US Army Corps
of Engineers
Waterways Experiment
Station

Miscellaneous Paper HL-95-1
January 1995

Sediment Impact Assessments for the Rio Guanajibo at Mayaguez and San German, Puerto Rico

by William A. Thomas

Approved For Public Release; Distribution Is Unlimited

Prepared for U.S. Army Engineer District, Jacksonville

Miscellaneous Paper HL-95-1
January 1995

Sediment Impact Assessments for the Rio Guanajibo at Mayaguez and San German, Puerto Rico

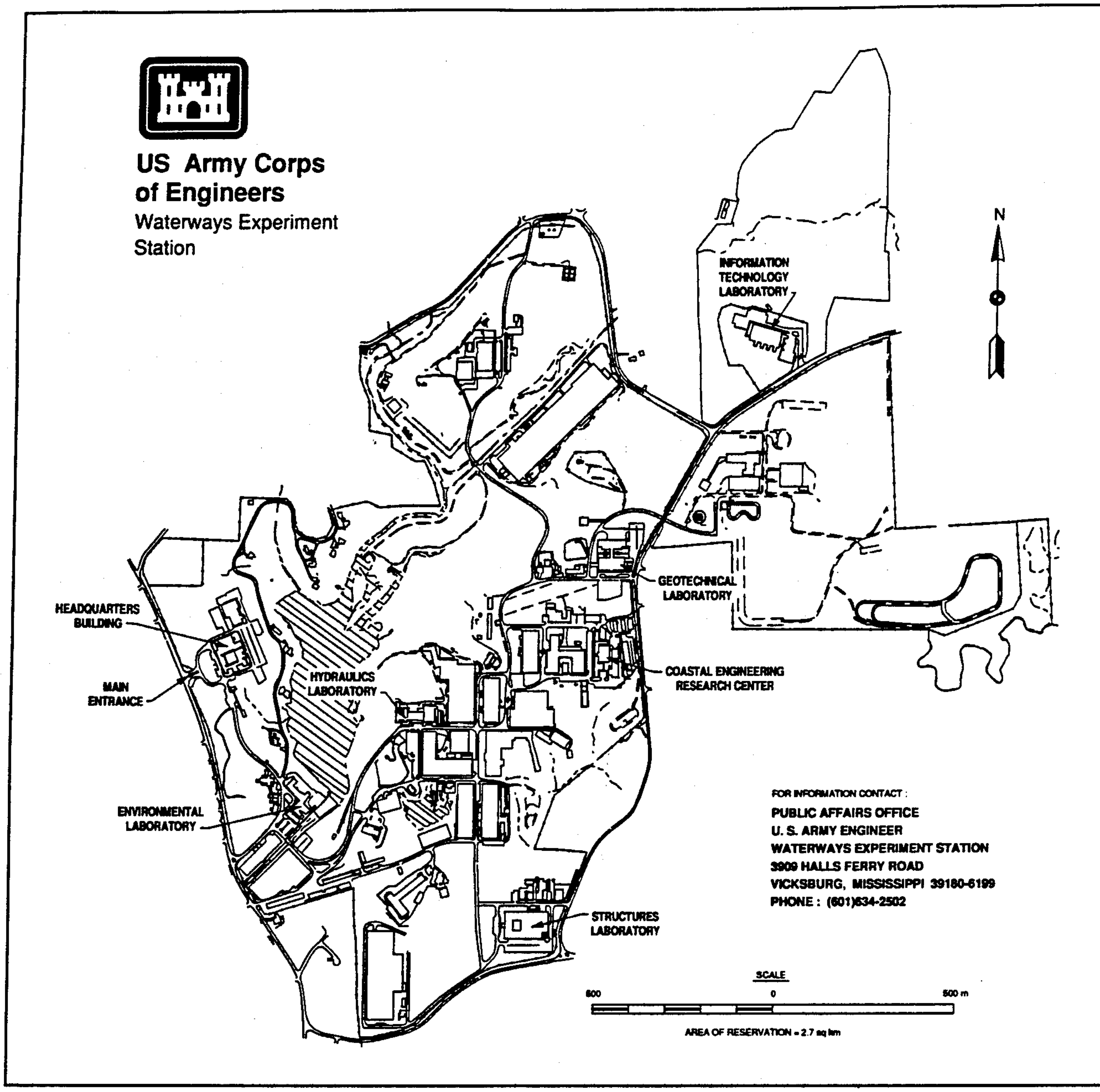
by William A. Thomas

U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

Approved for public release; distribution is unlimited

Prepared for U.S. Army Engineer District, Jacksonville
P.O. Box 4970, Jacksonville, FL 32232-0019



Waterways Experiment Station Cataloging-in-Publication Data

Thomas, William A., 1938-
Sediment impact assessments for the Rio Guanajibo at Mayaguez and San German, Puerto Rico / by William A. Thomas ; prepared for U.S. Army Engineer District, Jacksonville.
63 p. : ill. ; 28 cm. -- (Miscellaneous paper ; HL-95-1)
Includes bibliographic references.
1. Rivers -- Puerto Rico -- Flood control. 2. Channels (Hydraulic engineering) -- Puerto Rico. 3. River channels -- Sedimentation and deposition.-- Mathematical models. I. United States. Army. Corps of Engineer. Jacksonville District. II. U.S. Army Engineer Waterways Experiment Station. III. Hydraulics Laboratory (U.S.) IV. Title. V. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; HL-95-1.
TA7 W34m no.HL-95-1

Contents

Preface

This Sediment Impact Assessment for the Rio Guanajibo at San German and Hormigueros-Mayaguez Project areas, Puerto Rico, was conducted at the request of U.S. Army Engineer District, Jacksonville (USAEDSAJ). The work was performed at the U.S. Army Engineer Waterways Experiment Station (WES) and partially funded by the Flood Control Channels Research Program, Work Unit 32549, "Controlling Stream Response to Channel Modification."

This investigation was conducted during the period March to December 1993 in the Hydraulics Laboratory (HL), WES, under the direction of Mr. Frank A. Herrmann, Jr., Chief, HL, Dr. Larry L. Daggett, Acting Chief, Waterways Division, and Mr. Michael J. Trawle, Chief, Math Modeling Branch. The Project Engineer for this study was Mr. William A. Thomas, Waterways Division. Technical assistance was provided by Mrs. Dinah McComas and Mr. Rush Callahan, Math Modeling Branch.

Mr. Rafael Velez served as the Hydraulic Project Engineer, USAEDSAJ. Mr. Adam Stuart, USAEDSAJ, furnished the data and modifications to data sets during this study.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI and SI Units of Measurement

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
SI to Non-SI Units		
cubic meters	35.31473	cubic feet
meters	3.2808399	feet
newtons per square meter	0.020885	pounds (force) per square foot
Non-SI to SI Units		
metric tons	1,000	kilograms
tons (2,000 pounds, mass)	907.1847	kilograms

1 Introduction

The Rio Guanajibo drainage basin is located on the west end of the Island of Puerto Rico, Figure 1. It is about 29 km long and 13 km wide and has an area of 345 square kilometers. This report documents two sediment impact assessments for flood protection projects in that basin. The first project is a channel modification at San German, Puerto Rico. San German is about 18 kilometers (km) from the coast. The second project is levee protection for Mayaguez-Hormigueros. This project starts at the coastline and extends inland for about 8.6 km.

These projects are being formulated by the Jacksonville District, Corps of Engineers, and the sediment impact assessment studies were conducted at their request. Since these are separate projects, each project description is presented in this report where the study is described.

The purpose of a "sediment impact assessment" level sedimentation study is stated in Engineer Manual 1110-2-1601. In summary, it is to identify potential sedimentation problems and to propose a plan of study if significant problems are indicated.

There are two basic tasks in each of these sediment studies. First a field reconnaissance was conducted to evaluate the stability of the existing channel. Second, calculations were made for channel stability. Hydraulic parameters of width, depth, slope, and velocity were calculated from HEC-2 Tape95. These were averaged in each project reach and compared with channel stability relationships. They were also used to calculate two sediment transport rating curves. One curve was for existing conditions, which represents sediment inflow to the project reach. The other transport curve was for project conditions, which represents the outflow from the project reach.

At the San German Project site each of these curves was integrated with the long-term flow duration curve to produce an average sediment yield of bed material load. The difference between existing conditions sediment yield and plan conditions sediment yield, called a sediment budget, is one measure of the likelihood of sediment problems at the project. This approach was applied to the Hormigueros-Mayaguez Project site also, but the existing channel was determined to be unstable before reaching the sediment yield part of the assessment.

2 Field Reconnaissance

The field reconnaissance was conducted by Dr. Robert C. MacArthur of RCE Resource Consultants and Engineers, Inc., Davis, California, during the week of March 29 through April 2, 1993. He was accompanied by Messrs. Eric Holland and Rafael Velez of Jacksonville District and Mr. Ronald Heath of Waterways Experiment Station. They photographed the Guanajibo at entry points between Sabana Grande and its mouth and inspected the major tributaries at Highway 2 crossings. RCE took samples of the bed and bank sediments for use in stability, maintenance and reliability calculations. Results from their trip are reported in "Site Reconnaissance of the Rio Guanajibo River flood Control Project Area," dated May 1993. The following paragraphs were selected from that report.

> "In general the stream channels observed along the main Rio Guanajibo and up the lower portions of several of its major tributaries appear to be reasonably stable. No major channel or bank instabilities were observed during the field inspection of the Rio Guanajibo. Occasional bank sloughing was observed but this is to be expected in a high energy alluvial system. There is evidence that localized channel bed and bank erosion occurs during large flood events, especially near channel constriction, bridge crossings and locations where organic debris accumulates." p 4

> "Local deposition zones at the mouths of the tributary basins (fan head deposits) are characterized by a wide range of bed sediment sizes, from fine sands to coarse gravel, cobbles and some small boulders. There are sufficient large diameter materials to provide bed armor and pavement materials in the upper reaches of the Rio Guanajibo (eg. near Sabana Grande). The availability of good quality gravel has attracted the gravel mining industry to the project area. ... Some areas of the basin show outcrops of clay layers and Yauco Mudstone and andesite near the surface. These erosion resistant materials are exposed in the channels upstream from San German where present in-channel gravel mining operations are taking place. Clay outcrop bed controls are shown in photos 7-32 and 7-33 on page 15 of the typed field notes. Caution MUST BE GIVEN to these locations so these relatively thin erosion resistant deposits are not punctured, thus leading to the

exposure of more easily eroded alluvial materials below. Significant upvalley head-cutting could result." p 5

"Evidence that tributary incision is occurring upstream from the San German project reach is documented on page 15 of the field notes and shown in photographs 7-23 and 7-24." p 5

"Other flooding problems in the lower Guanajibo basin and coastal zone include getting the flood waters to an outlet (providing a dependable route for flood water to take to an outlet) and getting it through an outlet (providing enough head to push it through the outlet) to the sea. Floating debris and coastal littoral sand bars also inhabit free exiting of flows to the ocean. Shallow flooding through the mangrove forests may not receive much flow resistance unless they are choked with vines or debris. Once the flow depths exceed 5 to 8 feet, however, the flow will be resisted by the upper canopy of the tree cover. So flood flows may see a two staged flow resistance relationship with effective resistance going up abruptly after a given depth is exceeded (stage vs Manning n will be stepped possibly). Flow splits above the Cano Corazones and the Rio Guanajibo outlet channels may also be affected by seasonal changes in effective roughness and energy gradient due to planting, harvesting and cultivation activities in the floodplain. Hydraulic flow sensitivity analyses for range of possible roughnesses related to various cropping practices and crops ages should be considered to evaluate these effects." pp 13-14

"An interesting anomaly observed along the Rio Guanajibo River and some of its tributaries is that the main channels typically have gravel bottoms but have a very low width to depth ratio. Typical gravel bottom streams are wide and shallow. In the tropics there is a lot of fine suspended materials moving over the floodplain during high flows. The floodplain is also typically heavily vegetated. This encourages both vertical and lateral accretion of the banks due to accumulation of fines being held by the vegetation. Flow energy in the confined channels is still high enough to transport the gravel load through the system. The gravel bed load presently provides sufficient armoring of the channel bottom to control incision (see photos 10-21 through 10-24). The present system is stable and functions effectively as a small narrow main channel and a broad flat alluvial floodplain. Straightening, widening and/or altering the presently stable channel plan and profile may lead to channel avulsion and lateral migration." p 15

"Debris flows can provide several orders of magnitude more sediment loading to a river in a single event than is normally experienced during flooding season. Landslide and debris flows are common in the Maraca Mountains north of the Guanajibo River Valley (Monroe, 1979). Therefore, steep tributary streams draining in to the Guanajibo can provide large episodic sediment loads to the system. It is difficult to develop traditional sediment yield curves for systems that exhibit this type of episodic sediment production and loading." p 15

"Tributary inflows have a significant effect on the flows in the Guanajibo River, especially downstream for San German. The primary tributary to the Guanajibo is the Rio Rosario. The mean-annual discharge is approximately 35 cu. ft. per second, while the 30-day highest discharge was 190 cu. ft. per second during October. The differences in base flow between a wet year and dry year can be as much as 50 cu. ft. per second (U.S.G.S., 1985)." p 16

"Measured sediment data from streams in the Guanajibo Valley are very scarce. Miscellaneous suspended sediment samples have been collected since 1959 at Rio Guanajibo near Hormigueros and Rio Rosario at Rosario. According to the U.S.G.S. (1985) there are no bed-load data or data for the size gradation of the suspended load. The data collected at Rio Rosario are sporadic and inadequate for any significant correlations or load curve estimates. Data collected at Rio Guanajibo near Hormigueros has been worked up by the U.S.G.S. (1985) into an estimate for the mean annual suspended loads and yields at that location. Instantaneous water and suspended sediment load data are shown in Figure 3 [of the RCE report]. The load curve in Figure 3 only has limited applicability because the instantaneous flows only extend up to approximately 500 cfs, far below the estimated peak 100 year flow. Care must be exercised when attempting to extrapolate this curve to design events. It is also important to ask the U.S.G.S. whether this load relationship accounts for flows and sediment loads in the overbank areas of the floodplain." p 16

"According to U.S.G.S. estimates, the mean annual suspended sediment load at the Hormigueros gaging station is approximately 134,000 tons/year. The approximate suspended sediment yield at the site is approximately 1,120 tons/sq mi/yr (U.S.G.S., 1985). These estimates do not account for bed material load which may range from 5 to 15 percent of the total load (according to the writer's [RCE] estimate).

These estimated annual loads and yields do not represent the loads and yields possible from severe single events. Intense rainfall, mobilization of stored bed and bank materials, and contributions of high sediment and debris loads resulting from landslides and debris flows in the steep upper catchments can easily produce 2 to 10 times these average annual values in one event (MacArthur, et al., 1992). Elsewhere on the Island, the Rio Tanama basin produces [a] sediment yield of approximately 2,600 tons/sq mi/yr, or nearly 3 times higher than the Guanajibo system (U.S.G.S., 1985). The Rio Tanama basin is steeper, with greater and more intense rainfall and more agricultural development. Increasing the agricultural, gravel mining, road building and urbanization activities in the upper Guanajibo Basin will probably result in higher annual sediment yields until the basin heals again. Total load yield values upstream from San German may also be different from those measured near Hormigueros." p 17

As a result of this field reconnaissance RCE stated, "It is also advisable to conduct a more in-depth quantitative geomorphic investigation of the Guanajibo Basin to tie together the preliminary observations and hypotheses presented in this report." p 5

3 Rio Guanajibo at San German Project Reach

Project Description

The San German flood protection project widens the existing channel to a 65-m bottom width, Figure 1. The project length is about 1 km. The proposed project will follow the existing channel alignment. The project is being designed for flood protection up to a 10-yr recurrence interval flood. Bed material at this site is sand and gravel.

Geometry and n-values. The Jacksonville District furnished HEC-2 data files for existing and proposed project conditions, Table 1.

Table 1
San German Project HEC-2 Input Data Files

Existing	Project
SGEXST2.DAT	SGCI65I.DAT
SGCI65K.DAT	
SGEXST9.DAT	SGCI65P.DAT

The cross section layout is shown in Figure 2. Note that cross-section numbers increase in the downstream direction. Sections are coded left to right looking downstream. This data deck begins 1.6 km downstream from the project and ends at the upstream end of the project.

Sediment data. No sediment concentration measurements were available for San German. A few measurements are available at a USGS gage near Hormigueros, PR, but the water discharges are less than 400 cfs(11 m^3/s). Those concentrations range up to 400 mg/l. There are no gradation data to separate the suspended sediment into wash load and bed material load. There is a USGS gage on Rio Rosario near Rosario, PR. This is a tributary to the Guanajibo which enters near Hormigueros. Suspended sediment concentrations and particle size gradations have been measured there for several years. The mean value for percentage of sand in those samples is 22 percent.

Bed sediment and bank sediment samples were collected from the Guanajibo channel during the site visit of 29 March-2 April 1993. These data were sieved for particle size gradation, Figure 3. Samples 10-A and 10-B are 500 m upstream from the Highway 119 bridge at San German. They are the pavement and the sub-pavement materials, respectively. Samples 6B, 7 and 8 were taken near the Highway 2/368 bridge at Sabana Grande, a few km upstream from San German. These subpavement samples are sufficiently consistent with sample 10-B that it was selected for this sediment impact assessment. The D_{50} size is 13 mm.

Stability Evaluation for the Existing Channel

Average hydraulic parameters were calculated for the project reach, cross sections 15.1 to 13.0, using the SAM utility program, M95. That utility reads the HEC2 Tape95 output and averages cross section widths, depths, channel n-values and channel water discharges. Results, shown in the following table, used a length-weighted-average.

Table 2
Average Hydraulic Parameters for Each Water Discharge, Existing Channel[1]

Recurrence Interval	2-YR	10-YR	25-YR	50-YR	100-YR	SPF
Water Discharge, m^3/s	270	726	1266	1497	2011	2809
Water Surface Width, m	67	78	81	82	83	83
Hydraulic Depth, m	2.51	3.77	4.97	5.43	6.18	7.41
Slope, m/m	0.00305	.00305	.00260	.00246	.00241	.00212
Velocity, m/s	1.55	2.04	2.26	2.33	2.52	2.66
Channel n-value	.0657	.0657	.0657	.0657	.0657	.0657

[1] Length-weighted average over 19 cross sections, HEC2 DATA SET = SGEXST9.DAT

The basis for these average hydraulic parameters is shown in Figures 4 through 11. Figure 4 shows how the water discharge varies within the HEC2 data set. These water discharges are plotted versus cross section numbers from the HEC2 geometry, and in this case they span the entire HEC2 model. The project reach begins at "X SEC 15.1" on the abscissa and extends up to cross section number 13.

Figure 5 is the HEC2 water surface profiles for these discharges. Notice the legend keys on water discharge. In this case, it is the same as Figure 4. In the general case, the water discharge at the downstream end of the averaging reach is used in the legend to reference the plot. Figure 4 profiles provide that water discharge at each cross section. It can be used to define the legend for profiles through any portion of this Tape95 data set. Figure 5 shows calculated water surface profiles for these flows.

Figure 6 is the HEC2 water surface profile for the 2-yr flood for existing and project conditions. It shows the slope change in the project reach as well as the convergence of profiles upstream from the project reach. The channel over which the profiles return to preproject conditions is referred to as the "approach channel" in ER 1110-2-1405. That convergence is not yet complete in Figure 6 which indicates some additional design work is needed on the approach channel.

Figure 7 shows the channel velocities. They fluctuate through the project reach, but there is no trend in the existing channel. The average value will be used to test channel stability.

Figures 8, 9 and 10 are the hydraulic geometry parameters. The width and depth fluctuations are fairly common. The slope profile shows calculated values and not bottom slope. The average values will be compared with hydraulic geometry relationships.

Stability Analysis Based on Velocity. Using the D_{50} size from sample 10-B, 13 mm, Table 5-2 of EM 1110-2-1601 gives a critical velocity of 1.8 m/s for that size gravel. The average channel velocity in the project reach is 1.6 m/s for the two-year flood. That value is below the critical value indicating the existing bed is stable at the 2-yr flood.

Stability Analysis Based on Velocity and Depth. Figure 5.3.5 of the draft EM 1110-2-1418, gives a critical velocity of 1.5 m/s for D_{50} particles of 13 mm when the depth of flow is 2.5 m. This criterion indicates the existing channel is not stable due to particle movement at the two-year flood.

Stability Analysis Based on Bed Shear Stress. The average grain shear stress in the project reach is 19.63 n/m^2 (0.41 lb/ft^2). Critical shear stress for a particle size of 13 mm is 11.97 n/m^2 (0.25 lb/ft^2). Therefore, the shear stress parameter indicates the existing channel bed is not stable at the 2-yr flood.

Stability Analysis Based on Hydraulic Geometry. The three hydraulic geometry relationships for this analysis are shown on figure 11. The average channel width for the 2-yr flood peak, 67 m (220-ft) at 271 m^3/s (9550 cfs), is plotted on Figure 11a. That is a regime relationship between top width and the channel forming discharge. It indicates that the two year flood is a reasonable approximation to the channel forming discharge. Using that value and the D_{50} particle size of 13 mm, the regime depth should be 3 m (10 ft) and the regime slope should be about .0005 m/m. The existing slope, which is 0.003 m/m, is much steeper than the regime slope which indicates the existing channel stability depends on the inflowing sediment discharge and not on particle size in the bed.

