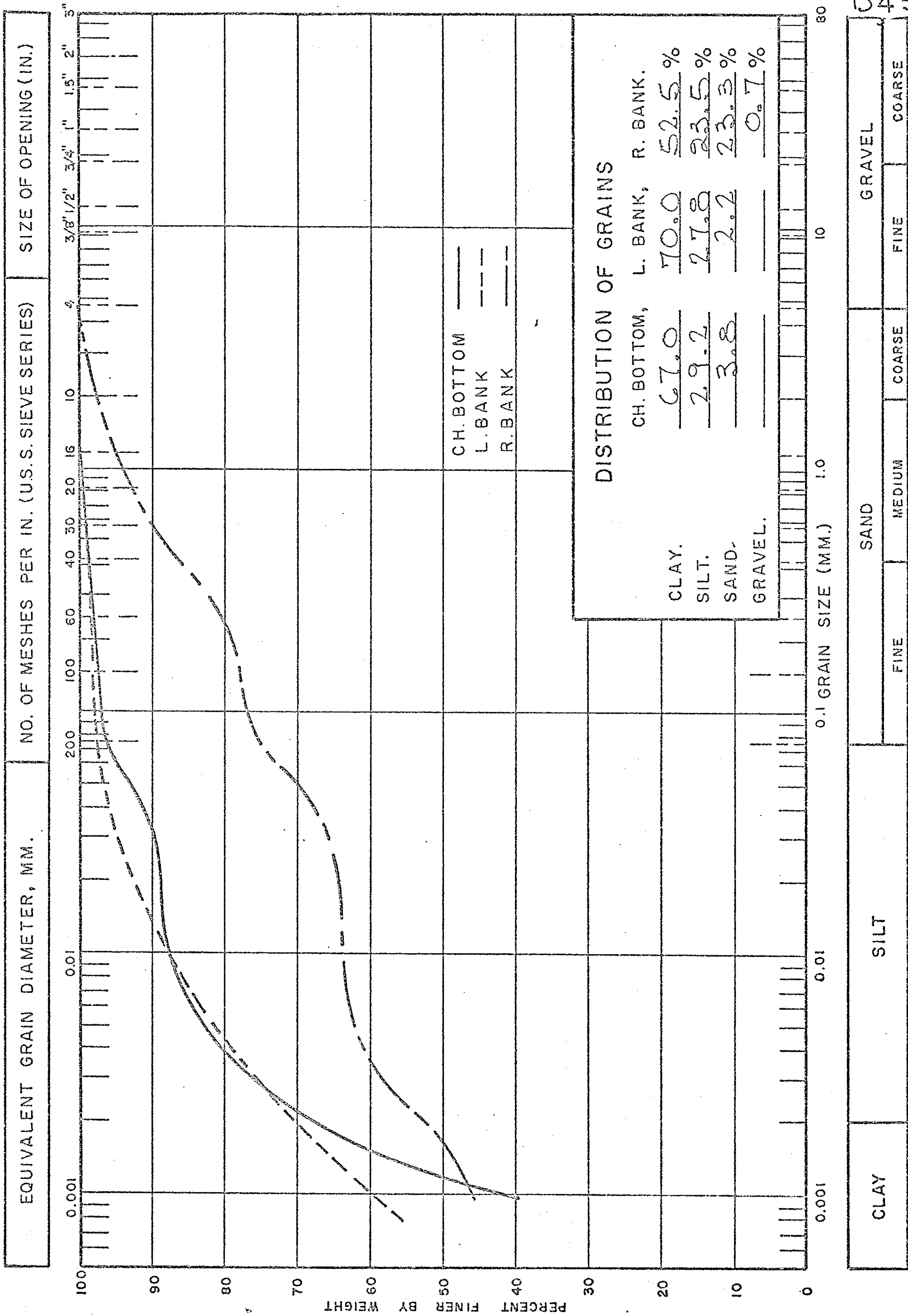
CROSS SECTION NO. S.28

DATE. October 6, 1969

SEINE RIVER DIVERSION

MECHANICAL ANALYSIS OF SEDIMENTS

FIGURE B.10



CROSS SECTION NO. S.32

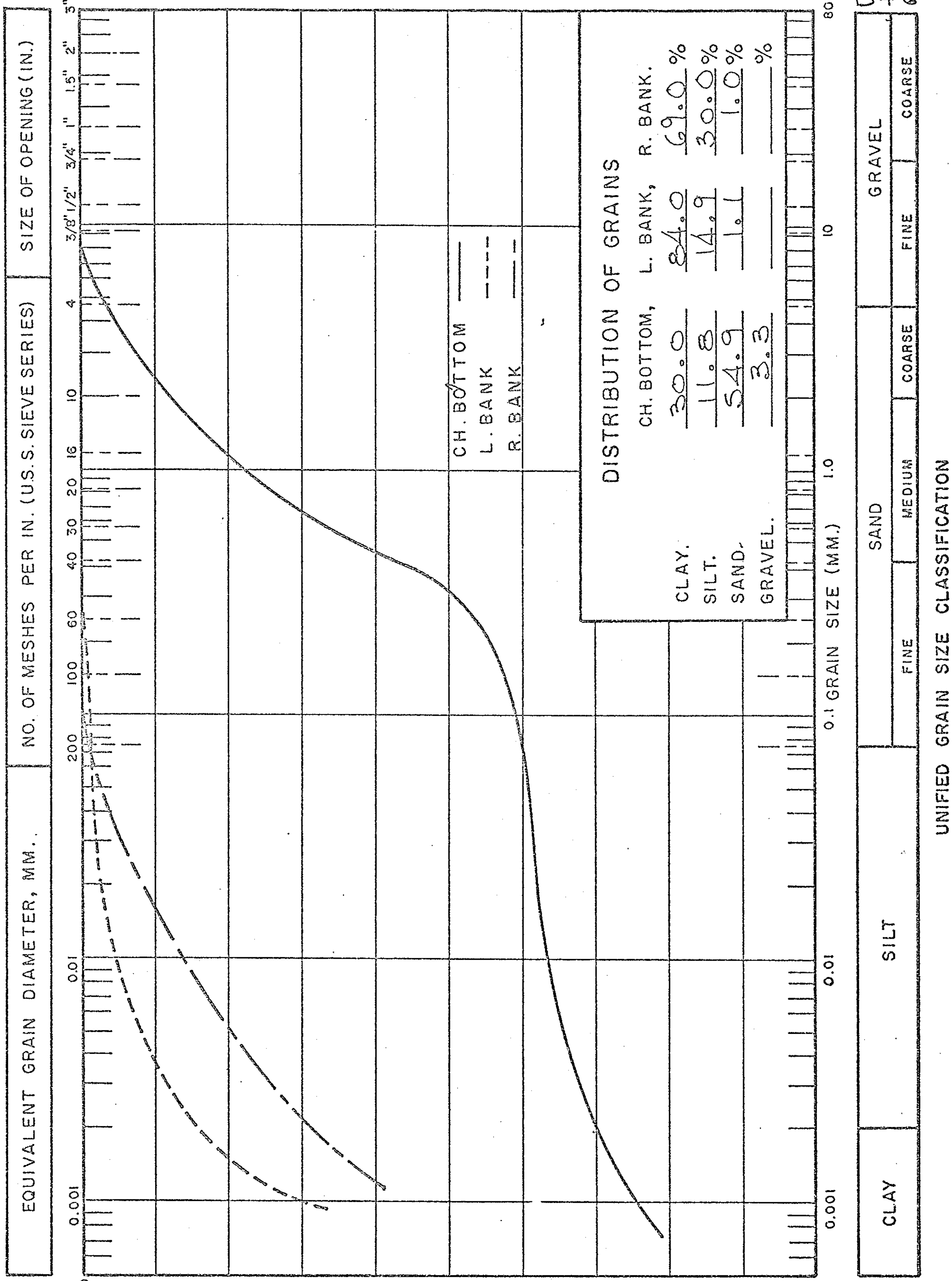
DATE. OCTOBER 6, 1969

SEINE RIVER DIVERSION

MECHANICAL ANALYSIS OF SEDIMENTS

FIGURE B.11

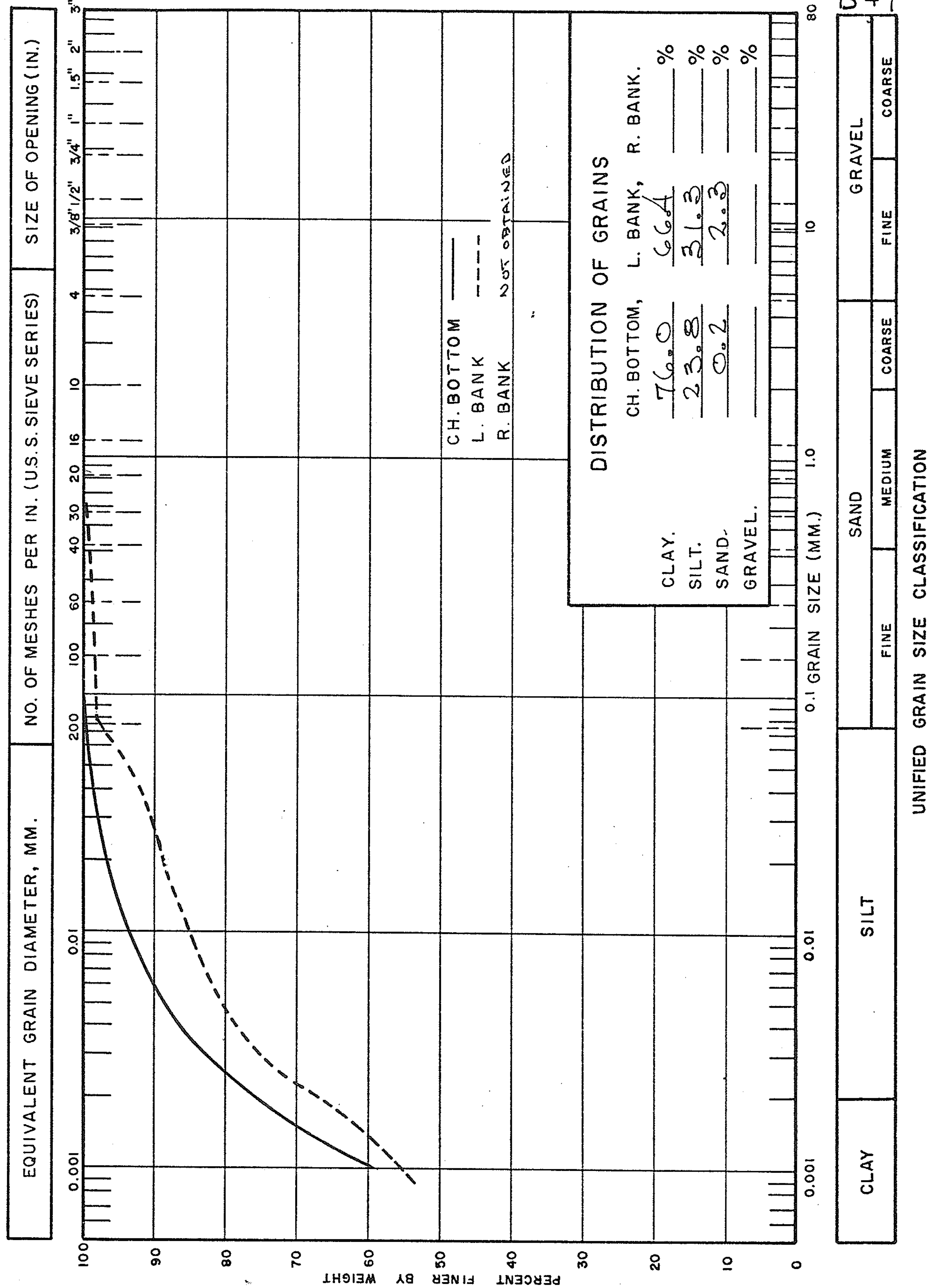
B46