Channel Stability Based on the Analytical Method. Figure 12 shows the calculated width-slope relationship from existing channel conditions. (Note: This calculation is available only in English units.) The inflowing sediment concentration, i.e. the bed material load entering the project reach, was calculated from a supply reach. For that calculation, the channel hydraulic properties from Table 2 were used to develop one representative trapezoid. The top width of that trapezoid is 220 feet (67.04 m) and the depth is 8 feet (2.51 m). The channel was given side slopes of 1V:2H which resulted in a bottom width of 190 feet (57.91 m). The effective bank roughness was assigned a value of 4 feet and Manning's n-value for the bank was calculated, by Strickler's Equation, to be 0.043. The Brownlie bed roughness predictor was used to calculate the bed n-value.

The results are peculiar in that they show such a well defined minimum. It is at a bottom width of 60 - 80 feet (18.29 - 24.38 m). Also, they indicate the stable slope is very sensitive to width as the channel becomes wider. The results also indicate the width-slope relationship is sensitive to the inflowing sediment concentration which is typical of streams which transport a significant sediment load.

The sediment size in this stream, 13 mm, is considerably larger than the 2 mm maximum size recommended for the Brownlie Equation. At this point in time, however, there is no alternative to Brownlie.

Summary. The results of the five stability tests are summarized in the following table. The velocity criteria indicates the bed is stable against erosion whereas the velocity-depth, bed shear stress and hydraulic geometry methods indicate that it is not. The analytical method reconciles those differences by

Table 3
Stability Analysis, Existing Channel

Method	Calculated	Critical
Velocity	1.6 mps	1.8 mps
Velocity and Depth	1.6 mps @ 2.51 m	1.5 mps @ 2.51 m
Bed Shear Stress	.41 lb/sf	.25 lb/sf
Hydraulic Geometry	See Fig 11	
Analytical Method	See Fig 12	

showing that the inflowing bed material load is both necessary and sufficient to preserve the existing slope. Therefore, the analytical method will be the primary stability test used for the proposed channel with velocity-depth, the bed shear and hydraulic geometry methods used as backup.

Stability Evaluation for the Project Channel

Average hydraulic parameters were calculated for the project reach using the same procedure that is described above for the existing channel. Results are shown in the following table.

Table 4
Average Hydraulic Parameters for Each Water Discharge, Existing Channel[1]

Recurrence Interval	2-YR	10-YR	25-YR	50-YR	100-YR	SPF
Water Discharge, m^3/s	270	726	1266	1497	2011	2809
Water Surface Width, m	82	91	95	96	93	98
Hydraulic Depth, m	2.57	4.02	5.22	5.68	6.46	7.65
Slope, m/m	.00198	.00240	.00236	.00228	.00226	.00207
Velocity, m/s	1.27	1.89	2.23	2.31	2.51	2.69
Channel n-value	.0658	.0658	.0658	.0658	.0658	.0658

[1] Length-weighted average over 18 cross sections, HEC2 DATA SET = SGCI65P.DAT

The proposed channel is wider; has about the same depth; and has a flatter water surface slope than the existing channel. Consequently, the velocity of the 2-yr flood is less than the existing channel velocity. The analytical channel method, Figure 13, indicates the project channel will require a slightly steeper slope to transport the inflowing sediment load than is required in the existing channel. Consequently, deposition can be expected in the project reach. Figure 11 shows only a small difference between the proposed and the existing hydraulic geometry. However, that difference also indicates deposition will occur in the project reach. Particularly, the water surface width plots outside the range of curves. This indicates the channel is too wide. In a gravel bed stream such as this, an overly wide channel will braid, form center bars and require bank protection to prevent flows from eroding the banks. Maintenance to remove those deposits will be required. In summary, for the existing sediment loading, the project reach is stable against erosion of the bed, but it is unstable from the standpoint of deposition.

Long-Term Maintenance

The rate at which sediment material will deposit can be estimated using a sediment budget calculation. That is made by comparing the existing bed material sediment yield with that predicted for the project channel. Both of these sediment yield calculations require a sediment transport rating curve and the long term flow duration curve.

Sediment Transport Calculation. The existing bed material transport appears to be in balance with the existing channel hydraulics in the project reach. That is, the field reconnaissance showed the existing channel to be alluvial and stable. Therefore, a sediment transport function can be used to calculate the bed material load for existing conditions.

There are no measured bed material loads in the project reach from which to confirm a sediment transport function. Therefore a function was selected using SAM.aid. This utility code compares the hydraulic data of Table 4 and the D_{50} of the bed samples with a library of 23 different test data sets. It matches as many parameters as possible, and checks how well each of 13 transport function performed on those data sets. The three best functions are displayed. In this case the best performer is a combination of Toffaleti-Schoklitsch. The calculated bed material sediment transport is shown in figure 14.

Hydrologic data. The Jacksonville District furnished their design flood hydrograph and a flow duration curve for the downstream end of the project reach. The flow duration data is shown in the Table 5.

Table 5
Flow-Duration Table

#	CMS	%	#	CMS	%	#	CMS	%
1	736.23	0.01	13	33.98	2.20	25	1.47	57.80
2	566.33	0.02	14	25.49	3.90	26	1.13	66.50
3	453.07	0.04	15	19.82	6.30	27	0.88	75.30
4	339.80	0.06	16	15.29	8.90	28	0.68	83.50
5	263.34	0.08	17	11.61	11.80	29	0.51	90.40
6	203.88	0.10	18	9.06	15.10	30	0.40	94.00
7	158.57	0.20	19	7.08	19.20	31	0.31	97.70
8	121.76	0.30	20	5.38	24.60	32	0.24	99.00

(Continued)

Table 5 (Concluded)								
#	CMS	%	#	CMS	%	#	CMS	%
9	93.44	0.40	21	4.25	30.30	33	0.18	99.70
10	70.79	0.60	22	3.11	38.80	34	0.14	100.00
11	56.63	0.90	23	2.46	45.00	35	0.00	0.00
12	42.47	1.40	24	1.90	51.20			

The flow duration curve was partitioned into 2,000 integration steps, as follows, and integrated with the bed material sediment discharge curve, Figure 14, to produce an average annual bed material yield.

MINIMUM FLOW, CMS	=	0.14
MAXIMUM FLOW, CMS	=	736.23
INTEGRATION INTERVAL, CMS	=	-0.37
NUMBER OF INTEGRATION STEPS	=	2000.

The resulting yield of bed material load is shown in Table 6.

Table 6 Calculated Bed Material Sediment Yield, Existing Conditions	
Time Period, Days = 364.89	
Water Yield, Cubic Meters = $187.3*10^6$	Mean Daily Flow, CMS = 5.9
Sediment Yield, Metric Tons = 27927	Mean Daily Load, T/D = 77
Cubic Meters = 18746	Mean Daily Conc, mg/l = 149.1

The calculation is made in tons. The yield is converted to a volume using a void ratio of 44 percent. The conversion factor is 1489.72 kg/m^3 or 0.67 m^3/metric ton. The same procedure was followed for the project channel. The resulting bed sediment yield is shown in Table 7.

Table 7 Calculated Yield, Project Conditions	
Time Period, Days = 364.89	
Water Yield, Cubic Meters = $187.3*10^6$	Mean Daily Flow, CMS = 5.9
Sediment Yield, Metric Tons = 11563	Mean Daily Load, T/D = 32.
Cubic Meters = 7762	Mean Daily Conc, mg/l = 61.

The sediment budget calculation is:

$$
\begin{aligned}
Y_d &= Y_e - Y_p \\
&= 18746 - 7762 \\
&= 10984 \text{ cubic meters}
\end{aligned}
$$

This converts to a trap efficiency of 59 percent. The yield estimate is not very dependable. However, trap efficiency is a relative measure of performance, and therefore, is more dependable than the yield quantity. A trap efficiency of 59 percent is sufficiently high that a more detailed sedimentation investigation is needed for this project. Whether it is needed at this level of project formulation or not depends upon project economics. That is, if having to excavate 10,000 cubic meters of sand and gravel from the project channel every year does not affect the decision to proceed with the project, the detailed study can be conducted during the later phases of project formulation. However, if project economics cannot afford to remove that volume of sand and gravel each year, the detailed study should be conducted now in an attempt to refine that maintenance quantity.

Project Reliability During the Design Flood

Reliability is a measure of the project performance during the passage of the design flood hydrograph. This is another sediment budget calculation, but it determines if sediment deposits will choke the channel during the passage of the design flood hydrograph. In this project that is the 10-year flood. Hourly ordinates are coded, Table 8, and integrated with the bed material sediment transport curves using SAM.yld. The results are shown in Table 9 for existing conditions and Table 10 for project conditions.

Table 8
Discharge Hydrograph Ordinates, CMS Time Between Ordinates, Hrs = 1.0000

15	15	12	12	12	15
15	16	17	18	19	50
110	395	840	700	490	350
275	231	200	175	151	140
131					

Table 9
Calculated Yields for 10-Yr Flood, Existing Conditions

Time Period, Days = 1.0	
Water Yield, Cubic Meters = $15.59 * 10^6$	Mean Daily Flow, CMS = 180.5
Sediment Yield, Metric Tons = 5048	Mean Daily Load, T/D = 5048
Cubic Meters = 3388	Mean Daily Conc, mg/l = 323

Table 10
Calculated Yields for 10-Yr Flood, Project Conditions

Time Period, Days = 1.000	
Water Yield, Cubic Meters = $15.59 * 10^6$	Mean Daily Flow, CMS = 180.46
Sediment Yield, Metric Tons = 3376	Mean Daily Load, T/D = 3376
Cubic Meters = 2266	Mean Daily Conc, mg/l = 216

The sediment budget for the design flood is about 1,000 cubic meters of deposition as follows:

$$
\begin{aligned}
Y_d &= Y_e - Yp \\
&= 3{,}388 - 2{,}266 \\
&= 1{,}122 \text{ cubic meters}
\end{aligned}
$$

This converts to a trap efficiency of 33 percent. The material will not be evenly distributed along the project reach. Rather, it will deposit first at the upstream end and work toward the downstream end. Even so, if spread over a channel 65 m wide, the increase in bed elevation would be less than 1/3 m. Much of that is expected to come after the peak.

Approach and Exit Channels

The approach channel is that reach of river upstream from the project reach over which the energy gradient returns to preproject conditions. Figure 15 shows the calculated stage-discharge rating curve at cross section 13. The with-project stage is from 0.3 to 0.8 m lower than preproject conditions which indicates the approach channel should extend further upstream. Figure 16 is another way to view the project impact on the energy gradient. It shows project velocities to be as much as 0.5 m/s faster than preproject velocities were at this section. In the design phase more attention needs to be given to the approach reach.

Some maintenance in the exit channel is likely immediately after the project goes into operation, but the reach of river which is the exit channel to this project is expected to function as it did historically. Velocities in the project reach are somewhat less with the project than with out it. Consequently, any deposition will have occurred before it reaches the exit channel.

Conclusions, San German Project

Although the channel modification is fairly minor, the calculated bed material load responded noticeably. The project channel trapped 59 percent of the inflowing bed material load. That large of a percentage is probably due to the coarse size of the bed material load at this site.

The quantity of sediment in this prediction, 11,000 cubic yards, is not very dependable. However, trap efficiency is a relative measure of performance, and therefore, is more dependable than the yield quantity. A trap efficiency of 59 percent is sufficiently high that a more detailed sedimentation investigation is needed for this project.

Project reliability during the design flood seemed assured. The same concerns about accuracy of the predicted quantity are appropriate here as were stated above, but even doubling the deposit to 2/3 of a meter does not seem to endanger the project since much of the deposit would come after the peak water discharge.

The calculated stage-discharge rating curve at cross section 13 is from 0.3 to 0.8 m lower than preproject conditions which indicates some additional work is needed to design the approach channel. That is a detail which can be handled in the next phase of project development. Some maintenance in the exit channel is likely immediately after the project goes into operation, but the reach of river which is the exit channel to this project is expected to function as it did historically.

4 Mayaguez-Hormigueros Project Reach

Project Description

The Mayaguez-Hormigueros flood protection project extends inland from the coastline for about 8.6 km, as measured along the channel. This project will consist of three levees, Figure 17. No channel modification will be made. The bed material at this site is sand and gravel. The hydraulic-sediment analysis of this project is complicated by the proposed ring levee around Guanajibo Homes because that levee creates a divided-flow condition. Part of the discharge passes out the main outlet of the Guanajibo River and the rest flows out through the Cano Corazones channel.

Geometry and n values. Jacksonville District furnished the HEC-2 data files shown in Table 11. The cross section layout for the models is shown in Figure 18. The primary outlet is the Rio Guanajibo River. This is modeled by cross sections 0 through 5.6, Figure 18. Notice that cross sections 2.6, 3.2, and 4.0 extend from the ring levee to the south side of the valley. Cross sections 1.7 through 0 describe the outlet of the Rio Guanajibo sufficiently far into the ocean to allow a tailwater elevation boundary condition which is independent of bed changes due to river sedimentation. The north ends of these cross sections terminate on an alignment which is a projection of the ring levee alignment. The south ends terminate on a projection of the river channel.

The cross section layout for the Cano Corazones outlet model is shown in Figure 18, also. It only models the divided flow condition. That extends from cross section 0 to cross section 7.86. Note that cross section 7.86 of the Cano Corazones outlet aligns with cross section 5.6 of the Rio Granajibo outlet. The dividing line between the two models is marked on cross section 7.86/5.6 in Figure 18.

The flows are added together at cross section 7.6 and the combined model continues upstream to cross section 88.

Table 11
Mayaguez-Hormigueros File Names for HEC2 Input Data

	Existing	Project
Rio Guanajibo River Outlet	exmaya.dat	m8rq3.dat
		m8wes1.dat
Cano Corazones Outlet	"	cano8.dat
Rio Guanajibo/Cano combined model	"	mouth8.dat
Rio Hondo Tributary	none	none

Bed Sediment Data. The suspended data is the same as described above. Bed samples were taken at locations shown on Figure 18. These were sieved and the gradations shown in Figure 19. The D_{50} is 0.45 mm.

Stability Evaluation for the Existing Channel

Average hydraulic parameters were calculated for the project reach between cross sections 65 and 88 using the SAM utility program, M95. That utility reads the HEC2 Tape95 output and averages cross section widths, depths, channel n-values and channel water discharges. Results, shown in Table 12, used a length-weighted-average.

The cross section values for these average hydraulic parameters are shown in Figures 20 through 26. Figure 20 shows how the water discharge varies within the HEC2 data set. These water discharges are plotted versus cross section numbers from the HEC2 geometry, and in this case they start just inside the mouth of the river. The project reach begins at "X SEC 1.7" on the abscissa and extends up to cross section number 88. The change in Q near cross section 20 shows how much of the water discharge was assigned, in the HEC2 model, to the Cano Corazones outlet.

Figure 21 is the HEC2 water surface profiles for these discharges. Notice the legend. It keys on total water discharge at the downstream end of the "averaging reach." In this case, that is the same as the downstream end of the model, Figure 20. However, in the general case, the water discharge at the downstream end of the "averaging reach" is used in the legend to reference the plot. Figure 20 profiles provide that water discharge at each cross section. It can be used to define the legend for profiles through any portion of this HEC2-Tape95 data set.

Figure 22 shows the total Q and that portion of the total Q which is conveyed in the channel, according to HEC2 calculations, for the 2-yr flood. This indicates the channel forming discharge is less than the 2-yr flood in this reach of the Guanajibo.

Table 12
Average Hydraulic Parameters for Each Water Discharge, Existing Channel[1]

Recurrence Interval	2-YR	10-YR	25-YR	50-YR	100-YR	SPF
Total Discharge, cum/s	375	1070	2013	2401	3278	4205
Water Surface Width, m	59	59	59	59	59	59
Hydraulic Depth, m	2.51	3.41	4.17	4.43	4.93	5.36
Energy Slope, m/m	.00072	.000801	.000837	.000844	.000873	.000922
Channel Velocity, m/s	.93	1.20	1.41	1.47	1.60	1.74
Channel n-Discharge, cum/s	138	241	346	384	467	552
Channel area, sqm	148.29	201.41	246.76	262.05	291.55	316.85
Channel n-Value	.0534	.0534	.0534	.0534	.0534	.0534
Averaging Parameter	1700.	1700.	1700.	1700.	1700.	1700.

[1] Length-weighted average over 18 cross sections, HEC2 DATA SET = SGCI65P.DAT; calculation option = 2.

The water discharge was decreased until it just filled the channel over most of the project length. That value is 50 m^3/s, Figure 23, which is considerably less than the 375 m^3/s of the 2-yr flood peak. The bank full discharge is even less than that at two locations: cross sections 5.6 - 16 and cross sections 62 - 88. These cross sections are shown in Figure 18. Water surface width is shown in Figure 24. In both the 5.6 - 16 and 62 - 88 locations, the channel is wider than the average. A water depth plot is shown in Figure 25. In reaches 5.6 - 16 and 62 - 88, the flow depth ranges from 0.6 to 0.8 m. That indicates zones of significant deposition in the existing channel within the reach of the proposed levees.

Summary. This project proposes levees, without channel modification, to provide flood protection. Such project features are the least likely to cause change to the existing sedimentation processes in the project reach. However, in this project reach two locations on Figure 23 indicate the existing channel has less than 50 m^3/s carrying capacity for water. That could be due to sediment deposition. This sediment impact analysis concludes that additional study will be required to determine how rapidly the existing channel of the Guanajibo will fill in those location.

Long-Term Maintenance

There are a few measured sediment concentrations at the Hormigueros gage. However, the measurements were made in water discharges less than 400 cfs (11 m^3/s). The suspended concentrations ranged up to 400 mg/l. These results cannot be extrapolated to the design flood peaks with any degree of confidence.

The RCE report documented a USGS estimate of 134,000 tons/year (121,500 metric tons/year) annual sediment yield at their gage near Hormigueros. There was no breakdown between bed material load and total load, and it is the bed material load which is of most interest in a channel/levee project. There is a USGS gage on Rio Rosario at Rosario which is a tributary to the Guanajibo. That gage has some particle size gradation data. The mean sand discharge from those measurements was 22 percent of the total suspended load. If that gradation were applied to the USGS estimate for the Guanajibo, it would result in about 29,480 tons of sand yield. Allowing 10 percent for the unmeasured load, the total bed material yield for the Guanajibo would be about 40,000 tons/year (36,300 metric tons/year).

A second approximation of bed material entering the project reach was made by using the sediment discharge rating curve calculated for San German. The resulting bed material sediment yield is 30,000 tons/year (27,200 metric tons/year). This assumes the concentrations from Rosario and the other tributaries between San German and Hormigueros are the same as the mainstem Guanajibo. (Those concentrations are probably greater than the mainstem since the tributaries are steeper, locally.) Averaging those two inflows gives 35,000 tons/year (31,700 metric tons/year) of sediment inflow to the project reach.

Finally, the bed material sediment load transported through the existing channel was calculated using hydraulics from HEC2. The reach of the river between the confluence of the Rosario and the Highway 114 crossing near Cerrillos-Guanajibo was used to develop the average hydraulic properties. Results are shown in Table 12. The calculated sand and gravel concentrations and discharges are shown in Table 13. The Hormigueros flow duration curve is shown in Table 14, and the resulting sediment yield is shown in Table 15. The specific weight of this sediment is estimated to be 1489.72 kg/m^3. That converts to 0.67 cubic meters/metric ton. Transport through the existing channel in the project reach is about 10,000 tons/year (8,793 metric tons/year). If 35,000 tons/year of sand and gravel are transported into the project reach and 10,000 tons/year are transported out of it, the trap efficiency of the project reach is 71 percent. Therefore, it should be an aggrading channel under existing conditions.

Table 13
Sediment Discharge Table

Q, CMS	0.0	10.0	50.0	100.0	375.0	1070.0	2013.0	2401.0	3278.0	4205.0
SC, mg/l	.00003	33.815	108.	97.077	51.421	65.582	65.550	65.169	66.916	61.427
QS, tons/Day (Metric)	0.0	29.2	466.6	838.7	1666.0	6062.9	11400.7	13519.1	18951.9	22317.2

Table 14
Flow-Duration Table

#	Q CMS	%(1) Time	#	Q CMS	% Time	#	Q CMS	% Time
1	736.23	0.01	13	33.98	2.20	25	1.47	57.80
2	566.33	0.02	14	25.49	3.90	26	1.13	66.50
3	453.07	0.04	15	19.82	6.30	27	0.88	75.30
4	339.80	0.06	16	15.29	8.90	28	0.68	83.50
5	263.34	0.08	17	11.61	11.80	29	0.51	90.40
6	203.88	0.10	18	9.06	15.10	30	0.40	94.00
7	158.57	0.20	19	7.08	19.20	31	0.31	97.70
8	121.76	0.30	20	5.38	24.60	32	0.24	99.00
9	93.44	0.40	21	4.25	30.30	33	0.18	99.70
10	70.79	0.60	22	3.11	38.80	34	0.14	100.00
11	56.63	0.90	23	2.46	45.00	35	0.00	0.00
12	42.47	1.40	24	1.90	51.20			

Note: (1) The percent of time the Q was equaled of exceeded.

Table 15
Calculated Yields Out of This Project Reach

Time Period:	Days = 364.877
Water Yield, Cubic Meters = 191128128.	Mean Daily Flow, CMS = 6.06
Sediment Yield, Metric Tons = 8793.	Mean Daily Load, T/D = 24.
Cubic Meters = 5902.	Mean Daily Conc, mg/l = 46.004

The volume of the channel between the highway 114 bridge near Guanajibo and the confluence with the Rosario is 250 thousand cubic meters. The above trap efficiency indicates that the channel would be full of sediment in only 7 years. That is not an acceptable conclusion because it is inconsistent with other observations unless, historically, there has been a maintenance program to remove channel deposits from this reach.

For example, the first observation is based on aerial photography. Such a high deposition rate would cause lateral migration of the channel as well as aggradation of the adjacent flood plain. In an effort to confirm that process, aerial photographs were obtained from the Corps of Engineers Project Office in Puerto Rico. Figures 27, 28 and 29 show the Guanajibo/Rosario confluence taken in 1936, 1963 and 1983, respectively. Figure 30 is an overplot of the channel from the 1936 aerial photo, the 1964 USGS Quadrangle (Mayaguez, P.R.) and the Corps of Engineers project survey map dated 1986. Whereas there are major channel changes at cross sections 65 and 69, telephone conversations with Mr. Roberto Cortes Colon' of the Corps of Engineers Project Office, Puerto Rico, indicated those were man made cutoffs. The overplot shows a high degree of lateral stability of the channel over that 50-year period. That does not support the trap efficiency calculation.

A possible explanation is that local interests are already maintaining this reach of the river channel. In addition to what might be ongoing locally, there are sand and gravel mining operations on both the Guanajibo mainstem and Rio Rosario, Figure 31. Removal of sand and gravel could explain why the channel is not filling as predicted by the calculations.

Another hypothesis is aggradation of the valley floor. A second observation in studying this reach of the Guanajibo was to compare topographic maps which were made at two points in time. The topograph survey dated 1986, made by the Corps of Engineers for this project, was compared with the 1964 USGS Quadrangle map between the highway 114 bridge and the confluence with the Rio Rosario. Although flood plain elevations are sparse on the 1986 map, there was no discernable aggradation of the flood plain over that 22 year period. This apparent stability of the existing valley floor is not compatible with the behavior which one would expect in a deposition zone. However, there is not enough existing data to understand why. Therefore, a detailed sedimentation study would be necessary to establish the long term trends in this project reach.

An alternative approach to the detailed sedimentation investigation is to recognize that levees do not change the flow distribution and the water surface elevation from historical values in this reach. Therefore, the long term maintenance requirements to maintain channel alignment and prevent aggradation will be the same with the project as has been required historically. That is, the levee project will not increase maintenance of this portion of the river over what it has been historically. That language should be included in the local cost sharing agreement.

The project plans should include sedimentation ranges, and the Jacksonville District should instruct the project sponsor on how to use those ranges to monitor aggradation/degradation of the channel and floodplain after the project goes into operation. A permanent stage-discharge gaging station should be established in this reach. Specific gage plots should be made annually to show trends in the water surface elevation over time. Whatever the historical level of maintenance has been would need to become a part of the future, project operation and maintenance agreement. That includes sand and gravel mining activities along the Guanijibo mainstem as well as the Rio Rosario in addition to the local maintenance activities in the project reach. This does not mean to mine at the historical rate. It means to use the gravel mining as one means of regulating the aggradation/degradation behavior of the channel in the project reach as measured by the sedimentation ranges and specific gage plots.

Project Reliability During Design Flood

Project reliability for this project cannot be evaluated with the existing data set. In concept, the larger the flood event, the more deposition would be expected in the project reach. The result could be a significant increase in water surface elevation for the levee design flood. A detailed sedimentation investigation would be needed to quantify this condition.

According to verbal communique with Roberto Cortes Colon' of the Corps of Engineers Project Office, Puerto Rico, the 1975 flood, which approximated the 100-yr flood peak, did not cause noticeable deposition in this reach. By analogy with that event, the levee should perform satisfactorily during the passage of the 100-yr flood.

Figure 32 shows conditions at the coast line after the 1975 flood. Note the size and location of both the mainstem Guanajibo and the Cano Corazones outlets. It will be necessary to protect the levees against erosion at both of these outlets since the channels can become wider and deeper as well as change alignments during a major flood. There are no theories to predict channel shifts. A detailed sedimentation investigation with HEC6 would predict the average depth of channel scour during a flood event.

Approach and Exit Channels

The approaching water surface with the project is slightly higher than existing conditions. However, it is not expected to be significant to project performance. This project exits directly into the ocean.

Conclusions, Hormigueros-Mayaguez Project

This sediment impact assessment has accomplished its purpose. It analyzed the present information on channel cross sections, bed gradations, topographic mapping and aerial photographs and revealed such inconsistencies between data sources that one must suspect there are sedimentation problems in this project reach. Those sedimentation problems have existed historically; therefore, the local project sponsor will understand them better than anyone else because that organization has dealt with them historically. The presence of the proposed levee project is not expected to intensify those sedimentation problems. To develop and document a scientific understanding of those problems and to use that understanding to predict the future behavior of this reach of the Guanajibo will require a detailed sedimentation investigation.

Evidence of sedimentation problems begins with a look at channel discharge capacity. The bank full discharge in the Hormigueros-Mayaguez Project reach of Rio Guanajibo is only about 50 m^3/s which is much lower than the 2-year flood found in the San German reach. There are two locations, shown by the reduction in channel capacity in figure 23, where the channel-full capacity is even less than 10 m^3/s. These reaches are between cross sections 5.6 - 16 and 62 - 88. The water depth plot, figure 25, indicates that could be caused by excessive deposition in the channel. Channel deposits in the downstream reach are associated with the ocean. Those in the upstream reach are associated with inflowing sand and gravel from upstream. Consequently, the existing channel is judged to be unstable.

One indicator of channel stability is trap efficiency. There are not sufficient measurements of the sediment discharge to allow a direct calculation of trap efficiency in the project reach, but that is not an unusual situation. The recourse is to use sediment transport theory to calculate those yields. That approach resulted in a trap efficiency of 71 percent of the inflowing sand and gravel load. That indicates the existing channel should be aggrading, which is supported by the loss in channel discharge capacity.

Aerial photographs and topographic maps were examined expecting to find large meander scars and flood plain aggradation. However, those symptoms were not present on the photographs and maps. A detailed sedimentation investigation would be required to resolve this inconsistency. Such an investigation would require additional suspended sediment concentration measurements and particle size gradation curves. Additional bed samples would be required. The detailed sedimentation investigation would include an HEC-6 analysis of sedimentation in the project reach by starting upstream from the project and continuing past the coastline into the ocean. The result from such an investigation could be a consistent description of channel and flood plain behavior in the project reach.

This would be in line with the RCE recommendation that "a more in-depth quantitative geomorphic investigation of the Guanajibo Basin to tie together the preliminary observations and hypotheses" should be conducted.

Rather than conducting the detailed sedimentation studies, the project sponsor could be made aware of the existing uncertainty in long term maintenance and project reliability. These levees typically do not cause a significant change in flow distribution and water surface elevation, from historical values, to result in major regime shifts in channel behavior. Therefore, the long term maintenance requirements, to maintain channel alignment and prevent channel and overbank aggradation, will be the same with the project as has been required historically. That is, the levee project will not increase maintenance of this portion of the river. If such language were included in the local cost sharing agreement, the detailed sedimentation studies could be avoided.

In either case, the project contract should install sedimentation ranges through this reach of the project and the Jacksonville District should instruct the project sponsor on how to use those ranges to monitor aggradation/degradation of the channel and floodplain after the project goes into operation. A permanent stage-discharge gaging station should be established in this reach. Specific gage plots should be made annually to show trends in the water surface elevation over time. Whatever the historical level of maintenance has been would need to become a part of the future, project operation and maintenance agreement. That includes sand and gravel mining activities along the Guanijibo mainstem as well as Rio Rosario in addition to the local maintenance activities in the project reach. This does not mean to mine at the historical rate. It means to use the gravel mining as one means of regulating the aggradation/degradation behavior of the channel in the project reach as measured by the sedimentation ranges and specific gage plots.

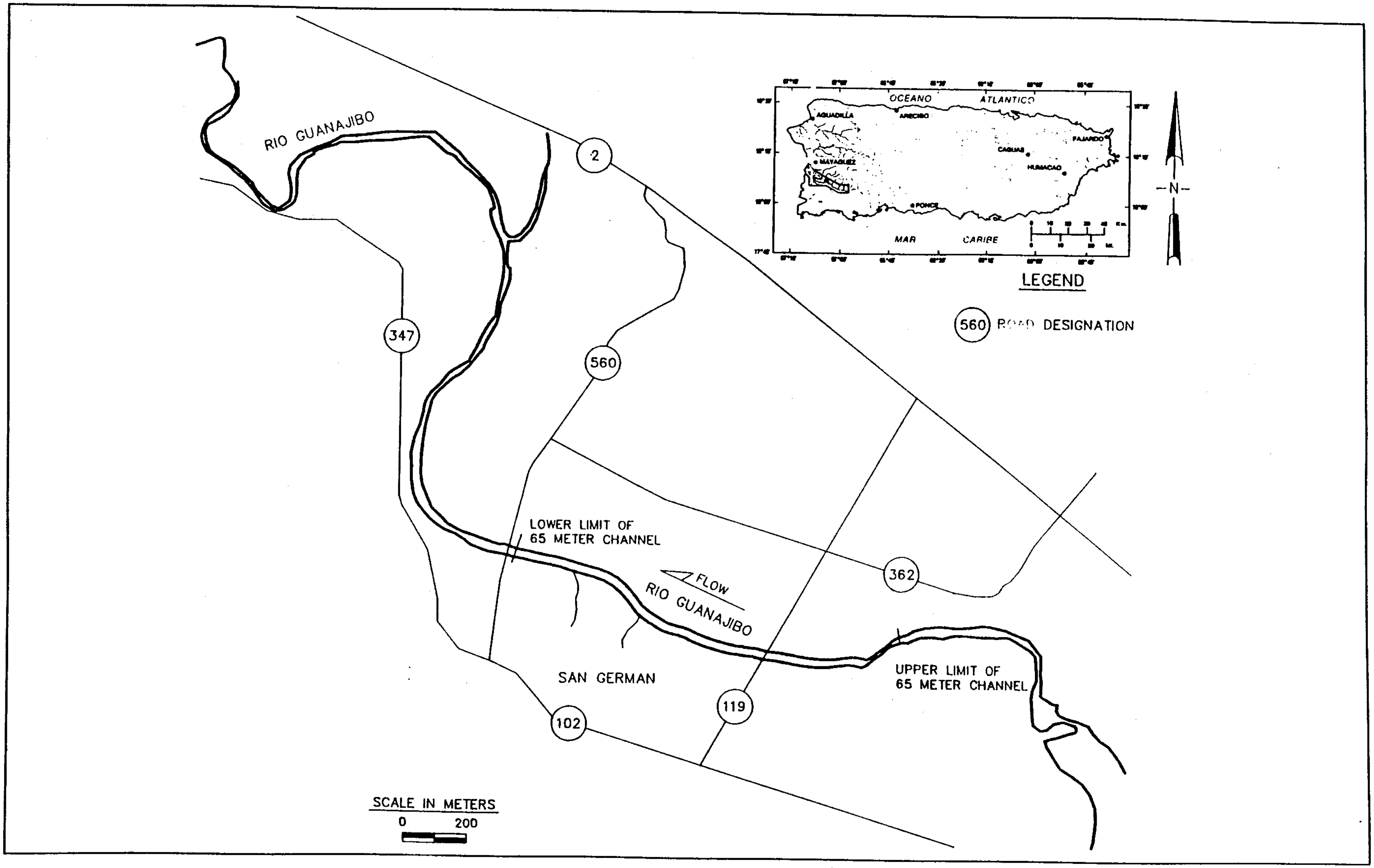


Figure 1. General location and San German Project Reach

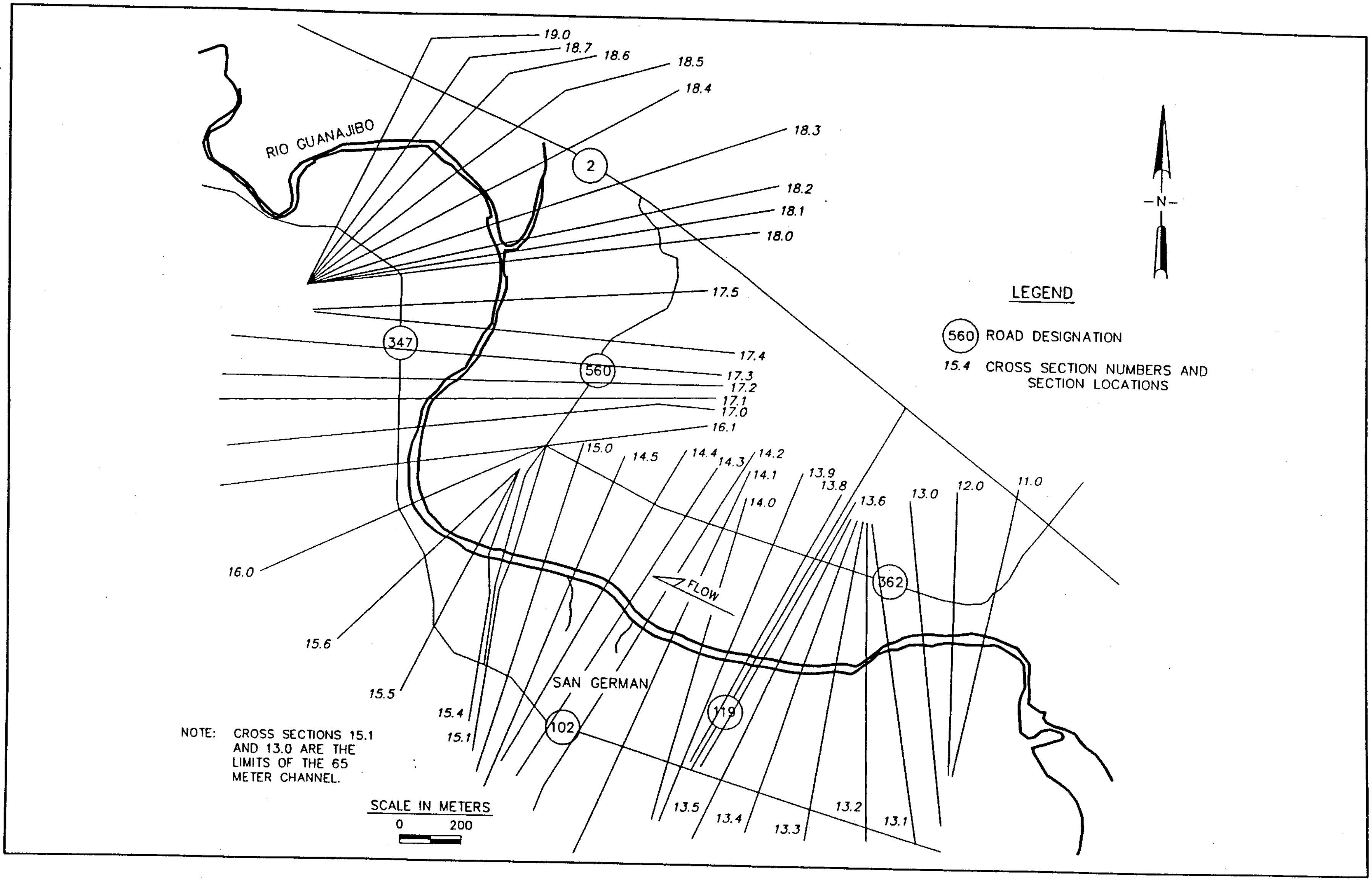


Figure 2. Cross section layout, San German Project Reach

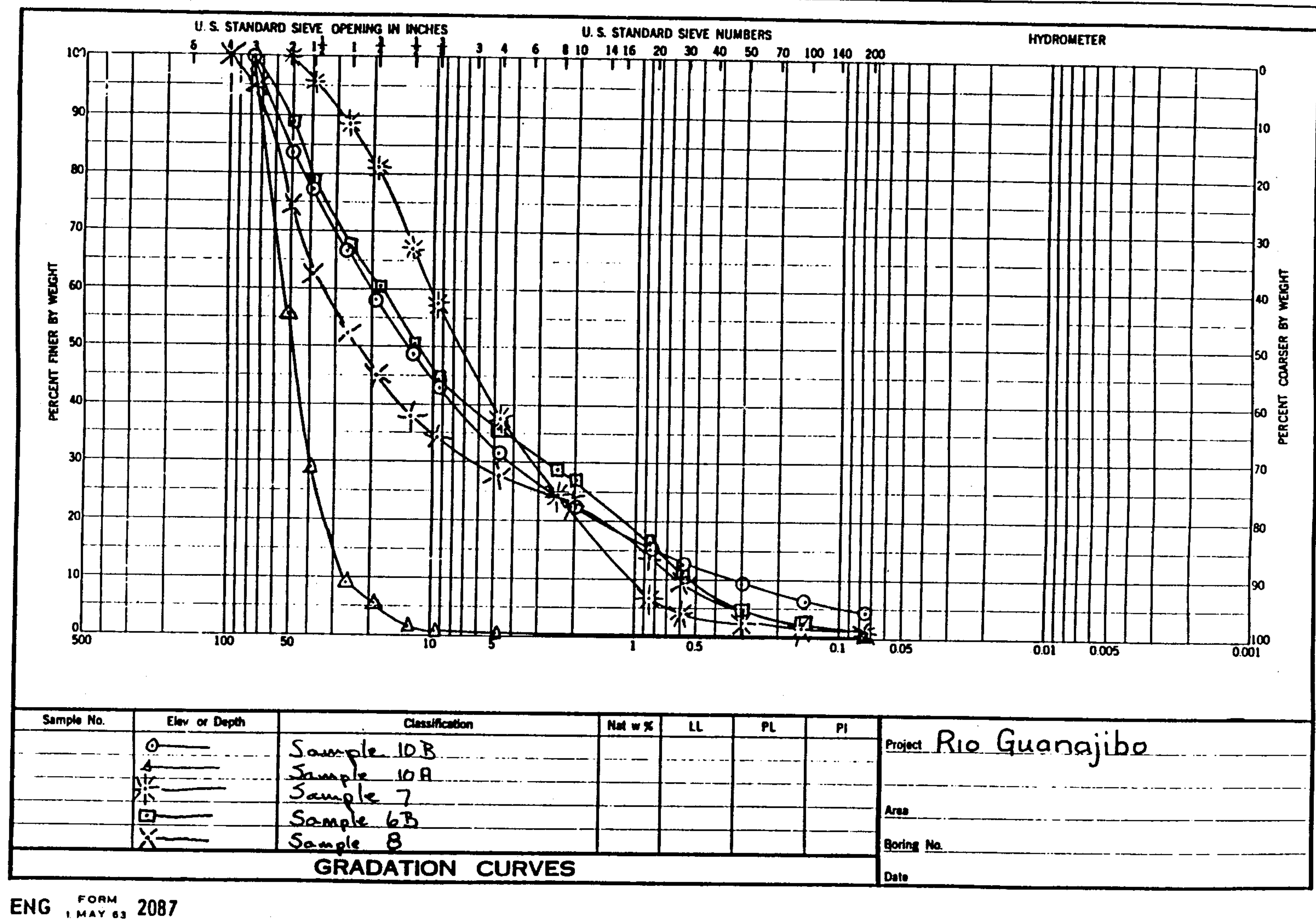


Figure 3. Bed sediment gradation curves, San German Project Reach

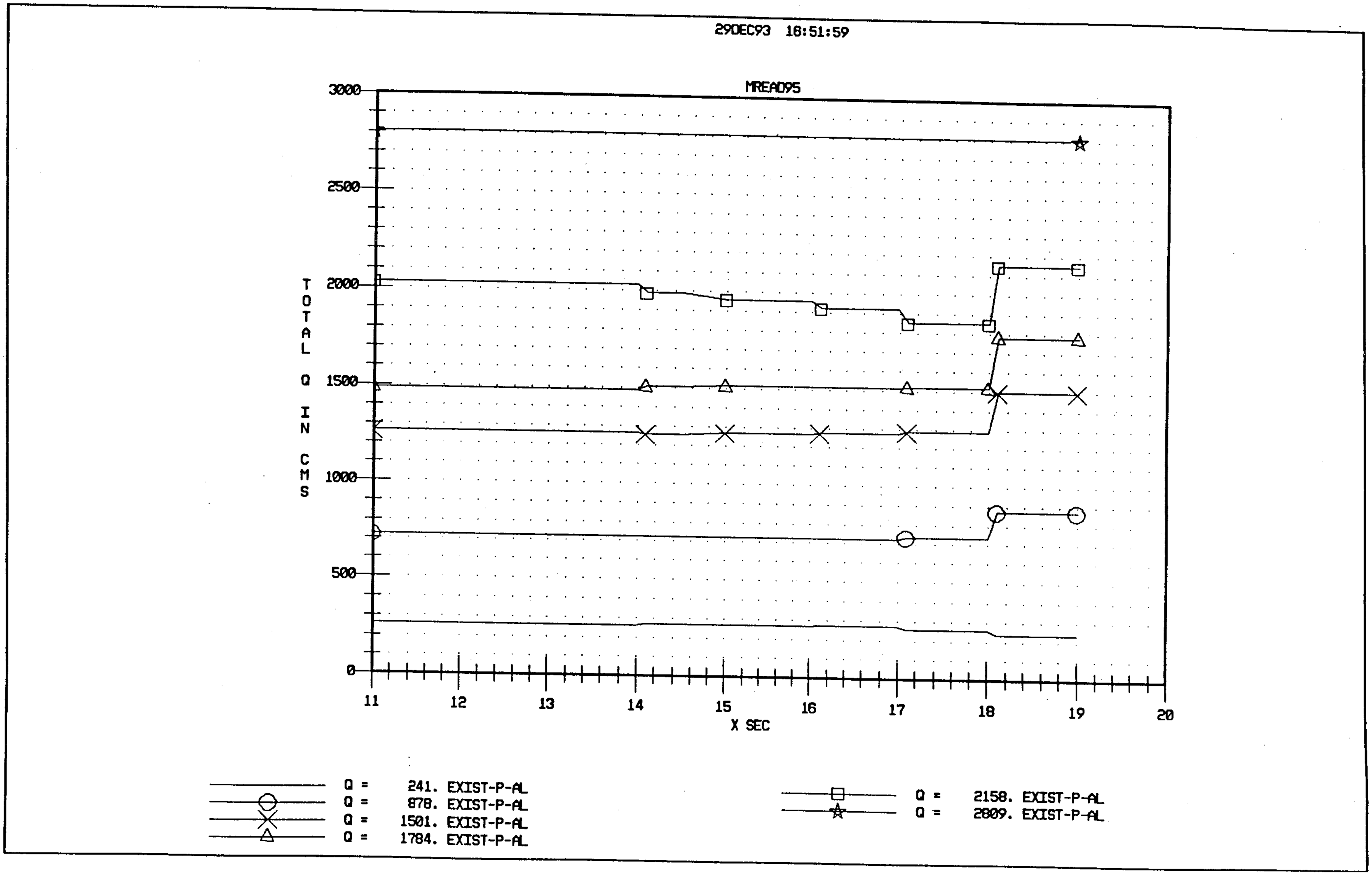


Figure 4. Water discharges, HEC2 model of existing channel, San German Project Reach