CROSS SECTION NO. S.37 DATE. October 6, 1969	SEINE RIVER DIVERSION MECHANICAL ANALYSIS OF SEDIMENTS

FIGURE B.12

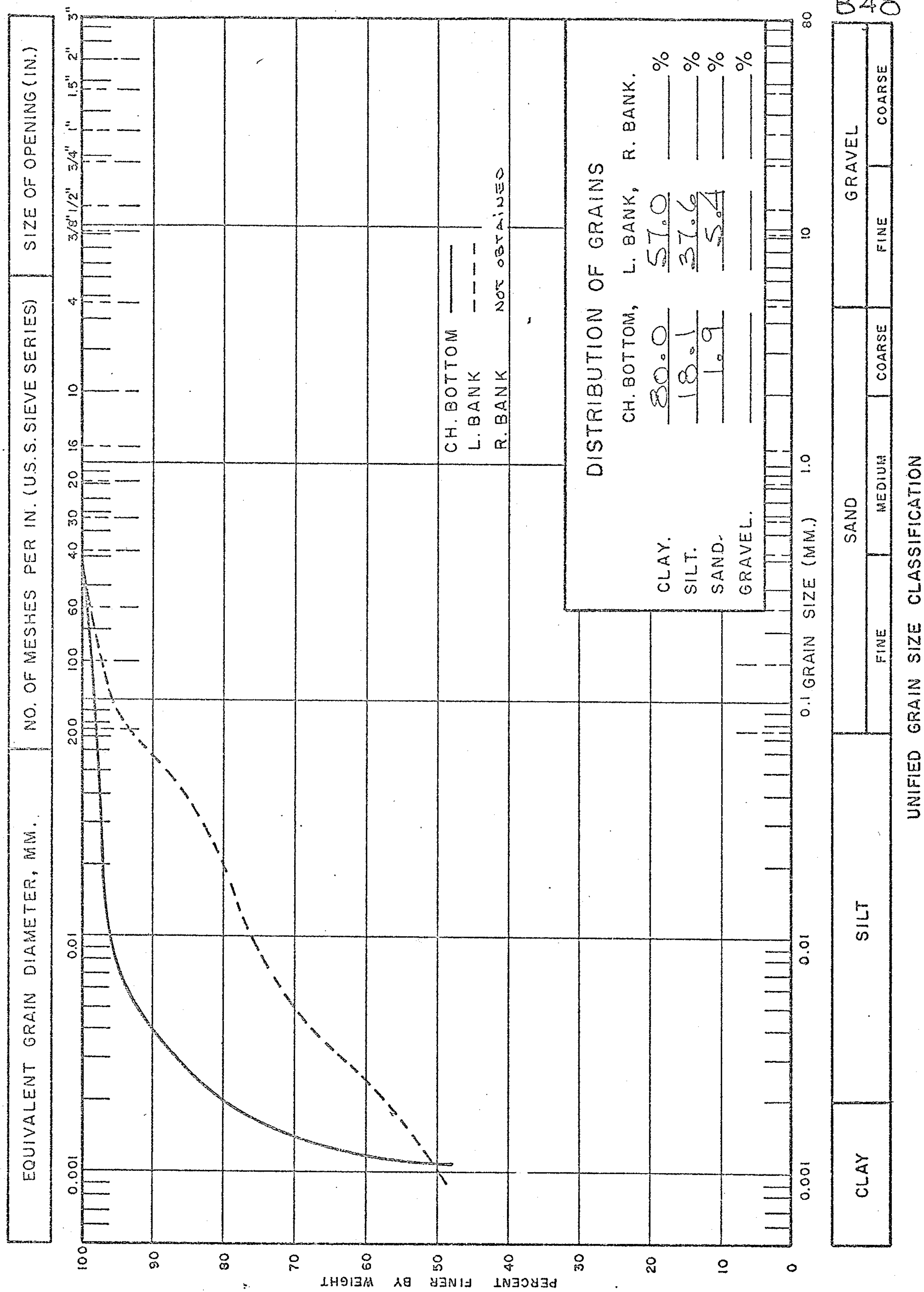
B 47



CROSS SECTION NO. S.41 DATE. OCTOBER 6, 1969	SEINE RIVER DIVERSION MECHANICAL ANALYSIS OF SEDIMENTS

FIGURE B.13

B48



CROSS SECTION NO. S.44

DATE. October 6, 1969

SEINE RIVER DIVERSION

MECHANICAL ANALYSIS OF SEDIMENTS

FIGURE B.11