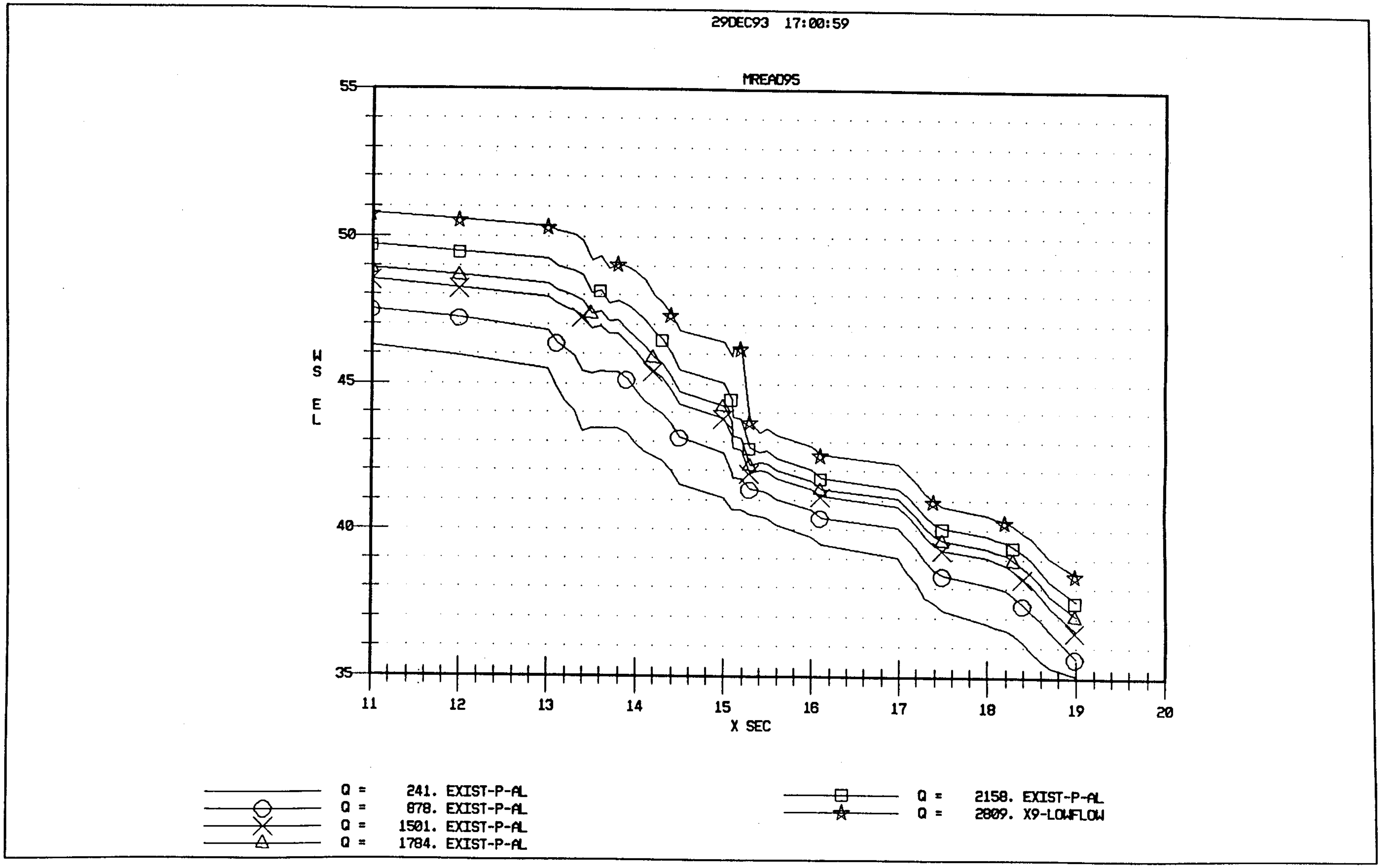


Figure 5. Water surface profiles, existing conditions, San German Project Reach

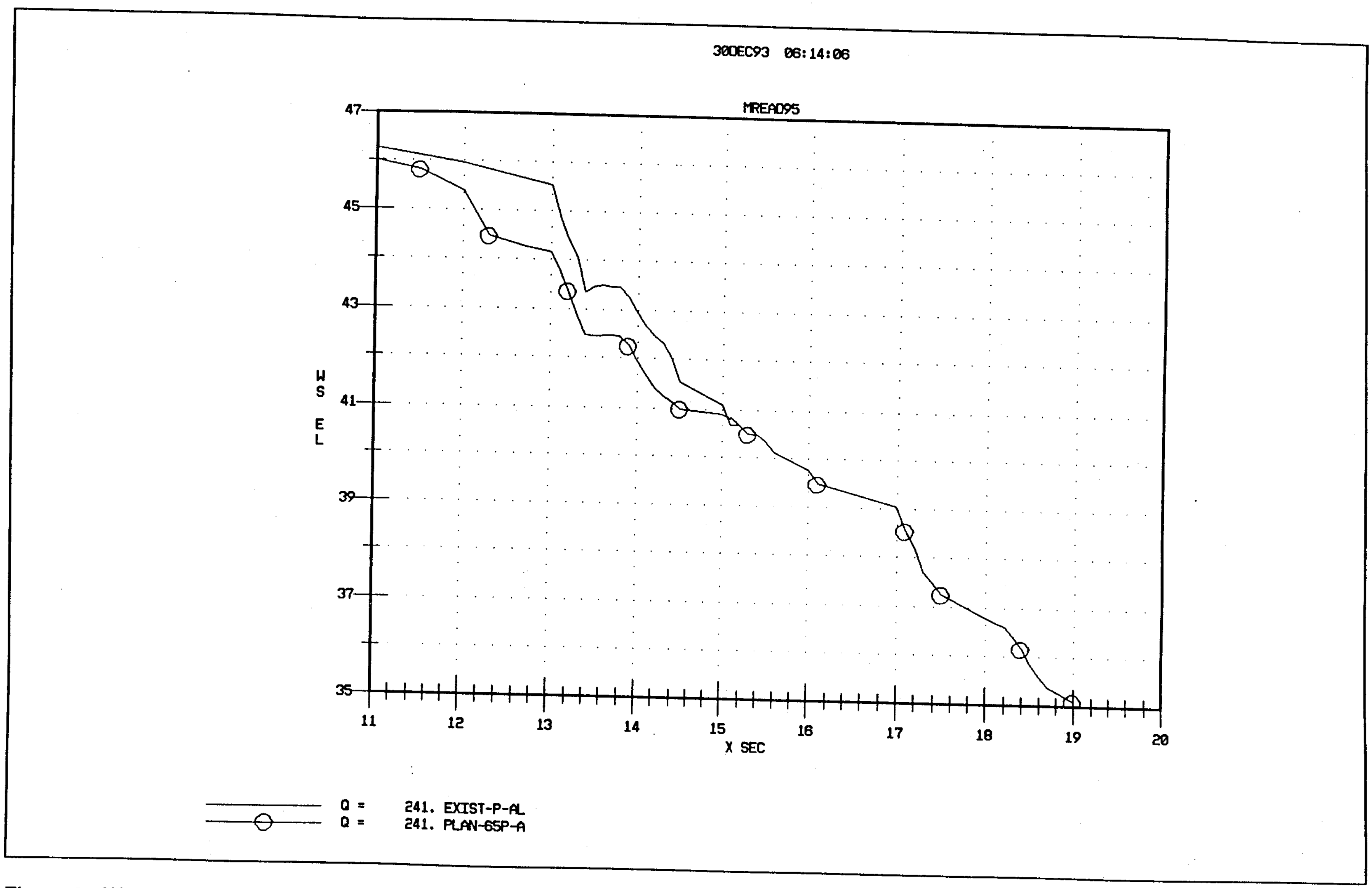


Figure 6. Water surface profiles, existing and project conditions, 2-yr flood peak, San German Project Reach

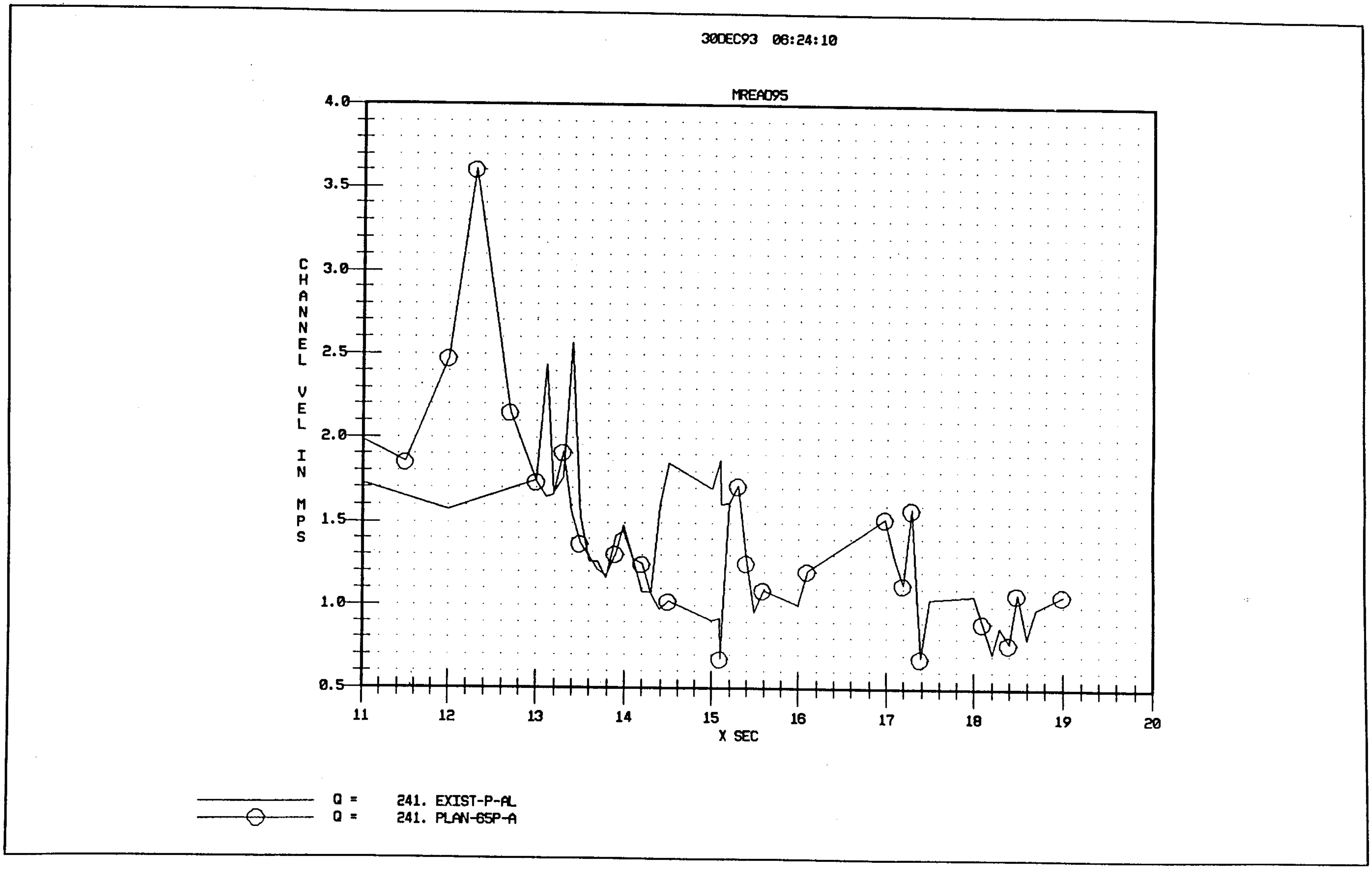


Figure 7. Channel velocities, 2-yr flood peak, San German Project Reach

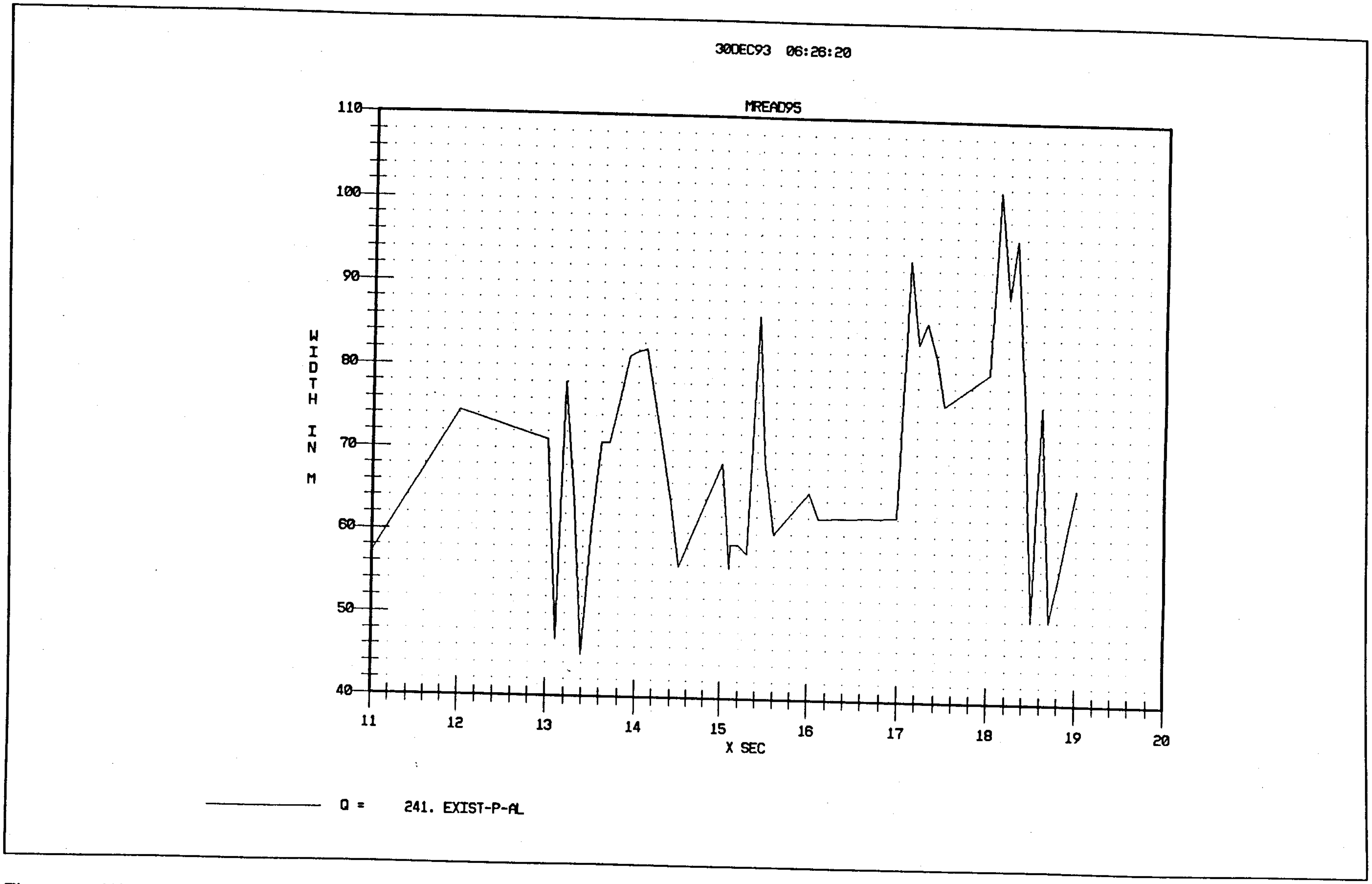


Figure 8. Water surface width, 2-yr flood peak, San German Project Reach

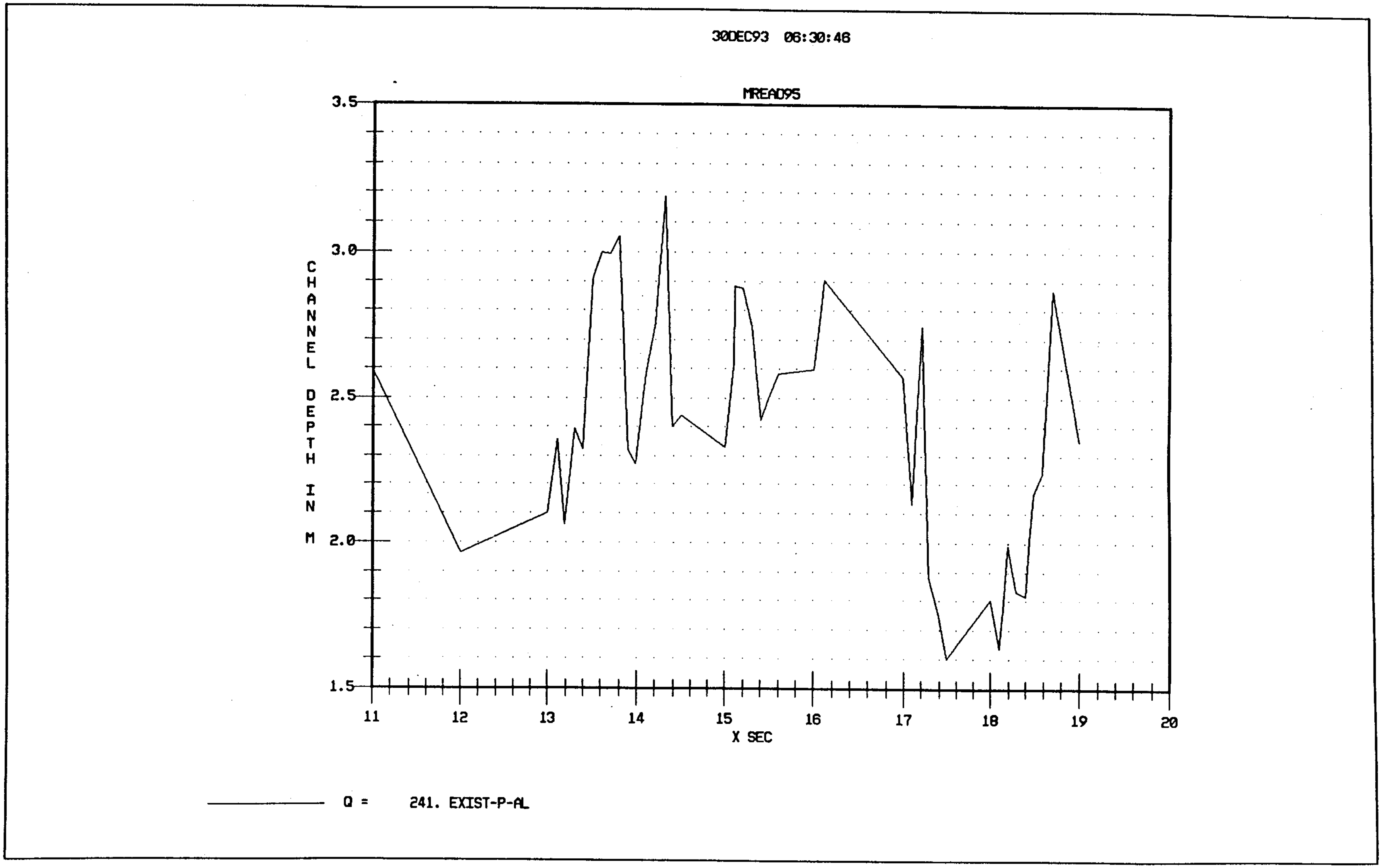


Figure 9. Water depth, 2-yr flood peak, San German Project Reach

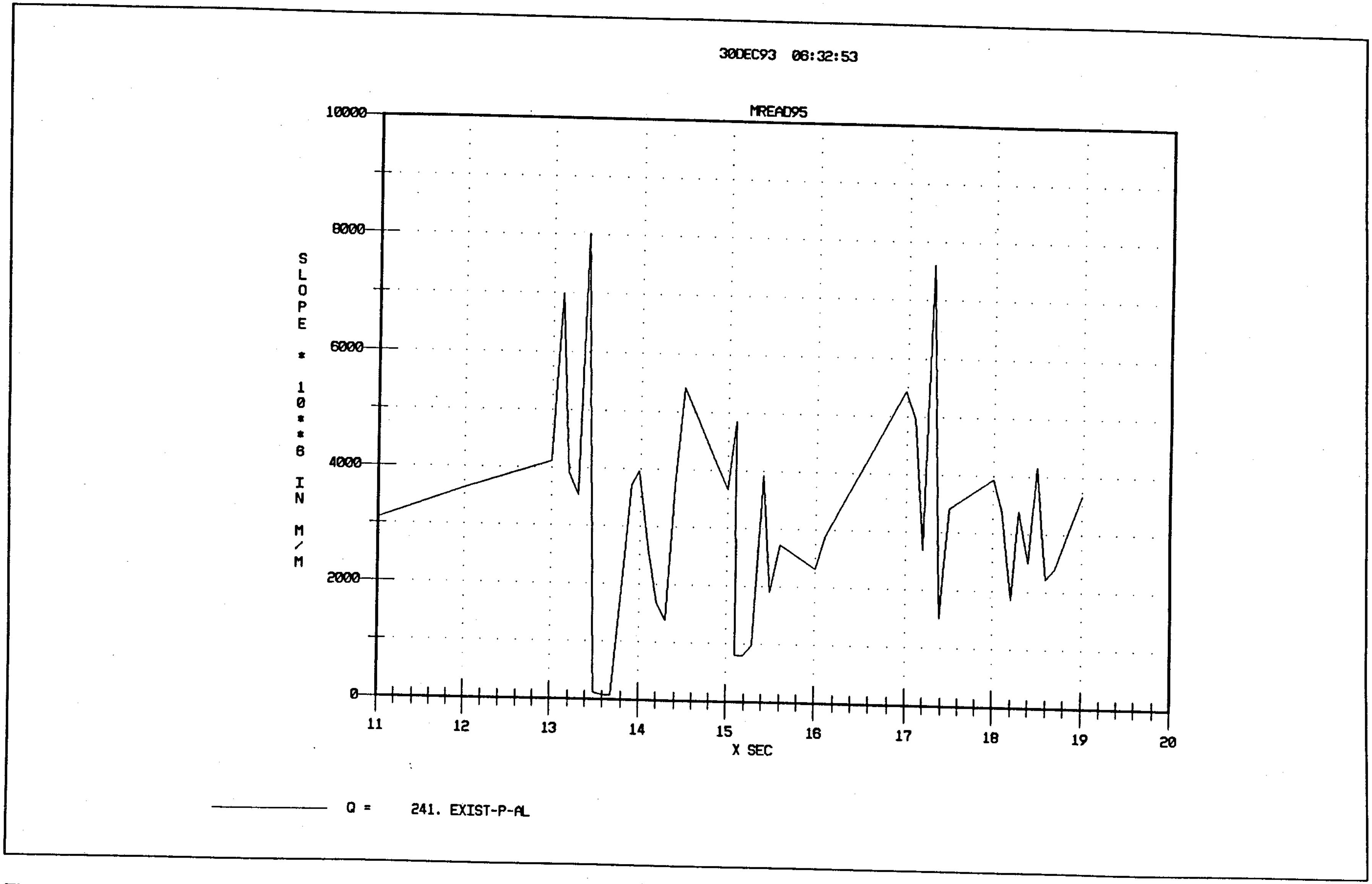


Figure 10. Energy slope, 2-yr flood peak, San German Project Reach

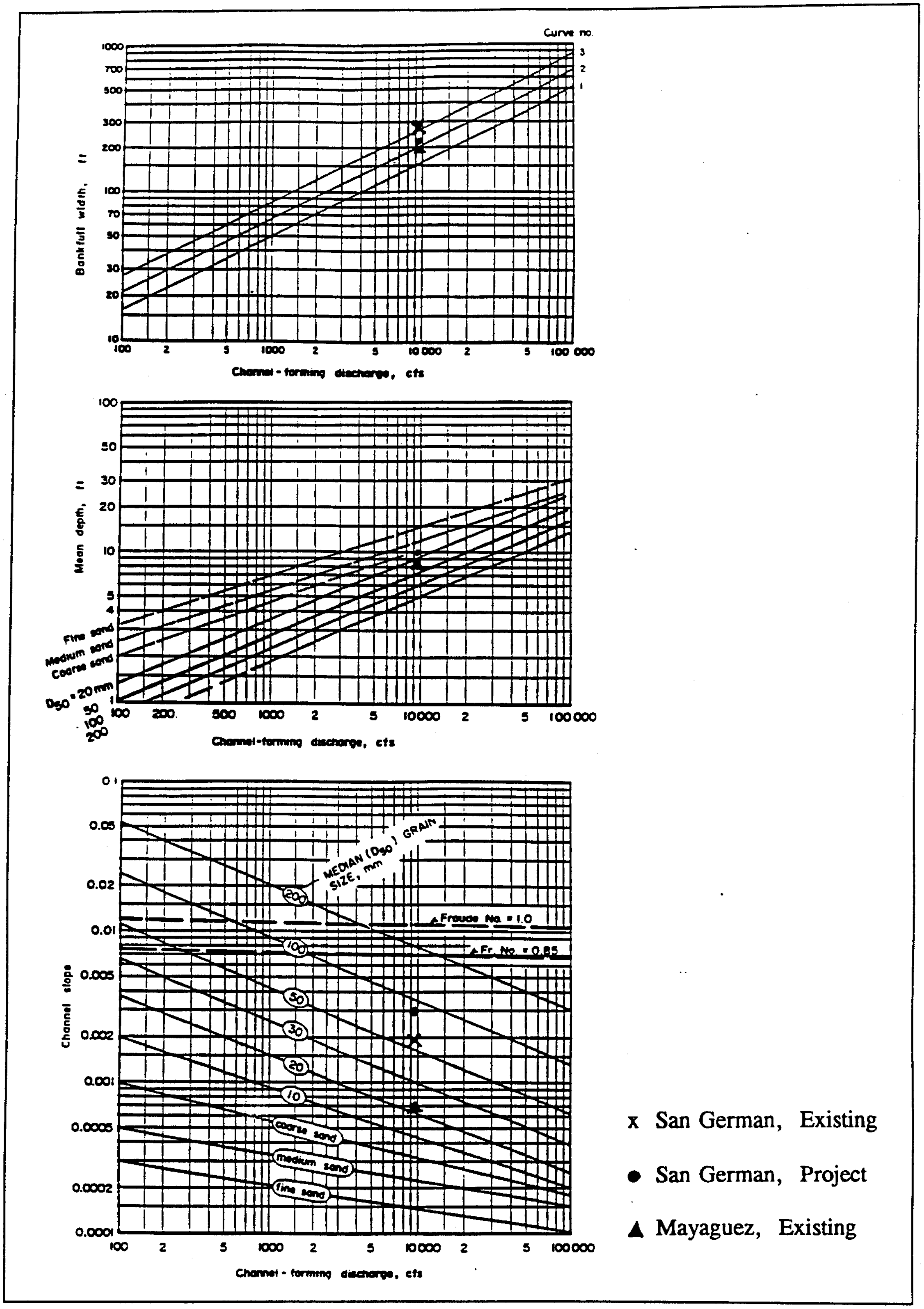


Figure 11. Hydraulic geometry charts

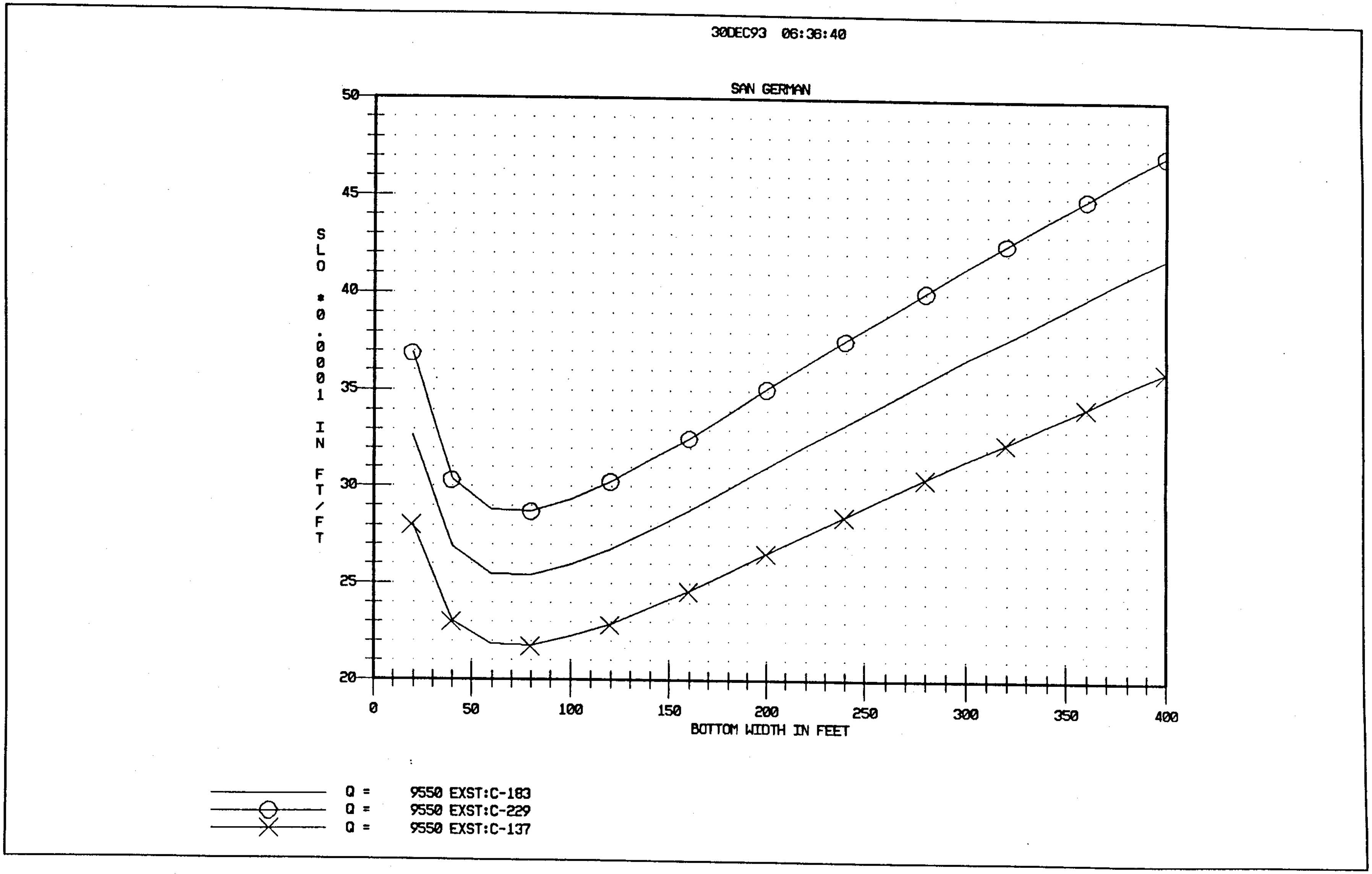


Figure 12. Calculated channel width and slope for existing conditions, stable channel analytical method, San German Project Reach

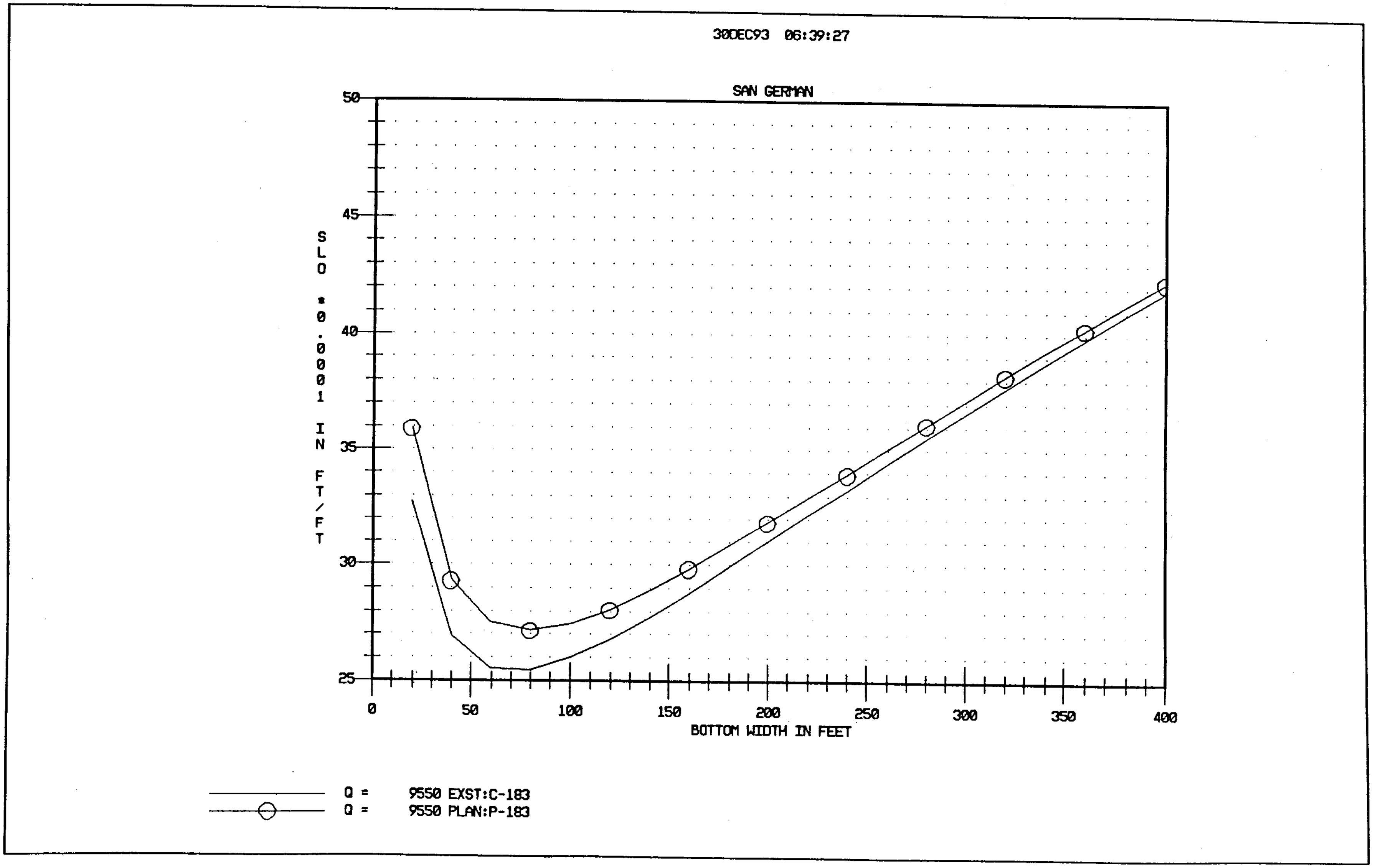


Figure 13. Calculated channel width and slope for project conditions, stable channel analytical method, San German Project Reach

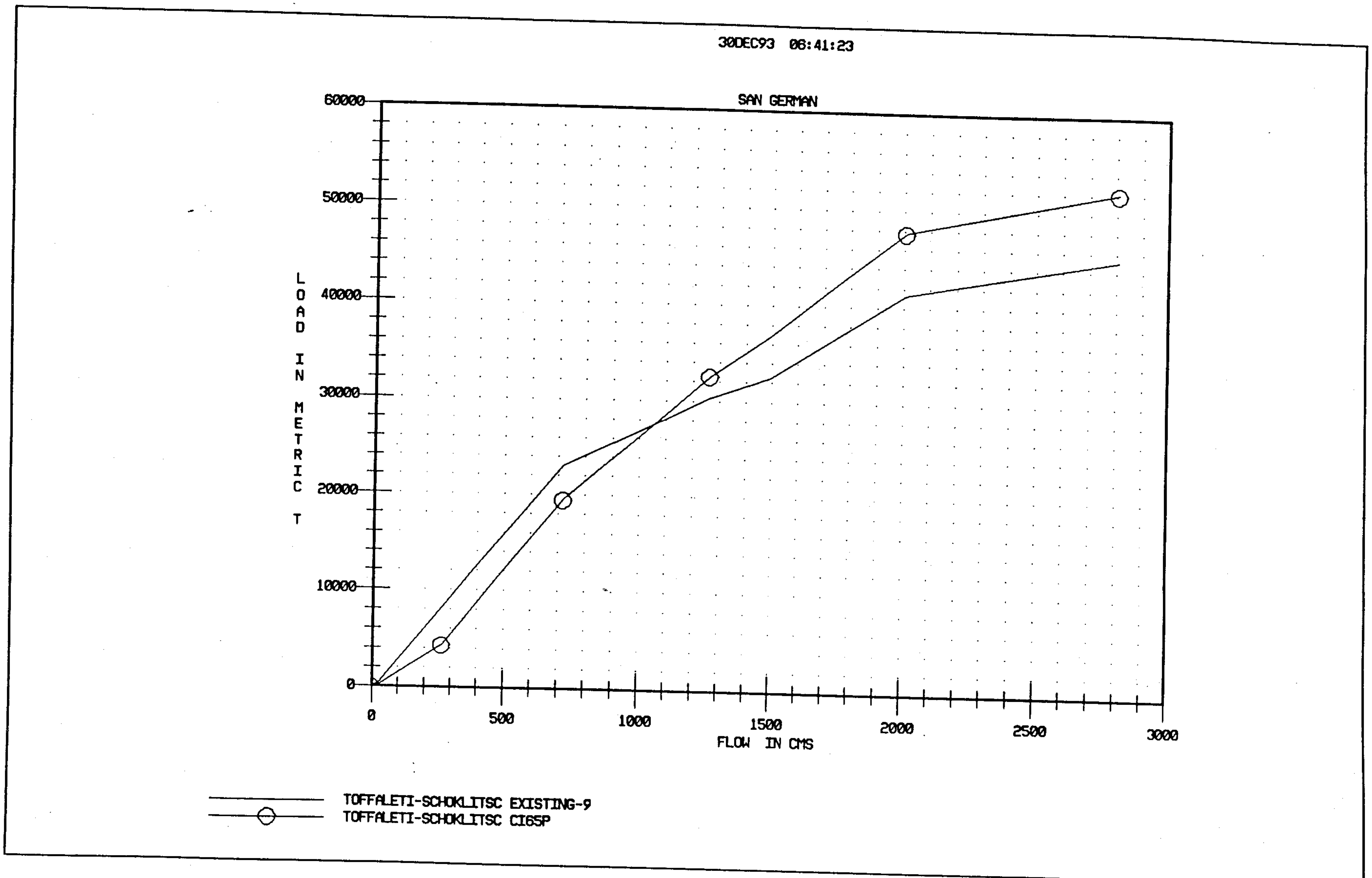


Figure 14. Calculated bed material sediment discharge curves, San German Project Reach

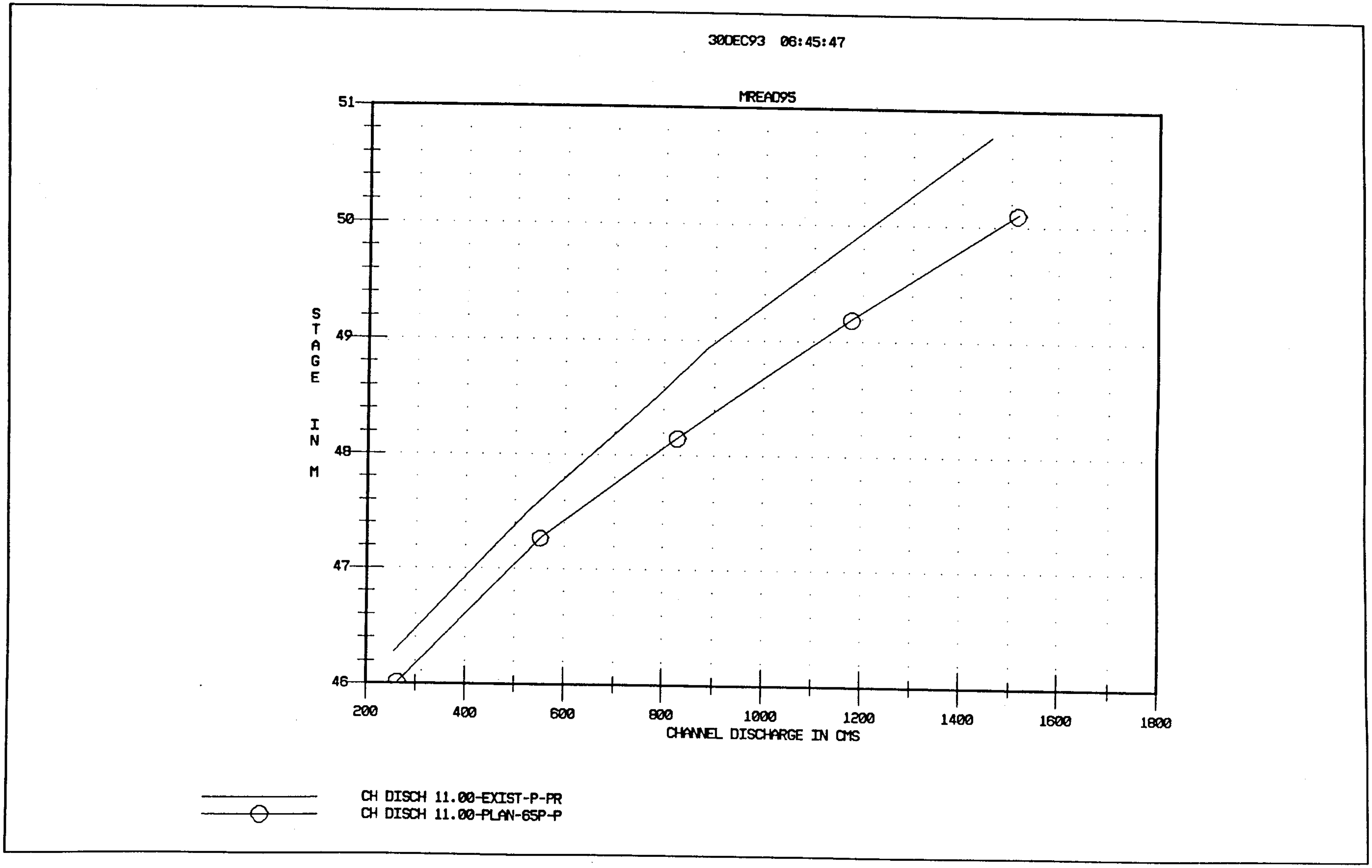


Figure 15. Calculated stage-discharge relationship, approach channel, San German Project Reach

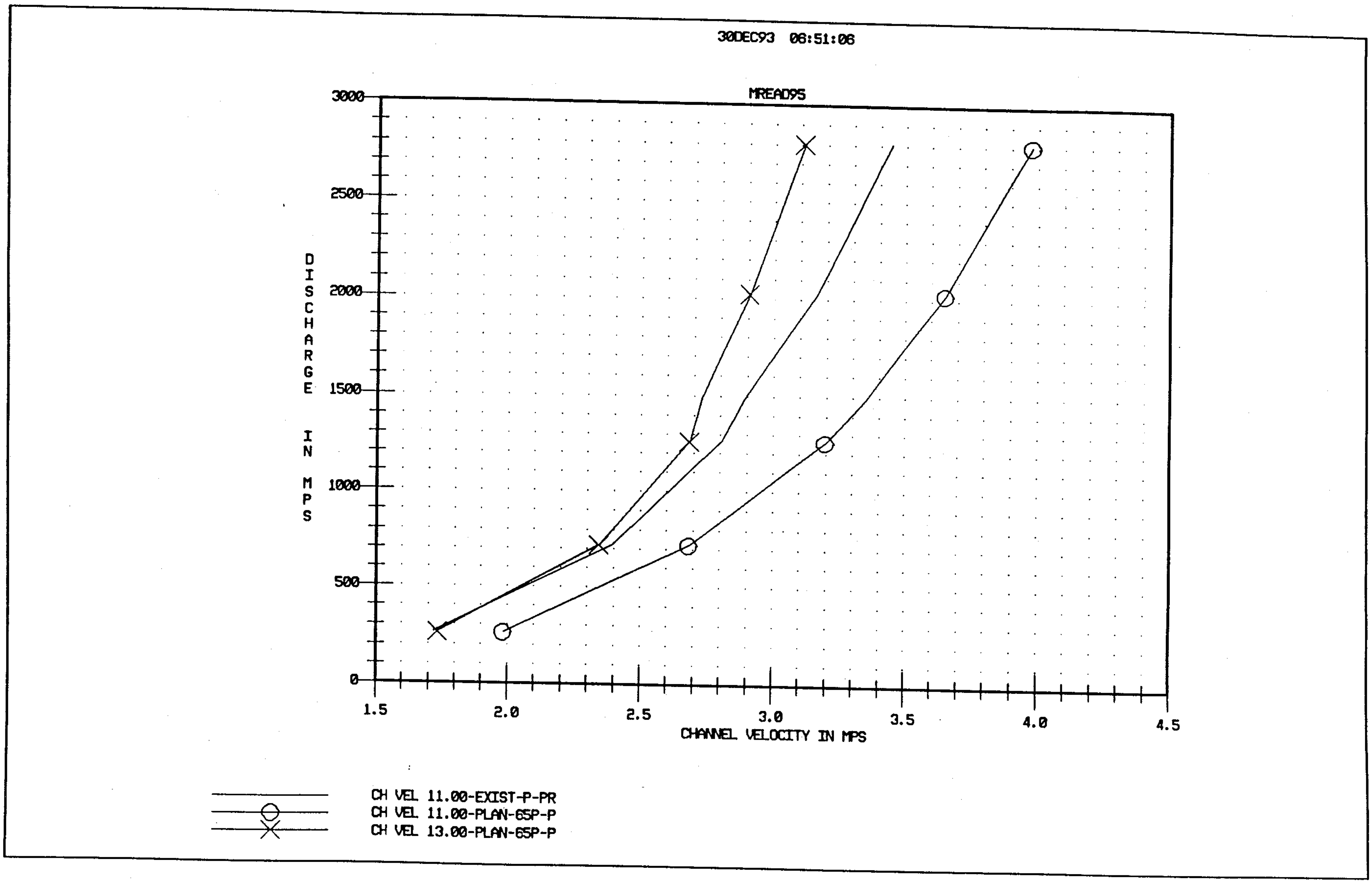


Figure 16. Channel velocity plots, approach channel, San German Project Reach

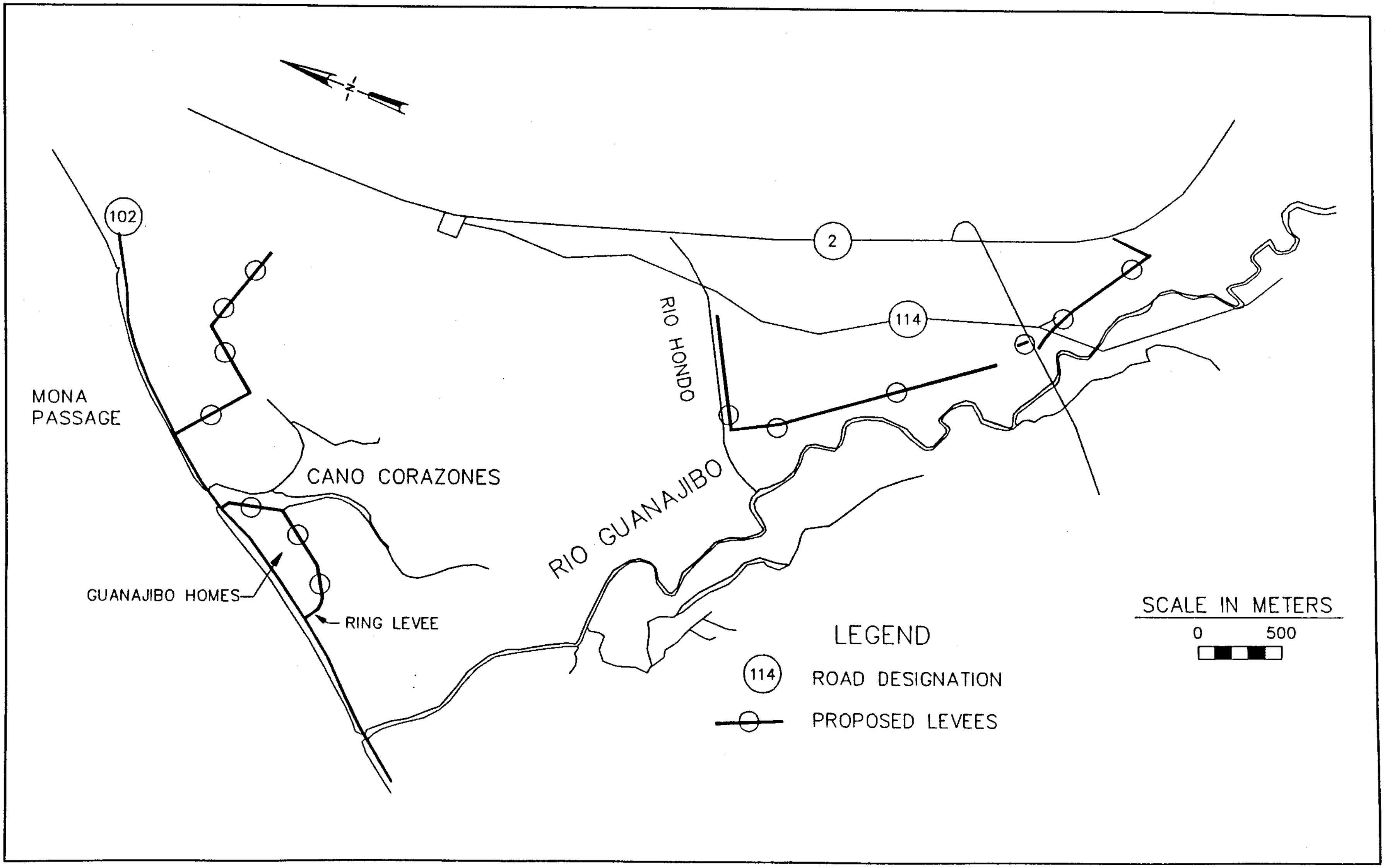


Figure 17. Project map, Mayaguez-Hormigueros Project Reach

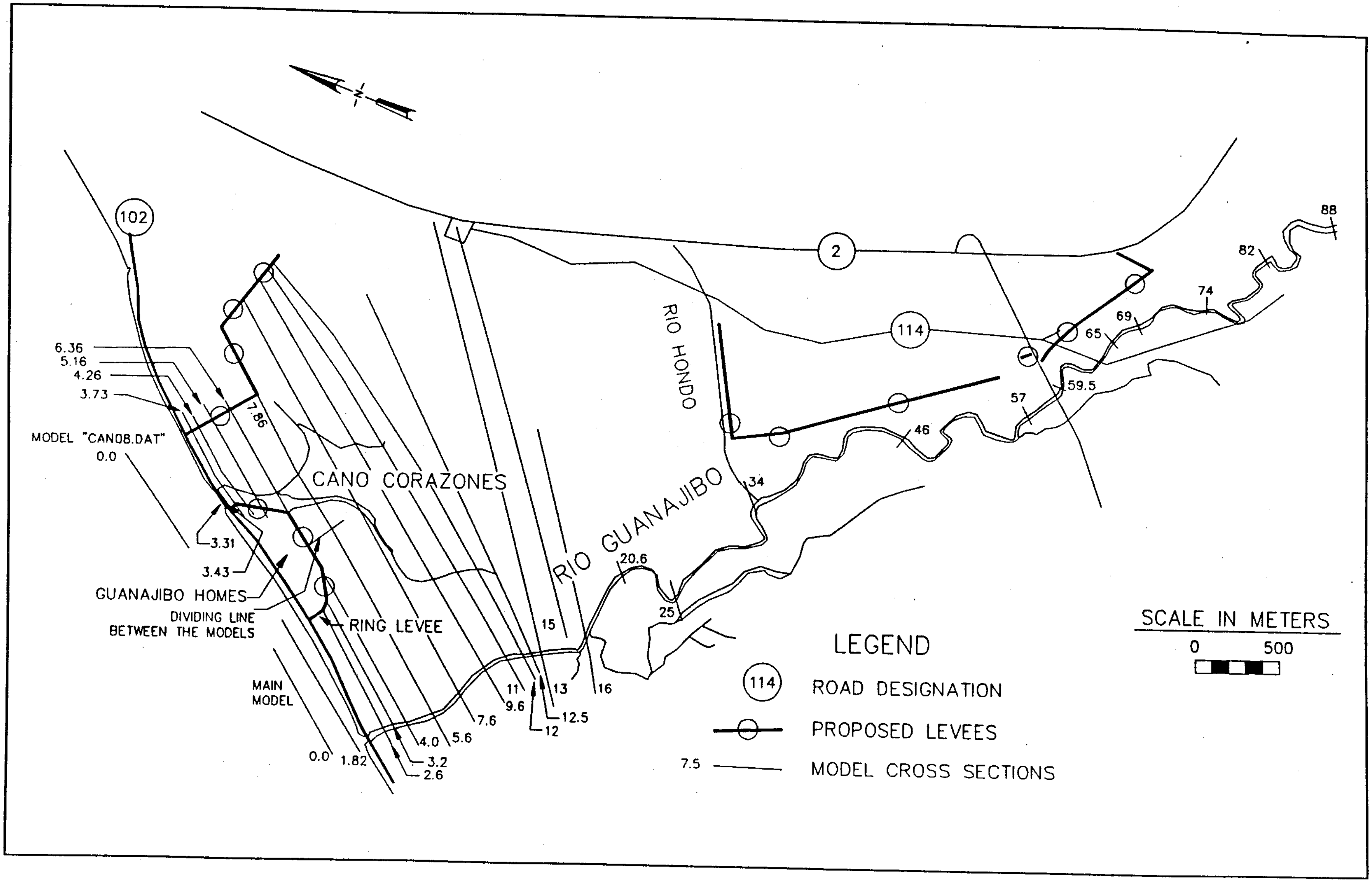


Figure 18. Cross section layout, Mayaguez-Hormigueros Project Reach

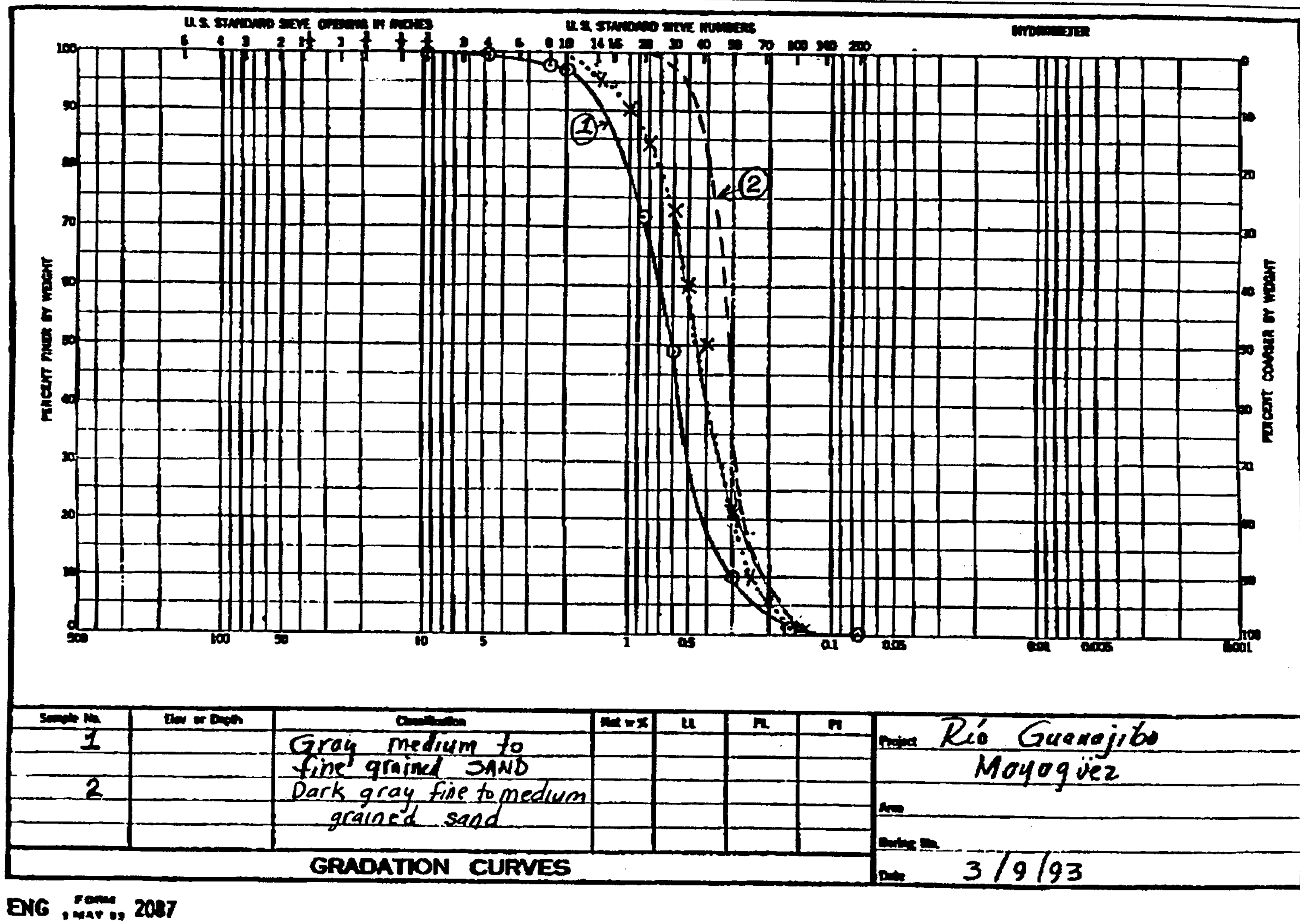


Figure 19. Bed sediment gradation curves, Mayaguez-Hormigueros Project Reach

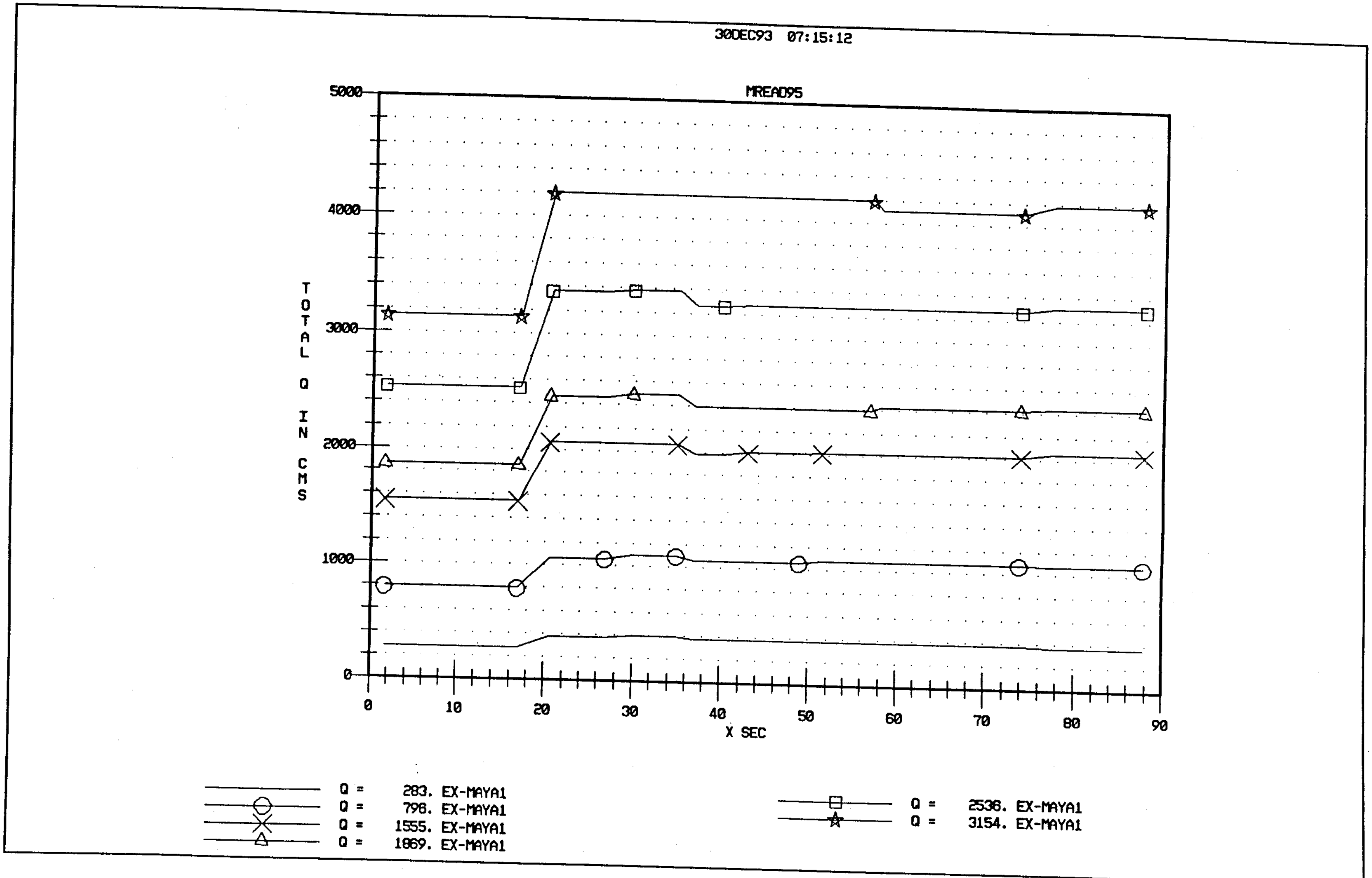


Figure 20. Water discharges, HEC2 model of existing channel, Mayaguez-Hormigueros Project Reach

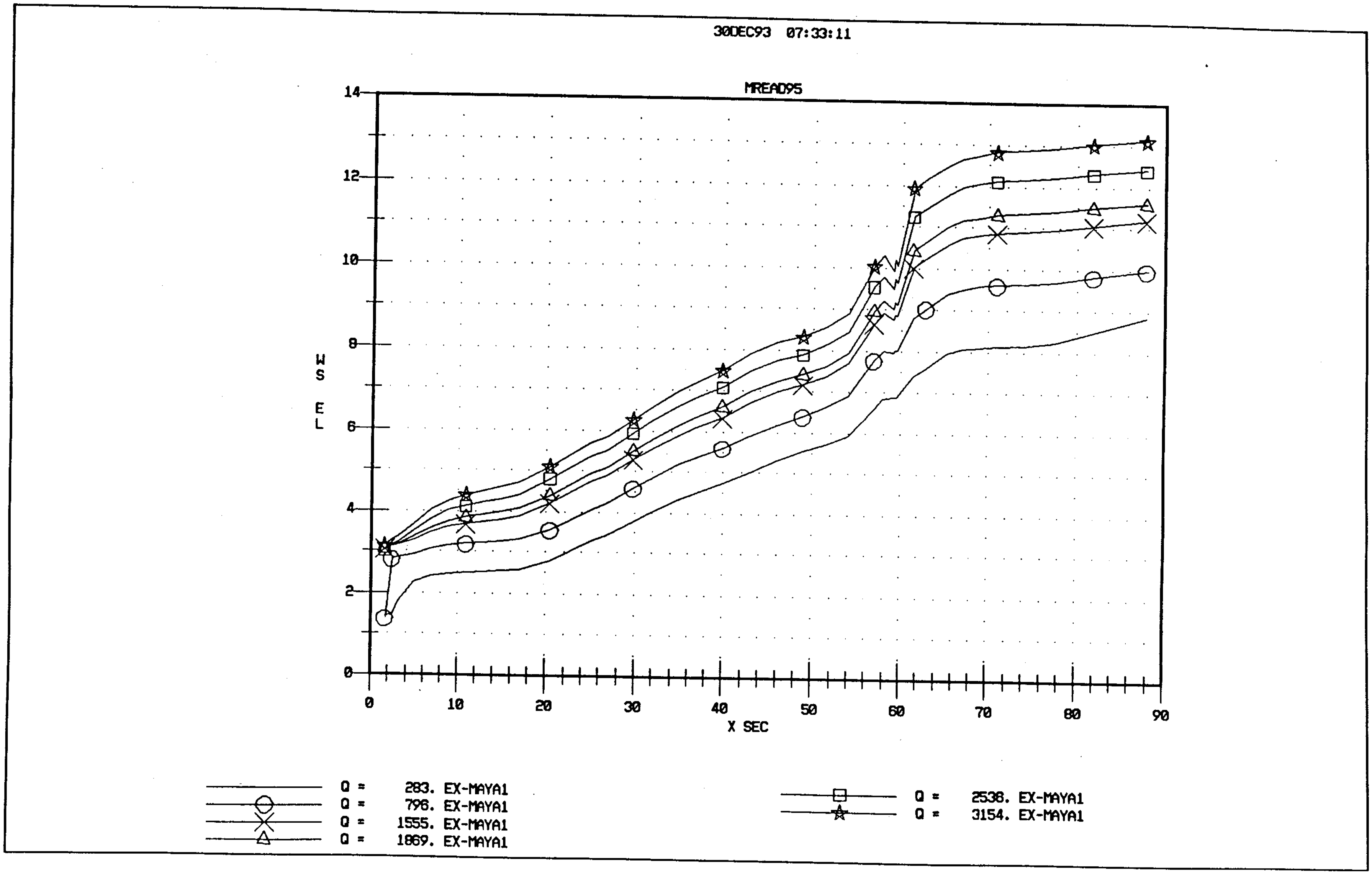


Figure 21. Water surface profiles, existing conditions, Mayaguez-Hormigueros Project Reach

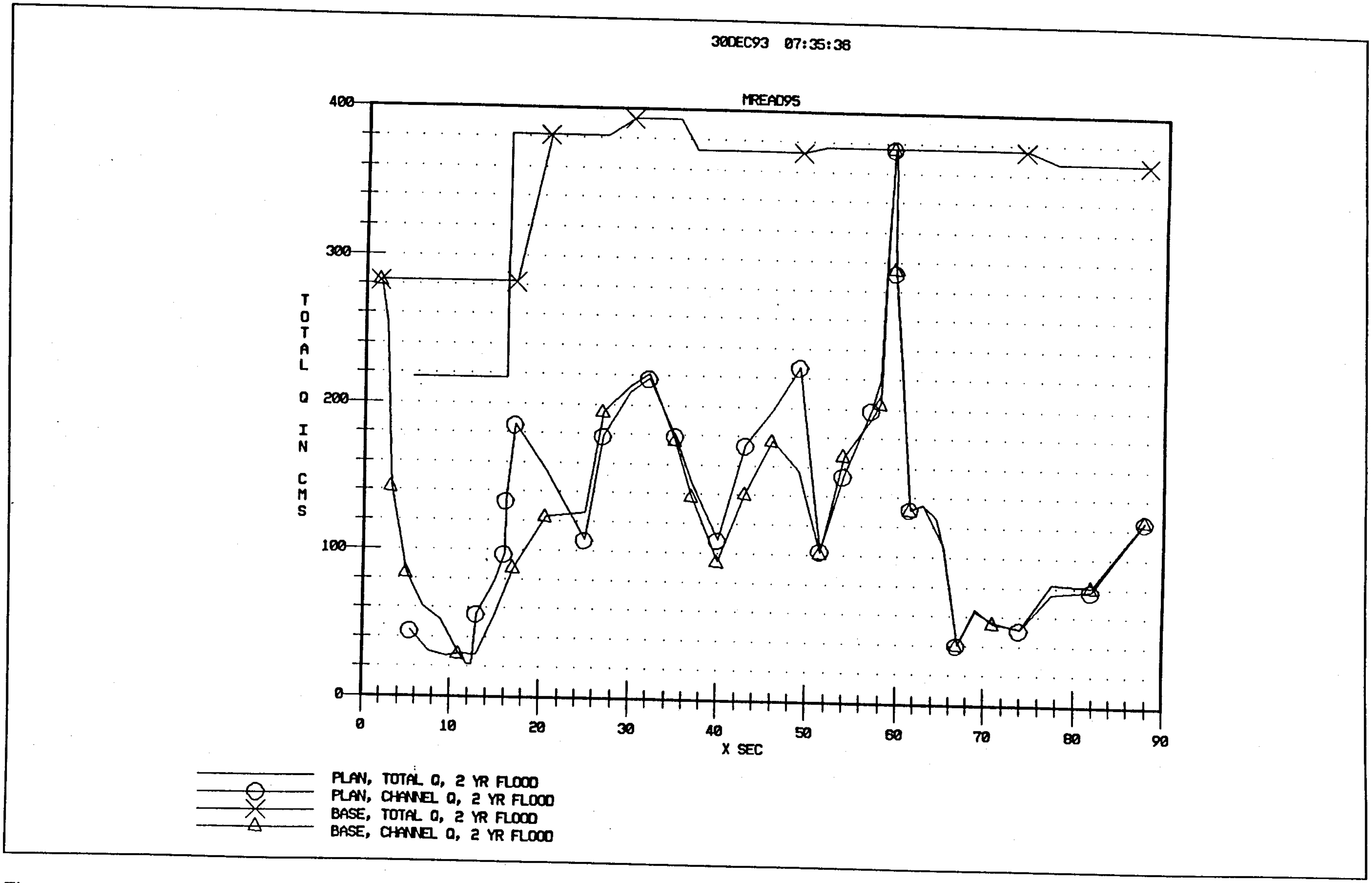


Figure 22. Channel discharge, 2-yr flood, existing and project conditions

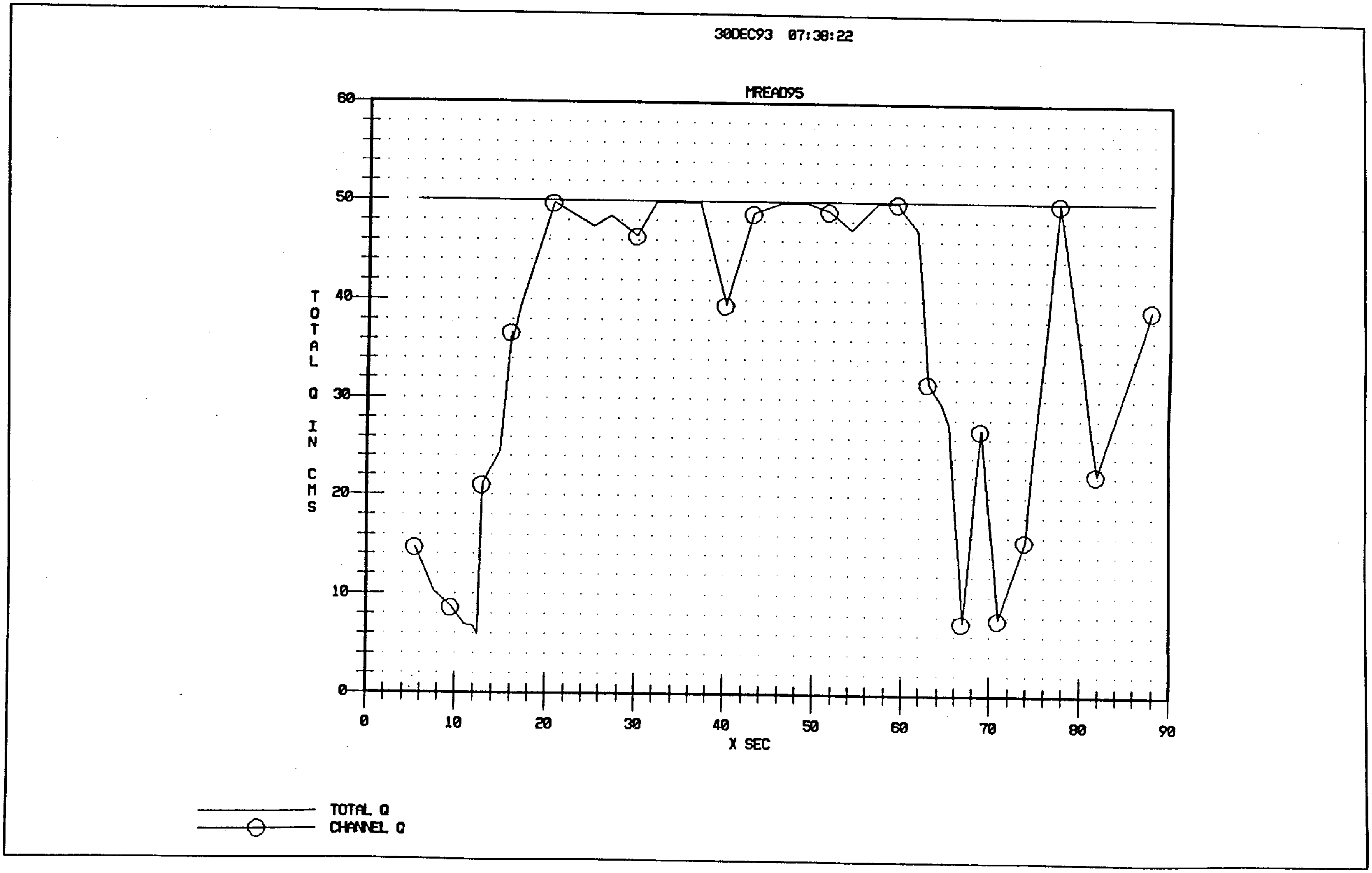


Figure 23. Channel discharge for 50 cms, Mayaguez-Hormigueros Project Reach

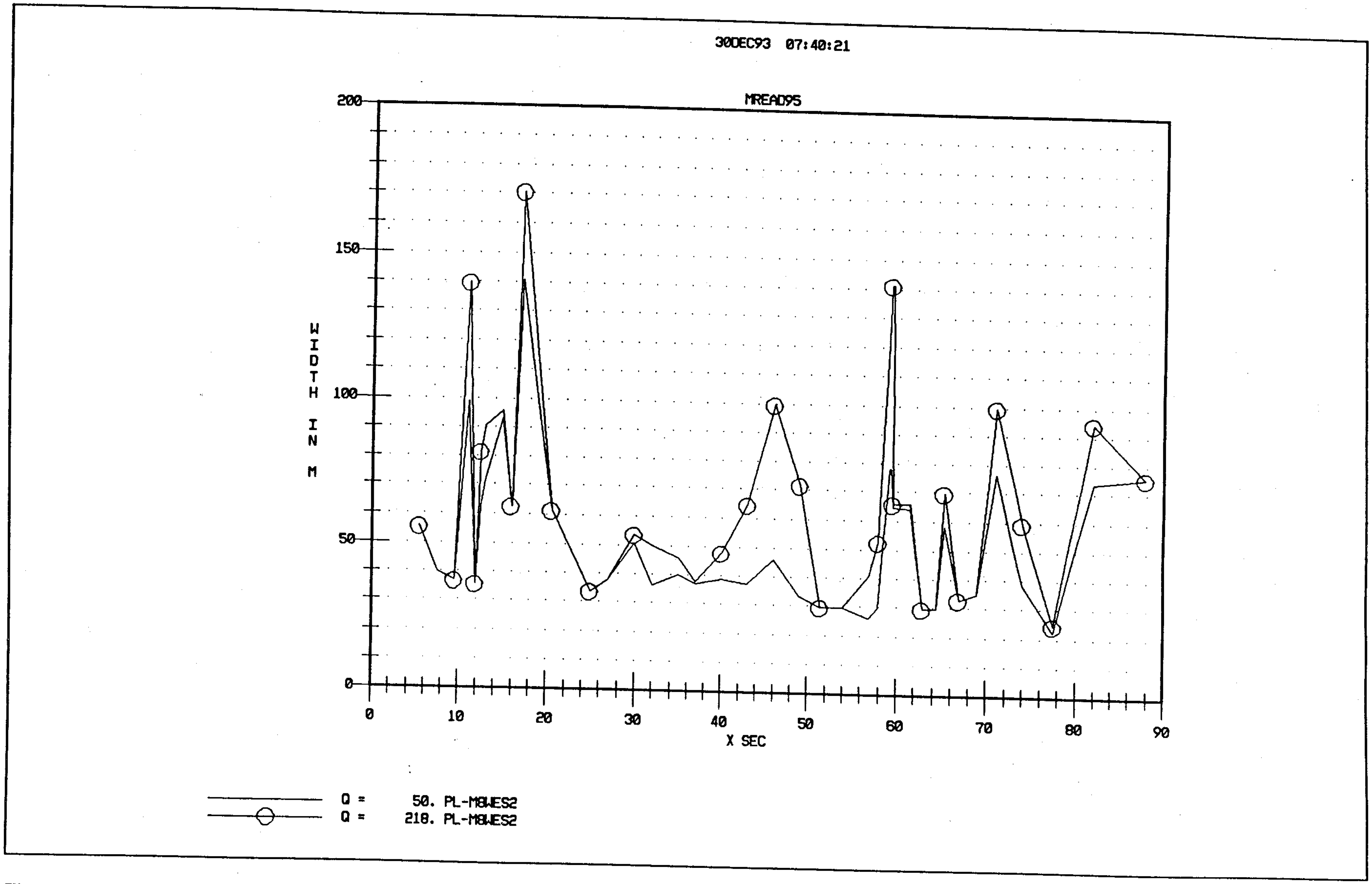


Figure 24. Water surface width for 50 cms, Mayaguez-Hormigueros Project Reach

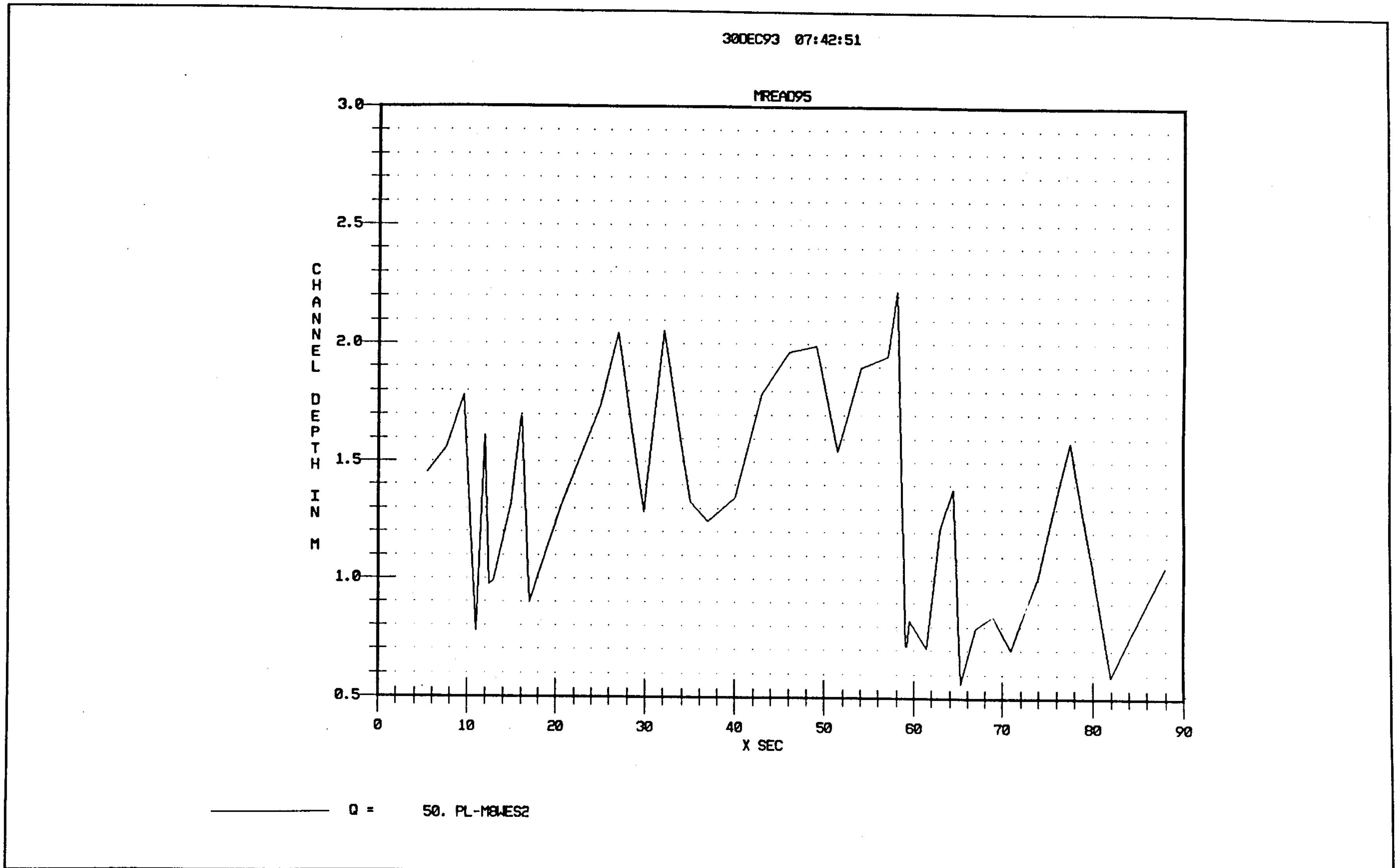


Figure 25. Water depth for 50 cms, Mayaguez-Hormigueros Project Reach

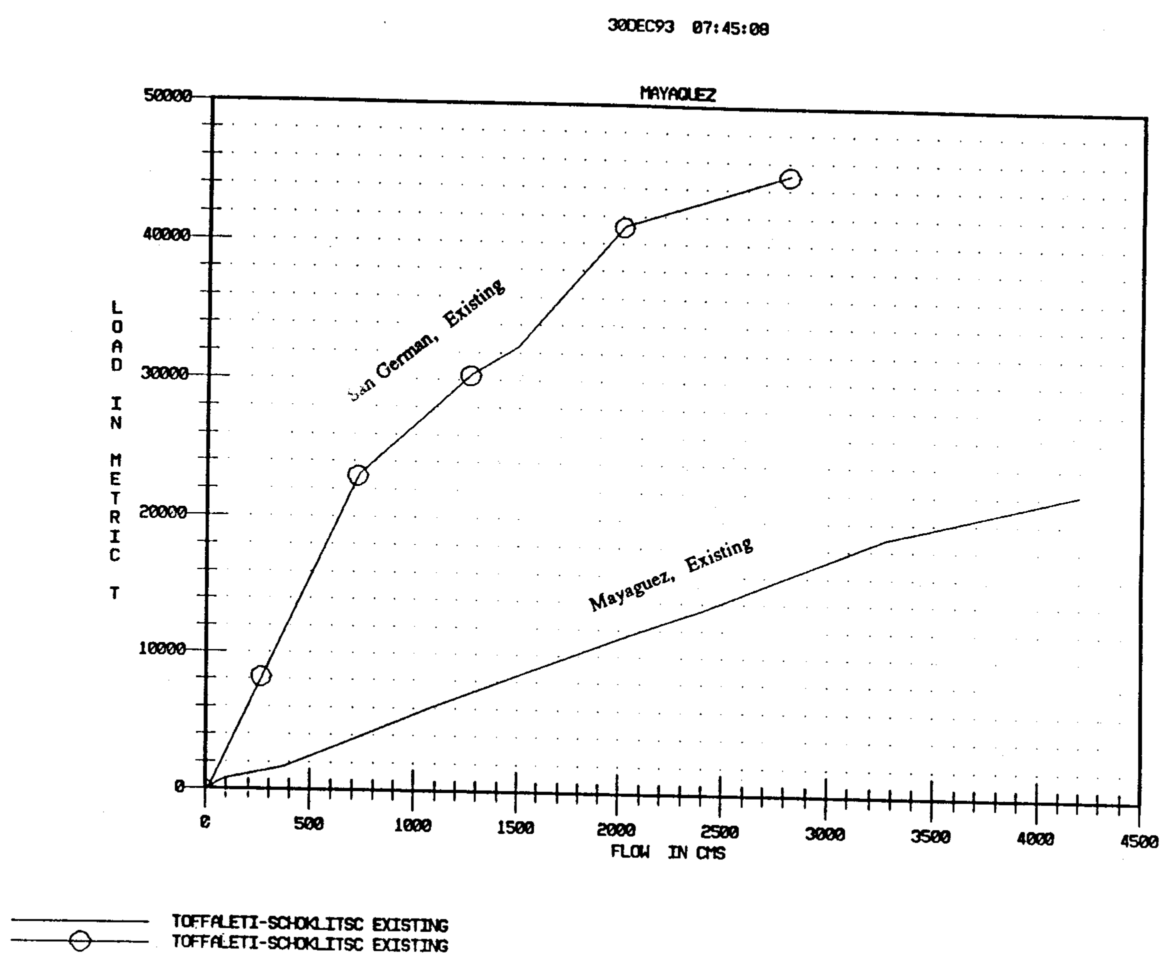


Figure 26. Calculated bed material sediment discharge curves, Mayaguez-Hormigueros Project Reach

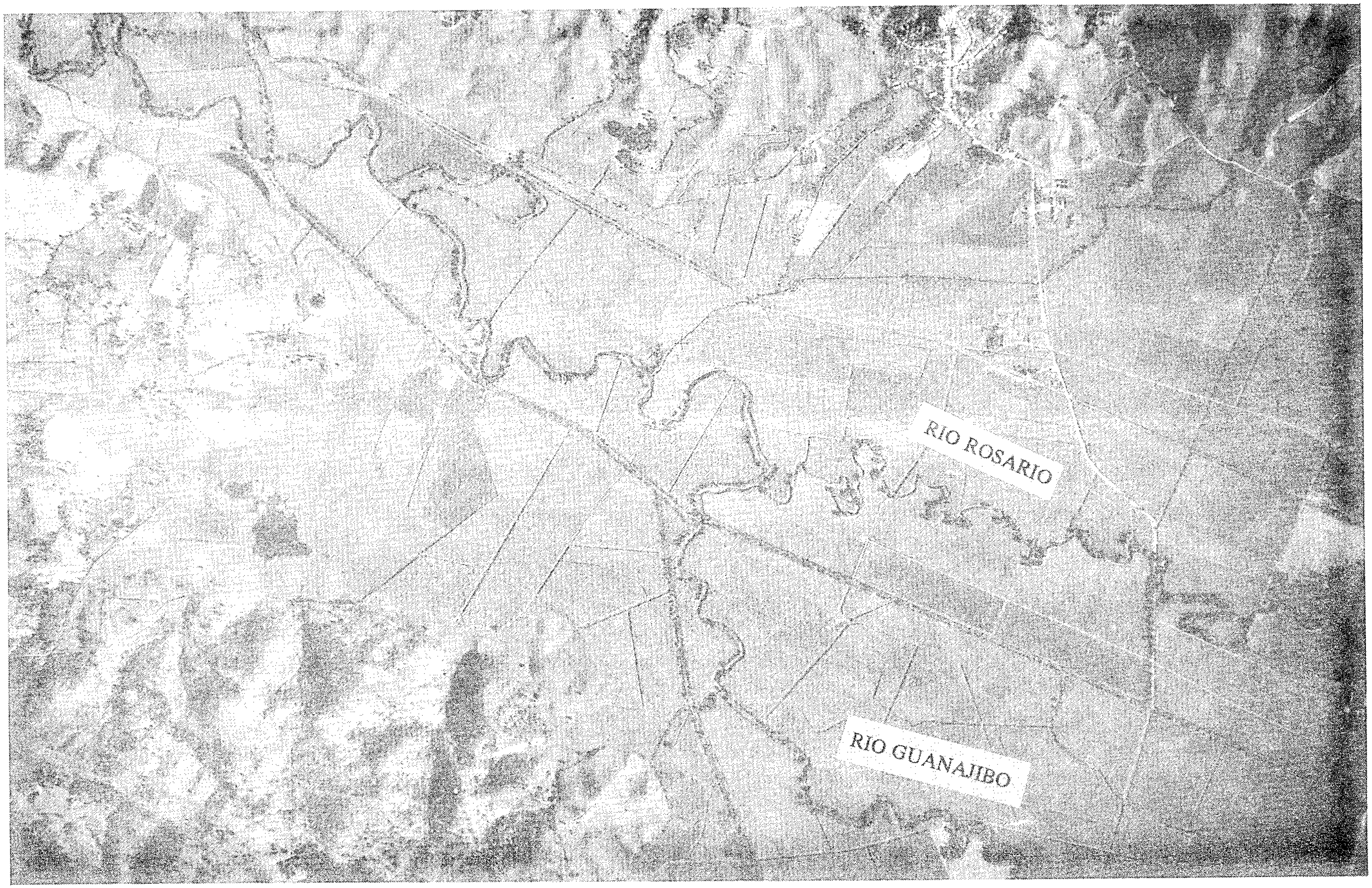


Figure 27. 1936 aerial photograph, confluence of Rio Rosario and Guanajibo

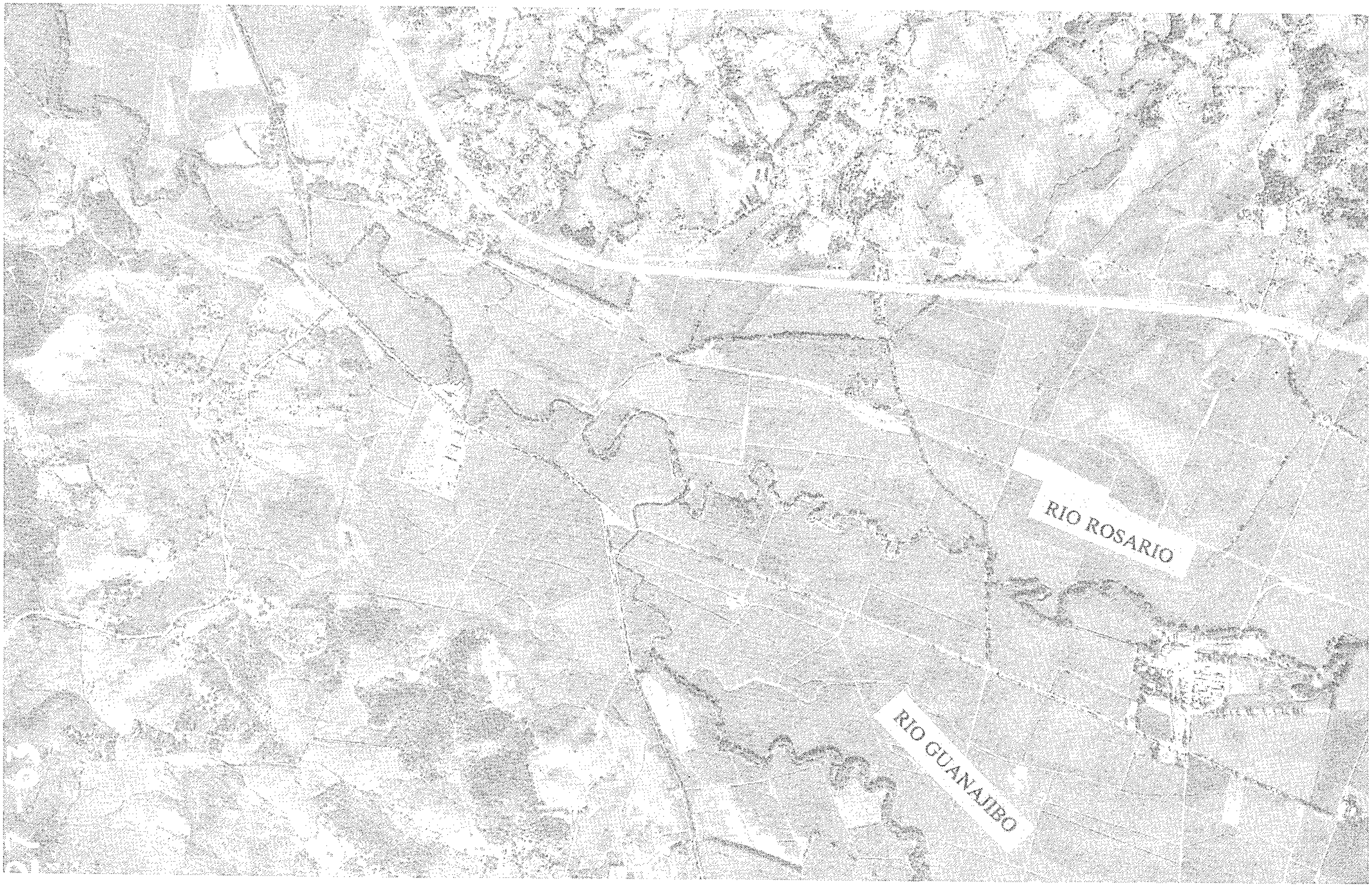


Figure 28. 1963 aerial photograph, confluence of Rio Rosario and Guanajibo

Figure 29. 1983 aerial photograph, confluence of Rio Rosario and Guanajibo

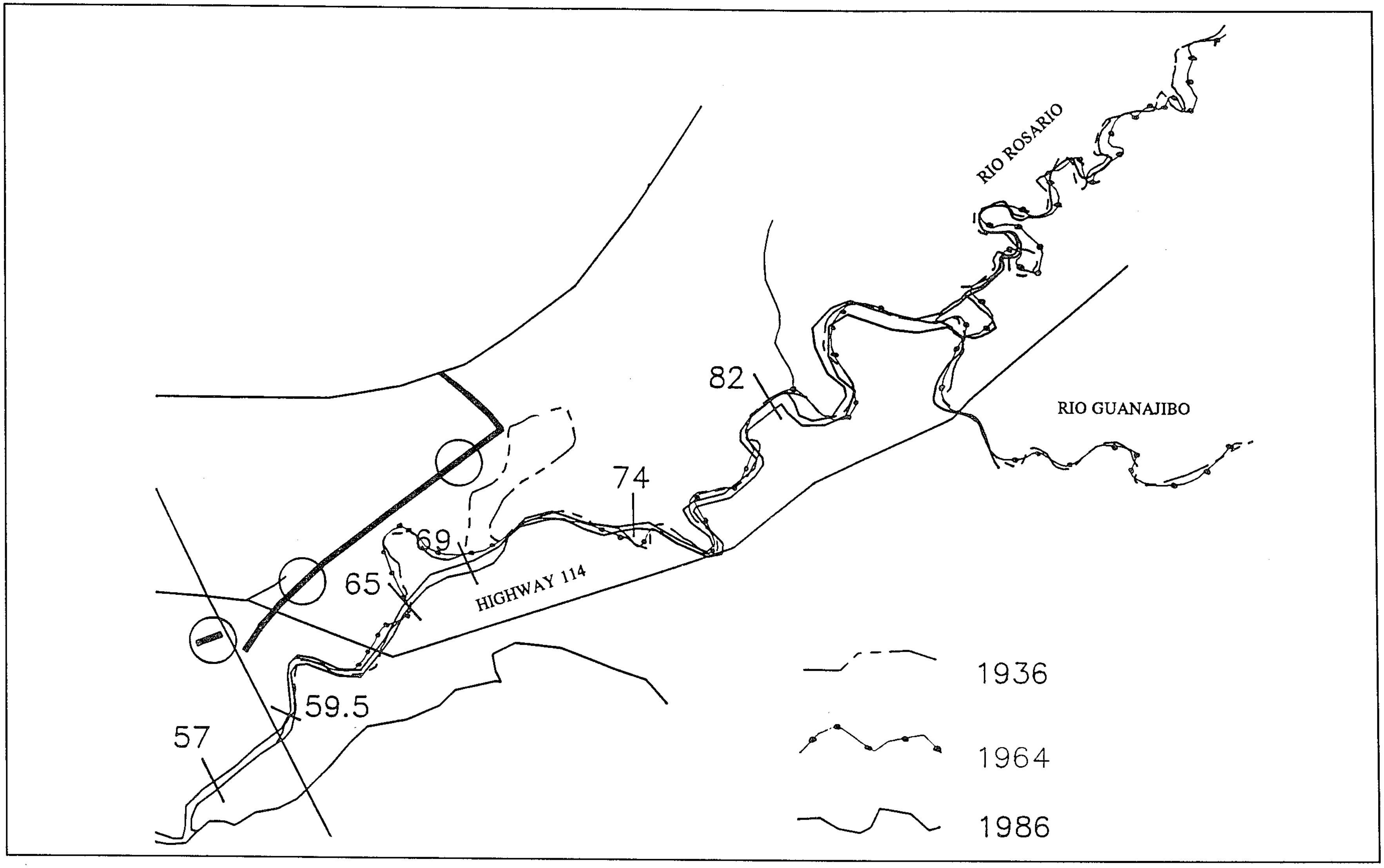


Figure 30. Overplot of 1936, 1964, and 1986 channels, confluence of Rio Rosario and Guanajibo

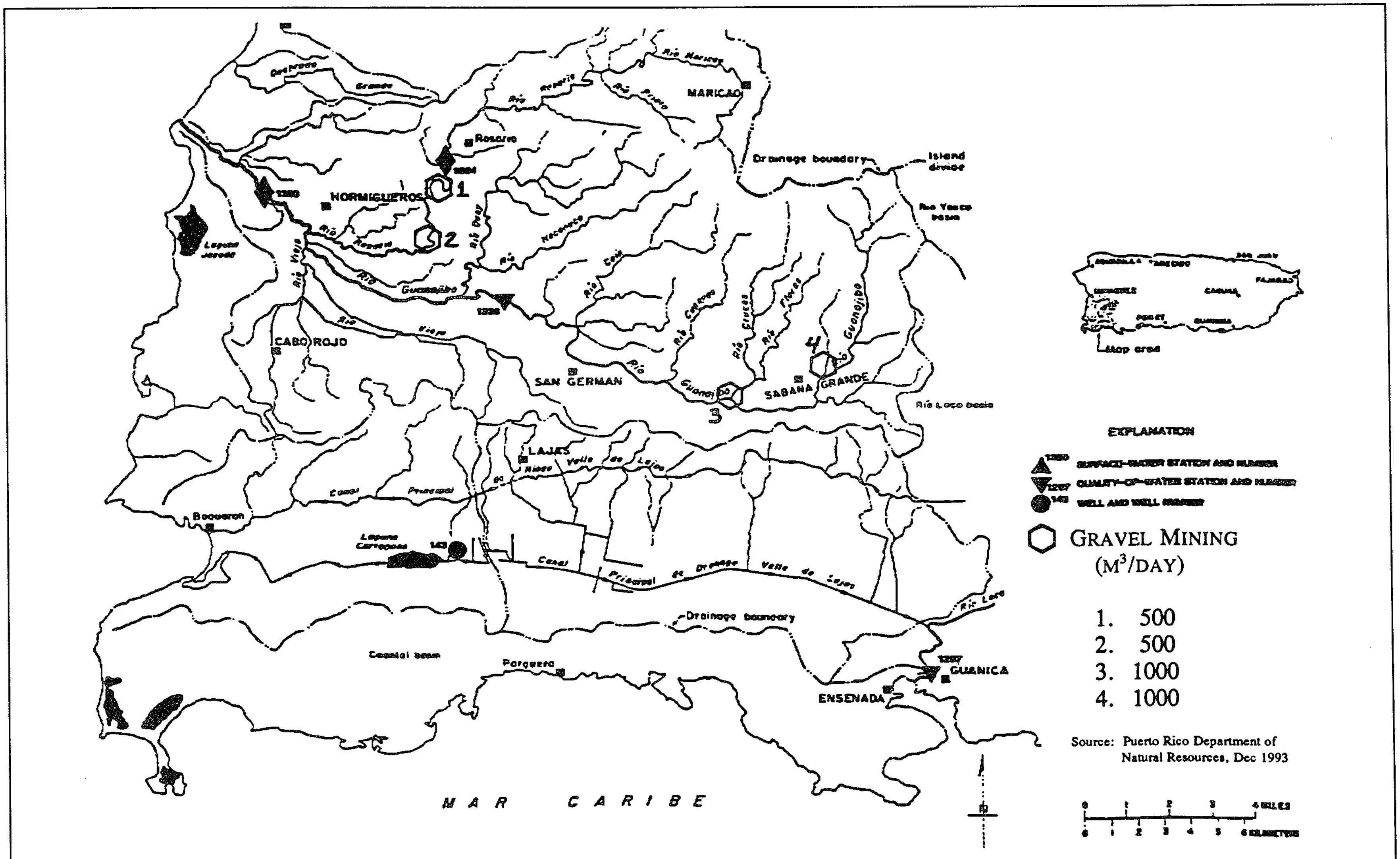


Figure 31. Gravel mining in the Guanajibo Basin

Figure 32. Road wash-out, Rio Guanajibo near Guanajibo Homes, 1975 Flood

Appendix A
References

Brownlie, William R. (1981). "Prediction of flow depth and sediment discharge in open channels," Report No. KH-R-43A, California Institute of Technology, Pasadena, CA.

Johnson, Karl G. (1981). "Flood of September 16, 1975 in the Guanajibo Valley, Puerto Rico," Department of the Interior, United States Geological Survey, Water Resources Investigation Open-File Report 81-805.

MacArthur, Robert C. (1983). "Site reconnaissance of the Rio Guanajibo River Flood Control Project Area," Resource Consultants and Engineers, Inc, 1477 Drew Avenue, Suite 107, Davis, CA 95616.

Thomas, William A., Copeland, Ronald R., Raphelt, Nolan K., and McComas, Dinah N. "Hydraulic design package for flood control channels (SAM), User Manual" (in preparation), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Headquarters, Department of the Army. DRAFT. "Engineering and design -- channel stability analysis for flood control projects," EM 1110-2-1418, Washington, DC.

__________. (1991). "Engineering and design -- hydraulic design of flood control channels," EM 1110-2-1601, Washington, DC.

__________. (1989). "Engineering and design - sedimentation investigations of rivers and reservoirs," EM 1110-2-4000, Washington, DC.

Appendix B
English-Metric Units and Conversion Factors

The following conversion factors are used in SAM:

Property	Multiply	by	To Obtain
Length	1 Meter	3.280829	Feet
Volume	1 Cubic Meter	35.31541	Cubic Feet
Force	1 Newton		Pounds Force
Pressure	1 N/M^2	47.880	lb/ft^2
Mass	1 Metric Ton	1.1025	English Tons
	1 Kilogram	2.205	lbm
Specific Weight of Water, γ	1 N/M^3	0.0063658	lb/ft^3
Specific Weight of Sediment, γ_s	1 ks/m^3	0.0624278	lb/ft^3
Sediment Discharge Rate	C(mg/1)	$0.0864{*}Q(m^3/s)$	Q_s Metric Tons/Day

Acceleration of Gravity:

$$g = 32.1740 \ f/s^2$$
$$= 9.8067 \ m/s^2$$

Specific Weight of Water: 1 cubic foot of water weighs 62.427 lbm in the U.S. FLT system of units.

$$\gamma = 62.427 \ lbm/ft^3$$

$$= 62.427 \ lbm \ {*}0.4535924 \ kg/lbm \ {*}35.314667 \ CF/m^3$$

$$= 1000 \ kg/m^3$$

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
January 1995

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Sediment Impact Assessments for the Rio Guanajibo at Mayaguez and San German, Puerto Rico

5. FUNDING NUMBERS

6. AUTHOR(S)
William A. Thomas

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Miscellaneous Paper HL-95-1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer District, Jacksonville
P.O. Box 4970
Jacksonville, FL 32232-0019

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This sediment impact assessment was conducted for two protection projects on the Rio Guanajibo. San German is a channel modification project designed for a 10-year level of protection. The existing channel was analyzed using five stability tests in the computer program, "Hydraulic Design Package for Channels" (SAM), and found to be stable because the historical inflowing sediment discharge was sufficiently high to prevent erosion of the channel bed. The proposed project channel is wider than the existing channel and has a flatter slope. The analytical method for stable channel design indicated deposition would occur, and the sediment yield study predicted a trap efficiency of 59 percent. That trap efficiency is sufficiently high that a detailed sedimentation study should be conducted. Project reliability during the passage of the design flood event was tested using a sediment budget approach, also. The calculated trap efficiency is 33 percent. This is expected to cause about 1/3 m of deposition, most of which comes after the peak discharge, and the project is judged to be reliable.

(Continued)

14. SUBJECT TERMS
See reverse.

15. NUMBER OF PAGES
63

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

13. (Concluded).

The Hormigueros-Mayaguez project is a levee project. The existing channel was determined to be unstable due to deposition at two locations. One was near the coastline and the other was near the upstream end of that project. This sediment impact assessment concludes that additional studies would be required to determine how rapidly the channel will fill in those locations. However, an alternative approach to the detailed sedimentation investigation, in this special case, is to recognize that these levees do not change the flow distribution or the water surface profile significantly from historical values in these reaches. Therefore, the long-term maintenance cost for dredging and bank protection with the project is expected to be the same as the local sponsor has experienced historically. If this approach is adopted, appropriate language should be included in the local cost-sharing agreement.

14. (Concluded).

Local flood protection
Mathematical models
Project maintenance
Puerto Rico
SAM
Sedimentation
Stable channel design